Acquisition and Utilization of Aquatic Habitat Inventory Information

Proceedings of a Symposium held 28–30 October 1981, Portland, Oregon

Organized by Western Division American Fisheries Society

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Proceedings of a Symposium
Held 28-30 October, 1981
Hilton Hotel, Portland, Oregon

Neil B. Armantrout, Editor

Organized by The Western Division, American Fisheries Society

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Forward

An interagency review was initiated in 1979 to improve inventory procedures used by several state and federal agencies in Oregon. Attempts were made to contact other agencies, groups and individuals known to be working on improvement of aquatic habitat inventory techniques. With no regular forum for an exchange of information on such developments, this was sometimes difficult. Most of the sources were located through referrals by other biologists. The difficulty encountered led to a proposal for a symposium, which was accepted by the Western Division of the American Fisheries Society. Response to the publicity about the symposium from all parts of North America was excellent. The resulting Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information was held October 28-30, 1981, at the Hilton Hotel in Portland, Oregon.

Aquatic systems exist in close relationship with other physical and biological systems. With the utilization of all resources increasing, the ecosystems in which aquatic habitat is found continue to be modified. The demand for use of aquatic habitat and other aquatic resources continues to increase. At the same time, the loss of habitat and the competing demands on the resource have placed added stress on the aquatic systems, resulting in a reduction in both quality and quantity. In an effort to maintain aquatic resources and balance competing demands, more precise information is needed on aquatic resources, including not only their availability, but also condition and trend, habitat requirements and management options. Increasingly, biologists are asked to develop management strategies alone or in cooperation with other resource uses, and to predict the outcome of options. This has created a need for improved methods of obtaining aquatic habitat inventory information, evaluating the condition of the aquatic resource, and developing management recommendations.

Inventory and evaluation provide the information on which decisions for aquatic habitat must be made. Improved capability for obtaining and analyzing infromation improves the management capability. With many levels of government facing financial difficulties, it is necessary to increase capability through improved procedures rather than just an increase in effort. Technical improvements in both the gathering and utilization of information provide a means for meeting some of these demands.

New techniques are being developed for conducting inventories, evaluating the results, and incorporating the information into the decision-making process. These techniques can be used for a range of inventories from localized sampling to the modeling of larger ecosystems. Computers have made it easier to incorporate new technology into the inventory process, and to handle the data obtained. These techniques, being developed by a variety of individuals and organizations, are often more cost-efficient.

An attempt was made in the Symposium to cover a wide range of topics. These included the defining and measuring of habitat components, relating components to species use of habitat, interactions with other resources, evaluating habitats, developing habitat management proposals, predicting habitat impacts, and the storage, retrieval and analysis of habitat information. Papers were offered that covered the range of topics. While these papers obviously represent only a part of the work underway, they do give an excellent introduction to current research.

Work on improvement of aquatic habitat inventory techniques continues. Much of this work is on refinements and improvements of existing techniques, while other work seeks to adapt and develop new technologies. Because of the continued growth in the field, many participants expressed the need for further meetings and symposia to provide for a continuing exchange of information. The new North American Journal of Fisheries Management, begun after the Symposium, will hopefully provide one forum for exchange. Certainly the needs that led to the development of the Symposium continue, and while they do, biologists working on aquatic habitat inventory research will need a method for exchanging information. This Symposium is part of an on-going process of information acquisition and dissemination, organized to fill a need. It is but part of an on-going process, the ultimate result of which, we hope, will be better management of our valuable aquatic resources.

Acknowledgement

We wish to thank the authors for their participation, and for their cooperation and patience in preparation of these Proceedings. We appreciate the efforts of all to participate in the Symposium. Unfortunately, not all authors who presented papers were able to submit their papers for publication. A copy of the program is included in order to recognize all who were on the program.

Authors contributed camera-ready manuscripts, which greatly eased the task of preparing the Proceedings for publication. Authors were asked to have their papers reviewed by at least two qualified individuals. The many review comments included with the manuscripts demonstrated the efforts of authors to see that their papers were reviewed, and were suitable for publication.

No meeting of this scope can be held without financial and other support. We gratefully acknowledge generous contributions made by the Alaska Department of Fish and Game, U.S. Burea of Land Management, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and the Western Division of the American Fisheries Society. In addition, many other groups, listed on the title page, assisted in sponsoring the Symposium.

Coordination with AFS chapters was through chapter representatives. These representatives worked to make members aware of the Symposium, and encouraged potential authors to submit papers. We wish to thank the following chapter representatives: Christopher Estes,Alaska; Willis Evans, Cal-Neva; Allan Thomas, Idaho; Don Duff, Bonneville; Bruce Smith, Colorado-Wyoming; Al Elser, Montana, and Bob Rulifson, Pacific International.

While many individuals contributed to the success of the Symposium, five deserve special thanks. Gordon Haugen and Robert White, the two presidents of the Western Division during the development and completion of the Symposium and Proceedings, provided constant encouragement, assisted in arranging financing, and in many other ways contributed to the effort. Larry Everson, in his role as Arrangements Chairman, helped in taking care of many of the details that make any such effort a success. Robert L. Herbst, in his banquet address, provided an excellent counterpoint to the technical discussions. We have, with his permission, included his address in the Proceedings. Phyllis Eaton, BLM, Portland, throughout provided support and assistance with many of the details of putting on the Symposium and preparing the Proceedings for publication.

Neil B. Armantrout
Symposium General Chairman

Dedication

ROBERT L. BOROVICKA

February 21, 1920 - June 22, 1982

Robert L. Borovicka, a fisheries biologist for 36 years, died June 22, 1982, near Bend, Oregon. Borovicka was a life-long Oregonian, having been born in Portland in 1920. He is survived by his wife Georgia, and their children Kathy, Tom, Jim, Angela, Carla and Bobbie Jo.

Borovicka graduated from Oregon State College in 1942 with a degree in Fisheries. He served four years as an artillery officer in World War II, remaining active in the Army Reserves until his retirement in 1966 as a Lt. Colonel, Artillery. In 1946, Borovicka began a 20-year career with the Oregon Game Commission. He was initially hired to conduct special lake and stream studies in Central Oregon, later being named as the District Biologist for the Bend District. From 1957 to 1966, he was the Chief, Coordinating Fishery Biologist for the Oregon Game Commission in their Portland Office.

In 1966, Borovicka left the Oregon Game Commission to go to work as the first Fisheries Biologist hired by the U.S. Bureau of Land Management. For many years, Borovicka assisted BLM offices in all states west of the Rockies. He remained in that position until 1977, when he became Chief of the Branch of Range, Watershed and Wildlife in the BLM Oregon State Office, a position he held until his retirement on April 30, 1982.

Borovicka was a member of the American Fisheries Society, joining initially in 1946, and was a Certified Fishery Scientist. He served on many committees at the Chapter, Division and National Level, and was one of the first presidents of the Oregon Chapter. He was a member of the American Institute of Fishery Research Biologists, and served as National President in 1977 and 1978.

Borovicka was involved in many projects, including the Alaska Pipeline, the California Desert Study, the development of programs for Threatened and Endangered Species, and was one of the founders of the Desert Fishes Council. He early realized the need for fisheries biologists to coordinate inventory and management efforts. He was instrumental in developing, in cooperation with the Oregon Fish Commission, the Oregon Game Commission, the U.S. Forest Service, and BLM, a cooperative inventory procedure. For six years he chaired an AFS committee seeking to develop inventory procedures that could be adopted by biologists nation-wide. From the beginning, he actively supported this symposium, both through efforts to obtain financial support, and in providing opportunities for BLM personnel to participate. Because of his contributions to the fisheries profession in general, and to development and improvement of fisheries inventory procedures in particular, we dedicate these Proceedings to the memory of Robert L. Borovicka.

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SESSION 1

Moderator: Neil B. Armantrout
Symposium General Chairman

BANQUET ADDRESS

by

Robert L. Herbst
Executive Director, Trout Unlimited

Ladies and Gentlemen, Friends, I am honored to address you tonight. To be amongst the foremost leaders in the fisheries, aquatic and analytical fields is a pleasure.

Flying out here to attend the American Fisheries Society Western Division's meeting, I could not help being awed by the numerous lakes, reservoirs and streams. For each stream, large or small, I know there are dedicated managers on the job protecting the resources and I know times are particularly rough today.

Today, there is an excitement to life because much happens every day. But we must retain our reverence for the environment, the stillness of a sunset, the spendor of a small mountain stream making its way to the sea. We must also see the activities we engage in, research, analysis and policy making, as vital and active ingredients to protecting the natural resources we prize.

We all know that natural systems contain endless and uncontrollable variability. We know we must be stewards of the land and water, and we must function as negotiators for the standards we expect. We must accept that there will probably never be two identical aquatic systems, so our inventory work will have to be used to make decisions without the precision certain mechanical models might demand.

We are going to have to be able to communicate our scientific findings between agencies and locales with accuracy so that whatever our expertise, we can have the benefit of our colleagues' findings to justify policies and long-range plans for our aquatic ecosystems. Perhaps our future success will be the strongest when we can use the information we now have and make conservative projections to protect fisheries habitat. We will be a hung jury with the habitat the loser, if we do not use current knowledge to act and enhance our diminishing fish-sustaining waters.

Where my plea for conservation would perhaps cause a fisheries manager to err on the side of protecting too much riparian area from domestic livestock grazing, my corollary would be to urge the researchers in this room to use every opportunity to carry on long-term, integrated studies. We cannot say that just because we haven't a perfect cure for a disease, we should offer no treatment!

In the past, sports fisheries management has consisted of three major activities: angling regulations, the oldest practice; artificial rearing and stocking; and habitat management--the protection, restoration and enhancement of streams and lakes. Even among early fishery managers who advocated habitat protection, manipulation of the habitat was sometimes done in an ineffective or counter-productive way. There was much to learn. Much still remains to be discovered.

Important progress in restoring basic habitat in many abused streams has been made by fisheries managers and the clean water crusade. For a period of time, fisheries managers' multi-faceted concerns seemed to go unspoken and all the public heard was that we need good water quality. Whereas, it is vital for fish to have clean water, there is a broader concept of habitat suitability that field and office fishery managers must address. We do the broader subject of aquatic habitat a greater service if we think of total stream quality and lake quality. The holistic concepts encompass not only water quality, but also structural habitat. Thus, we are approaching the concept of environmental quality, which we will have once the biotic component is included.

It is obvious that our past management did not include all these considerations. Sometimes the riparian area and a stream bottom of a small nursery stream were destroyed without considering the serious effects of this habitat degradation on the adult fish habitat 150 miles downstream. It is time to use the inter-relationships of aquatic programs as we know them, to make policy decisions to optimally utilize aquatic habitat.

This conference itself is tangible evidence that we are looking at a more balanced approach to fisheries management and habitat quality. We must recognize what healthy and suitable habitat is. From this, we can treat a degraded habitat to ameliorate its current shortcomings from past abuses. Today, burgeoning attention to stream habitat by the State and Federal agencies (most recently and commendably the United States Forest Service and Bureau of Land Management) has positively effected management of riparian zones. The call of the future for all agencies and private citizens is to protect our habitat. We must keep unfailing commitments to research, inventory collecting, management, and evaluations of results.

Let us remind ourselves, this evening, that three-quarters of the earth's surface is covered by water and one-quarter by land; therefore, it is surely true that the good Lord intended that man fish three-quarters of his time and plow one-quarter of his time. And thus, the work you do with aquatic habitat when looked at in this light is one of the most important of all responsibilities.

Since you have focused on the technical matters of aquatic habitat in the many sessions of this conference, I want to talk with you, generally, about the environmental ethic that is growing in this country--the tough decisions that are involved as each new fiber is added to its muscle.

You represent the core of that effort in our Nation, and, as you have come to expect, new jobs await your attention and ingenuity. Many of you also represent the battlefield itself--the place where conflicting interests are contending as this ethic takes shape.

Like me, you find yourself wrestling with your own desires for things that neither the economy nor the environment can support. How far are we prepared to go, as a Nation, in accommodating both development and preservation? How far are we prepared to go in our private lives to express our public environmental ethic?

This is not a quiz, and no grades will be posted. I throw out the question only as a setting against which to think tonight about some of the decisions we are making now, as a Nation. The grades on this kind of quiz will appear later, written on the face of our land and water--stamped on the quality of our lives.

It has been popular in the recent past for businessmen and environmentalists to look upon each other as "the enemy." Most issues of environmental conflict have been couched in terms of "either/or." This polarization has reached ridiculous proportions. The uninitiated might believe that all business people hate clean air/have never enjoyed landing a trout from a clean mountain stream/could care less about their children's chances of seeing a wild plant or animal outside a zoo or a botanical garden.

And environmentalists have been painted as people who never drive to work in a car, always walk or ride a horse/use candles to light their homes/never had beer from a throw-away can. You all know how ridiculous that is.

What we actually have today is a situation where the people who think of themselves as environmentalists are beginning to concede that the material and economic needs of a modern society will be met. They are coming to grasp the fact that extremist demands have cost them credibility and hurt their cause.

On the other hand, business-oriented people are learning that unless the environment is protected--unless everyone practices wise conservation--unless we pay attention to the signs that tell us where the natural systems are in trouble--the special interests and enterprises of business and industry are going to be adversely affected as is the bottom line in financial statements and stockholder reports.

A recent State Department report analyzes an event you may not have heard about--the time just a few years ago when the Panama Canal ran dry. Ship owners and canal managers were shocked to find that indiscriminate clearing of tropical forests in the Canal's watershed area had actually so altered the flows of runoff, that many ships had to be routed around the tip of South America--at great expense to the shippers and also to the managers of the Canal.

This is just one of the realities that is tapping our economists on the shoulders and saying, "Hey, look--I am a factor to be reckoned with, too!"

According to the State Department report, some authorities are predicting that mismanagement of the watersheds in Central America will render the Panama Canal useless by the time it comes under full Panamanian control at the end of this century. If that happens, then all the sound and fury over the Canal Treaty will have signified nothing.

And the repercussions from disruption of Canal traffic will effect everyone who uses anything that must be shipped from one coast to the other. Where are our priorities? While we argued about a treaty, a Canal was going down the drain. This is one of those elusive ties between seemingly disconnected events--the clearing of a Central American forest and the costs of a business in your home town. Environment and economics are two sides of one coin--and coin is exactly what we are talking about.

Another painful example, closer to home, is the Three-Mile Island incident in Pennsylvania. We really do not know yet whether or not it was a "disaster," or for how many people, and over what period of time. We all hope the effects will prove negligible.

But that accident has made it clear--we have not been careful enough! The checks and safeguards were not fail-safe. We have not considered all the environmental risks, nor do we know yet the extent of the impact that incident may still have.

What happened at Three-Mile Island may not be the beginning of the end for nuclear power development, but it certainly was a well-timed warning that too much has been taken for granted. Everyone thought someone else was doing what needed to be done.

And, after all is known and done, we still have not added up all the costs. We really do not know yet what "honest book" would show--what the net gains or losses to society would be from pursuing the nuclear path.

If this is really the way to go into the future, we should not be afraid to look at all the costs in the light of whatever alternatives are available. But if we are to look at all the costs of any resource issue in balancing the uses of our resources, then expanding public education and understanding becomes essential. You can and must play a vital role in that effort.

Our work is anything but completed. Two years ago, I was sharply reminded of this when a reporter telephoned me about an Interior Department announcement that the California pupfish faced extinction.

The very first question from this shaper of public opinion was, "Mr. Secretary, who the hell gives a damn about the pupfish? I mean, why should we really care? I cannot even smell it, feel it or see it. Who cares?"

I asked him if he would like to see the eagle, buffalo and whooping crane become extinct. His answer was, "No, but then, they are different." My thought was "Why? Who is to decide which species should stay, and which ones man should exterminate? Where should we draw the line and who should draw it?"

Then he said, "Worthless, silly species can hold up very important projects providing hundreds of jobs." I asked him to give me an example and I received the expected answer. "The snail darter is worthless and it has stopped the Tellico Dam." My immediate thought was, "Who says the snail darter is useless, and, equally, who says the Tellico Dam is wonderful?" And what about all the other values and costs?

But let us put aside the economics of that dam and concentrate on the question of the values of a species of life, because it is a good one.

First, regardless of religion, most people agree that "creation" took place in the natural order, And, as such, what right do we have to purposefully eliminate a life form?

Second, the "natural order" really constitutes a very important answer and reason--all life is a part of a local or broader ecosystem. Removal of one spoke, so to speak, from the wheel makes it weaker. Too many spokes gone and the wheel collapses. Thirdly, the quality of life in our Nation constitutes all of our environment. And, very importantly, plants and fish can be indicators of environmental quality and even human life itself--the canary in the coal mine concept. Exemplified by DDT--its presence worldwide in the tissues of most living things indicated something was wrong, which led to its control. Trout life, of course, is the litmus test of the highest quality water resource.

Finally, life may have an economic value now, but, if it does not, there is no reason to accept our present ignorance of its value. Scientists may yet uncover a value in years to come.

Penicillin was a mold on cabbage.

Sponges in the coastal waters recently yielded a drug to control certain virus infections.

Rubber from trees was only relatively recently discovered, and I could go on with numerous other examples.

Suffice it to say, new drugs, treatment measures, chemicals, and beneficial uses are being discovered every year. Most are from the little-known forms of animal and plant life. Once extinct--all these values and potentials are lost forever.

I suppose we could ask the same question of human life itself. What is it worth?

Boiled down, maybe we are worth a few dollars of chemicals economically. Of course, we could say we are worth more as we have a certain talent such as writing--but then, so do many others. And, if that is a yardstick, what good is a baby?

We are all replaceable--there is no indispensable man. In fact, some have said human life is like a thumb in the ocean, a dent and occupation of space while there. But gone, it is difficult to see the change of a lower water level.

Of course, we all know better--human life is valuable, sacred and cherished--each individual is important and can make a difference. But, I submit, so is "all life."

One of the objectives I strive for constantly is to awaken in the minds of those on opposite sides of specific environmental battles the larger sense in which we are all in it together. I try to suggest that the old adversary stances we all hold so dear may be based on premises that are slightly skewed, and that they tend to lock us into no-win positions. I try to suggest different concepts that might give us room to move again--possibly with new insights as to how we could better deploy our strengths.

One such deliberately jarring note is the idea of nature as a tough, old bird who fights her own battles in unexpected ways. I tried it out on the engineering fraternity at the Corps of Engineer's Environmental Seminar. I told them I thought part of the problem between them and us was that we always seem to be coming at them in the role of obstructionists.

I reminded the engineers that the backlash many people had so confidently predicted when Earth Day forces began to gather ten years ago has failed to materialize. Instead, the environmental movement has gathered strength. In the face of the energy crunch, it is picking up punch and additional advocates.

We do not have to cover everything with concrete and pour oceans of fossil fuel into it to assure ourselves of "enough energy."

The key word here is "enough." If we concentrate on the limits to our energy supplies, it only sends us scurrying anxiously in search of more--more nuclear, more fossil fuel, more geothermal, more solar, more hydro, more, more, more.

But, if we concentrate on the limitations to our use of energy--limits imposed by the biosphere before the point of no return arrives--before the environment can no longer absorb the heat and other wastes that the use of energy entails--then we find ourselves with an entirely different kind of situation. The question becomes not one of quantity but of quality . . . of what kind of growth we can accomplish with what we have.

We owe it to ourselves to nourish that spark of self control--that inclination, however slight, to deny ourselves immediate gratification long enough to count the eventual costs.

We are running out of room and strength to grow in the "more" sense of the word growth. We can still manage to squeeze enough oil and gas out of the ground and enough electricity out of uranium to spoil most of the rest of our natural energy systems--like streams, salt marshes and bottomland hardwoods; but, nowhere on the horizon are there the pools of energy we would need to maintain all of the structures we think we need.

Bridges, tunnels, dams, highways and highrises--all those monuments to our vaunted "growth" --are subject to the inexorable Second Law of Thermodynamics. And like most spoiled children who have not learned that "more" and "better" do not necessarily have anything to do with each other, we have not cared much about repairing. As things wear out, we lose interest in them. We want bigger, newer, louder, shinier, and always, more things.

If we can break the spell of our anxiety for more power, we can see some hopeful signs around. The past ten years have demonstrated that rivers of water can be cleansed and fish can be reintroduced into streams that have been almost lifeless for a hundred years. A new respect for species that many people still consider "silly and worthless" stopped a highway and stymied a dam. And, in the precious interval of time gained--in the momentary hush of the juggernaut--we have time to ask ourselves, "What Is Progress, What is Growth?"

Back in the Thirties, Aldo Leopold had a grasp of the developer mentality. He saw the problem as one of perception. What actually constitutes true worth? Leopold put it this way:

> "Wild things, I admit, had little human value until mechanization assured us of a good breakfast and until science disclosed the drama of where they come from and how they live. The whole conflict boils down to a question of degree. We of the minority see a law of diminishing returns in progress; our opponents do not."

Probably, our opponents never will, so the battle becomes one for the minds--the perceptions--of the public.

You may be wondering what energy and systems have to do with aquatic habitat and with "preserving fish and wildlife in the 80's." My answer is this: the focus on energy and the effects on our world of getting and using energy, are setting in perspective the relationship of many problems we once pursued on solitary tracks. We no longer have that luxury and perhaps it is just as well. The strictures of space and the drying up of cheap power sources are problems we never had to face in the past--and we are facing something else too--a dawning grasp of the consequences of the choices.

You and I have stretched our concept of fish to the habitat, without which a fish is either finished or diminished. Do we fight to save the larger set of world processes that surround our fish and contribute to it--and to our experience of it? Or do we simply settle for saving the tiny center of this larger process?

The answer, of course, lies partly in what we can do. As space shrinks and as carrying capacity is more and more diverted to human built, engineered processes, the battle gets tougher and the questions loom larger--the need for conscious choices becomes more urgent.

At first we asked small questions. "Can we save this fish?" Then our concepts and our questions stretched to "Can we preserve this habitat? This species?"

Today we are facing questions of even larger scope. Can we curb our appetite for this or that project that takes another bit of fish and leaves a poorer world--marching on toward manufactures sameness?

Where does the event that once was just a human and the event that once was just a fish become a process that either enriches or dimishes both?

And so the challenge is before us as always to enlighten people so they care about the quality of their lives which will then be reflected in their own habits, decisions, and support so that we can have both development and preservation - A BALANCE.

A politician was asked, during a campaign, to state his stand on the use of whiskey. The politician's answer was:

I had not intended to discuss that most controversial subject at this particular time. However, I want you to know I do not shun a controversy regardless of how frought with emotion it is. You've asked me what my position is on the "use of whiskey" and this is just exactly how I stand on that issue:

If when you say whiskey --

- You mean the bloody monster,
- If you mean the poison scum that dethrones reason and literally takes the bread from mouths of little children,
- If you mean the evil drink that topples the Christian man and woman from the pinnacles of righteousness into the bottomless pit of dispair and hopeless mess,

Then I am against it with all the power at my command!

BUT

If when you say whiskey --

- You mean the art of conversation,
- If you mean the philosophical wine,
- If you mean the ale that is consumed when good fellows get together that puts a song in their hearts, laughter on their lips, and the warm glow of contentment in their eyes,
- If you mean Christmas cheer,
- If you mean that stimulating drink that enables man to forget, if only for a little while, life's great tragedies,
- If you mean the drink, the sale of which pours millions of dollars into our treasury which is used to provide tender, loving care for our pitifully aged and infirm, to build highways, schools, and fish hatcheries,

Then I am for it!

This is my stand and I will not compromise.

"We must make a living, but, when we do, it must be worth living!"

In conclusion, I say, every age must make its own pact with destiny; its high moral purpose must be shaped in terms of the needs of THAT age. The urgency of this age is to face up to the end of abundance--to explore the common ground where men and women of good sense and goodwill can work out ways of living that make us proud to be human.

AQUATIC HABITAT INVENTORIES - THE CURRENT SITUATION

Neil B. Armantrout
Symposium General Chairman

INTRODUCTION

Fisheries habitat management is a relatively new field. Fisheries developed first as exploitation of natural populations of marine and freshwater fishes. With relatively abundant populations of fish, habitat and population management were neither needed nor practiced. The earliest efforts at fish management were probably the Oriental fish breeders who domesticated several species of food and ornamental fish. It was only when demand for fish as food and sport, particularily the more esteemed species such as the salmonids, began to greatly surpass demand that widespread fisheries management came into being. Initially, these efforts were almost entirely aimed at management of populations.

Development of aquatic inventories developed along with fisheries management, but more as a parallel than as a part of such management. Most aquatic inventories, in the broadest sense, were exploitational, looking for additional populations of desirable species. These efforts were often part of a larger program of exploration and scientific inquiry that developed during the 18th and 19th centuries. Three general types of activities can be identified.

- The growth of populations and the expansion of Western countries into unexploited and undeveloped areas of Africa, Asia and the Americas. Expeditions, such as the major ocean voyages of exploration and the Lewis and Clark Expedition in the U. S., were sent out to explore new areas, and to catalogue resources of value to the originating nations. Some expeditions were broad both in range of interests and area covered, while others concentrated on more limited goals or geographic areas.

- The increased interest among people in biology, science, and systematics. Following the publications of Linnaeus' landmark work, biologists sought to systematically classify the plant and animal kingdoms. Collections in Europe, where most of the early work was done, were augmented by collecting expeditions to nearly all parts of the world. Many of these collecting efforts were part of the larger journeys of exploration mentioned earlier. Together with the anatomical classifications, work was begun on habitat description and zoogeography.

- The decline of a number of popular or economically important fish populations. Inventories were begun to determine the location of new populations of harvestable fish, and to determine the condition of existing, known populations. Habitat and population management associated with these efforts was a major factor in developing fisheries management.

Two general themes characterized early inventory efforts. One was the desire to systematically classify fish species, and to show their general distribution and relation to other populations; and the second was to summarize, in general terms, the existing types of fish habitat. Primary interest was in species, not in habitat. Many of the differences in habitat were instinctively noted, particularly in relation to distribution patterns, but few, if any, of these early inventories attempted to systematically determine habitat components or to relate habitat components to patterns of fish distribution or population condition.

In the United States, trends followed those in Europe. Following a period of exploration in the early 18th century came a period of expansion and settlement. Fisheries management really began to develop in the latter part of the 19th century as the growing population and declines in some species began to create shortages of some popular fishes.

Efforts were concentrated on a few groups, such as salmonids, centrarchids and catfish, that were of interest for food and for a rapidly growing sport fishery. Inventories were still very much exploitation-oriented, examining population levels, life cycles and habitat requirements of key species. Agencies developed in the states to oversee both fisheries management and harvesting of freshwater fishes, while the Federal government still provided the major efforts for marine fishes.

As fisheries programs developed on into the 20th century, emphasis continued to be largely on species management. This emphasis is reflected in most of the research published in the first half of the century. Fisheries textbooks and university curricula designed to train biologists followed the same pattern, and still do today. As might be expected, inventory methods concentrated on population dynamics. This is not to say there was no interest in habitat; however, fishery agencies charged with managing resources seldom had the funds or personnel to move beyond trying to manage populations.

As a result, inventories continued to emphasize population values, species values, and harvest impacts without a strong habitat emphasis. When major problems developed, they were often handled on a case-by-case basis without being part of larger basin-wide habitat inventories or planning.

RECENT TRENDS

Around 1970, there was a shift in inventories away from species emphasis to a greater emphasis on habitat. There are four factors I believe contributed to this shift. The first was the passage of the National Environmental Protection Act and similar Federal and State legislation that required the preparation of environmental impact statements. These laws made it necessary to describe the existing habitat in an area, its current condition, and to project the impacts of specific management actions. Much more detailed habitat data were required than for population management.

The second factor was the legislation, particularily the "organic acts" of the U. S. Bureau of Land Management and the U. S. Forest Service that required Federal land management agencies to conduct regular and detailed inventories, and to use the information obtained in making land management decisions. The agencies have greatly increased their field staffs of aquatic and wildlife biologists, and have moved aggressively to fulfill the legislative mandates. In many of the states with which I am familiar, habitat inventories are done largely by the Federal agencies. Federal agencies are sometimes perceived by the states as infringing on the rights of the states to manage aquatic resources. None of the Federal regulations direct Federal agencies to manage fish population, and Federal agencies continue to recognize state perogatives in population management, but the overlap between the two missions is obvious, since actions taken in habitat management are going to influence population management. In many cases, state and Federal agencies have been able to work closely, using the overlapping missions as a way for states to achieve some of their management goals through influencing Federal land management decisions.

A third factor is the decline in the availability of the aquatic resources to meet increasing demands. The quality and quantity of habitat have declined even as increased populations have sent more fishermen into the field. The decline in both quality and quantity of habitat stems from the competing use of streams and lakes for agriculture, industry, domestic use, livestock, energy development, recreation, and other uses. Alteration of the fish habitat to satisfy other demands has been the principal factor in the loss of fish habitat. It is seldom that there is a wholesale alteration of a basin; rather, losses have been the result of long series of smaller, accumulative alterations. The biologists are increasingly called upon to assist planners, providing input that can reduce negative impacts and help develop mitigation for other projects.

The fourth factor is the greater capability to conduct inventories and to process and store information obtained. Better instrumentation, remote sensing, and computers are among the many recent technological advances increasing the ability of biologists to conduct inventories, and to tailor their efforts for specific purposes.

Fisheries management is very much in a transitional phase. The factors mentioned are part of a larger change in resource management, which includes both a greater awareness of the values of natural systems and increased pressure on those systems. The shift in emphasis from a largely species approach to one putting greater stress on habitat is part of this transition. It has led to a number of trends in aquatic habitat inventories, trends which are represented in the papers to be given at this symposium.

- Data processing is becoming a major tool, and not only for storage and retrieval of data, but also for actual management of resources.
- More cooperative efforts are being made, not only within and between fisheries agencies, but also for actual management of resources.
- There is a greater degree of integration of aquatic resource inventory and planning with similar efforts for other resources.
- There is a much better definition of specific habitat components and better methods for measuring these components.
- Biologists are developing methods for relating the condition of specific habitat components to fish populations, and for predicting impacts of changes on the habitat and subsequently, on fish populations.
- Many inventories are being done for a specific purpose or resource use, rathern than for a broader management program
- A much wider range of inventory procedures, tailored to specific needs, is being developed and employed.

RECOMMENDATIONS

Based on the experience gained while organizing this symposium, and in the many discussions with participants and other biologists, I would like to offer some suggestions for future emphases in aquatic inventory development. These are really an extension of some of the current trends, but, I feel, need to be emphasized.

The first is the obvious need for a greater cooperation among biologists and improved exchange of information. Here in Oregon there is an excellent working relationship between the State and Federal land management agencies, more so perhaps than in any other western state. This has been of value for all involved in providing for exchanges of information, ideas and data. While it may not be possible to achieve a similar degree of cooperation in other states, I do think it is possible for all workers in the field to make a greater effort to coordinate and cooperate in developing and implementing aquatic habitat inventory systems.

This symposium is an outgrowth of a review of the cooperative inventory procedures used by agencies in Oregon. In the process of attempting to find what other workers were doing in the field, contacts were made with many government agencies, private groups and universities. It was obvious that a major problem was lack of a regular forum for exchange of information on developments in aquatic inventories. This symposium was an attempt to provide such a forum. What is needed is a regular forum for continued exchange of ideas and information. The new American Fisheries Society Journal of Fisheries Management could provide such a forum if biologists will use it. Such a regular, continuing forum is sorely needed.

The second recommendation is to put much more effort into integrating inventories for aquatic resources with inventories of other resources. As Dr. Clifford Hawkes discussed, a Five-way Team, representing five Federal agencies, is attempting to develop coordinated inventories for several resources. These kinds of efforts are needed to provide information for management of aquatic resources in cooperation with other resources. Biologists need to be familiar with these other resources, and be able to explain the needs of aquatic resources in relationship to other uses of aquatic systems.

Aquatic resources, and streams in particular, present a unique problem. Most other resources, such as soils, vegetation and timber, are dealing primarily with a stationary resource. Aquatic resources, on the other hand, are dynamic, and represent a summation, or integration, of influences from throughout a basin. Because streams are largely transport channels for water and dissolved and suspended materials, they can be influenced by any actions in the basin which alter normal run-off and erosion patterns. Fish habitat is determined by the amount of water, its quality, and interaction of the water with the substrate. Changes in a basin which alter any of the normal processes can alter the stream as habitat. A quick example is a diversion dam across the river which can permanently alter or eliminate habitat downstream for many miles. As a result, biologists need to be familiar with the impacts of other resource uses in a basin, and be able to determine their impacts on the aquatic habitat.

A third recommendation is to take advantage of developments that can improve the inventory capabilities of biologists. Some of these developments were mentioned earlier; many will be discussed during the symposium. Computer utilization would be perhaps the major advance that provides a new, highly useful tool for biologists. Remote sensing and many new instruments represents other examples of such advances. Aquatic biologists have been comparatively slow in adopting many of the new techniques. Since many of the techniques were developed for use with other resources, biologists are often unaware of their existence. Lack of funds, limited time and personnel, and the emphasis on species rather than habitat management have also contributed to the slow adoption of new techniques.

A fourth recommendation, and one which could greatly help in efforts to improve and integrate aquatic resource inventories, is a standardization of inventory components.This may be a very difficult recommendation to implement. I think just about every biologist at one time or another has developed his or her own inventory system. These systems tend not to be that different from one another, but each is developed for what the biologists feel is their own particular need. Some efforts have been made to develop a uniform inventory system. The American Fisheries Society, under the chairmanship of Bob Borovicka, attempted over a number of years to develop just such a uniform procedure, but were never able to find one acceptable to a majority of the committee members.

What I would suggest is a system similar to that developed by George Holton and associates in Montana, and, to a more limited extent, in other states and Canada, which provides a range of components developed in an automated storage and retrieval format. Some of these systems will be discussed in the symposium. The system I would recommend would not have a single field inventory form or procedure--the one real sticking point in trying to agree upon a single system--but, rather, would have standard definitions for habitat components and minimum standards for measurements of the components. Each biologist would then be free to use those components needed for his particular purpose, but with results that would be understood and recognized by other biologists. This would greatly facilitate efforts at exchanging information, automating inventories, integrating aquatic inventories with other resource inventories, allow for better analysis of aquatic habitat information and simplify development of new technologies and programs.

CONCLUSION

We are seeing major changes in aquatic habitat inventory capabilities. In the many discussions I have had, and the papers reviewed for this symposium, I have been impressed with some of the work being done in Canada. I was generally unfamiliar with work underway in Canada prior to this symposium, but have very much appreciated the opportunity to become familiar with the extensive inventories, and inventory procedure research, underway in Canada. We have a good cross-section of the work represented in this symposium. Hopefully, this symposium will fulfill its purpose as a forum for biologists to exchange information and ideas, and, ultimately, to better manage the aquatic resources that are so basic to life.

A CONCEPTUAL FRAMEWORK OF PROCEDURES TO SUPPORT NATIONAL ASSESSMENTS OF RENEWABLE RESOURCES[1]

Clifford L. Hawkes[2]

Abstract.--A conceptual framework is presented of procedures being developed by scientists at USDA Forest Service, Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colo. These procedures are to support national assessments and appraisals of renewable resources. The framework incorporates linear programming models to generate a range of feasible alternative ways of managing the nation's forests, range lands, agricultural lands, and associated waters. Each alternative consists of a management action, the joint costs, the jointly produced multiple renewable resources, and the resulting benefits and socio-economic impacts. Alternatives are sequentially generated at three hierarchical geographic levels: management unit, regional, and national. The alternatives generated at a lower level become inputs to the next higher level.

National assessments and appraisals of the renewable resources of the nation's forests, range lands, agricultural lands, and associated waters can provide a basis for improving the condition of the land and its ability to produce resources. Assessments provide information about the existing renewable resource situation and a range of possible situations or trends that could occur in the future given that various management strategies were applied to the nation's land and associated waters. Thus, assessments provide agency decision-makers, legislators, and the public with a basis for determining how the land will be managed. And they provide insight into what the results would be, over a period of time, of managing the land in a certain way. This paper presents a conceptual framework of procedures being developed at the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colo., to support national assessments and appraisals of renewable resources.

Various laws either mandate national assessments and appraisals of the nation's renewable resources, or they provide additional direction as to what assessments and appraisals should encompass and be. The Forest and Rangelands Renewable Resources Planning Act (RPA) of 1974, as amended by the National Forest Management Act of 1976, provides a legal mandate to conduct an assessment of renewable resources on forests and rangelands every 10 years. The Soil and Water Resources Conservation Act (RCA) of 1977 requires an appraisal of soil, water, and related resources every 5 years.

Adequate inventories (relatively direct measurements of existing, as opposed to future, stocks of the resources) and records for developing management policies for federal lands are required by the Federal Land Policy and Management Act of 1976. The Multiple Use-Sustained Yield Act of 1960 requires a joint or integrated consideration of the major outputs from the national forests. Environmental impacts of management activities must be evaluated to comply with the National Environmental Policy Act of 1969. The Resources Planning Act as amended by the National Forest Management Act, requires planning and assessments consistent with the Multiple Use-Sustained Yield and National Environmental Policy Acts. The planning and assessments must also be coordinated with the requirements of the Forest and Rangeland Renewable Resource Research Act of 1978, the Cooperative Forestry Assistance Act of 1978, and the Public Rangelands Improvement Act of 1978.

The RPA requires the Forest Service to take a lead role in developing techniques for conducting assessments of the nation's forests and range lands. In response to that requirement, the Land and Resources Management Planning (LRMP) Research

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[1]Paper presented at the symposium on acquisition and utilization of aquatic habitat inventory information. [Portland, Oreg., October 28-30, 1981.]

[2]Clifford L. Hawkes is a Research Aquatic Biologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Unit was established in October of 1981 at the Rocky Mountain Station. Research responsibilities of the LRMP Research Unit include developing analytical procedures for use in multilevel land and resource management planning. The procedures are designed to improve current analytic methods of estimating and evaluating ecological, economic, and socio-economic effects of land and resource management alternatives.

Agencies other than the Forest Service are required to conduct assessments, appraisals, inventories, or similar endeavors. For this reason, the Soil Conservation Service, the Bureau of Land Management, and the Fish and Wildlife Service are cooperating with the LRMP Research Unit at the Rocky Mountain Station.

The RPA specifies two tasks that must be carried out in an assessment that are particularly relevant to LRMP research efforts:

1. Analysis of present and anticipated uses, demand for, and supply of, the renewable resources, with consideration of the pertinent supply and demand price relationship trends.
2. Evaluation of opportunities for improving natural resource yield of tangible and intangible goods and services, with estimates of investment costs and direct and indirect returns to the Federal Government.

The remainder of this paper presents the conceptual framework developed by Wong (1980) and by scientists at the Rocky Mountain Station (Hoff 1982, Joyce et al. in preparation[3]) which provides the structure for the assessment-related research being conducted by the LRMP Research Unit at the Rocky Mountain Station.

This framework was put together given that national assessments of renewable resources must consider these resources to be produced jointly from the land, rather than separately. That is, the major interactions in the processes producing the different individual resources must be considered. The resource categories that are to be included are timber, forage, wildlife, fish, water, recreation, and minerals. Also, the assessments must be developed through a multidisciplinary process which will include ecological, economic, and sociological perspectives and analyses. And, the assessments must provide information needed for natural resource land management decision-making at three levels, the management unit level (e.g., Forest Service National Forest, Bureau of Land Management District), the regional level, and the national level.

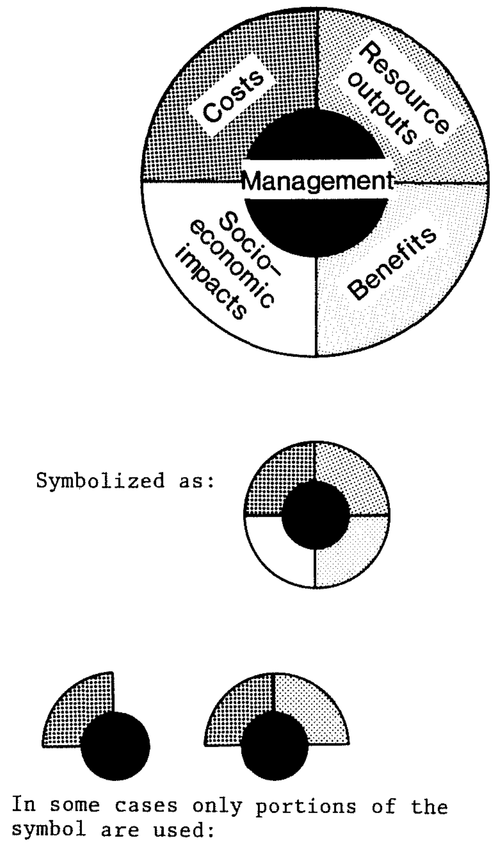

Figure 1.--Details of the symbol used to represent alternatives.

The framework incorporates the need for assessments to portray a range of resource opportunities or alternatives. Each alternative (Fig. 1) consists of a unique combination of (1) the particular mix of jointly produced resource outputs that result from the land management; (2) the joint cost of producing this mix or set of resource outputs; (3) the benefits accruing from the resources produced; and (4) the socio-economic impacts that result. Benefits are economic measures of the value to society of all outputs. Socio-economic impacts include distribution and stability of employment and income, which directly or indirectly results from the management activity.

Operation of the procedures making up the conceptual framework and which generate the alternatives begins with analysis areas, the smallest land units that are considered. Analysis areas are usually made up of pieces of land that are not contiguous, but which are considered to be relatively homogeneous in terms of resource output production response. They are combined to make up a management unit such as a National Forest.

It should be pointed out that, at the present time, the land units or analysis areas which form a management unit, such as a National Forest, usually do not represent true ecosystems. However, in some cases a watershed represents a single

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[3]Joyce, L. A., B. McKinnon, J. G. Hof, T. W. Hoekstra, and J. Whelan. (in preparation) An Overview of Integrated Resource Production Analysis. USDA Forest Service General Technical Report RM-000. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

analysis area; and many ecologists would consider this to be an ecosystem (Lotspeich 1980, Hynes 1977, Odum 1969, Likens, et al. 1977).

Nevertheless, at this point in the overall framework or assessment procedure, we are interested in modeling the ecological behavior of the land or analysis areas. And, specifically we are interested in modeling the response of analysis areas to application of management actions. Thus, in order to predict the resource outputs that would result, the predictive model of the analysis area being used must include all the variables that would be affected by a contemplated management action. The analysis area is considered to respond to application of the management action in terms of a unique set of jointly produced resource outputs that would result through various interacting processes.

In order to predict the response of analysis areas to management actions the following steps must be completed:

1. The landscape must have been classified into analysis areas or homogeneous response units.

2. Given the analysis areas, each with unique characteristics, the significant variables describing the structure of and processes within the analysis area have to be identified. The variables affected by the management actions must be included.

3. Models must be developed to predict the resource outputs of the analysis areas.

4. Observed or calculated data for the variables must be obtained for use in the models of the analysis areas.

Thus, given information concerning the significant variables for an analysis area and a model of the analysis area, the response to a particular and appropriate management action can be predicted. That response is given in terms of a set of jointly produced resource outputs. A unique combination of information is formed by linking a specific management action that could be applied to an analysis area with the joint cost of that management and with the predicted set of resource outputs (Fig. 2).

This procedure is repeated on the same analysis area for an array of different and appropriate management actions. The entire procedure is repeated for each analysis area within a management unit (e.g., National Forest) (Fig. 3). The result is an array of combinations. It is essential that the predictions of the jointly produced resource outputs be as accurate and precise as possible. Errors introduced at this point are accumulated through the entire assessment procedure and could result in very low quality, or even useless or misleading information, making up the national alternatives.

All the information on the area combinations for the analysis is entered into a management unit linear programming model (or alternatives generator). The management-unit-level linear programming models analyze the detailed land production information. They assign optimal (according to selection criteria and under any constraints imposed) allocation of land to management actions, and they estimate joint resource output capabilities of the land so managed. The analysis process involves selecting out a group of the jointly produced resource-output/management-action/joint-cost combinations, from all of those developed for all the analysis areas contained in a management unit (e.g., National Forest). This group of combinations is calculated to meet one selection criteria, given any constraints imposed.

Some examples of criteria which might be used for selecting these combinations are the following:

1. To maximize cash flow (which is a way of emphasizing market goods).

2. To maximize present net worth (which includes market and nonmarket benefits that can be measured).

3. To emphasize nonmarket goods and services. Examples of nonmarket resource outputs include dispersed recreation, wildlife and fish habitat, and environmental quality.

4. To emphasize regional economic development.

Some examples of constraints that might be imposed are the following:

1. Suspended sediment concentrations in streams shall not exceed a specified concentration.

2. Viable populations of all wildlife and fish species currently existing on an analysis area will be maintained.

3. Buffer strips no less than 200 feet wide will be left along all streams.

4. Water temperatures 25 miles below all dams will not exceed 60° F.

Each of these groups of selected combinations forms part of one management unit alternative (i.e., joint resource outputs, management, and joint costs) (Fig. 1). The linear programming model is linked to a socio-economics model and through this linkage, socio-economic impacts are estimated. The linear programming model or alternatives generator also estimates benefits, thus completing the elements for one management unit alternative. A range of alternatives is generated by using several different selection criterion. Each criterion used results in one alternative. Different alternatives can also be generated by introducing or varying the constraints.

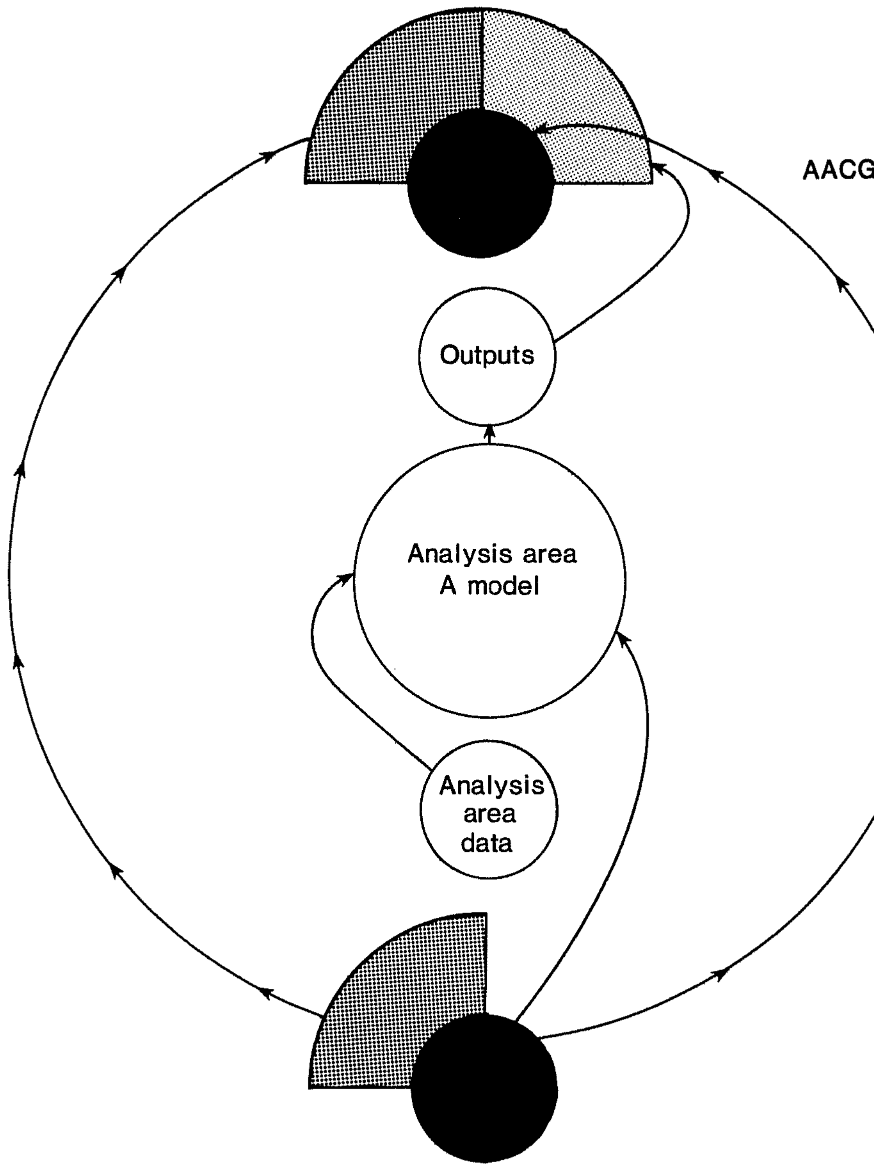

Figure 2.--Analysis area combination generation (AACG) scheme for generating an analysis area joint-resource-outputs/management-action/joint-cost combination.

A diagram of the overall conceptual framework (Fig. 3) schematically shows the process of generating alternatives at the regional and national levels, as well as at the management unit level. The alternatives generated at the regional and national levels are also produced by linear programming models (alternatives generators) linked to socio-economic impacts models. These models also estimate benefits. However, a linear programming model at the regional or national level only utilizes alternatives as input, and only those alternatives generated at the level immediately below it. Each of these linear programming models selects alternatives from the lower levels according to specific criteria similar to the criteria used at the management unit level. An additional difference from the procedure at the management unit level is that the regional and national level linear programming models do not analyze detailed land production information as do the management unit models.

The national alternatives that are generated by this process provide national level agency decision-makers, legislators, and the public with a range of feasible possibilities from which to choose in specifying what the agency will do. And, they provide a picture of the results to expect, in terms of resource outputs, benefits, socio-economic impacts, and costs for each of the alternatives. Alternatives generated at the regional and management unit levels provide similar information for renewable resource planners and managers as well as for the general public. Each national alternative can be traced back through the process to all the regional and management unit alternatives and to the analysis area joint-resource outputs/management-action/

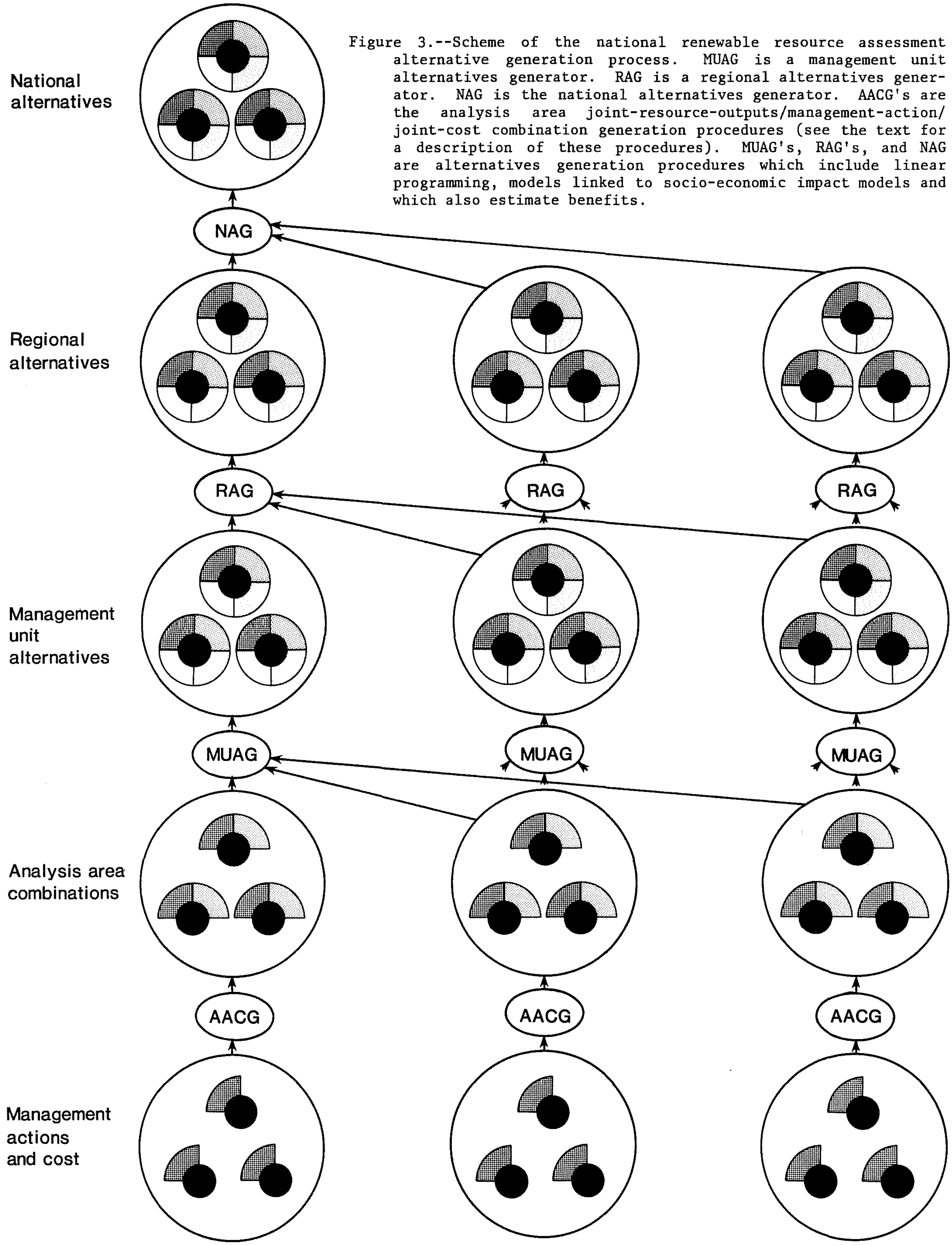

Figure 3.--Scheme of the national renewable resource assessment alternative generation process. MUAG is a management unit alternatives generator. RAG is a regional alternatives generator. NAG is the national alternatives generator. AACG's are the analysis area joint-resource-outputs/management-action/joint-cost combination generation procedures (see the text for a description of these procedures). MUAG's, RAG's, and NAG are alternatives generation procedures which include linear programming, models linked to socio-economic impact models and which also estimate benefits.

joint-cost combinations that were used in arriving at any specific national alternative.

To summarize the process:

1. Analysis areas are identified and modeled. The models must include the variables that would be affected by the management action;

2. Data relevant to the variables in the model are obtained;

3. An appropriate management action is considered that could be applied to an analysis area;

4. Analysis area response is predicted in terms of sets of jointly produced renewable resource outputs;

5. That response has a particular quality and quantity;

6. The management action, its joint cost, and the jointly produced resource outputs associated with that management action, as applied to a particular analysis area, are linked together and represent one unique combination;

7. Joint-resource-output/management-action/joint-cost combinations are generated for each management action that might be applied to a particular analysis area.

8. All such combinations from all the analysis areas within a management unit are then put into the management unit alternatives generator, which is a linear programming model linked to a socio-economic impact model and which also estimates benefits;

9. The management unit alternatives that result are then put into regional alternatives generators, which are also linear programming models, are also linked to socio-economic impact models, and which also estimate benefits;

10. Regional alternatives are input into the national alternatives generator, which is, again, linked to a socio-economic impact model and which also estimate benefits, to produce the national alternatives.

11. Each national alternative can be traced back through the process to all the regional and management unit alternatives and to the analysis area joint-resource-outputs/management-action/joint-cost combinations that were used in arriving at any specific national alternative.

12. Any one of the national alternatives that might be selected by decision-makers for implementation will provide the basis for managing the nation's forests, range lands, agricultural lands, and associated waters.

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SESSION 2A

Moderator: Tom Webber
Aquatic Studies Branch,
Victoria, B.C.

The Following Not Included in Proceedings:

C.S. Shirvell, Canada Fisheries and Oceans, Halifax, N.S.
Objective Differentiation of Pool and Riffle Habitat Based on Transect Data

SYSTEMATIC AQUATIC BIOPHYSICAL INVENTORY IN BRITISH COLUMBIA, CANADA[1]

T.W. Chamberlin[2]

Abstract.--A methodology for describing and mapping stream reaches at a detailed reconnaissance level (1:50 000) has been developed and applied on about 3.5×16^6 km^2 in British Columbia. The inventory is based on a hierarchy of watershed, reaches, and point samples and may be applied at various levels of sampling intensity.

Inventory data is stored on maps and in the B.C. Aquatic Data Base with a similar hierarchical structure, and can be sorted and retrieved to serve a number of planning and management functions. Some applications and limitations of the inventory system are discussed.

INTRODUCTION

Aquatic system inventory in British Columbia has traditionally served the needs of management agencies responsible for the various resources of river and lake systems. Hence, there have long been surveys of fish populations, enhancement opportunities, discharge, water quality, channel erosion and sedimentation, and floodplains. These surveys were, and are, carried out by separate agencies. Moreover, the data, maps and reports generated are limited in distribution, at different scales, use differing methods and are very difficult to integrate for basin level, or comparitive analyses (fig. 1) such as required by strategic planning.

Such a state of chaos is, of course, normal in a developing region which emphasizes separate and development oriented management of its natural resources.

In 1975 a small section of the (then) Environment and Land Use Committee, Secretariat was charged with developing an integrated approach for the description of aquatic systems parallel to those already existing for terrestrial systems (Thie and Ironside, 1976) in Canada. Walmsley (1976) described the early system and contrasted it to the soil, terrain, vegetation, climate and wildlife surveys which comprised the basic components of British Columbia's biophysical methodology of that time.

A series of workshops and discussions with data users confirmed that consistent overlaps exist in required information and that a core of aquatic biophysical data could be defined which served many user's needs.

Aquatic systems contain a number of processes and characteristics which are scale and time dependent. Table 1 from Welch (1976) illustrates this hierarchical arrangement of processes in fluvial systems. These differences of process and scale are nowhere better represented than in British Columbia with its range of climate and topography from desert to mountain rainforest. This system variability led to the rough classification of types of surveys and related applications illustrated in table 2. Again, however, a survey of users and

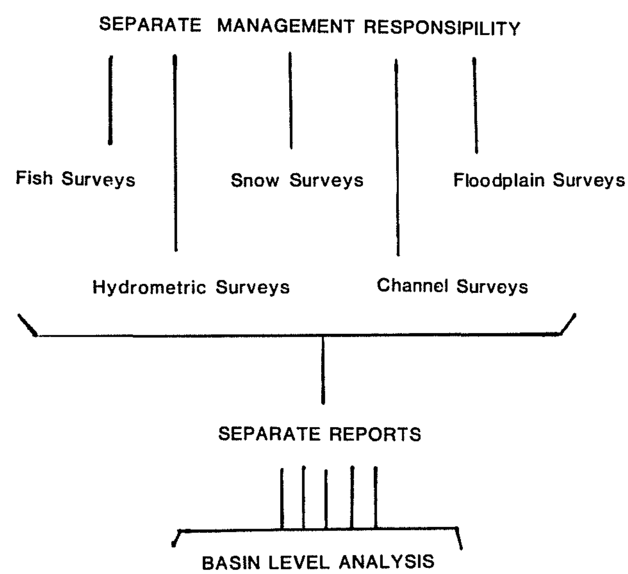

Figure 1.--Separate Surveys

[1] Paper presented at Symposium on Aquisition and Utilization of Aquatic Habitat Inventory Information, Portland, Oregon. October 28-30, 1981.

[2] Acting Head, Standards and Data Unit, Aquatic Studies Branch, B.C. Ministry of Environment, Victoria, B.C.

management applications suggested that many of the same basic kinds of aquatic information could be gathered at the various inventory scales, although at different levels of intensity and accuracy. Figure 2 illustrates this component biophysical approach.

These considerations led to a choice of a base inventory mapping scale of 1:50 000 at the reconnaissance level as most appropriate and flexible for British Columbia. The methodology has since been generalized (in the Yukon) to 1:100 000 and refined (in greater Vancouver) to 1:5000, but the basic format has remained consistent for about 5 years. During that time about 250 1:50 000 map sheets (National Topographic Series) have been covered, an area of about 3.8×10^6 km^2. Figure 3 illustrates the areas of British Columbia which have received systematic aquatic biophysical surveys. As can be seen, the surveys tend to leap major basins with a single bound, and hence are usually oriented to major resource planning and assessment problems. Harding (in press) describes some applications of the data. The reconnaissance survey is frequently supplemented by more intensive single purpose surveys of fish populations, water quality, etc. which can be efficiently priorized using the reconnaissance level information.

In the discussion which follows, repeated reference will be made to the reach, a biophysical entity defined as "a repetitious sequence of physical processes and habitat types" (Chamberlin, 1980a). At the reconnaissance level of inventory, the reach is the basic sampling, mapping and management unit. The most important function of the inventory process is to describe the reach's properties.

Table 1.--A Hierarchy of Fluvial Environments

FLUVIAL ENVIRONMENT	ECOLOGICAL LAND CLASSIFICATION LEVEL AND PRESENTATION SCALE	SUITABLE CLASSIFIERS	CONTROLS
RUNOFF RESPONSE	Facet 1:1000	Length of overland flow Drainage density Infiltration capacity Local relief	Physiography Soils Vegetation
HYDRAULICS	Type 1:10 000	Bedforms Roughness	Discharge Gradient Sediment Parent material
REACH HABITAT	System 1:50 000	Bank form Riverine vegetation Bedload Riffles, pools, falls, rapids Depth, width	Physiography Channel dynamics Debris load
CHANNEL PATTERN	System 1:50 000	Sinuosity index Pattern class	Debris load Energy relations
VALLEY FORM	System 1:50 000	Plan pattern Cross shape Terraces Under and over-fit	Tectonic history Geomorphic history Eustatic history Geology
DRAINAGE TOPOLOGY	System-District 1:50 000-1:250 000	Bifurcation Order Magnitude Basin shape	Growth Geology
DRAINAGE PATTERN	District-Region 1:250 000	Pattern River capture	Geology
RIVER REGIME	Region 1:500 000+	Lag time Basin size Precipitation Snow Base flow Etc.	Climate Physiograpy

1 Adapted from Welch, 1978, p. 33.

Table 2.--Levels of Aquatic Survey

LEVEL	OBJECTIVES	SAMPLING	NO. OF SAMPLES
I Broad Overview	REGIONAL Comparisons 1:100 000 to 1:500 000 Provincial planning	REMOTE Sensing Existing data only 80 ch. to ERTS imagery	NONE
II Reconnaissance	BASIN comparisons 1:50 000 Reaches defined obstructions located Fish sp. presence/absence Regional or strategic planning	AERIAL observation Reach parameter estimates Few point samples 20 - 80 ch. aerial photos	FEW
III Detailed Inventory	MANAGEMENT 1:10 000 - 1:20 000 Habitat types described Population sizes measured Sub-regional or Operational planning	GROUND transects Reaches subsampled Detailed aerial photos	MANY
IV Intensive Studies	SITE SPECIFIC Engineering design Population ecology Time functions established Productivity estimates Project design	REPETITIVE sampling Experimental work	MANY

INVENTORY METHODOLOGY

Factors Related to the Level of Survey

From table 2 it is apparent that several survey factors are affected by the choice of reconnaissance inventory scale. Observation is primarily aerial and is derived from air photo interpretation (usually at a scale of 1:50 000±) and helicopter overflights at about 70 km/h. Ground sample density is very low (1-3 per basin) and all reaches may not even be sampled. Many reach parameter values are visual estimates rather than measured values and as a general rule the reach is neither walked or subsampled.

Because of the emphasis which we place on remote sensing, air photo interpretation skills become very important in the survey process. Our biologists and technicians have had to develop an appreciation for fluvial geomorphic processes, basic channel hydraulic theory and the interrelations between channel patterns and aquatic habitat types. This has been an enlightening process with the useful byproduct of a generation of fish biologists becoming equally fluent in the jargon of geology and geomorphology.

In the reconnaissance survey, ground sampling is usually opportunistic, serving as a check on remote sensing interpretations and as a indicator of fish species distribution rather than as the primary sampling for reach descriptors. Limited access and once only sampling severely restrict the utility of "point" measurements unless they are known to be characteristic of the reach being sampled.

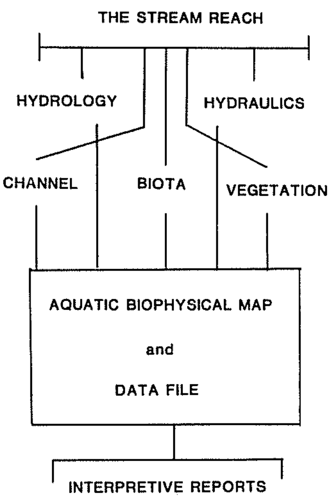

Figure 2.--Biophysical Survey

The Biophysical Reach

The concept of a relatively homogeneous river reach is certainly not new. In the British Columbia survey process, the reach forms the basis for sampling strategy, mapping and management interpretations. At the reconnaissance scale, the inventory describes the general abundance of geomorphic elements and biotic characteristics for each reach. Figure 4 illustrates the reach data card with the major categories of information highlighted. From these data and air photos, the likelihood of various complexes of habitat types may be inferred, and hence the most appropriate locations for more detailed sampling.

Reaches defined at the reconnaissance scale aggregate a substantial amount of in-stream habitat variability. For example, an entire valley of meandering alluvial stream and all its pool-riffle complexes would be identified as a reach. Only where basic geologic and hydraulic process controls change would a new reach be defined (e.g. major slope or materials supply difference). We definitely encourage "lumpers" rather than "splitters" at the reconnaissance level of aquatic inventory.

The Point Sample

As has been mentioned, the point sample is primarily designed to provide ground truth for air photo interpretations, define fish species presence or absence, and give a spot measurement of water flow and quality. Ground sampling also provides the ellusive but invaluable "feel" for a system required by most biologists before interpretive conclusions can be made.

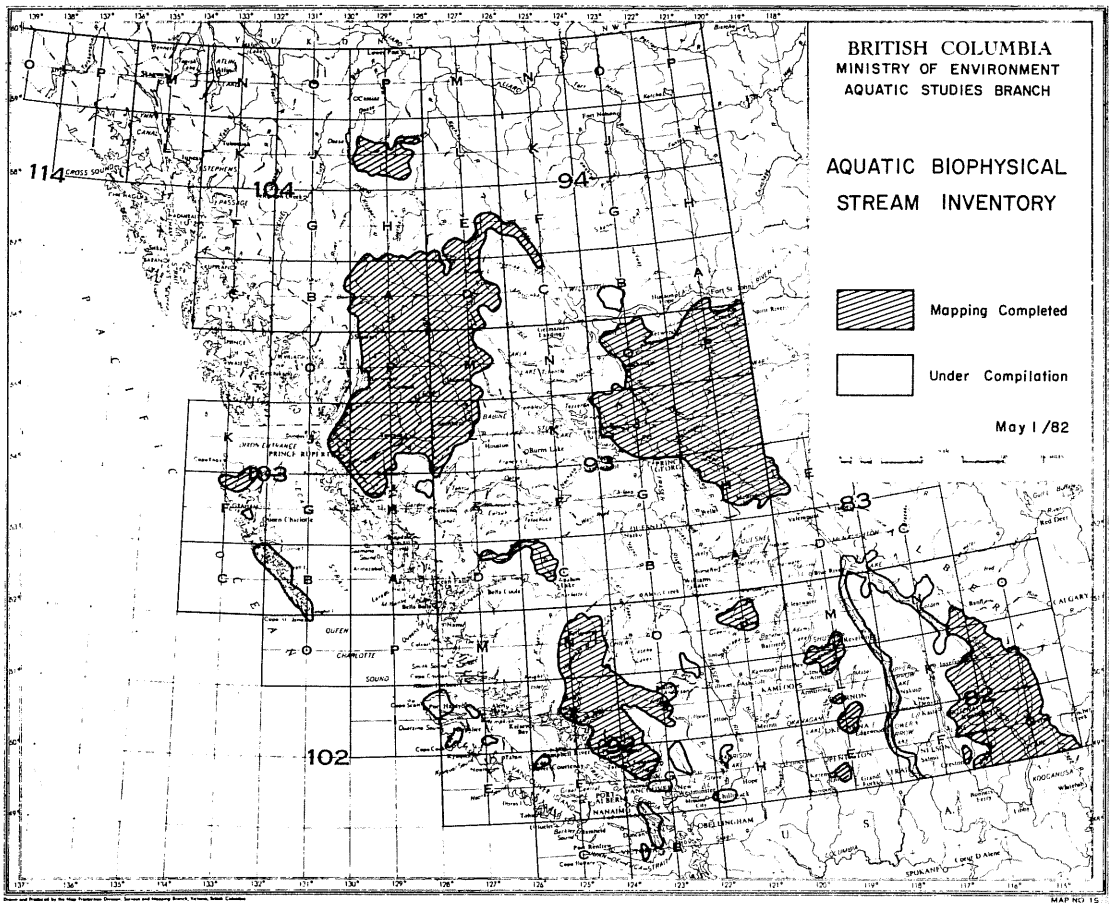

Figure 3.--Areas of British Columbia Covered by Aquatic Biophysical Surveys

Point sample data (fig. 5) are very similar to those describing reaches, with greater emphasis placed on descriptions of bed and bank materials and hydraulic factors. Point data characterize a fictitious "point", averaging the variability across the stream and, in fact, within the immediate up and downstream environment of the sample location. The parameter fields for the point sample incorporate data of varying accuracy, ranging from measured to subjective low-moderate-high assessments. It follows that interpretations based on point sample data must be carefully designed to recognize the limitations of reconnaissance sampling methods.

In the more intensive biomass loading surveys done in British Columbia, (deLueew, in press) point sample data are collected for each basic habitat type within a reach, leading to a more accurate characterization of the distribution of habitat types within reaches. These intensive surveys are an invaluable complement to the reconnaissance level survey, as they add to our capability to make inferences from the larger geomorphic indicators observable through remote sensing.

The Mapping and Data Compilation Process

Field data about reaches, points and fish samples are compiled in the office. The compilation process, including editing, mapping and data entry, occupies about twice that of field operations. It cannot be overemphasized that this phase is critical to the transformation of survey data into useful information.

Aquatic Biophysical Maps, compiled and presented at a scale of 1:50 000 on a topographic base, summarize 4 basic physical reach

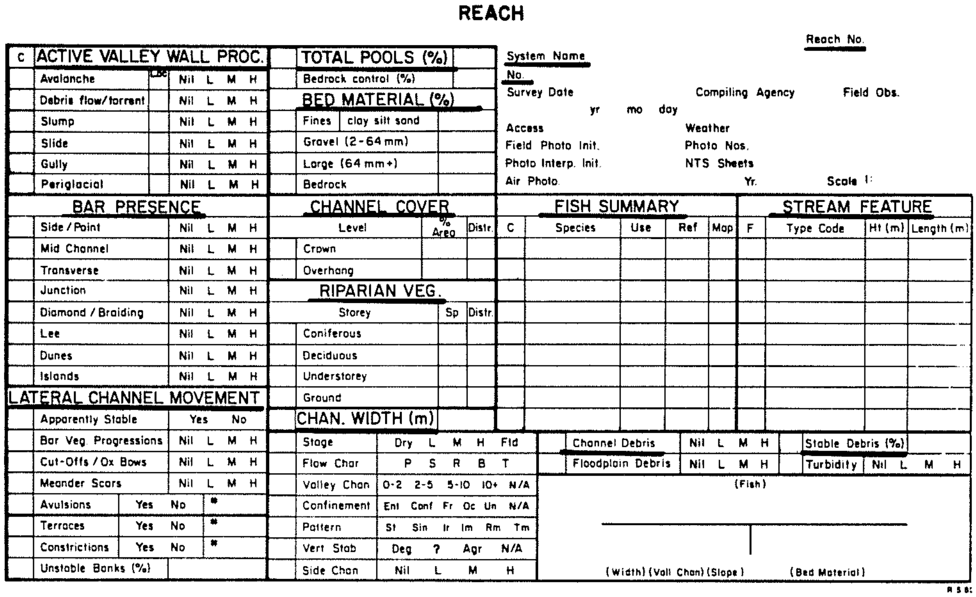

Figure 4.--The Reach Data Card

properties (channel slope and width, floodplain width, bed material), fish species present, and in-channel features. Sample point locations are also mapped. Figure 6 illustrates a typical map and fig. 7 shows portions of the current map legend.

It should be emphasized that this standard map displays only a small subset of the data captured during the survey. Maps have been devised with emphasize other reach properties, or which isolate particular features of interest (e.g. waterfalls higher than 1 metre). The advent of computer mapping linked to the data base will permit specific derivative or interpretive maps to be produced as required. Such a system (CAPAMP - Computer Assisted Planning And Mapping Program) is being implemented in the B.C. Ministry of Environment during 1982.

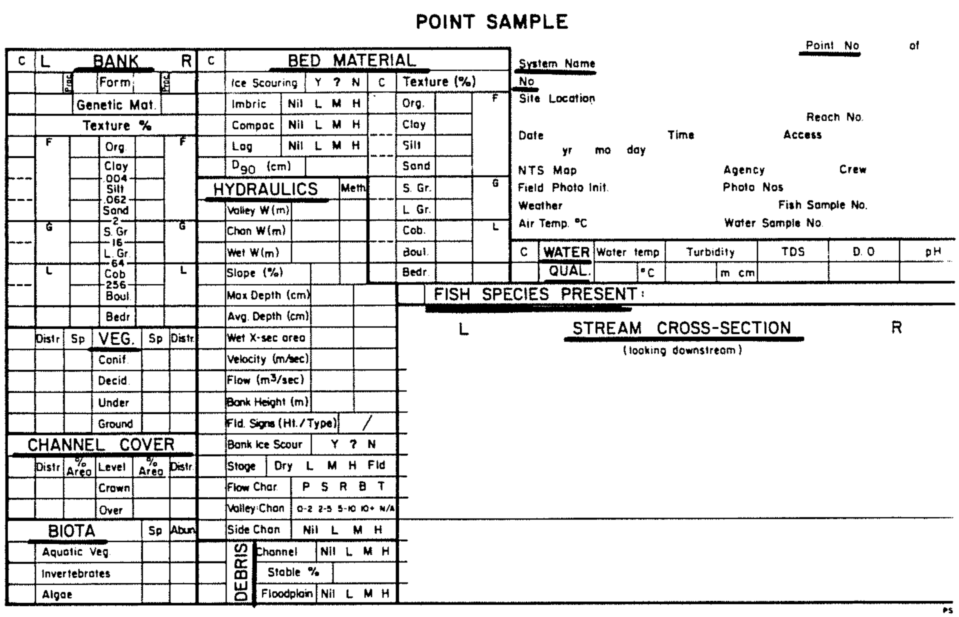

Figure 5.--The Point Sample Data Card

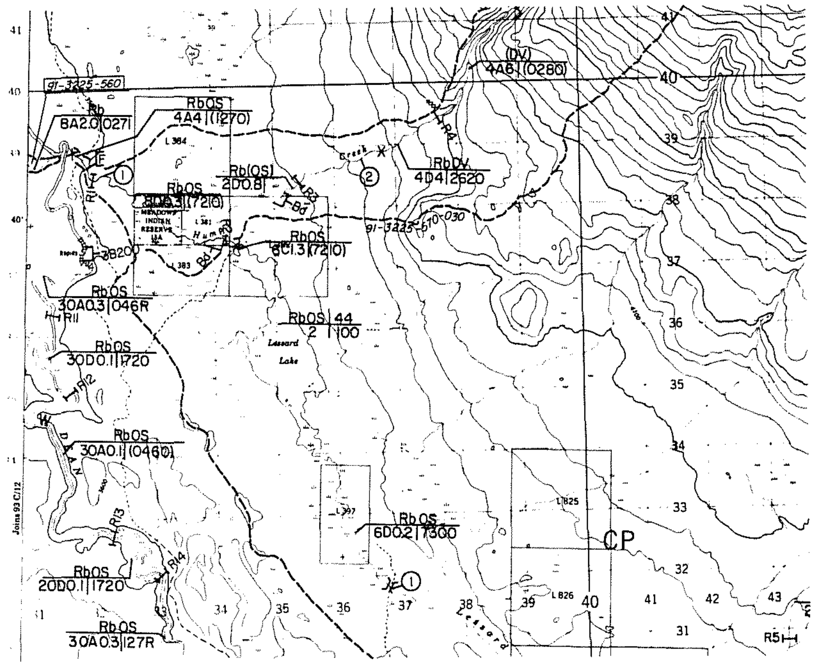

Figure 6.--Portion of an Aquatic Biophysical Map

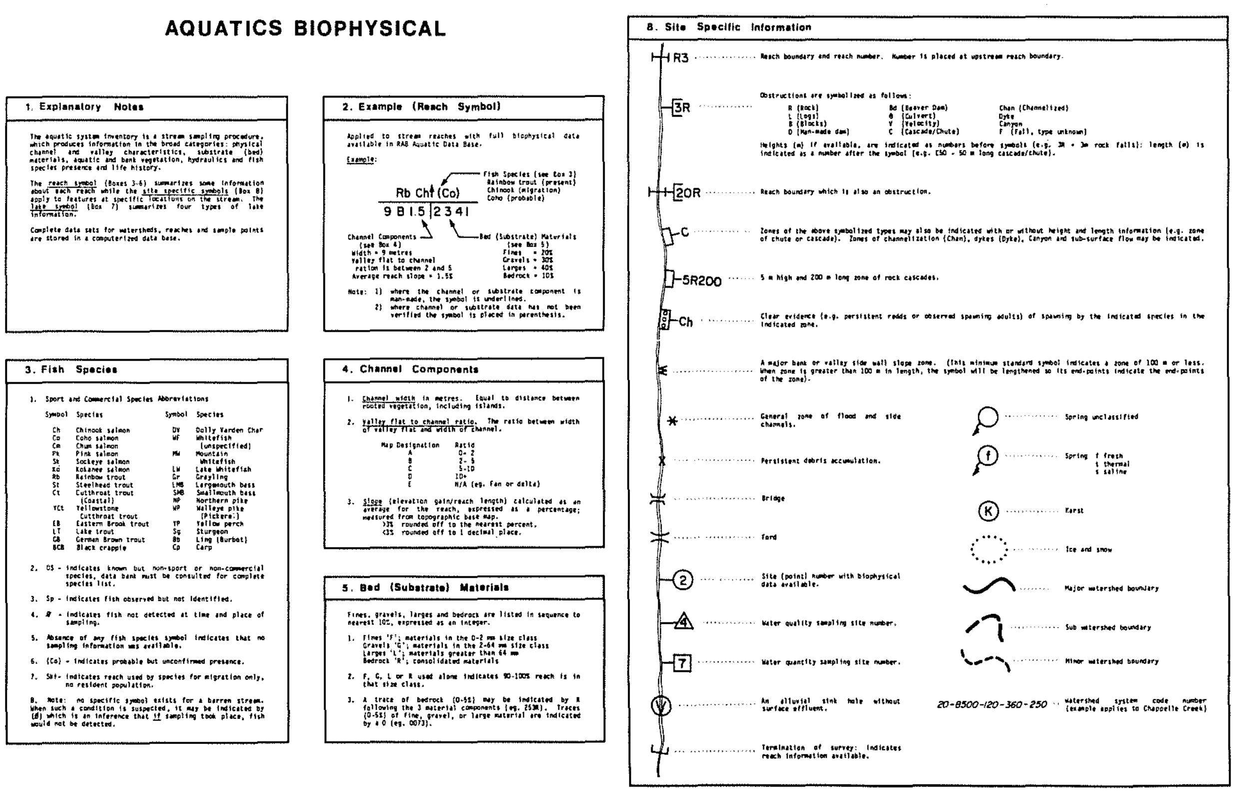

Figure 7.--Aquatic Biophysical Map Legend

Data compilation also includes a process during which the location (latitude, longitude) and distance upstream from mouth of all features, sample locations and reach boundaries are digitized. This process provides the relational (upstream-downstream) ordering for the data base and serves to structure several of the tabular output tables. Digitizing table accuracy is ±0.2 mm, although cartographic and survey limitations make this a very optomistic upper limit.

Data compilation is completed when all reach, point, fish and map digitizing data have been successfully edited and entered into the B.C. Aquatic Data Base.

THE B.C. AQUATIC DATA BASE

British Columbia's Aquatic Data Base is a hierarchical system, structured by watershed, reach, point and fish sample. It is accessed through the hierarchical watershed code described by Shera and Grant (1980) and presented later in this session. The tributary hierarchy defined by the watershed code, together with the upstream-downstream relational hierarchy defined by the digitizing process, create an ordered spatial and temporal data base suitable for a variety of applications. It also has the capability to provide the structure for storing any other data (e.g. cultural or economic) which are associated with stream channels or basins. Basin watershed codes are available for all of B.C. and much of the Yukon through eight levels of system hierarchy, and may soon be implemented in Alberta.

The B.C. Aquatic Data Base structure parallels the organization of field data described above. A system level file stores basin morphometric data such as area, perimeter and elevations as well as a history of surveys and other studies. The reach, point and fish files handle data from those respective field cards whilst the digitized map feature data are apportioned to their respective reaches.

Sets of specialized data for particular systems (e.g. detailed population data) may be handled through files which are coordinated with but not actually part of the main Aquatic Data Base.

Report outputs from the Aquatic Data Base are available in a variety of standard formats, basically paralleling the file structure described above. Examples of three standard report formats are illustrated in figs. 8-10.

The Aquatic Data Base is written in MARK IV, a high level programming language, and is fully documented. It is operated on the B.C. Government's IBM 1130 system and can be accessed by outside users for the processing of compatible data sets. Standard statistical analyses can be applied to any portion of the Data Base.

Future developments to the Aquatic Data Base will emphasize linkages to other sets of aquatic data of importance to the Ministry of Environment's management responsibilities. These include water, water quality and fisheries management, all of which clearly require integrated information management.

INTERPRETATIONS AND APPLICATIONS

The systematic inventory system described above contains a broad range of aquatic biophysical data, hopefully central to a wide variety of interpretive applications. Some interpretations have become more or less standard, although frought with the usual uncertainty; these are briefly summarized here. It must be re-emphasized that in British Columbia we are in our infancy with respect to understanding the application of biophysical inventory data to the processes controlling aquatic systems.

Fisheries Productivity and Capability

Present productivity is not normally estimated from the reconnaissance survey since biomass loadings are not measured and sampling is done once only. Rather, the observed habitats serve to suggest capabilities for fisheries productivity. Such information is used by the habitat protection biologist in land use planning, in the design of habitat improvement or enhancement surveys and as input to the strategic level of resource management where comparisons between alternative resource values are required.

Regionalizations of fisheries capabilities from the systematic inventory data have been attempted in the Columbia Basin, in the N.E. Coal Block (Peace River Drainage) and on some coastal systems. These high level generalizations have usually been mapped at a scale of 1:250 000, and hence are most appropriately used for basin level planning such as the choice of alternate transportation corridors, townsite or port locations and for determining management area priorities.

In the near future we intend to merge the higher intensity biomass loading surveys carried out by the B.C. Fish and Wildlife Branch with the reconnaissance level systematic inventory to improve our regionalization capability.

AQUATICS DICTIONARY REPORT - NUMERIC LISTING PAGE 1

RAB	NO.	EQUIS	WATERSHED NAME	STREAM ALIAS	L/R BANK	LOCATION COMMENT	DATA AVAILABLE
91 3225	000 000 000 000 000	212200	DEAN RIVER				R/P
	050 000 000 030 000		NOOSKULLA C				
	060 000 000 000 000		NAN C				
	070 000 000 000 000		NUGLEIGH C				
	100 000 000 000 000	212201	SAKUMTHA RIVER				R
	020 000 000 000		SKUCE C				
	120 000 000 000 000		BERNHARDT C				
	160 000 000 000 000	212202	KALONE C				R
	210 000 000 000 000		CRAG C				
	240 000 000 000 000	212203	TAKIA RIVER				
	100 000 000 000	212204	TAHYESCO RIVER				
	020 000 000		UNNAMED C		R		
	050 000 000		COMPASS C				
	030 000		TZELTSAYTSUL C				

Figure 8.--Aquatics Dictionary Report - Numeric Listing

FEB 15, 1982 AQUATICS INVENTORY SYSTEM - POINT SAMPLE AND FEATURE LISTING SUMMARY PAGE 1

SYSTEM NUMBER	91 3225 600 000 000 000 000	SYSTEM NAME	TUSULKO RIVER	NUMBER OF REACHES	9
MAXIMUM ELEVATION (M)		MAINSTEM AZIMUTH (DEG)		NUMBER OF LAKES	
OUTLET ELEVATION (M)		LENGTH LONG AXIS (KM)		NUMBER OF POINTS	4
AREA (KM2)		MAINSTEM LENGTH (KM)	39.2	SURVEY YEAR	
PERIMETER (KM)		EXTENT MAINSTEM SURVEYED (KM)	25.9	MAP SCALE	1/
NTS MAP SHEETS	093C11 093C12				

KM FROM START OF SURVEY C	FEATURE	LENGTH (M)	HEIGHT (M)	ELEV. (M)	LATITUDE	LONGITUDE
	OUTLET					
0.0	REACH 1.00 (R)					
1.2	ROCK	20	1.0		52 35 26	125 28 20
1.7	REACH BREAK 1.00	1700		1097	52 35 12	125 28 27
1.7	REACH 2.00 (R)					
2.5	FLOOD/SIDE CHANNEL ZONE				52 34 57	125 28 56
3.0	REACH BREAK 2.00	1300		1116	52 34 53	125 29 07
3.0	REACH 3.00 (R)					
3.6	SLUMP				52 34 44	125 29 29
3.9	ROCK	30	2.0		52 34 44	125 29 45
4.9	ROCK	10	1.0		52 34 36	125 30 27
5.7	ROCK	10	5.0		52 34 29	125 31 06
5.9	ROCK	30	2.0		52 34 26	125 31 09
6.1	ROCK		10.0		52 34 19	125 31 16
9.0	ROCK		4.0		52 34 00	125 31 17
9.5	ROCK		2.0		52 33 59	125 31 40
9.5	REACH BREAK 3.00	6500		1265	52 33 59	125 31 40
9.5	REACH 4.00 (R)					
9.7	SLUMP				52 33 56	125 31 46
10.2	DEBRIS ACCUMULATION				52 33 55	125 34 06
10.4	SLUMP				52 33 53	125 34 14
10.7	DEBRIS ACCUMULATION				52 33 48	125 34 22
11.0	SLUMP				52 33 47	125 34 35
11.4	SLUMP				52 33 41	125 34 51
12.1	FLOOD/SIDE CHANNEL ZONE				52 33 35	125 35 13
13.1	SLUMP				52 33 38	125 35 48
14.6	SLUMP				52 33 29	125 36 39

Figure 9.--Point Sample and Feature Listing Summary Report

FEB 09, 1982 AQUATICS INVENTORY SYSTEM - FISH SPECIES DISTRIBUTION

SYSTEM NO:	91 3225 600 000 000 000 000	SYSTEM NAME (OR ALIAS):	TUSULKO RIVER		
NO. OF REACHES:	9	MAINSTEM LENGTH (KM):	39.2	MAX. ELEV. (M):	
NO. OF LAKES:		AREA (SQ. KM):		OUTLET ELEV. (M):	
NO. OF POINTS:	4	PERIMETER:			

FISH DISTRIBUTION BY REACH

REACH	DISTANCE UPSTREAM (KM)	COMMENT NUMBER	SPECIES *	USE * +	REFERENCE
1.00	1.7	03	(DOLLY VARDEN)		
			RAINBOW TROUT		
2.00	3.0	05	(DOLLY VARDEN)	S R	
		05	(RAINBOW TROUT)	S R	
3.00	9.5	01	(DOLLY VARDEN)		
4.00	16.6	03	(DOLLY VARDEN)		
5.00	19.4		(DOLLY VARDEN)		
6.00	20.9		(DOLLY VARDEN)		
		01	RAINBOW TROUT	R	
7.00	22.5		(DOLLY VARDEN)		
8.00	25.9	02	(DOLLY VARDEN)	S R	
		02	(RAINBOW TROUT)	S R	

* ( ):INFERRED + R:REARING
M:MIGRATION
S:SPAWNING

Figure 10.--Fish Species Distribution Report

Channel Stability and Floodplain Evaluation

The second major area in which the systematic data are being applied is in the evaluation of channel stability. A study to compare the utility of the B.C. Aquatic Data Base in delineating channel stability categories similar to those of the U.S. Forest Service method described by Pfankuch (1975) is presented elsewhere in this symposium (Karanka, et al., in press). A derivative of these assessments is the indication of extent and type of near-stream flooding as inferred from soil, vegetation and terrain indicators.

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USING THE BRITISH COLUMBIA HIERARCHICAL WATERSHED CODING SYSTEM TO ORGANIZE BASIN DATA[1]

W. Patrick Shera[2]

Abstract.--A hierarchical numbering system for coding basins has been developed and used to store and retrieve data about the watersheds of British Columbia and the Yukon. The system can be applied across eight levels of basin hierarchy, and used for all information which is geographically associated with a basin.

INTRODUCTION

Stream channels and their tributaries are naturally organized, directional, and hierarchical. These characteristics readily lend themselves to organizing data files about channels and other similarly-ordered aspects of the landscape (such as basins).

The concept of the watershed coding system consists of repeatedly dividing and subdividing the landscape on a watershed basis into smaller and smaller units until some desirable minimum basin size is identified. Each basin is assigned a watershed code number based on its hierarchic position relative to its receiving waters. This code plus the distance upstream from the channel's mouth permits accurate locating of site specific channel features.

The British Columbia watershed coding system was designed to organize data collected at a reconnaissance scale inventory through up to eight levels of basin hierarchy. Six years of testing on some 14 000 basins has proven it sufficient to catalogue all channels and basins large enough to be represented on a 1:50 000 scale topographic map.

Although initially designed to organize the computerized British Columbia Aquatic Data Base, this watershed coding system can accommodate any information which is associated with a basin. It is equally applicable to manual files and is even being used to organize photographs of landscape features. Its use can be expanded to catalogue strategic planning information which uses the watershed basin as a management unit.

[1] Paper presented at the Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information (Portland, Oregon, 28-30 October, 1981).

[2] W. Patrick Shera is Standards Coordinator (Acting), Aquatic Studies Branch, B.C. Ministry of Environment, Victoria, B.C. V8V 1X4.

METHODOLOGY

The British Columbia watershed coding system consists of dividing and subdividing the landscape into units based upon watersheds and sequentially and hierarchically numbering those units. A channel is assigned the number used to designate its drainage basin.

A watershed number is assigned to each basin depending upon its hierarchy within the overall drainage, i.e. sub-basins have numbers that are subsets of their parent basin's number (fig. 1). Further, sub-basins of equal hierarchy are numbered in series with lowest numbers nearest the basin outlet and highest numbers nearest the headwaters. Therefore, two numbers that are numerically similar are geographically proximal. Generally, neither basin size nor channel discharge is a criterion for a watershed's location in the hierarchy. Its relationship to receiving waters dictates its position in the hierarchy.

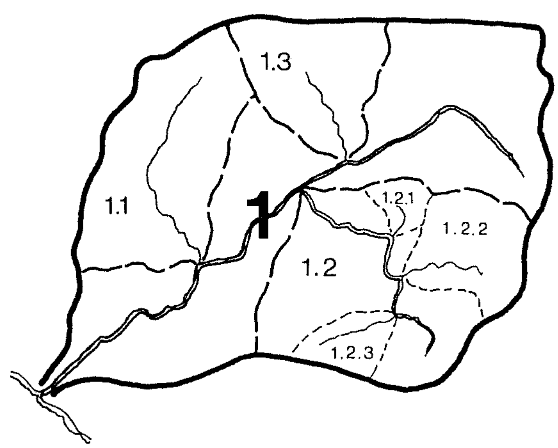

Figure 1.--A simplistic hierarchical watershed coding system

In this context, "hierarchy" means the opposite of "order" (Strahler, 1952). The greater the number of groups of digits ("fields") used to designate a channel, the lower its order. It is possible to accommodate the upper-most tributary of an eighth-order channel (example shown in fig. 4) with this 21 digit, seven-field system. However, lesser orders are more customary.

In practice, each level of hierarchy uses a group, or field of digits. In the predominantly mountainous terrain of British Columbia, a 21 digit number composed of seven fields of two, three or four digits each, enables cataloguing up to eight levels of basin hierarchy. For an area of British Columbia's size and complexity, this enables cataloguing all the channels of sufficient size to appear on 1:50 000 topographic maps. Instructions on the methodology for cataloging basins according to the hierarchical watershed code are detailed in Shera and Grant (1980).

The initial landscape breakdown subdivides British Columbia into nine principal drainages and one arbitrary coastal unit (fig. 2). The nine principal drainages each have up to nine of their largest tributaries designated by the second digit of the 21 digit number (fig. 3). These may or may not be hierarchically assigned and are a "convenience" to shorten the overall code number length. For example, the Kootenay River, a Columbia ("3") tributary, is subdivided into lower Kootenay ("34") and upper Kootenay ("35") at the Libby Dam based on convenience, not hierarchy.

The coastal unit ("9") is subdivided according to island groupings and other arbitrary divisions e.g. "94" Graham Island, "95" Moresby Island, etc.

Each of these two-digit or "major" watersheds is then repeatedly subdivided on a strictly hierarchical basis until the desired level of detail is attained (fig. 4).

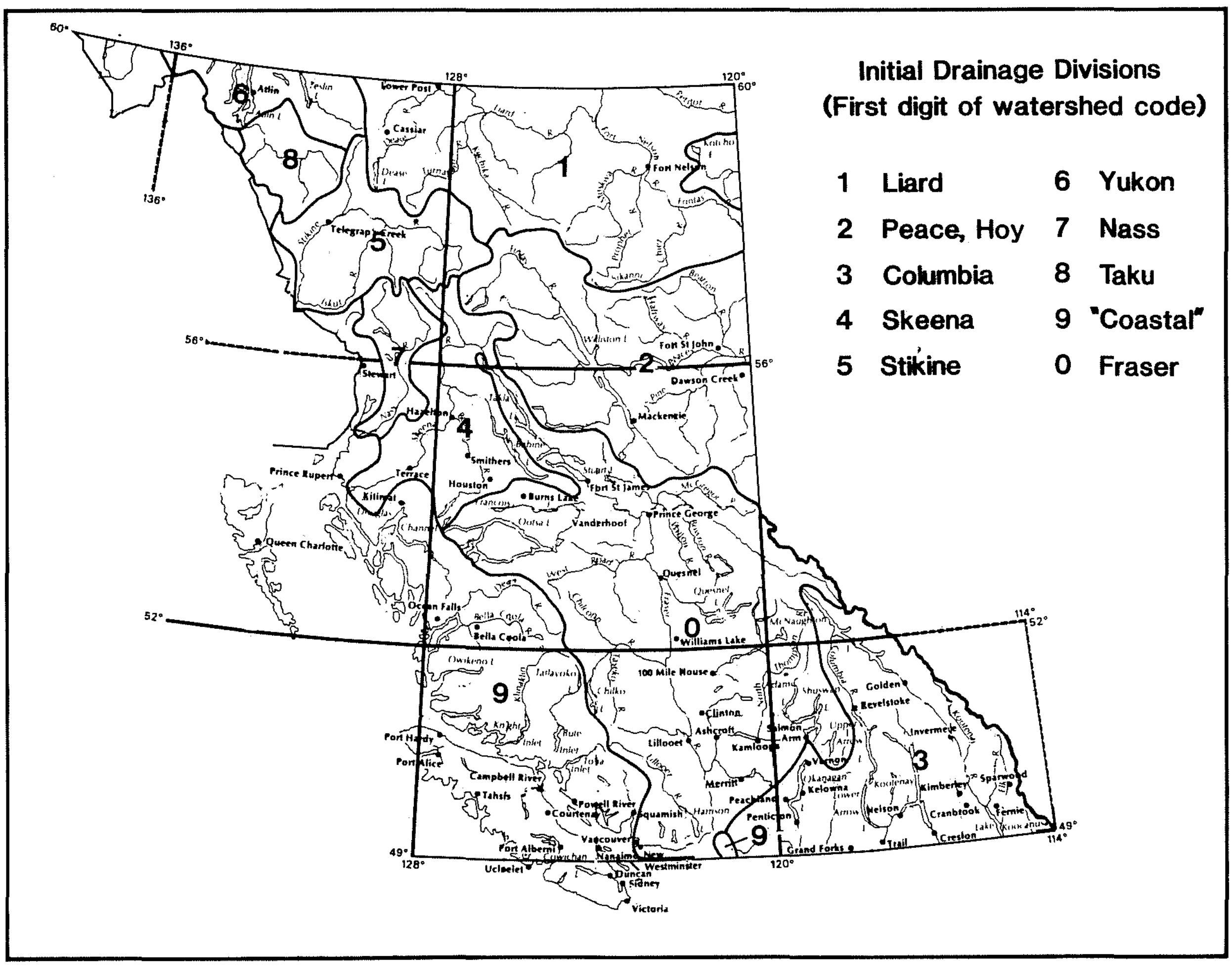

Figure 2.--Initial drainage divisions. British Columbia divided into its nine principal drainages

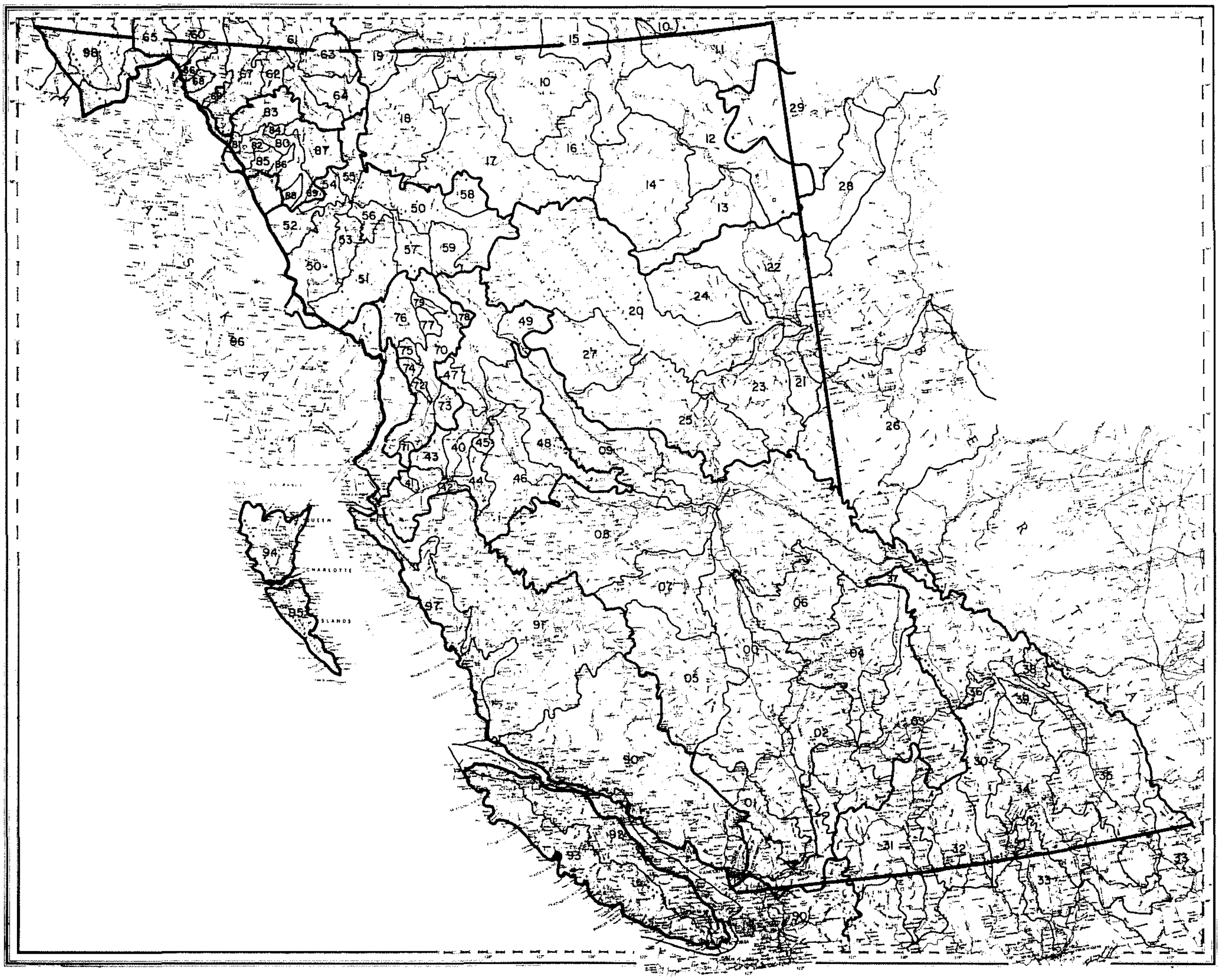

Figure 3.--Major watershed code numbers. The watersheds delineated on this map show the first two levels of an eight level hierarchical tributary numbering system used in the British Columbia Aquatic Data Base

These watershed code numbers and their gazetted names or aliases are assembled in numerically and alphabetically sorted "dictionaries" for British Columbia streams (tables 1 and 2). All further data collected on these basins is then filed by watershed code number.

As site specific data about channel information is collected, it is located by channel distance from the stream mouth. General data is located by reach (Chamberlin, 1980). The reach number or distance to the stream mouth plus the watershed code number provides a site specific filing system for any channel-related data. The aquatic biophysical inventory methodology for generating and handling this data is described by Chamberlin (1980).

PROBLEM AREAS

There are three main types of problems encountered in attempting to use this system of watershed indexing. Two are the natural and man-made aberrations within the landscape and the other results from difficulties imposed by study scale and graphic presentation of data (referred to as Administrative Problems).

Natural Problems

Natural problems are posed by disjunct drainages, internal drainages, and very complex drainage patterns.

Disjunct drainages are indexed as though a continuous channel connected the two most logical points of the channel sections as inferred from topography.

Internal drainages such as kettle lakes and systems ending in sinks are relatively uncommon in British Columbia (as compared to Central Canada or U.S.A.). Although internal, these drainages fall within the logical bounds of some larger, encompassing basin. They are indexed as usual to the larger basin level, then an arbitrary but reasonable designation made as though they were tributary to the most likely nearby channel. A note that the basin is an internal drainage is made in the dictionary listing for the system.

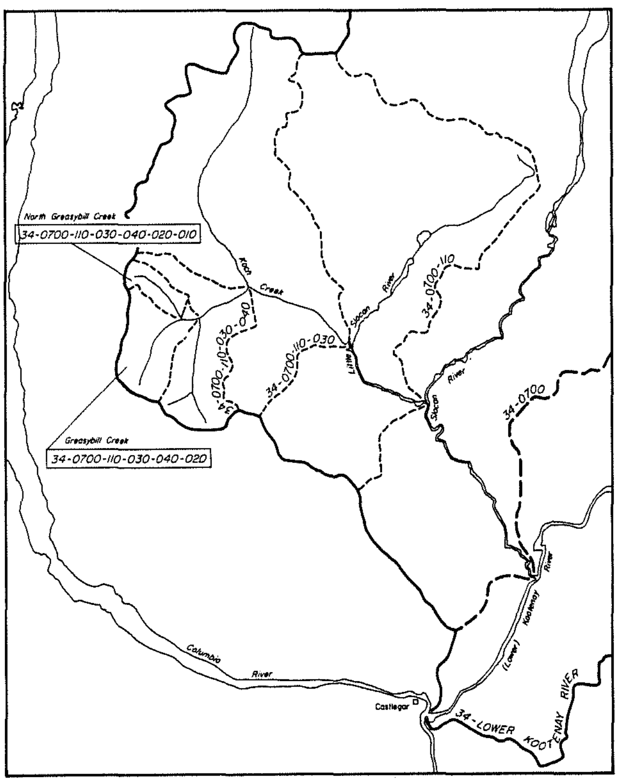

Figure 4.--Generalized watershed subdivisions showing the relationship of the length of the watershed code number to the relative channel hierarchy. North Greasybill Creek is in the eighth hierarchic position relative to its ultimate receiving waters, the Columbia River.

Most of British Columbia's terrain is mountainous with relatively simple linear or radial drainage patterns. More complex drainages such as dendritic drainage patterns with higher drainage densities are found in the fine textured soils of the prairies. These drainages may require additional fields in the watershed code number because of the resulting higher channel orders encountered. In general, linear drainages appear to have more low-order tributaries (i.e. require fewer fields but more digits per field) and dendritic drainages have fewer, higher order tributaries (i.e. require more fields but fewer digits per field). Therefore, the coding concept remains unchanged, only the number and size of fields within the watershed code number may need to be rearranged.

Table 1.--Example segment of a numeric dictionary for the area around North Greasybill Creek (shown in fig. 4)

Watershed Code Number							Watershed Name
34	0600	000	000	000	000	000	DURHAM C
	0700	000	000	000	000	000	SLOCAN R
		010	000	000	000	000	GOOSE C
			010	000	000	000	GANDER C
		020	000	000	000	000	LANGHILL C
		030	000	000	000	000	JACOB C
		040	000	000	000	000	UNNAMED C
		050	000	000	000	000	ARVIL C
		060	000	000	000	000	GREAVISON C
		070	000	000	000	000	GROOM C
		080	000	000	000	000	WOLVERTON C
		090	000	000	000	000	COWIE C
		100	000	000	000	000	JAMIE C
		110	000	000	000	000	LITTLE SLOCAN R
			010	000	000	000	AIRY C
			020	000	000	000	TALBOTT C
			030	000	000	000	KOCH C
				010	000	000	UNNAMED C
				020	000	000	RUSSEL C
					010	000	MILTON C
				030	000	000	COUGAR C
				040	000	000	GRIZZLY C
					010	000	UNNAMED C
					020	000	GREASYBILL C
						010	NORTH GREASYBILL C
				050	000	000	UNNAMED C
				057	000	000	UNNAMED C
				060	000	000	UNNAMED C
				070	000	000	DAGO C
			060	000	000	000	HODER C
			080	000	000	000	BANNOCK BURN
			100	000	000	000	ROBERTSON C
		120	000	000	000	000	MCFAYDEN C

Table 2.—Example segment of an alphabetic dictionary for the area around North Greasybill Creek (Little Slocan R., Fig. 4)

Watershed Code Number	Watershed Name
92 3600 000 000 000 000 000	LITTLE QUALICUM R
92 2770 000 000 000 000 000	LITTLE RIVER C
5 1000 010 000 000 000 000	LITTLE SAND C
30 0100 010 000 000 000 000	LITTLE SHEET C
34 0700 110 000 000 000 000	LITTLE SLOCAN R
00 5100 660 000 000 000 000	LITTLE SWIFT RIVER
54 0700 000 000 000 000 000	LITTLE TAHLTAN RIVER
00 0600 020 070 000 000 000	LITTLE TAMIHI C
34 0700 340 060 000 000 000	LITTLE TIM C

Man-made Aberrations

Four types of man-made landscape aberrations pose problems to the system: diversions, new reservoirs, fluctuating reservoir levels, and political boundaries.

Extensive diversions are considered as a tributary to their receiving waters, and a note made in the data bank of the parent stream and the diversion channel. Small scale diversions can be treated like distributaries and included in the data bank as part of the parent stream. A statement that the distributary is a diversion is contained in the data bank for the parent channel.

Reservoirs pose two problems: they may appear after a system has been catalogued which can alter the hierarchy of tributary channels and their water level usually fluctuates markedly.

In the case of a reservoir appearing after a system has been catalogued, a comment is made in the dictionary that that system has been partially flooded and its hierarchy changed. Fluctuating water levels are treated analogously to coastal systems entering a tidal area i.e. an arbitrary low-water "mouth" location is designated and appropriate comments are made in the data bank as to the fluctuating water level.

Arbitrarily imposed boundaries such as political boundaries along meridians or parallels of longitude or latitude, pose special problems. Basins occurring at least partially within British Columbia are ranked relative to their hierarchy to the receiving waters as though the boundary did not exist. However, the coding for the receiving waters and its tributaries ignores basins wholly outside the Province (fig. 3). This causes some inconsistencies along all four British Columbia boundaries, but the basics of the watershed coding system remain valid in these areas.

Administrative Problems

Increasing the scale of mapping increases the number and order of channels represented. This problem could be solved by increasing the number of fields and the size of each field. However, expanding the 21 digit code makes it unwieldy. Levels of detail requiring such increases should consider a modification of the basic filing system to accommodate alpha-numerics, hexa-decimal cataloguing, or an arrangement of files and subsets. A numeric system was chosen for 1:50 000 mapping because although somewhat cumbersome, it is more convenient for manual files.

Increasing the data to be catalogued can be accommodated if there is a corresponding reduction in scale. If the scale cannot be reduced, additional basins can be catalogued by increasing the field size of a few key fields, usually at the "major" watershed level.

A cartographic dilemma arises when representing basins on maps; the lowest order, basins which require the longest number will be the smallest polygon present (fig. 4). This can be solved by using a presentation scale that is suitable to the intensity of information being shown.

Officially gazetted names are the only names used in the dictionary. All others are listed as "unnamed" and identified first by alias, if any, and then by a location comment and the stream bank from which they enter their receiving waters, e.g. "Unnamed - left bank - from Chain Lake, Mt. Baldy". The mouth of the unnamed stream may also be designated by using the UTM grid system present for most mapped areas.

CODE USE AND ACCESS

As previously mentioned, the resultant code numbers and the associated stream name code assembled in numerically. and alphabetically - sorted dictionaries (table 1 and 2). Besides name, number and location comments, these also contain such information as non-gazetted or alias names and what type of inventory information (reach, point, fish, etc.) is available in the computer data bank on that particular system.

The watershed code number for a particular basin is usually first looked up in the alphabetic dictionary (table 2). Once determined, the code number in the numeric dictionary (table 1) is used to derive the previously mentioned information. Because of the logic of the coding system, the numeric dictionary can also be used to determine the upstream and downstream adjacent channels to a stream, its tributaries, and its receiving waters. It is especially important to use the numeric dictionary to check the context of a position for any of the many "unnamed" streams.

CONCLUSION

Chamberlin (1980) outlines the three principal objectives of the Aquatic Studies Branch data base as ensuring that data is: 1) not lost; 2) organized so that it is easily retrievable; 3) available and useful for making resource decisions.

This watershed coding system is used to index all inventory data collected for the B.C. Aquatic Data Base. The inventory methodology (Chamberlin, 1980) is being used and data being contributed to comparable data bases by at least two government agencies in other provinces (Quebec and the Yukon), several other B.C. provincial government agencies, and at least six private consulting firms in B.C.

This hierarchical watershed coding systemm labels and organizes the data from the preplanning stage of an inventory through fieldwork, to data manipulation and modelling in the computer. It is a proven aid to meeting these objectives.

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A BRITISH COLUMBIA STREAM HABITAT AND FISH POPULATION INVENTORY SYSTEM[1]

A. D. de Leeuw[2]

Abstract.--An intensive stream inventory, preceding habitat restoration and enhancement projects, has been developed and employed on some sportfish producing waters. Gradient determined reaches are repeatedly sampled within 6 designated hydraulic unit types (eg. pool, riffle, etc.) using 21 parameters. Fish populations are usually sampled by electroshocking and expressed in no./m^2 and g/m^2 for each species and age class. Average hydraulic unit data (eg. fish densities, habitat quantity/quality) are applied to a reach as a whole and standing stocks can be tallied on a system-specific basis. Biostandards and carrying capacity estimates can be realized from intensive assessment of fully recruited stream habitats.

INTRODUCTION

The British Columbia Ministry of Environment has developed a number of general and specific purpose inventory methods to meet a variety of resource management objectives. The Fish Habitat Improvement Section of the Ministry's Fish and Wildlife Branch routinely conducts intensive fisheries inventories throughout the Province. The overall mandate of the Section is to provide a specialized service to regional fisheries managers in the form of alternatives for improvement of fisheries through habitat manipulation and creation.

The primary or cornerstone element in meeting this objective is development of a comprehensive inventory system designed to document both the physical and biological aspects of stream ecosystems. Information is collected for designated stream reaches on a site-specific basis, and the data is compiled and applied (depending on the objective) to the entire reach, stream, or drainage system as a whole. In this manner the distinct types, overall distribution and approximate amount of habitat and associated fish populations are estimated on a sample-specific, reach-specific, and system-specific basis, ultimately allowing for multiple stream comparison.

In 1979, Fish Habitat Improvement undertook a wide-ranging inventory of 253 streams in 39 watersheds in the Lower Mainland of British Columbia. The study was designed to examine existing habitat/fish associations in these streams, and to indicate general enhancement opportunities (principally for sea-run cutthroat trout) on a system-specific basis. To meet these terms of reference with a single field season for data collection, it became necessary to devise a quick yet realistic method to inventory streams. Since its development it has been shown to be extremely useful and appropriate in a number of subsequent investigations, and at present, with some variation of intensity and modification of specific techniques to address particular questions, forms the basis of most Section inventories/assessments. The general methodology is outlined here to guide those wishing to adopt a similar approach for studies of habitat/fish associations in streams.

METHODOLOGY

Field data collections focus primarily on stream morphometry and associated fish populations. Generally, both are sampled concurrently during low flows, usually in late summer. Sampling is carried out on a site-specific basis within previously designated reaches. Depending on project budget, and temporal or physical constraints, each reach can be sampled once, or more often depending on the resolution required.

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[1]Paper presented at the symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. [Hilton Hotel, Portland, Oregon, October 28-30, 1981.]

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Reach Determination

The intent of partitioning stream systems into component reaches is primarily to identify and quantify specific habitat types and their corresponding fish utilization. Stream partitioning or reach break location may be based on a variety of parameters (such as discharge, stream topography and land use, etc.). Stream gradient (in percent) is almost exclusively employed since it can be easily obtained from large scale topographical maps, and usually clearly reflects distinguishable reach or habitat types in the field. Generally, 6 reach types are recognized (Table 1), but any number of gradient/reach types can be used, as long as there is consistency.

Table 1.--Reach type and percent gradient.

Reach Type	Gradient (%)
1	0
2	0-0.5
3	0.5-1.0
4	1.0-3.0
5	3.0-7.0
6	7.0+

Working from topographic maps, reach breaks are identified where stream gradient changes from one interval (ie. 0%) to another (0-0.5%). Figure 1 relates number of contours per inch to percent gradient on contour maps with scale of 1:25,000. Stream gradient can be calculated as follows:

$$\frac{[\text{contours per inch X contour interval (in inches)}]}{25{,}000} \text{ X } 100 = \%\text{ gradient}$$

A thin plexiglass ruler facilitates counting contours per inch and determining reach breaks by percent gradient. A similar method employing graphs of different slopes can be used for various alternate scale maps with differing contour intervals. If available, a computer digitizer can be used. Past experiences have shown reasonable accuracy and success in locating reach breaks on 1:25,000 and even 1:50,000 mapping. However, with

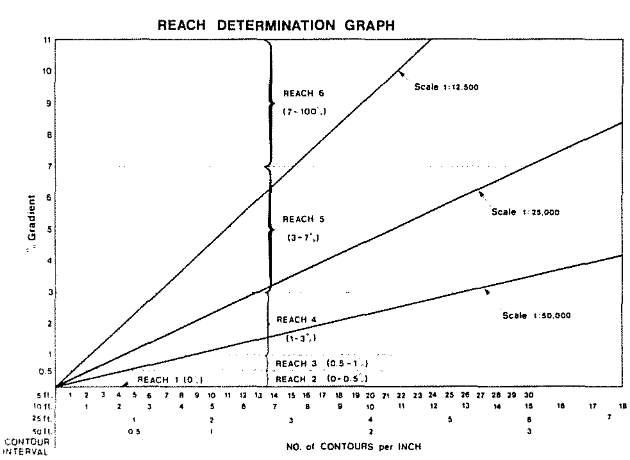

Figure 1.--Reach determination graph.

smaller scale, the accuracy can be expected to diminish, and air photo interpretation or flight reconnaissance should be used to delineate reaches. The advantage of using air photo interpretation is that general features of the stream such as channel form, discharge and overall stream morphometry can be used to locate reach breaks. Related land use and access information can also be obtained.

By using this method, an entire stream system can be partitioned into its component reaches prior to entering the field. In the Lower Mainland study, all streams and reaches were identified by numerical codes for rapid computer processing of field data. In less extensive studies, however, data processing may be done manually, eliminating the necessity for such coding.

The general method used was to give a primary code to the mainstem stream, and secondary and tertiary codes to tributaries. Thus by observing the code, streams and reaches could be readily located and identified. The following is an example of this approach:

Reach Code (Reach 5 on Coghlan Cr.)

Reach Type (0.5-1% Gradient)

CODE 09-06-0-0-5-3

Primary Code 09 = Salmon River

Quarternary Code (Tertiary Trib.)

Tertiary Code (Secondary Trib.)

06 = Secondary Code (Primary Trib.) Coghlan Cr.

After all streams, tributaries and reaches have been identified, field work can proceed. To increase field efficiency, knowledge of road access to reaches and sample areas is advised.

Physical Stream Inventory

Prior to data collection, a visual assessment is made to verify the mapping-based reach breakdown, and to assess the uniformity of the particular reaches under study. If, in fact, a given reach is found to be grossly non-uniform or the field-determined gradient is widely different from the range suggested by the map-based reach breakdown, then maps have to be consulted for possible error in reach break location. It must be remembered, however, that changing substrates can account for considerable habitat variability over a relatively uniform gradient. On large streams air photo interpretation can also be used to correct faulty map-based reach partitioning.

The degree of variability may require further reach delineation based on field ground-truthing. Once the reach and its uniformity have been established, representative sample sites can be selected. In the Lower Mainland study, six different hydraulic types were recognized, but any number of types can be included (again consistency is essential).

Falls (F) A very fast white water cascade (often vertical). Only its length, width and depth are measured. Height is also measured if it is deemed a problem to fish passage.

Riffle (R) A shallow area (generally) of a stream, where the water surface is broken into waves by bed material wholly or partially submerged.

In some streams, a pocket-step-pool situation often occurs in what appears to be a large uniform riffle. It is often impossible to discern a typical pool, riffle, glide sequence on such a reach. The method used to adequately describe this type of habitat is to take the glides and pools out of the riffle and collect data on each, individually, until an adequate number of units has been measured. The total area (length and width) of the stream section within which these units are located is then measured by tape or pacing. The sum of the areas of previously measured glides and pools is subtracted from the total area of the stream section measured to give the total area of the riffle. Data is then collected for the riffle.

Glide (G) A section of flowing water (slow to fast, shallow to moderately deep) with the surface unbroken by bed material.

Pool (P) An area of the stream that is deep and of slow velocity relative to contiguous hydraulic types.

Glides, pools and riffles generally occur together, forming complexes (longitudinally and laterally).

Slough (S) A stream section of very low (to nil) velocity where pools, glides or riffles are absent (usually of uniform depth).

Ditch (D) A man-made slough.

Ditches and sloughs generally occur independent of other hydraulic types at seasonal low water periods.

Where sloughs or ditches are encountered, a single uniform 25 or 50 m section is usually described. Additional 25 or 50 m sections may be sampled if the slough or ditch is not uniform. A general breakdown of habitat unit types relative to reach gradient is as follows:

Table 2.--Reach type and dominant hydraulic unit types.

Reach Type	% Gradient	Hydraulic Unit Types Present[1]
1	0	mainly S & D, some P & G
2	0-0.5	mainly P & G, some R & S & D
3	0.5-1.0	mainly P & G & R
4	1.0-3.0	mainly P & R, some G
5	3.0-7.0	mainly R, some G & P, also some F
6	>7.0	mainly R, some P, some F

[1]This is what is usually found; exceptions can occur.

Within each of these units, twenty-one instream parameters are measured, and primarily relate to fish habitat, notably cover (shelter areas). In the field notes, an additional three variables pertaining to the reach code may be recorded.

Within each reach, a sample of twelve consecutive hydraulic units is described, on the assumption that this number of units should adequately "characterize" the reach. The list of parameters used to describe each unit is as follows:

1. Stream Name and Code: From previously coded contour maps.

2. Reach Number and Gradient Type: All reaches are numbered consecutively in an upstream direction. The reach type (1 to 6, based on gradient interval from mapping, Table 1) and the actual gradient interval (%) are also recorded.

3. Reach Length (m): Previously measured on mapping (chartometer or plastic ruler), or determined from air photo interpretation.

4. Hydraulic Unit: This refers to the previously defined sample units F, R, G, P, S, D. All of the following parameters are measured within each hydraulic unit.

5. Length (m): The length of the hydraulic unit being inventoried, measured with meter stick or measuring tape.

6. Wetted Width (m): The wetted width of the hydraulic unit at time of inventory. Where width is not uniform, the average width is entered.

7. Channel Width (m): The mean width of the channel from rooted vegetation is to rooted vegetation (terrestrial). Mean annual high water level is used in the absence of vegetation.

8. Area (m^2): Computed in field by multiplying length by wetted width.

9. Average Depth (m): The average depth of the hydraulic unit being measured (employing full length and cross-section).

10. Velocity (m/sec): Recorded primarily to enable computation of discharge in a given reach. The velocity measurement is usually taken in a riffle or glide section, where depth and width are fairly uniform. The common "floating chip" method is used (timing a free floating object along a specified distance and dividing the travel time in seconds by distance travelled). Usually three or four measurements are taken for each estimate to ensure "accurate" results. Discharge does not usually change significantly within a reach, but the presence/location of tributaries must be considered.

The velocity measurement itself may be included in later analyses.

11. Instream Log (m^2) X Depth (m): Pertains to the cover afforded stream salmonids by debris piles, stumps, root wads, and fallen trees within the wetted area of the hydraulic unit under study. These are measured in both area (m^2) and depth (m). Depth is the distance from the top of the debris pile to the bottom of the unit being measured (bottom of the pool, riffle, glide, etc.).

12. Instream Boulders (m^2): A group of boulders in reasonable proximity to each other (where each boulder is 30 cm in diameter or larger) is considered acceptable cover for trout. A single boulder of similar dimensions imbedded in much smaller substrates is not. Conversely, a boulder (or boulders) associated with cobbles (in the order of 15 to 25 cm) may constitute cover. The general intent is to make some assessment (and quantification) of the available cover afforded by stream substrates (notably boulders). Such measurements include the actual area of the boulders, because the interstices underneath also constitute cover.

    Discretion and common sense must be used in measuring this variable. Extremely large boulders (eg. 2 m dia. or larger) and bedrock are often deeply imbedded in the accompanying substrate matrix, thereby decreasing the total available cover. Such anomalies have to be excluded in the assessment (ie. subtracted from the total boulder groupings' area).

13. Instream Vegetation (m^2): The area (m^2) of submerged vegetation in the hydraulic unit being measured. It does not include algae covering the substrate, since this is not generally considered trout cover.

14. Overstream Vegetation (m^2): A measure of overhead (organic) cover within 1 m (vertical) of the water surface; the total area of the water surface with riparian vegetation leaning over it.

15. Cutbanks (m^2): Cutbanks are also important areas of shelter for salmonids. A cutbank (or undercut) occurs where a bank has been eroded by the stream to form a hollow underwater. Usually the upper soil layers are so bound by root structures that they remain intact. The effect is to create a series of cavities within the stream bank in which trout can hold. Assessment of this parameter is made by probing with the meter stick into cutbanks and measuring the depth. Average depth horizontally (into the bank) times the length along the bank produces the area.

16. Turbidity (m): An approximate measurement of light penetration. A meter stick is lowered vertically into the water column until the tip disappears from sight. The depth to this point constitutes the turbidity measurement. A scale of 0 to 1 m is generally employed.

17. Gradient (%): This meausrement is made with a Suunto optical clinometer (Model PM-5/360 PC). The usual method is to stand with feet placed at exactly the water surface level, and to flag a nearby branch (etc.) at eye level. By walking as far as possible up or downstream within the reach under study, and again standing at exactly water level, the clinometer is sighted back to the previously flagged location. Two or three measurements are made along a reach, and the average is recorded. The further the distance between flagging and sighting, the greater the accuracy of measurement. Isolated sections within a reach can (and often do) differ from gradients indicated on contour maps. However, if the distance over which the gradient is measured is long enough, the figure is usually within the range described for that reach from contour maps. Discrepancies sometimes occur on the low gradient reaches but these are usually related to the inadequacy of hand-held clinometers in measuring extremely low gradients. Suunto maintains that values on their clinometer can be read directly to one percent and can be estimated to one-fifth of one percent (ie. 0.2%).

18. Fines (%): Visual estimate of percent composition of streambed substrates in the size range 0.0-0.1 cm.

19. Small gravel (%): Visual estimate of percent composition of streambed substrates in the size range 0.1-4 cm.

20. Large Gravel (%): Visual estimate of percent composition of streambed substrates in the size range 4-10 cm.

21. Cobble (%): Visual estimate of percent composition of streambed substrates in the size range 10-30 cm.

22. Boulder (%): Visual estimate of percent composition of streambed substrates in the size range 30+ cm.

23. Bedrock (%): (includes hardpan)

24. Compaction: This represents a qualitative, personal judgement on the "looseness" of spawning or other substrates (ie. gravel). It is obtained by dislodging the substrate with one's foot and assessing the degree of compaction. If it is significantly compacted, a "1" is entered; if it is loose, a "0" is recorded.

25. Temperature (°C): All thermometers are standardized prior to field work. The measurement is made by holding the entire thermometer underwater. Several readings are made to ensure accuracy.

For the purposes of the Lower Mainland study, a computer program was devised to array the physical

Table 3.--An example of physical stream descriptor (parameter) summary. Coghlan Creek, Reach 5. Code: 09-6-0-0-5-3.

	Pool		Riffle		Glide	
	Value	%	Value	%	Value	%
Ave. length	11.9	54.1	4.3	19.5	14.5	26.4
Ave. wetted width	2.2	68.7	1.0	39.6	0.9	34.4
Ave. channel width	3.2	0.0	2.7	0.0	3.0	0.0
Ave. depth	0.2	0.0	0.0	0.0	0.1	0.0
Ave. area	25.8	70.2	5.7	15.6	13.0	14.2
Total number in reach	72.7	0.0	72.7	0.0	29.1	0.0
Total area in reach	1876.4	70.2	417.5	15.6	378.2	14.2
Ave. area in log debris cover	1.1	0.4	0.0	2.5	0.1	0.7
Ave. area boulder cover	0.0	0.0	0.0	0.0	0.0	0.0
Ave. area instream veg. cover	0.0	0.0	0.5	3.3	0.0	0.0
Ave. area overstream veg. cover	0.0	0.0	0.0	0.0	0.1	0.6
Ave. area cutbanks	0.3	0.7	0.0	0.0	0.0	0.0
Ave. area total cover	1.4	1.1	0.5	5.8	0.2	1.3
Ave. percent fines	82.8	82.8	48.0	48.0	92.0	92.0
Ave. percent small gravel	14.0	14.0	34.0	34.0	7.5	7.5
Ave. percent lg. gravel	3.0	3.0	16.0	16.0	0.0	0.0
Ave. percent cobbles	0.0	0.0	1.0	1.0	0.0	0.0
Ave. percent boulders	0.0	0.0	1.0	1.0	0.0	0.0
Ave. percent bedrock	0.0	0.0	0.0	0.0	0.0	0.0

field data into summary tables (program on file, 1980). Each variable measured is recalculated for average and percent values for each hydraulic unit over all units measured within any given reach. Therefore, each table printed shows the characteristics of the reach as a whole, and also how much of each hydraulic unit type is present within a reach (Table 3). Limited amounts of raw field data (<100 units) can be processed manually.

On some large stream systems, it may be impossible to inventory each reach individually. If this is the case, some reaches may be extrapolated from data obtained on other similar reaches. This involves, of course, a qualitative judgment as to when two reaches become sufficiently similar to allow representation of one by another, and, if at all possible, this option should be avoided. Generally speaking, it is better to take fewer replicate samples per reach and complete more reaches than it is to extrapolate for some reaches. Variability tends to be greatest between, rather than within, reaches.

Fish Population Inventory

Two distinct methods of censusing fish populations are generally employed. On small streams, sampling includes the entire wetted width, while on larger systems it may be that only part of the wetted width is sampled. Within each of these two categories, either discrete hydraulic units (ie. pools, riffles, etc.) are sampled individually, or a number of connecting units are sampled collectively. In the latter case, a section representative of the reach is selected for fish sampling.

Where the entire width is sampled, two fine meshed nets are placed between banks, one upstream and the other downstream, enclosing the area to be sampled. These nets are well secured to the stream bottom and bank to minimize movement of fish into and out of the isolated sampling area (Fig. 2). In very

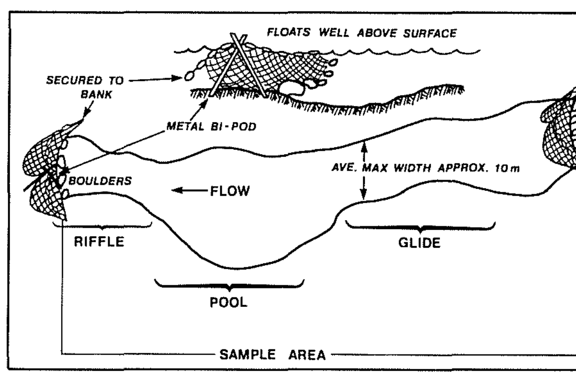

Figure 2.--Bank to bank isolated sampling area.

small streams, natural barriers such as extremely shallow riffles or falls have been used as a substitute for the upstream net. A downstream net is always employed. Where sampling is limited (by logistics) to only a portion of the stream width, efforts are always made to totally enclose the sample site with netting (usually deployed in an arc isolating a section of stream bank and edge habitat). Within the enclosure, fish are typically removed by electrofishing (seining may be used in deep water habitats). The removal method of electrofishing is used (Seber and LeCren, 1967)[1] and efforts are made to capture as many fish as possible (ideally all) at each sample site. In relatively simple areas (where capture efficiency is high) only one capture effort is conducted. An estimate of the total population (by species, age group, etc.) at the site is provided by the equation:

$$\tilde{n} = c/\tilde{p}$$

where $\tilde{n}$ = an estimate of the total population size
c = number of individuals captured
$\tilde{p}$ = an estimate, based on substantial experience, of the proportion of fish captured (as a check on capture efficiency a visual count of remaining fish can be made by snorkeling).

In more complex areas, or where visibility is impaired, two separate captures may be conducted at one site, and respective population estimates made by the following equation:

$$\tilde{n} = \frac{C_1^2}{C_1 - C_2} \quad \text{and} \quad \tilde{p} = \frac{(C_1 - C_2)}{C_1}$$

$$\text{with variance } (\hat{n}) = \frac{C_1^2 C_2^2 (C_1 + C_2)}{(C_1 - C_2)^4}$$

where $\tilde{n}$ = an estimate of the total population size
C_1 = number of individuals in first capture
C_2 = number of individuals in second capture
$\tilde{p}$ = an estimate of the proportion of fish captured

Each separate capture effort usually consists of three "passes" over the entire area of the sample site. On the first pass, fishing is initiated at the downstream net and is methodically continued from bank to bank as far as the upstream net. Short bursts of electric power (ie. approximately 3 seconds each) are used to stun fish. Once the upstream net is reached, the procedure is repeated again, this time in the opposite direction (towards the downstream net). In the second pass, an attempt is also made to chase remaining fish into the bagged portion of the downstream net. A third pass is generally identical to the second. One or more people in addition to the electroshocker operator are present with dip nets to increase both safety and capture efficiency. A dip net is also attached to the end of the anode pole. Stunned fish which are collected by both the electroshocker operator and attendants with dip nets are placed in plastic buckets containing water (and aeration devices if necessary). Alternating current can produce best results in swiftly flowing streams, where the majority of fish are chased and captured in the downstream net. Direct current, which draws fish to the anode pole by positive galvanotaxis, is most effective in slow to moderate velocity habitats.

[1]Seber, G.A.F. and E.D. LeCren. 1967. Estimating population parameters from catches large relative to the population. J. Anim. Ecol. 36:631-643.

In large streams where bank to bank isolation is not practical, and difficulties may also be encountered in attempting to isolate a portion of edge habitat, the instream side of the sampling area may have to be left open (Fig. 3). Extra care must be

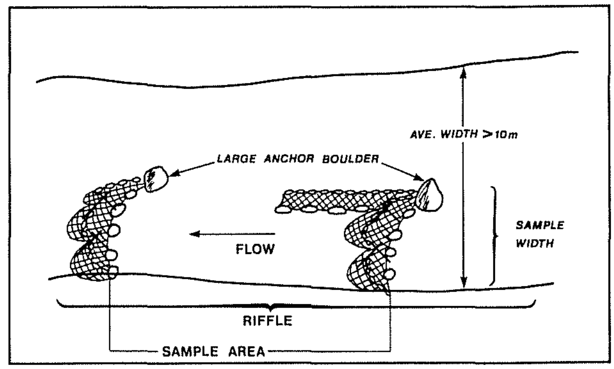

Figure 3.--Partially isolated sampling area.

taken in this instance to minimize disturbance of fish in the sampling area during net installation, and the actual sampling operation. In these areas, snorkel observations may augment electrofishing results in relation to the distribution and abundance of fish species and age groups in habitat at the site or for the reach as a whole. Sampling edge habitat is particularly useful in determining fry populations in large streams.

Beach seining is used almost exclusively in deep, slow-moving habitats where stream substrate is small and no lead line obstructions are present.

In the one capture method, when an attempt is made to remove all fish from the sampling site, an estimate of capture efficiency is ascribed to the sample. If abundant, complex cover affords refuge for fish and many cannot be captured, a low capture probability is assigned ($\tilde{p}$ = 0.5-0.6), and a decision may be made to conduct a second capture. Conversely, if observations indicate the majority of fish were captured, a high probability may be assigned ($\tilde{p}$ = 0.7-0.9).

All fish are anaesthetized in a well-aerated, aqueous solution of 2-phenoxyethanol prior to handling. Fish are enumerated and identified to species. Fork lengths (tip of snout to fork in caudal) of all individuals are taken and recorded. Weight samples are also taken. When weighing, fish should be blotted dry prior to placement on the balance to reduce the influence of extraneous moisture. Scales are removed from fish of representative sizes for age determination. The area of the enclosed sample site is accurately measured for the computation of fish densities (fish numbers/weight per unit area). After processing, fish are returned to the sample site. With experience and care, few mortalities should result from fish capture and data collection.

Additional Considerations for Field Inventory

Although a minimum crew size of two can sample both stream morphometry and fish biota as described above, field efficiency is greatly enhanced with a crew of three. Generally speaking, three people can comfortably obtain all of the desired information from three sample sites in an eight hour day. However, the size of the project area and/or problems with access may result in excessive travel time and reduced sampling efficiency. When travel logistics are minimized through the use of helicopters, 4 to 7 sites can be sampled in a day by a three-person crew. In past inventory/assessments with access restraints, as many as 14 sites have been sampled in a day by operating 2 three-person crews with helicopter transport. While one crew is sampling, the other is being transported to the next site. Travel (distance/access limitations) is the primary constraint on the achievement of high field efficiency.

Data Manipulation

Prior to its interpretation, all raw field data is transformed to a more useful format.

Physical Inventory Data

For each reach inventoried, physical data is expressed in total, average, and percent values for each hydraulic unit type measured (Table 3). If a combination of pools, glides and riffles were inventoried, then the total and percent values for these units are computed and presented on a reach-specific basis. Methods of calculation are described below. All underlined parameters are from Table 3.

<u>Average length</u>

Value - The lengths of all similar hydraulic units (ie. all pools) are totalled, and the average calculated (ie. average length per pool).

% - The sum of all lengths of similar hydraulic units is divided by the total sum of the lengths of <u>all</u> hydraulic units inventoried, and the result is multiplied by 100 (ie. total length of pools = x % of total length inventoried).

<u>Average wetted width</u>

Value - The widths of all similar hydraulic units are totalled, and the average computed (ie. average pool width).

% - At each similar hydraulic unit inventoried, the wetted width is divided by the corresponding channel width, and the average value over all of these similar units is calculated. The result is multiplied by 100 (ie. on the average, the wetted width of pools = x% of the channel width).

<u>Average channel width</u>

Value - The channel widths of similar hydraulic units are totalled and the average is computed (ie. average channel width for pools).

% - Not calculated.

<u>Average depth</u>

Value - All depths of similar hydraulic units are totalled and the average is calculated (ie. average depth of pools).

% - Not calculated.

<u>Average area</u>

Value - The area is computed for each similar hydraulic unit, then the average of these values is calculated (ie. average area of a pool).

% - The sum of the areas of all similar hydraulic units is divided by the sum of the areas of <u>all</u> hydraulic units inventoried. The result is multiplied by 100 (ie. the percent that total pool area represents of the total area inventoried).

<u>Total number in reach</u>

Value - The total length of the reach is divided by the stream length inventoried (sum of all lengths of all hydraulic units). The result is multiplied by the number of similar hydraulic units (ie. pools) actually measured (ie. the number of pools in the reach).

% - Not calculated.

<u>Total area in reach</u>

Value - The length of the reach is divided by the stream length inventoried (as above), and the result is multiplied by the sum of all areas of similar hydraulic unit types within the sample area (ie. the total pool area in the reach).

% - Same as % of average area.

<u>Average area of log debris cover</u>

Value - For all similar hydraulic units, the areas of log debris are totalled and the average calculated (ie. the average area of log debris cover in pools).

% - The sum of areas of log debris cover within similar hydraulic units is divided by the sum of the areas of these hydraulic unit types. The result is multiplied by 100 (ie. the percent of pool area providing log debris cover).

<u>Average area of boulder cover</u>

Value - As for above but for boulder cover.

% - As above but for boulder cover.

<u>Average area of instream vegetative cover</u>

Value - As above, but for instream vegetative cover.

% - As above, but for instream vegetative cover.

<u>Average area of overstream vegetative cover</u>

Value - As above, but for overstream vegetative cover.

% - As above, but for overstream vegetative cover.

<u>Average area of cutbanks</u>

Value - As above, but for cutbanks.

% - As above, but for cutbanks.

<u>Average area of total cover</u>

Value - The sum of all average cover values.

% - The sum of all % cover values, and the result can be greater than 100%.

<u>Average percent fines</u>

Value - The average % fines is computed for all similar hydraulic units inventoried (ie. the average

% fines in substrates of pools).
% - Same as value.

Average percent small gravel
Value - Computed similarly to above.
% - Same as value.

Average percent cobbles
Value - Computed similarly to above.
% - Same as value.

Average percent boulders
Value - Computed similarly to above.
% - Same as value.

Average percent bedrock
Value - Computed similarly to above.
% - Same as value.

Fish Population Inventory Data

For the capture data at each fish sampling site, all fish of a given species are grouped into age classes by length frequency and scale analyses. Population estimates are then conducted on a species-specific basis and age class-specific basis. Specific numerical densities (numbers/m^2) are then calculated by dividing the number of individuals within each age class of any species by the area sampled. The procedure for calculating the weight density (g/m^2) is similar to derivation of the numerical density, but here it is the weights of individuals which are considered, rather than the number of fish. However, not all fish at all sample sites are weighed. All that is necessary is to obtain a sample of weights from 30 to 50 individuals of a given species in the stream. After the completion of field activities, regressional analyses are conducted between fish weights and corresponding lengths taken in the field to provide a system-specific, species-specific weight-length conversion equation in the form:

$$W = k\ F.L.^x$$

where W = individual weight (grams)
k = condition factor
F.L. = fork length (millimeters)
x = exponent, usually 3

In calculating the weight density of a given species/age class at a particular sample site, the population estimate (number of fish) for that species/age class is multiplied by the site-specific mean weight of individuals in that age class sample. This is, however, not the weight of the individual of mean length for the site-specific capture for that age class, but rather the weight calculated for the length:

$$\sqrt[x]{\frac{\Sigma\ F.L.^x}{n}}$$

where $\Sigma F.L.^x$ = the sum of all lengths, each to the power x (usually 3), for all fish in the species/age class sample
n = the number of fish in the species/age class sample.

These computations can be done manually if necessary. However, simple programs, requiring only the input of individual fish lengths for a given sample/age group, can be prepared for small (pocket-size) programmable computers (eg. Hewlett-Packard 67).

For a given species, the condition factor (k in the equation $W = k\ F.L.^x$) can differ from one location to another depending on food supply, temperature, growth rates, etc. Consequently, it is always advisable to collect system-specific weight data. Furthermore, as seasonal variation in temperature regime or food production, for example, can cause year to year variation within a system, so new weight data should be collected for each year of study in on-going investigations of one system (ie. monitoring programs).

APPLICATION OF DATA

Stock Assessment

Once the weight and/or numerical densities for each age class and species have been obtained, the standing stock for that species/age class can be calculated on a reach-specific or system-specific basis. This is accomplished by multiplying the appropriate densities by the total reach or system area.

If discrete hydraulic units are sampled (ie. pools, riffles or glides) then the specific fish densities are multiplied by the total area of these corresponding units in the reach, rather than the reach area as a whole. These totals (for specific hydraulic units) are then summed to obtain the grand total in the reach. Reach totals can then be added to obtain the estimated standing stock or abundance of fish in particular age groups or species for the stream as a whole. The standing stock estimate of juveniles can then be used to speculate on the entire range of population dynamics possibilities and to generate estimates of production (existing and potential). These estimates can then be used to direct and develop resource management decisions, particularly with respect to fisheries protection and enhancement.

Stock Distribution

If a number of reaches within a drainage have been sub-sampled, the general species distribution can be determined by comparing results from different sample locations. Furthermore, it may be possible to identify habitat preferences of individual species by linear regression of stream morphometry parameters on sampled fish densities. Quantification/computation of the various physical variables (see Physical Inventory Data) allows a multitude of possible simple and/or multiple regression analyses with sampled fish densities. Positive and negative correlations between fish densities and specific physical variables (or groups of variables) may indicate significant relationships between the physical environment and fish production within systems, within watersheds, and with larger geographical units.

Fish density anomalies within reaches or entire stream systems can often reflect a production problem or constraint. If, for instance, the estimated number of trout fry is low relative to the number of parr in the same system, then it may be that egg to fry survival for that particular year was low, or that poor adult escapements accounted for the depressed fry densities.

By the same token, an abundance of trout fry in one reach and relative absence in another reach of the same system may suggest a variety of possibilities including localized recruitment (availability of spawning substrate), reach-specific availability of suitable fry habitat, etc. It is in such instances that regressional analyses mentioned above may be very useful in defining the significant effects (or not) of the various physical variables.

Habitat Improvement

Since the distribution and quantity of habitat types within each reach of a given system can be identified, restoration or enhancement of fish habitat (ie. increase cover, introduce spawning substrates, etc.) can be more efficiently carried out. If a number of reaches contain an abundance of rearing habitat (ie. boulder and log debris cover), but poor spawning substrates, the number of juvenile salmonids in these areas may be severely limited by poor recruitment. This situation can be rectified by introduction of spawning substrate or implementation of a fry stocking program. On the other hand, a stream system may contain a large amount of spawning substrate, but lack rearing capability. Again, low densities of parr could result. In such cases, strategic introduction of boulder groupings, root masses and riparian vegetation can often greatly improve rearing conditions, juvenile fish production, and ultimately smolt yield (in the case of anadromous species).

There can be no denying that experienced "intuition" is extremely valuable in developing fisheries management options, and that many strategies (like those mentioned above) can simply be devised by employing a "trained eye". At the same time, for moderate or high accountability management of stream fisheries, detailed and integrated biophysical assessment as outlined in this paper will allow for clear discussion of present and future production possibilities.

LANDFORM SUBDIVISIONS AS AN INTERPRETIVE TOOL FOR

STREAM AND FISH HABITAT ASSESSMENT[1]

E.A. Harding[2]

Abstract.--Analysis of an extensive aquatic inventory data base showed similarities in stream characteristics and fish distributions within landform units. The use of landforms units is suggested as an interpretive tool to better utilize aquatic inventory data.

INTRODUCTION

Historically, aquatic inventory in British Columbia has been carried out to provide basic biological and physical descriptions of lakes and streams for which little information was previously available. These inventories were completed for a wide variety of areas throughout the Province and usually on a reconnaissance level. Generally the data were stored in either limited edition catalogues, habitat maps or manuscript reports. Until recently little could be done to integrate or interpret this information since the data were not collected in a standardized manner nor available in one reference library.

In 1975 a newly developed Aquatic Inventory System (Chamberlin, 1980) was used to systematically inventory the aquatic resources of a 40,000^2 km coal reserve in northeastern British Columbia. This multidisciplinary project became known as the "Northeast Coal Block Study" (Figure 1).

A total of 500 ground sites were sampled and over 1,000 stream reaches were classified and mapped during the two year program. As well as providing impact evaluations for coal development, data maps, and a more detailed computer data base, there was also a need to summarize the large amount of data. The approach adopted was to characterize stream habitat and fish populations on the basis of landform or physiographic units. The result was the creation of "Aquatic System Units" (Harding, 1979).

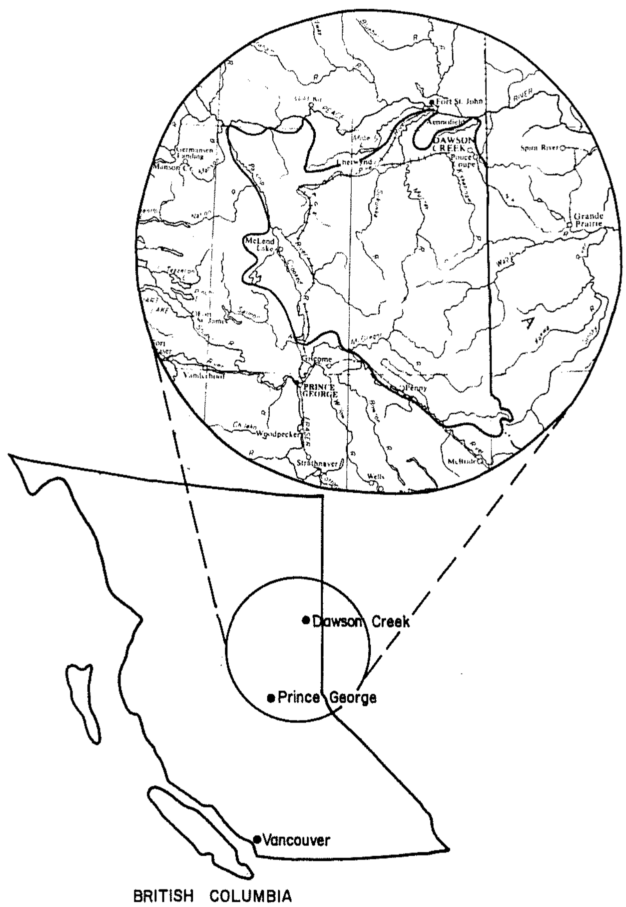

Figure 1.--N.E. Coal Study Area

[1] Presented at the "Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information." Hilton Hotel, Portland Oregon, Oct. 28-30, 1981.

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LANDFORM SUBDIVISIONS

Holland (1964) defined the basic physiographic or landform units of British Columbia. These units were based on similarities:

1. in processes of erosion and deposition;
2. of bedrock in response to erosion;
3. in the history of mountain formation by folding and faulting (Orogeny).

The landforms are specific mountain ranges, foothills, plateaus and major drainage basins. In Canada they approximate the "Land Region" as described by Lacate (1969) or the "Ecodistrict" as described by Wiken (1978). Within the "Ecoclass" System defined by Corliss et al (1973) Holland's units most closely compare to the "Section Unit".

In the Coal Block Study, the following landform subdivisions were defined (Figure 2):

1. Alberta Plateau,
2. Foothills (North),
3. Foothills (South),
4. Rocky Mountains (East),
5. Hart Ranges (West),
6. Continental Ranges (West),
7. Rocky Mountain Trench and
8. Interior Plateau.

The east, west divisions were incorporated to take into account climate changes on either side of the mountains. The Hart Range is in the Arctic drainage and the Continental Range is in the Pacific Drainage. The foothills were also divided north and south due to major differences in surficial materials. Within each unit description there was a further subdivision of river channels to either alluvial (unconfined) channels or entrenched channels.

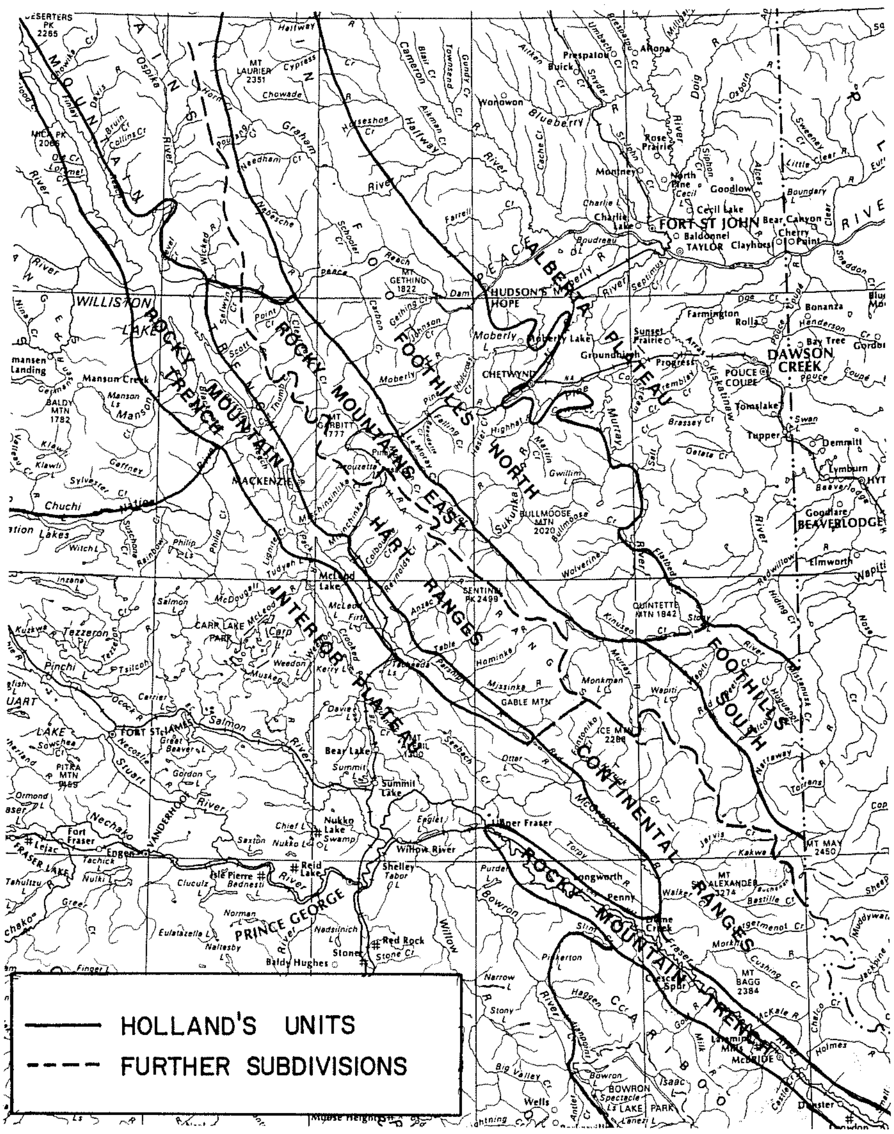


Figure 2.--Holland's landform units.

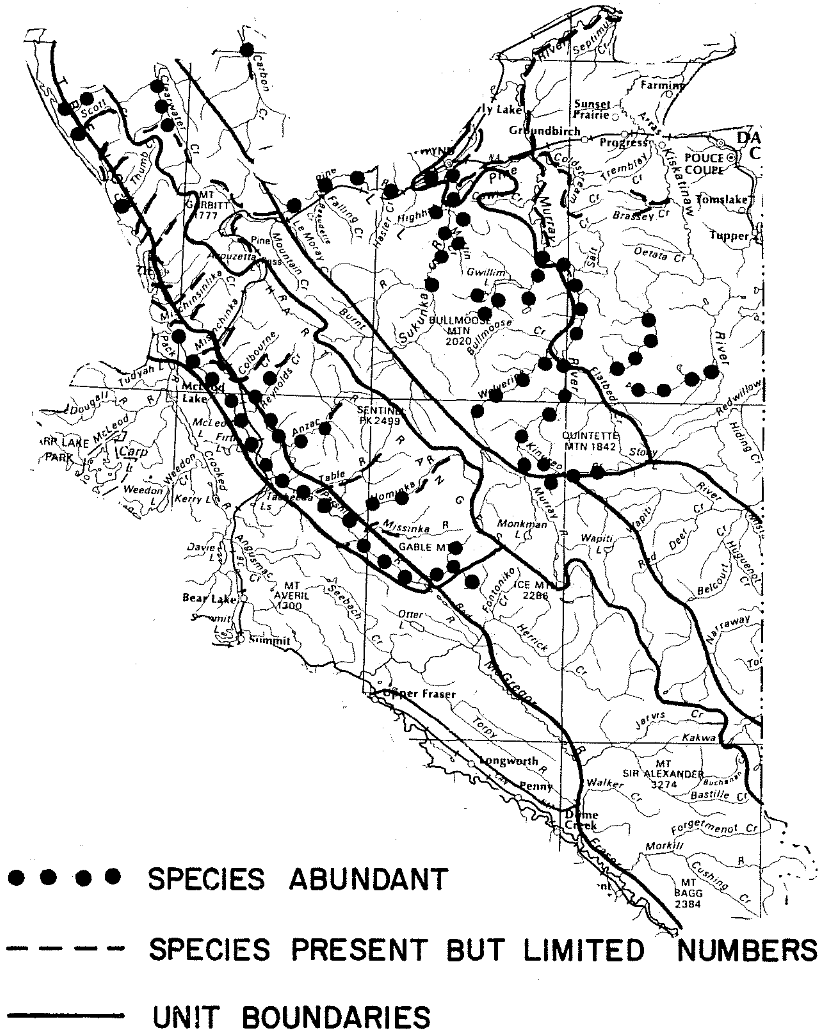


Figure 3.--Arctic grayling distribution.

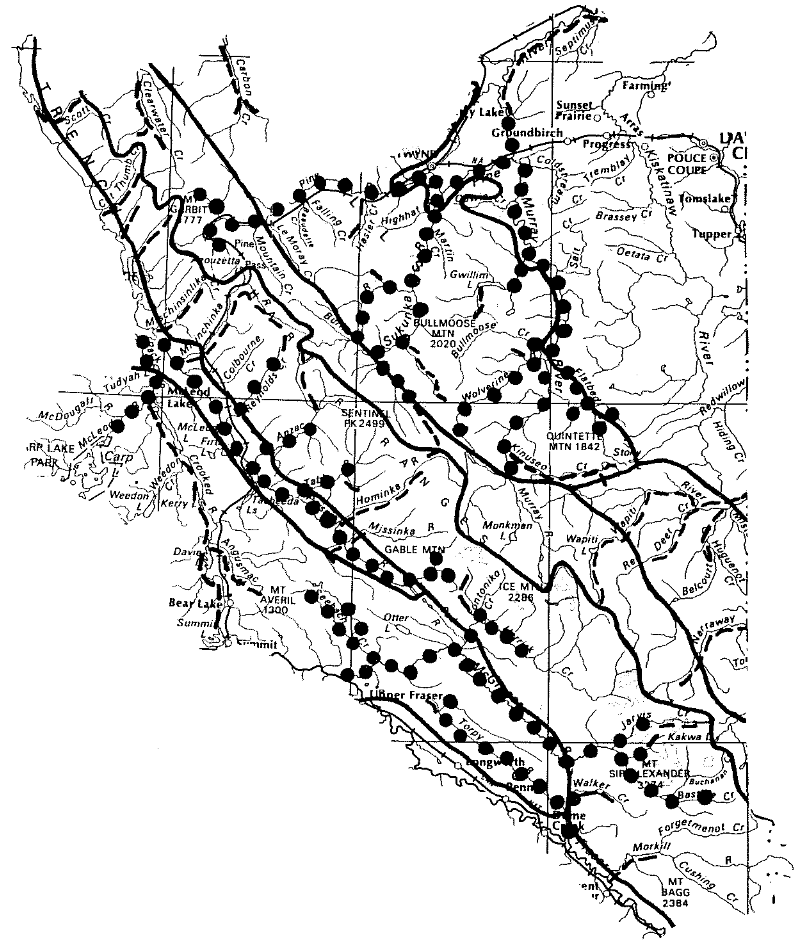
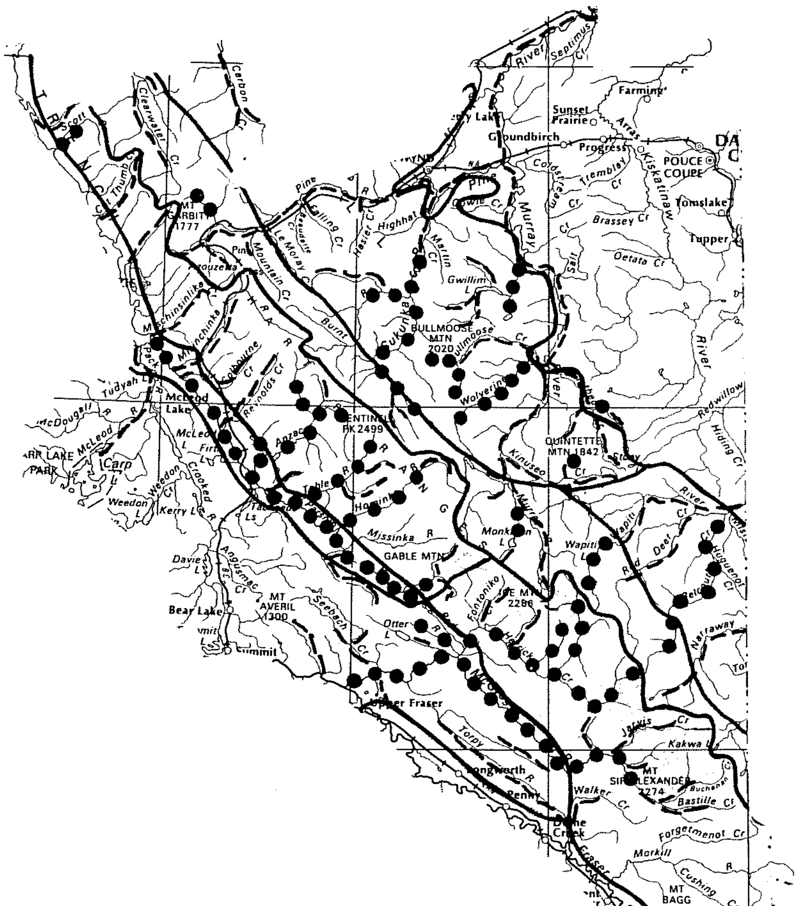


Figure 4.--Mountain whitefish distribution.



●●●● SPECIES ABUNDANT

– – – – SPECIES PRESENT BUT LIMITED NUMBERS

——— UNIT BOUNDARIES

Figure 5.--Dolly Varden distribution.

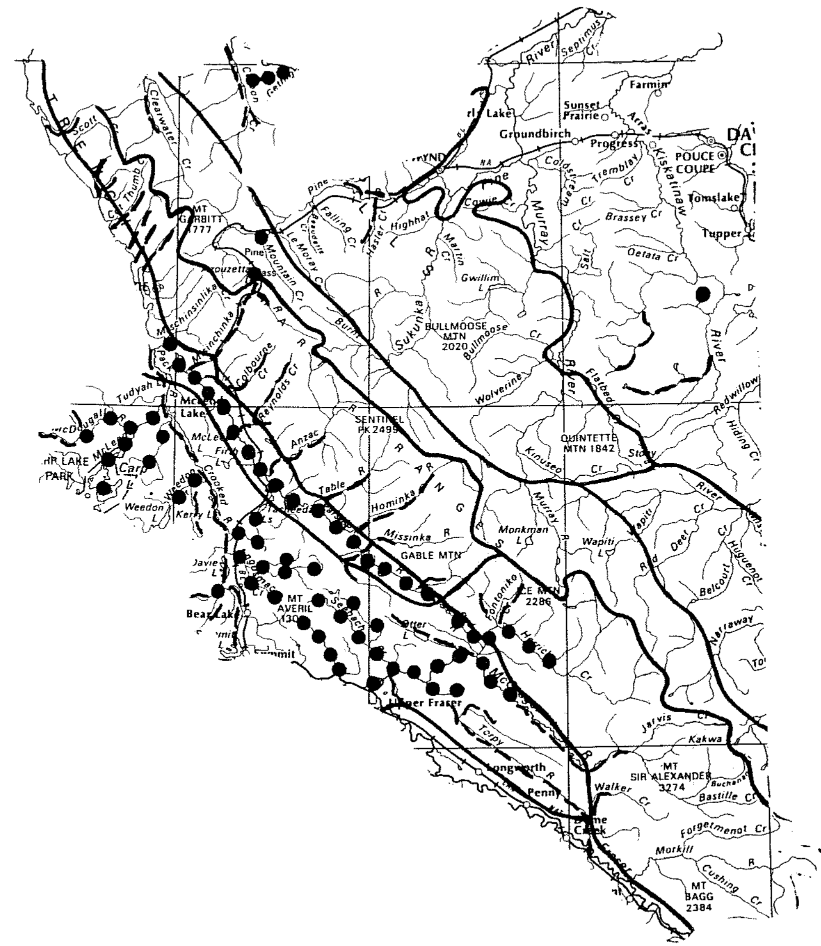


Figure 6.--Rainbow trout distribution.

LANDFORM DESCRIPTIONS

Because of the homogeneity of individual landform units general physical factors could be described for each unit. For example:

1. The Alberta Plateau is composed mainly of fine textured morainal and lacustrine deposits which are actively eroded causing significant long term suspended sediment loading. This unit has the lowest elevations and smallest snow accumulation of the study area hence, spring runoff occurs much earlier and stream temperatures warm much faster than in the adjacent landform units.
2. The Foothills North is composed of much coarser materials, with only isolated pockets of lacustrine sediments. Suspended sediment loading occurs only during peak rainfall or runoff events. Spring runoff lasts longer and stream temperatures are colder than the Alberta Plateau.
3. The Rocky Mountain (East) is composed predominately of steep, bedrock controlled channels, with numerous waterfalls and rapids. Water temperatures are colder than those in the Alberta Plateau and suspended sediment levels are lower than those in the Foothills and Alberta Plateau.

Each Landform Unit is described in this manner and in addition the major influences of climate are described to provide a complete picture of the influencing biophysical factors. The main limit to this information is the quantity and quality of available physical data.

FISH DISTRIBUTIONS

The major sport fish species in the study area were Arctic grayling (Thymallus arcticus), mountain whitefish (Prosopium williamsoni), Dolly Varden char (Salvelinus malma) and rainbow trout (Salmo gairdneri).

Over the 2 year field program sufficient variation in species distributions were noticed to suggest that climate and geology could be controlling fish distributions. An overlay of Holland's (1964) Landform units on maps of fish distribution showed enough similarities in pattern to support this contention.

As an example, in Figure 3 Arctic grayling distribution is confined mainly to the Foothills North Unit and the Rocky Mountain Trench (North), with an isolated population in the Alberta Plateau. There is also numerous instrusions of grayling into the Hart Ranges, but this may only reflect a transition between Trench and Hart Range streams. It is interesting to note that grayling do not occupy the Interior Plateau on the west side of the Trench. A noticeable division in the density of grayling in the Pine River (located in the upper third of Foothills North Unit) corresponds exactly with the Holland's boundary line between the Foothills and the Rocky Mountains.

Mountain Whitefish (Figure 4) have a much broader distribution within the study area and have successfully colonized most areas except for the Alberta Plateau and the east side of the Rocky Mountains. However, areas of greatest whitefish abundance were found in the Foothills North and Rocky Mountain Trench.

Dolly Varden char (Figure 5) are well distributed throughout the study area and have adapted well to the mountain regions. However, they have not colonized either the Interior or Alberta Plateaus.

Rainbow trout (Figure 6) are restricted to the Interior Plateau and Rocky Mountain Trench (North and South). They are also found in the Hart and Continental ranges but like Arctic grayling they have not been completely successful in colonizing those units. Rainbow trout are abundant in the Peace River north of the study area. Despite the lack of physical barriers to migration they have not utilized the Foothills North or Alberta Plateau Units. The small numbers of rainbow found in the Foothills may be attributed to artificial stocking.

DISCUSSION

The data collected during the "N.E. Coal Study" appears to indicate that fish distribution is closely related to physiographic or landform units. These units thus provide a valuable tool for the protection, management and enhancement of these fisheries resources.

The landform approach, will show resource managers the size and limits of range for a given species. For instance; Arctic grayling distribution (Figure 3) if viewed without the landform overview would suggest a potential for stocking or species extension over a broad area. With the landform unit overview it is readily apparent that grayling are abundant within some units, and only a few sites remain with potential for species introduction. Adjacent units do not presently contain grayling and may not be suitable for stocking.

Rainbow trout distribution (Figure 4) is restricted mainly to the west side of the study area, and there is a large concentration in the Peace River at the North end of the study area. Rainbow in the Peace River could conceivably have migrated into the Foothills and Alberta Plateau, (since there are no barriers) introductions of rainbow into the Foothills over 10 years ago however, resulted in only a limited population of rainbow localized to the stocking sites. Once again interpretation of landform units would suggest that introduction of rainbow into the east side of the study area is not a valid management option.

Due to the close correlation of fish distributions to landform units it is also feasible that landform units could form a logical basis for the establishment of "Fisheries Management Units". Within such units specific management regulations or prescriptions could be made eliminating the need for many "blanket" angling regulations. For instance there is a spring fishing closure in this region to protect spawning fish, however, this makes little sense in areas where there are predominately mountain whitefish and Dolly Varden char which are fall spawners.

In the case of environmental protection, landform units would provide the key to highlighting areas where fisheries values are particularly high. For example the Foothills North is the most productive area on the east side of the study area. This unit is in the center of the proposed coal development and therefore is an area of key concern for environmental protection.

As useful as the "physiographic" or "landform" units are there is always a reason to further sub-divide. However, if further stream sub-division is required it should be done on the basis of channel morphology rather than a land classification. Parameters such as "meander pattern" or "channel slope" are much stronger stream classifiers than vegetation or soil associations. Also, the use of "Stream Order" (Strahler, 1952) as an additional classification tool would have greater significance when related to landform units. For example a first order stream on a plateau is entirely different from a first order stream in mountainous terrain.

It is important to point out that landforms are not a rational basis for doing aquatic inventory. Systematic inventory is best done by the basin approach (Shera and Grant, 1980), using the landforms only as an interpretive tool. Finally landforms are only a tool and will never replace good inventory data, however used properly available landform information can only enhance data interpretation.

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THE APPLICATION OF BRITISH COLUMBIA AQUATIC INVENTORY DATA TO CHANNEL STABILITY EVALUATION[1]

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T.W. Chamberlin[3]

Abstract.--Several methodologies for evaluating channel stability have been applied in British Columbia utilizing the British Columbia Aquatic Data Base for storage and processing of inventory information.

United States Forest Service channel stability ratings are stored in a separate file coordinated with the B.C. Aquatic Data Base.

Channel stability ratings similar to the U.S.F.S. ratings have also been developed from the B.C. Aquatic System Data Base.

INTRODUCTION

Stream channel stability is a persistent theme in diverse river engineering, streamside land use, and aquatic management problems throughout British Columbia. Most concerns about stream stability are associated with lateral migration of the channel, which can have such diverse effects as changing navigation routes, undermining streamside structures, eroding valley bottom lands, and degrading instream habitat for fish populations, particularly salmonids.

The range of stream sizes of interest to aquatic resource managers and the diverse climatic and geomorphic conditions in British Columbia dictate a flexible approach to the evaluation of channel stability. Basin-wide processes and major structural controls along the valleys may be the most important factors affecting the type and location of channel migration in some watersheds; in others, local factors such as bank texture and channel debris characteristics may be dominant. This wide range in stream size and scale of processes has resulted in the development of two general methodologies for reconnaissance level channel stability evaluation in British Columbia.

The first approach emphasizes the use of aerial photography to classify channel form and process, identify structural controls on channel width along the valley, and, in detailed evaluations of particular reaches, to quantify the rates of change over time. The use of aerial photography is limited by the visibility of channels.

The second approach utilizes ground-based survey information to evaluate local factors along the stream channel such as bank texture, bed compaction and channel debris characteristics. This methodology is used primarily on small streams. The applicability of the two methodologies overlaps on stream channels of about 4th order (Strahler, 1964) in both coastal and interior British Columbia.

Data from both types of channel stability surveys are entered into the British Columbia Aquatic Data Base, outlined by Chamberlin in another paper at this symposium (Chamberlin, in prep.). The mapping scale for channel stability surveys is generally 1:20 000 when compiled from ground surveys and large scale aerial photography. Overview mapping from smaller scale aerial photography is generally compiled at 1:50 000 and uses information derived from the standard Aquatic Biophysical inventory process.

METHODOLOGIES BASED ON AIR PHOTO INTERPRETATION

Overview Channel Stability Evaluations

Overview evaluations of channel stability are derived from the standard Aquatic Biophysical Inventory maps and Data Base. In most reconnaissance study areas where channel stability is identified as a specific concern, normal 1:50 000 scale photography is supplemented with larger scale photos to facilitate more detailed

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[1] Presented at American Fisheries Society Symposium on "Acquisition and Utilization of Aquatic Habitat Inventory Information", Portland, Oregon, October 28-30, 1981.
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analysis of system reach structure and characteristics. Field survey cards are completed as for a standard aquatic biophysical inventory.

The system, reach and features data files provide a considerable amount of channel stability information at an overview level. Two types of information are particularly relevant: reach structure, and channel form and process. Reach structure is the combination of changes in valley to channel width ratio, channel width and slope along the channel. These changes reflect the structure of the many formerly glaciated valleys in British Columbia, which typically have discontinuous flood plains of varying width, and "steps" in their longitudinal profiles.

Channel form and process are indicated by the frequency and types of bars and islands along the channel, the degree and type of lateral migration process, and the pattern or sinuosity of the channel. These channel characteristics provide an indication of the types and frequencies of lateral activity present, and are frequently correlated with changes in the reach structure of the system. The channel form and process descriptors used by the British Columbia Aquatic Inventory System are adapted from Kellerhals, Church and Bray (1976).

Detailed Photogrammetric Evaluation

Channel change over time can be quantified from a sequence of aerial photographs. Some of the variables which can be measured are listed in table 1. Channel stability is defined in terms of the relative rates of change in channel width, pattern, and lateral migration which can be differentiated between reaches. Variations in the rates of change over time can be compared with changes in river regime, land use or geomorphic events to determine the factor(s) controlling the changes.

This approach has been used in a number of channel stability evaluations in British Columbia such as the Elk River, on Vancouver Island (fig. 1) (Karanka and Kellerhals, 1980). In this basin, encroachment of the channel on the valley flat was reducing elk habitat within a provincial park. At the same time, changes in the aquatic habitat were reducing the fish potential of the system (Tredger, 1979). The maximum amount of change occurred between 1931 and 1966 (fig. 2). Analysis of aerial photographs showed that the mainstem channel of the Elk River could be divided into two reaches, based on differences in channel properties and their rates of change. A sequence of aerial photographs showed three peaks in the rates of change of channel width over time, occurring after 1946, 1957 and 1975 (table 1).

The basin history indicated that the first peak was associated with a surge caused by a landslide into a headwater lake. The effects of the surge were probably aggravated locally along the channel by an increase in debris jams and a reduction in bank stability due to clearcut logging of the valley flat. The second, and major peak was associated with a river diversion which nearly doubled the mean annual flow of the system and increased peak flows up to 30%. The effects of the river diversion were aggravated by a coincident doubling of the frequency of major rain-on-snow flood events in the region. The last peak, after 1975, is associated with a flood having a 25 year recurrence interval.

The data from photogrammetric evaluation of river channel stability are added to the reach data file of the B.C. Aquatic Data Base as separate "inventories" keyed to the date of the aerial photography.

The advantages of the method are that the rates and types of lateral change can be quantified by reach and related to contemporary environmental changes within the watershed over the time span of photography. These are significant advantages in regions such as much of British Columbia where long term hydrometric and sediment data are lacking.

The main limitations of the method include the frequency of air photo coverage and the degree to which the channel is obscured by vegetation or poor image quality on the aerial photographs.

GROUND-BASED RATING METHODOLOGIES

United States Forest Service Channel Stability Rating

The channel stability rating approach was originally developed by the U.S. Forest Service in Idaho (Pfankuch, 1975), and has subsequently been expanded into a methodology proposed by the United States Environmental Protection Agency for evaluation of total potential sediment yield from non-point silvicultural sources (Rosgen, Knapp and Megahan, 1980). The initial methodology involved the rating of 15 "indicators" of channel stability, covering characteristics of upper and lower banks, and the bed of channels (table 2). Experimental application of this approach in British Columbia was initiated in 1978 for studies of small watershed where photogrammetric analysis was impracticable. About 70 reach evaluations were done in 8 study areas (fig. 1) during 1978 and 1979.

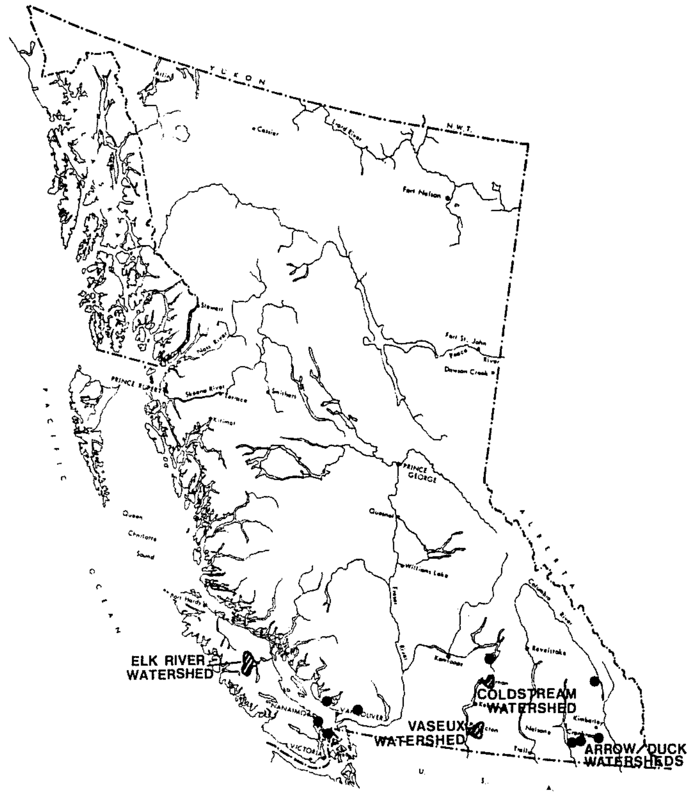

Figure 1--Stream channel stability study areas in British Columbia referred to in text

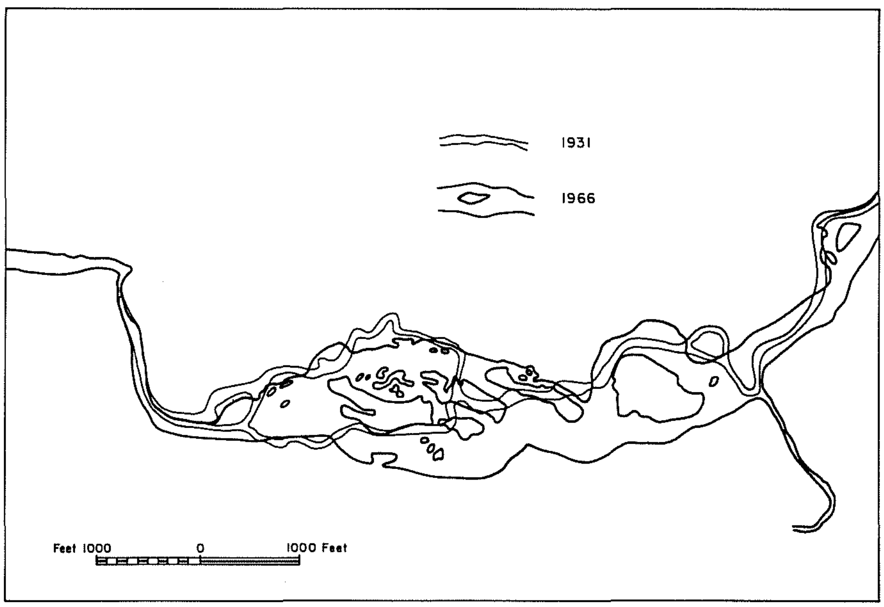

Figure 2.--Section of the Elk River on Vancouver Island illustrating channel changes between 1931 and 1966 aerial photography

Table 1.--Channel Measurements from Aerial Photography

Reach 1 Parameter	1931	1951	1957	1962	1966	1972	1975	1977
Average channel width (m)	44.4	66.3	69.3	100.2	151.6	141	113.8	125.4
Change in channel width (m/yr)		1.1	0.5	6.2	12.8	- 1.8	- 9.1	5.8
Sinuosity (length of channel/length of valley)	1.2	1.2	1.4	1.3	1.3	1.3	1.3	1.3
Multiple channels (percent channel length)	17	26	21	38	42	25	34	30
Reach 2								
Average channel width (m)	26.5	36.5	30.0	34.1	56.1	49.9	50.1	50.1
Change in channel width (m/yr)		0.5	- 1.1	0.8	5.5	- 1.0	0.1	0
Sinuosity (length of channel/length of valley)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Multiple Channels (percent channel length)	4	6	2.5	10	20	8	10	16

1) Area - average channel width x channel length
2) Area measured on digitizer

More comprehensive applications of the approach, including the correlation of channel stability ratings with basin suspended sediment rating curves as proposed in the EPA methodology, were undertaken in 1980 and 1981 in the Arrow, Duck, Vaseux and Coldstream watersheds of the southern interior of British Columbia (Karanka in prep.; Hawthorn and Karanka; 1982). U.S.F.S. channel stability ratings were evaluated at over 100 sites and suspended sediment was sampled near the mouths of the watersheds over a range of discharges. Channel stability ratings between the Coldstream and the other three systems differed substantially. Nearly 40% of ratings in the Coldstream system were in the "poor" category, compared with 20%, 15% and less than 5% in the Arrow, Vaseux, and Duck Creek systems respectively. These differences in stability indices corresponded with differences in the suspended sediment rating curves of the four systems (fig. 3), with the Coldstream system showing a 10 to 30-fold greater suspended sediment concentration at a given discharge than the other systems.

The U.S. Forest Service channel stability ratings for these systems are stored in the B.C. Aquatic Data Base in a file coordinated to the other data files by watershed system code, reach, point number and time of survey.

Stability Ratings from Aquatic Biophysical Inventory Data

Much of the data in the B.C. Aquatic Data Base is gathered for standard biophysical inventories not specifically concerned with channel stability. The feasibility of "interrogating" the data base to determine channel stability ratings on small channels not originally surveyed specifically for channel stability was undertaken as a sub-project of the Coldstream study. Both U.S. Forest Service channel stability ratings and regular Aquatic System point and reach data were collected. It became apparent that, while both data sets describe similar bank and bed variables, reliable ratings of the 15 USFS channel stability indicators could not be made directly from the B.C. Aquatic System data. An indirect approach was therefore developed, based on the factors affecting channel stability represented by the 15 indicators.

The U.S.F.S. methodology measures two types of factors affecting channel stability ratings, and gives them roughly equal weights.

Table 2.--U.S. Forest Service Channel Stability Ratings (Schematic)

USFS Stream Attribute	Weighting	
Upper Bank		
1. Upper Bank Slope	2	
2. Frequency/Size Mass Wasting	3	
3. Upper Bank Debris	2	
4. Upper Bank Plant Root Density	3	Total Upper Bank = 10
Lower Bank		
5. Channel Width to Depth Ratio	1	
6. Lower Bank Debris	2	
7. Lower Bank Rock Content	2	
8. Lower Bank Sloughing	4	
9. Bar Formation	4	Total Lower Bank = 13
Channel Bed		
10. Bed Material Angularity	1	
11. Bed Material Brightness	1	
12. Bed Material Compaction & Overlap	2	
13. Bed Material Size & Stability	4	
14. Bed Material Scouring & Deposition	6	
15. Bed Material Algae Density	1	
		Total Channel Bed = 15

Rating Scores and Classes
- Weighting x 1 = Excellent
- Weighting x 2 = Good
- Weighting x 3 = Fair
- Weighting x 4 = Poor

1. "local" factors such as bank vegetation density, bank texture and form, bed debris, texture and compaction;

2. evidence of bank failure and bed material movement.

In the British Columbia Aquatic Data Base, the "local" factors are covered mainly by point data, while evidence of bank failure and bed material movement are evaluated by reach data. Thus the estimations of channel stability ratings equivalent to the U.S.F.S. ratings depend on the availability of representative point data within the reach being evaluated. In the Coldstream study it was possible to estimate reliable channel stability ratings from the B.C. Aquatic System Data Base because of repetitive point sampling within reaches and the derivation of reach parameters from ground observations. In the Arrow and Duck Creek studies, representative points were chosen within the accessible reaches.

Significant correlations of -0.81 and -0.94 were found between channel stability ratings derived from the B.C. Aquatic Data Base and U.S.F.S. data in these study watersheds (figure 4). The negative correlation results from the equating of low ratings with low channel stability rather than high channel stability as in the U.S.F.S. system.

The following problems limit the use of the B.C. Aquatics Data Base for systematic channel stability evaluations:

1. The intensive sampling designs in the study watersheds apply to only a few of the reconnaissance level inventories undertaken by the Aquatic Studies Branch.

2. The Aquatic System Data Base contains uneven amounts of information about the channel stability factors rated by the U.S.F.S. methodology. Some factors, like bank vegetation, are adequately covered, while others such as evidence of bed scour and deposition are covered only indirectly.

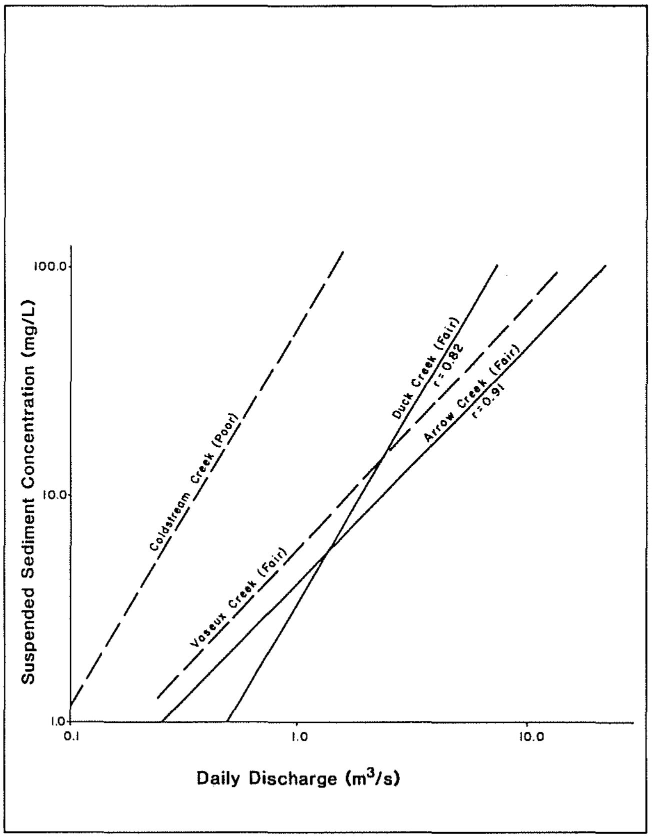

Figure 3.--Suspended sediment rating curves for British Columbia watersheds having the United States Forest Service channel stability ratings

DISCUSSION

The purpose of the reconnaissance level channel stability evaluations outlined in this paper is to "flag" particular reaches which either have channel stability problems or have the potential for instability under changing conditions of discharge and sediment load. In the reaches thus identified, resource planning should be focused on the types of land use and streamside management which can impact or be impacted by lateral activity of the channel. Reconnaissance inventory data is generally not adequate, however, for detailed site evaluations such as required for the location of structures infringing on the stream environment.

The main limitations of the air photo interpretation approach are the size of channels which can be evaluated, and the lack of data about local factors along the channel such as bank and bed texture. The channel stability rating approach, while providing data about the local factors not interpretable from aerial photos, is limited by the field survey requirements. The field sampling design must be sufficiently intensive for statistical analysis of reach properties, and requires a ground examination of each reach adequate for identifying a representative point sample site.

This paper has outlined several methods for analysis of the channel stability of stream reaches which have the requisite data filed in the B.C. Aquatic Data Base. The potential of the Data Base is not so much in the analysis of individual reaches, as in the classification of reaches by a variety of multi-variate techniques. When such reach classifications are linked to a computer mapping system, interpretive maps and regional summaries of channel stability by reach type could be produced for any region of the Province.

The development of methods for classifying reaches by various properties is anticipated as the next major objective of channel stability analysis, in coordination with the development of linkages to computer mapping systems.

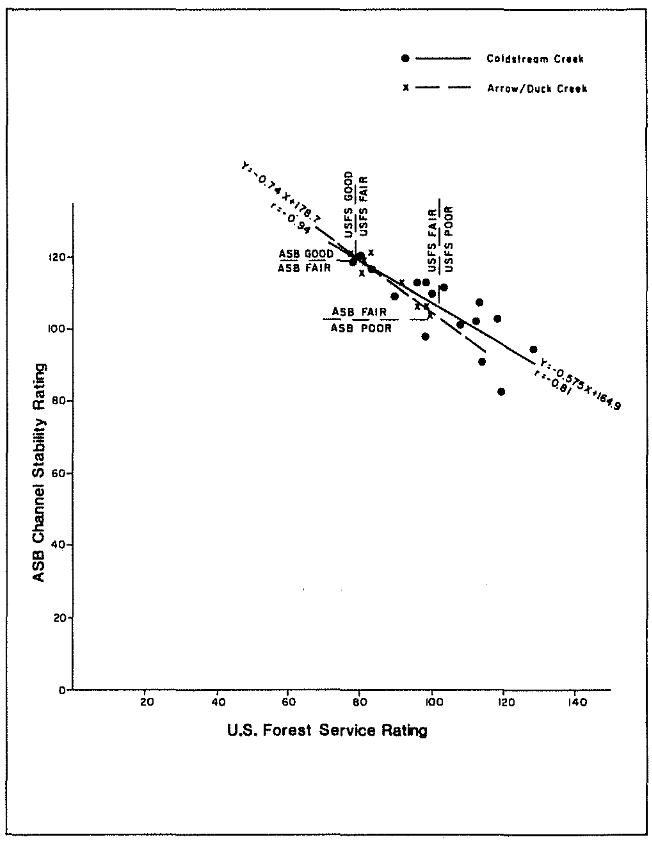

Figure 4.--Correlations between United States Forest Service and B.C. Aquatic Studies Branch channel stability ratings

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A FISHERY RESOURCE SAMPLING METHODOLOGY FOR SMALL STREAMS[1]

D. G. Price[2]

Abstract.--A computer compatible methodology to sample fish populations in small streams is described. This methodology was developed to inventory fish populations in multi-drainage areas where energy developments are anticipated. The method uses conventional sampling techniques and has been used at more than 400 sampling locations in California. Electro-shocking provides the basis for quantitative estimates of population density, standing crop, and species composition. Physical measurements are taken concurrently to determine the characteristics of the water and stream channel. Qualitative information on the general nature of the stream is also collected. These data are recorded on a standardized form and put into a computer program for data management and analysis. The computer program reports physical characteristics of each station, calculates population parameters, and produces length frequency histograms. The program also estimates total stream and drainage populations if required. All data collected are stored in a standardized format for other analyses such as correlation, classification, and hypothesis testing.

INTRODUCTION

A systematic, computer compatible package of commonly used sampling methods and techniques was developed to inventory fish populations in small streams as part of The Geysers Known Geothermal Resources Area Fishery Investigations (Price et al. 1979, Price et al. 1980). The major objective of this methodology is to provide a quick and conventional technique to collect data on fishery resources and aquatic habitat. With these data, resource managers can develop appropriate management plans and precautions for construction activities. The benefits of a proposed management plan can then be assessed through the evaluation of quantitative baseline data (Platts, 1978). The sampling methods used in this package are conventional and are not effective for streams more than five feet deep or with flows greater than 25 cubic feet per second, because fish are easily able to avoid the electroshocker field, or the stream is too deep for the crew to maneuver in. In some larger streams, however, the technique is useful in selected habitats. For example, a large river section can be sampled with this methodology if only riffle areas are selected. Other techniques like diving observations, beach seining, or chemical treatment can be used in large pool and deep run habitats. Combining these techniques gives results similar to this procedure.

This paper consists of two major parts:

1. Descriptions of the sampling design and sampling procedure.

2. A discussion of data management including data recording, auditing for errors, computations, and a description of computer program developed to report the data.

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[1]Paper presented at the symposium on the Acquisition and Utilization of Aquatic Habitat Inventory Information, (Portland, Oregon, October 28-30, 1981.)

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METHODOLOGY FOR SAMPLING FISH IN SMALL STREAMS

Reconnaissance Survey

An initial reconnaissance survey is conducted to identify major stream types capable of supporting fish and to locate likely access points. The study area, usually an entire drainage, is best surveyed by helicopter (small study areas with good road systems may be surveyed by car). Major stream types and access roads are located and marked on United States Geological Survey topographic maps.

Streams that are too large to sample with these techniques are separated for special sampling. In most areas the drainage areas should be categorized into four or less major stream types.

Determine each stream type by making visual observations of the surrounding vegetation and stream channel characteristics. Include an additional stream type for special areas, if necessary, although the areas may be similar to other stream types. Common stream types can be described as:

1. Agricultural (low gradient, low elevation, open, cultivated land).
2. Chaparral-oak woodland (moderate gradient, moderate elevation, chaparral covered slopes).
3. Conifer forest (high gradient, high elevation, fir and pine forests).
4. High meadow (low gradient, high elevation, open grassland).
5. Special study area (may be included where additional stations are required within any existing stream type).
6. Other types, as necessary.

Sample Design

After a reconnaissance survey, develop a map indicating the locations of major stream types and of proposed sampling stations. Locate two or more replicate sample stations within each stream type in each stream in the drainage. The number of replicates used should include a sufficient number of sample points to provide a sample mean approaching the true population mean for each variable measured in a stream type. There is no upper limit to the number of stations in each stream type, but in most cases, five stations are adequate. In short stream sections only two stations may be possible.

Sampling Procedure

All equipment necessary for sampling is carried in backpacks to the general station location. A representative 30 meter section of stream is selected for sampling at the location. Two block nets, separated by a 30 meter measured distance, are set in the stream to prevent the movement of fish into and out of the sampling station. Rocks are set along the lead line to hold the net on the stream bottom. Sticks and rocks are used when necessary to hold the float line above the water surface.

Several physical and water quality parameters are measured up to 30 meters above the upstream block net prior to fish sampling. Air temperature is measured in the shade with a laboratory thermometer. Surface water temperature is measured with the same thermometer in running water, and a bottom water temperature is measured at the bottom of pools within the sampling station. The times at which all temperatures are measured are recorded. Conductivity is measured in micromhos/cm with an electronic conductivity meter. A colorimetric determination of pH is made at streamside. A water sample for turbidity analysis is collected by slowly immersing a 500-ml polyethylene bottle in the stream. The bottle is kept cool to minimize bacterial or algae growth. The sample is analyzed with a turbidity meter (NTU method) within 24 hours. Dissolved oxygen is measured in mg/l by the Winkler method (Hach Chemical Company 1964; American Public Health Association et al. 1971). The sample is fixed at streamside and analyzed within 24 hours.

A backpack electroshocker with two hand-held probes is recommended to sample fish populations. The fish sampling crew consists of a "shocker," who operates the electroshocking unit, and two "netters," who each carry a fine-mesh, long-handled dip net for capture of stunned fish. Captured fish are retained in a water-filled bucket with an inner plastic pail. A screened hole in its bottom facilitates the removal of fish from the water-filled buckets. All crew members wear water-proof rubber gloves and hip boots or chest-high waders.

Starting at the downstream block net, the shocker wades upstream through the sampling station operating the electroshocking unit. The two netters remain to the side and/or slightly behind the shocker. Stunned fish are netted and placed in the water-filled bucket. The timer on the shocker records the effort expended on each pass.

Two or three passes of equal effort are conducted at each station in order to estimate fish population size by the methods of Seber and LeCren (1967) or Leslie and Davis (1939), respectively. A special table (available from the author) based upon the Seber and LeCren population estimation procedure, is used to determine the maximum number of fish that can be caught on the second pass relative to the first pass to insure less than a ten percent error in the total population estimate. If the number of fish captured on the second pass exceeds the appropriate number listed in the table, a third pass is necessary. These population estimation procedures assume:

1. All fish have an equal probability of being captured on each pass.

2. The capture of one fish does not interfere with the capture of another.

3. No births, deaths, immigration or emigration occur during sampling.

Prior to sampling, it is convenient to develop a list of species that are likely to exist in the drainage. This makes it easy to assign each species a code number for recording on data sheets. Any unexpected species can be assigned a new code. Species of particular interest (those species for which length frequency data are desired) are determined and indicated as, "designated species".

After each pass, fish are identified to species and enumerated. For each designated species, the fork lengths of all individuals are measured to the nearest millimeter on a measuring board. For each nondesignated species, fork lengths of up to 27 representative individuals are measured. These fish lengths are recorded on the data sheet.

A displacement method is used as a technique for determining the approximate biomass of each species (Leitritz and Lewis 1976). The amount of water displaced by all individuals of each species captured on each pass is measured in a 1000-ml graduated cylinder. This method assumes that one milliliter of water displaced is approximately equal to one gram of fish flesh. If an individual fish is too large to be placed in the cylinder, it is weighed with a spring scale. Fish captured on each pass are released below the downstream block net prior to later passes.

After the final electroshocking pass is completed, several physical stream measurements and estimations are made. Ten stream widths are measured to the nearest tenth of a meter of wetted area at each sampling station. Beginning at either the upstream or downstream block net, one width is measured every three meters through the station. Emergent areas in the stream (exposed rocks, gravel bars, logs, etc.) are included as part of the total width measurement. Along each width measurement transect, three depths (at the quarter, half, and three-quarter points of the stream width) are measured to the nearest centimeter. If the point of depth measurement is located in an emergent area, a depth of zero is recorded.

Stream velocities are measured (with an electronic meter) at a selected location near the station. A visual estimation of streamflow is made at streamside as well.

The following physical characteristics are visually estimated at each sampling station:

1. Percentages of the total stream surface area composed of pools, riffles, and runs.

2. Percentage of the total stream surface area with cover (hiding areas) suitable for fish.

3. Percentage of the total stream surface area with canopy (overhead vegetation and shade).

4. Percentages of the total bottom area composed of compacted clay, silt, sand (0.3 cm), gravel (0.3-7.5 cm), rubble (7.5-30.5 cm), boulder (30.5 cm), and bedrock.

Each station is located on a USGS topographic map, and the elevation is recorded. Photos are taken at each station for documentary purposes. Figure 1 is a flow chart summarizing the general survey procedure carried out at each sampling station.

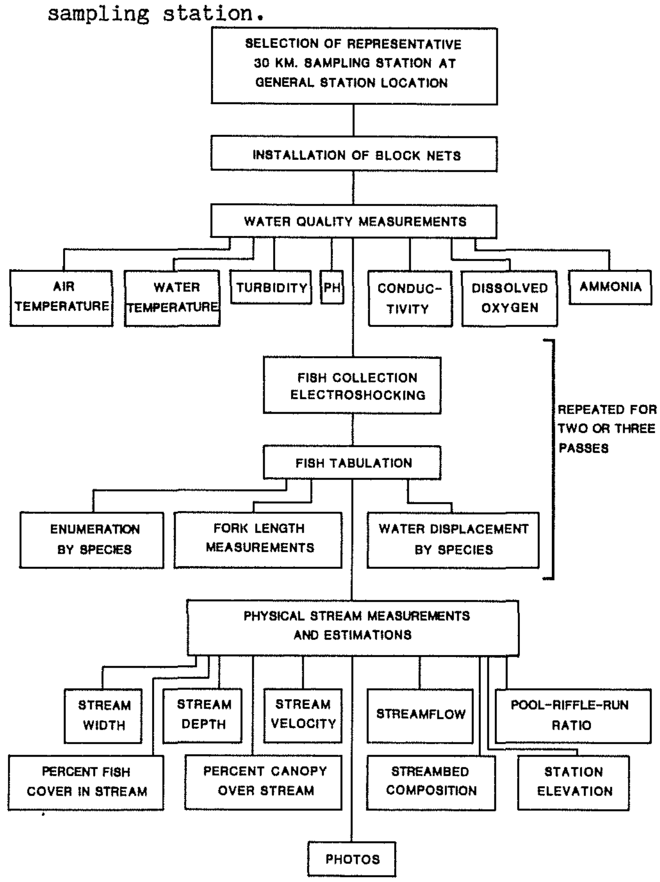

Figure 1. Flow diagram of general station sampling procedure.

DATA MANAGEMENT SYSTEM

A computerized data management system was developed to provide analysis and reporting support for the systematic survey of fish populations and aquatic habitat. Data sheets from the field study are keypunched and organized into a separate file for each survey of a drainage area. Each drainage area consists of one or more streams which are further partitioned into stream types.

The system is based on a computer program which processes data from the files and makes it available on four levels of analysis: the station, the stream type, the stream, and the drainage. The system is designed so that there is virtually no limit on the number of stations, stream types, streams, or drainages which can be analyzed in a single run. This is accomplished through a hierarchical separation of the four levels.

The computer program consists of a main part for data input and basic computations, and a separate internal subroutine for each report produced by the system. In order to accomodate changes in species lists or species designation in different watersheds, several versions of species lists are maintained. A stream length file contains length records (in meters) for each stream type comprising the streams and drainages studied.

The Data

Figure 2 displays the input data format of the fish inventory methodology. Field Data is keypunched onto standard 80 column IBM cards. The first 39 columns contain identical information on each card from a particular station. In particular the drainage name (Col. 1-12), the stream name (Col. 13-23), the station number (Col. 24) and the stream type (Col. 25) together uniquely identify the station. Column 40 of each card gives the card type. There are always eight cards at each station containing environmental data; one each of card types 1-5 and three type 6 cards. There is no defined limit to the number of type 7 cards (which contain fish data).

Fish data are recorded on the type 7 card and are grouped by pass and by species within a pass. There can be up to 99 cards for each species observed during a pass. The first card contains the species code, number collected, total biomass, and up to nine fish lengths. The succeeding cards each contain a sequence number and length observations.

The Auditor

An auxiliary program was designed to scan field data and detect various kinds of errors before operating the main program. The AUDITOR tests for missing data and for the violation of the specified range of variables. After errors in the raw data are corrected, the MAIN DRIVER program can be used to produce reports. The user has four basic options:

1. Produce reports at the terminal.
2. Route reports to a line printer.
3. Display graphics on a CRT graphics terminal.
4. Output data to magnetic tape.

The Computations

All calculations are initially completed on a station by station basis. The following calculations are made for each station:

1. Mean stream width (meters): $\overline{W} = 1/10 \sum_{i=1}^{10} W,$

   where W = stream width measurement in meters and i = the width transect number.

2. Wetted surface area (square meters): $A = 30 \overline{W}$ (30 meters is the length of each station).

3. Wetted surface area (hectares) $A_h = A/1000$.

4. Mean stream depth (inches):

   $$\overline{D} = 1/40 \sum_{i=1}^{10} (D_{1i} + D_{2i} + D_{3i}),$$

   where D_1 = depth measurement at the mid-point of stream width transect, D_2 = depth measurement at the first quarter-point of stream width transect, and D_3 = depth measurement at the three-quarter-point of stream widthtransect. To calculate the mean, the summation is multiplied by 1/40 rather than 1/30 to include a depth measurement of zero at the stream bank for each of the 10 width transects.

5. Wetted volume (cubic feet): $V = (1/100)$ DA_h.

6. Mean velocity (meters per second):

6. $\overline{V}_j - \sum_{i=1}^{3} V_{ij}/3$, where $\overline{V}_j$ = mean

   velocity at transect j, V_{ij} = water velocity at quarterpoint i of transect j.

7. Streamflow (cubic meters per second): $Q = W\ (1/100)\ D_j\ V_{jj}$, where W_j = width at transect j, D_j = mean depth of transect j in cm.

8. Streamflow (cubic meters per second): $C = (35.3)Q$.

Individual population estimates are calculated for each fish species at each station. Ninety-five percent confidence limits are calculated for each population estimate. At two-pass stations, population sizes and confidence

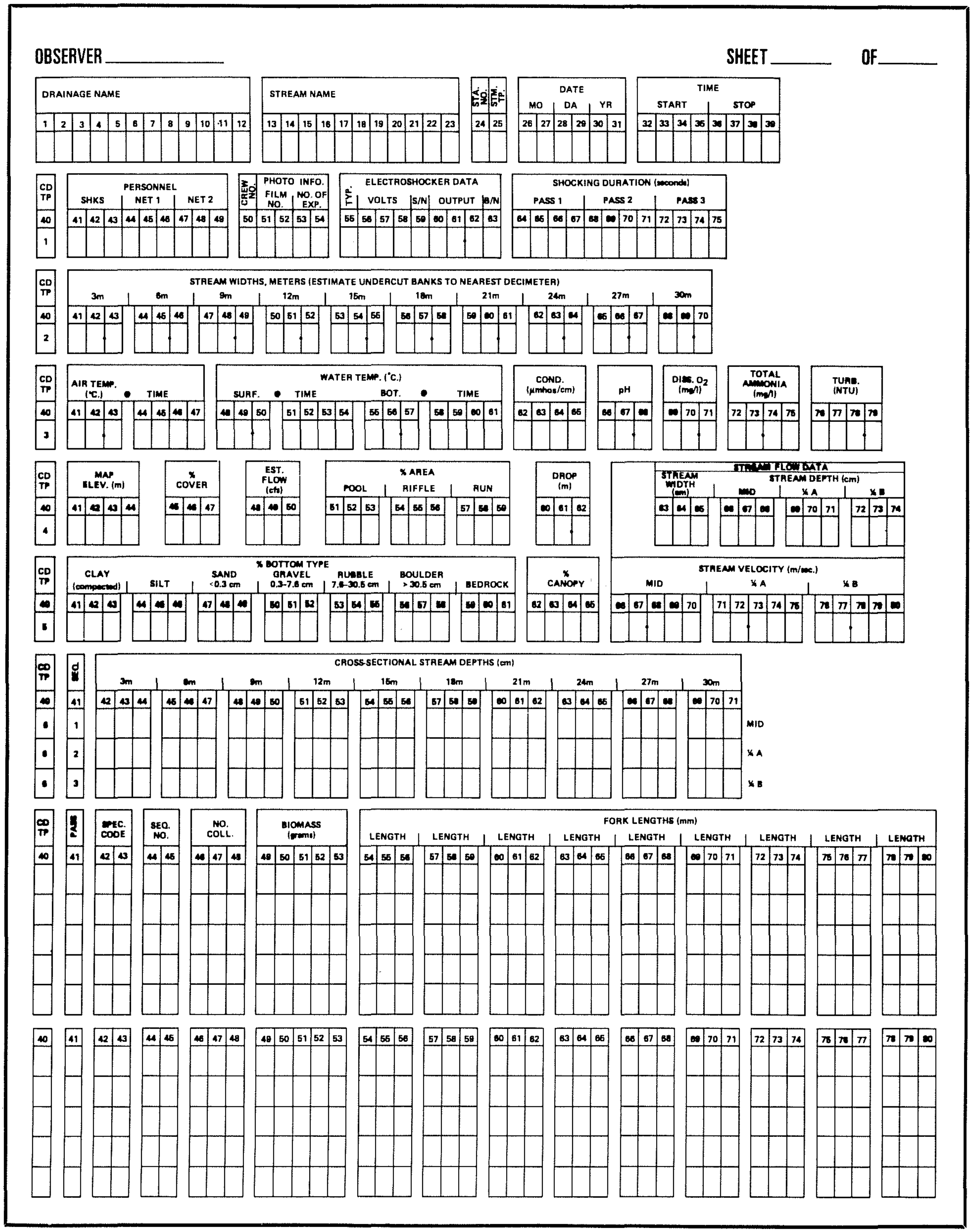

Figure 2. Input Data Format for the Fish Inventory Methodology.

intervals are estimated by the methods described by Seber and LeCren (1967). The following formulae are used:

$$\hat{N} = C_1^2/(C_1 - C_2)$$

$$\text{Var } \hat{N} = C_1^2 C_2^2 (C_1 + C_2)/(C_1 - C_2)^4,$$

where N = the population estimate, C_1 = the catch on the first pass, and C_2 = the catch on the second pass. For the calculation of confidence intervals, the square root of the variance is multiplied by 2 to approximate 95 percent confidence limits (Seber and LeCren 1967; Robson and Regier 197')

At three-pass stations, a least squares linear regression of the cumulative catch (Y) versus the catch per unit of effort (X) is used to estimate the population (Leslie and Davis 1939; Libosvarsky 1966; Ricker 1975; and Everhart et al. 1975). Catchability was calculated as the slope of the regression line for each species for three-pass stations. Catchability is the rate at which a species is collected on each pass.

Thus, it is an index of how efficiently a species is captured by electroshocking. The lower the catchability value, the more susceptible a species was to electroshocking. The following formulae are used:

Let $y_i = a + bx_i$

where y = the catch and x = cumulative catch on the ith pass. Using a least squares regression to estimate a and b gives:

$$a = \bar{y}$$

$$b = L_{xy}/L_{xx}$$

$$\text{where } L_{xy} = 3 \sum_{i=1}^{3} x_i y_i - \sum_{i=1}^{3} x_i \sum_{i=1}^{3} y_i$$

$$\text{and } L_{xx} = 3 \sum_{i=1}^{3} x_i^2 - \left[\sum_{i=1}^{3} x_i\right]^2$$

Catchability (C), is therefore L_{xy}/L_{xx} and the population estimate $\hat{N}$ is given by the value of x (the cumulative catch) when the catch y = 0:

$$\hat{N} = \frac{(\bar{X} - \bar{Y}/C)}{3}$$

A 95 percent confidence interval for the population estimate can be estimated from ± 2 SE where SE is the "standard error of the estimate":

$$SE = \frac{L_{xx} L_{yy} - L^2_{xy}}{(n-2)\, n\, L_{xx}}$$

$$\text{where } L_{yyy} = 3 \sum_{i=1}^{3} y_i^2 - \left[\sum_{i=1}^{3} Y_i\right]^2$$

If the catch on a pass is greater than or equal to the catch on a previous pass, the above methods of estimating population sizes cannot be used; in these cases, population sizes are estimated by summing the catches on all passes. However, there are two exceptions to this general rule for individual species at three-pass stations. If the catches on the first and second passes are equivalent but greater than the catch on the third pass, or if the catches on the second and third passes are equivalent but less than the catch on the first pass, a population estimate is calculated for that species by the Leslie method.

The replicate stations in each stream type form the basic unit for subsequent analysis. A mean fish population estimate per 30 meters of stream is calcuated for each stream type from the replicate station estimates. These mean estimates are expanded to include the entire length of the stream type; stream type means are multiplied by 33.3 (the number of 30 meter sections in a kilometer) and by the total number of kilometers in the stream type. Stream type estimates are added to determine stream and drainage totals for each species.

Species composition is calculated for each sampling station using the following three methods:

1. Species composition by numbers based on population estimates.

$$PE_i = (100)\, N_i \,/ \sum_{i=1}^{n} N_i,$$

where PE = percentage of the total population estimate represented by the population estimate of species i, N_i = the population estimate of species i, and n = the total number of species at the station.

2. Species composition by numbers based on actual catch.

$$AC_i = (100)C_i / \sum_{i=1}^{n} Ci,$$

where AC_i = percentage of the total catch represented by the catch of a species i, C_i = the actual catch of species i, and n = the total number of species at a station.

3. Species composition based on the biomass of the actual catch.

$$B_i = (100) b_i / \sum_{i=1}^{n} b_i,$$

Where B_i = percentage of the total weight of the actual catch represented by the biomass of the actual catch of species i, b_i = the biomass of the actual catch of species i, and n = the total number of species at the station.

Species composition estimates for stream types, streams, and drainages are calculated in a similar manner by using the appropriate totals calculated for each stream segment.

An estimate of the standing crop (in kilograms per hectare) of each species in each 30-meter sampling station is calculated according to the following formula:

$$\text{Biomass Density}_i = (1/1000)\ B_i / A_h,$$

where Biomass Density_i = standing crop in kilograms per hectare of species i, B_i = biomass in grams of the actual catch of species i, and A_h = surface area in hectares of the sampling station.

Standing crop estimates of each species for stream types, streams, and drainages are calculated in a similar manner by the following formula:

$$\text{Biomass Density}_{ti} = (1/1000) \sum_{j=1}^{n} b_{ij} / \sum_{j=1}^{n} A_j,$$

where $\text{Biomass Density}_{ti}$ = total standing crop in kilograms per hectare of the actual catch of species i at sampling station j, A_j = surface area in hectares of sampling station j, and n = total number of stations in the stream segment under consideration.

The lengths of each designated fish species are divided into five millimeter size classes for each stream and drainage. These data are then presented as length frequency histograms for each species.

The Reports

The program produces several reports that summarize the data. The reports and their purposes are listed below:

Station Environmental Report

The primary purpose of this report is to summarize the environmental characteristics of the station. In addition, person-hour data is included for project management and shock duration data is given for catch per unit of effort computations. The environmental profile can be summarized in terms of spatial, flow, water quality, streambed, and stream cover characteristics.

Station Population Report

The station is the sampling unit used to determine the fish populations of the drainage. In the field an attempt is made to capture all fish by passing through a 30 meter section of stream with the electroshocker. There are always at least two passes, even if no fish are found on the first pass. Depending on the results of the second pass, a third pass may be used.

Station Length and Biomass Report

Mean length is computed for each observed species and if at least seven specimens were caught, the standard deviation, skewness, and kurtosis are computed. If 30 or more of a species were counted at the station then a length histogram is displayed. Biomass is accumulated directly from the raw data. The biomass density is based on the estimated wet area of the station

Stream Type Population Report

This report summarizes the populations of stations included within the stream type and uses their mean to estimate the total population of the stream type. A second estimate of stream type population is derived from the population densities. The population densitites of the observed stations are used to estimate a mean density (fish per hectare) for the stream type, and this is multiplied by the estimated area of the stream type.

Stream Type Biomass Report

Stream type biomass is treated in the same manner as stream type population. The mean biomass of the observed stations is multiplied by the total number of observable stations in the stream type to obtain a total biomass estimate.

Stream Type Length Report

Fish length data are treated differently than either population or biomass data. Samples from each observed station are combined into a single sample for the stream type. Sample statistics are then computed. For species with 30 or more observations in the streamtype, a fish length histogram is printed.

Stream Population Report

This report displays the population estimates from each stream type within the stream and uses these data to estimate the total population of the stream. Since the stream types span the stream, the sum of the stream type populations is used to estimate stream population.

Stream Biomass Report

This report displays the biomass of each stream type within the stream and uses these data to estimate the total biomass of the stream.

Stream Length Report

In this report the fish length samples from the constituent stream types are combined into a single sample for the entire stream. Fish length statistics are computed for this sample and if there are at least 30 observations a histogram is printed.

Drainage Population, Biomass, and Length Summaries

These reports are generated with the same techniques used in the stream reports, but utilizing stream data rather than stream type information.

TO USERS OF THE METHOD

The method described in this paper is complex because it assumes that a complete drainage will be sampled, and that almost all data will be collected at each station. In practice, this would be a rare occurrence. The method is more commonly used for small surveys in a single stream. It has even been used to sample a few isolated stations. In quick turnaround surveys, many variables may be missing. The extensive software described in the report and the complexity of the outputs are an overkill when a small survey is needed. New software has been developed to evaluate these same data sheets on a station-by-station basis. The program will accept extensive missing data. This has increased the flexibility of the method.

The long-term goal for this methodology and the extensive data it produces is to evaluate habitat preferences for fish species occurring in streams. I will send data sheets to those interested in using these basic methods to process their data.

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A SYSTEM OF NAMING HABITAT TYPES IN SMALL STREAMS, WITH EXAMPLES OF HABITAT UTILIZATION BY SALMONIDS DURING LOW STREAMFLOW[1]

Peter A. Bisson, Jennifer L. Nielsen, Ray A. Palmason and Larry E. Grove[2]

Abstract.--Fish habitat in small streams is classified into a number of types according to location within the channel, pattern of water flow, and nature of flow controlling structures. Riffles are divided into three habitat types: low gradient riffles, rapids, and cascades. Pools are divided into six types: secondary channel pools, backwater pools, trench pools, plunge pools, lateral scour pools, and dammed pools. Glides, the last habitat type, are intermediate in many characteristics between riffles and pools. Habitat utilization by salmonids was studied during summer low streamflow conditions in four western Washington streams. Most age 0+ coho salmon (Oncorhynchus kisutch) reared in pools, particularly backwaters, and preferred cover provided by rootwads. A few large coho occupied riffles and sought the cover of overhanging terrestrial vegetation and undercut banks. Age 0+ steelhead trout (Salmo gairdneri) selected riffles with large wood debris; while age 1+ steelhead preferred plunge, trench, and lateral scour pools with wood debris and undercut banks. The largest individuals of both steelhead age classes were found in swiftly flowing riffle habitats. Age 0+ cutthroat trout (S. clarki) preferred low gradient riffles but switched to glides and plunge pools when steelhead and coho were present, thus suggesting that they had been competitively displaced from a preferred habitat. Age 1+ and 2+ cutthroat preferred backwater pools when coho were absent but avoided them when coho were present. Cutthroat of all age classes generally favored cover provided by wood debris in both pool and riffle habitats.

INTRODUCTION

Identification of the important components of stream habitat is essential if we are to accurately assess environmental change, understand ecological segregation within multispecies communities, or determine the need for stream enhancement projects. Most fishes in small streams are habitat specialists (Gorman and Karr 1978) and utilize specific locations within stream channels throughout their freshwater life cycles in response to different spawning, feeding, and overwintering requirements (Northcote 1978). Within the Salmonidae competition plays a key role in habitat utilization when food is limited (Kalleberg 1958; Keenleyside and Yamamoto 1962; Hartman 1965; Chapman 1966a; Mason 1969; and many others) and such density dependent interactions result in habitat partitioning that facilitates the coexistence of several species as well as multiple age classes (Rosenzweig 1981). Habitat shifts can occur when conditions unsuitable to feeding develop (Hunt 1969; Bustard and Narver 1975a; Mason 1976; Peterson 1980) leading to the breakdown of territories and the aggregation of individuals into protected spaces. Utilization of particular locations within the stream varies greatly in time and space, and although small streams tend to be structurally complex, few if any areas of the channel are not occupied at one time or another.

Fishery biologists have traditionally classified streams into a variety of zones based on channel characteristics (e.g. Platts 1974; Moreau and Legendre 1979), associated biota (e.g., Huet 1959), or a combination of physical, chemical, and biological features (e.g. Binns and Eiserman 1979). Habitat requirements have often been presented as tolerance ranges or preferenda for certain water quality conditions. While tolerance limits for such parameters as

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dissolved oxygen and temperature have been defined with relative precision for many fish species, lack of a precise language describing the components of the physical environment may limit our ability to predict a stream's productivity for a species of interest. The often-used names 'riffle' and 'pool' convey a notion of relative water depth and current velocity, but beyond this they give little indication of living conditions relative to substrate, flow patterns, and cover. Not surprisingly, considerable variation exists in fish utilization of these general categories within the stream (Allen 1969). The terminology discussed in this paper represents an attempt to classify habitat in greater detail. Results of limited field evaluations indicate that the system can be a useful tool in assessing stream conditions and in describing spatial segregation among coexisting fish populations.

METHODS

Terminology

There appears to be no widely accepted set of habitat definitions for small streams. Although riffles and pools are the basic units of channel morphology and will always develop in natural streams as a mechanism of self-adjustment to the law of least time rate of energy expenditure (Yang 1971), the actual configuration and hydraulic properties of these units are highly variable. The continuous gradation in depth and velocity between pools and riffles has spawned terms such as 'run', which appear frequently in fisheries literature, often without detailed explanation. In attempting to construct a precise and consistent set of descriptive terms we have utilized definitions from the Glossary of Geology (Gary et al. 1974) wherever possible.

Riffles

Three types of riffle habitats were identified. Low gradient riffles (Fig. 1) were shallow (< 20 cm deep) stream reaches with moderate current velocity (20-50 cm/sec) and moderate turbulence. Substrate was usually composed of gravel, pebble, and cobble-sized particles (2-256 mm). An upper gradient limit for this habitat type was arbitarily set at 4%. Rapids (Fig. 2) possessed a gradient greater than 4% with swiftly flowing water (>50 cm/sec)

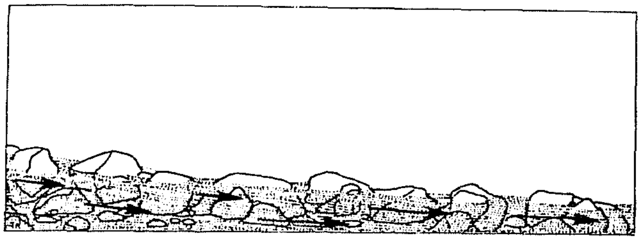
Figure 1. Low gradient riffle.

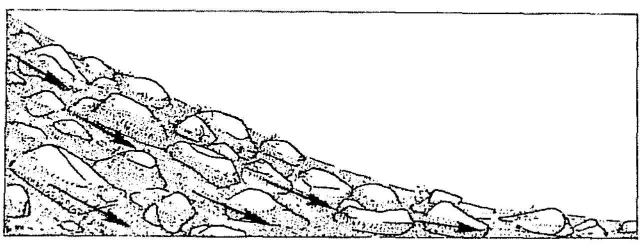
Figure 2. Rapids.

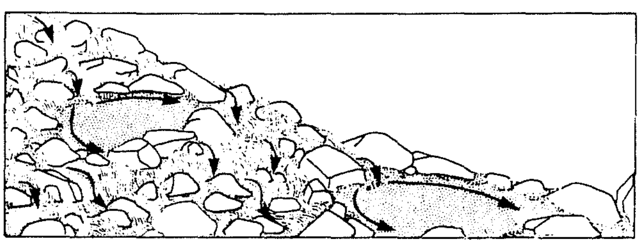
Figure 3. Cascade.

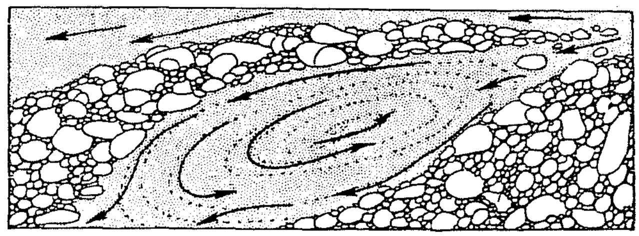
Figure 4. Secondary channel pool.

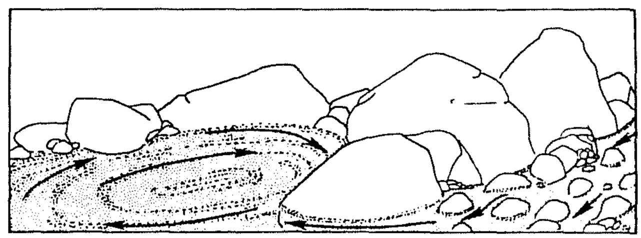
Figure 5. Backwater pool associated with boulders.

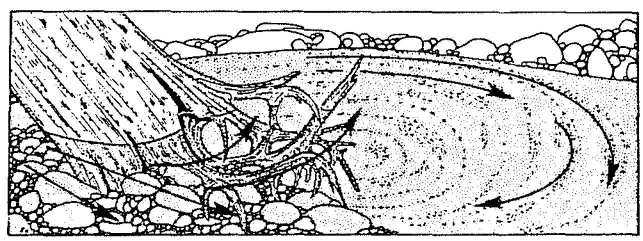
Figure 6. Backwater pool associated with rootwad.

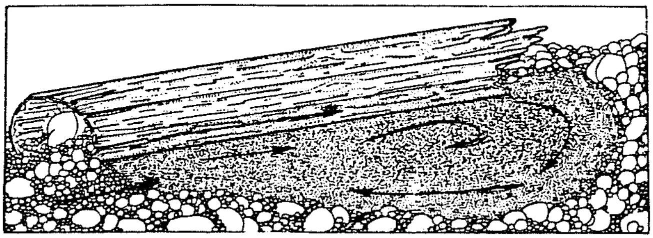

Figure 7. Backwater pool associated with large debris.

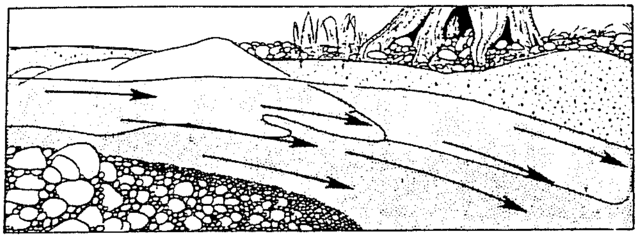

Figure 8. Trench pool associated with bedrock.

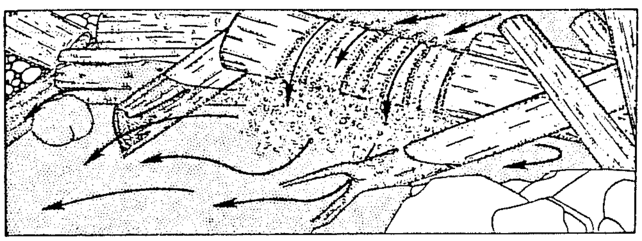

Figure 9. Plunge pool associated with large debris.

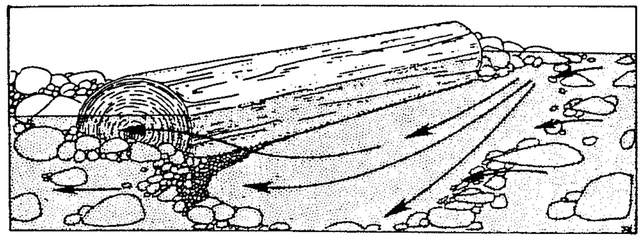

Figure 10. Lateral scour pool associated with large debris.

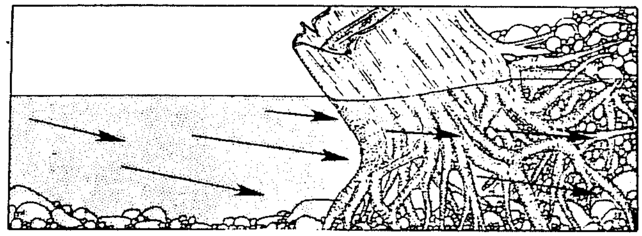

Figure 11. Lateral scour pool associated with rootwad.

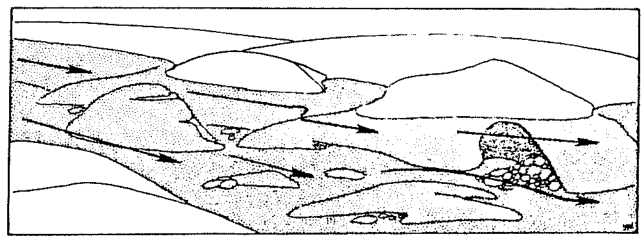

Figure 12. Lateral scour pool associated with bedrock.

having considerable turbulence. The substrate of rapids was generally coarser than the substrate of low gradient riffles, and during low streamflow conditions large boulders typically protruded through the surface. Cascades (Fig. 3), the third type of riffle habitat, were the steepest. Unlike rapids, which had an even gradient, cascades consisted of a series of small steps of alternating small waterfalls and shallow pools. The usual substrate of cascades was bedrock or an accumulation of boulders; however, this habitat type was occasionally found on the downstream face of woody debris dams.

Pools

During low streamflow conditions there were six pool types, which were associated with the presence of bedrock outcroppings, large rocks, or large tree stems and rootwads in the channel. Secondary channel pools (Fig. 4) were those that remained within the bankful margins of the stream after freshets. During the survey period (June-September) most of these pools had disappeared, and those remaining had little flow through them. Secondary channel pools were usually associated with gravel bars, but many contained sand and silt substrates. Backwater pools (Figs. 5-7) were found along channel margins and were caused by eddies behind large obstructions such as rootwads or boulders. This pool type was often quite shallow (>30 cm) and tended to be dominated by fine-grained substrates. Like secondary channel pools, backwater pools possessed current velocities that were very low. Trench pools (Fig. 8) were long, generally deep slots in a stable substrate. Channel cross sections were typically U-shaped with a coarse-grained bottom flanked by bedrock walls. Current velocities in trench pools were the swiftest of any pool type and the direction of flow was most uniform. Plunge pools (Fig. 9) occurred where the stream passed over a complete or nearly complete channel obstruction and dropped vertically into the streambed below, scouring out a depression. This pool type was often large, quite deep (>1 m), and possessed a complex flow pattern radiating from the point of water entry. Substrate particle size was also highly variable. Lateral scour pools (Figs. 10-12) differed from plunge pools in that the flow was directed to one side of the stream by a partial channel obstruction. Often an undercut bank was associated with this pool type. Dammed pools

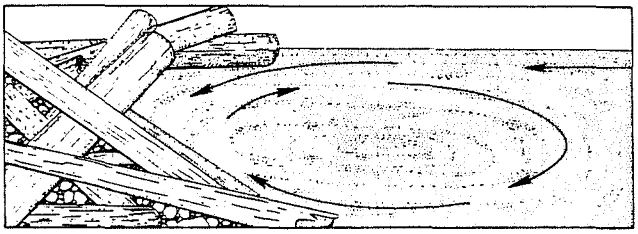

Figure 13. Dammed pool associated with large debris.

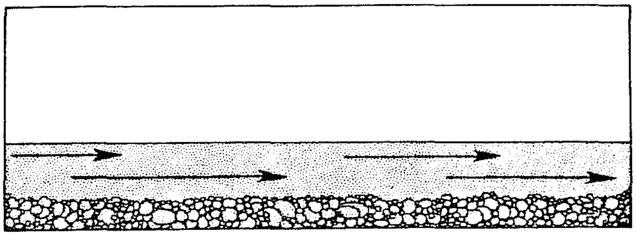

Figure 14. Glide.

(Fig. 13) consisted of water impounded upstream from a complete or nearly complete channel blockage. Typical causes of dammed pools were debris jams, rock landslides, or beaver dams. Depending upon the size of the blockage, dammed pools could be very large. Water velocity in this pool type was characteristically low and substrates tended toward smaller gravels and sand.

Glides

A third general habitat category existed that possessed attributes of both riffles and pools. Glides (Fig. 14) were characterized by moderately shallow water (10-30 cm deep) with an even flow that lacked pronounced turbulence. Although they were most frequently located at the transition between a pool and the head of a riffle, glides were occasionally found in long, low gradient stream reaches with stable banks and no major flow obstructions. The typical substrate was gravel and cobbles. The term 'run' has been applied to this habitat type, but we feel that the designation 'glide' is a more precise descriptor of the habitat conditions. Similar usage of the term has previously been adopted by Cuinat et al. (1975) and Chapman and Knudsen (1980).

Cover

Eight distinct kinds of cover for fishes were identified. These included three kinds of wood debris - rootwads, large debris (tree stems), and small debris (branches, twigs, etc.) - that differed in the amount of overhead cover and flow modifications they provided within the channel. Overhanging terrestrial vegetation and undercut banks were two kinds of cover that were largely governed by the condition of the riparian zone. Water turbulence acted as cover when the presence of bubbles prevented a clear view of the water beneath (Lewis 1969). Rocks functioned as cover in two ways, by providing overhanging ledges and by providing crevices for hiding. Finally, maximum depth was itself a form of cover from non-diving terrestrial predators (Stewart 1970). We assumed that the primary function of cover during the summer was protection from predation.

Sample Locations and Inventory Techniques

Sample locations were chosen to encompass a wide variety of stream conditions in western Washington. Nineteen sites consisting of channel reaches 0.2 - 1.3 km long were located in four streams. Three of the streams (Newaukum River, Salmon Creek, Thrash Creek) were Chehalis River tributaries; the fourth stream (Fall River) was part of the Willapa Bay drainage system. The sites included 700 individual habitats totaling approximately 7,800 m axial length, 33,600 m^2 wetted surface area, and 8,900 m^3 volume. Channels ranged in size from third to fifth order with 1-8% gradient. Parent rock type was either sandstone or basalt. Streamside vegetation varied according to forest management history; recently clearcut sites were dominated by shrubs, second growth forested sites were dominated by red aler (Alnus rubra), and old growth forested sites were dominated by mixed conifers. All sample locations possessed natural populations of salmonids, although some sites were above upstream migration blockages and contained only resident non-migratory cutthroat trout. There was no evidence that any of the sites had been fished by anglers.

Each stream reach was surveyed on foot and the location of different habitat types, as well as significant flow controlling structures, was drawn to scale on a map (Fig. 15). Contour lines based on depth measurements were drawn within pools to enable volume estimation. Wetted surface areas were determined by counting squares on gridded paper that was superimposed on the maps. Axial length was figured as the distance along the thalweg or greatest linear dimension of a habitat unit parallel to the direction of flow. Reach summaries were constructed by summing the lengths, areas, and volumes of each habitat type and expressing each group as a percentage of the total. The amount of cover in each habitat was rated on a relative abundance scale of 0-3, where a score of zero indicated that the particular kind of cover was essentially absent and a score of three indicated a very abundant condition. Substrate was noted as predominant type, i.e., the physical and/or biological type most prevalent within a habitat unit.

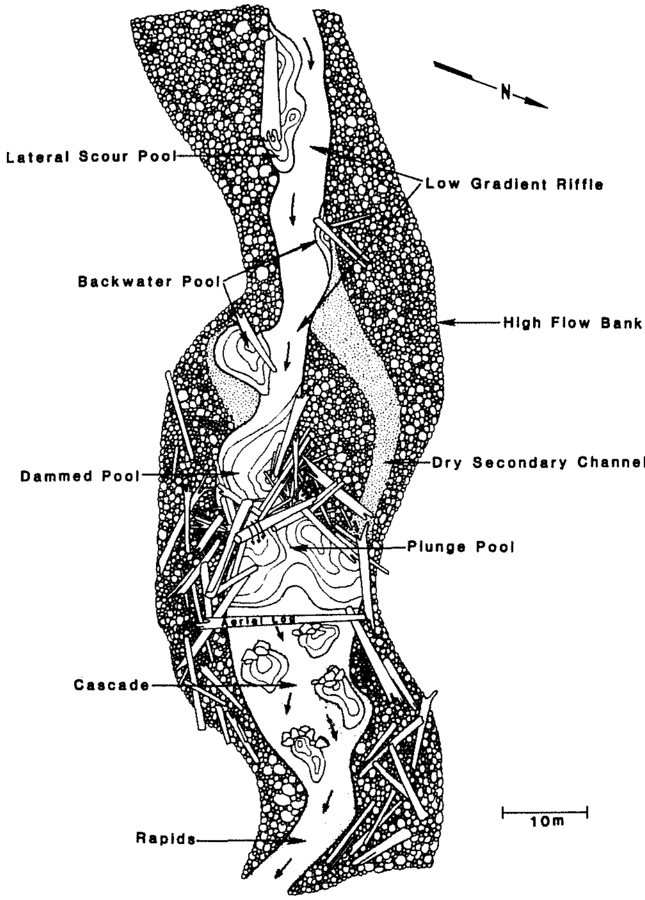

Figure 15. An example of a stream channel map showing locations of various habitat types.

Fish populations were sampled by isolating individual habitat types with blocking nets and electrofishing the habitat three times, retaining separately the fish captured on each pass. Individual biomasses were determined from length-weight relationships (Bisson and Sedell 1982 in press) and age class abundance was figured from size frequency distributions and scale samples. Population density and biomass estimates were based on a removal summation method of calculation (Carle and Strub 1978). Sculpins (*Cottus* spp.) were also captured but their biomasses are not reported in this paper. Approximately 28% of the total number of habitats inventoried were sampled for fish populations, resulting in the capture of 11,385 salmon and trout.

In order to quantify habitat utilization by species and individual age classes it was necessary to relate the fraction of the population found within a particular habitat type to the relative abundance of that habitat type in the stream. The formula used was based on the electivity index of Ivlev (1961):

$$(1)\ \text{Utilization} = \frac{\text{habitat specific density} - \text{average total density}}{\text{average total density}}$$

where

habitat specific density = average density in the habitat type of interest

average total density = average density over the entire stream reach, all habitats combined

Values of this habitat utilization coefficient theoretically range from minus one, indicating total non-use of a habitat type, to positive infinity as a greater proportion of the population resides in the habitat type of interest. A value of zero indicates that the population occurs in the habitat type in proportion to that type's abundance in the stream.

FIELD TRIALS

Habitat Characteristics

Although variation in size and frequency of habitat types was related to stream order, basin geology, and land management history, average dimensions of the different habitats are given in Table 1 for comparison. Overall, glides had the greatest individual length and surface area but pools had the greatest volume. Despite their relatively large size, glides were infrequent and accounted for a small fraction of total stream space. Pools were the dominant habitat category, accounting for about 50% of stream length and almost 80% of stream volume. Lateral scour pools were the most common type and also possessed the greatest surface area. Secondary channel pools, backwater pools, and dammed pools were smallest and least frequent. None of the sample sites contained beaver dams, log jams, or major landslides, thus accounting for the absence of large dammed pools in the reaches that were surveyed. Low gradient riffles were both the largest and most abundant riffles type, while rapids and cascades tended to be small and less frequent. Riffles averaged 40% of stream length but accounted for only 16% of stream volume

Large woody debris, including rootwads, was the most abundant cover in pools, while rocks were the primary cover in riffles. Depth was important cover in pools having large water volumes (lateral scout, plunge, and trench). Turbulence created cover where falling water formed bubbles in plunge pools, rapids, and cascades. In general, cover quantity and diversity was greater in pools than in riffles or glides.

Habitat Utilization

During the summer very few individuals of any fish species occupied secondary channel pools (Table 2). Many of these habitats had become isolated from the main channel and they often possessed high temperatures and dense algal growths. Although it is likely that secondary channel pools are utilized at other times of the year, particularly in large rivers (Sedell et al. 1980), lack of use of these habitats during low streamflow periods by salmonids is similar to the findings of studies of other stream fishes (Tramer 1977; Williams and Coad 1979).

Backwater pools were heavily utilized by age 0+ coho salmon, although coho in backwaters were smaller than average (Table 3). Preferential use of this habitat type by coho may have been related to a dependency on terrestrial food during summer that has been found by other investigators (Chapman 1966b; Mundie 1969). No other species displayed as strong an association with backwater pools as did coho; however, where anadromous forms were absent, yearling and older cutthroat also preferred this habitat type. In general, fish size in backwaters tended to be smaller than average.

Trench pools were selectively utilized by coho and yearling steelhead, and by age 1+ and 2+ cutthroat in anadromous zones. Where coho and steelhead were absent, all cutthroat age classes exhibited a mild avoidance of this pool type. Underyearling cutthroat collected from trench pools were smaller than average. Plunge pools were selected by coho, yearling steelhead, and all cutthroat age classes except age 0+ fish in areas upstream from an anadromous zone. Coho in plunge pools were the largest of those taken in any pool type.

Lateral scour pools were preferred by older age classes of both steelhead and cutthroat. Individuals collected from this pool type were average size, except for age 0+ cutthroat which tended to be slightly smaller than average in non-anadromous areas. Owing to the relative abundance of this habitat type, over 25% of all salmonids occurred in lateral scour pools.

An insufficient number of dammed pools were sampled to yield satisfactory evidence of relative habitat utilization or average fish weight. Flow pattern in this pool type would seem to be favorable to coho and there is ample evidence from other studies (Bustard and Narver 1975b; Nickelson and Hafele 1979; Everest and Meehan 1981) that coho utilize impounded water in streams. Provided there is sufficient depth and cover, dammed pools should also provide favorable habitat for age 1+ steelhead and age 1+ and older cutthroat.

Low gradient riffles were selectively occupied by underyearling steelhead and

Table 1. Average habitat size and percent of total stream (in parenthesis).

Habitat Type	n	Average Habitat Size / % of Total: Length (m)	Area (m^2)	Volume (m^3)
Pools				
Secondary Channel	26	9 (<1)	34 (<1)	8 (<1)
Backwater	74	8 (10)	29 (7)	8 (7)
Trench	34	15 (8)	70 (8)	26 (10)
Plunge	38	14 (5)	77 (5)	45 (10)
Lateral Scour	146	16 (28)	102 (35)	43 (50)
Dammed	5	7 (<1)	30 (<1)	18 (1)
Riffles				
Low Gradient Riffles	197	11 (26)	51 (25)	7 (12)
Rapids	114	7 (13)	25 (9)	3 (3)
Cascades	21	8 (<1)	30 (<1)	6 (<1)
Glides	43	15 (9)	92 (11)	15 (6)

Table 2. Habitat specific utilization coefficients.

	Anadromous Zone						Above Anadromous Zone		
	Coho	Steelhead		Cutthroat			Cutthroat		
Habitat Type	0+	0+	1+	0+	1+	2+	0+	1+	2+
Pools									
Secondary Channel	-1.00	-0.99	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Backwater	6.74	-0.46	0.21	-1.00	-0.52	-0.75	-0.36	0.42	0.80
Trench	1.07	0.14	1.16	-1.00	0.54	0.99	-0.21	-0.16	-0.23
Plunge	0.93	0.10	2.23	1.41	0.79	0.92	-0.54	1.09	1.61
Lateral Scour	-0.46	0.07	0.89	-0.08	1.14	1.83	0.18	1.04	0.88
Dammed	Insufficient Samples								
Riffles									
Low Gradient	-0.75	0.50	-0.70	0.26	-0.23	-0.71	0.45	-0.73	-0.78
Rapids	-0.99	0.50	0.98	-0.45	-0.67	-0.20	-0.10	-0.83	-0.90
Cascades	-0.97	0.79	0.58	-1.00	0.70	-1.00	-0.24	-0.80	-0.89
Glides	-0.91	0.34	0.86	1.42	-0.77	-0.92	0.00	-0.79	-0.33

Table 3. Size differences among salmonids captured in individual habitat types, expressed as percent deviation from overall average weight. Data for n $\leq$ 5 are omitted.

	Anadromous Zone						Above Anadromous Zone		
	Coho	Steelhead		Cutthroat			Cutthroat		
Habitat Type	0+	0+	1+	0+	1+	2+	0+	1+	2+
Pools									
Backwater	-12	-11	-2		+4	-9	+27	-2	-21
Trench	-2	0	+5		-1	+3	-21	-5	
Plunge	+14	-1	-2		-4	+2	+8	-2	+3
Lateral Scour	+1	-2	-5		+4	+4	-9	0	+1
Riffles									
Low Gradient	+1	+5	-16		-13	-7	+11	+26	
Rapids	+21	+12	+15		+10		-20	+7	
Cascades		+29	-4		+18		-8	-6	
Glides	+5	-15	-19			-26	+6	-9	

cutthroat, and were not preferentially used by other age classes. Cutthroat in anadromous zones were smaller than average while those in non-anadromous areas were larger than average, thus suggesting that competition with steelhead had reduced cutthroat growth rates in low gradient riffles. Evidence for competitive dominance of underyearling cutthroat by underyearling steelhead was also provided by the reduced utilization of low gradient riffles by cutthroat where steelhead were present compared to sites where steelhead were absent. Platts (1977) found that cutthroat were displaced to secondary habitats in the presence of juvenile chinook salmon and steelhead, but Hartman and Gill (1968) speculated that differences in the distribution of underyearling cutthroat and steelhead were related to microhabitat variation in spawning preferences of adults.

Utilization of rapids and cascades was limited mostly to steelhead. Both habitats were strongly avoided by most coho, yet the few individuals that occurred in rapids were much larger than average. Underyearling and yearling steelhead favored both habitats and seemed to grow well there. Chapman and Bjornn (1969) have also observed that steelhead occupy swifter water as they become larger and these authors felt that preference for faster water was associated with increased exposure to food organisms. However, while steelhead preferred fast water riffles, cutthroat, for the most part, did not.

Glides were selectively utilized only by steelhead and by underyearling cutthroat. Insufficient numbers of age 0+ cutthroat were collected from sites possessing coho and steelhead to permit determination of size variation; however, ages 0+ and 1+ steelhead occurring in glides were the smallest of those found in any habitat type.

Cover Associations

In both pool and riffle habitats the densities of age 1+ and older trout tended to increase in association with increased cover (Table 4) but age 0+ salmon and trout were relatively unaffected by cover conditions, although some positive associations did exist between underyearling densities and certain cover types. Our finding that older trout were more responsive to increased cover agrees with the

Table 4. Average correlations (r^2) between age class density and cover types within habitats.

	Coho	Steelhead		Cutthroat		
Cover Type	0+	0+	1+	0+	1+	2+
	---------------------Pools---------------------					
Rootwad	+0.19	-0.05	+0.34	+0.05	+0.04	+0.13
Large Wood Debris	-0.27	-0.11	+0.23	+0.05	+0.40	+0.25
Small Wood Debris	-0.16	-0.07	+0.18	+0.20	+0.15	+0.17
Terrestrial Vegetation	0.00	+0.12	+0.09	-0.24	+0.04	+0.12
Undercut Bank	0.00	+0.12	+0.26	-0.13	+0.22	+0.37
Turbulence	-0.01	-0.26	-0.04	-0.34	+0.05	+0.21
Underwater Boulders	-0.78	-0.25	-0.54	-0.49	-0.23	-0.09
Maximum Depth	-0.14	-0.29	-0.02	-0.42	+0.03	+0.44
	-------------------Riffles--------------------					
Rootwad	-0.03	-0.21	-0.29	+0.02	-0.16	+0.24
Large Wood Debris	-0.03	+0.31	+0.42	-0.30	+0.46	+0.43
Small Wood Debris	0.00	+0.03	+0.11	+0.40	+0.07	+0.27
Terrestrial Vegetation	+0.80	+0.11	-0.13	-0.04	+0.07	+0.11
Undercut Bank	+0.37	-0.50	-0.42	0.00	+0.35	+0.43
Turbulence	-0.42	-0.27	+0.19	-0.31	+0.40	+0.20
Underwater Boulders	-0.46	-0.08	-0.19	-0.25	+0.43	-0.07
Maximum Depth	-0.51	-0.20	+0.46	-0.45	+0.43	+0.57

stream enhancement results of Saunders and Smith (1962) and Hunt (1978), who noted that cover additions improved the productivity of older trout more than it did underyearlings.

Wood debris proved to be a preferred cover type for age 1+ steelhead and age 1+ and 2+ cutthroat. The strongest associations were observed with large debris pieces, especially in riffle habitats. Preference of yearling steelhead for large debris has been documented by Bustard and Narver (1975a) and both Osborn (1981) and June (1981) have shown that older cutthroat rely heavily on large wood debris for cover. Underyearling steelhead did not respond positively to increased wood debris in pools but utilized large debris in riffles. Underyearling cutthroat showed a slight positive response to increased debris in pools and a definite preference for small debris in riffles. The utilization of small debris by underyearling cutthroat may be similar to the cover preferences of age 0+ brown trout (S. trutta), which have been shown to decline following small debris removal (Mortensen 1977). Age 0+ coho exhibited a mild positive response to increased rootwad abundance in pools, but were unaffected by other kinds of debris. Association of coho with wood debris has been previously demonstrated by Lister and Genoe (1970) and Bustard and Narver (1975a, 1975b).

Overhanging terrestrial vegetation and undercut banks along riffles were strongly preferred by coho, although riffles were inhabited by relatively few individuals of this species (Table 2). Overhead banks and vegetation may have been selected because they provided more terrestrial food, resulting in bigger fish (Table 3). It seems unlikely that coho used these kinds of cover for shade because no obvious preferences for bank cover were observed in pools, and Ruggles (1966) has shown that addition of shade structures to experimental channels actually reduced coho holding capacity. Weak positive responses to increased bank undercuts and overhanging vegetation along riffles were displayed by age 1+ and 2+ cutthroat, which, like coho, were rare there. However, steelhead in riffles did not select overhanging vegetation and actually appeared to avoid riffles with undercut banks. Ages 0+ and 1+ steelhead and ages 1+ and 2+ cutthroat showed mild preferences for bank cover in pools.

Turbulence and underwater boulders were not selected by most species, except yearling cutthroat in riffles. The absence of significant response by steelhead to increased boulder cover was surprising in view of the strong attachment to this cover type shown for steelhead by Hartman (1965) and Facchin and Slaney (1977), and increases in age 1+ steelhead carrying capacity following experimental boulder placement in a Vancouver Island stream (Ward and Slaney 1979). We have no explanation for this disparity in observations except to speculate that increased turbulence and boulder density may have hindered feeding activity by making visual sighting of food organisms more difficult. Within habitats, deeper water was preferentially utilized only by age 1+ and older trout. Underyearlings of all species avoided deep water, preferring instead to reside in shallower areas along habitat margins. Positive associations between increased depth and fish size have been observed in both rainbow trout (Lewis 1969) and cutthroat (Griffith 1972).

APPLICATION OF THE SYSTEM

The system of naming habitat types that is described in this paper proved to be workable during low streamflow conditions. The habitat types became easy to recognize after some practice, and disagreements between independent classifiers were usually few. Approximately 100 m of stream channel could be mapped by one person in a day depending upon channel complexity. However, rapid inventory of the habitat types present in a stream, without dimensional measurements, could proceed much faster.

We were generally less satisfied with the cover evaluations. The majority of disagreements arose over what numerical score was to be assigned to the cover conditions within a particular habitat. In addition, the technique that was employed treated all kinds of cover equally, and it was obvious that a score of 3 (very abundant) for one cover type was not necessarily equivalent, in terms of overhead shading or protection from predation, to a high score for another cover type. For example, the kind of cover provided by wood debris, bank characteristics, or channel morphology was different from one another in nature and did not fit well into an equally weighted scale that was based on relative abundance. Wesche (1980) has discussed the subjectivity involved in measuring cover and has proposed a cover rating that intregrates bank, channel, and substrate characteristics for both small and large streams. Other workers have devised comprehensive numerical indices of habitat conditions that have been used to predict stream carrying capacity, (Bovee and Cochnauer 1977; Binns and Eisermann 1979) but these models do not easily separate fish preference for habitat type from preference for cover type.

We found that within individual habitats certain kinds of cover were preferred to others; however, a more rigorous approach would be to follow population changes after experimentally adding different kinds of cover to streams. For example, Boussu (1954) added small debris (interwoven willow branches) to a Montana stream and recorded large increased in underyearling and yearling rainbow trout and brook char biomasses. More recently, Ward and Slaney (1979) found that logs and boulders placed together in riffle areas of a Vancouver Island stream significantly enhanced ages 1+ and 2+ steelhead, but were not heavily utilized by underyearling coho. The results of our summer field studies indicate that wood debris, especially large stems and rootwads, was the most generally favored cover type and may hold the greatest promise for enhancement projects.

Although the terms 'selected' and 'preferred' have been applied in this paper to habitat and cover utilization by salmon and trout, it is likely that the spatial segregation we observed was an outcome of both physical habitat requirements and biological interactions. What appeared to be a preferred habitat in one stream was not always so in another; cutthroat trout, for example, occurred in different habitats when coho and steelhead were present than when they were the sole salmonid species. Chapman (1966a) has pointed out the importance of interspecific competition in governing habitat selection by salmonids, but behavioral observations have shown that competitive displacment can occur both within a single age class (Mason 1969) and between cohorts of a species (Jenkins 1969). The intensity of territorial defense in certain tropical reef fishes is related to physical habitat conditions, high quality habitats being aggressively defended (Itzkowitz 1979). However, Slaney and Northcote (1974) have shown that when food is abundant territories are small and agression is minimized in underyearling rainbow trout. Thus, the actual location of fishes in a stream channel will be influenced by the presence of competitor and predator species, population density, and food availability, as well as preferences for specific habitat types.

The complex interaction of a fish population with its physical and biological environment usually makes it difficult, if not impossible, to accurately predict either the standing crop or production of a species of interest in a particular stream. What can be determined, however, is the suitability of stream conditions irrespective of a species' presence or absence, which may be due to a variety of factors other than physical habitat. The detailed classification system presented here can be used to assess stream suitability once specific habitat and cover associations are known. We might predict, for example, that underyearling coho will be favored in streams possessing many backwater pools with rootwad cover and terrestrial vegetation overhanging the riffles, whereas yearling and older cutthroat will be favored where there are deep plunge and lateral scour pools with large logs and undercut banks. Although the system worked for the western Washington streams we studied, it is by no means comprehensive. Other habitat types may exist in larger rivers, or in small streams during freshets, and these will require additional description.

ACKNOWLEDGEMENTS

We thank our many friends and colleagues who assisted us in developing the classification system and in the field trials, including R.E. Bilby, S.H. Duncan, V.W. Era, J.T. Heffner, J.A. Rochelle, K.O. Sullivan, and J.W. Ward. Helpful comments on an earlier version of the paper were provided by R.J. Behnke and R.L. Beschta. The project originally evolved from discussions with J.R. Sedell, whose thoughtful advice we gratefully acknowledge.

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SESSION 2B

Moderator: Willis Evans
U.S. Forest Service
San Francisco, Calif.

The Following Not Included in Proceedings:

Edward Connor and Bill Trush, Sagehen Creek Research Station, Truckee, Calif.
Policy Directives and Implications of Aquatic Habitat Inventories for Instream Flow Assessments Within California.

Bruce Wagner, Boeing Computer Services,Seattle, Washington.
Environmental Data Management Utilizing a Statistical Data Base Management System: Scientific Information Retrieval (SIR).

Gary G. Lawley, Envirosphere Company, Bellevue, Washington.
Improving Study Designs for Habitat Inventory Studies.

STREAM INVENTORY GARBAGE IN--RELIABLE ANALYSIS OUT:

ONLY IN FAIRY TALES

William S. Platts[1]

Abstract.--The success or failure of stream inventories depends on the suitability, accuracy, and combination of the selected habitat measurements. Accuracy is difficult to evaluate and seldom do we know what the true mean of the measured variable is in stream habitat assessment. This report defines the precision and repeatability that can be expected when measuring selected aquatic habitat conditions in Intermountain West streams.

INTRODUCTION

Recently there has been an increase in the number of procedures and models to evaluate the status and potential of streams as habitats for fish. Binns (1979) has developed a Habitat Quality Index (HQI) to predict trout standing crop in Wyoming streams. The USDI Fish and Wildlife Service uses a cluster of aquatic habitat descriptors in a predictive model to quantify the effects of change in stream flow on fish survival, and an aquatic habitat evaluation procedures model (HEP) and habitat suitability index model (HSI) for obtaining data and making the interpretations needed for decisionmaking. Wesche (1976) developed a cover rating model to determine aquatic habitat conditions and fish standing crops. Cooper (1976) employed an aquatic habitat survey model for measuring stream channel conditions to provide information for land use planning.

The success or failure of each of these approaches to habitat assessment depends on the suitability, accuracy, and combination of the selected habitat measurements.

Problem

Difficulties arise in developing accurate, complete methods because of problems encountered in attempting to objectively and quantitatively determine the true state of an aquatic system (Platts 1976). In addition, aquatic specialists commonly collect their data during the warmer months of the year (from June through September) when access, streamflow, and water clarity are optimum for aquatic observation. Aquatic habitats and their biotic communities are seldom evaluated during floods, annual high flows, extreme low flows, anchor ice buildup, ice flow scouring, debris jam breakups, and sudden toxic flushes. Because some of the more important factors limiting fish populations often occur during these periods of no data collection, the actual changes in environmental conditions over time have not been determined. A valid understanding of the environmental mix of conditions that controls the fishery, therefore, eludes us.

The correct combination of measurements to determine the environmental conditions must be entered into the model if results are going to be usable. Platts (1974, 1976) demonstrated that while masses of environmental data can be gathered during the warmer months, completely reliable information on the limiting factors is still lacking. These studies also demonstrate that additional descriptive variables are needed if adequate quantification of stream condition is to be gained. Unfortunately, today's methodologies are often guided by land management agencies' demand for expendiency and are modified to fit low budgets. Therefore, the analyses of fishery habitat and fish reaction to changes are often of low value. When this is the case, the deficiencies in the methods should accompany the acquired data so a user can identify the reliability of the interpretations, otherwise many poor resource management decisions could be made. If unreliable inventory data enter the computer, there is no way a reliable analysis will come out.

Solution

The solution is to build a valid, objective, quantitative, and repeatable procedure that will provide an accurate evaluation of the stream and its biotic communities under any set of conditions over time and space. Because the ideal objective procedure has not been developed, we need to use the best mixture of objective and subjective

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methods available. At the same time, the accuracy and precision of the data base must be defined. We have to accept that many of our measurements will have to be done by the eye alone. Although the eye can be precise, often we do not have the discrimination needed to capture this precision because of the gray boundary areas, or the un-explicit area of confusion that prevents the transfer of precise eye data.

Seldom do we know true measurements in stream habitat assessment. We just hope that our sample mean and its confidence interval has a small enough bias so the intervals will bracket the true mean. Because bias can easily enter any stream inventory, often the sample mean does not approximate the true mean.

This report defines the precision and repeatability that can be expected when measuring selected aquatic habitat conditions in Intermountain West streams. This will allow data collectors to better identify problems within their methodology and to apply corrective solutions.

STUDY DESIGN AND SITES

The aquatic habitat evaluation methods presented here have been used on 51 streams in Idaho, 2 in Utah, and 3 in Nevada. The Idaho streams are mainly in the Idaho Batholith, and the Utah-Nevada streams are representative of those found in the Basin-Range physiographic province. A description of the study streams is given in Platts (1974), Platts and Megahan (1975), Platts (1978)[2], and Megahan et al. (1980). A detailed description of the methods used in the testing appears in Platts et al.[3]. The random transect line intercept clustering method was used to obtain the habitat data for the testing. Transect spacing was mainly at 3 m intervals. Of the 56 streams studied, 6 in Idaho and Nevada were selected as examples for demonstrating variation, repeatability, and precison of measurements. Repeatability of each variable was rated as poor, fair, good, or excellent using the key in Table 1. Repeatability as defined here is the ability of many sample means collected over time to approximate the expected true mean over time. Precision was derived from the scatter around each variable's mean as represented by the confidence intervals. Confidence intervals less than ± 5% of the mean were rated excellent, ± 6 to 10% good, ± 11 to 20% fair, and over ± 21% poor.

Most observers collecting the data had advanced degrees in fisheries or closely related fields, were experienced, and well trained, and had excellent equipment.

EVALUATING PRECISION AND REPEATABILITY

Extreme natural fluctuations in the condition of the aquatic habitat and the resulting fish population can make interpretations from small sample sizes almost useless. For instance, in 1979 we initiated livestock grazing in a pristine meadow that surrounded a stream containing a sampled bull trout (Salvelinus confluentus [Suckley]) population. Fish were collected using the four-step depletion method and the maximum likelihood analysis. Sample size ranged from 272 in 1976 to 1,516 in 1979. As shown in figure 1, an example of study design bias would be that if fish numbers had been determined only in 1979, 1980, and 1981, the conclusion could be that cattle grazing decreased fish populations by 75 percent. However, if 1978 and 1979 were the study years, the conclusion could be that cattle grazing was beneficial. Therefore, the sample design can often be set or interpreted to get a desired answer whether knowingly or unknowingly. Many conclusions have been reached in past studies in this way, though usually not intentionally.

Most aquatic habitat attributes discussed here have been rated on their ability to be measured successfully and repeatedly. Although repeatability is subjectively determined, this type of analysis does red-flag some variables that need further study. Long-term, annual measurement of certain variables, such as bank undercut and bank stability, can be checked with photo points to determine if the variable was really changing as much as measurement data indicated. Also, channel profiles give us some idea of channel and streambank stability in which to evaluate certain variable measurements.

The precision of instantaneous measurements over time can be rated effectively by analyzing the confidence intervals around each of the sample means (figs. 2 through 5). Instantaneous measurements are defined as a series of measurements of the same unchanging population within a short time. An example of an instantaneous measurement is a series of stream width measurements over a reach taken within a few days to monitor a uniform flow condition.

Repeatability over time looks at variations from the expected mean in a group of measurements.

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[2]Platts, W.S. 1978. The effects of livestock grazing on aquatic environments, riparian environments, and fisheries in Idaho, Utah, and Nevada - A study Plan. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. INT-1651(250). Boise, Idaho. 100 p.

[3]Platts, W. S., W. F. Megahan, and G. W. Minshall. In press. Stream riparian and biotic evaluation methodology: its design, use and value. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report. Ogden, Utah.

Table 1.--Evaluation key for rating repeatability of habitat measurements.

		Go to	Rating
1a.	The condition can be measured with an instrument	2	
1b.	The condition must be estimated by eye	4	
2a.	The instrument discriminates with high accuracy	3	
2b.	The instrument discriminates with unacceptable accuracy		poor
3a.	The observer reads the instrument without bias	4	
3b.	The observer reads the instrument with unacceptable bias		poor
4a.	The condition to be measured is well defined	5	
4b.	The condition to be measured is poorly defined		poor
5a.	The measured condition is capable of good class discrimination	6	
5b.	The measured condition is not capable of good class discrimination		poor
6a.	The measured condition closely parallels the expected mean over time		excellent
6b.	The measured condition approximately parallels the expected mean over time		good
6c.	The variation between the measured condition and the expected mean over time is tolerable		fair

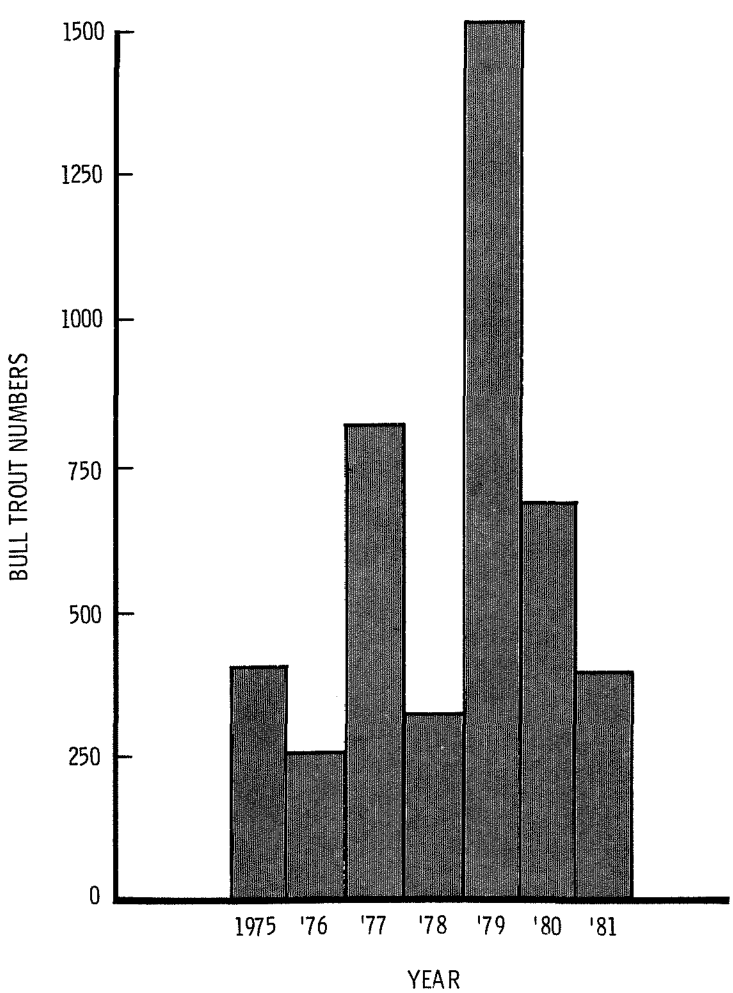

Figure 1.--Annual numbers of bull trout in the Upper Stolle Meadows study site in the South Fork Salmon River.

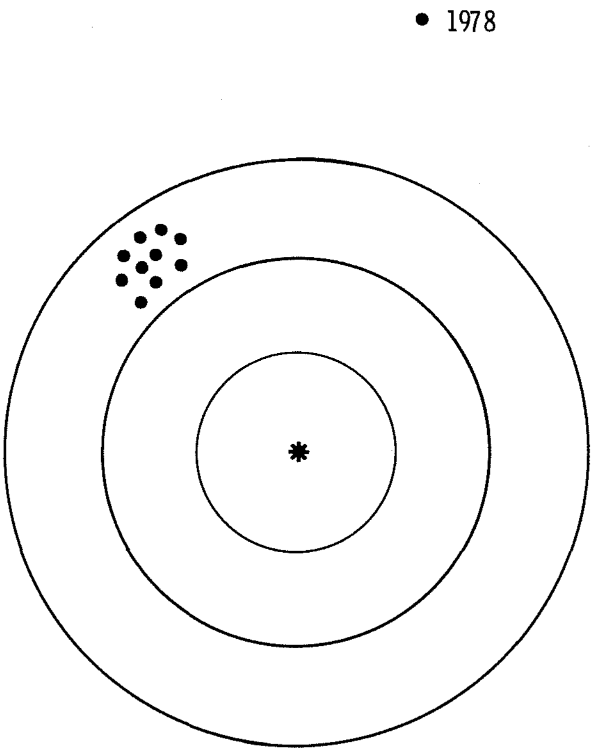

Figure 2.--At the Idaho study site, 1978 instantaneous measurements had excellent precision around the streambank alteration sample mean, but accuracy was poor because of bias in the measurements.

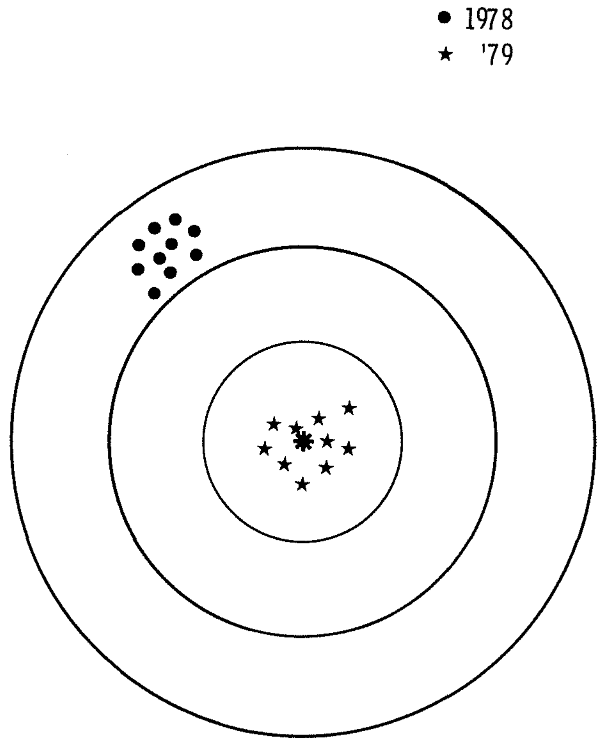

Figure 3.--The 1979 instantaneous measurements had high precision and accuracy but repeatibility over time was low, due to bias in the 1978 samples.

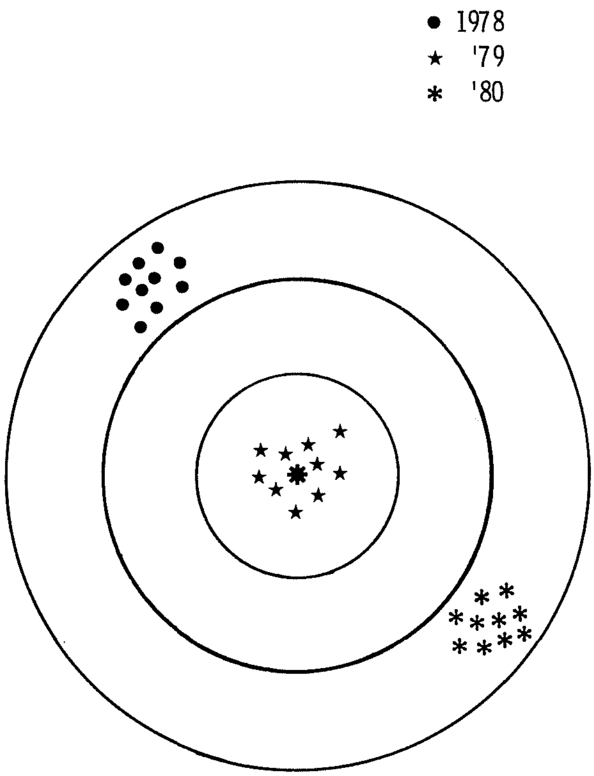

Figure 4.--The 1980 instantaneous measurements again had high precision but low accuracy. Repeatibility over time is low, but if all sample observations were averaged, accuracy would be high.

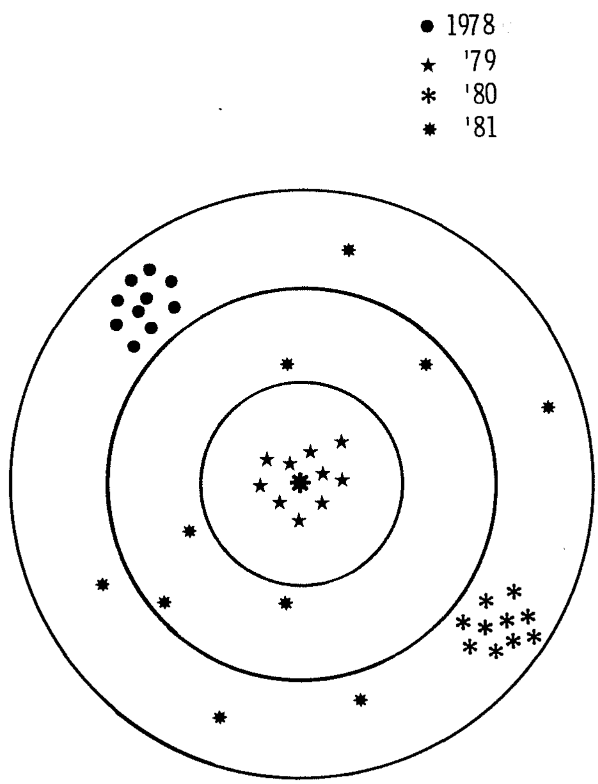

Figure 5.--The 1981 instantaneous measuremets had low precision, but accuracy was high. Repeatability over time was not good.

For example, annual stream depth sample means collected at the same flow over several years could be compared for repeatability success with the expected means gained from an analysis of climatology or flow data and channel profiles. Of course, this assumes that the climatological variables are measured accurately. If channel profiles and flows were identical each year, the annual mean stream depths would be expected to be the same; therefore, a subjective estimate of observer error could be gained.

A wide misconception is that once you have subjectively measured a habitat condition, you have positively identified its true mean. This is false because you may have missed the true mean by many magnitudes even though precision was high. An example is our pool and riffle measurements where one year on a study site the pool-riffle ratio is high, while on the same study site the next year it is low. The photo points show that no major channel change took place and the difference in the two annual sample means must be due to observer error even though the precision of instantaneous measurements of the samples was high.

To evaluate the success in repeatability over time, a series of annually acquired habitat measurement means were graphed over time (most for 7 years) to compare how the sample means performed compared to their expected performance (fig. 6). This evaluation procedure can have credibility on certain measurements such as stream width and depth where climatic knowledge will allow an independent estimate of how the mean is expected to perform over time. Annual width and depth means would be expected to be high during those years of high precipitation and low during drought years. However, other measurements such as streambank stability can fluctuate from numerous factors making accurate analysis difficult. We compensated for this by using photo points taken over time. In some cases it appeared the streambank had changed little, while the data from year to year showed high fluctuations.

RESULTS

Water Column

The constant, three-dimensional movement of streams and the unpredictable fluctuations in flow rate make some measurements of the water column difficult to obtain accurately. In our study, however, average stream width and depth exhibited good precision and repeatability because the points determining their boundaries were easy to define (table 2). We found that streamside water depth was difficult to measure with satisfactory precision because the angle of the streambank controlled where the depth was to be measured. The arc of direct sunlight as the sun rotates around the midpoint of the transect was measured accurately because it could be measured with a clinometer and the boundaries of the measurement were identifiable.

The subjective measurements of water column condition, such as pool, riffle, and pool quality, are hard to measure with high precision and repeatability. Problems arise in using the eye to differentiate pools from riffles, glides, runs, and pocket water, because they are not separated by clearly defined boundaries. However, the precision of measurement by an observer may be high because even though he or she may be discriminating the classes incorrectly, at least it is done uniformly. The problem arises when the next observer makes the measurements and the pool-riffle ratio begins to vary widely from year to year even though the stream structure does not change. This is often as great an error as that caused by not taking natural variation into account.

In our instantaneous pool quality measurements, we had a confidence interval (CI) of $\pm$ 8% (all CI in this report are at the 95% level), which is within acceptable limits. When we evaluated the repeatability over time, it was only fair because of bias. Therefore, caution must be used in interpreting pool-riffle data.

The Blackfoot River in eastern Idaho was the only stream where we felt we could successfully classify runs because they dominated the water column and stood out from the other classifications. In most cases, accurate discrimination of glide, run, and pocket water was difficult, so these classifications were dropped from the testing.

Riffles in the study streams were difficult to classify for the same reason pools were. Riffles in streams with high (over 3%) or low (less than 0.5%) channel gradients were the easiest to classify. The confidence interval around the means on instantaneous measurements was $\pm$ 17%. This is not good precision when you are attempting to pick up small changes in amount of riffle from year to year. It's the best that we could expect, however, under present guidelines. Repeatability over time was rated poor.

Streambank

Monitoring changes in streambank soil and vegetation alteration over time was difficult because the subjective guidelines were not well defined (table 3). However, the precision of the instantaneous measurements was fair, with a confidence interval of $\pm$ 12% around the mean for the soil alteration and excellent ($\pm$ 3.1%) for vegetative stability. Over time, repeatability for both measurements was fair to good, while repeatability over time was fair for vegetative stability and poor for soil alteration.

Table 2.--The average expected repeatability, precision, and confidence intervals of water column measurement means from 6 selected streams in Idaho and Nevada. Confidence intervals are at the 95% level and expressed as percent of the mean.

	Confidence interval	Precision	Repeatability over time
Water Column			
Stream width	5.4	Good	Good
Stream depth	8.2	Good	Good to Excellent
Streamside water depth	16.6	Fair	Fair to Good
Pool (percent)	10.3	Good	Poor
Pool (quality)	8.0	Good	Poor to Fair
Riffle (percent)	12.5	Fair	Poor
Sun arc angle	1.1	Excellent	Good
Bank to bank width	Very wide	Poor	Poor
High water stream width	Very wide	Poor	Poor

Table 3.--Expected repeatability, precision, and confidence intervals of streambank measurement means from 6 selected streams in Idaho and Nevada. Confidence intervals are at the 95% level and expressed as percent of the mean

	Confidence interval	Precision	Repeatability over time
Streambank			
Streambank soil alteration	12.3	Fair	Fair to Good
Streambank vegetative stability	3.1	Excellent	Fair to Good
Streambank undercut	18.5	Fair	Good
Streambank angle	4.4	Excellent	Good
Streambank rock content	Very wide	Poor	Poor

We failed in our efforts to differentiate between natural or artificially caused soil alteration. Only on streambanks recently damaged by livestock grazing could we rate artificial alteration with confidence. The difficulty lies in attempting to visualize how the streambank looked prior to the alteration, and rating the amount of alterations based on this perception. The problem is that the guidelines do not clearly define what an unaltered streambank should look like.

We are attempting to substitute a cross-section channel bank profile, determined by using an engineer's scope and stadia rod, to better evaluate the amount of streambank alteration. Even though the instrument makes this method much more accurate, it does not allow identification of artificial or natural alteration.

The precision around the streambank undercut means were high (CI = ± 18%) mainly because of high natural variation. It was possible to measure undercut accurately with a measuring rod when the two points of measurement were correctly identified. The consistency of measurement over time was only fair because the two points of the measurement cannot always be identified accurately.

Good precision and repeatability were easily gained in measuring bank angle. If the angle was less than 90°, however, the multiple undercuts caused some confusion as to what two points determined the angle measurement. Instantaneous precision was excellent (CI = ± 4.4%) and repeatability over time rated good. This measurement and its interpretations can be used with confidence, mainly because a clinometer was used to determine the angle measurement.

Channel gradient was obtained successfully because the elevation difference between two points determining the gradient was gained with an engineer's level and stadia rod. The two measurement points were clearly defined by the water surface. The difficulty that arises in measuring channel gradient is in determining the horizontal distance between the two elevation points. Some methods measure this distance along the bank or waters edge, which can lead to error. A measurement following the middle of the stream channel gives better accuracy.

We could not accurately measure streambank rock content by eye because of vegetative covering and the sudden changes that occurred in streambank soils. Soil pits with gradation sieving would be necessary to make this measurement.

Streambottom

The amount of boulder making up the stream channel surface can be determined fairly accurately by visual methods if there isn't a high amount of rubble between 279.4 to 302.3 mm in particle size. The eye has difficulty separating this gray area surrounding the boundary line (<254 mm and > 356 mm) unless each boulder is individually measured. In our study, precision was poor (CI = ± 40.9% of the mean) because the amount of boulder was highly variable and scattered in small amounts throughout the channel (table 4). Repeatability over time rated good, however, because boulder was easy to identify and measure and there was little instream movement of boulder from year to year. In most of our study streams, if a boulder was intercepted by the transect line one year it would still be in the exact spot for measurement the following year. In photo points taken annually on the South Fork Salmon River, large boulder had almost always remained stationary in the channel over a 16-year period. Some streams, especially Pacific coastal streams, efficiently transport boulder and variation of measurement over time could be higher.

Measurement of the amount of rubble by eye also had poor precision (CI = ± 35.9%) mainly because of its high natural variation in the channel, but also because of the difficulty in accurately classifying sediment particles between 63.5 to 88.99 mm in diameter. Rubble, like boulder, tended to remain in place year after year in many streams; thus, repeatability over time was fair to good.

The precision for gravel (CI = ± 6.4%) was much higher (good) because gravel was more uniformly distributed in our study stream channels. Repeatability over time, however, was poor. The major reason was the bias that developed in identifying gravel at both ends of the size class. Sediment particle sizes between 63.5 to 76.1 mm were often mistakenly identified as rubble, while particles near the 4.75 mm range were often classified as fine sediment. Because of this poor discrimination, caution must be used in interpreting the data collected.

The precision around the means for both coarse fine sediment and fine fine sediment was poor to fair (CI = ± 27.7 and 17.3% respectively). Repeatability over time only rated fair, so difficulty existed in collecting reliable fine sediment data. Interpretation of the results should be done carefully.

The precision for substrate embeddedness was good (CI = ± 5.4%), and repeatability over time rated good. This measurement was dependable, and the only problem that occurred was interpreting how much of the underside portion of the particles was actually embedded with fine sediment. In our evaluation, if the particle was in contact with a particle larger than fine sediment, then there was no embeddedness. If it was held up by fine sediment, then that portion in contact was classified as being embedded.

Instream vegetative cover had poor precision (CI = ± 26.2%), mainly because of its large natural variation. Even though precision was poor, repeatability over time was fair. Major changes in cover would have to occur, however,

Table 4.--Expected repeatability, precision, and confidence intervals of streambottom measurement means from 6 selected streams in Idaho and Nevada. Confidence intervals are at the 95% level and expressed as percent of the mean

		Confidence interval	Precision	Repeatability over time
Streambottom				
Boulder		40.9	Poor	Excellent
Rubble		35.9	Poor	Good
Gravel		6.4	Good	Fair
Fine sediment	Coarse	27.7	Poor	---
	Fine	17.3	Fair	Fair
Embeddedness		5.4	Good	Good
Instream vegetative cover		26.2	Poor	Fair
Channel stability		Very high	Poor	Poor

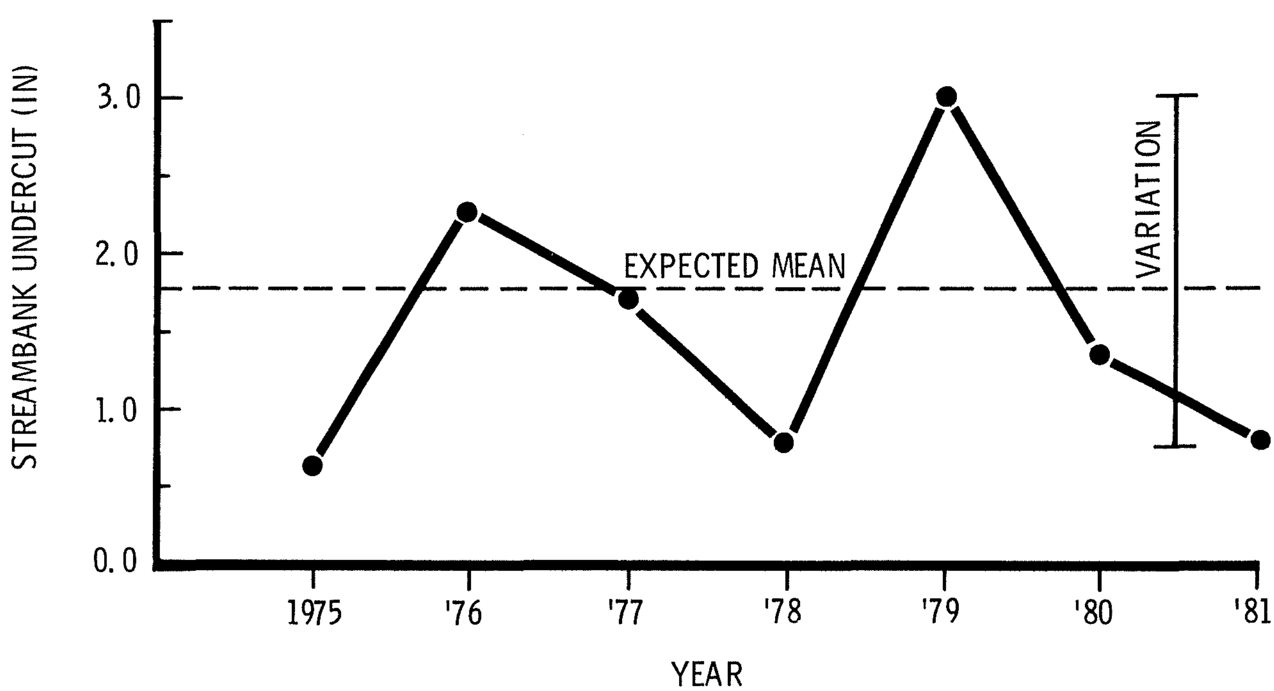

Figure 6.--Streambank undercut annual sample means from the Idaho study site.

Table 5.--Expected repeatability, precision, and confidence intervals of riparian measurement means from 6 selected streams in Idaho and Nevada. Confidence intervals are at the 95% levels and expressed as percent of the mean.

	Confidence interval	Precision	Repeatability over time
Riparian			
Streamside cover	4.1	Excellent	Fair
Vegetation use	12.0	Good	Good
Vegetation overhang	15.7	Fair	Fair
Habitat type	3.6	Excellent	Good
Fish streamside environment	4.9	Excellent	Good

Table 6.--Comparison of average vegetation utilization estimates in percent using the electronic capacitance herbage meter versus the visual method of estimation. Based on 10 sites in Idaho, 2 in Nevada, and 1 in Utah.

	1979			1980		
Study Area	Meter	Visual	Δ	Meter	Visual	Δ
Idaho Sites (10)	44.5	43.6	0.9	57.5	59.9	2.4
	Range 2-14 percent			Range 2-11 percent		
Nevada Sites (2)	81.0	68.0	13	62.5	57.0	5.5
	----			Range 2-9		
Utah Site (1)	84.0	76.0	8	104.0	87.0	17

before collected data could significantly show a change.

Riparian

Riparian measurements were made mainly without instruments, so more subjective judgment entered into the measurement. Determining the streamside vegetative cover had high precision (± 4.1%) because the dominant cover type tended to be uniform and observers classified the same cover types consistently even though they may have been doing it incorrectly (table 5). As a result repeatability over time was only fair, again demonstrating that the interpretation of certain measurements must be done with caution.

Vegetation use by animals was estimated with good results. Precision and repeatability over time were good. The eye was capable of estimating the use almost as well as estimates gained by using the electronic capacitance meter (table 6).

Vegetation overhang, while an actual instrumented measurement, still had only fair precision (CI = ± 15.7%) because of large natural variation. Repeatability over time was fair to good.

The streamside habitat type measurement is a new approach to evaluating the streamside environment and needs further definition and development to be useful. We are, however, getting high precision at this time, but only good repeatability. In the Idaho streams, the fish streamside environment measurement had excellent precision and good repeatability over time.

Before fishery biologists have adequate inventory procedures, special effort is needed in inventory design and testing. We by-passed this step of development in our desire to get on with the job. This by-pass has hurt the credibility of our work and special effort should be extended over the next decade to put our inventory procedures in order.

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A PREDICTIVE FISH HABITAT INDEX MODEL USING GEOMORPHIC PARAMETERS

Milton G. Parsons[1], James R. Maxwell[2], and David Heller[3]

Abstract. A physical and statistical relationship was determined between geomorphic parameters and a fish habitat quality rating score for 38 undisturbed streams surveyed on the Siuslaw National Forest. The rating score was determined by base flow, pool to riffle ratio, pool quality, riffle quality, and stream shading characteristics. A backward step-wise regression analysis showed a statistically significant correlation between this rating score and four geomorphic variables.

INTRODUCTION

In the past decade, increasing user demand and environmental awareness have multiplied the complexity of forest management. Concern for water quality and fisheries productivity has particularly increased in the Pacific Northwest. On the Siuslaw National Forest, increasing timber demands, declining fish runs, and State concern over waning salmonid habitat quality on National Forests have created major issues. With the passage of the National Environmental Policy Act (1969) and the National Forest Management Act (1976), a more formal process of planning and decision making on Federal lands emerged. Thus, techniques for quantifying the tradeoffs between management of various resources are needed.

The Fish Habitat Index (FHI) was developed to meet this need. The index is a rating of the value of the fish habitat of an area. It is derived by multiplying habitat quantity (acres of salmonid habitat) by habitat quality (a numerical indicator of habitat condition). The purpose of the index is to display to land managers the tradeoffs between forest harvesting and fish habitat.

The development of the index has been an interdisciplinary effort involving Forest and District personnel in fisheries, soils, and hydrology. A crude FHI was initially used in the Forest Timber Resource Plan (1979) to include fish habitat in the decision making. Since then, the index has been refined for the Siuslaw Forest Plan through a variety of data-gathering and analytical activities.

The conceptual basis for the index model is that salmonid production potential is controlled by the quantity and quality of available habitat. The model requires three major assumptions: 1) a single set of parameters accurately reflects habitat requirements for maintaining all life stages of all salmonid species; 2) changes in habitat conditions affect all species equally; 3) multiplying habitat quantity by habitat quality reasonably reflects trends in the salmonid production potential of habitat.

The FHI is computed for three different time periods:

1. The natural FHI is computed to assess inherent fish habitat conditions without the influence of management. This represents a base line from which to assess the effects of management. It infers what fish habitat conditions were before comprehensive management of the Forest began in 1940.

2. The present FHI is computed to assess fish habitat conditions today, as affected by management activities since 1940. It represents a given benchmark from which to forecast future trends.

3. The future FHI is computed to forecast relative changes in fish habitat conditions through future decades for each management alternative.

The FHI is computed differently for natural conditions than for managed (present and future) conditions. Natural habitat quantity is the acres of fish-bearing streams. Natural habitat quality

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is a dimentionless number between 0 and 10 predicted by a regression equation using geomorphic parameters. Managed habitat quantity is reduced from natural levels by the acres of fish-bearing streams blocked to migrating salmonids by logjams, and is replenished as these barriers are removed. Managed habitat quality is reduced from natural levels by impacts from sedimentation, temperature increases, debris supply disruptions, and debris torrents (sluiceouts), and is replenished as these impacts are mitigated.

This paper discusses only the portion of the model that computes the natural FHI. In the methods section, we first present the techniques used to stratify the Forest into analysis units and explain the derivation of the data base for this portion of the model. In the results section, we describe how estimates of natural habitat quantity and quality are made for each land stratum. A paper describing the entire FHI model will be issued later in 1982.

STUDY SITE

The Siuslaw National Forest occupies 630 thousand acres in the central Oregon Coast Range. The Forest has a maritime climate with an average annual precipitation of 100 inches of which about 80 inches becomes runoff. Steep dissected slopes, cohesionless soils, and heavy precipitation contribute to active erosion processes. Sideslope steepness averages more than 60 percent, and ranges to 120 percent along many channels and headlands. The density of stream channels average 6.5 miles per square mile. Lands considered high risk for accelerated erosion following clearcutting or road construction compose 41% of the forest land available for timber harvest.

Of the 3,200 miles of perennial streams on the Forest, nearly 1,200 miles support anadromous salmonid fish. Five of the seven major coastal river systems that provide the largest numbers of steelhead and salmon to the estuarine and fresh-water sport fisheries of Oregon are partially included in the Siuslaw National Forest. The annual net economic value of the sport and commercial fisheries attributable to the Forest is about 22 million dollars.

Two major natural vegetation zones occur on the Forest, Sitka spruce and western hemlock. The Sitka spruce zone occurs along the coast, and it is only a few miles in width where it extends up river valleys (Franklin and Dyrness 1973). The western hemlock zone covers the rest of the Forest. The major commercial coniferous trees on the Forest are Douglas-fir, western hemlock, Sitka spruce, and western redcedar. The major commercial use of the Forest is timber production. An average of 380 million board feet of timber has been sold annually on the Forest during the past 10 years.

METHODS

Stratifying the Land Base

Because more than 240 watersheds and six salmonid species exist on the Siuslaw National Forest, some generalization is needed to provide information that is meaningful to decision makers and the public. Assessing individual watersheds or species is impractical. Yet, variation in land and stream characteristics throughout the Forest justifies some stratification of the land base into relatively homogeneous blocks in order to model inherent similarities. The land systems inventory was used to delineate these strata.

The land systems inventory is a hierarchical land classification. Its purpose is to delineate units of land having differences in land capability and suitability. The system integrates inventory needs for many resources for interdisciplinary decision making. The delineated units reflect the action of climate on geology over time to produce an orderly array of landforms, soils, and vegetation. The units are useful as analysis, implementation, and monitoring areas.

Land systems inventory concepts have been presented by Wertz and Arnold (1972), Wendt et al. (1975), Region 1 of the USDA Forest Service (1976), and Platts (1980). Berry and Maxwell (1981) completed a land systems inventory for the Siuslaw National Forest. Units of land are described at nine hierarchical levels. Each succeeding level becomes more homogeneous in characteristics to satisfy increasingly specific information requirements. The landtype association level was used in applying the FHI model to Forest planning.

Fifteen landtype associations were defined on the Forest. These units average about 40,000 acres and reflect differences in patterns of lithology, geomorphic process, landforms, and vegetation. The 1:31,680 Soil Resource Inventory (SRI) was used as the basis for mapping.

The SRI mosaic was color coded to reflect the composite lithology, process, and landform features of each SRI landtype. Associated color patterns were used to draw preliminary landtype association boundaries. The mosaic was then taken to each District, where hydrologists, fisheries biologists, soil scientists, and foresters refined the mapping based on local knowledge of landform and vegetation conditions. The result was a base multiple-resource map that reflects major differences in land productivity, erosion hazard, water and sediment yield, and stream structure. FHI assessments were made independently for each landtype association.

Determining Habitat Condition

In 1978 the Siuslaw National Forest began a stream assessment program. The goal is to describe the physical habitat of streams, assess the productivity of resident and anadromous fisheries, and document the short and long-range impacts of Forest management on the fisheries resource. As part of the program, a method to objectively assess the quality of salmonid habitats was developed. An intensive review of the literature and of habitat evaluation methods from Regions 4, 5, and 10 of the Forest Service and western districts of the BLM was made. From this review, Dave Heller and Steve Zemke, fisheries biologists from the Mapleton Ranger District, developed the habitat condition score (Parsons, 1979).

The method calculates a numerical index of fish habitat quality for each stream surveyed on the Forest. Criteria of streamflow, pool-riffle ratio, stream surface shading, pool quality, and riffle quality are used to calculate a Habitat Condition Score (HCS) for each reach. Reach scores are weighted by length and are used to develop an overall HCS for the stream. The full range of scores varies from 0 (very poor) to 10 (optimum). An adjustment factor is applied in cases of recent sluiceout, accelerated debris loading, erosion or deposition, or high salmonid population levels. The habitat condition score is useful as a means of comparison and for long-term resource monitoring and evaluation. Table 1 illustrates how the HCS was calculated for a stream. It displays the weights assigned to each component of the habitat being evaluated.

Table 1. Habitat Condition Score - Alder Creek, Hebo Ranger District.

Reach II - Alder Creek

Component (Data)	Rating	X	Weight	=	Score
I. Flow (0.5-1 CFS)	3		7		21
II. Pool:Riffle (7:3)	7		5		35
III. Shade (85-95%)	9		3		27
IV. Pool Quality (Depth 0.8-1.4 ft; Effective Cover 45-59%)	7		5		35
V. Riffle Quality					
A. Water Depth (0.2 ft)	4				
B. Bottom Comp. (Boulder-Rubble)	6				
C. Condition (Sediment)	5				
	15/3	X	5	=	25
Total			25		143
Unadjusted Score = 143/25			=		5.7

Adjustments:

Moderate Nos. Salmonids	+ 0.5
Adjusted Score	6.2

Overall Score - Alder Creek

Reach	Score	X	Miles	=	Weight
I	6.0		0.5		3.0
II	6.2		1.7		10.54
III	4.0		0.6		2.4
			2.8		15.94/2.8 = 5.7

To generate a data base which would allow us to predict natural habitat quality, we need HCS values for undisturbed watersheds. The stream assessment program had surveyed 38 such watersheds on the Forest by 1980. We derived an HCS for each watershed. Our next job was to develop a model that would predict these HCS (natural habitat quality) values with reasonable accuracy.

Selecting Geomorphic Parameters

Geomorphic parameters describe physical characteristics of drainage basins and stream networks. Since 1933 at least 49 publications have documented the use of geomorphic parameters to model annual runoff, baseflow, peak flow, and sediment yield. In addition, the use of geomorphic parameters to assess fish habitat quality has a foundation in the literature. Thompson and Hunt (1930) stressed the importance of the entire watershed, not just the stream, to stream productivity. Slack (1955) showed biological stream productivity is directly related to physical watershed characteristics controlling drainage pattern, flow rates, gravel sizes and shapes, channel gradients, and stream and slope stability. Ziemer (1971) developed an index system relating pink salmon escapement numbers to five geomorphic parameters in Alaska. Burton and Wesche (1974) related four geomorphic parameters to an index of standing crop of trout in small Wyoming streams and confirmed the model with standing crop estimates in other streams. Swanston, et al. (1977) developed a regression formula with eight geomorphic parameters to estimate the productivity of salmon streams in 200 watersheds in southeast Alaska. We have taken a similar approach, using geomorphic parameters to estimate quality of fish habitat on the 38 undisturbed watersheds surveyed on the Siuslaw National Forest.

Marston (1978) identified 73 geomorphic parameters from the literature that had been used to model mean annual runoff, base flow, mean annual peak flow, and sediment yield. We judged 32 of these parameters to have strong enough correlations with factors contributing to the quality of fish habitat to merit our attention.

We also identified two others in the course of our analysis. The symbols and names of these 34 parameters are shown in Table 2.

Table 2. Geomorphic Parameters

Number	Symbol	Name
1	BA	Basin Area
2	BP	Basin Perimeter
3	BL	Basin Length
4	BR	Basin Relief
5	TNS	Total Number of Streams
6	TSL	Total Length of Streams
7	TSR	Total Relief of Streams
8	RR	Relief Ratio
9	B	Bifurcation Ratio
10	SLR	Stream Length Ratio
11	SRR	Stream Relief Ratio
12	SSR	Stream Slope Ratio
13	SLB	Stream Length Ratio/Bifurcation Ratio
14	SRB	Stream Relief Ratio/Bifurcation Ratio
15	SSB	Stream Slope Ratio/Bifurcation Ratio
16	DD	Drainage Density
17	WTF	Watershed Topography Factor
18	CC	Compactness Coefficient
19	SF	Stream Frequency
20	RD	Relative Density
21	LOF	Length of Overland Flow
22	C	Circularity
23	CCM	Constant of Channel Maintenance
24	FF1	Form Factor 1
25	L	Lemniscate
26	RER	Relative Relief
27	RN	Ruggedness Number
28	TE1	Transport Efficiency 1
29	TE2	Transport Efficiency 2
30	TSP	Texture Slope Product
31	TR	Texture Ratio
32	MS	Mainstream Slope
33	LWR	Basin Length to Width Ratio
34	ARF	Basin Area Relief Factor

The 34 geomorphic parameters were measured or derived for 240 basins distributed across the 15 landtype associations on the Forest. Stream networks were delineated using contour crenulations (Marston, 1978) and were ordered using the system of Horton (1945) as modified by Strahler (1957). Figure 1 demonstrates the delineation and ordering system.

The map of landtype associations was overlaid with a map of the 240 basins so that each sample basin was associated with a landtype association. The values of geomorphic parameters could then be averaged for each landtype association.

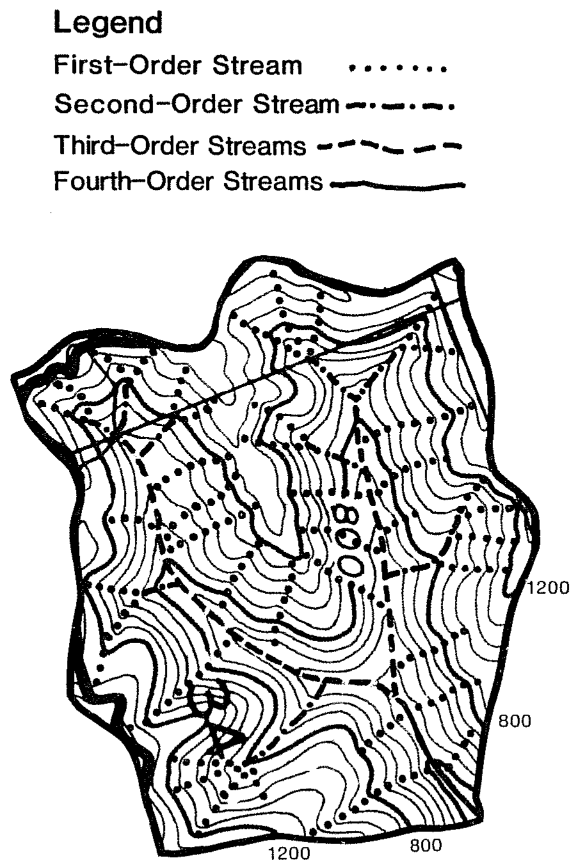

Figure 1. Delineation and ordering of drainage network.

The 240 sample basins were selected from sixth code subwatersheds, as described in Forest Service Manual 2570. These subwatersheds average about 4,000 acres in size, and are used to schedule management activities and facilitate resource inventories and monitoring. The subwatersheds were delineated on a 1:126,000 Forest map.

One fourth-order sample basin was selected in each subwatershed for geomorphic analysis. At least 80% of the subwatersheds contained only one fourth-order basin. Since only one selection was possible, these sample basins were the same ones that would have been selected randomly. About 15% of the subwatersheds had two fourth-order basins; in at least 10% of them, the two basins were not obviously different in size, and the sample basin was selected randomly. In the other 5% of the two basin subwatersheds, the basins were obviously different in size, and the larger basin was selected. In the last 5% of the subwatersheds there were three fourth-order basins; the sample basin was selected randomly in all but five at the most. In summary, the sample basin in 95% of the subwatersheds was in effect selected randomly. Calvin (1981) in his report on the model design concluded that sample bias was not significant enough to influence the validity or outcome of our modeling effort.

RESULTS

As stated earlier, the objective of calculating the natural FHI is to assess inherent fish habitat conditions without the influence of management. This represents a base line from which to assess the effects of management. It infers what fish habitat conditions were before comprehensive management of the Forest began in 1940. Since the product of quantity and quality constitutes the index, it is important that we understand how these values were derived.

Natural habitat quantity for each landtype association is the acres of salmonid habitat. The length of fish-bearing streams was measured on total resource inventory (TRI) compartment diazos using a HP-9874-A sonic digitizer which operates from a Hewlett Packard 9845-S desk-top computer. The length of streams blocked by natural falls and chutes was compiled from the stream survey reports and subtracted from the total stream mileage. Average bankful stream widths were calculated from stream survey data for each landtype association. Thus, the area of fish-bearing streams in each landtype association was calculated and expressed in acres.

Natural habitat quality for each landtype association is a dimensionless number between 0 and 10 predicted by a regression equation using four geomorphic parameters as the independent variables. The fish habitat condition score was calculated for the 38 undisturbed streams and these scores were then used as the dependent variables. The 34 geomorphic parameters were the independent variables used in a backward step-wise regression analysis run on the data from the 38 undisturbed basins. Since the analysis was to predict conditions on undisturbed basins, and the sample size of the undisturbed basins was only 38 of the 240 basins for which geomorphic parameters were calculated, it was imperative that there be no differences in the geomorphic parameters between the disturbed and undisturbed basins. In order to investigate this possibility, the distribution of all variables of interest was examined.

An ordered listing was made of the values of each variable, with the values for the undisturbed basins flagged for easy observation. Calculations were also made of the percent of the values of the undisturbed basins which were in the top 25 and the bottom 25 of the 240 values listed. If the values of the undisturbed basins were evenly or randomly distributed throughout the 240 basin values, 16% (representing four basins) of the top or bottom 25 values would be expected to be values of undisturbed basins. Only three variables showed a significantly different distribution for undisturbed basins. These were: Form Factor 1 (FF1), Basin Relief (BR), and Lemniscate (L). Since only three of 64 percentages (5%) showed statistical significance at the 5% significance level, exactly what would be expected if no differences existed, the disturbed basins could be assumed to have the same distributions as undisturbed basins. Thus the analysis for development of a model for undisturbed basins could be run using all 240 basins.

To reduce the number of independent variables used in the model to predict FHI, the correlation matrix of the independent variables over all landtype associations was examined for evidence of collinearity. Where a high correlation was found between two variables, one of them was deleted from further consideration. The variable deleted was the one which also showed high correlations with other independent variables, or seemed less likely from a biological point of view to be related to the fish habitat condition score.

The correlation coefficients between the fish habitat condition score and the independent variables were also examined. Variables with a low correlation, indicating low predictive ability, were deleted. These procedures reduced the number of independent variables from 34 to 10 for futher development of the predictive model. With the reduced number of independent variables, it was possible to run a regression analysis on the data from the 38 undisturbed basins. A backward step--wise regression analysis was run on the following independent variables:

BP =	Basin Perimeter	BL =	Basin Length
BR =	Basin Relief	DD =	Drainage Density
CC =	Compactness Coefficient	RD =	Relative Density
BA =	Basin Area	MS =	Mainstream Slope
LWR =	Basin Length to Width Ratio	ARF =	Basin Area Relief Factor

The first four variables coming into the model are BP, BR, BA and CC in that order, with all four regregression coefficients being significantly greater than zero at $P = .05$. No other regression coefficients were significant. The resulting regression equation for calculating the FHI (natural quality number) is:

$$\text{FHI (natural quality number)} = 6.56 + 1.44\ BP + .00089\ BR - 2.02\ BA - 5.62\ CC$$

The coefficient of determination is 0.60, meaning 60% of the variation in the FHI is explained by the four independent variables. The standard error of estimate, with 33 degrees of freedom, is 0.82, a reduction from 1.22 with 37 degrees of freedom. The results are obvious with four variables contributing significantly and no other variables even approaching significance. The regression equation can be used to estimate the FHI (natural quality number) for a given landtype association by substituting the mean values for basin perimeter, basin relief, basin area, and compactness coefficient for that landtype association, and calculating the FHI natural quality number.

The natural FHI number is determined for each landtype association by multiplying the quantity, or acres of habitat, times the quality number as predicted by the regression equation.

DISCUSSION

The Siuslaw National Forest has two valuable new tools to aid in the management of land and water resources. One is the land systems inventory, which divides the Forest into large blocks of land having distinct traits of lithology, land and channel form, and vegetation. The other is the natural FHI, which combines the quantity and quality of salmonid habitat into a simple measure of the inherent habitat condition of the fisheries resource.

These two tools are used together to improve our understanding of the resource base and influence decisions affecting resource investment and land allocation. The traits of each landtype association define distinct potentials for water and sediment yields, land hazards, timber production, and quantity and quality of fish habitat. The inherent value of the fisheries habitat resource can be estimated for each landtype association. Fisheries restoration and enhancement funds can be invested in the potentially more productive stream systems.

The natural FHI constitutes a base level from which departures due to management can be calculated. A series of models has been developed which quantitiatively and qualitatively assess the relationships between timber production and salmonid habitat. These models will help the land manager to determine the most balanced mix of resource investments and land allocations for each landtype association. A paper describing these additional models will be issued in 1982.

ACKNOWLEDGMENTS

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A PROPOSED APPROACH TO DETERMINE REGIONAL PATTERNS IN AQUATIC ECOSYSTEMS[1]

Robert M. Hughes and James M. Omernik[2]

Abstract.--This paper describes a general approach that relates patterns in terrestrial regions to patterns in stream channels and fish communities. To demonstrate the approach, we examined three of Bailey's (1976) Midwestern ecoregion sections. We found few significant differences in stream ecosystems, but severely disturbed streams across the three sections.

INTRODUCTION

Our objectives in this paper are to (1) demonstrate a method to select similar watersheds based on attributes we believe to be responsible for certain stream characteristics; (2) demonstrate how those characteristics of stream channels conform to the regional patterns of the responsible watershed attributes; and (3) show how fish communities conform to the regional patterns in watershed attributes and characteristics of stream channels. We use the term watershed in a general sense, realizing that in 40% of the conterminous U.S. topographic definition of watersheds may be difficult or impossible (Hughes and Omernik 1981).

The basic premise of our approach is that stream characteristics reflect watershed characteristics, that detectable spatial patterns in watershed attributes exist, and that streams in similar watersheds generally have similar physical and biological characteristics (Omernik et al. in press). The idea that biota exist in regional patterns determined by their physical environments is not new. Dice (1943) characterized the biotic provinces of North America based on peculiarities in climate, physiography, soil, and biota. He considered biotic provinces as having imprecise boundaries and acting as centers of dispersal and differentiation. Bailey (1976) developed a different, more refined map of hierarchical ecoregions, but both workers were primarily concerned with terrestrial ecosystems.

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Rawson (1939) contended that geographic location and morphology govern a lake's ecological characteristics, but only recently (Likens and Bormann 1974, Hynes 1975, Warren 1979) has it been explained why a stream cannot be meaningfully studied in isolation from its watershed. Rickert et al. (1978) related slope, age and type of bedrock, soil associations, and land management to stream channel stability and fish habitat in a 541 km^2 mountainous area of southwestern Oregon. Platts (1979) demonstrated how stream channels and fish communities were related to land forms, soils, and climax plant communities in a 1028 km^2 mountainous area of central Idaho. Warren (1979) suggested that a rational watershed/stream classification should synthesize geomorphology, soil, vegetation, and culture, rather than consider them separately, and the synthesis and classification should be hierarchical and based on the potentials of the land area or water body of interest. Warren was concerned with small watersheds, but we feel his synthesis of terrestrial characteristics also may occur at a regional level. When important, additional components, such as lithology, major migration routes or migration barriers, may be considered. Fewer components, such as land use or land form, can be weighted more than others when they incorporate most of the variability or the greatest extent of an area.

Initially, we assumed that Bailey's 1976 map of ecoregion sections would discriminate among aquatic ecosystems in the Midwestern Corn Belt. The map did not prove wholly satisfactory, possibly because Bailey emphasizes a single, different variable at each level of his hierarchy. For example, his sections were largely determined by potential natural vegetation. Thus, we developed a different method to determine common properties, or regional patterns, in watersheds.

Our approach concentrates on similarities and general conditions of mapped data rather than on masses of raw data. Components are emphasized based on our judgment of ecologically important features. It is a synoptic approach for clarifying broad, regional patterns of aquatic ecosystems. Such an approach is needed to improve our understanding of site-specific data on aquatic ecosystems. In this paper we will first outline our approach, then give an example of how it was used. Because of budgeting constraints our field study was cursory and our methods were crude, thus only large differences in variables were likely to be evident.

METHODS

Determination of Homogeneous Areas and Study Sites

National 1:7,500,000-scale maps of land surface form, soil types, potential natural vegetation, land use, precipitation, and ecoregions (U.S.D.I.-Geological Survey 1970, Bailey 1976) were used to determine homogeneous areas in the Midwest with similar watersheds. Each national map varied in accuracy, the data for each map were hierarchically clustered at different levels of resolution, and the overlaps among the maps varied spatially. This variation is a major reason for overlaying several maps rather than using just one or two. The homogeneous areas determined from the overlays

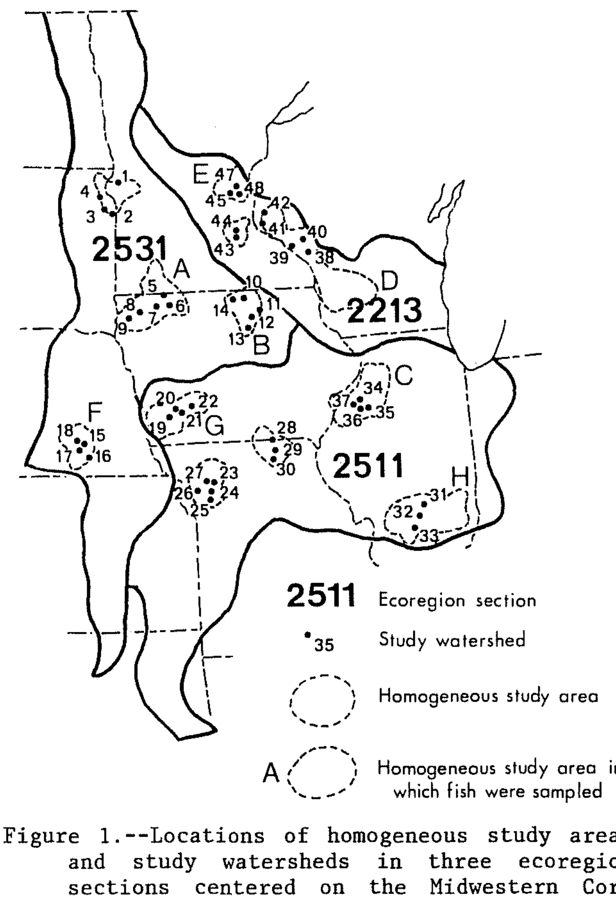

Figure 1.--Locations of homogeneous study areas and study watersheds in three ecoregion sections centered on the Midwestern Corn Belt.

represented watershed conditions typical of the three Bailey sections.

The general method used to determine regional patterns is outlined in 8 steps.

1. <u>Select the geographic region(s) of interest and stream characteristics of concern</u>. We selected the Midwestern region shown in figure 1 because of its economic importance; its homogeneity in land use, land form, soil, and vegetation; and the opportunity to examine the significance of three of Bailey's Midwestern ecoregion sections which represent three different provinces and two different divisions in his ecoregion hierarchy. We were concerned with the following stream characteristics: patterns in riparian vegetation, stream channelization, riparian cattle, mean particle size of

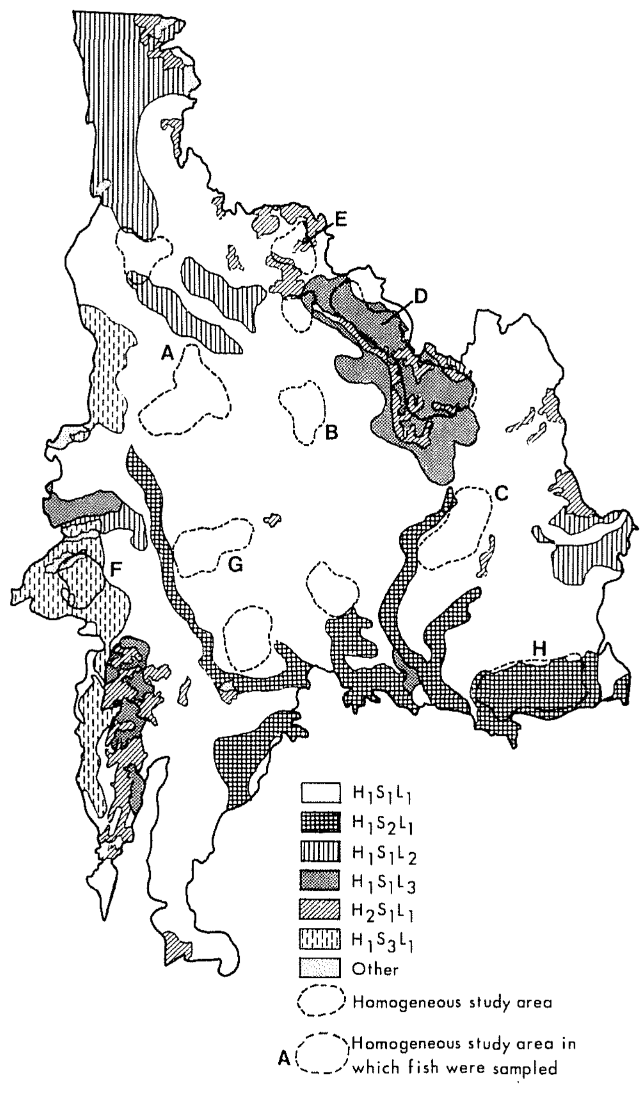

Figure 2.--Selected combinations of watershed attributes and homogeneous study areas for the study region. For identification of symbols, see table 1. Potential natural vegetation omitted for sake of clarity.

Table 1.--Selected categories of watershed characteristics for the study region. Numbers and letters in parentheses refer to map units from the respective maps in U.S.D.I.-Geological Survey (1970) and Bailey (1976).

Characteristic		% Coverage	Category
Land Use ------	H_1	94	Cropland (1-3)
	H_2	6	Remaining land uses (4-urban)
Soil Suborders	S_1	85	Moist soils (A_4, A_{6-8}, E_{12}, M_{3-8}, S_{2-4}, U_{4-6})
	S_2	9	Wet soils (A_{1-2}, M_{1-2})
	S_3	6	Dry soils (M_9)
Land Form -----	L_1	82	Smooth, rolling, and irregular plains and open hills of low relief (A_2, B_2, C_2)
	L_2	10	Poorly drained plains (A_1)
	L_3	8	Rugged, hilly areas (B_3, C_3)
Potential ----- Natural	P_1	74	Grasslands (66, 72, 73)
Vegetation	P_2	26	Forestlands (89, 91)

stream substrate, and fish community structure.

2. Determine the desired level of resolution. We were interested in Bailey's sections 2511, 2531, and 2213, an area of about 650,000 km^2. These sections represent different provinces and divisions of Bailey's ecoregions, yet the climate, land form, soil, vegetation, and land use differ only slightly. We felt such subtle differences would permit more rigorous examination of our approach than would the more striking differences found among and within ecoregions in the mountains and plains of the western United States. Any differences identified in stream characteristics between such subtly-varying sections would provide strong support for systems such as ours or Bailey's that represent regional patterns of several integrated watershed characteristic over large areas.

3. Choose watershed characteristics that are likely to control stream characteristics. We selected land surface form, soil types, potential natural vegetation, land use, and precipitation.

4. Determine the percent of the region covered by the different categories of each watershed characteristic. The categories and their percent coverage are shown in table 1 and figure 2 for the three sections as a whole.

5. Select homogeneous study areas. These should include the most typical areas and some that are expected to reveal the range in generally typical conditions. The most typical areas are determined by overlaying maps that show the distributions of the major subcategories of the predominant watershed categories. For example, plains may predominate in an area but rolling plains may be much more common than smooth and irregular plains, thus rolling plains would be the land form in this overlay. Our Midwest study areas are delineated by the dotted lines on figures 1 and 2.

6. Within each homogeneous study area, randomly select study reaches that represent different-sized watersheds. In the Midwest, we selected reaches that represented topographic watersheds of approximately 325, 100, and 15 km^2. The mean annual runoff in this region averaged 13 cm and ranged from 5 to 25 cm (U.S.D.I.-Geological Survey 1970). Flows at the lower, middle, and upper reaches were perennial, occasionally intermittent, and usually intermittent or ephemeral, respectively.

7. Investigate the study reaches and their watersheds to insure that they are representative of the homogeneous study area. During the summer of 1980 we examined the reaches from the air and the ground. We randomly selected 3 comparably-sized, lower reaches in each homogeneous study area from which to sample fish.

8. Compare the ranges in anthropogenic and nonanthropogenic characteristics in order to determine general relationships.

Riparian Characteristics and Channelization

We determined the extent of the riparian forest in the three sections by examining 1:40,000-scale aerial photos and 1:63,360-scale photo mosaics. Streams were divided into upper, middle, and lower sections where watersheds were approximately 15, 100, and 325 km^2. The entire mainstems of these sections were examined for percent of total length with (1) riparian forest greater than 12-m wide, (2) riparian forest 6 to 12-m wide, and (3) riparian forest less than 6-m wide. Stream sections with trees on only one side were categorized as being without riparian forest; such areas were uncommon. The extent of stream channelization was measured from the same aerial photography and for the same stream sections that were used to determine the extent of riparian forest. Straight sections were considered channelized. Evidence of cattle at each study site was determined from field notes and photographs.

Stream Substrate and Water Quality

Substrate was examined at the lower reaches of the study streams. Dominant characteristics of the stream bed were estimated visually by two persons walking approximately 100-m of stream. All sites contained fast and slow water sections. Geometric mean diameter of the substrate was calculated from the proportion of the stream bed that was covered by mud, sand, gravel, or cobble. The water was classed as clear or turbid depending on whether pool bottoms were visible or not and flows were ranked as low or high from the current velocity, depth, and width at riffles.

Fish Communities

Between 25 August and 12 October 1980, fish were sampled from 100-m sections of the lower reaches. Each reach was sampled three times in one day with 3 to 6-m long, 0.3 to 0.9 cm mesh seines, backpack electrofishers, or both. The three samples were combined into one measure of total catch. A record drought had occurred during the preceding months, but heavy local rains during August and September produced such high flows that fish were sampled from only 22 of the 47 sites. The single day's sample, the variable sampling methods, and the small number of samples distorted our estimates of the presence and relative abundances of species. However, the homogeneous study areas clustered independently of sampling methods.

The catch per unit area and several estimates of fish community structure (H', s, Q, F, BI, CI) were determined for each reach. Weights of fish were estimated from length-weight values in Carlander (1969, 1977) so that the above parameters could be calculated from numbers or weights. Species diversity, H', was calculated as $-\sum_{i=1}^{s} p_i \log p_i$, where s = species richness of a sample, and p_i the proportion of species i in the entire sample. Q and F are tolerance and trophic indices similar to the indices that Hilsenhoff (1977), Chutter (1972), and Word (1978) used to evaluate ecosystems from the structure of macroinvertebrate communities. Q = [0.1 (LT) + 1.0 (LI) + 10(I)]/[T + LT + LI + I] where T, LT, LI, and I refer to the densities of tolerant, less tolerant, less intolerant, and intolerant species. Tolerance was judged relative to sedimentation, turbidity, reduced low flow, ubiquity, and range expansion from discussions of each species in Pflieger (1975), Carlander (1969, 1977), Scott and Crossman (1973), Smith (1979), and Lee _et al_. (1980). Similar to Q, F = [0.5 (O) + 1.0 (I) + 5 (IP) + 10 (P)] / [O + I + IP + P] where O, I, IP, and P are the densities of omnivores, invertivores, invertivore-piscivores, and piscivores. The foraging guilds were determined from discussions of each species in Pflieger, Carlander, Scott and Crossman, Smith, and Lee _et al_. The biointegrity index, BI (Karr 1981), incorporates rankings of species richness; abundance; number of darter, sunfish, sucker, and intolerant species; and proportions of omnivores, insectivorous cyprinids, green sunfish, top carnivores, hybrids, and diseased fish. One, three, or five points are given to each category depending on whether that category is ranked as indicating low, moderate, or high biointegrity, respectively. The points for all twelve categories are then summed. The composite index, CI, was designed for use on large rivers; it was calculated as $0.5 \ln N + 0.5 \ln W + H_N + H_W$. Its components respectively consist of numbers, weight, numerical diversity, and weight diversity (Gammon and Reidy 1981).

All the above data were examined for general relationships by the use of Pearson's correlation coefficient (r) and for significance by the use of analysis of variance and Spearman's rank correlation coefficient (r_s). A cluster analysis, using the Canberra metric coefficient, was used to help identify similar fish communities and characteristic fish species. That coefficient is sensitive to proportional versus absolute differences, is affected only by the individuals or groups being compared versus the range of all individuals or groups, and is not dominated by outstandingly abundant species (Sneath and Sokal 1973, Clifford and Stephenson 1975).

RESULTS

Riparian Characteristics and Channelization

Stream channelization was most extensive where row crops were most prevalent. In such areas, 60-70% of the middle and upper stream sections were channelized (Omernik _et al_. in press). An average of 35% and 53% of the lower stream sections were channelized and had less than a 6-m strip of riparian trees, respectively (table 2). Riparian forest greater than 6-m wide generally existed only along the lower stream sections and was frequently lacking even there in the drier, western half of the Corn Belt. The correlation between channelization and depletion of riparian forest was significant and F, the index of foraging guilds (table 3), had a significant negative correlation with each. Uncultivated riparian areas generally existed

Table 2.--Stream environments and the catch and community structure of fish communities in typical Midwestern streams. The streams with the lowest predicted integrity, based on stream substrate, turbidity, and flow, are listed first.

Stream and Location (from fig. 1)	% Channelized Upstream	% of Banks with ≤ 6 m Strip Riparian Trees Upstream	Cattle Present at Site	Geometric Mean Diameter of Substrate (mm)	Catch		s	Q	F	BI	CI
					no/m^2	g/m^2					
Little Sioux 5	47	57	+	0.1	0.9	0.9	12	0.01	0.56	32	2.21
Beaver 38	13	60		0.1	0.1	0.1	7	0.25	0.84	27	3.57
Tarkio 19	82	81		0.1	2.4	0.8	5	0.06	0.79	34	3.08
Elk (Iowa) 11	29	68	+	0.5	0.0	0.2	8	0.47	4.26	38	0.89
W. F. Mid. Nodaway 22	90	94		0.5	1.1	1.8	9	0.05	0.79	34	5.15
West Nodaway 21	22	69		0.7	1.8	2.1	10	0.04	0.86	38	4.44
Elk (Wisconsin) 40	19	57	+	1.0	0.7	0.7	11	0.21	0.99	36	4.83
Indian 35	34	42		1.0	0.8	0.8	13	0.11	0.89	38	3.21
Stony 6	76	90	+	1.0	0.3	2.0	13	0.21	0.98	42	4.28
Turkey 17	20	45	+	1.5	4.9	3.0	9	0.05	0.86	38	4.95
E. F. Kaskaskia 33	4	9		1.5	1.6	3.2	15	0.24	1.14	41	6.03
Swan 16	19	26		1.5	1.6	9.5	10	0.22	0.86	34	3.28
Little Cedar 14	13	40	+	1.5	0.8	1.5	22	0.21	1.22	38	6.48
Hickory 32	13	17		1.5	1.9	5.0	16	0.18	1.06	46	6.57
L. Waumandee 39	31	68	+	1.5	0.3	0.6	13	0.72	1.07	46	4.11
Walnut 36	40	52		1.6	0.1	0.6	13	0.73	1.53	40	2.85
Big Muddy 7	47	98	+	1.7	0.7	5.4	17	0.74	0.79	47	2.09
Pope 37	44	39		1.7	0.1	0.9	14	0.85	0.84	42	3.94
Sunrise 47	20	61		1.7	0.1	0.8	14	0.97	0.84	44	3.46
Big 31	20	7		2.1	2.4	3.4	19	0.84	1.14	54	5.98
Deer 10	48	62		2.2	0.2	0.5	20	2.05	0.95	44	4.65
N. B. Sunrise 45	46	30		2.8	0.2	1.1	15	4.72	0.99	48	4.13

Table 3.--Correlations among three habitat variables and seven measures of fish community structure. Pearson's r is in bold face; Spearman's r is underlined (values > 0.42 and 0.57 significant at 5% and 1% levels, respectively).

	% Channelized Upstream	% Banks with ≦ 6 m Strip Riparian Trees Upstream	Mean Diameter of Substrate	Number Caught/m²	Weight Caught/m²	s	Q	F	BI
% Banks with ≦ 6 m Strip of Riparian Trees	.67								
	.62								
Geometric Mean Diameter Substrate	-.21	-.40							
	-.03	-.39							
Number Caught/m²	-.14	-.26	-.08						
	-.15	-.23	-.16						
Weight Caught/m²	-.22	-.30	.21	.40					
	-.17	-.30	.23	.68					
s	-.25	-.37	.75	-.19	.11				
	-.12	-.40	.79	-.06	.29				
Q	.09	-.18	.62	-.33	-.16	.34			
	.00	.18	.76	-.63	-.23	.53			
F	-.14	.02	-.11	-.23	-.19	-.14	.00		
	-.44	-.42	.28	-.15	-.11	.35	.29		
BI	-.09	-.29	.77	-.02	.14	.67	.50	.03	
	.04	.20	.82	-.13	.24	.76	.67	.38	
CI	-.28	-.49	.34	.37	.16	.47	-.02	-.38	.29
	-.41	-.39	.21	.45	.38	.38	-.12	.32	.22

only along middle and lower stream reaches and unchannelized upper reaches. Sixty-one percent of the sites were used by cattle (Omernik et al. in press) and cattle were present at 36% of the sites from which fish were sampled but at none of the sites predicted to have the greatest integrity (table 4).

Some stream channel characteristics showed significant differences when compared across sections. Section 2531 had significantly less riparian forest in the upper stream sections ($F_{2,44}$ = 7.33, p = 0.01) and significantly more channelization in the most typical upper and middle stream sections ($F_{2,17}$ = 4.19 and 5.08, p = 0.05) than sections 2213 and 2511. Section 2511 had significantly more riparian forest in the middle and lower stream sections ($F_{2,44}$ = 9.03 and 6.50, p = 0.01) than sections 2213 and 2531. Cattle were present at 70, 53, and 57% of the sites in sections 2531, 2511, and 2213, respectively. No significant differences in riparian vegetation and channelization existed among the most typical homogeneous study areas and the less typical homogeneous study areas (southeastern Nebraska, southern Illinois, and Wisconsin).

Stream Substrate

All reaches but Tarkio Creek were sand-bottomed, though several had extensive silt deposits. The reaches are ranked in table 2 in order of increased geometric mean diameter, by increased standard deviation of substrate when diameters were equal, by increased turbidity when substrates were equal, and by increased flow when turbidities were equal. Because of the greater stability and heterogeneity provided by coarse substrate, the reaches toward the bottom of table 2 were predicted to have greater integrity than those with high amounts of mud. S, Q, and BI were significantly correlated with the mean diameter of the substrate (table 3). No significant difference in substrate size existed among the streams in Bailey sections or among most typical and less typical homogeneous study areas.

Fish Community Structure

S and H' calculated from weights and numbers of fish were highly correlated (r = 0.79 and 0.83, respectively), as was Q calculated from numbers and weights (r = 0.84), so only those values for s, Q, and F that were calculated from numbers are presented in table 2. Significant positive correlations existed between number caught and weight caught and number caught and Gammon and Reidy's CI (table 3). S had a significant positive correlation with Q and Karr's BI. Q and BI had a significant positive correlation.

No significant difference in integrity or catch existed in fish communities among Bailey sections or among most typical and less typical homogeneous study areas. Also, a cluster

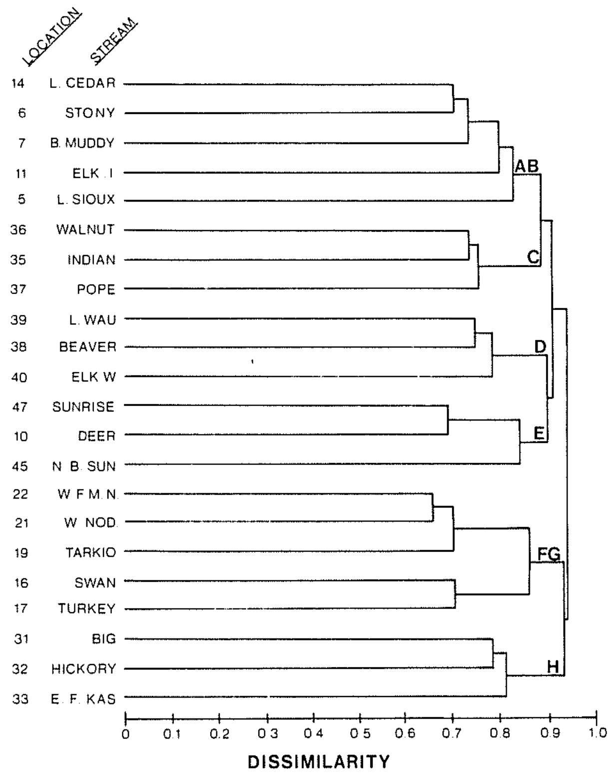

Figure 3.--Cluster dendrogram of fish communities for 22 Midwestern streams. Clusters were drawn from simple averages of Canberra metric coefficients that were calculated from data that had been standardized by attribute total. Stream locations as given in Figure 1. AB-H refer to major clusters and homogeneous study areas as shown in figures 1 and 2.

analysis of fish communities produced six major clusters (fig. 3) that are essentially unrelated to Bailey's sections and related to our homogeneous study areas only 67% of the time (fig. 1). Stream reaches that clustered together were generally in close proximity and usually were consistent with the homogeneous study areas, although in some cases clustered reaches encompassed more than one homogeneous area and crossed boundaries of ecoregion sections. For example, the homogeneous areas in northwest and north central Iowa clustered together, as did the homogeneous areas in southwest Iowa and southeast Nebraska. This occurred whether the streams were in the same river basin, as in southeastern Nebraska and southwestern Iowa, or in two separate basins, as in northern Iowa. Also, one northern Iowa reach with coarse substrate was clustered with the two east central Minnesota reaches. The six major clusters were also clustered into three larger clusters (ABC, DE, and FGH) that follow a north-south pattern similar to summer temperatures. Table 4 shows the fish species that best characterize the streams of each cluster. Nearly all the dominant

Table 4.--Dominant, subdominant, and characteristic fishes of clusters A-F, figure 3 arranged in order of numerical dominance.

Cluster	Species			
A	fathead minnow	green sunfish	johnny darter	tadpole madtom[2]
B	red shiner[1]	bluntnose minnow	horneyhead chub	johnny darter
C	johnny darter[1]	fathead minnow[1]	brook stickleback[2]	
D	johnny darter[1]	northern hog sucker	blackside darter[2]	
E	red shiner[1]	sand shiner[1]	fathead minnow	
F	red shiner[2]	bluntnose minnow	redfin shiner[2]	blackstripe topminnow[2]

[1]Numerically dominant in all or most of the streams in this cluster.

[2]Found in all the streams of this cluster but absent or rarely present in other clusters.

and subdominant fish were species that tolerate turbidity, sedimentation, and intermittent flows.

DISCUSSION AND CONCLUSIONS

The three Bailey sections have similar land use, soil type, and land form and a grassland type of potential natural vegetation (fig. 2 and table 1). Thus it is not surprising that the sections showed few significant differences among channel characteristics and no significant differences in characteristics of dominant fishes. In all three ecoregion sections, riparian forest was usually missing or minimal, a large proportion of the streams were channelized, cattle watered or grazed at most sites, stream substrates were typically sand, and fish communities were dominated by species tolerant of sedimentation, turbidity, and reduced summer flows.

The present condition of these stream communities can be compared with historical conditions. Trautman (1981), Smith (1971, 1979), and Quick (1925) traced stream changes in Ohio, Illinois, and Iowa, respectively, since the time that the region was settled by Europeans. They describe clear, meandering streams, with some coarse substrates, bordered by wetland and trees as representative of the conditions prior to channelization, drainage, deforestation, and intensive agriculture. Trautman documents the great abundance and large size of fish, especially piscivores and invertivore-piscivores that were prized by fishermen.

Representatives of these groups of fishes are now generally absent, replaced by the smaller, turbidity- and sediment-tolerant invertivores and omnivores of little value to fishermen. Since the approach used to select streams in our study picked typical watersheds, the characteristics of the sampled streams should be representative of streams in this part of the country. Historical comparisons suggest that these streams and their fish communities have deteriorated substantially since the area was first settled by Europeans.

It is unlikely that Midwestern streams will regain the conditions described above, but increases in macrophytes, snags, rock, gravel, meanders, wetlands, and riparian forest will increase water clarity and substrate stability and heterogeneity in sand-bottomed prairie streams. Such changes will improve the habitat for desirable species and sizes of fish. Stream morphology, substrate, flow, and riparian communities are extremely important to fish community structure in small Midwestern streams (Gorman and Karr 1978, Karr and Dudley 1981). Such physical characteristics are largely ignored by most state and federal water quality laws that focus on water chemistry, for example, the Clean Water Act of 1977.

The similarity in type of dominant fish in Midwestern streams is probably a function of the lack of large differences in substrate, climate, and land use (i.e., disturbance) in the Midwest. Thus, where only subtle differences exist among Bailey's sections, it may be desirable to examine the guild structure of aquatic communities over larger areas than sections, perhaps at something like the province or division level of Bailey's ecoregion hierarchy.

Although the guilds of the dominant fishes in the study area were similar, the cluster analysis indicated that there were identifiable groupings of fish species (fig. 3 and table 4). The species groupings clustered geographically, but the clusters did not correspond to the Bailey sections or to the selected combinations of watershed attributes (figs. 1 and 2). Some clusters crossed the boundaries of homogeneous study areas and major river basins, indicating that the attributes that control the distribution of these Midwestern fish species are other than the watershed attributes we selected to delineate the typical and representative areas. These other attributes could be stream gradient, summer water temperature, and the maximum particle size of soils. Biological factors such as competition, disease, and migratory ability also affect species distributions, as do such biogeographic factors as faunal richness, migration routes, and the size, age, and heterogeneity of the basin. All the above attributes are unmapped and thus useless for determining regional patterns.

However, this comparison indicates that certain general characteristics of fish communities correspond to broad patterns in terrestrial features, particularly those associated with physical habitat characteristics. Finer resolution of factors controlling distributions of particular fish species in the Midwest will have to consider those other, unmapped factors. This means that predictions of particular dominant and characteristic fish species in Midwestern streams will be useful for evaluating integrity only in areas with sizes in the same order of magnitude as our homogeneous study areas.

Several measures of fish community structure were used to evaluate the reaches. The cursory nature of the sampling makes conclusions about the significant correlations difficult. However, the negative correlation of number caught and Q suggests that species intolerant to sedimentation may be more likely to occur where total fish densities are relatively low. The significant correlations between geometric mean diameter of the substrate, Q, BI, and s are expected because increased mean substrate size should increase habitat heterogeneity and, therefore, provide habitats for more species. Also, Q and BI include measures of the number of species or individuals present that are intolerant of sedimentation so they should be expected to correlate with substrate size. S and Q are independent measures of integrity; their positive correlation and relation to our visual evaluations of stream integrity indicate that both are useful to evaluate integrity. There was a significant negative correlation of F with channelization and riparian forest. Possibly the reduced riparian forest, which also results from channelization, resulted in reduced leaf fall, reduced numbers of leaf-eating macroinvertebrates, and reduced numbers of fish dependent on those macroinvertebrates.

Whatever measures are used to evaluate ecological integrity, they should generally agree with one's common sense and aesthetic evaluation of the reach, at least at the extremes within a given ecological region. Estimates of density, biomass, H', and s occasionally may not do this (Green 1979, Hoekstra 1981, this study). We suggest that tolerance indices similar to Q or BI should be included in evaluations of biological integrity. Also, stream substrate should be included in estimates of stream integrity because such habitat is relatively easy to observe; offers considerable insight into the available foraging, cover, and reproductive opportunities at the site; and is associated with several measures of community structure.

Regardless of the cursory nature of this field study, we have described (1) a method that may be useful for selecting similar watersheds based on patterns of land form, soil, potential natural vegetation, and land use; (2) the degree to which riparian forest and channelization in the Midwest conform to Bailey's sections; and (3) the degree to which Midwestern fish communities respond to geometric mean diameter of substrate.

The method for determining regional patterns should be useful at whatever level of resolution the user desires, if appropriate maps or data are available. Its greatest potential applicability is to help us understand diffuse impacts on ecosystems. We believe it may be useful to management agencies in at least five ways. (1) It should aid in the determination of regional and ecologically meaningful management units rather than site-specific or purely political management units. Such ecological units provide an objective and logical basis to synthesize large amounts of data from ecologically similar stream ecosystems and to extrapolate about unstudied streams. Because it provides a means to determine typical and potential conditions of streams in similar watersheds, it should (2) improve the mechanism for classifying and evaluating the attainability of stream uses and (3) allow an ecological means to rank the priority of proposed stream improvements. (4) It should be useful for determining regional criteria and standards for naturally-occurring pollutants if water chemistry data are also used to determine watershed patterns. See Omernik (1977) for an example of stream nutrient patterns. And (5) it should help us select regional index streams, or least disturbed streams in large relatively homogeneous areas, against which environmental changes can be assessed. Potentials of streams with similar watershed areas, discharges, and watershed characteristics could be assessed by comparing fish guilds and dominant fish species in typical streams with the guilds and dominant species in least disturbed sites (Karr 1981, Hughes et al. in press). However, the better we can understand the relationships between aquatic communities and channel, water, and watershed characteristics, the better we can determine the most important watershed characteristics, the critical categories of those characteristics, and the typical and potential communities of large regions.

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AN INTEGRATED LAND-AQUATIC CLASSIFICATION[1]

Frederick B. Lotspeich & William S. Platts[2]

Abstract.--This paper develops a simple classification system based on causes of differences between classes of lands and integrates the riverine system into the land classification. The classification system integrates various resource components, with climate and geology as controlling, independent variables. Because of their homogeneity and simplicity, first order watersheds are used as the basic unit cell in the classification. Soils and vegetation are used to delineate individual classification units, which are then integrated into higher levels of classification.

IMPORTANCE

A resource inventory is a must for local, state and national planning. The past two decades many laws have been enacted such as the Resource Planning Act of 1975 and the National Forest Management Evaluation Program, and the Resources Planning Act of 1980 have made it clear that this inventory and assessment work will be done. To do this job requires a land (land includes water) classification system because an inventory without classification is just an unorganized list almost impossible to work with.

This paper develops a simple classification system based on causes of differences between classes of lands and integrates the riverine system into the land classification.

PAST PROBLEMS IN CLASSIFICATION

Classification schemes to date do not attain a truly integrative ecological land classification that includes aquatic systems. Those who did try to build the all-encompassing classification system had little success but they did develop ideas for future success. The most progressive land classification systems developed today are those of Bailey (1976 and 1978) and Wendt, Thompson and Larson (1975). They use many aspects of the physical environment to describe the various levels in a hierarchy of land classes. They fail, however, to stress the concept of watersheds as ecosystems and did not work the aquatics into their system.

Platts (1974 and 1979) demonstrated that the terrestrial and aquatic systems could be integrated into one system on selected lands. Platts (1980) further made a strong plea for classifiers to develop linkages between the terrestrial and aquatic habits. Failure to integrate these two seemingly different systems arises because all schemes proposed to date do not consider the watershed as the unit, with water as an essential ingredient dictating its function.

Lotspeich (1980) outlines a scheme for land classification based on ecosystems using watersheds as the basic units of identification. In this concept, stream order one, would be the basic ecosystem and would be the unit cell of a drainage system. Lotspeich stresses that geoclimatic factors develop landscapes to provide the physical basis for ecosystem development.

Our classification uses the best out of the past classifications referenced and bridges the gaps created in the past by considering water as the active ecosystem agent. Streams and lakes become an integral part of the system, thereby avoiding the artificial schism between terrestrial and aquatic phases of the land.

CLASSIFICATION PRINCIPLES

Any land classification should meet certain proven principles. Our land classification is based on the following principles:

1. Should result in integration of components.
2. Should be based on causes of differences.
3. Based on ecological systems, not uses.
4. The basic system is the first order watershed.
5. Lands should be arranged by classes according to their natural attributes.

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6. The system must be hierarchal and mappable.

7. The classification must use a common, easily understood vocabulary.

INTEGRATION

Integration is, or ought to be, the central theme when developing a land classification system and resource inventory. Why is this true and how do we achieve it? Integration is the noun form of integrate which is defined as "to bring together (parts) into a whole". In land classification the whole is the natural landscape-ecosystem- and the parts are the components (vegetation, soils, water, and wildlife). Climate and geology are also ecosystem components but their role is different from those listed earlier and will be discussed in a later section.

When a properly integrated land classification is finally accomplished all interacting components will fall into place in proportion to their relative importance to the functioning of the system. This can only occur where all elements are considered as interacting entities at each level during the classifying process. Intergration must permeate the entire effort of classifying and not be an afterthought to be undertaken after each component has been neatly pigeonholed by separate, independent classifying systems. By using a minimum of independent variables to relate other components of the ecosystem, the classification system is simplified and integration is one resultant of the completed effort.

THE CAUSAL APPROACH

A fundamental principle of any classifying effort is that it is better to set up classes of objects being classified according to causes of differences between classes than according to the effects that differences produce. This simply means that variables are selected that control all other variables which interact but do not control the functioning of the ecosystem. In land (ecosystem) classification climate and geology are the independent variables controlling evolution and functioning of the system. All other components are dependent variables that condition the system during their interactions but do not control it.

Geology and climate (geoclimatic) interactions give form to the land through erosional processes and provide energy and water that are essential for the existence of our biosphere. Since water is an intrinsic element to all ecosystems and which is provided by precipitation, it follows that climate is one of the independent variables governing ecosystems. Geology (in its broadest sense) provides the landform and inorganic nutrients to the biosphere hence rates as the other independent variable. Because water is vital to landform processing and ecosystem functioning, we must conclude the geoclimatic interactions control all other component evolution and functioning. Therefore, any land classification that considers water as an essential component of ecosystems integrates waters - streams and lakes - into the classification system.

Using two variables at all levels of classification results in a simplified system without resorting to specialized nomenclature for each component. This simplification also results in placing streams into the ecosystem as in integral unit without the need for individual treatment as a component needing separate classification. This leads to a brief discussion of watersheds and stream ordination.

ORDERED DRAINAGES

One of our basic principles of land classification is that the basic ecosystem is the first order watershed. Not only is it the basic system, it is also considered as the unit cell of landscape by hydrologists and physical geographers. A common problem when studying ecosystems is that of defining their boundaries. By using watersheds as the physical constraints of ecosystems, the watershed boundary naturally forms the ecosystem boundary because there is limited interaction between watersheds. Using this principle also leads to simplification because first order drainages are more homogeneous than higher order watersheds; complexity increases as stream order increases and watersheds become larger.

Another advantage of using first order watersheds as the basic ecosystem is that the aquatic subsystem is in its simplest form as are other systems within the watershed. In a given watershed, the stream reflects all other subsystems - components - that condition how the ecosystem functions within its geoclimatic constraints, i.e. it is the integrated resultant of the system. Progressing downstream, aquatic ecosystems become more complex as stream order increases with heterogeniety of the geoclimatic controls. The continuum concept was developed in recognition of how aquatic systems respond to changing environmental controls as stream order increases. We perceive stream ordination as a valuable tool in showing how the physical environmental controls are integrated into the aquatic system. Stream order is not a control in land classification but rather is the resultant of the geoclimatic independent variables. Aquatic systems are conditioned by other systems within a watershed; these are the subject of the following section.

VEGETATION AND SOIL

Other land classification systems look at soil and vegetation as separate entities to be classified individually. We view these two important components of ecosystems as one unit because they respond, during their evolution and function, to the same mutually shared environmental controls, climate, geology, time, and topography (landform). This unit of vegetation and soil we refer to as a tessera, defined as an individual unit of a mosaic. By this usage, a first order watershed, as the unit cell of drainage systems, may have several tesserae in response to the geoclimatic conditions. One of these might be the stream (aquatic phase).

Under similar geoclimatic conditions tesserae tend to repeat themselves as the unit cells are then closely similar as units of the landscape. As a corollary, streams draining these repeating cells will be closely similar because they reflect the geoclimatic variables of the watershed. When the unit cell-the first order drainage-is perceived to be the basic ecosystem, it delineates the boundary of the system and becomes the simplest system in a hierarchy of systems. This gives us a starting point from which to integrate and classify lands according to the causes of their evolution and function. By recognizing that geoclimatic interaction is the controlling force over all other components of the ecosystem, we avoid unnecessary nomenclature, often specialized, while at the same time achieving simplicity.

CLASSIFICATION FORMAT

Domain

The highest level is the Domain, as proposed by Bailey and is based on a broad climatic separation of arid and humid regions and described using a map scale of 1:7,500,000. This division cuts across geologic elements and should be thought of as a broad band of transition (ecotone) between deserts and grassland on the arid to semi-arid lands to humid forest lands. Soil patterns also reflect this transition zone. Those soils in the humid system have rainfall sufficient for percolation to groundwater and are considered open systems because energy and matter are transported through the system. Those soils in the drier zone operate as closed systems because rainfall does not reach the water table but cycles within the system. Both types of soils are independent of geologic origin (Hunt 1972). Figure 1.

Province

Our Province level delineates large landforms of the order of $10^5 km^2$ and refers to physiographic units as shown by Hunt (1974). At this level drainage patterns can be identified but lack detail. Bailey uses the term, but he delineates its boundaries using vegetation as

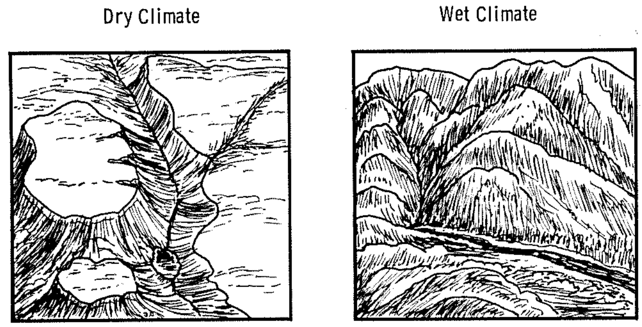

Figure 1. The domain separates the country into arid and humid regions independent of geology.

the criterion; this violates our principle of classifying by causes because vegetation is the resultant of geoclimatic interaction. Landforms at this level have taken millions of years to form and are relatively hemogeneous as to geologic structure and general lithology. A diversity of macroclimatic patterns, with resultant large vegetation patterns that may appear uniform but are really quite complex, may cut across many of these extensive physiographic units at this level of differentiation. Figure 2.

Section

The Section is the first level that is affected by a single, macroclimatic type that starts to influence a landform in its entirety. Here, close correspondence between macroclimate and landform patterns begin to emerge. Land areas are large, $10^4 km^2$, with map scales of 1:500,000. Vegetation and drainage patterns are now visible but still too small to show watersheds or drainage patterns in detail. At this level climatic

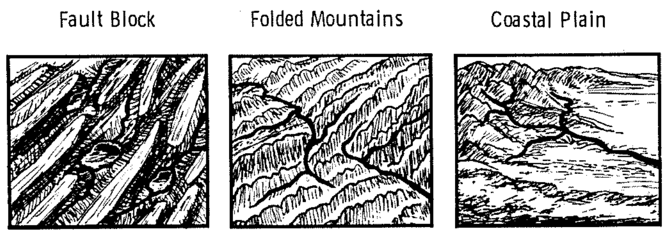

Figure 2. The province level separates lands by physiography independent of climates and is a reflection of geologic structure and geomorphic process.

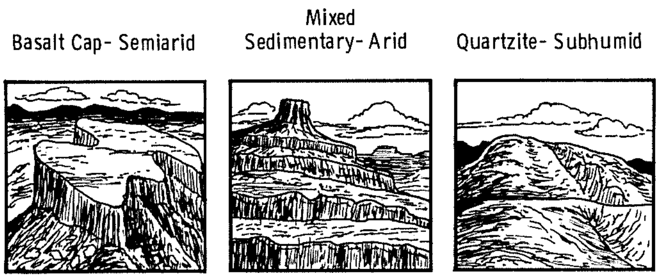

Figure 3. The section separates land according to present and immediate past climates and transcends geology.

patterns, reflected in changes in vegetation patterns, show an orderly succession as elevation changes. However, because of the large size of the area covered at this scale, vegetation details are not clearly discernible. No usable climatic classification has yet been devised to fit the zonation reflected by vegetation at this scale. Figures 3 and 4.

Region

Regions are on the order of $10^3 km^2$. Areas of this level would be mapped at 1:250,000, a medium scale. This particular scale is important because complete topographic coverage of the entire nation has been attained, whereas many blank areas still remain at scales of 1:62,500 and 1:24,000. Details of vegetation patterns

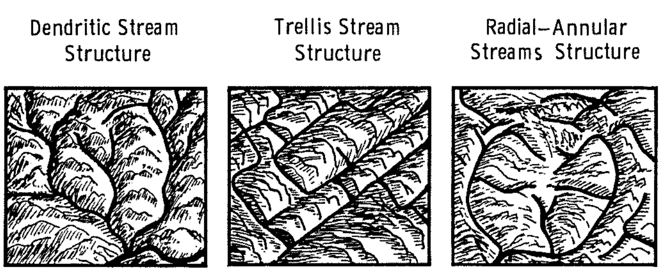

Figure 4. This is a composite of figures 1-3 and illustrates how a combination of geo-climatic factors separates lands into relative uniform types.

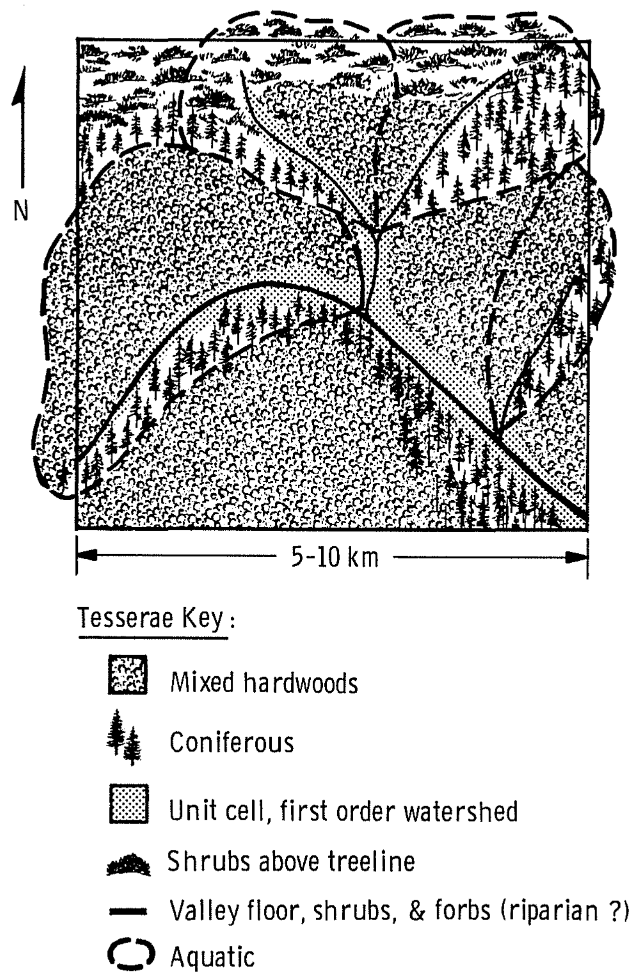

Figure 5. The region is the level at which meso-climate becomes dominant over macro-climate and local geologic influences.

relating to topography and elevation are becoming visible, and details of drainage patterns as they relate to lithology and structure are becoming evident. Many finer details of local topography applying to stream order and small watershed are not visible. At this level landform interpretation first becomes important as a reconnaissance tool for evaluating the suitability of various land uses. Because of local landform at this level, under a relatively homogeneous climatic type, mesoclimatic diversity becomes evident. Climatologists do not carry their classifications down to this level and much work needs to be done here because this forms a gap between the lowest level of climatic types and the next level at which we suggest a solution when the landscape becomes less complex. Figure 5.

Land Type Association

The word "association" implies interaction of various elements of the landscape. At this level (1:60,000 to 1:20,000) the interpretation of the geology makes its most valuable contribution to land classification. Individual lithologics become important because they influence landforms under an identical macroclimate. This is the highest level that details of stream habitats, and mosaics of vegetation are becoming evident as influenced by mesoclimate and local units of the landscape. Units are still large enough to view the landscape in generalities but contain enough detail that an individual tessera can be identified as it reflects local irregularities. Local rainfall may be uniform as measured within a watershed, but precipitation effectiveness (precipitation minus evapotranspiration) is strongly influenced by whether we measure effectiveness near the ridgetops or at the concavity at the toe of slopes.

Overall, geology is more homogeneous at this level and we can see how lithology influences and controls the drainage pattern and stream habitat (Figure 5). The basic ecosystem, outlined in first order watersheds, can now be identified. Geomorphic processes dominated by climate, and lithology causing landscape evolution, can be determined at this level. To simplify problems in classification, balance must be retained between the role of geoclimate and soils-vegetation interaction because we are now dealing with fewer environmental variables of ecosystem development.

A dilemma exists at this level in equating local climates (i.e., opposing north-south slopes) within landscape units. The solution lies in mesoclimate classification of the tesserae composing the mosaic of the landscape. Employment of the equivalent latitude concept, which equates potential incoming radiation to degree and orientation of slope of land units, may be a solution to this problem at 1:60,000 and below and is especially applicable to land units where rainfall occurs uniformly over a given area.

Another technique for interpretive geology that could possibly be developed into a routine tool in land classification, was used by the military Intelligence Division, Corps of Engineers, during World War II. Using topographic and geologic maps, terrain intelligence folios were prepared by teams of experts that included foresters, soil scientists, geologists, engineers, and hydrologists (Hunt 1950). These teams successfully assembled reliable data for terrain evaluation for army field operations including water supply, trafficability, airport siting, and cover for troops during combat in a timely and effectual method of land planning, without technical "jargon." Similar procedures would aid materially in inventorying and classifying land, using existing topographic and geologic information with minimum field checking for validation. The success of this procedure is a compelling reason for genetic geomorphic evaluation of landscapes.

We have devoted a lengthy discussion to Land Type Association because this level identifies the first order ecosystem as the unit cell of the drainage pattern. At this level we can separate various subsystems, such as tessarae and aquatic communities. Moreover, this is the level most useful to planners because there is sufficient detail to separate ecosystems that require more intensive study. At lower levels of classification more detail is added as individual tesserae and streams are treated as ecosystems within the first order watersheds.

Land Type

This level of the order of 10 km^2 is the building block for land use evaluations and the more detailed planning efforts. Interrelationships of rock type and the land surface environment dominates over other geologic forces. Stream habitats can be identified and integrated as aquatic types within the terrestrial type and compared with similar land types over large geographic areas (Platts 1974 and 1979).

DISCUSSION

Integration is one essential goal of a land classification system if it is to be of maximum use to resource managers. This goal then permits the manager to see the interrelationship of the whole to its various components throughout the heirarchy of classes composing the system. We achieve this by using geoclimatic factors as independent variables that control evolution and function of watersheds as ecosystems. Waters, streams and lakes, are essential ingredients of these systems and reflect - integrate - all the interacting components of the basins they drain and through which they flow. This approach permits managers to exercise knowledgeable judgements when making decisions regarding land units as producing entities for Man's benefit.

We strongly recommend that our hypothesis for classifying land environments be based on geoclimatic causes that result in differences under natural conditions. This hypothesis can be tested in the field. Several sites need to be studied to obtain a broad spectrum of geomorphic, climatic, and riverine features.

The fishery does not act in isolation, and much of its success or failure is determined by the adjoining areas from which it receives its energy and habitat quality. The fisheries are controlled by the lands around them and by the hydrology of their drainage basin. Because similar fisheries can be expected to respond in a like manner to a similar land management practice that stresses or benefits the fishery, our classification would increase our capability of predicting the benefits and eliminating the stresses. Our classification allows the extrapolation of research results and, most important, the transfer from area to area of fishery management experience. The impact from the land uses which have placed our fisheries in their present position can be reduced and integrated with the resources of the surrounding land.

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SESSION 3A

Moderator: Allan Thomas
Bureau of Land Management
Boise, Idaho

A METHOD FOR PREDICTING RIPARIAN VEGETATION POTENTIAL[1] OF SEMIARID RANGELANDS

Michael R. Crouse and Robert. R. Kindschy[2]

Abstract.--Predicting the potential of riparian areas to recover after protection from livestock is difficult because examples of pristine riparian communities have generally been destroyed by excessive grazing. This paper describes a method for predicting riparian site potential of streams and reservoirs in semiarid climates such as southeastern Oregon. The method is based on physical characteristics of stream and reservoir riparian zones, such as extent of water level fluctuation, persistence of flow, scouring, and soil type. These factors have been organized into keys for field use. Predicting the potential of riparian sites is essential to set priorities for the expenditure of funds to enhance and monitor those sites.

INTRODUCTION

In recent years, most rangeland managers have come to recognize the importance of riparian vegetation associated with streams, reservoirs, and springs. In semiarid rangelands, riparian areas are distinct from the drier upland vegetation. Consisting of grasses, forbs, sedges, woody shrubs and trees, riparian vegetation is often the only green succulent vegetation available during the summer. These areas are an oasis for wildlife; 280 of 360 terrestrial wildlife species in southeastern Oregon use riparian zones more than any other habitat (Thomas et al. 1979). Riparian vegetation is of critical importance to trout and species in desert streams because the vegetation provides escape cover, helps lower summer water temperatures through shading the stream, and retards streambank erosion that can result in siltation of spawning gravels and rearing areas (Phillips 1971). Riparian areas are also focal points for human recreational activities. Excessive grazing in riparian areas conflicts with these other uses, degrading fish and wildlife habitat and lowering water quality and aesthetic appeal.

Detrimental effects of grazing on fish and wildlife habitat provided by riparian vegetation have been well documented (Platts 1981), and rangeland managers are now attempting to come to grips with this problem. As a result, many biologists have been involved in inventories to determine the present habitat condition of riparian areas. Most soon realize, however, that the present habitat condition cannot be meaningfully assessed without first knowing the ecological potential of the various sites, that is, what would be the climax plant community under pristine conditions? Answering this question is generally not possible because a long history of grazing and other disturbances have eliminated most examples of the pristine community. Yet, knowing the pristine community is essential, not only to assess the present habitat condition, but to select riparian areas that have the greatest potential to respond to protection from livestock grazing.

The purpose of this paper is to share a system we have developed for predicting the ecological potential of riparian areas associated with streams and reservoirs in semiarid rangelands. Our system is based on observations of riparian areas that have been protected from livestock grazing for many years by fencing or by natural barriers such as rough terrain and slope. For example, many riparian areas were fenced in the 1960's during the Vale project, a multimillion dollar range improvement program. We observed that some protected areas responded almost immediately while others did not, even after many years of protection. Based on such observations we identified the important physical characterisitics that determine the potential of streams and reservoirs to support riparian vegetation. The pristine and recovered riparian communities we studied to identify these characteristics were located in southeastern Oregon, but the principles may be applicable to similar semiarid rangelands elsewhere.

STREAMS

Bowers et al. (1979) have divided streams in southeastern Oregon into three distinctive zones; boulder, floodway, and pastoral (Fig. 1). The boulder zone is found in the headwaters of

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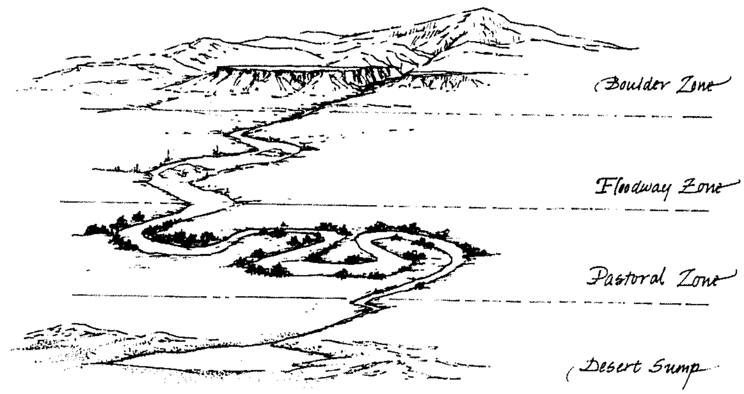

Figure 1.--Physiographic characteristics of southeastern Oregon streams (from Bowers et. al. 1979).

streams that typically originate in steep mountains. Water flowing at high velocity down gradients greater than 8% has carved narrow channels through V-shaped gorges. The stream channels and banks are composed almost entirely of coarse gravel, rubble and boulders. The floodway zone begins where the gradient and water velocities gradually decrease. Here, the streambanks are composed of much finer material and are more vulnerable to erosion than in the boulder zone. The streams flow through braided channels that often shift and form gravel bars. Beaver frequently dam streams in this zone causing further meandering and braiding that greatly expands the riparian zones. The best quality trout habitat is often found in this zone, but at the same time, these areas are the most severely impacted by livestock because of their accessibility. Occasionally, the floodway zone of a stream is confined by narrow vertical walled canyons. Such streams are severely scoured during spring freshets, when debris can be lodged six meters or more above the canyon floor.

The pastoral zone includes the lower reaches of the streams where water flow is sluggish and the streambed is composed primarily of silt and sand. Streambanks are composed of fine textured soils and are generally lined with trees. The upper reaches of the pastoral zone and the lower sections of the floodway zone are often flood irrigated for hay and crop production. The streams eventually flow into larger river systems or sometimes onto a desert playa where they disappear underground or evaporate.

Physical characteristics determines the capacity of each stream zone to develop a riparian vegetation community. The most important physical factors are the extent of water fluctuation and persistence. Soil type is another influencing factor but the stream gradient and flow regime generally dictate the soil composition. Many southeastern Oregon streams are intermittent, flowing only in the spring and early summer. The boulder and floodway zones of such streams retain water in the soil substratum only long enough to support a few plant species such as herbaceous sage (Artemisia ludoviciana), flannel mullein (Verbascum thapsus), various sedge or rush species; (Juncus, Scirpus, Carex) and limited shrub or coyote willow (Salix exigua). Low gradient, intermittent streams are dry by mid-summer except for isolated pools. These pools are surrounded by densely rooted sedges, grasses and forbs, but very few woody plants. Perennial streams in the boulder zones support a narrow band of willow, mockorange (Philadelphus lewisii), chokecherry (Prunus virginiana) and scant herbaceous vegetation that can take root in the rocky streambanks.

The most productive and diverse plant communities are found in the lower reaches of the floodway zone (Figs. 2 and 3) and in the pastoral zone. Decreased gradient and water velocity result in deposition of finer silt and gravel ideal for herbaceous plant growth and moderate annual stream flows disturbs areas that create seedbeds for woody plants. The riparian community might be composed of thinleaf alder (Alnus tenuifolia), Pacific willow (Salix lasiandra), coyote willow, black cottonwood (Populus trichocarpa), clematis or virginsbower (Clematis ligusticifolia), woods rose (Rosa woodsii), mockorange, and a dense stand of robust sedges and forbs. At elevations greater than 1500 meters, the dominant tree species is often quaking aspen (Populus tremuloides) rather than cottonwood, alder or tree willow.

An interesting phenomenon occurs in the floodway zones of streams that undergo opposite extremes in water level fluctuations. Streams confined by narrow, vertical walled canyons are often severely scoured by spring runoff which destroys rigid woody plants (Fig. 4). Pliable herbaceous plants survive on the canyon floor but trees and shrubs persist only at the fringes of the flood plain. Conversely, the same herbaceous plant community may dominate streams where almost no water fluctuation occurs. These streams are fed by voluminous springs and are often lined by densely rooted mats of grasses, forbs and sedges. One possible explanation for the lack of woody plants is that many species, such as willow, are ecological opportunists that rapidly invade disturbed areas. Without significant fluctuations in water level to produce minor scouring of streambanks, herbaceous plants thrive and preclude establishment by woody species.

Occasionally, desert stream drain through alkaline soils, resulting in riparian soil pH's that few tree and shrub species can tolerate. The riparian

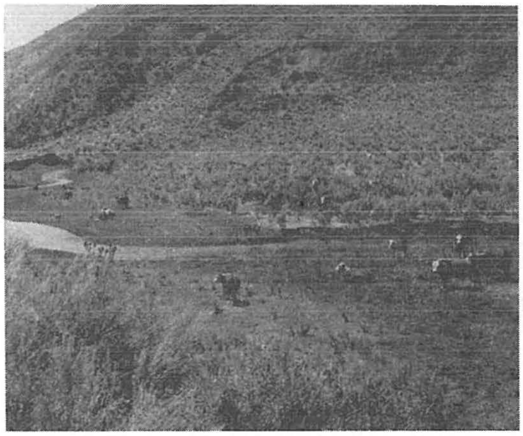

Figure 2.--Cattle concentrate all summer at high potential riparian sites on Willow Creek, a floodway zone stream near Vale, Oregon. In this pasture all woody vegetation is browsed to ground level.

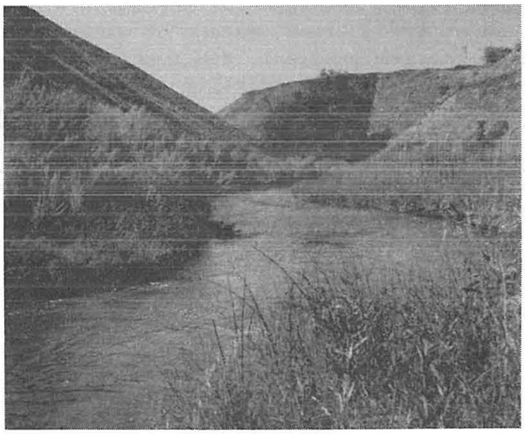

Figure 3.--An adjacent pasture on Willow Creek achieved rapid succession of riparian vegetation after only one year of protection from cattle use. Many young willows are present in the lush herbaceous growth along the stream.

community is restricted to alkali bullrushes (Scirpus sps.), black greasewood (Sarcobatus vermiculatus), silver buffaloberry (Shepherdia argentea), saltcedar (Tamarix gallica), and other salt tolerant species.

Figure 4.--Owyhee River Canyon normally is severly scoured by high volumns of water during the spring snow melt. Woody vegetation is uncommon.

RESERVOIRS

To achieve better livestock distribution on public grazing lands, thousands of stock ponds and reservoirs have been constructed in southeastern Oregon. The vast majority, however, go dry during the summer, leaving only a small number that have the potential to support riparian vegetation. The main factor influencing plant communities around reservoirs is water fluctuation. The evaporation rate in southeastern Oregon is greater than one meter a year, and when drawdown exceeds one meter vertically and six meters horizontally, most riparian species do not receive enough subsurface moisture to survive (Fig. 5). The most dense and diverse riparian zones are associated with reservoirs that have only minor fluctuations in water level and gently sloping shorelines (Figs. 6 and 7). The riparian community around such reservoirs might include tree and shrub willows, cottonwoods, meadow grasses, rushes, and sedges. These sites are ideal for planting exotic species including Chinese elm (Ulmus parvifolia), Russian olive (Elaeagnus angustifolia), and Siberian peashrub (Caragana arborescens), where such introductions do not threaten the native flora. Some springfed reservoirs that undergo almost no water level fluctuations support few woody plants. Competition from densely rooted herbaceous species, which pioneered site succession, may prevent invasion by shrubs and trees. Padgett (1982), however, attributed the dominance of herbaceous plant communities in marshy riparian zones to insufficient soil aeration for growth of woody plants.

Soil type is another factor that influences riparian communities around reservoirs. Extremely rocky shorelines limit the riparian zone to a narrow band of willow, cattails, bullrushes and herbaceous species. Riparian zones with highly alkaline soil support only salt tolerant species.

Figure 5.--Twin Springs Reservoir has been fenced since 1966. A general lack of soil, and extreme fluctuation in water level because of evaporation loss precluded extablishment of riparian vegetation.

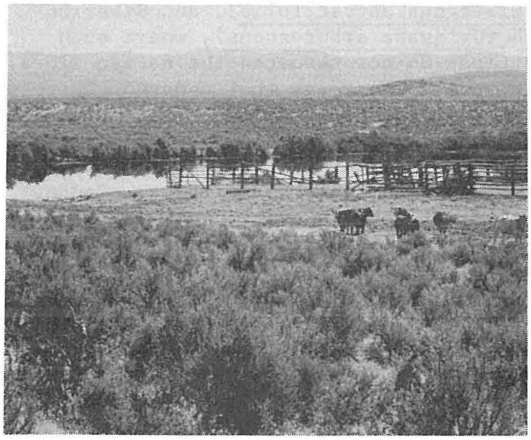

Figure 6.--Kane Springs Reservoir before exclusion of cattle, September, 1964.

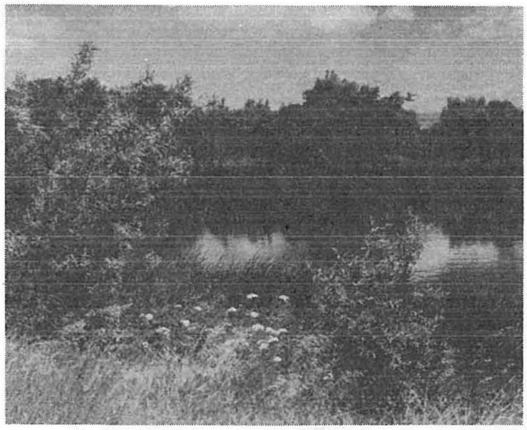

Figure 7.--Dense riparian vegetation at Kane Springs after six years of protection from grazing by cattle. Russian olive in foreground were planted in 1965. Background shrubs are predominately wild rose.

APPLICATION

Physical factors influencing riparian potential have been organized into keys for field use (Tables 1 and 2). These keys identify the plant species most commonly associated with stream and reservoirs of certain physical characteristics. The characteristics assessed for streams are persistence of stream flow, extent of water level fluctuation, stream gradient, and type of soil. For example, Willow Creek (Figs. 2 and 3), a perennial floodway zone stream with fine textured soils undergoes minor fluctuations in water level and has the potential to support a dense and diverse riparian community of trees, shrubs, and herbaceous species (see Table 1; 7b). The reservoir shown in Figure 5 has almost no potential for a riparian zone because of extreme fluctuations in water level and a rocky shoreline (see Table 2; 3a).

After using the keys to predict the potential riparian community of a stream or reservoir, an investigator can then more accurately classify the present condition of the riparian habitat. For example, Willow Creek (Fig. 2) can support dense and diverse riparian vegetation, but the present community has been reduced by grazing to closely cropped herbaceous species and is classified in poor condition. The wide gap between the potential and present riparian community along Willow Creek indicates the high potential of this stream for recovery if protected from grazing (Fig. 3). In contrast, a severely scoured stream like the Owyhee River (Fig. 4) has only a limited capacity to respond if protected from grazing. These keys enable an individual with limited botanical knowledge and experience to predict the potential plant community, classify the present community condition, and make intelligent management decisions.

TABLE 1

Key for Assessing Riparian Vegetation Potential of Streams

1a. Stream flow intermittent

- 2a. Water not in soil all year...Mullein, low sagebrush, biscuit root.
- 2b. Water in soil all year.
  - 3a. Stream gradient less than 1%; dry in mid-summer except for isolated pools...Dense mats of sedges, grasses, and forbs around pools; few or no woody species.
  - 3b. Stream gradient greater than 1%...Herbaceous sage, mullein, sparse willow and other shrubs.

1b. Stream flow perennial

- 4a. Stream flow does not vary seasonally (springfed)
  - 5a. Soil highly alkaline...Alkali bullrush, greasewood, buffaloberry, salt cedar.
  - 5b. Soil not highly alkaline...Densely matted sedges, forbs, grasses, cattails; few or no woody species.
- 4b. Stream flow varies seasonally
  - 6a. Water level fluctuations extreme; severe scouring common...Vegetation limited to sparse stands of grasses, forbs and sedges; woody plants found only in areas protected from scouring.
  - 6b. Water level fluctuations moderate
    - 7a. Soil extremely rocky; gradient generally greater than 5%...Narrow band of willow, mock oragne, chokecherry, sparse stands of grasses and forbs.
    - 7b. Soil fine in texture; gradient generally less than 5%...Tree willow, cottonwood, alder, aspen (above 1500 m), dogwood, mock orange and other shrubs, dense stands of grasses, sedges and forbs.

TABLE 2

Key for Assessing Riparian Vegetation Potential of Reservoirs

1a. Water level of reservoir unstable

2a. Water level fluctuates more than one meter vertically and six meters horizontally so that majority of basin is dry by mid summer.

3a. Shoreline soil extremely rocky...No vegetaion.

3b. Shoreline soil fine in texture; bottom gradient less than 5%...Sparse sedges and watergrasses.

2b. Water level fluctuates less than one meter vertically and six meters horizontally so that majority of basin is moist all year.

4a. Shoreline gradient exceeds 20%.

5a. Shoreline extremely rocky...No vegetation.

5b. Shoreline soil fine in texture...Narrow band of shrub willow, cattail, bullrush, grasses and forbs.

4b. Shoreline gradient less than 20%.

6a. Shoeline extremely rocky...Narrow bank of cattails, bullrushes, grasses, sedges and forbs; a few shrub species possible.

6b. Shoreline soil fine in texture...Tree and shrub willow, cottonwood, alder, rose, and other shrubs, diverse and densely rooted grasses, sedges and forbs. Suitable for planting exoitic species such as Chinese elm and Russian olive.

1b. Water level of reservoir constant (springfed)

7a. Soil highly alkaline...Alkali bullrush, salt grasses and other salt tolerant species.

7b. Soil not high alkaline...Densely rooted sedges, forbs and grasses, few or no shrubs or trees.

MANAGEMENT IMPLICATIONS

Today, land managers are much more aware of the critical importance of riparian habitats to fish and wildlife. However, it is our responsibility as biologists to identify for them the riparian areas that have the greatest potential to recover if protected. We are applying the principles outlined above to advise our range managers on riparian management decisions. For example, we recently determined that several reservoirs scheduled for fencing had little potential to support riparian vegetation because of water level fluctuations, so we recommended reservoirs with higher potentials. Based on our riparian inventories we selected critical stream habitats from which livestock should be excluded and recommended no changes in grazing systems for streams with low potentials. We were also asked by our range managers to predict the response of riparian communities to grazing systems that reduces or eliminates grazing during the hot summer months when most of the damage occurs (Fig. 8). We set specific goals for riparian community response under these grazing system and designed a monitoring system to determine if the riparian goals were being met. Identification of riparian potential is the foundation of our riparian monitoring procedure and is essential for making all riparian management recommendations and decisions.

Figure 8.--Excellent reestablishment of willows has occured along Pole Creek near Juntura, Oregon, where yearling cattle have been grazed from mid March through May for the past five years.

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MISSOURI'S METHOD OF EVALUATING STREAM HABITAT[1]

Otto F. Fajen[2] and Richard E. Wehnes[3]

Abstract.--The purpose of this methodology is to determine the degree to which the present status of a stream differs from our best estimate of its pristine condition. The ranking of 10 components constitutes the basis of the methodology. Habitat quality parameters include barriers to fish movement, urbanization, condition of riparian vegetation, condition of flood plain, land use and flow regime. These elements are each rated on a scale of 0 to 10. Habitat alteration functions include impoundment, channelization, water quality, and streambed condition. These elements are each rated on a scale of 0 to 1. The ten components can be combined to calculate a habitat quality index (HI):

$$HI = \frac{\Sigma P_i}{N_p} \times f_1 \times f_2 \times f_3 \times f_4$$

which can serve as a guide in environmental assessment, land acquisition and basin planning.

INTRODUCTION

Missouri is blessed with an aquatic diversity that is unequaled, from Ozark streams in the south to prairie streams in the north. In a pristine state, these streams provided a wide variety of habitats for fishes, invertebrates, and associated terrestrial communities. But man's activities have altered the natural state of many of these streams in varying degrees, sometimes beneficially but, more often than not, deleteriously. Changes in surface area, channel length, depth, productivity, flow, permanence, terrestrial vegetation and economic values have redirected the natural evolution of our stream systems towards reduced aquatic and riparian habitat diversity. Variance from the pristine state reduces a stream's ability to maintain a diverse aquatic life for present and future values. It is our view that maintaining entire fish communities and their associated species supercedes values relating to a single species.

Pressures to use Missouri streams for various purposes are great, and are increasing every year. As resource managers, it is important for us to evaluate intended use so that water use and associated alterations are balanced with habitat quality. Stream classification and establishing the relative scarcity of the various types of streams is a first step. But within each type, streams must be evaluated, so that the natural values within each stream can be protected, or damage mitigated if they are altered. Our objective is to propose a methodology that will evaluate the habitat quality of Missouri streams.

In order to be effective and have wide applicability to the many types of streams found in Missouri, an aquatic habitat evaluation system must do several things. It must 1)measure the problems affecting stream ecosystems, not the symptoms, 2) be unbiased in its approach so that one type of stream (e.g., a high quality prairie catfish stream) is not arbitrarily judged lower than another (e.g., a clear, Ozark smallmouth bass stream), 3)be capable of being duplicated by trained personnel, 4)be easy to use and quick to complete, and 5) be separate from, but complementary to, stream classification systems.

The proposed stream habitat evaluation methodology assumes that pristine conditions are optimal and that the degree of variance from this state can be measured. The methodology is intended to be a relatively unbiased approach to determine

[1]Paper present at the Symposium on Aquisition and Utilization of Aquatic Habitat Inventory Information (Portland, Ore. Cctober 28-30, 1981)

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the extent to which changes in streams have altered their ability to maintain naturally diverse aquatic communities.

Is another stream habitat evaluation procedure really necessary? Federal agencies such as the U.S. Fish and Wildlife Service and the U.S. Army Corps of Engineers as well as several state conservation agencies have a variety of evaluation procedures for stream habitat. We find these systems contain elements more properly applicable to stream classification than stream habitat evaluation. Our method will evaluate stream habitat condition in a diagnostic sense with absolutely no reference to class or type. In this procedure a stream with a bullhead population may rate as high or higher than a stream with a trout population. The purpose is to identify the parameters that may limit habitat quality and indicate those that must be altered to restore an approximation of pristine conditions.

PROCEDURE

The Missouri Stream Habitat Evaluation Procedure (SHEP) is comprised of 10 components, which form the basis of the evaluation methodology. Components are divided into two major groups: habitat quality parameters and habitat alteration functions. Habitat quality parameters are used collectively to measure the variation from the pristine state. Manmade barriers to fish movement, watershed urbanization, condition of the riparian vegetation, floodplain erosion, watershed land use and flow alterations all define the extent to which a stream has been modified. Habitat alteration functions are intrinsic factors which directly and proportionately affect habitat quality, and often are limiting to the continued existence of all or part of a fish community. Poor water quality, channelization, impoundment or streambed condition will all determine the extent of change in the fish community regardless of parameter values.

The assignment of values to the various rating categories is based on our experience with Missouri streams. These values may be debatable and some flexibility may be required if SHEP is used elsewhere. We feel, however, that consistency in their use will outweigh any precision that may be lacking.

Habitat Quality Parameters

Each of the following parameters is relatively distinct (although there may be some interrelationships), and can be rated on a scale of 0 to 10:

P_1 - Barriers to Natural Fish Movement

The response of fish to barriers is varied and in some cases passage around a barrier is possible by culverts, fishways, etc. (Nelson, et al., 1978). However, species such as darters, suckers, drum and others have seasonal movement patterns (Pflieger, 1975; Funk, 1955) and, to some extent, can be prevented from reaching upstream areas (spawning, etc.) by instream structures. Structures may or may not be circumvented during flooding depending on their height and the velocity and volume of flow. To rate this parameter, determine the location of all dams, weirs and other structures that may restrict fish movement into the area to be rated (Table 1).

Table 1. Rating values for parameter P_1, barriers to fish movement.

Rating	Qualification
10	No manmade obstructions to free passage of fish upstream
8	No dams or other structures causing a vertical drop of more than 1 foot during low flow
5	No dams or other structures causing a vertical drop of more than 3 feet during low flow
3	No dams or other structures causing a vertical drop of more than 10 feet during low flow
0	One to several dams or other structures each causing a drop of more than 10 feet during low flow

P_2 - Urbanization

The development of cities, towns, subdivisions, etc., all historically have had a negative impact on receiving streams. Impacts can range from water quality problems and sedimentation from riparian abuse to altered flow regimes and habitat destruction. To rate this parameter, determine the location and extent of urban areas from current city maps, topographic maps and aerial photographs (Table 2).

Table 2. Rating values for parameter P_2, urbanization.

Rating	Qualification
10	Less than 5 percent of watershed in urban development
8	Five to 10 percent of watershed in urban development
5	Ten to 40 percent of watershed in urban development
3	Forty to 70 percent of watershed in urban development
0	Seventy to 100 percent of watershed in urban development.

P_3 - Condition of Riparian Vegetation

Riparian vegetation serves a variety of functions, ranging from temperature amelioration in summer months and a filter protecting the stream from adjacent incompatible land uses (Gregory & Stokoe, 1981; Erman, et al., 1977) to a source of instream cover and food. To rate this parameter, determine from aerial photographs or an on-the-ground inspection the condition of the perennial vegetation in a 50 to 100 ft. (15 to 30 m) wide band on each stream bank (Table 3).

Table 3. Rating values for parameter P_3, condition of riparian vegetation.

Rating	Qualification[1]
10	Ninety to 100 percent of banks protected by perennial vegetation
8	Sixty to 90 percent of banks protected by perennial vegetation
5	Forty to 60 percent of banks protected by perennial vegetation
3	Ten to 40 percent of banks protected by perennial vegetation
0	Zero to 10 percent of banks protected by perennial vegetation

[1]If vegetation is totally comprised of perennial grasses (fescue, etc.), deduct two points.

P_4 - Condition of the Floodplain

Erosion and sedimentation are important determinants of habitat quality that can affect water quality, substrate and instream habitat as well as fish diversity and biomass (Darnell, et al., 1976; Cordone & Kelley, 1961). Symptoms of floodplain damage include eroding flood channels, eroded fields and overbank deposition of sand or gravel. To rate this parameter, aerial photographs, onsite inspection of the floodplain and interviews with agencies responsible for such data (e.g., Soil Conservation Service) will be necessary. This parameter is necessarily flexible to take into account gradations between the qualifications (Table 4).

P_5 - Land Use of Watershed

The extent to which the watershed is protected by vegetation or appropriate soil conservation practices will affect water quality and substrate as well as flow alterations and erosion potential. To rate this parameter, aerial photographs and interviews with agencies responsible for such data (e.g., Agricultural Stabilization and Conservation Service) will be necessary (Table 5).

Table 4. Rating values for parameter P_4, condition of the floodplain.

Rating	Qualification
10	Little or no evidence of active or recent erosion of the floodplain during floods
5	All segments show evidence of occasional erosion of the floodplain. Stream channel essentially intact
0	Floodplain severely eroded and degraded, stream channel poorly defined with much lateral erosion and much reduced flow capacity

Table 5. Rating values for parameter P_5, land use of watershed.

Rating	Qualification
10	More than 80 percent of watershed protected by timber, improved pasture, terraces, or other conservation practices
8	Sixty to 80 percent of watershed protected by timber, improved pasture, terraces, or other practices
5	Forty to 60 percent of watershed protected by timber, improved pasture, terraces, or other practices
3	Twenty to 40 percent of watershed protected by timber, improved pasture, terraces, or other practices
1	Zero to 20 percent of watershed protected by timber, improved pasture, or other practices

P_6 - Flow Alteration

Natural flow regimes including periodic floods, are important factors in forming and maintaining stream channels and habitats (Fraser, 1972). Structural measures in the watershed can modify flooding and flow patterns and thus alter stream habitat. To rate this parameter, determine the location of all impoundments and farm ponds in the watershed and determine the degree of flow control (Table 6). For the purposes of this parameter, a farm pond is defined as a man-made pond or lake less than 2 hectares in size. This includes those built for livestock watering, fishing, etc. An impoundment is defined as a man-made pond or lake greater than 2 hectares in size. These are typically flood control, irrigation, recreation or water supply reservoirs.

Table 6. Rating values for parameter P_6, flow alteration.

Rating	Qualification[1, 2]
10	Less than 1 percent of watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds
8	One to 30 percent of watershed controlled by impoundments and/or 50-60 percent of the watershed controlled by farm ponds
5	Thirty to 60 percent of watershed controlled by impoundments and/or 60-75 percent of the watershed controlled by farm ponds
3	Sixty to 95 percent of watershed controlled by impoundments and/or 75-85 percent of the watershed controlled by farm ponds
0	Ninety-five to 100 percent of watershed controlled by impoundments and/or greater than 85 percent of watershed controlled by farm ponds

[1]If levees occupy more than 50 percent of the banks, deduct two points.

[2]Add two points for simulation of preimpoundment flow regime.

Habitat Alteration Functions

Each function has the power to reduce the habitat quality rating, depending on the type and extent of habitat alteration. Functions are expressed on a scale of 0 to 1.0:

f_1 - Channel Modification

The adverse impacts of channel modification on aquatic communities are well documented (Congdon, 1971; Tarplee, et al., 1971; Funk & Ruhr, 1971), although some of the effects can be mitigated (Griswold, et al., 1978). We identify three types of modifications: clearing and snagging which leaves the channel intact but removes instream and riparian vegetation (Hickman, 1975); channel realignment, which cuts a new, straighter channel and eliminates the old meandering channel (Congdon, 1971); and channel paving, where the channel is lined with concrete, asphalt, corrugated metal or some other material. This alteration function is calculated by:

> Channel Modification Rate = 1.0 - (percent stream reach modified, expressed as a decimal, X percent fish reduction, expressed as a decimal).

Table 7 lists the appropriate fish reduction values. The best sources of information are ASCS and USGS aerial photographs, topographic maps and USGS orthophotoquad maps. Some government agencies (e.g., Soil Conservation Service) may maintain up-to-date information on the extent of channelization.

Table 7. Percent fish reduction used in calculating function f_1, channelization.

Channel Modification	% Fish Reduction
Clearing, Snagging	25
Channel Realignment	80
Channel Paving	95

f_2 - Impoundment

An impoundment irreversibly alters the impounded stream reach, both physically and biologically. The historic fish community is changed in part because reproduction and survival of typical lotic fish species are decreased by habitat losses, whereas the reproduction and survival of typical lentic fish species are enhanced by gains in favorable habitat. Once impounded, a stream's ability to function as a stream is altered, as impacts extend upstream and downstream from the lake (Fraser, 1972). This alteration function is calculated by:

> Impoundment Rate = 1.0 - (percent of reach affected by each type of degradation, expressed as a decimal, X type of degradation, expressed as a decimal).

Table 8 lists the appropriate degradation values. The best sources of information are aerial photographs and information from governmental agencies (e.g., Corps of Engineers, Soil Conservation Service, etc.).

Table 8. Percent degradation used in calculating function f_2, impoundment

% Degradation	Qualification
0	Stream not impounded
30	Stream reach impounded during a 1 in 75 year flood event
50	Stream reach impounded during a 1 in 50 year flood event
80	Stream reach impounded during a 1 in 25 year flood event
100	Stream reach impounded at normal or conservation elevation of impoundment

f_3 - Water Quality

Changes in water quality can produce a variety of effects, some even beneficial. For this reason, information for determining this rating should be provided by those persons trained in water quality methods (Table 9).

Table 9. Rating values for function f_3, water quality.

Rating	Qualification
1.0	Stream water unpolluted. No pollutants detected by standard methods
0.8	Occasional above normal levels of one or more water quality constituents usually present, but detectable only by analysis
0.5	Occasional visible signs of over-supply of nutrients
0.4	Occasional local fish kills averaging once in 4 years or less frequently
0.2	Occasional local fish kills occurring more frequently than once in 4 years
0.0	Grossly polluted waters with fish kills occurring annually or more frequently

f_4 - Streambed Condition

Fishes have a variety of substrate preferences; a local community is determined by those substrates made available by local geological features. Under pristine conditions, the transport of particulate material along a streambed would occur at a rate consistent with the geologic rate of decomposition of consolidated substrates. Under disturbed conditions, transport and redeposition of local deposits of silt, sand, gravel and rubble is accelerated. To calculate this function, compare present conditions with those assumed to be pristine (Table 10). The precise definition of pristine conditions is difficult and in some circumstances, a watershed hydrologist can assist in determining this function.

Habitat Index Calculation

An overall aquatic habitat index (HI) can be calculated using the above values. An HI is found by averaging the parameters and reducing this mean by the appropriate alteration functions, or:

$$HI = \frac{\Sigma P_i}{N_p} \times f_1 \times f_2 \times f_3 \times f_4$$

where P_i is the individual parameter values, N_p is the number of parameters used, and f is each alteration function. HI will vary from 0 to 10, and is used as an indicator of habitat quality. Values less than three indicate very poor, degraded habitat; values eight and above indicate near-pristine conditions; and values in between indicate varying degrees of degradation.

Table 10. Rating values for function f_4, streambed condition.

Rating	Qualification
1.0	No apparent unstabilized material in channel with substrate of bedrock, boulders, rubble, gravel or firm alluvium
0.9	Traces of unstabilized silt, sand, or gravel in quiet areas, pools large with firm substrate
0.8	Quiet areas covered by unstable materials, deep pools restricted to areas with greatest scour
0.7	Pools shallow, filled with silt, sand or gravel, riffles contain noticeable silt deposits
0.5	Streambed completely covered by varying thicknesses of transported material such as silt, sand, and gravel
0.0	Stream channel nearly or completely filled with unconsolidated, transported material; no surface flow except during floods

Field Application

Two streams were used as examples for the SHEP methodology -- West Fork of Big Creek in Harrison and Daviess counties in northwest Missouri, and Big River in St. Francois and Washington counties in east central Missouri. West Fork of Big Creek is a typical modified prairie stream. The area is agrarian with 50 percent row crops, 30 percent grass and pasture and 15 percent timber. Parts of the stream have been channelized (approximately 20 percent of the stream length). Substrates are variable, but sand and silt dominate. Erosion and sedimentation are chronic problems that adversely affect soil productivity, and stream habitat quality. The Soil Conservation Service proposed a project to reduce sediment delivery to the stream by 50 percent, and SHEP was used to document existing conditions. Observations at 11 sites along with aerial photos, topographic maps and interviews with SCS engineers, hydrologists and biologists, to calculate an HI. Individual parameter and function values (Table 11) indicate that the stream suffers from an erosion and sedimentation problem due to poor farming practices that has manifested itself in an unstable substrate. The overall stream quality is fair (4.82). Potential remedial measures could include soil conservation practices to reduce sediment delivery to the stream and habitat improvement measures in channelized reaches.

Table 11: Calculation of a SHEP Habitat Index for West Fork Big Creek, Missouri.

Parameter/ Function	Description	Rating
P_1	No barriers to fish movement	10
P_2	< 5% urbanization	10
P_3	75% of banks protected	8
P_4	Erosion present but localized	7
P_5	45% timber and pasture; few conservation practices	4
P_6	No impoundments; < 50% farm ponds	10
f_1	20% of length channelized	0.82
f_2	No impoundments	1.00
f_3	One localized water quality problem	0.90
f_4	Silt and sand covering quiet areas	0.80

$$HI = \frac{\Sigma P_i}{N_p} \times f_1 \times f_2 \times f_3 \times f_4 \qquad HI = 4.82$$

Table 12: Calculation of a SHEP Habitat Index for Big River, Missouri.

Parameter/ Function	Description	Rating
P_1	Three mill dams	3
P_2	< 5% urbanization	10
P_3	90% of banks protected	10
P_4	Little active erosion; highly localized	9
P_5	> 80% timbered or in conservation practices	10
P_6	No impoundments; < 50% farm ponds	10
f_1	No channelization	1.00
f_2	No impoundments	1.00
f_3	Heavy metals problem in upper reaches	0.80
f_4	Traces of fine material in upper reaches	0.90

$$HI = \frac{\Sigma P_i}{N_p} \times f_1 \times f_2 \times f_3 \times f_4 \qquad HI = 6.24$$

Big River is an Ozark stream. Land use is variable, but the floodplain and watershed are in timber or pasture. Three small mill dams are present on lower Big River. Stream substrates are mostly gravel, cobble and boulder, except in some of the upper reaches where erosion off of barite and lead tailings piles adds fine particles to the river. Water quality, while generally good, is compromised by the lead tailings contributing to a heavy metals problem in some of the fishes. The U.S. Army Corps of Engineers proposed a multipurpose reservoir project and SHEP was used to document existing conditions. Observations at 11 sites along 30 miles of Big River, along with aerial photos, topographic maps and interviews with the Corps of Engineers personnel, allowed the calculation of an HI. Individual parameter and function values (Table 12) indicate that, with the exception of three mill dams, only a heavy metals problem due to erosion of a lead tailings pile in the watershed keeps the stream from a near-pristine condition. Overall stream quality is good (6.24). Potential remedial measures could include stabilizing the tailings pile to reduce erosion of fine particles and the source of heavy metals (Dr. James R. Whitley, personal communication).

DISCUSSION

Most habitat evaluation methods were conceived to assist in project impact analyses. Existing conditions can be rated and future impacts can be predicted with the Missouri SHEP. When coupled with the stream classification and index of scarcity outlined by Fry and Pflieger (1977), impact analysis and tradeoff negotiations can be conducted with full realization of how much habitat is involved, its relative scarcity and the ability of a mitigation proposal to offset those losses.

The simplicity of the Missouri SHEP allows other uses that may or may not be possible with other systems. SHEP is not labor-intensive, utilizes available information from governmental agencies, aerial photos, topographic maps, a minimum of field time and is cost effective. A field check to insure the accuracy of the aerial photos plus some documentation of substrate condition and any special or localized problem is all that is required. This methodology can be used in a wide variety of circumstances:

1) Impact analysis in reviewing Section 404 permit applications, PL-566 projects, etc. The methodology can, for example, be used to measure the quality of a stream to be channelized and predict the ultimate habitat quality if the project is permitted.
2) Decision-making in land acquisition programs. The methodology would identify and document the existing habitat quality of tracts of land under consideration for purchase and can assist in choosing the best quality streams for the acquisition dollar. In addition, SHEP will document problems in the stream reach under consideration, so that an estimate of whether the problems can

be corrected can be made before the tract is bought.

3) As a measuring tool in assessing the long term habitat effects of basin-wide land treatment projects, such as a non-structural approach to flood control and soil conservation proposed by agencies such as the Soil Conservation Service.

4) Monitoring of aquatic habitat as part of river basin planning, a continuing effort by a state fish and wildlife agency to keep up with statewide stream habitat quality, or other short or long term study that could be used as a planning tool.

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CONSIDERATIONS IN THE DEVELOPMENT OF CURVES FOR HABITAT SUITABILITY CRITERIA

Donald J. Orth[1], Ray N. Jones[2], and O. Eugene Maughan[2]

Abstract.--Data on preferred depth, velocity, and substrate were collected for adult and juvenile smallmouth bass (Micropterus dolomieui), adult green sunfish (Lepomis cyanellus), and adult and juvenile orangebelly darters (Etheostoma radiosum) and used to develop suitability curves. Depth and velocity suitability curves for adult smallmouth bass based on data obtained by angling were significantly different than those based on data obtained by electroshocking. Habitat availability had an important effect on the curves derived for juvenile smallmouth bass and orangebelly darters, but in most cases this could be overcome by sampling a wide range of habitat types and measuring the amounts of each type of habitat sampled. Habitat use varied among size groups of smallmouth bass, green sunfish, and orangebelly darters. There were also seasonal differences in the habitat used by orangebelly darters but the effect of season was masked by differences in habitat availability.

INTRODUCTION

Habitat suitability criteria, a component of many aquatic habitat evaluation systems, are expressed in the form of suitability curves for use in Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980, 1981) and the Instream Flow Incremental Method (Stalnaker 1979). To develop these curves, optimum ranges of habitat variables are assigned weighting factors of one and the least suitable ranges are assigned values near zero. Since these approaches have only recently been developed existing data from the literature have often been used to derive the suitability curves. Often this information is fragmentary and more information is needed on the habitat required by each life stage; therefore, it is appropriate that methods for developing these curves be evaluated and guidelines established.

Bovee and Cochnauer (1977) described methods for developing habitat suitability curves. These included subjective concepts, such as range and optimum, and parameter overlap, as well as objective concepts, such as frequency analysis. Although the subjective methods are difficult to defend, even frequency analysis has limitations. The data for frequency analysis are relatively easy to obtain, but to be unbiased, the method requires equal sampling effort in all habitat types. It is our experience that habitat suitability criteria based on relative density estimates may be more accurate than those based on frequency analysis (Orth and Maughan 1982). Another major problem in developing habitat suitability curves is the differential sampling efficiencies among habitat types. Most biologists agree that catchability differs in different habitats, but except for the preliminary work by Whaley and Maughan (1978), we know of no other attempts to quantify these differences.

In this paper, we describe the development of habitat suitability curves for smallmouth bass (Micropterus dolomieui), and green sunfish (Lepomis cyanellus) and investigate the importance of sampling technique, habitat availability, and intraspecific size differences on the habitat suitability curves. Although habitat suitability curves have been developed for the orangebelly darter (Etheostoma radiosum) by Orth and Maughan

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(1982), we have collected additional data to determine the significance of intraspecific size differences and seasonal differences in habitat selection. Glover Creek, a warmwater stream in southeast Oklahoma, was the study area. The average gradient is 2.3 m/km (range:1-19 m/km) and the predominant substrate types are rubble, boulder, and bedrock. Water quality is very good and turbidity and suspended solids are generally low (Orth and Maughan 1982).

METHODS AND MATERIALS

Smallmouth bass were sampled quarterly at 16 sites from January 1978 through September 1979 using a boat-mounted, pulsed DC, electrofishing unit equipped with two hand-held anodes or a pulsed DC backpack electrofisher (Smith-Root Type VII). Depth, velocity and substrate types were determined at each capture location. Depth (cm) was measured with a metric wading rod, mean water velocity (cm/s) was measured with a pygmy current meter, and substrates were classified according to a modified Wentworth particle size scale. Substrate types were categorized and each category given a numerical value from 1 to 8, corresponding to detritus, mud, silt, sand, gravel, rubble, boulder, and bedrock. Mixtures of adjacent categories were given intermediate values.

In addition to electroshocking samples, adult smallmouth bass and green sunfish were also collected by angling. A total of about 27 stream kilometers were sampled by biologists fishing with artificial lures in May and August 1979. At each location where fish were collected, the following information was taken: depth, surface velocity, substrate type, and total length (mm) of fish. Surface velocity (V_s in cm/s), measured by timing a float, was converted to velocity at 0.6 depth ($V_{.6}$) by the equation:

$$V_{.6} = 1.119\ V_s^{\ .8842}\ (r = 0.943;\ P < 0.0001).$$

This equation was derived from field data on Glover Creek.

Orangebelly darters were collected quarterly with pulsed DC electroshockers from 2 sites from October 1979 to July 1980. Population estimates, densities, and quantitative estimates of habitat availability were made at each site (Jones 1981). Habitat utilization was determined by placing a numbered marker buoy at each capture location. The captured darters were then placed in a small, plastic jar, numbered to correspond with numbered marker buoys. After sampling, fish were measured for total length (nearest mm) in order to evaluate differential habitat utilization between size groups. Water depth, water velocity at .6 depth, and substrate type were measured at each capture location.

Depth, velocity, and substrate frequency distributions were tabulated for adult smallmouth bass and green sunfish, and chi-square goodness-of-fit tests (Conover 1971:185-187) were used to determine if the distributions were significantly different from a uniform distribution over the sampled range of the habitat variables. If this test indicated significant deviation from uniformity, the optimum range was assigned a weighting factor of one, and weighting factors for other intervals were obtained by dividing the frequencies in other intervals by the average frequency in the optimum range (Bovee and Cochnauer 1977). Suitability curves were then drawn to fit the weighting factor data. The independence of fish length and depth, velocity, and substrate frequency distributions was tested with chi-square tests for independence (Conover 1971:154-156).

An effort was made to account for the bias due to the habitat available at the time of sampling for only the orangebelly darter and juvenile smallmouth bass. This was done by measuring habitat availability each season. Water depth, current velocity, and substrate type were measured at 1-m intervals along permanent transects. These transects ran perpendicular to the direction of flow and were located at approximately 15-m intervals along the length of each sampling site. These point measurements represented average values of water depth, water velocity, and substrate type for a segment 1-m wide, and extending halfway to the nearest upstream and downstream transects. Surface area of each segment was then equal to length times width. The amount of surface area at each site for each interval of depth, velocity, and substrate type was calculated by summing the areas of those segments for each respective interval of depth, velocity, and substrate type.

Frequencies of occurrence of juvenile smallmouth bass in one-way depth, velocity, and substrate tables were divided by the amount of area sampled in the respective interval to obtain estimates of relative density. For orangebelly darters frequencies of occurrence were multiplied by the ratio of estimated population size to the number captured. The adjusted frequencies were then divided by the areas sampled to obtain estimates of actual density (number/m^2).

A chi-square goodness-of-fit test (Conover 1971:185-187) was used to test the null hypothesis that the frequency distributions have the same distributions as the amount of habitat sampled, that is, densities do not vary over the sampled range of the habitat variable. This procedure was then repeated separately for juveniles and adult orangebelly darters. Intervals for which observed values were greater than expected values indicated preferences and the highest density, within that range, identified the most preferred interval. A chi-square test of independence (Conover 1971:154-156) was then used to test the null hypothesis of independence of size (juvenile and adult) and habitat parameters.

RESULTS

Smallmouth Bass - Adult

Adult smallmouth bass were most frequently captured at depths of 40 to 100 cm in slow to moderate current velocities (0-19 cm/s), near boulder substrates (Figure 1). Data based on

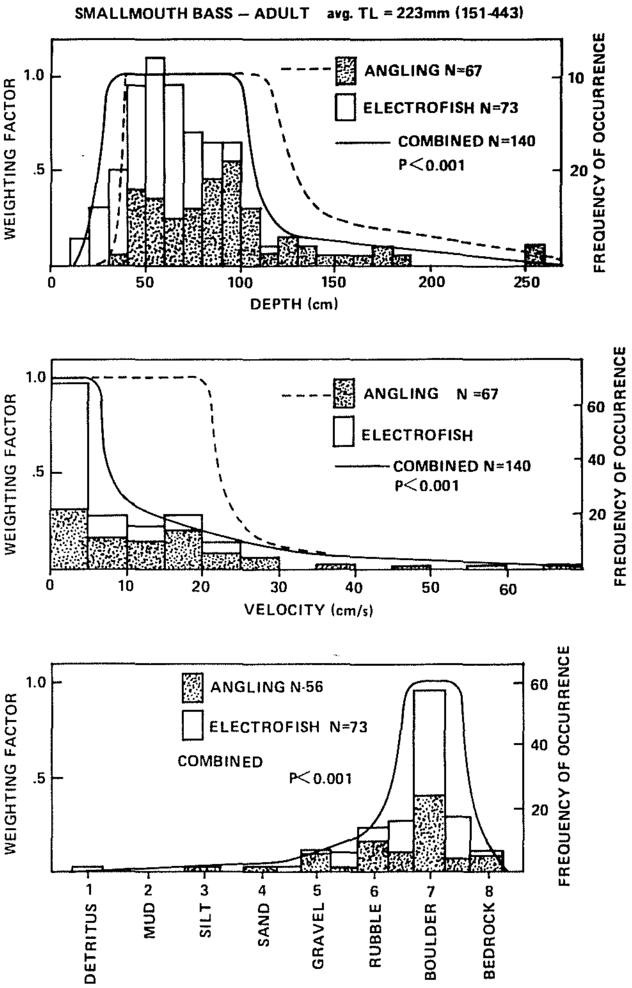

Figure 1.--Depth, velocity, and substrate frequency distributions and suitability curves for adult smallmouth bass in Glover Creek.

electrofishing were biased toward the shallower depths, since habitat deeper than 120 cm could not be sampled with the gear used. The depth frequency distribution based on electrofishing data was significantly different from that based on angling data according to the chi-square test for independence (P <0.001). Although the angling data may be biased, the depth suitability curve based only on angling data (Figure 1) probably more closely represents the preferred habitat of adult smallmouth bass in Glover Creek.

Smallmouth Bass - Juvenile

Juvenile smallmouth bass were most abundant in relatively shallow areas, usually in or near riffles, where velocities were 10-20 cm/s, over substrates ranging from gravel to boulders. Densities varied significantly over the range of depths (P <0.001) and velocities (P <0.0005) sampled, but did not vary significantly (P <0.10) over the substrate range (Table 1). Habitat

Table 1.--Total area sampled, frequency of capture, and relative density of juvenile smallmouth bass in relation to depth, velocity, and substrate type in Glover Creek, January 1978 to September 1979.

Variable and interval	Area sampled (m^2)	Frequency	Relative density (Frequency/ Area)
Depth (cm)			
0- 9	2,253	8	.004
10-19	2,466	40	.016
20-29	2,688	25	.009
30-39	2,220	13	.006
40-49	1,425	12	.008
50-59	1,340	11	.008
60-69	956	8	.008
70-79	849	2	.002
80-89	847	0	.000
>90	1,400	5	.004
	16,444	124	
	T = 43.9 (9 df) P <0.001		
Velocity (cm/s)			
0- 9	10,336	86	.008
10- 19	2,168	23	.011
20- 29	1,368	10	.007
30- 39	792	5	.006
40- 49	474	0	.000
50- 59	517	0	.000
60- 69	332	0	.000
70- 79	190	0	.000
80- 89	178	0	.000
90-119	90	0	.000
	16,445	124	
	T = 17.3 (5 df) P <0.005		
Substrate			
Detritus	20	0	.000
Sand	188	0	.000
Sand-Gravel	34	0	.000
Gravel	319	4	.012
Gravel-Rubble	2,059	20	.010
Rubble	3,177	22	.007
Rubble-Boulder	6,412	42	.007
Boulder	2,989	31	.010
Boulder-Bedrock	209	1	.005
Bedrock	1,038	4	.004
	16,445	124	
	T = 7.5 (5 df) P >0.10		

suitability curves were fitted to the relative density data (Figure 2), thereby eliminating

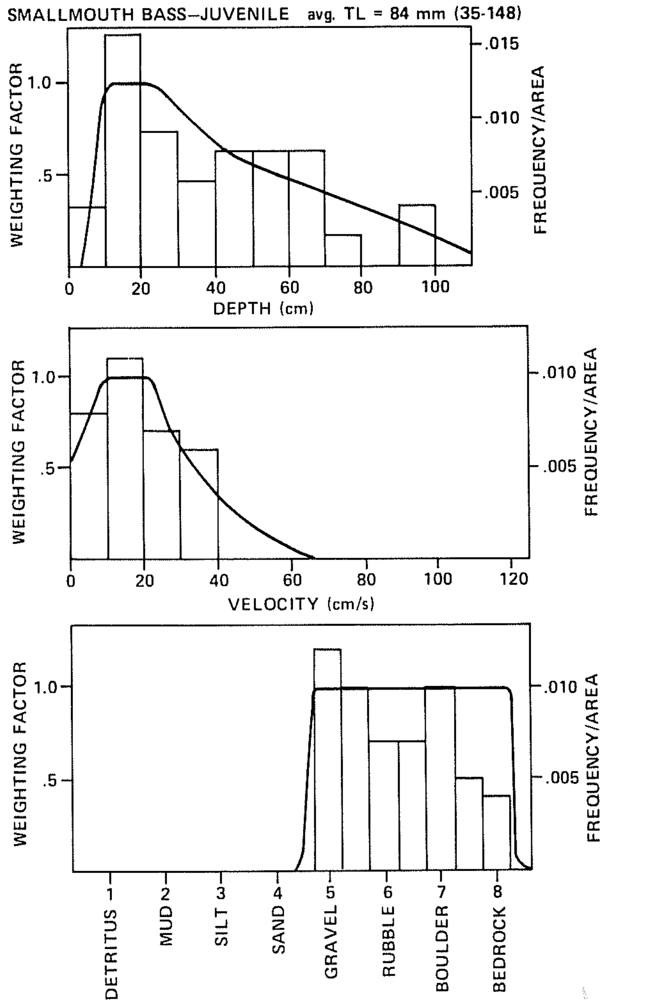

Figure 2.--Relative density estimates and suitability weighting factors in relation to depth, velocity, and substrate, for juvenile smallmouth bass in Glover Creek.

bias that would have been depicted by the curves if the raw frequency data had been used. This bias would have been greatest in the velocity and substrate curves because the distributions of the amount of area sampled over the range of velocities and substrates were non-uniform (Table 1). An example of this bias is represented by the velocity data. Although relative densities were not highest at velocities of 0-9 cm/s and over rubble-boulder substrate, habitat suitability would have been projected to be highest in these ranges if the raw frequency data were the basis for defining the suitability curves (Table 1).

There was a definite trend (P <0.001) for the smallmouth bass to inhabit microhabitats of greater depths as they grew (Table 2). The greatest change in the preferred depth range occurred between smallmouth bass less than 100 mm long and those 100 mm long or longer. Conversely, no significant differences were found between observed and expected frequencies in the test for independence of fish length and velocity (P >0.10). In the test for independence of fish length and substrate type, there were significant differences between observed and expected frequencies (P <0.001; Table 3). Smallmouth bass less than 100 mm long inhabited substrates of gravel-rubble, and rubble-boulder (5.5, 6.0, and 6.5) more frequently than expected and those 100 mm long or longer used substrates of boulder, boulder-bedrock, and bedrock (7.0, 7.5, and 8.0) more frequently than expected.

Green Sunfish - Adult

A total of 254 adult green sunfish were captured by angling in Glover Creek, usually in areas 40 to 120 cm deep, with little or no current (0-4 cm/s), and boulder substrate (Figure 3). Within the optimum depth range there were no significant differences (P >0.25) between observed frequencies and expected frequencies obtained by assuming a uniform distribution (Figure 3).

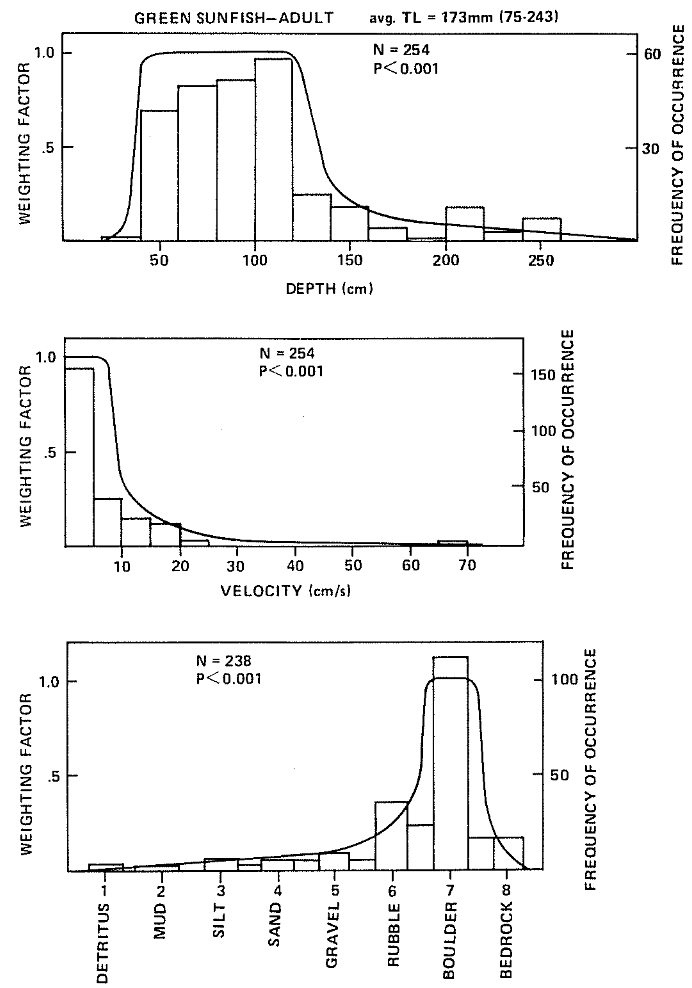

Figure 3.--Depth, velocity, and substrate frequency distributions and suitability curves for adult green sunfish in Glover Creek.

Table 2.--Observed frequencies of smallmouth bass and expected frequencies (in parentheses) assuming independence of fish length and the water depth at capture locations.

Total length (mm)	Depth (cm) 5-19	20-34	35-49	50-64	65-84	85-260	Totals
35-99	23 (7.87)	21 (10.40)	10 (10.40)	2 (10.68)	3 (9.28)	2 (12.37)	61
100-149	3 (4.00)	6 (5.29)	4 (5.29)	11 (5.43)	4 (4.71)	3 (6.29)	31
150-199	1 (6.71)	5 (8.87)	13 (8.87)	11 (9.11)	14 (7.91)	8 (10.54)	52
200-249	1 (5.81	4 (7.67)	6 (7.67)	10 (7.88)	8 (6.84)	16 (9.12)	45
250-450	0 (3.61)	1 (4.77)	4 (4.77)	4 (4.90)	4 (4.26)	15 (5.68)	28
Totals	28	37	37	38	33	44	217
T = 116.30 (20 df) P <0.001							

Table 3.--Observed frequencies of smallmouth bass and expected frequencies (in parentheses) assuming independence of fish length and substrate type at capture locations.

Total length (mm)	Substrate 1.0-5.0	5.5	6.0	6.5	7.0	7.5 & 8.0	Totals
35-99	1 (4.15)	15 (5.92)	16 (9.48)	22 (13.03)	6 (21.91)	1 (6.52)	61
100-149	1 (2.11)	0 (3.01)	3 (4.82)	7 (6.62)	16 (11.14)	4 (3.31)	31
150-199	7 (3.19)	0 (4.56)	7 (7.30)	5 (10.04)	22 (16.88)	6 (5.02)	47
200-249	4 (2.85)	4 (4.08)	4 (6.52)	5 (8.97)	16 (15.09)	9 (4.48)	42
250-450	1 (1.70)	1 (2.43)	2 (3.88)	5 (5.34)	14 (8.98)	2 (2.67)	25
Totals	14	20	32	44	74	22	206
T = 75.98 (20 df) P <0.001							

Table 4.--Observed frequencies of green sunfish and expected frequencies (in parentheses) assuming independence of fish length and depth at capture locations.

Total length (mm)	Depth (cm) < 80	80-119	≥ 120	Totals
< 140	22 (15.81)	14 (18.70)	7 (8.50)	43
140-159	16 (12.50)	13 (14.78)	5 (6.72)	34
160-179	29 (23.53)	22 (27.83)	13 (12.65)	64
180-199	14 (16.54)	21 (19.56)	10 (8.89)	45
≥ 200	12 (24.63)	40 (29.13)	15 (13.24)	67
Totals	93	110	50	253
T = 19.41 (8 df) P <0.025				

The null hypothesis that depth at capture locations was independent of fish length was rejected (P <0.025; Table 4). Green sunfish longer than 200 mm were captured at depths of 80-119 cm more frequently, and green sunfish shorter than 140 mm were captured at depths less than 80 cm more frequently than would be expected if depth of capture was independent of fish length. Velocity at capture locations was independent of fish length (P >0.25), but substrate and fish length were not (P <0.025; Table 5). Green sunfish shorter than 140 mm used rubble (6.0) more frequently and boulder-bedrock and bedrock (7.5 and 8.0) less frequently than would be expected.

Orangebelly Darter

Orangebelly darters inhabited riffle areas almost exclusively every season. Smaller individuals were occasionally collected along the shorelines and shallow area of pools but adults showed no tendency to move out of riffles into deeper water except during periods of extremely low flow.

Typically, the entire range of available depths, velocities, and substrates were utilized by orangebelly darters but preferences were exhibited for particular intervals every season. In addition, preferences appeared to shift seasonally with changes in the availability of depths, velocities, and substrates. Although data were collected every season, only that from two seasons are presented here. During October 1979, water levels were low, surface flow was reduced, and the larger boulder substrates were partially exposed in the riffles. Under these conditions, orangebelly darters preferred depths greater than 10 cm (P <.001), water velocities less than 9 cm/s (P <.05), and rubble and rubble-boulder substrates (P <.001) (Figure 4A, B, C, respectively). In contrast, water levels increased during January 1980 with considerable flow over riffle areas. Under these conditions, orangebelly darters preferred depths greater than 20 cm (P <.001), water velocities from 10 to 30 cm/s and greater than 50 cm/s (P <.001), and gravel-rubble substrates (P <.001) (Figure 4D, E, F).

Juveniles exhibited preferences significantly different from those of adults for at least one habitat parameter every season. For example, in October 1979, juveniles and adults differed in utilization of depth (P <.001) (Figure 5A and B) but not during January 1980 (P <.25) (Figure 5C and D). However, significant differences were observed in relation to water velocity during both seasons (P <.001) (Figure 6), and no significant differences were observed in relation to substrate type for either season (Figure 7).

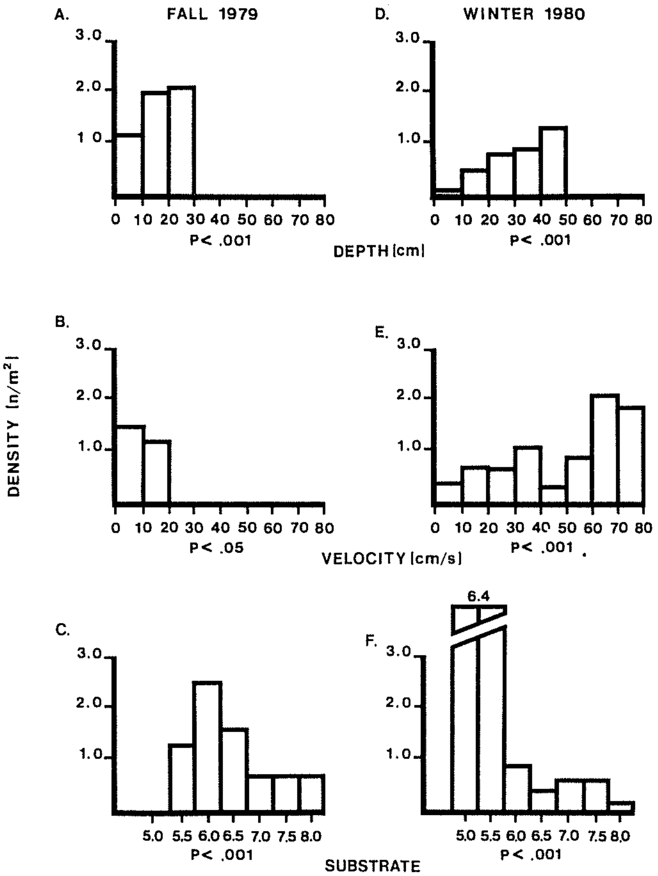

Figure 4.--Density estimates in relation to depth, velocity, and substrate for orangebelly darters in fall 1979 (A,B,C) and winter 1980 (D,E,F).

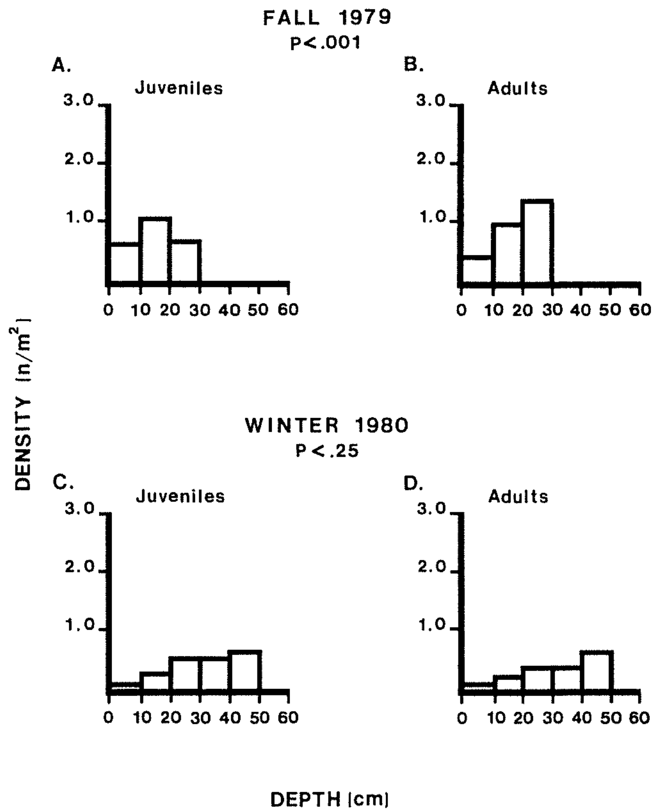

Figure 5.--Comparison of density estimates in relation to depth for juvenile and adult orangebelly darters in fall 1979 (A,B) and winter 1980 (C,D).

Table 5.--Observed frequencies of green sunfish and expected frequencies (in parentheses) assuming independence of fish length and substrate at capture locations.

Total length (mm)	Substrate 1.0-5.5	6.0	6.5	7.0	7.5 & 8.0	Totals
< 140	3 (6.08)	15 (5.91)	2 (3.88)	18 (18.90)	2 (5.23)	40
140-159	7 (4.86)	3 (4.73)	2 (3.10)	16 (15.12)	4 (4.19)	32
160-179	7 (9.57)	9 (9.30)	8 (6.11)	32 (29.77)	7 (8.24)	63
180-199	10 (6.23)	4 (6.06)	4 (3.98)	16 (19.38)	7 (7.98)	41
≥ 200	9 (9.27)	4 (9.01)	7 (5.92)	30 (28.83)	11 (7.98)	61
Totals	36	35	23	112	31	237
T = 30.03 (16 df) P <0.025						

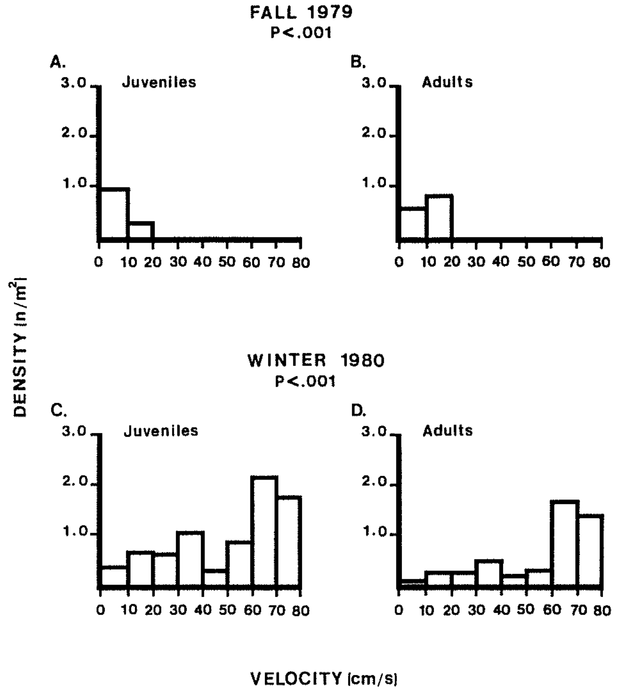

Figure 6.--Comparison of density estimates in relation to velocity for juvenile and adult orangebelly darters in fall 1979 (A,B) and winter 1980 (C,D).

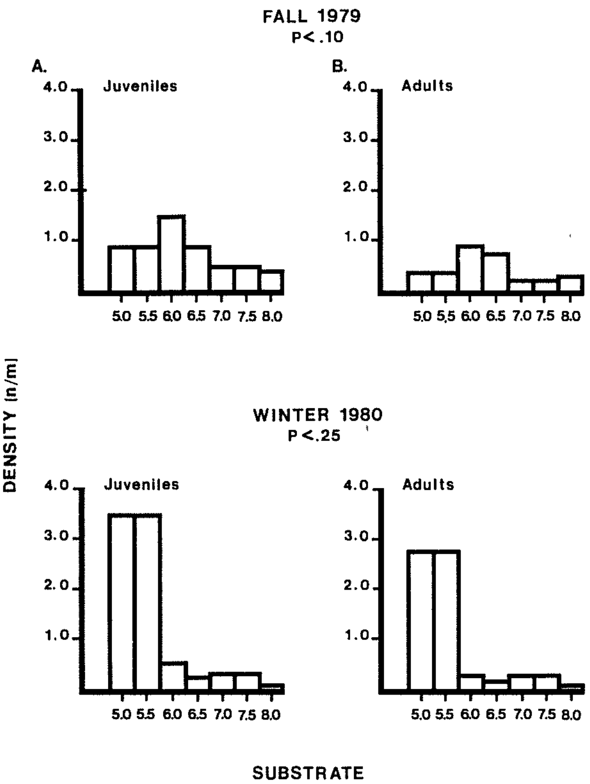

Figure 7.--Comparison of density estimates in relation to substrate for juvenile and adult orangebelly darters in fall 1979 (A,B) and winter 1980 (C,D).

DISCUSSION

Three principal types of potential biases are associated with the development of habitat suitability curves. The first type arises when the distributions of the depth, velocity, and the substrate types sampled are not uniform, the second when sampling efficiencies vary over the range of each habitat variable, and the third when habitat use varies among size groups or seasons (Orth and Maughan 1981). One way to deal with the first bias is to sample relatively equal amounts of area in each depth, velocity, and substrate interval, and then apply a frequency analysis technique (Bovee and Cochnauer 1977). In streams, however, depth, velocity, and substrate are not uniformly distributed and, therefore, data on habitat availability must be collected to determine the amounts of area sampled over each habitat variable. Relative density estimates can then be calculated and the habitat suitability curves developed. The potential biases due to differential sampling efficiencies, seasonal changes, and changes in habitat preferences among size groups are discussed under species headings.

Smallmouth Bass - Adult

There were differences in the depth and velocity suitability curves determined from angling and electrofishing, although both curves showed the same general trends. Depth suitability curves declined markedly at depths greater than 120 cm based on both types of data. The velocity suitability curve based on angling data showed selection of higher velocities than data collected by electrofishing. The curve based on angling is probably the more reliable of the two velocity curves (Figure 1), since the optimum velocity range determined for adult smallmouth bass in streams (Munther 1970; Klauda 1975) is the same (0-20 cm/s) as that projected by this curve.

Both angling and electrofishing data showed selection for boulder substrate. This selection for boulder substrates may, in fact, be related to needs for cover. Adult smallmouth bass spend most of their time (79-91%) in position-holding and shelter-using behaviors in areas of low to moderate current velocities (Klauda 1975). One limitation of these data may be that the preponderance of boulder substrate in Glover Creek resulted in bias due to non-uniform sampling distributions. For example, other studies have indicated that smallmouth bass also prefer gravel and rubble substrates (Reynolds 1965; Paragamian 1981). The apparent selection for boulder substrate may in fact be an artifact of the method used (i.e., frequency analysis) to derive the curve.

Smallmouth Bass - Juvenile

Juvenile smallmouth bass selected shallower areas of the stream and utilized smaller substrate types (gravel and rubble) than did adults; the greatest shift in habitat use occurred where the fish were about 100 mm long. On other species, such as the bluegill (Lepomis macrochirus), similar differences in the habitat used by different length groups have been attributed to predation forcing smaller fish into cover (Werner et al. 1977). For smallmouth bass, however, these differences could also be related to the distribution of prey, such as aquatic insects (Surber 1941; Lachner 1950; Pflieger 1966; Paragamian 1973), which are more abundant in the riffle habitats of streams (Surber 1939; O'Connell and Campbell 1953).

Green Sunfish - Adult

Suitability curves for adult green sunfish were based entirely on angling data and because of absence of habitat availability data could not be adjusted for any bias due to non-uniform distributions. The depth and velocity suitability curves probably have no significant biases due to non-uniform distributions, since a variety of depths and velocities were sampled at flow levels that were exceeded 36-37% of the time during the period of record (1961-1974). In addition, preference for low velocity (0-5 cm/s) and moderate depths (40-120 cm) was also noted by Minckley (1963), Jones (1970), and Moyle and Nickols (1973).

In the present study, green sunfish were found most frequently near boulder substrate; however, other authors have found them over all substrates (Jenkins and Finnell 1957; Trautman 1957; Moyle and Nickols 1973). The preference for boulder substrate may indicate a cover-seeking response since Summerfelt (1967) noted that this species was invariably associated with cover and in Glover Creek potential cover was provided primarily by boulders. However, it may also represent the preponderance of boulder substrate in Glover Creek.

Different sized green sunfish occupied different depths and substrates, but similar current velocities. Larger green sunfish tended to select areas of greater depth and larger substrate types. In their social hierarchies, larger green sunfish dominate smaller ones (Greenberg 1947). In laboratory studies on bluegills, subordinate individuals were excluded from preferred temperature areas at low densities (Medvick et al. 1981). Therefore, rank in the dominance hierarchies may affect habitat use as it does in two species of trout, Salmo (Jenkins 1969). If dominant individuals inhabit the preferred areas and other individuals occupy less suitable habitat, the preferred habitat of the dominant individuals may in fact be the most preferred habitat of that species. Future attempts to refine habitat suitability criteria should, therefore, consider the influence of social structure on habitat selection.

Orangebelly Darter

Adult and juvenile orangebelly darters preferred riffle microhabitats throughout the year as was found in previous studies (Scalet 1973; Orth and Maughan 1982). These studies did not, however, investigate seasonal variation in habitat utilization. As the availability of a wider range of depths and velocities increased between seasons, orangebelly darters tended to prefer the deeper, faster areas in riffles. However, substrate preferences did not appear to vary much between seasons. The effect of season on habitat selection is masked by the differences in habitat availability among seasons. In an unregulated stream, it is impossible to hold habitat availability constant while evaluating the effect of season on habitat selection.

Our data on habitat utilization by the orangebelly darter show that seasonal shifts in habitat preferences should be anticipated when habitat suitability curves are being developed for management purposes. Data collected during only one season may not accurately reflect the habitat requirements for a given species. Special attention should also be focused on habitat utilization during the spawning season, as many species have specific requirements. This rationale is particularly applicable to streams that are subject to wide seasonal variation in flow. Stream fishes have become adapted to their particular environment and its changes over a long period of time. If only one particular set of habitat conditions is sampled, the resultant curves will be biased.

At the same time, serious consideration should be given to possible intraspecific differences in habitat requirements. Our data on the differences between juvenile and adult orangebelly darters provides adequate evidence that such differences do indeed exist. Adults tended to use deeper portions of the riffle having faster current, while juveniles inhabited the shallower areas with slower current. If population success is to be expected, assurances must be made for the success of the species at each stage of growth and maturity. The decision whether separate suitability curves need to be developed for different size groups of a species will depend on the similarity of habitat preferences among size groups and the level of resolution needed in the habitat assessment.

Recommended Guidelines

The following guidelines are recommended to aid in the development of meaningful and unbiased suitability criteria curves for physical habitat variables. These are not intended to be a complete list nor are they recommended for all situations. In many cases, the level of resolution needed will determine the amount of time and effort that can be devoted to the development of suitability curves. For the development of suitability criteria that will be generally applicable, these guidelines should be considered.

1. Sampling techniques should be evaluated to determine which one provides the least bias for the fish species under investigation. Bias due to the sampling technique used can arise due to either (1) movement of fish from holding locations prior to capture or (2) differential catchability along the gradient of the habitat parameter under study.

2. Habitat availability at the time of sampling should be quantified to allow for computing relative density estimates on which to base habitat suitability curves.

3. Sampling should be conducted at a time and in areas such that the target species under study has a wide range of habitat conditions (including unsuitable habitat) from which to select. This requires some preliminary knowledge of habitat preference of the species or life stage in order to design an appropriate sampling scheme.

4. Size of fish within life stages should be measured concurrently to allow for analysis of the significance of intraspecific differences in habitat selection among size groups.

5. Sampling should be conducted at several different stream flow levels within each season to evaluate the significance of seasonal changes in microhabitat preference.

6. Laboratory experiments should be conducted to determine velocity tolerances to aid in defining the upper limit of the velocity suitability curve.

7. Since interspecific and intraspecific interactions are also known to affect habitat selection in some species, the population should be near carrying capacity when sampling is done and relative abundance of other species which utilize similar habitats should be determined.

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SYSTEM FOR REMOTE MONITORING OF CHANGES IN AQUATIC HABITAT RESULTING FROM WATER-LEVEL FLUCTUATIONS[1]

Duane A. Neitzel, C. Dale Becker, and Duane H. Fickeisen[2]

Abstract.--We used a remote, pressure-sensitive radiotelemetry system to monitor water-level fluctuations in sloughs along the Hanford Reach of the Columbia River below Priest Rapids Dam. The sloughs are important spawning and nursery areas for smallmouth bass and other resident fish. Water levels in these sloughs fluctuated as much as 2 m in 24 hours. The impact to aquatic communities in the sloughs varied with river discharge and with air and river water temperatures. Changes in slough water temperature, which fluctuated as much as 14 C in 24 hours, were one of the major impacts to the aquatic habitat.

INTRODUCTION

Consumptive and nonconsumptive use of water from rivers, lakes, and reservoirs results in fluctuating water levels (Ward and Stanford 1979; Fraser 1972; Becker et al. 1981). Fluctuating water levels affect aquatic habitats and the organisms residing in these habitats. To understand and quantify the effects of water-level changes, continuous monitoring of fluctuations and other environmental conditions (e.g., water temperature and weather) is desirable. The habitats affected may be in remote locations, and therefore continuous monitoring of water levels is difficult. We used a radiotelemetry system that permits continuous remote recording to study water-level fluctuations in three sloughs adjacent to the Columbia River at Hanford.

Study Site

The Hanford site, located in southeastern Washington, is managed by the U.S. Department of Energy (fig. 1). The Columbia River runs through or adjacent to the northern and eastern borders of the site. Columbia River flow through this reach is regulated at Priest Rapids Dam. Priest Rapids Dam is a hydroelectric power generating dam and is operated in a peaking mode. Changes in daily and weekly power demands from Priest Rapids Dam cause water levels in the Columbia River at Hanford to fluctuate.

The sloughs and backwater areas where we conducted our studies are important spawning and rearing areas for several species of resident fish (Becker et al. 1981). The smallmouth bass (Micropterus dolomieui) is the most economically and politically important resident fish that uses the sloughs (Henderson and Foster 1956; Montgomery and Fickeisen 1978; Montgomery et al. 1980). The sloughs are also temporary nursery areas for anadromous out-migrants, especially fall chinook salmon (Oncorhynchus tshawytscha) fry.

The sloughs are in remote or out-of-the-way areas. Therefore, continuous monitoring of water level and water temperature resulting from fluctuation in river flow required automatic recording equipment that was easy to set up and did not require daily maintenance.

METHODS

Water Levels

We used a pressure-sensitive radiotelemetry system to monitor water levels. The system has six components: transmitter, receiver, antenna, pulse-rate decoder, power source, and recorder. The components were developed at the Department of Ecology and Behavioral Biology at the University of Minnesota (Tester and Siniff 1976).

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[2]Duane A. Neitzel, C. Dale Becker, and Duane H. Fickeisen are research scientists at Pacific Northwest Laboratory, Richland, Washington. The laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

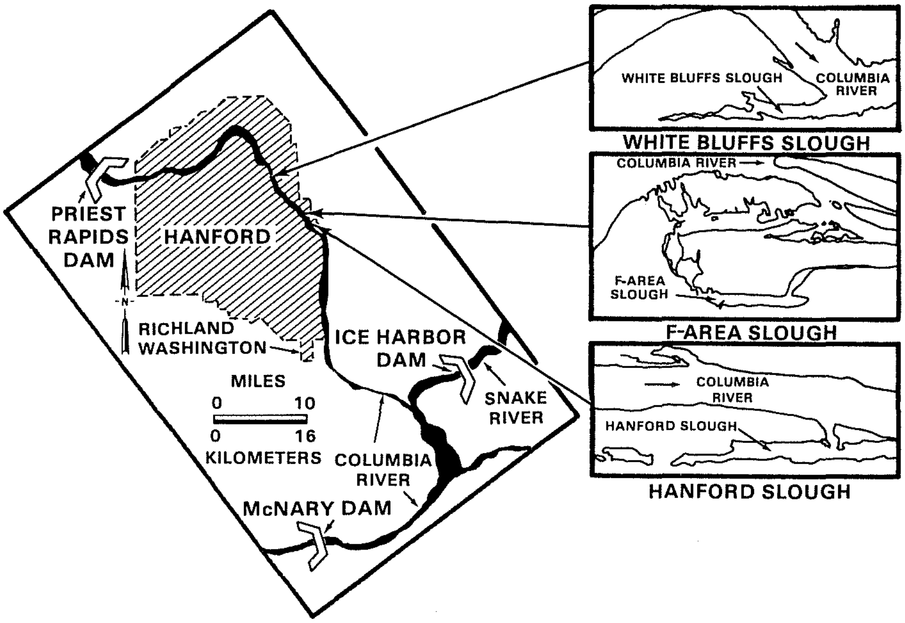

Figure 1.--Map showing the U.S. Department of Energy Hanford site and details of study sites.

We developed the monitoring system when our research program began in 1978. The equipment was available at reasonable costs. Because we had not selected a specific study location, we wanted the recording equipment to be portable and easily installed at different locations. Reasonable cost and portability are the two most desirable features of our radiotelemetry system. Its features compare favorably with other water-level recording systems, such as stilling wells and chart recorders (table 1).

The transmitter was originally designed to monitor swimming depth of adult salmon and sturgeon, and could be attached to those large fish. The transmitter we used was increased in size to accommodate a longer-lived battery and, thus, was too large to be attached to the fish. The transmitter we used was placed in the water at a point selected for monitoring changes in water depth. Transmission was selected in 1 MHz increments over a 1 MHz range. The units transmitted at 53 MHz. The unit included a battery, transmitter, and pressure sensor, all encased in epoxy. The transmitter unit was about 15 cm long and 4 cm in diameter, and it weighed less than 0.5 kg.

A signal was passed from the transmitter to a radio receiver located onshore. The receiver included a programmable scanner, which enabled one receiver to pick up signals from several transmitters, each of which was operating at a unique frequency. Radio reception was aided by an antenna.

A pulse-rate decoder was connected to the receiver. The pulse-code modulation, or the interval between pulses, was used to provide water-level information. When water levels rose, water pressure on the tag increased, and this increased the transmission pulse rate. The decoder counted the number of seconds per 10 pulses. This information was recorded as milliamperes. Milliampere readings were made directly from the paper strip-chart recorder and converted to water depth by using calibration data generated by placing the unit at known depths.

Water Temperature

Water temperatures were monitored at the same times and places as water-levels. Water temperatures were recorded with submersible thermographs. Thermographs were placed near transmitters so that temperature changes could be associated with water-level changes.

Table 1.--Comparison of radiotelemetry water-level monitoring system with other monitoring systems.

Features	Telemetry System	Other Systems
Cost		
One location	-	-
Multiple locations	+	
Calibration	Complex	Simple
Resolution		+
Accuracy	-	-
Labor		
Installation	Simple	Moderate
Monitoring		+
Portability		

+ indicates advantage.
- indicates systems are comparable.

Topographical and Meteorological Monitoring

Water-level and water temperature data provide information about physical changes in an aquatic habitat affected by water-level fluctuations. However, in order to use these data for predicting or quantifying impacts, it was necessary to collect additional habitat information. We determined that topographical and meteorological data could provide important habitat information for predicting impacts at a specific location. The data we collected and used included beach or shoreline exposure, water body volumes, air temperatures, and insolation.

The extent of beach exposure was estimated by means of a calibrated wire rope laid perpendicular to the shoreline. The water/shoreline interface was noted for a range of water levels.

We also measured soundings (i.e., depth measurement) and shoreline distances, and used the data to calculate slough areas and slough volumes for a range of water levels. In figure 2, a cross section and an areal view of a body of water illustrate how water-level fluctuations can be correlated with changes in the area and volume of a body of water.

Air temperature and insolation both affect the amount of warming that occurs in a slough during the day. For these studies, we used data from the Hanford weather station, which is located about 18 km from the area we monitored.

Smallmouth Bass Monitoring

While monitoring water-level fluctuations, we also monitored smallmouth bass spawning. We marked bass nests and monitored the frequency of abandonment and spawning success in relation to water level and temperature changes.

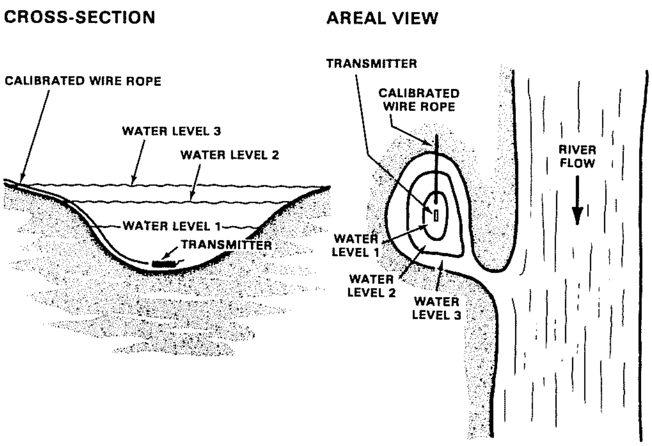

Figure 2.--Illustration showing how a cross section and areal view of a body of water can be used to correlate water levels to water-body volumes.

RESULTS AND DISCUSSION

The data from the monitoring system were analyzed for each 24-hour period. Water levels fluctuated as much as 2 m and water temperatures as much as 14 C within 24 hours during the periods monitored (spring and summer, 1978-1980). Maximum water-level fluctuations did not correlate directly with maximum water temperature fluctuations. For example, between July 10 and 15, 1978, water levels at White Bluffs Slough fluctuated between 0.5 and 1.0 m each day. Water temperatures fluctuated about 5.0 C. At the same location between April 25 and May 1, 1978, and with similar water-level fluctuations, the water temperature changed as much as 11.0 C daily.

We examined air temperature and insolation data during the study period to explain the lack of correlation between water-level fluctuation and water temperature fluctuation. What occurred in June is illustrated in figure 3. The water level in the river rose and flooded the slough with river water. The water temperatures in the river and the slough became similar. Then the water level dropped and the water in the slough was isolated. The sun warmed the slough water. When the water level increased, the warmed slough water was mixed with cooler river water and the slough water temperature dropped abruptly. When the river temperatures were higher, as occurred in the late summer, water-level fluctuations did not cause large temperature fluctuations because the difference between the slough water temperature and river water temperature was not as great in the summer as in early spring.

We concluded that one of the main physical impacts to the aquatic habitat from fluctuating water levels is fluctuating water temperatures. Temperature fluctuations are most likely to occur during the spring in sloughs adjacent to the mid-Columbia River, because the river water temperatures are low, the water-level fluctuation is large, and air temperatures are warm.

Although we have not completely examined the bass spawning data that we collected, our initial examination indicates that fluctuating water temperatures result in three main impacts to fish populations using the sloughs: thermal shock, interruption of spawning, and abandonment of developing eggs and fry.

Montgomery and Fickeisen (1978) and Montgomery et al. (1980) also studied smallmouth bass in these sloughs. They concluded that water-level and temperature fluctuations influenced bass movements and spawning.

Power production, irrigation, and other consumptive and nonconsumptive uses of water result in water-level fluctuations that affect aquatic habitats. To predict the type and extent of the impact, physical changes that occur within aquatic habitats must be monitored and correlated with

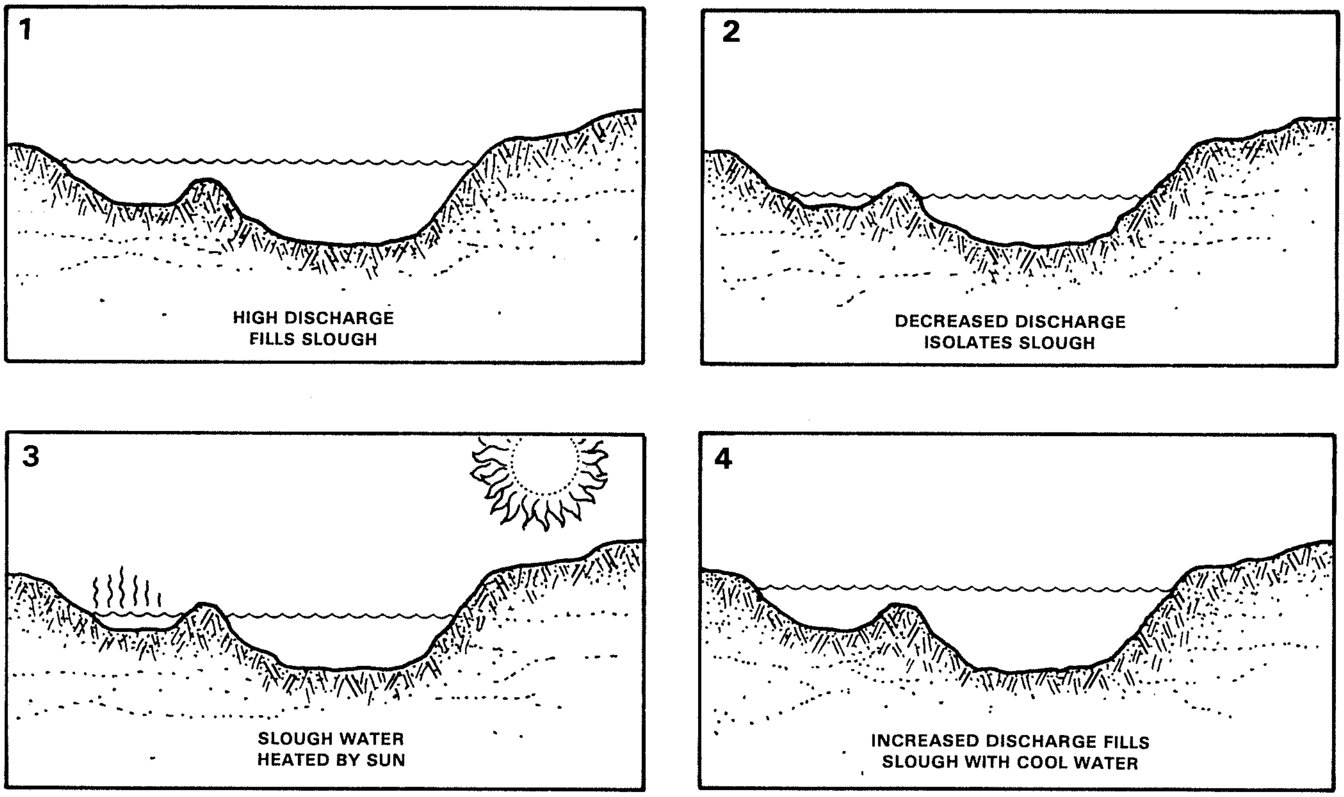

Figure 3.--Illustration of the effects of water-level fluctuations and insolation on water temperatures in a slough.

biological observations. The monitoring system discussed here is one method that can be used to collect data from aquatic habitats affected by changes in flow and temperature.

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A METHOD FOR MEASURING MICROHABITAT COMPONENTS FOR LOTIC FISHES AND ITS APPLICATION WITH REGARD TO BROWN TROUT[1]

Jeffrey C. Gosse[2] and William T. Helm[3]

Abstract.--A technique was developed for quantitatively defining the precise microhabitat of lotic species in situ. Scuba equipment was modified to allow observations of fish in high velocity streams and at low temperatures. Variables measured include water and fish depth, mean velocity, substrate, velocity at the fish's location, and light intensity. Physical activity and life stage were vital subdivisions in defining microhabitat requirements of brown trout. The ability to observe the fish and take measurements at their precise location was highly important in defining their microhabitat.

INTRODUCTION

Most studies examining microhabitat have been done in artificial streams with limited habitat types available and usually have measured only a few variables (Butler and Hawthorne 1968, Baldes and Vincent 1969, Hartman 1963). Giger (1973) states that much of the data available are unquantified. Although the value of controlled studies is recognized, it was felt that with the present state of knowledge, in situ measurements would be needed to determine the full range of microhabitat variables utilized and to avoid the limited habitat usually found in artificial streams.

A field methodology was developed to allow monitoring of all habitat types available within the river system studied. The method allowed for visual observation of undisturbed fish in order to determine their precise location and physical activity at the time of observation, and included the ability to locate and observe hidden fish. Subjective variables such as "cover" were defined by such quantifiable constituents as depth, overhead light, and distance to and relative location of tactile surfaces.

Microhabitat variables were measured at observed brown trout (*Salmo trutta*) locations during daylight hours. The study was conducted from August 1977 to March 1978 in the Logan River system and from June 1978 to February 1979 in the Provo River system (Gosse 1981).

SITE DESCRIPTION

Logan River

Microhabitat data were obtained primarily in the canyon portions of the Logan River system, Cache County, Utah. The Logan River and its major tributary, the Blacksmith Fork, are typical of the Intermountain Area. Both originate on high elevation watersheds and course through canyons with high gradients, becoming widely meandering streams with lower gradients in the valley floodplain (Fig. 1). Streamflows are primarily governed by runoff from the mountain snowpack.

Microhabitat data were collected in Logan Canyon from the confluence of Right Hand Fork to the upper reaches of the reservoir at the canyon mouth. Data were collected in the Blacksmith from its source to approximately 0.5 km below the canyon mouth. Microhabitat data were collected in Right Hand Fork from 300 m above Cowley Canyon to the confluence with the Logan River.

Brown trout and mountain whitefish (*Prosopium williamsoni*) are the dominant species from Right Hand Fork to the confluence with Blacksmith Fork. Cutthroat trout (*Salmo clarki*) and mottled sculpin (*Cottus bairdi*) are also abundant in both the Logan and Blacksmith. Rainbow trout (*Salmo gairdneri*) and mountain sucker (*Catostomus platyrhynchus*) occur infrequently and Utah chub (*Gila atraria*) are found in the Blacksmith Fork. In Right Hand Fork, age 0 and juvenile brown trout are the dominant species, with cutthroat trout and

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and mottled sculpin occurring occasionally. Brook trout (Salvelinus fontinalis) occur above the area studied.

Provo River

Microhabitat data were collected on a 9.8 km section of the Provo River, Utah from Deer Creek Reservoir to the Olmsted Diversion in Provo Canyon. The three tributaries (Provo Deer Creek, North Fork, and South Fork) which join the Provo in this reach were included in the study during spawning season.

Brown trout are the predominant fish species present in this section of the Provo. Natural populations of mountain whitefish and mottled sculpin also inhabit this part of the river. Yellow perch (Perca flavescens) were observed in the upper reaches of the site. They are most likely immigrants from Deer Creek Reservoir and probably are not reproductively sustained in the study area.

METHODS

Observation Techniques

Scuba was utilized to observe fish and measure the various variables. Certain modifications of normal scuba techniques and equipment made the observations feasible. The diver wore up to 75 kg

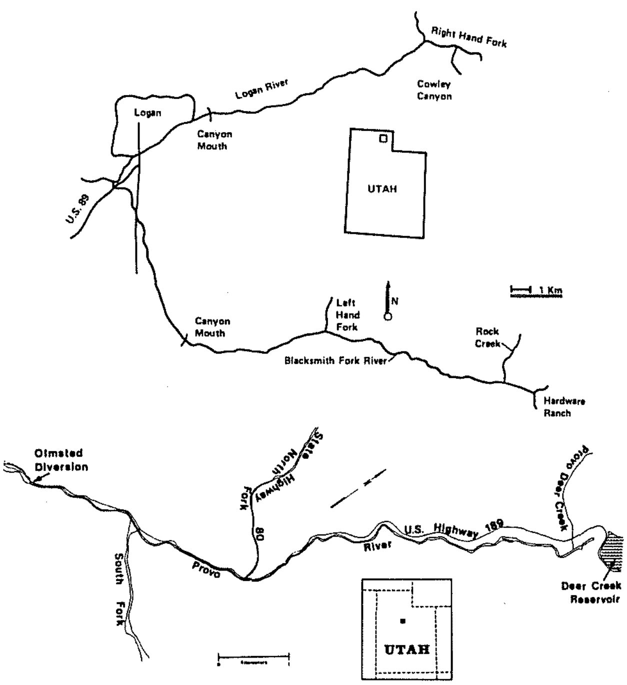

Figure 1. Study areas on the Logan (upper) and Provo River (lower) systems, Utah.

of lead weights to remain stationary on the bottom in the strong currents.

A surface to diver sonic communication system allowed the diver to transmit to and receive data from the surface personnel. Variables that could be measured entirely by the diver were relayed to the surface for recording. Since only the probes of the electronic meters were submersible, the diver would place them in position and then instruct the surface personnel to read the meter.

A specially designed exhaust system vented air bubbles downstream from the diver to avoid frightening the fish. In addition, all equipment used by the diver was dark-colored or color camouflaged to blend better with the surroundings. The diver's movements were purposely slow and unobtrusive, with the diver orienting and moving upstream to approach the fish from behind to minimize frightening them.

Fish could normally be identified by species and observed from distances of 1.5 to 3 m, depending on water clarity and shadows. Under normal conditions, fish were seldom disturbed by the presence of the diver, especially when observed from several meters. When poor visibility forced the diver to approach closer than 1.5 m, fish were often frightened before they could be observed. Fish that were obviously frightened were not utilized for data.

This technique is more dangerous than normal scuba diving because of the additional equipment involved, underwater obstructions, and the desirability of using only one diver for observations. Special safety plans (Gosse and Helm 1979) should be invoked before diving.

Physical Habitat Features

Physical variables believed most likely to define trout microhabitat were measured as precisely as possible exactly where a fish was located. When several fish were observed in the same microhabitat, measurements were made in a location representative of the entire area, usually near the middle of the group.

Total depth of the vertical water column occupied by the fish was measured to the nearest centimeter. Fish depth, distance of the fish from the stream bottom, was estimated to the nearest centimeter using a calibrated rod for reference. For a group, an estimated average depth was used.

Three water velocities were measured to the nearest 3 cm/second using an electronic current meter. (Measurements were originally made in the English system to the nearest 0.1 foot/second and have been converted.) The velocity of water at the precise location (including depth) occupied by the fish is referred to hereafter as the fish velocity. When the probe (3 cm diameter) was considerably smaller than the fish, it was placed at the location occupied by the fishes head. The mean velocity was taken at four-tenths of the water depth measured from the river bottom. Surface velocity was measured immediately below the water surface.

The amount of light reaching various parts of the microhabitat was measured to 0.01% of full sunlight (1.076 X 10^5 lx) on a logarithmic scale using a solar illuminance meter. The light intensity at the river surface (including shadowing by overhead canopy) was considered surface light. Overhead light was the light intensity at the position occupied by the fish, measured vertically. Maximum light was the maximum light intensity reaching the fish, regardless of direction.

The type of substrate was recorded as rock (>30 cm), rubble (8-30 cm), gravel (0.3-8 cm), silt (<0.3 cm), plant, or other. The other category consisted of detritus, roots, branches, or occasionally man-made materials.

Biological Distinctions

Brown trout were classified into three life stages which could be determined from observation of total length and knowledge of growth rates from other studies. Age 0 were fish that emerged during the current year. Fish one year of age or older that had not reached sexual maturity were considered juveniles. Adults were sexually mature fish. Fish that would spawn during the fall were considered adults during summer seasons. During the winter seasons, fish were kept in the same life stage they had occupied during the fall.

The physical activities of the fish were divided into easily observable categories. Fish that remained stationary with no swimming motion (normally by lying on the river bottom) were regarded as resting. Fish that maintained a stationary position by actively swimming against a current were listed as stationary swimming. Swimming without orientation toward current (found only in low velocity water) that did not produce a net change in location was labeled random swimming. Fish that were observed to consume particles (during stationary and occasionally random swimming) were considered feeding. Spawning was used for adults actively engaged in spawning, redd excavation, fanning, and redd defense. Baldes and Vincent (1969) categorized four types of "microhabitat" which correspond to the activities of resting, feeding, and spawning. They did not consider stationary nor random swimming.

RESULTS

Physical Microhabitat

The means and standard deviations of the important microhabitat variables for the different activities are presented in this section. These variables are fish velocity, mean velocity, fish depth, water depth, overhead light, and substrate. For overhead light, 80% ranges are given instead of standard deviations because of the wide range of values encountered. That is, not more than 10% of the observed values lie above or below the respective range. Substrate is presented as percent occurrence.

Mean velocities are provided in this section, although they are not as accurate in describing microhabitat as fish velocity. They are included because many habitat evaluation models still use mean velocities rather than fish velocities. Baldes and Vincent (1969) also found that bottom (fish) velocities were superior to mean or surface velocities.

Distance to the nearest thigmotactic surface is not presented because it was nearly identical with fish depth. Surface and maximum light and surface velocity proved to be inferior variables to overhead light and fish velocity, respectively, and are not included.

Adults. Each of the five variables presented (Table 1) exhibited a significant ($P < 0.05$) difference among means for the various activities. The activities of stationary swimming and feeding appear identical to an observer except that during the latter, fish were observed to engulf drifting food particles. The activities were recorded and analyzed separately. There were no significant ($P > 0.05$) differences between these two activities in the Logan system for any of the five variables. Some variables were significantly ($P < 0.05$) higher for feeding in the Provo River (Table 1). Both activities occur primarily over rubble, with gravel and silt comprising decreasing amounts of substrate.

Overhead light for resting activity was significantly ($P < 0.05$) lower than for any other activity (Table 1). Only 6% (14 individuals) of the resting fish were observed in more than 5% of full sunlight. Areas of deep shadow adjacent to high light intensity areas appear to be premium habitat for this activity. Devore and White (1978), Baldes and Vincent (1969), Butler and Hawthorne (1968), and Needham and Jones (1959) have all found brown trout attracted to shade.

For resting activity, fish and mean velocities were significantly ($P < 0.05$) lower than the other activities except for random swimming and Provo tributary spawning. Fish depth for resting activity was significantly ($P < 0.05$) lower than for any other activity. Most resting activity occurred on silt substrate, with most of the remainder occuring on gravel or detritus.

Spawning variables were quite similar between the Logan system and the tributaries of the Provo River (Table 1). Water depths were not significantly ($P > 0.05$) different, although spawning in the main Provo River was found to occur in significantly ($P < 0.05$) deeper water than in either the Logan or the Provo tributaries (Gosse and Helm 1979). Spawning was the only activity for which gravel comprised the major substrate. Although 25% of the the spawning substrate in both river systems was rubble, this actually represents areas where spawning fish had eroded the gravel layer

Table 1. Mean values with SE ( ) for selected variables describing adult brown trout microhabitat in the Logan and (when noted) Provo River systems.[1]

Variable	Stationary Swimming	Logan Feeding	Provo Feeding	Random Swimming	Resting	Logan Spawning	Provo Trib. Spawning
	Activity						
Sample size	225	20	57	45	222	45	85
Fish velocity[3] (cm/second)	24 (13.9) B[4]	21 (7.77) B	30 (15.1) A	6 (4.82) D	15 (9.39) C	21 (18.5) B	12 (10.5) C
Mean velocity[3] (cm/second)	40 (21.8) B	43 (25.3) A,B	43 (22.9) A,B	9 (9.57) D	27 (16.6) C	46 (16.3) A	40 (19.9) B
Fish depth[3] (cm)	10.7 (7.16) C	11.5 (4.89) C	46.3 (17.7) A	36.9 (15.3) B	0.8 (2.24) E	5.1 (5.22) D	-b -
Water depth[3] (cm)	92 (48.6) C	106 (28.1) C	168 (77.0) B	225 (102) A	88 (62.5) C	36 (21.4) D	30 (8.09) D
Overhead light[3] (% full sunlight)	7.8 B	7.4 B,C	13.0 A	6.0 B,C	1.2 D	5.2 C	7.5 B,C
range-lower	0.5	5	10	5	0.01	5	5
range-upper	50	50	50	50	5	10	10
Substrate (%)[3]							
rock	1	0	28	2	5	0	0
rubble	43	75	28	9	8	25	25
gravel	29	15	35	0	19	73	75
silt	18	10	9	29	55	0	0
plant	4	0	0	36	1	0	0
other	5	0	0	24	12	2	0

[1]Overhead light is presented with an 80% range while substrate is presented as percent occurrence.
[2]Data not available.
[3]Significant (P < .05) differences were found among the activities for this variable.
[4]Activities not sharing a common letter for a variable had significantly (P < .05) different means.

above rubble. Adults seldom if ever spawned where rubble was the original surface substrate.

For all activities except random swimming, the mean velocities were significantly ($P < 0.05$) higher than the respective fish velocities (Table 1). Fish depths (distance above the river bottom) for the various activities were usually well below the depth where mean velocity is measured.

Juveniles. Fish and mean velocities and fish and water depths for stationary swimming and feeding were not significantly ($P > 0.05$) different in the Logan River (Table 2). Overhead light was signficantly ($P < 0.05$) lower for feeding than for stationary swimming. Rubble, gravel, and silt were the dominant substrate types for the two activities. Feeding activity for juveniles in the Provo had significantly ($P < 0.05$) different values for mean velocity, fish and water depth than in the Logan system. Light was not significantly ($P > 0.05$) different between Provo feeding and stationary swimming in the Logan system.

Random swimming had significantly ($P < 0.05$) lower fish and mean velocities and significantly ($P < 0.05$) higher values for fish and water depth (within the Logan system) than for any other activity. This activity occurred over all substrate types except rock, with silt and rubble occurring infrequently. Light levels were similar to those of other activities.

Resting activity for juveniles had low velocities and significantly the ($P < 0.05$) lowest fish depth. Silt was the dominant substrate, with gravel being the second most prevalent. Resting had more observations in the lower light intensities than other activities, but the mean was not significantly ($P > 0.05$) lower than feeding or random swimming (Table 2).

Table 2. Mean values with standard deviations ( ) for selected variables describing juvenile brown trout microhabitat in the Logan and (when noted) Provo River systems.[1]

	Activity				
Parameter	Stationary Swimming	Logan Feeding	Provo Feeding	Random Swimming	Resting
Sample size	327	52	88	61	78
Fish velocity[2] (cm/second)	21 (13.0) A[3]	24 (10.3) A	24 (12.1) A	6 (5.61) C	9 (6.37) B
Mean velocity[2] (cm/second)	34 (20.9) A	37 (16.4) A	27 (15.7) B	9 (9.88) D	21 (16.8) C
Fish depth[2] (cm)	9.5 (6.75) C	10.1 (7.11) C	51.5 (18.9) A	39.3 (6.27) B	0.6 (1.90) D
Water depth[2] (cm)	88 (33.5) B	77 (26.8) B,C	189 (73.9) A	194 (56.3) A	71 (26.6) C
Overhead light[2] (% full sunlight)	8.6 A	4.6 C	8.4 A,B	6.1 B,C	3.2 C
range-lower	0.5	5	5	1	0.05
range-upper	50	10	50	50	50
Sunlight (%)[2]					
rock	3	0	0	0	5
rubble	34	46	11	13	6
gravel	38	40	57	25	26
silt	22	14	20	7	59
plant	1	0	12	26	0
other	2	0	0	30	4

[1]Overhead light is presented with an 80% range while substrate is presented as percent occurrence.
[2]Significant ($P < .05$) differences were found among the activities for this variable.
[3]Activities not sharing a common letter for a variable had significantly ($P < .05$) different means.

Age 0. Stationary swimming and feeding together represent 87.5% of all age 0 observations (Table 3). Although these activities had quite similar values for velocities, depths, and light, the difference between each pair of variables was significant ($P < 0.05$). Substrate composition was similar between the two activites with some increase in rubble during feeding.

Silt was the predominant substrate for resting activity, which may correspond with the lower fish velocity associated with the activity. Both depths and overhead light were significantly ($P < 0.05$) lower than for any other activity.

The small sample size for random swimming allows a wide margin of error. Both velocities were low while both depths and light measurements were significantly ($P < 0.05$) higher than for any other activity. The substrate was primarily silt with some plant and rubble.

Trends By Life Stage. The frequency of the various activities follows a pattern with a significant ($P < 0.05$) difference in occurrence of activities among life stages (Table 4). Resting was observed with increasing frequency as age increased, while stationary swimming and feeding became less frequent with increasing age of fish.

Some microhabitat variables exhibit general trends when examined by life stage. Overhead light intensities decrease for most activities with increasing age (Tables 1-3). Velocities increase with increasing age. Fish and water depths increase with increasing age, with the greatest difference between age 0 and juveniles. Substrate size increases with age for the activities of stationary swimming and feeding. It should be remembered that all observations were made during daylight hours, and twilight and night observations would probably produce different frequencies of occurrence.

Table 3. Mean values with standard deviations ( ) for selected variables describing age 0 brown trout microhabitat in the Logan River system.[1]

Variable	Activity			
	Resting	Stationary Swimming	Feeding	Random Swimming
Sample size	41	274	76	9
Fish velocity[2] (cm/second)	6 (5.94) C	15 (8.50) B	18 (9.14) A	9 (9.78) C
Mean velocity[2] (cm/second)	24 (16.8) B	27 (17.0) B	34 (18.2) A	18 (21.9) B
Fish depth[2] (cm)	0.3 (.775) D	4.7 (3.45) C	5.9 (3.08) B	9.6 (8.63) A
Water depth[2] (cm)	47 (22.6) C	62 (23.2) B	73 (39.6) A	83 (54.3) A
Overhead light[2] (% full sunlight)	4.2 D	13.4 C	20.0 B	36.8 A
range-lower	.05	1	5	5
range-upper	50	50	50	50
Substrate (%)[2]				
rock	10	2	0	0
rubble	0	10	28	11
gravel	24	53	30	0
silt	59	33	34	78
plant	0	3	8	11
other	7	0	0	0

[1]Overhead light is presented with an 80% range while substrate is presented as percent occurrence.
[2]Significant (P < .05) differences were found among the activities for this variable.
[3]Activities not sharing a common letter for a variable had significantly (P < .05) different means.

Table 4. Percent occurrence of various activities for three life stages of brown trout in the Logan River system.

Life Stage	Activity			
	Resting	Stationary Swimming	Feeding	Random Swimming
Adult	40	40	4	8
Juvenile	15	63	10	12
Age 0	10	69	19	2

Microhabitat Selection

Fish were not randomly distributed with regard to habitat variables. For example, when fish velocity is compared with mean velocity (within the same water column) all three life stages were consistently found in slower velocities than the mean velocity of the column.

Fish also were not distributed randomly within the column in regard to depths. As was observed in the summary tables, trout were consistently found near the bottom rather than being located throughout the water column (Tables 28-30). This trend is most apparent for certain life stages and activities, for example, resting adults.

Measurements of velocity, light, and depth were made on a series of cross sections in the Provo River (Gosse and Helm 1979). The mean one SE of these variables (as determined from microhabitat observations) were defined as suitable habitat for resting fish. Using this definition, useable habitat ranged from 3 to 15% of the total habitat (Gosse 1981).

In the Logan River system, age 0 were found primarily in a tributary, Right Hand Fork. Age 0 were found in the main Logan and Blacksmith Rivers, but never in abundance. The microhabitat variables recorded for age 0 in Right Hand Fork were not different in any way from habitat which could be found in the main rivers. Right Hand Fork differs from the Logan and Blacksmith primarily in that it is much smaller and few adult trout are found there except during spawning season.

In the Provo River, nearly all age 0 fish were located in the main river. They were strongly associated with shallow shoreline areas, usually in conjunction with dense macrophyte beds. Such beds are rare in the Logan system. Although juveniles and adults from the Provo were generally found in as deep or deeper water than in the Logan system, Provo age 0 fish were located in shallower areas than age 0 in the Logan system.

DISCUSSION

Physical Microhabitat

Adults. By definition, fish could be classified as feeding only if observed to engulf particles. The vast majority of feeding occurred during what otherwise would have been classified as stationary swimming. Occasionally, trout were observed to feed during random swimming activity.

There was little difference between most variables for feeding and stationary swimming. Water depth for feeding was deeper in the Provo, but this was true for most Provo observations and appears to represent more deep water habitat in the Provo.

Much of the feeding activity in the Provo was observed near the middle of the water column and occasionally near the surface. Most Logan feeding was on drift near the river bottom. This accounts for the increased fish depth in the Provo and the smaller difference between fish and mean velocity.

Overhead light is an important microhabitat variable for resting adults. The 80% range for resting did not overlap the 80% ranges for any other activities except stationary swimming. The majority of resting adults were associated with much lower light values than was found for other activities. This activity also requires relatively low water velocities and medium water depths. Since resting is one of the major daytime activities of adults and the center for other activities (Baldes and Vincent 1969), it is important that this combination of variables be available in a stream.

While spawning variables were similar between the Logan system and the Provo tributaries, they were somewhat unique compared to other activities. The 80% light range may be indicative that light intensity must be low for this activity to occur. Gravel substrate was obviously important for spawning activity. Evidently shallow water depths are preferred but not required microhabitat. In the Logan system where acceptable spawning habitat occurred in a variety of water depths, only the shallow depths were utilized. In the main Provo River, acceptable spawning habitat located in shallow water depths was extremely limited, and fish were observed to spawn in significantly deeper water.

Random swimming occurs primarily in pools of quiet water, as indicated by its associated variables of deep water and substrate characteristic of deep pools. The very low mean velocity indicates the entire water column must be of a low velocity. This activity would probably become more important in rivers where more deep, quiet water habitat was available.

Juveniles. The similarities between stationary swimming and feeding variables follow the same trends found for adults for velocities, depths, and substrate. Light was lower for Logan feeding than for stationary swimming.

Most variables for random swimming were similar between juveniles and adults. Substrate composition was different, with an increase in gravel and a great decrease in the amount of silt and detritus present for juveniles. This difference may be random chance resulting from small samples, or it may indicate different locations within pools. Juveniles did not exhibit the large shift toward low light intensities for resting as was noted for adults. This relaxed requirement for low light makes more resting habitat available to juveniles than for adults.

Age 0. The trends established for juveniles and adults do not completely follow for age 0 among the different activities. Stationary swimming and feeding, although similar, have significant differences between each of the continuous variables.

Resting activity for age 0 did exhibit the same trends found for the older fish. Light intensities were lower than for other activities and similar to those of juveniles.

Random swimming was an infrequent activity for age 0 and usually occurred in shallower pools than required for juveniles and adults. Although velocities were low, mean velocity was higher for age 0 than for the older life stages. Generally, shallow areas have higher mean velocities than the deeper pools.

Trends By Life Stage. The data represent the frequency with which various activities were observed on a random search basis. No attempt was made to quantitatively determine the amount of time spent in each activity. Thus, although there is probably a correlation between the frequency with which an activity is observed and the percent of time spent in that activity, the data are not an accurate measurement of the latter.

The high resting frequency for adults has several possible explanations. Butler and Hawthorne (1968) also observed that adult brown trout were very inactive and spent up to 3 hours without moving. Needham and Jones (1959) indicated that they were more active at night than in daylight.

Viewed in conjunction with the pronounced tendency of resting adults to seek low light, resting may represent a strong avoidance of the generally more exposed feeding sites during daylight hours. It may represent an optimal feeding strategy, where feeding occurs only when food is most available. Younger life stages may not use this strategy because they are less dominant, and not able to compete effectively during the prime feeding periods.

Increased adult resting activity may also represent an optimal energy strategy. Stationary swimming and feeding require a higher energy expenditure than resting. Adults expend more total energy while swimming to maintain position than younger fish, although food particle size is essentially the same. Thus, younger fish have a greater net gain of energy per food particle, and may be able to feed efficiently during less optimum periods.

Activity. The fact that there are significant differences among activities for every variable and every life stage indicates that for precise, microhabitat definition, the physical activity of the fish must be taken into account. Combining the various activities produces total and preferred ranges which could be misleading for many variables. For example, adult brown trout were often found in light intensities as high as 50% full sunlight and often utilize rubble and gravel substrate. But these locations were utilized during the activity of stationary swimming. During resting activity, adults seldom if ever utilized such locations.

The danger of such errors should be readily apparent. If activities are ignored (or as a result of methodology, unavailable) the variable ranges will be very broad. Habitat evaluations using this wide range could inadvertently produce high ratings while providing little if any habitat for certain essential activities. Only if the total range for each variable were adequately provided could one be certain that habitat for all activities was available. When a variable range is defined without using activities, it represents the range which must be present in totality to provide necessary habitat for all activities, not just the range within which variable values must occur.

When activity isn't considered, a similar problem exists with means, modes, or other measurements of central tendency. Each will be shifted in the direction of the activity in which the fish were predominantly engaged. A mean calculated in this manner may be totally outside the acceptable range of less frequent but essential activities, such as resting or spawning. It is important that the required microhabitat be available for each essential activity for each life stage being considered. Baldes and Vincent (1969) state that all of these microhabitats ". . . must be available within the movement radius of the fish." This distance will change with activity and life stage, with fish traveling farther for spawning than for feeding or cover.

Since the activity of the fish is vital in defining brown trout microhabitat variables, the proper methodology must be used to determine activity along with the other variables. This is probably true for most of the trout species. Collection methods such as electrofishing preclude observation of precise fish locations, and are not normally appropriate for determining the microhabitat of brown trout.

Seasons. In Results, microhabitat was analyzed by activity but not by season. The data collected in this study have not indicated changes in microhabitat resulting from seasonal changes per se. This is not to say that the microhabitat choices of trout are not altered seasonally. But the alterations appear to be in the choice of time spent in various activities. The most obvious example is spawning season, which is the only time when adults utilize spawning microhabitat.

The relative importance of the different activities does appear to change seasonally and probably diurnally. Both Chaston (1968) and Swift (1964) found diurnal changes in brown trout activity and the latter also found seasonal differences. But given a specific activity, there appears to be no shifts of variables over seasons. One potential exception to this statement was found in the Provo River, where velocities and depths for various activities did shift as a result of major changes in volume of flow (Gosse and

Helm 1979). Discharge fluctuations (natural or man-made) could conceivably produce variable shifts.

Seasonal changes were also observed for age 0 during the first 6 to 8 months of life. In the Provo system, age 0 were first observed in June, and exhibited quite different microhabitat selection than when observed at later dates in either the Logan or Provo river systems. It is probable that microhabitat should be determined for a fourth life stage: emergents (<3 g live weight).

Potential Variable Changes

One of the primary reasons for conducting this study in the field was for the wide variety of microhabitats from which the trout could select. But even within the Logan and Provo River systems, there are certain habitat limitations. Understanding the available ranges for the different variables will elucidate potential biases in the data.

The Logan and Provo Rivers and their respective tributaries are all high gradient streams. The streams provide upper velocities far in excess of the ranges that trout were found to occupy, and it seems unlikely that additional studies or data will exceed these upper ranges (for fish velocity). Studies conducted in lower gradient streams may find a downward shift in velocities for certain activites, both in the upper range and in the mean. Lower ranges already reach 0 cm/s for many activities and cannot be shifted in these cases.

Except for the activity of random swimming, fish are located near the river bottom and standard deviations are small. Other authors (Baldes and Vincent 1969, Devore and White 1978, Jenkins 1969) have also found brown trout located at or near the bottom. Streams with increased depth are not likely to produce any shifts in fish depth since there was no indication of increasing fish depth with increasing water depth in this study, except for random swimming. Streams with higher mean depths may produce an upward shift in fish depth for random swimming activity.

Fish depth appears to be one of the most stable variables, both in terms of variance and in potential shifts expected in furture studies. Other authors (Baldes and Vincent 1969, Devore and White 1978, Jenkins 1969) also found brown trout located at or near the bottom. The benefit of such stability is that it allows one to confidently measure stream variables (velocity and light) at predicted fish depths in habitat evaluations as opposed to using values averaged over the entire water column.

Water depth is one of the least stable variables studied, as indicated by the large standard deviations associated with it. Both the means and upper ranges will probably shift in streams with a different average depth than the Logan system. The main Provo River had a greater mean depth than the Logan River system. Mean water depth for spawning activity was significantly ($P < 0.05$) deeper in the main Provo River, than in either its tributaries or in the Logan system. Feeding activity for Provo juveniles and adults also occurred in significantly ($P < 0.05$) deeper water than in the Logan system.

Brown trout were found to utilize all types of substrate commonly found in the stream for one activity or another. Habitat, where all variables are appropriate for an activity, will probably be utilized regardless of substrate type, with two important exceptions. For spawning activity, substrate compositon appears vitally important and spawning will probably always occur in gravel or gravel covered rubble. When macrophytes were available, they were widely utilized by the trout. Plants serve as cover (reduce overhead light), reduce velocities, and support food organisms. Boussu (1954) found trout utilizing rooted and floating macrophytes for cover.

Further studies will probably show that other than during spawning and a positive attraction to macrophytes, substrate per se has little or no importance in microhabitat choices by trout. At the present time this is still a matter of conjecture. Until suitable studies are conducted to test this hypothesis, caution should be exercised in using substrate as a major component of a microhabitat model or stream evaluation system.

Streams with increased amounts of overhead canopy, undercut banks, and submerged root development would provide more low light habitat as would streams with more macrophytes. This would probably result in a lower mean for light intensities for most activities. Night and twilight observations would also shift the mean downward.

Interactions Among Variables

Interactions between two variables were examined by developing two-way tables which list observations by interval for any pair of variables desired. Only one life stage and activity were considered at a time. It was expected that development of two-way tables would indicate interactions in habitat selection. For example, brown trout might accept higher light values if water depth increased, with depth substituting for shading, or vice versa. Similarly, to occupy a preferred velocity, the trout may accept a shallow depth. Interactions were tested using r (coefficient of linear correlation). Only a few interactions of this type were found (Gosse 1981).

Generally, the fish appear to select the value of each variable independently of the values chosen for other variables. Although a few combinations of variables did exhibit interactions, there does not appear to be interactions among variables for most activities and life stages.

Just as it was originally expected that interactions among variables would be found, it seemed probable that when fish were found at the outer ranges of one variable, they might shift toward the optimum of another variable. An instance where such an interaction might be expected but does not occur is between overhead light and thigmotactic quadrants for resting adults. This type of interaction was not found. When a fish utilized a value outside the preferred range of one variable, the probability that it would be near the optimum (or conversely the outer range) of another variable was not changed.

Microhabitat Selection

Critics have suggested that possibly the microhabitat variables found were not selected by the fish, but simply representative of the variables available in the rivers. Since measurements were usually made only where fish were located, this point should be considered. While it is true that the fish must choose from the ranges of variables available within the rivers, there is strong evidence that the fish are actively selecting microhabitat, and are not locating randomly within the rivers.

Within a water column, fish velocity is consistently lower than mean velocity for the different activities and life stages. Fish depth is consistently very low, and always much lower than water depth. The extremely low light values associated with resting adults compared to the values found for other activities and life stages indicates strong selectivity. Similarly, the substrate and water depth utilized by spawning adults cannot be considered random selection of available habitat. In this study and others (Baldes and Vincents 1969, Saunders and Smith 1962, Wankowski and Thorpe 1979) trout were found in clumped distribution throughout the rivers, rather than evenly or randomly distributed, indicating specific microhabitat selection.

Cross sectional mapping in the Provo River found an average of only 7% of the river was within the acceptable ranges for resting microhabitat. Helm et al. (1982) found a large proportion of brown trout located in predictable portions of a stream. In both studies, suitable areas were defined from variable ranges utilized by the fish. These values are obviously not a representative portion of the rivers, but microhabitat specifically selected by the trout.

The idea of active microhabitat selection is additionally supported by the apparent fact that under certain conditions these choices may be behaviorally altered. Age 0 in the Provo were found in shallower areas than those inhabited by the adult trout. Age 0 in Right Hand Fork were found to utilize deeper water, but few adult brown trout were found in this tributary.

In both river systems, age 0 seldom utilized habitat occupied by adult trout, although they were known to utilize the same type of habitat when adults were absent. The tentative explanation is that age 0 either behaviorally avoid habitat occupied by adults or that they fail to survive in such habitat (as a result of predation). Whatever the mechanism, it appears that exclusion of adult trout is an added requirement of age 0 habitat. Saunders and Smith (1962) found age 0 isolated from older brown trout, while Boussu (1954) found age 0 trout increased numerically in most sections when older trout decreased.

This type of behavioral reaction may produce additional complications in other river systems. Changes in the presence or absence of certain life stages, competitor species, or more probably, predator species, could modify the requirements for brown trout microhabitat.

Applications And Limitations Of Data

It is necessary to determine values acceptable to the trout for the different variables, by life stage and activity, in order to apply the data presented in this report. Accepting the entire range the trout were found to occupy for a variable would often result in too broad a definition, and would include values that the majority of the trout appear unwilling to utilize. Conversely, simply defining the mean or mode of a variable as acceptable is too restrictive a definition and would exclude much acceptable habitat.

One plausible method of defining preferred ranges of variables would be to develop tolerance intervals which would include a specified percent of the populations. They can be developed for both normal and skewed distributions (Remington and Schork 1970). The wider the tolerance interval, the greater the chance of including marginal habitat while the narrower the interval, the greater the chance of excluding acceptable habitat.

These data were obtained from streams where brown trout were present in abundance and factors such as water chemistry, annual flows, temperature and dissolved oxygen were not measured. Presence of abundant trout populations indicated these latter variables were acceptable and were normally uniform throughout the study areas.

Attempts to correlate habitat evaluations with fish locations will be most successful when used in a negative sense. A reach of stream that has small amounts of acceptable habitat will probably contain few fish. These data should be capable of predicting where fish will not be, because values are beyond the determined range of a variable. It is possible, however, to have reaches with acceptable habitat and few or no trout because of factors (angling pressure, predation, or inadequate food) unrelated to physical microhabitat.

Binns (1972) has developed a model that predicts relative abundance of brown trout in different streams based upon macrohabitat variables. His model was designed to identify differences between streams, not evaluate any specific reaches within a stream. Ultimately models will probably include both macro- and micro- physcial variables as well as chemical and biological variables.

CONCLUSIONS

The methodology presented here proved highly successful for quantitatively measuring trout microhabitat variables in situ over a wide range of natural habitats and conditions. The technique proved highly mobile and was effective during all seasons. Neither cold temperatures, high water velocities, nor overhead cover were serious obstacles in observing trout. Trout could normally be approached from downstream without being frightened. A special air exhaust system and color camouflaging helped the diver approach within observation distance.

The physical activity and life stage of the fish are vital subdivisions in defining microhabitat requirements. Analysis must include both factors in order to define variables precisely and to describe all required microhabitats. Studies which fail to take these factors into account may provide misleading results. Microhabitat variables were not found to change seasonally, but the percent occurrence of various activities did change with season and life stage.

Variables found to be most important in defining trout microhabitat were fish velocity, fish depth, water depth, and overhead light. Substrate and mean velocity were also presented but both appear to be less important and precise than the former variables.

For most activities and life stages, fish depth was low (<15 cm). This, then, rather precisely defines the depth at which measurements of velocity and light should be made in conducting habitat evaluations. Water depths varied greatly among activities and life stages with older fish generally occupying deeper water. There were definite lower limits for water depths, but upper limits were not as obvious, except for spawning.

Fish velocity varied among life stages and activities, with adults generally occupying higher velocities than younger fish. Mean velocities were consistently higher than fish velocities.

Low light intensities became increasingly important with increasing age. The upper 80% light range never exceeded 50% full sunlight for any activity or life stage. It was not apparent that there was a strong selection for substrate type, except during spawning and an attraction to macrophytes.

With a few exceptions, each variable appears to be selected largely independently of the values of the other variables. There was also no indication that utilization of a value outside the preferred range of one parameter increased the probability of utilization nearer the optimum of other variables.

Trout appeared to be definitely selecting specific microhabitat areas from the total range of habitat available in each stream. They were observed in clumped distribution and were not randomly nor evenly distributed. Age 0 trout appear to require physical isolation from adult brown trout as part of their microhabitat requirements.

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LIFE HISTORY, MICROHABITAT AND HABITAT EVALUATION SYSTEMS[1]

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Abstract.--The brown trout (Salmo trutta) distribution in a 90 m reach of the Blacksmith Fork River, Utah was mapped, and compared to a map of the physical microhabitat components of depth, fish velocity and light. Fish were found to occupy a predictable portion of the available habitat, indicating that measurements of the appropriate components can be used to determine the amount of usable fish habitat.

Recommendations for habitat evaluation systems include: 1) that the system be species specific, 2) that the species be divided into behaviorally characterized size groups and 3) that the ranges of microhabitat components be characterized for each of the activities comprising the daily routine for each size group of each species.

INTRODUCTION

Two objectives will be addressed in this paper. First is a test of the applicability of our microhabitat measurements to habitat evaluation by comparing a habitat map to a fish distribution map. Second, recommendations for refining habitat evaluation systems will then be presented.

An important objective of stream habitat evaluations is to estimate the portion of available habitat which is usable by fish. The following definitions are a restatement of descriptions used by Voos (1981).

1) Available habitat is the total range of habitat component values found in stream environments

2) Suitable habitat is that portion of the which is defined as suitable for use by fish

3) Usable habitat is that portion of the available habitat which falls within the range judged to be suitable habitat for the target fish species.

METHODS

Information derived from Gosse and Helm (1982) is the basis for the following. A 90 m section of the Blacksmith Fork River in northern Utah was mapped, utilizing a transect spacing of 2 m in areas of non-uniform channel structure, and 4 m where channel structure was relatively uniform. Current velocity and light intensity at fish depth, and total depth were measured at 1/2 m intervals along each transect. Maps were then constructed depicting the usable habitat for resting and for feeding trout (Gosse 1981). Suitable habitat components were defined as depths greater than 20 cm, current velocity less than 15 cm/second (for resting trout) and less than 45 cm/second (for feeding trout), and light intensities less than 5% of incident (for resting trout) and less than 50% (for feeding trout). Fish from this study area were included in the large sample used to establish the range of habitat component values which would be designated as suitable habitat, but comprised less than 3% of the total example.

A modified scuba technique (Gosse and Helm 1982) was used to locate brown trout in this area of stream for comparison with the previously constructed map. A series of 15 dives over a 35 day period insured coverage of all parts of the area. Stream discharge varied little during this period. Some 116 brown trout were observed and measured at 68 locations. The same series of component measurements mentioned above was made at the location of each fish sighted. Fish locations for various activities and fish sizes were then transferred to maps. Finally, fish location maps were overlayed on maps of depth, current velocity and light intensity.

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RESULTS

Most fish observed were in areas identified as usable habitat (Fig. 1). An examination of the components measured at sites occupied by brown trout compared to previously mapped values at those sites (Table 1) indicates a high percentage of the sites occupied by brown trout were identified as usable habitat on the map. Fifteen of 19 occupied sites were in suitable component ranges for resting trout, although only 12 of those 19 sites were so mapped. Thus the map showed 7 of 19 sites (37%) in unsuitable microhabitat, when in reality only 4 of 19 (21%) were so situated, for a sampling error of 3/19 or 16%. Most incorrectly indentified sites were situated between transects, and a greatly increased mapping intensity would be required to reduce this relatively small error.

Forty-five of 49 sites were in suitable component ranges for feeding trout, although only 37 sites were so mapped. In this case the map showed 12 of 49 sites (25%) in unusable microhabitat, when by measurement only 4 of 49 (8%) were so situated, for a sampling error of 8/49 or 16%. For both resting and feeding fish, mapped microhabitat components correctly indentified brown trout locations with an accuracy of 84%. A chi-square test of the hypothesis that sites were distributed uniformly in the study area, that is, proportionally in both usable and unusable microhabitat, was significant (P < 0.01) for both feeding and resting sites (Table 2).

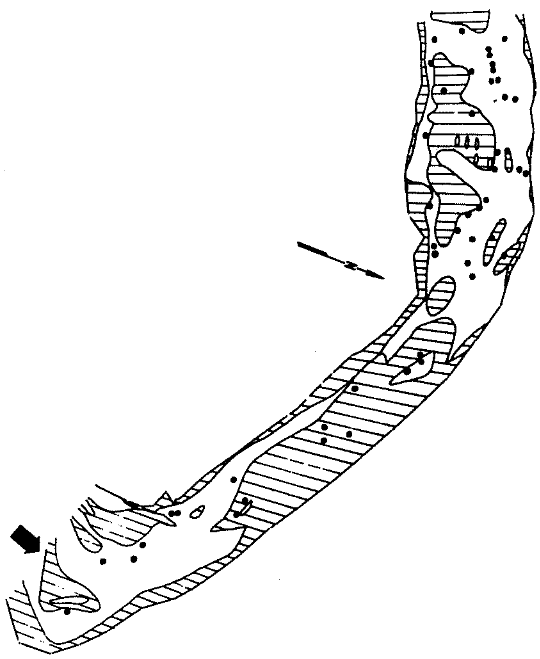

Figure 1. Feeding brown trout locations (dots) in the Blacksmith Fork River, Utah. Hatched areas represent regions where depth, velocity and/or light were outside the defined suitable ranges. Dots along shoreline mark ends of transects.

Table 1. Habitat components at sites occupied by brown trout compared to components as mapped at those locations. Values above the diagonal line are the number of occupied sites which were in the designated mapped component ranges; below the line the number of occupied sites which by measurement were in the designated component ranges. Suitable microhabitat ranges are underlined. All fish were in suitable depths.

Current velocity	Resting	
	Light	
cm/second	0-5% of incident	above 5% of incident
0-15	12 / 15	4 / 1
Above 15	2 / 3	1 / 0

Current velocity	Feeding	
	Light	
cm/second	0-50% of incident	above 50% of incident
15	15 / 20	1 / 1
16-30	12 / 20	1 / 2
31-46	10 / 5	2 / 0
Above 46	5 / 1	3 / 0

Increasing the resting fish velocity and light ranges by as little as 6 cm/second for current velocity and 20% for light would affect three (16%) fish locations. Increasing the ranges for feeding fish by 6 cm/second for current velocity and 15% for light would affect 7 (14%) fish locations. Thus the ranges of the physical components which are established as suitable have a marked effect on the estimates of the amount of usable habitat.

Table 2. Comparison between distribution of brown trout and of usable and unusable habitat.

Activity	Chi-square	P
Feeding	31.2	less than .01
Resting	98.9	less than .01

According to the suitable ranges, a portion of the depth, velocity, and light ranges occupied by resting trout should also be suitable for feeding trout, and this indeed occurred. Some areas were used almost exclusively for resting, where feeding fish were seldom if ever found. Such areas were typically close to the stream bank where brushy vegetation extended closely over and often into water of 20 cm or more in depth. Areas of both very low current velocity and light intensity appear to provide ideal resting microhabitat.

Brown trout were not uniformly distributed throughout usable microhabitat. This may indicate that some unmeasured component influences selection of sites within usable areas, or that trout exhibit preferences within the ranges of measured components. We do not yet know enough about the utilization of habitat, and the affect of small differences in component values to explain this.

DISCUSSION

Typical daily activity patterns of adult brown trout include moving from regions of low velocity, deeply shaded water where they have been resting, into somewhat faster water to feed, and back to resting habitat again one or more times each 24 hours (Gosse 1981, Kimball 1972). Juveniles occupy much the same total habitat, but by a temporal adjustment reduce spatial competition. Although there are no specific measurements of the distances these fish will travel between resting and feeding sites they must be within the movement radius of the fish (Baldes and Vincent 1969). Circumstantial evidence suggests that this distance would be much less than 100 meters (Gosse 1981). Long reaches of modified stream channel with excellent macroinvertebrate population levels, extensive areas of feeding microhabitat but very little resting microhabitat contained very few brown trout (Wydoski and Helm 1980). High densities of trout were related to areas with larger amounts of resting microhabitat interspersed with feeding microhabitat (Gosse 1981).

Age 0 fish have greater limitations on their habitat than do adults and juveniles. Distances between resting and feeding areas must be shorter, and resting areas must have structural complexity (Fraser and Cerri 1982) or shallow water depths where predaceous adults seldom venture (Gosse and Helm 1979).

It is clear that brown trout selectively occupy and utilize a predictable portion of the total habitat available to them. Further, given reliable suitability ranges, microhabitat components can be measured in a stream to determine the amount of usable habitat for each size group and each activity. To be applicable, measurements must be made at depths in the water column similar to those occupied by fish, related to fish size and activity. A limited number of components, measured in this fashion, may be adequate to describe brown trout habitat.

Habitat suitability functions may be developed to differentially weight the value of components within the suitable range. The simpler procedure of equating values within the range defined as suitable, which was utilized here, functioned well.

The applicability of suitability ranges derived from one region for use in another is not yet known. To be most useful such information should be widely applicable, but considerable variability from region to region, or stream type to stream type would decrease the accuracy of evaluation in any one region or stream type. Such a determination must await further testing.

Experimental procedures as described here, such as 2 m spacing between transects, would not be suitable for practical applications. Some practical projections can be made, however. Spacing transects more than 10 m apart produced maps with insufficient detail, as did spacing measurements at more than 2 m intervals along transects on this 13 m wide stream. Transect spacing was not critical for calculating the amount of usable habitat however, so long as a sufficient number (five or more) of randomly selected transects was used.

RECOMMENDATIONS

Based on our experience to date we recommend that physical habitat evaluation procedures be based on the habitat requirements of individual species, since our current research indicates there may be great differences in requirements among species. The components of the inventory system must also have some demonstrable effect upon the target species.

The life history of each species should be known well enough to determine whether there are behavioral differences which dictate the nature and time of use of various components of the physical habitat. Separation of the population into size groups based on behavioral differences may be necessary. Similarly, the various activities which comprise the daily routine of each size group of each species must be determined in order to establish their habitat component ranges. Potential seasonal differences in behavior and activities should also be evaluated. Suitable habitat component ranges for each activity should be established by determining fish utilization in a variety of streams encompassing a wide range of available habitat component values.

In addition, if habitat evaluation is to be most useful there is a need for information on:

a) Incorporating habitat diversity through development of realistic weighting factors for describing the usable habitat,

b) Rating for each size group, each activity and each season,

c) Dynamic evaluation integrating different flow regimes over various periods of time in order to quantify the amount of usable habitat at various flows and the affect of the frequency and duration of those flows.

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ESTIMATING SPAWNING HABITAT USING WATERSHED AND CHANNEL CHARACTERISTICS[1] (A Physical Systems Approach)

John F. Orsborn[2]

Abstract: Field investigations to measure the spawning habitat in a stream are time-consuming and expensive. Enough information is available to derive relationships and estimate spawning habitat within reasonable limits of accuracy. This paper explores the data from a study of steelhead spawning sites in Washington and develops new relationships between watershed, channel, flow and spawning habitat characteristics.

INTRODUCTION

A reach of stream is a dynamic system which exhibits interrelationships between varying amounts of flow and the physical boundaries of the system. A portion of the boundaries, the gravel bed, is used as a reproductive medium for anadromous and resident fish.

This paper explores some physical interrelationships between stream flows and the geometry of the channel which provide good spawning habitat. It is well known that streams flowing within certain bed and bank material exhibit consistent relations among width, depth, velocity and discharge (Tennant 1975; Orsborn and Deane 1976). Also, consistent relationships between basin characteristics and streamflow have been proven (Orsborn 1974, 1981). Therefore, the basin and channel characteristics are interrelated. Because the spawning habitat is part of these geometric flow systems, we should be able to estimate the amount of spawnable habitat in terms of flow, channel and/or basin characteristics.

What basic elements constitute this or any other physical system and its analysis? These elements include: 1) objectives as measures of performance; 2) the system environment; 3) resources within the system; 4) functional components of the system; and 5) management.

Although some of these elements may seem vague in terms of a spawnable reach of stream, we might improve clarity by considering two systems--one analytical and the other physical as shown in table 1. The analytical system for estimating spawnable habitat will be developed following a brief review of some methods currently available for estimating various aspects of spawning habitat and reproduction.

EXAMPLES OF METHODS FOR HABITAT ESTIMATION

A series of studies by the U.S. Geological Survey were conducted in western Washington streams and have yielded a wealth of data on spawning area, channel and basin characteristics (Collings and Hill 1973; Collings et al. 1972a and 1972b). Swift (1976) applied spawning and rearing criteria and developed a series of regression models for estimating discharges which satisfied various levels of steelhead spawning habitat. The basin and study reach characteristics of drainage area, reach altitude, mean basin altitude and reach slope were found to give the best correlation with spawning "optimum" flows. The reach slopes were actually the average slopes of the streams in the watersheds upstream of the study sites. This factor is discussed in more detail in a later section.

Combining these four variables in sequence, the correlation coefficient varied from 0.85 to 0.89, but the standard error was reduced only from 50 to 45 percent of the optimum spawning flow. By introducing the width of the channel at the toe of the banks the correlation coefficient increased to 0.96 and the standard error was reduced to 26 percent. The relationships for

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Table 1.--Analytical and physical systems describing a spawnable stream reach.

Element	Analytical Model	Physical Prototype
Objectives	Estimation of spawnable area.	Reproduction of fish.
Environments (Outside the system's control)	Physical boundaries of channel and water surface with flow entering from upstream.	Factors external to the gravel medium with flow from watershed entering and passing over and through gravels; land use impacts on quality.
Resources	Energy in the water medium due to gravity in balance with boundaries to form spawnable gravel deposits and provide desirable spawning conditions; data on streams; hydrologic cycle (time and variability).	Gravel, water flow, water temperature, chemistry and time arranged in cyclic patterns within deviations from the mean to which species have adjusted. These deviations include waterfalls and rapids which "deviate" from the usual swimming effort required to travel upstream.
Components (Functions)	Discharges; slope; channel cross section; basin characteristics relating to streamflow; resistance and boundary stability.	Gravel as a medium for eggs to receive water, oxygen; adult fish spawning; eggs incubation, hatching and emergence.
Management (Planning* and controlling the system)	Supplemental activities conducted within the natural cycles based on feedback to system through the hydrologic cycle.	Plan* to match controlled flows to natural conditions in artificial system; replan* based on new objectives and feedback.

* Planning applicable only to artificial systems with controlled releases; otherwise, control rests with natural hydrologic cycle.

estimating spawning and rearing discharges for salmon were generalized by Collings (1974) with similar results to those mentioned above for steelhead.

Swanston, Meehan and McNutt (1977) expanded the number of geomorphic terms in a management model to include several factors which they felt would help decide whether streams were either good or poor producers of pink and chum salmon. The additional independent terms not usually included in geomorphic types of analyses were: basin area with slopes greater than 34°; an avalanche index; the length of stream with an acceptable spawning gradient (<12%); the number of passage obstructions in the channel; and the number of lakes in the stream system.

Of the various regression models developed, an eight-variable function was tested. Its independent variables were: drainage basin area; basin area with greater than 34° slope; the Horton bifurcation ratio; the total length of streams; basin relief; the length ratio and basin orientation. Although these models were developed for management purposes, they seem to be data exhaustive and depend on statistical tests without being concerned with the physical significance of the parameters.

In a recent paper Newcombe (1981) discussed a new method for estimating changes in fish populations caused by changes in discharge, or an incremental analysis procedure. Using the weighted usable area concept, based on depth and velocity criteria, he was able to simplify field work and delete many factors used by other investigators. The main relationship was developed between weighted usable area and the mean discharge of each life-history phase. The method did require a considerable amount of field data for development, but ways of making further reductions are suggested. The method was compared with Tennant's categories ranging from <10% to 100% of average annual flow (poor to optimum habitat conditions). But, as shown by Orsborn and Deane (1976) and as mentioned by Tennant (1972), the percentages of average annual flow which provide poor to optimum conditions are dependent on channel geometry and the hydrologic characteristics of the stream.

These brief remarks covering existing methods of habitat estimation have described essentially three approaches, each governed by study objectives, but each dealing with the physical relationships between basin and stream characteristics, and spawnable area. The USGS summary reports by Collings (1974) and Swift (1976) used regression models of basin, channel and reach geometry to estimate spawnable area based on extensive transect data. The planning decision models developed by Swanston, Meehan and McNutt (1977) statistically tested the significance of numerous geomorphic basin and stream factors (variables) to decide whether a stream is potentially productive or non-productive, either very good or very poor. Newcombe's (1981) approach dealt with actual use of certain areas of the stream for spawning and rearing functions. This is a simplified approach to the commonly utilized area of analysis called in-stream flow methodology. The method developed in the next section of this paper relates the amounts spawnable area and discharges to basin, channel and streamflow characteristics which are physically interrelated.

DEVELOPMENT OF THE CONCEPTS

In the evaluation of flow analysis in streams, the first equation developed which considered the resistance of the boundary was described by Chezy (Rouse and Ince 1963). His equation was derived out of the necessity to design a water supply channel from the Yvette River to Paris in 1768. Chezy noted the relationships between observations at different cross sections in different streams and stated that it would be interesting to have similar, accurately measured observations on a wide variety of streams. We are fortunate to have such measurements made by the U.S. Geological Survey.

There is also a vast amount of excellent transect data in the files and reports of other federal and state agencies. A wide variety of empirical models could be developed for geological stream types which could then be combined into a generalized model. The expectation of this paper is that it will provide one basic step in that direction.

In applying the relationships among streamflow and and channel characteristics to the analysis of potential fisheries habitat, criteria must be selected based on observations. For example, Hunter (1973) made numerous observations and collated available data on preferred spawning depths and velocities. The ranges of spawning depths and velocities for numerous salmonid species are summarized in fig. 1.

The amount of potentially spawnable area increases as a function of discharge to a maximum value, and then decreases as shown in fig. 2. One of the first publications in which this relationships was described was written by Rantz (1964). The potential spawning area can be established according to the criteria of depth, or velocity, or both in combination. A typical descriptive relationship between spawnable area and streamflow is shown in fig. 2. The concepts of "optimum flow" or "maximum" spawning area are somewhat misleading though and practical limitations are discussed later. There are numerous

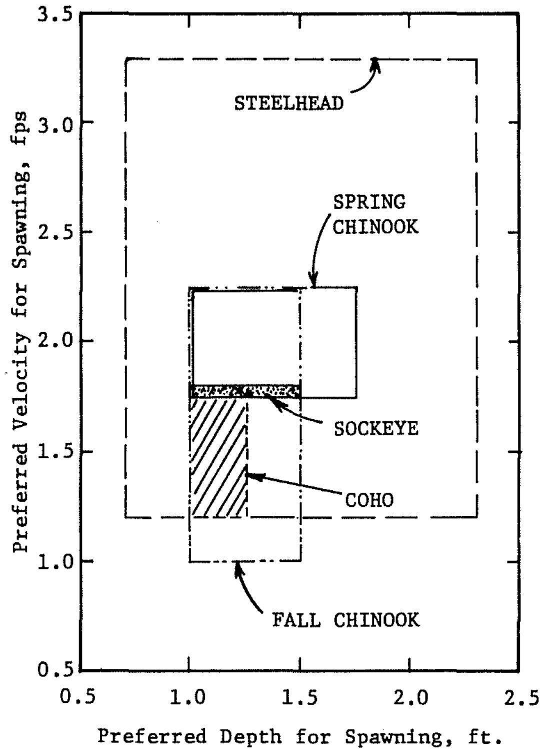

Figure 1.--Preferred ranges of depth and velocity for spawning salmon and steelhead.

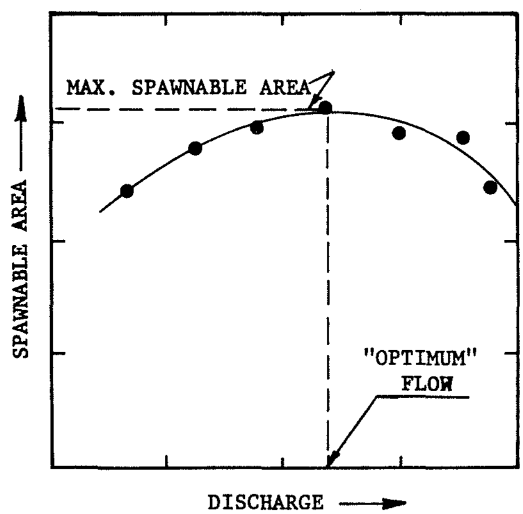

Figure 2.--Nomenclature for relationship between spawnable area and discharge.

other relationships between the potential spawning area and streamflow which need practical interpretation, but are not part of this paper.

Rantz (1964) developed a mathematical relationship for estimating optimum spawning discharge (Q_o) such that

$$Q_o = 0.89(Q_m)^{1.09} (W/DA)^{1.44} \quad (1)$$

in which: Q_m is the mean discharge; W is the stream top width; and DA is the drainage area. The optimum discharge (Q_o) was plotted as a function of mean discharge (Q_m) and then lines of different values of (W/DA) were superimposed on the original graph. The multiple correlation coefficient was 0.912, and at six degrees of freedom, a coefficient of 0.886 would be significant at the one percent level. Although the actual data points displayed a considerable amount of scatter, the relationship in eq. 1 does demonstrate that relationships do exist between spawning flows, mean annual discharge and channel and basin characteristics.

There are numerous ways for classifying streams, but with respect to fisheries needs, the method developed by Shirazi and Seim (1979) seems to fit very logically. The size distribution of streambed materials must be related to the local energy slope at the dominant bedload moving discharge, and thus the stream power.

In order to complete the analysis of factors affecting the potential spawning area in a particular stream reach, one must know the hydrologic characteristics at the site. Characteristic flows would include a mean flood flow (or bankfull flow), mean annual flow and a mean low flow. In addition, an estimate of the ranges of migration season flows should be known. An investigation of watersheds and flow relationships was completed by Strahler (1958) using dimensional analysis. One dimensionless number derived in this study using Newton's second law was a form of the Froude number of the watershed such that in dimensionless form

$$\frac{q}{\sqrt{gH}} \quad (2)$$

The term q represents the discharge per unit of channel cross sectional area, g is the acceleration due to gravity and H is the basin relief which accounts for all the potential energy of the stream flow in a basin.

If q is considered as a discharge per unit of drainage area (A), and eq. 2 is multiplied top and bottom by (A), then

$$\frac{q}{\sqrt{gH}} \cdot \frac{A}{A} = \frac{Q}{\sqrt{gH}\,A} \text{ ;or}$$

$$Q = C\sqrt{H}\,A \,. \quad (3)$$

Using this simple relationship and the gaging station records for the mid-coast region of Oregon, Orsborn (1981) developed a very adequate hydrologic model for the Suislaw National Forest. The model estimates for ungaged sites: flood flows of 2- and 50-year recurrence intervals; the mean annual flows (QAA) and their variability; low flows of 2- and 20-year recurrence intervals; the family of maximum, mean and minimum duration curves; the maximum, mean and minimum daily flows for the migration season of October-April and all other months; and the 30-day as well as 2-day low flows.

The form of eqs. 1 and 3 implies that the optimum flow (Q_o) is a function of basin characteristics above the reach in question, and the materials, gradient and channel geometry of the reach. Utilizing these, and a few additional interpretations, a new method for estimating spawnable area in an ungaged reach of stream is explored in the next section.

APPLICATION OF CONCEPTS

The study reaches closest to the gaging stations were used for development of this spawning habitat estimation model using data from Collings (1971) and Swift (1976).

The station identification numbers and stream names used in figs. 3-5 are given in table 2. Their locations are shown in fig. 3.

Various parameters were tested individually and in combination against the discharge (QMSA) at which the maximum spawning area is available at each study reach. Exploratory plots were made for : QMSA versus average annual flow (QAA); $A\sqrt{H}$ from the watershed analysis; and a ratio of the two-year peak flood flow (QF2P) to average annual flow (QAA).

Table 2.--Study reaches near USGS gaging stations.

Station No.	Stream Name
3	Dewatto River
6	Kalama River
7	North Fork Nooksack River
10	Elochoman River
12	Humptulips River
13	Green River
16	Wynoochee River
19	Deschutes River
20	Dosewallips River
26	Bear Creek
29.2	Issaquah Creek
32	North Nemah River
34	South Prairie Creek

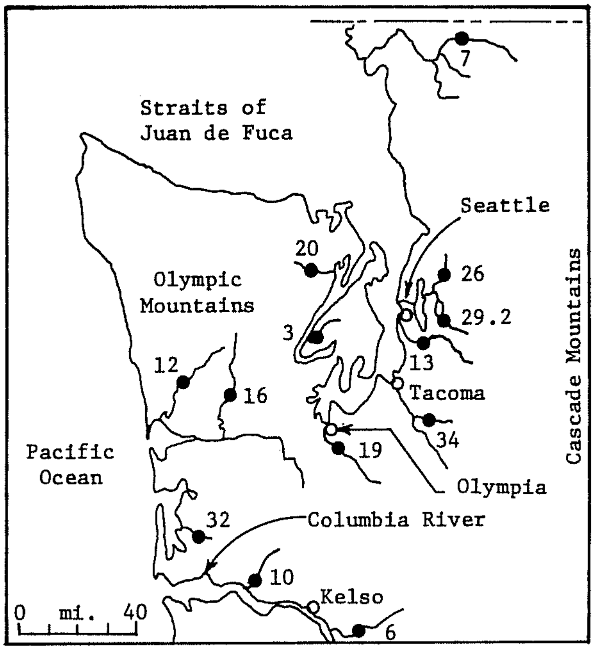

Figure 3.--Location of study reaches in western Washington. See table 2 for reach numbers and stream names.

The best combination of basin, channel and flow factors tested turned out to be as shown in fig. 4.

$$QMSA = 40\left[\frac{A\sqrt{H}}{SC}\quad\frac{(QAA)^3}{(QF2P)^2}\right]^{0.33} \tag{4}$$

The only term not previously defined symbolically is (SC), the slope of the channel. The values given by Swift (1976) for the mean channel slope between headwaters and the study reach were used. If local slopes in the spawning reaches were to be used, a closer correlation would probably result than is shown in fig. 4. The relief term (H) was determined by using the mean basin elevation as published by Collings (1971), subtracting the station elevation, and multiplying by two. Utilizing the differential elevation between the headwater basin contour and the station may improve the relationship in fig. 4 as well.

Two sets of limits are shown in fig. 4. The pair of long dashed lines nearer the solid mean line denotes values of ±15 percent about the mean if the three extreme points are deleted from the regression. Referring to fig. 2, the flatness of the spawning area-discharge

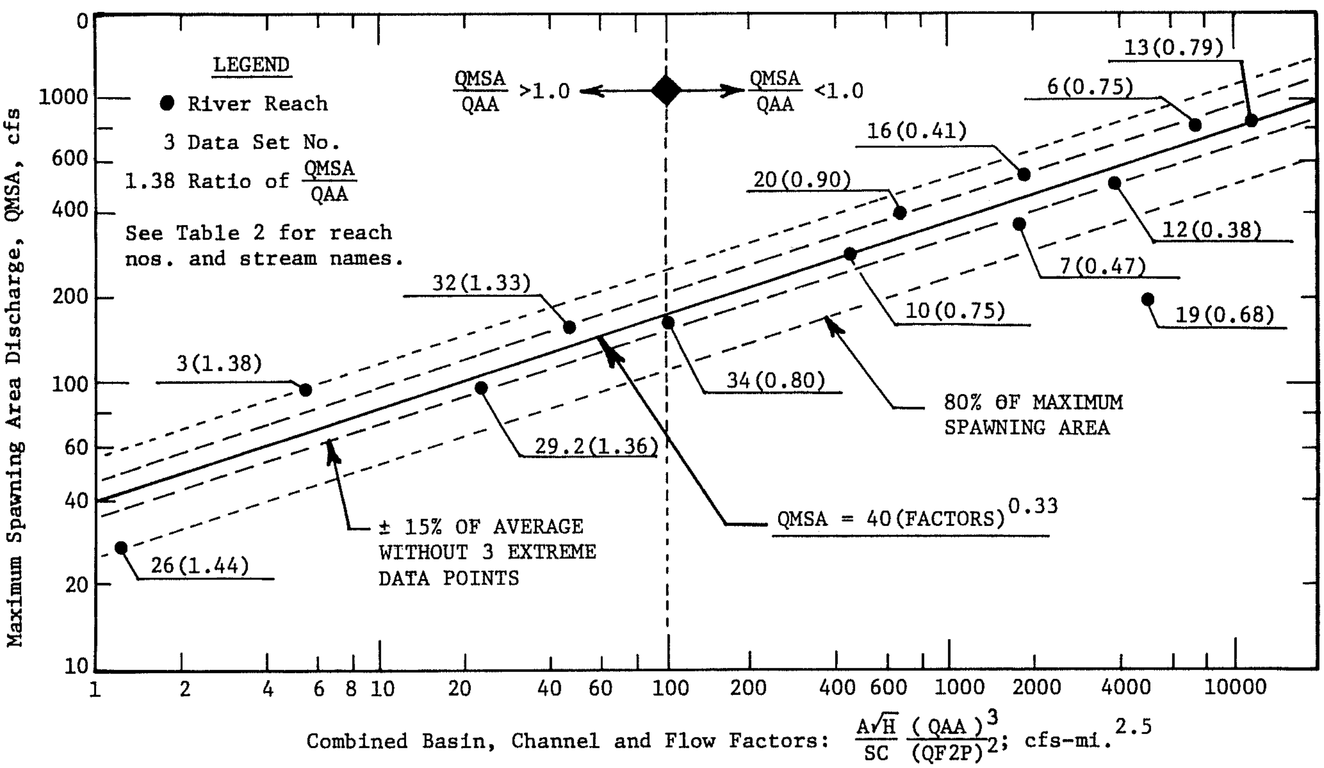

Figure 4.--Steelhead spawning discharge with maximum available area related to basin, channel and flow factors in western Washington streams.

relationship is noted. By examining the actual graphs for each study reach it was found that even for a 50 percent change in flow about the optimum, about 80 percent of the maximum spawning area would be available. Therefore, the two outer boundaries formed by short dashed lines in fig. 4 denote flows ±50 percent about the "optimum" flow as denoted by the mean line. Note that all the thirteen stations are included within these ±50 percent flow lines.

Considering the facts that: discharge measurements are considered to be good at ±5 percent; the actual area available for spawning in most reaches changes during flood periods; the depth and velocity criteria themselves have some variability; and that the fish will spawn at the required time and place even at half-body depth, then this approach to estimating spawning area seems quite adequate.

Note in fig. 4 that when the combined factors (x-axis) are less than 100, (QMSA/QAA) >1.0 and when the combined factors are greater than 1.0, (QMSA/QAA <1.0). Average flow is included to allow for the (QMSA/QAA) relation, and flood flow is included to account for a channel-forming factor. Either gaging station records or streamflow estimates are needed at the estimation site.

With this hydrologic necessity in mind another method was explored for quick estimation of the maximum spawning area without having to know any flows. Part of the data in Swift (1976) included a table which gave the total streambed area for bankfull flow.

By plotting the maximum spawnable area (MSA) versus the bankfull streambed area (BFA) as shown in fig. 5, a series of physical relationships can be examined. Assuming that the MSA and BFA are measured with equal accuracy then the variations in the plotting points in fig. 5 must be due to differences in channel geometry for the most part. The equation shown in fig. 5 for the solid line is merely a rough approximation of a mean value considering all thirteen station points. Data points 6 and 12 are for the Kalama and Humptulips Rivers, respectively. If these two points are neglected the equation of a line gives

$$MSA = 0.45(BFA)^{1.25} \qquad (5)$$

with only stations 7 and 10 (North Fork Nooksack and Elochoman Rivers) not fitting this new line (line not shown in fig. 5 to avoid crowding).

There is an obvious upper limit to this relationship which occurs when the maximum spawnable area occurs at bankfull flow

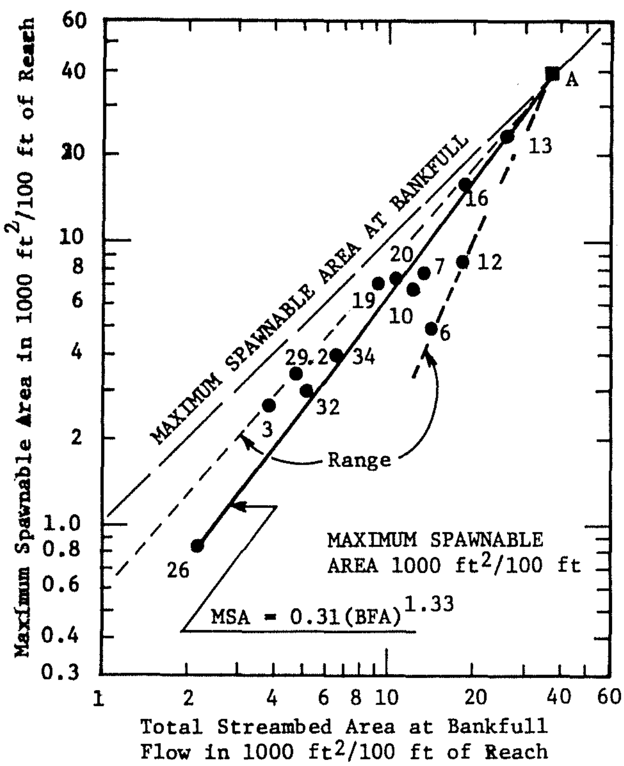

Figure 5.--Maximum spawnable area related to bankfull streambed area in western Washington streams. See table 2 for reach numbers and stream names.

conditions. As streams get larger (e.g., the Green River, No. 13), they approach this condition. The geometry would probably be a wide channel with low banks, and essentially rectangular in cross-section. This geometry has been assumed without having seen the Green River site, or any of the other transect stations. Note that the upper short-dashed line through stations 3, 29.2, 19, 16 and 13 defines the real (assuming the channels are in a natural condition) maximum upper limit that could be expected to occur in any stream.

Before concluding these remarks, another observation should be made. Recalling fig. 4, stations with x-axis values less than 100 had (QMSA/QAA) ratios greater than 1.0. These same four stations (nos. 3, 26, 29.2 and 32) are also the four smallest streams in terms of spawning area, though not the least efficient in terms of MSA/BFA. These streams are the Dewatto River (3), Bear Creek (26), Issaquah Creek (29.2), and the N. Nemah River (32). The (QMSA/QAA) values of greater than 1.0 are 1.38, 1.44, 1.36 and 1.33, respectively, with an average of 1.38 and a variation of only ±4.4 percent. Considering the relative accuracy of the various components in the analysis, it probably means that these streams all have geologic and hydrologic characteristics which require a flow about 38 percent greater than the average to achieve the maximum spawnable area. The two streams which require the least flow to achieve the maximum spawnable area are the Humptulips (12) and Wynoochee (16) Rivers. Their (QMSA/QAA) ratios are only 0.38 and 0.41, respectively. Both of these rivers drain to the south in long, narrow watersheds out of the Olympic Mountains and into the Chehalis River (see fig. 3).

DISCUSSION OF RESULTS

The fact that spawnable area in a stream is related to basin, channel and streamflow factors has been demonstrated using data which could be improved by other measurements. Definite relationships have been shown which exist between optimum spawning flows and the average annual flow in streams within hydrologic-geographic provinces. Also, physical limits and a simple, consistent relationship between the maximum spawnable area and the bankfull bed area of streams has been shown to exist. This defines an upper physical limit--normally there could be no larger amount of spawnable area. It therefore appears that further analysis is warranted and that thorough theoretical and verifying field studies should be undertaken to develop the interties between basin and channel morphology, hydrology, river mechanics and the potential of a stream for fish production.

Proposed steps would include: (1) reexamination of the thirteen tests sites near gaging stations to determine constancy over time, in spawning area and flows relations; (2) reexamination of the other USGS test reaches farther from the gages; (3) classification of the stream sections by such channel characteristics as the spawning habitat analog of width to depth ratio, and the relationships between water surface width, mean depth, mean velocity and discharge; and (4) a thorough analysis of each reach using fluid mechanics, control volume techniques and factor analysis to develop the theory behind a technically sound, quick, inexpensive and useful method of spawning habitat assessment.

The spinoffs from the development of such a methodology are obvious to persons familiar with current methods of instream flow need analysis. These methods are time-consuming, field data-intensive and computer-exhaustive.

We have the data, the fundamental physical relationships and the knowledge of upper and lower physical boundary conditions which cannot be exceeded in the real world. An in-depth analysis should be able to bring a better degree of order to our current methods of analyzing spawning and rearing habitats, as well as determining the impacts of incremental flow withdrawls on instream flow needs. The physical relationships exist--all we have to do is made certain we do not violate those relationships when we generate our models, imperfect as they are. A good place to start would be to realize that what we call "optimum," based on the availability of spawning gravels within a certain range of flow and depth criteria, probably does not exist at spawning time. The fish try to spawn at places where they are the most certain that interflow through the gravels will provide the highest probable hatching success. Also, the fish spawn in only 40-60 percent of the "spawnable area" depending on the diversity of the habitat, and under the existing flow conditions when they are biologically stimulated to spawn.

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A TECHNIQUE FOR MAPPING STREAM CHANNEL TOPOGRAPHY AND HABITAT USING THE RDS/PAL COMPUTER PROGRAMS[1]

Robert A. Ruediger [2] and John D. Engels [3]

Excellent quality topographic maps of wadeable stream channels can be produced directly from field data using the Forest Service Road Design System (RDS) computer programs. A two-man crew can survey 1200+ feet of stream per day. Procedures necessary for acquisition and submission of field data are outlined. Stream reach habitat components may be added to the contour pit to create a stream habitat map.

INTRODUCTION

Topographic maps of stream channels have been prepared by a variety of methods ranging from simple free-hand sketches to labor intensive plane table and alidade or transit-stadia surveys. The choice of method has been dictated by the surveying background of the individuals involved and by the amount of time available for mapping. While adequate maps can be prepared by these methods, these approaches require a considerable amount of drafting time and can become a very expensive item to produce. While biologists have been conducting these types of mapping surveys, road engineers have had access to highly sophisticated computer programs for a number of years. In a synthesis of these two disciplines, the Bureau of Land Management's (BLM) Coos Bay District has been making use of the Forest Service Road Design System (RDS), to prepare highly detailed site surveys of wadeable stream channels. Via direct use of existing and available Percent Abney Level (PAL) and associated plotter programs, we have been able to obtain highly accurate 1-foot contour maps at considerably lower cost. The procedure is time efficient; a two-man crew can survey 1200+ ft. of stream in a day and no office time is required to draw the map.

"The road design system...consists of a series of interrelated computer programs with the purpose of performing the many tedious and repetitious mathematical calculations required in road design." The system includes the capability of plotting most engineering graphics; a Forest Service version of Calcomp's General Purpose Contouring package is used to generate the contour map. PAL is a compass traverse program which computes elevation from input of percent slope along the traverse (USDA-Forest Service 1981). The percent slope input format makes the survey procedure so simple and fast. RDS system access is readily available to U.S. Forest Service (USFS) and Bureau of Land Management personnel.

This technique has been used to generate contour plots of stream channels for stream habitat improvements, road planning (i.e., bridge and culvert layout), bank stabilization surveys and hydraulic improvements (channel changes, weirs, etc.). A stream channel is similar to a road in overall shape and profile and lends itself easily to the survey procedure. The technique is applicable to nearly any wadeable 4th-6th order (Strahler 1952) stream.

THE PAL SURVEY

The following procedures enable fisheries personnel to obtain all necessary data to produce the stream channel contour map, however we want to emphasize that coordination with road engineers knowledgeable in the RDS system is essential for best results.

Equipment needed for the survey includes a staff compass, clinometer, 100 ft. reinforced cloth tape, two height of instrument (H.I.) sticks (saplings or cane fishing poles are

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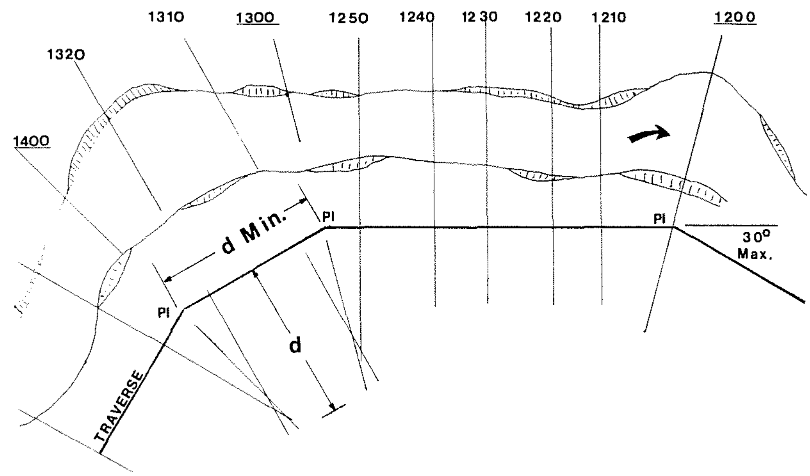

Figure 1. Typical layout of the RDS/PAL survey along a stream channel showing the traverse, cross-sections and section numbers.

adequate), wood "P" stakes, and a field notebook. A 200 ft. metal tape, marking crayons, and plastic flagging may also be useful.

Traverse

The PAL survey involves staking a traverse, or "P" line, up or along the stream channel using the staff compass and tape (fig. 1). The traverse must be continuous and should run generally parallel to the stream. A straight line traverse, consisting of only two points, is often feasible. If the stream is curving, the traverse should be located on the inside of the curve. This reduces intersection of cross-sections and overlapping of contours within the primary mapping area.

Points at which the traverse changes bearing are angle points (PI's). Deflection angles should not exceed 30° (fig. 1). Smaller deflection angles reduce or eliminate contour overlap caused by the contour rounding feature in the computer program. Minimum distance (d) between angle points should be equal to the cross-section width on the interior side of the angle, measured from the traverse centerline. This will also reduce contour overlap.

Slope distance and percent slope ahead of each section is recorded. Percent slope is measured using two H.I. sticks of the same height and a clinometer. With percent slope measured to one-half percent, and slope distances of 50 ft., accuracy to 0.1 ft. is possible.

To insure that all the topography is used on the contour plot, it is recommended that a "dummy" traverse point be placed at the beginning and end of the project (i.e Sec. 1000 would be input with 10' slope distance, 0% slope and the bearing ahead; fictitious topography data would be entered [i.e. 0.30 0/0 0/30] - Section 1005 would be the first point that physically resides on the ground and would have the measured slope distance and % slope ahead entered with topography data on the right hand side of the book. . .The last point on the ground would be an intermediate point preferably [although it could be an angle point with the same bearing ahead as the previous PI] with a slope distance ahead of 10' and a % slope ahead of 0%; fictitious topography data would be entered).

Topography

Topography data is taken in the form of cross-sections. The key to cross-section placement is to take enough cross-sections to adequately define channel variations. Cross-sections must be taken perpendicular to the traverse. At angle points, cross-sections should bisect the angle since the program makes that assumption and does its interpolation accordingly. It is usually desirable, but not required, that cross-sections be taken at the angle points.

Cross-section are taken by recording slope distance and percent slope to all important channel features along the cross-section (fig. 2). A maximum of 44 shots may be taken to the left and right of the traverse; for a total of 45 shots, including the 0/0 at the centerline. It is required that at least one shot be taken on either side of the "P" line. Cross-sectional widths may vary if done gradually. The maximum width change allowed on a given side of the traverse equals the distance between adjacent sections.

Starting points and/or cross-sections should be permanently located or referenced if future resurveys are planned. This is important if it is necessary to reproduce particular cross-sections to document channel changes.

Specific Guidelines

1. Beginning criteria

   a. Station (use 10+00 unless extending an earlier survey). This will enable you to extend your survey beyond its original "beginning" without getting into negative section numbers which are not allowed.
   b. Elevation (assign or pick from topography map unless extending an earlier survey, minimum allowed is 100.00 ft.).
   c. Coordinates (use N 50,000.000 E 100,000.000 unless extending an earlier survey or leaving another survey).

The beginning criteria must be stated before the first cross-sectional data is entered (fig. 3).

2. Section numbers

   a. Angle points (PI's), beginning of project, and end of project must be designated by making the last two digits of the section number zero's (100, 200, 1700, etc.). The last station of the "P"-line must be designated in this manner. Section numbers may range from 00 to 99900. It is recommended that some 'room' be left at the beginning of the project should it become necessary to extend the survey in that direction (i.e. using a beginning section number of 1000 would allow 9 additional PI's [100-900] should this become necessary).
   b. Intermediate points are then assigned section numbers in ascending sub-increments of at least 5. The last 2 digits of an intermediate point section number shall never be zero. Sub-increments of 5 are used for intermediate points so that additional sections can be added at a later date, if desired.

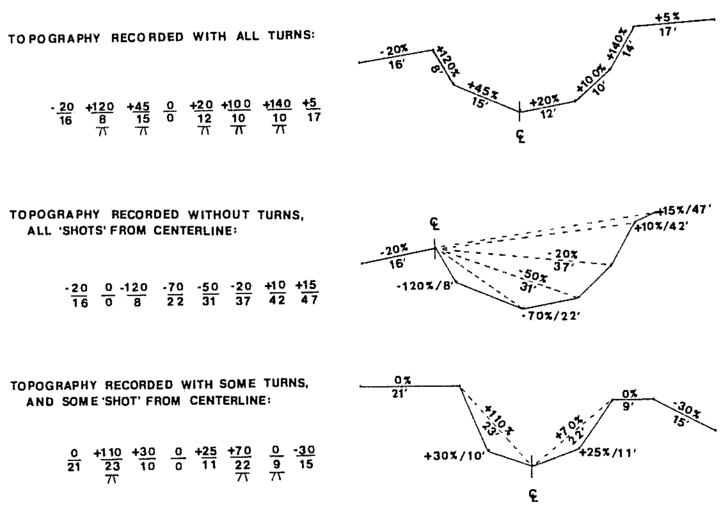

Figure 2. Three methods to "shoot" and record topography (cross-section data of a stream channel for the RDS/PAL survey.

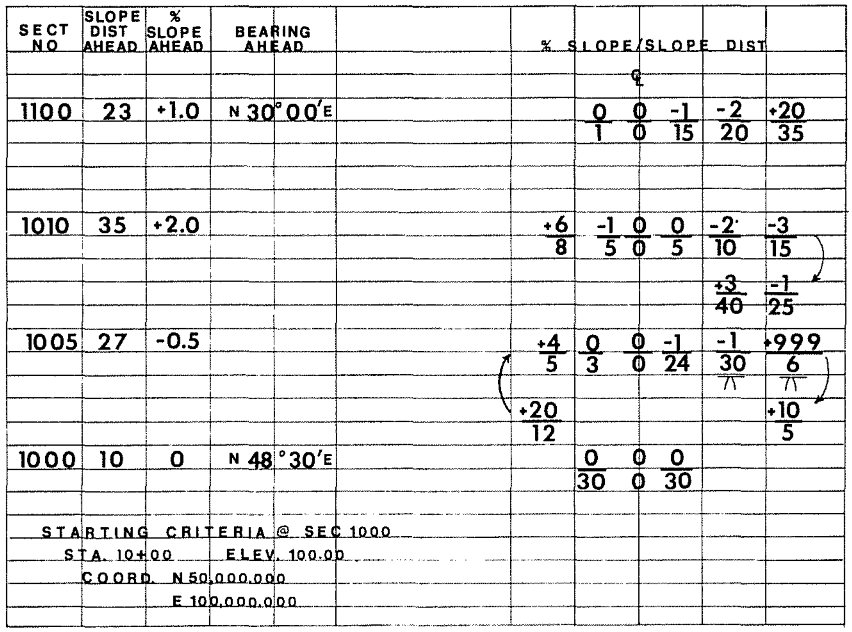

Figure 3. Field note format for the RDS/PAL survey with traverse data (left) and topography data (right).

3. Slope distance along traverse

Recording slope distance to the nearest foot is recommended; however, distances may be established to the nearest one-hundredth foot.

4. Percent slope along traverse

Record the percent slope ahead at each station to the nearest one-half percent. An abney level or clinometer is suitable for this measurement.

5. Bearing

Record the bearing ahead at each angle point (PI) to the nearest quarter degree. Cardinal directions must be expressed by quadrant (i.e. North would be entered as N00°00'W or N00°00'E). Fractional bearings must be expressed as deg/min (S05°30'W).

Care must be taken in the placement of angle points and in designating the new bearing ahead, particularly at sharp bends in the stream channel, to prevent cross-sectional lines from intersecting. However, due to the interpolation and rounding algorithms in the computer software it is more desirable to intersect cross-section lines than to truncate them. The traverse should be placed on the inside of the stream curvatures whenever possible.

6. Topography (Cross-sections)

a. Percent slope with slope distances as with traverse.
b. o/o must be entered at each section on centerline. This symbol (o/o) indicates to the computer where the cross-section originates in relation to the 'P'-line.
c. Minimum topography left and right will be 25 feet (50 feet total); this is a general recommendation. We recommend that the traverse be on the periphery of the mapping area and not down the channel center, whenever feasible. In this case, a shot 1 ft. from the "P" centerline (away from the stream) would be common; satisfying the requirement for at least one shot on either side of centerline.
d. Use turns ( ) where useful. Turns are especially useful where gravel bars obstruct visibility along the transect line and at or above the stream banks. Turn symbols ( ) must be shown directly below the last reading recorded prior to moving the instrument within the cross-section (fig. 2).

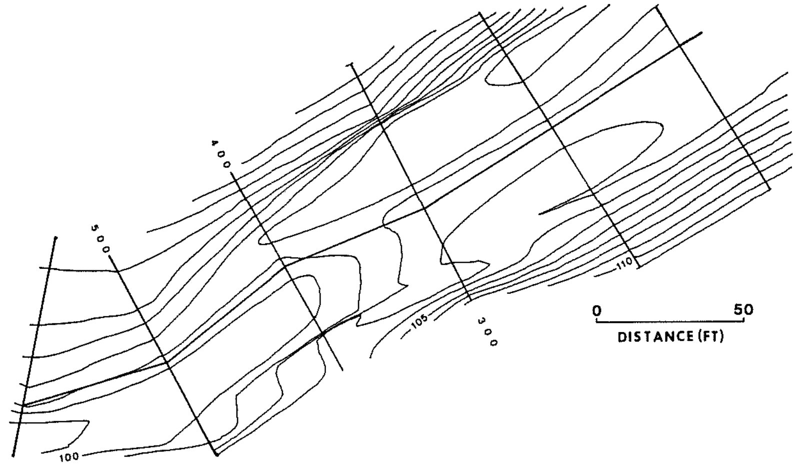

Figure 4. Representation of a computer generated contour plot produced by the RDS programs.

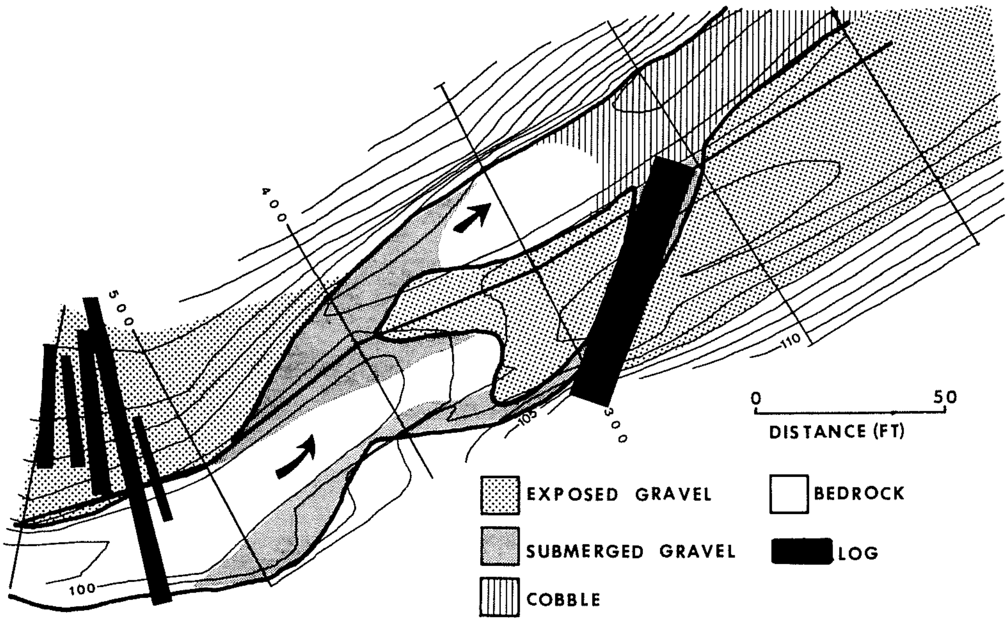

Figure 5. Stream habitat map using the RDS generated contour plot as a base map.

Figure 2 gives examples of cross-sections with (1) turns made at each channel feature, (2) with no turns involved (all points "shot" from the traverse), and (3) a combination of "P" line shots and turns. Also shown is how these examples would be recorded in the data books. Our experience has been that improper placement of turn symbols ( ) or ommission of the symbol was the most common error made in the data. Each time a turn is made, the person handling the instrument must move to the point of the turn. The following measurements of percent slope and distance are taken from this new location, with the new location being 0 feet for the distance measurements.

Vertical changes in the streambed or banks can be handled using turns and special notations of (+999) for percent slope in an upward direction or (-999) for percent slope in a downward direction. If the special ±999 notations are used, a turn must be made at both ends of the vertical. The height of the vertical bank is recorded as slope distance. This should not be used unless the bank is vertical or overhanging. In case of an overhang, pick a point midway in distance between the bottom and top of bank and define it as vertical; the system will not accept an overhang.

Data Submission for BLM/USFS Processsing

Figure 3 shows how PAL survey data must be recorded. Note that section numbers are in ascending order on the left side of the page; this is the standard engineering format. The left page is for "P"-line information. The right page is for cross-section data. The symbol(o/o) must be at the center of all cross-sections. Percent slope and slope distance are recorded in the form percent slope/slope distance. If cross-section data is too long for one line it is continued directly underneath; arrows are used to show that the line is continued. These arrows must be shown in a clockwise manner because data is fed into the computer from the extreme left to the extreme right of the cross-sections.

Data from BLM is submitted to the BLM Denver Service Center; USFS data is submitted to the appropriate USFS Regional Office. Field notes should be submitted to minimize errors caused from copying. All data submitted must be uncluttered and legible at arm's length. Two forms must accompany the data, (1) EDP Transmittal Sheet, Form 9100-10 (BLM) or Form FS-7700-500 (USFS), and (2) EDP Transmittal for Plotter Programs, Form 9100-106 (BLM) or Form FS-7700-501 (USFS). A copy of each form should be completed for each stream reach to be mapped. The following items should be completed on the EDP Transmittal Sheet:

1) Project name and No. - an identifying name for the stream reach.

2) New Job, Old Job - indicate whether this is the first submission of data for this project or whether previous data has been submitted and stored.

3) Job ID No. - The number will be assigned by processor. This number is specific to each reach and should be retained for future access to the data. Job ID Number is the file code for your project. Fill in if accessing previously filed data.

4) Section Numbers - indicate first and last station in the reach.

5) Card Types - check 12, 13, 54 (BLM only).

Under Field Data Reduction and Preliminary Design check the first boxes for

6) TRAV (BLM only).

7) PAL (BLM, USFS) (store after-check Yes, USFS only).

8) UPDATE - check RT-54 (USFS only).

For contour maps these items should be completed:

1) Contour plot (BLM) or Trav Plot (USFS)-check, also check the box at Trav (BLM) and indicate desired scale and contour interval. Scales are available from 1" = 1' to 1" = 9999'. From our experience a scale of 1" = 10' or 1" = 20' is best for 3rd - 6th order

Contour intervals are available in integral increments from 1 ft. to 50 ft. with the following limitations:

(a) For scales of 1" = 1' to 1" = 99', the contour interval may vary from 1 ft. to 10 ft. A 1 ft. contour interval is best suited for fisheries work.
For scales of 1" = 100', the contour internal may vary from 2 ft. to 20 ft.
For scales of 1" = 101' to 1" = 9999', the contour interval may vary from 5 ft. to 50 ft.

To obtain channel cross-sections complete:

2) Cross-section Plot - check, also check "'P'-line" and indicate the desired scale. Scales of 1" = 1-9999' are available.

Contour Maps, Data Print-out, and Cross-sections

The field notebook, a computer print-out of the data, the contour map (fig. 4)and cross-sections (if requested) are usually returned within two weeks. Standard contour maps are plotted on 36" velum sheets. Length of stream reach per sheet will depend on channel sinuosity and plot scale. Angle point section numbers and boss contours are enumerated on the contour plot. Each map section also includes date, contour interval, scale, project name and

ID number, designer's name and North declination. Standard contour maps are printed in three colors; "P"-line in blue, cross-sections in black, and contour lines are in red with black boss lines.

Computer print-out of the survey data includes three sections: (1) original "P"-line and cross-section data from field notes, (2) traverse data with station elevations, and (3) topography reduced to rod/distance. Errors or potential errors are flagged on the reduced topography print-out (3). "Overhang" and "centerline missing" errors must be corrected. Overhangs occur whenever the distance of one topography point is less than the previous point, measured from the centerline (i.e. distance recorded wrong, turn symbol missing, etc.). It should be stressed that errors such as incorrect bearings, slope distance, or percent slopes will not be indicated and will be plotted as submitted. Consultation with personnel knowledgeable in RDS is advised before error corrections are attempted.

Stream channel cross-section plots at each station along the "P"-line are also available. Each cross-section plot includes the station number, "P"-line location and distance and elevation along the "P"-line.

DEVELOPING THE HABITAT MAP

Once the contour plot is available, the stream habitat map can be developed (fig. 5). The intensity of the habitat survey depends on the use of the final product. Three methods of locating habitat features, in order of increasing accuracy, are (1) ocular, (2) bearing and distance survey, and (3) photographic. Figure 5 was developed from an ocular survey using the contour plot as the base map. Oregon State University, Department of Fisheries and Wildlife, has developed a system for taking low level (50-100 ft.) aerial photographs of stream channels. Combining overhead photographs with the PAL survey should produce highly detailed and accurate stream habitat maps. The "P" line stakes serve as reference points for accurate location of habitat features in the field. Field notes or photographs can then be easily referenced to the traverse on the contour plot. Important habitat characteristics include the waterline; flow patterns; pool, riffle and run areas; gravel bars; boulders and logs; riparian vegetation; waterfalls; side channels and over-flow channels; and substrate type (bedrock, boulder, cobble, gravel, sand, silt), etc.

DISCUSSION

The habitat map provides the fishery biologist or stream manager with an accurate representation of a stream reach. From the map, the location and quantity of various stream habitat components can be determined. Pool area and volume, riffle area, and area of the different substrate types (bedrock, boulder, cobble, gravel and sand) are a few examples of measurements that can be taken directly from the map. Fish spawning and rearing habitats can also be quantified. Patterns of erosion and deposition can be recorded, including future pattern changes. Formation of gravel bars and scour areas are greatly influenced by structures in the stream such as logs, root wads, or boulders. High flows may move these structural components within the stream channel sometimes resulting in dramatic changes in habitat. Documentation of such changes can be accomplished with little effort or expenditure of time.

On the Coos Bay District we used the PAL technique to develop base maps for stream habitat improvement projects. The maps have provided us with the site specific information necessary to design structures to create spawning habitat and pools to increase available rearing area for anadromous salmon and trout. Using these mapping procedures we can accurately resurvey stream reaches after projects are constructed to determine what effects the projects have on the stream channel and fish habitat.

This paper is intended to acquaint the biologist with the PAL survey procedures and some of its capabilities, and should not be considered the final word on the subject. We encourage and advise consultation and coordination with road engineers knowledgeable of RDS/PAL procedures to insure best initial results. We also strongly recommend consultation with the Engineering Computer Applications Unit, BLM-Denver Service Center, Denver, Colorado, for expertise on the Forest Service Road Design System.

ACKNOWLEDGEMENTS

We would like to thank Glen Coffman and Tommy Hubert of the BLM-Denver Service Center, Engineering Computer Applications Unit, for reviewing an early draft and for their willingness to share their knowledge of the RDS System. We would also like to thank Neil Armantrout and Robert House for reviewing the manuscript.

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SESSION 3B

Moderator: Al Elser
Montana Fish, Wildlife and Parks
Miles City, Montana

The Following Not Included in Proceedings:

Cleveland Steward and Q.J. Stober, Fisheries Research Institute, Seattle, Wash.
Salmonid Habitat and Population Dynamics in an Urban Stream.

THE MONTANA INTERAGENCY STREAM FISHERY DATA STORAGE SYSTEM

George D. Holton, Robert C. McFarland, and Burwell Gooch[1]

Abstract.--The Montana Interagency Stream Fishery Data Storage System allows the Montana Department of Fish, Wildlife and Parks, the U.S. Forest Service, the U.S. Bureau of Land Management, and other agencies to enter stream fishery survey information into a common computer file for retrieval by anyone interested. The system facilitates access to fishery information by resource managers and planners. Resource developers use it to identify streams that should receive special consideration. It is a synthetic approach as it contains mostly interpreted information instead of individual data items. The system is operational and serving well.

The Montana Interagency Stream Fishery Data Storage System was developed as a means for pooling and computerizing fishery data collected by state and federal agencies so that it would be readily accessible to resource managers. Emphasis is placed on fish and fish habitat information. Items of interest to planners such as land ownership, access, and the potential of a water for supporting fishing pressure are also included. The information stored is a description of each individual stream reach at a single point in time.

Development of the system began in 1973 as a cooperative effort between Montana Department of Fish, Wildlife and Parks and Region One of the U.S. Forest Service. More recently the U.S. Bureau of Land Management has participated.

As a first step in getting information into the system, a large variety of data on each stream reach is summarized on the stream data input form (Fig. 1). The complexity of the form is due, in part, to our attempt to serve all agencies involved. The system allows for flexibility of data input in that not all information provided for on the form is necessary for any particular survey.

Insight into the Montana Interagency Stream Fishery Data Storage System can best be gained by examining the example form completed for a hypothetical stream (Fig. 1) and the resulting computer printout (Fig. 2). Salient features of the form and printout are described below; Roman numerals correspond to those on the form and printout.

<u>The data input form (Fig. 1)</u>:

I. The study stream is identified and specific location of the stream reach under consideration is documented. Ideally, each stream will be divided into reaches that are defined as lengths of the stream with distinct physical or biological characteristics. A reach can be as short as 0.1 km (328 feet) or may include the entire stream.

II. Information on all fish species present, their abundance, and the use they make of the reach is recorded. By "use" we mean, does a species complete its life cycle in the reach, migrate in to spawn, or what?

III. Fish standing crop, fisherman use, and catch data are entered in this section, when available.

IV. Factors limiting the fishery and management recommendations are indicated by entering "x's" in appropriate boxes.

V. Open fields (those accepting words and statements) are provided for information not entered elsewhere on the form.

<u>The printout (Fig. 2):</u>

VI. The first section of the printout identifies the stream and the particular reach under study. Location data include the hydrologic unit code, the Department of Fish, Wildlife and Parks region number, the Forest Service district code, and mountain range and wilderness area designations, where appropriate. These are focal points for file searches.

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INTERAGENCY STREAM FISHERY DATA INPUT FORM — Page 1

CARD 1

STATE	OVERLAP	STREAM NAME	HYDROLOGIC UNIT CODE (1–5)	STREAM ORDER	STATE WATER CODE: DRAINAGE	WATER	WATER TYPE	REACH: NUMBER	LENGTH Km	RATING	RESOURCE VAL.	SPORT FISH VAL.	HABITAT & SPECIES VALUE	WATER USE CLASS
30		SUPER CREEK	10070005	03	23	61320	01	001	3212	4				

CARD 2 — UPPER REACH BOUNDARY DESCRIPTION

TOWNSHIP	RANGE	SECTION	SUB-SECTION	LATITUDE (DEGREES, MINUTES, SECONDS)	LONGITUDE (DEGREES, MINUTES, SECONDS)	LANDMARK NAME	ELEVATION METERS	RATING	AV. WETTED WIDTH METERS	RATING
T 09S	R 14E	16	A			RAVEN CREEK	26580	6	30	3

CARD 3 — LOWER REACH BOUNDARY DESCRIPTION

TOWNSHIP	RANGE	SECTION	SUB-SECTION	LATITUDE (DEGREES, MINUTES, SECONDS)	LONGITUDE (DEGREES, MINUTES, SECONDS)	LANDMARK NAME	ELEVATION METERS	RATING	AV. WETTED WIDTH METERS	RATING
T 06S	R 14E	12	AB			CHARLIE LAKE	17165	6	177	3

CARD 4 — Channel Definition Point (for mapping)*

TOWNSHIP	RANGE	SECTION	SUB-SECTION	LATITUDE (DEGREES, MINUTES, SECONDS)	LONGITUDE (DEGREES, MINUTES, SECONDS)	Tributary To - Name	COUNTIES* 1 Farthest down-stream	2	3	4
T	R					YELLOWSTONE RIVER	095	067		

CARD 5 — ADMINISTRATIVE LOCATIONS / BANK OWNERSHIP (1 Km of STREAM = 2 Km of BANK)

MOUNTAIN RANGE	WILDERNESS OR PRIMITIVE AREAS 1	2	FOREST SERVICE: REGION	FOREST	DISTRICT	BUREAU OF LAND MANAGEMENT: DISTRICT	AREA	F&W SERVICE: INDIAN OR MILITARY RESERVATION OR NAT'L WILDL REFUGE	F&G REGION	OTHER AGENCY: AGENCY	DISTRICT OR AREA	OWNER 1 CODE	Km	OWNER 2 CODE	Km	OWNER 3 CODE	Km	OWNER 4 CODE	Km	RATING
BTH	131		01	08	02				5			-FS	64.4							6

CARD 6

CAPABILITY AREAS OR LAND TYPES: CODE	CODE	CODE	ACCESS* 1: LETTER	Km	RESTRICTION	2: LETTER	Km	RESTRICTION	3: LETTER	Km	RESTRICTION	4: LETTER	Km	RESTRICTION	RATING	ROAD PROXIMITY <100M %	100-600M %	>600M %	% POCKET WATER	INGRESS*
			J	6.4		H	25.8	X							4	0	0	100		1

* SEE INSTRUCTIONS

WRITE LEGIBLY - USE SOFT PENCIL OR FELT POINT PEN - USE PRINTED CAPITAL LETTERS INCLUDING I, Ø, Z AND S

Figure 1.--Hypothetical example of fishery data input form.

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INTERAGENCY STREAM FISHERY DATA INPUT FORM

Page 2

CARD 8

WATER FLOW – FLOW DURING SURVEY: M³/SEC	MONTH	DAY	YEAR	RATING	WATER STAGE*	NORMAL LOW FLOW INCL. MAN-CAUSED: M³/SEC	RATING
85	08	19	79	3	3	42	1

OTHER PHYSICAL AND CHEMICAL DATA

VALLEY WIDTH: METERS	RATING	AVERAGE RIPARIAN WIDTH: METERS	RATING	ACTIVE CHANNEL MEASUREMENTS – AVERAGE CHANNEL WIDTH: METERS	RATING	AVERAGE CHANNEL DEPTH: METERS	RATING	AVERAGE MAXIMUM POOL DEPTH AT LOW FLOW: METERS	RATING	GRADIENT: %	RATING
110	3	35	2	11	3	.8	3	14	3	23	8

RATIO (%): POOL	RUN	RIFFLE	RATING	POOL: % BOTTOM TYPES – HARDPAN or BEDROCK	BOULDERS Over 26 cm	RUBBLE 6.4-26 cm	GRAVEL 2mm-6.4 cm	FINES UNDER 2mm	RATING
20	30	50	3	0	15	45	35	5	3

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

CARD 9

OTHER PHYSICAL AND CHEMICAL DATA (Cont.)

RUN: % BOTTOM TYPES – HARDPAN or BEDROCK	BOULDERS Over 26 cm	RUBBLE 6.4-26 cm	GRAVEL 2mm-6.4 cm	FINES UNDER 2mm	RATING	RIFFLE: % BOTTOM TYPES – HARDPAN or BEDROCK	BOULDERS Over 26 cm	RUBBLE 6.4-26 cm	GRAVEL 2mm-6.4 cm	FINES UNDER 2mm	RATING
0	28	55	17	0	3	0	25	55	20	0	3

Sinuosity: RATIO	RATING			TEMP. DATA AVAILABLE	AV. (NORMAL) PEAK WATER TEMPERATURE: °C	RATING	SPRING CR. Y or N	AFFECTED BY LAKE Y or N	INUNDATED BY BEAVER PONDS: % OF REACH	RATING
12	2			X	15	4	N	Y	0	3

TOTAL ALKALINITY*: NORMAL LOW	RATING*	NORMAL HIGH	RATING	WQ DATA IN: STORET	MAPRS	D 90: CM	Rating	Side Channel* Occurrence
10	4	22	4		X	5	3	W

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

CARD 10

OTHER PHYSICAL AND CHEMICAL DATA (Cont.)

SPECIFIC CONDUCTANCE*: NORMAL LOW	RATING*	NORMAL HIGH	RATING	TURBIDITY (JTU)*: NORMAL LOW	RATING*	NORMAL HIGH	RATING	pH*: NORMAL LOW	RATING*	NORMAL HIGH	RATING	TOTAL DISSOLVED SOLIDS (MG/L)*: NORMAL LOW	RATING*	NORMAL HIGH	RATING
53	5			0	4	10	4	68	4	80	4	20	4	50	4

SUITABILITY FOR*: RESIDENCE	SPAWNING	REARING	OF: SPECIES
2	1	3	013

NON-FISH. USE & FLOATING: IRRIGATION	STOCK WATERING	DOMESTIC WATER SUPPLY	INDUSTRIAL WATER SUPPLY	POLLUTION DILUTION	RECREATION	HIGHEST: POWER BOAT	CANOE	NON-FLOATING
	X							X

SPECIAL VALUE: HATCHERY EGG SOURCE	COMMERCIAL FISHING	WATER VOLUME	IMPROVES WATER QUALITY	NUTRIENTS & FISH FOOD	LOCAL COMMUNITY IMPORTANCE	Important fishery for most considered	Sp.Con. Other than Fish

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

CARD 11

CHANNEL STABILITY RATING ELEMENTS

KEY 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL SCORE
2	3	2	6	2	5	2	9	7	2	2	5	8	7	2	64

POOL CLASSES: % CLASS 1	% CLASS 2	% CLASS 3	% CLASS 4	% CLASS 5	RATING	CLASS 1, 2, 3 POOLS: % BED ROCK	% DEBRIS	% BANK SCOUR	% BOTTOM SCOUR	RATING
15	20	50	10	5	3	0	20	5	75	3

HABITAT RATINGS: STREAM COVER	BANK CONDITION	BANK STABILITY	CHANNEL STABILITY	STREAMBED SEDIMENT	COMBINED RATING	TYPE	SUBSURFACE COVER
3	4	4	3	3	E	M	F

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

II

CARD 13

HABITAT VALUE FOR FISHES OF SPECIAL CONCERN

SPECIES CODE	Habitat Code	SPECIES CODE	Habitat Code	SPECIES CODE	Habitat Code	SPECIES CODE	Habitat Code	SPECIES CODE	Habitat Code
013	S								

FISH POPULATION*

SPECIES	CODE	ABUN.	USE
SPECIES	003	R	L
SPECIES	013	C	L
SPECIES	085	U	H
SPECIES	063	U	L
SPECIES	056	R	H
SPECIES	039	C	L
SPECIES	130	R	L
SPECIES			
SPECIES			

RATING: 6

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

CARD 14

FISH POPULATION (Cont.) — Enter Data Quality Rating in col. 71 card 11

SPECIES	CODE	ABUN.	USE
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			
SPECIES			

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75

Figure 1.--Continued.

SERIAL NUMBER CHX

INTERAGENCY STREAM FISHERY DATA INPUT FORM

Page 3

III

CARD 15 — FISH POPULATION (CONTINUED)

STANDING CROP: NUMBER AND WEIGHT OF FISH PER 300 METERS

Species Code	Number	Minimum Length (CM)	Biomass (KG)	Month	Year	Rating	Species Code	Number	Minimum Length (CM)	Biomass (KG)	Month	Year	Rating	Species Code	Number	Minimum Length (CM)	Biomass (KG)	Month	Year	Rating	Fish Planted Regularly? Y or N	Species Code	Artificial Fishery?	Growth Rate *	% Potential Fish Biomass Low %	High %
013	35	15	39	08	79	4															N			F	90	100

CARD 17 — SPORT FISHING PRESSURE / FISH IN CREEL

Man-Days per Year per 10 KM: Point Estimate	Standard Deviation	Year	Rating	% of Allowable Fishing Pressure Low %	High %	Year	Species Code	%	Av. Length (CM)	Max Weight (KG)	Species Code	%	Av. Length (CM)	Max Weight (KG)	Species Code	%	Av. Length (CM)	Max Weight (KG)	Species Code	%	Av. Length (CM)	Max Weight (KG)	Rating
51	13	75	4	50	60	77	013	89	19	03	003	1	15	01	085	10	28	17					6

IV

CARD 19

Section	Item	Entry
Debris Loading — Condition	Insufficient	
	Balanced	
	Stable Excess	X
	Unstable Excess	
	Not Sure	
	Loading Potential Y or N	Y
Imbeddedness — Pools	<25%	X
	25-50%	
	51-75%	
	>75%	
Imbeddedness — Riffles	<25%	X
	25-50%	
	51-75%	
	>75%	
Aquatic Plants & Aquatic Invertebrates*	Non-filamentous Algae	N
	Filamentous Algae	N
	Higher Plants	N
	Stoneflies	C
	Mayflies	C
	Caddisflies	C
	Dragonflies Damselflies	
	Beetles	
	True Flies	C
	Aquatic Earthworms	
	Snails	N
	Fingernail Clams	N
	Other Clams & Mussels	N
Invertebrate Species Diversity	Index Name	S
	Index Number	325
Habitat Trend	Improving	
	Deterior.	
	Static	X
	Esthetics *	A
Fishery Value Would Be Higher Except For: Limiting Factor – Physical, Climatic & Biological	Temperature	X
	Low Nutrients	X
	Spawning Area Lack	
	Pools Inadequate	
	Riffles Inadequate	
	Ice	
	Steep Gradient	X
	Excessive Flow Fluct.	
	Bedload Movement	
	Hi Erosive Drainage	
	Turbidity	
	Lack Bank Undercut	X
	Barrier to Fish Pass.	
	Overpop. Rough Fish	
	Overpop. Game Fish	
	Low Aquatic Invertebr.	
	Lack Bank Cover	
	Hard to Fish	
	Disease Parasite	
	Spawners Poached	
	Overharvest Sport Fish	
	Overharvest Nonsp. Fish	
	Other	
Man-Caused Pollution	Gas Super-Saturation	
	Mining	X
	Related Thermal	
	Effluent Commercial	
	Chemical Commercial	
	Organic Excessive	
	Siltation	
	Irrig/Run-off Related	
	Domestic Sewage	
	Domestic Stock	
	Weedicides Pesticides	
	Other	

CARD 20

Section	Item	Entry
Channel Alterations	Altered Length Meters	
Cause	Mining, Road or RR, Dredge, Flood & Ice, Agriculture, Dwelling, Other	
Type	Channelization, Relocation, Straightening, Constricting	
	Now Stable %	
Bank Encroachment By:	Road or RR	
	Dike	
	Dwelling	
	Agriculture	
	Mining	X
	Stock Trampling	
	Other	
Domestic Livestock	Length Grazed Meters	3220
	Compatability 1=Low 5=High	4
Watershed Abuse	Road Const., Logging Practices, Mining Practices, Overuse by Stock, Overuse by Game, Overuse by People, Other	
Water Removed or Fluctuated For	Agriculture, Power, Industry, Municipal, Other	
Management Needs and Recommendations	Need Survey	
	Pollution Abatement	X
	Red. Man Caused Flow Fluct, Irrigation Improvement, Improve Bank Cover, Bank Stabilization, Bank Fencing (KM) of Fence, Watershed Restoration, Barrier Removal, Beaver Control, Stock Beaver, Change Fish Species, Improve Spawn Area, Channel Improvement, Remove Excess Debris, Improve Legal Ingress, Improve Physical Access, Limit Access, Reduce Recreation Conflict, Improve Esthetics, Enforce Regulations, Stocking Needed, Change Fish Regulations, Change Mgt of Commercial Fsh	

V

CARD 21

OTHER LIMITING FACTORS OR MANAGEMENT NEEDS (WRITE OUT)

DATA SOURCE: Enter Month, Year, Field Person to be contacted concernino data & Agency (Example: 10/79 Peters, FWP)

and ADDITIONAL INFORMATION: Enter type information, agency, person to contact if pertinent

← 09/80 MARCUSON FWP, SEE JOHNSON, S. 1977, SUPER CR

CONTINUED ON TWO CARD 22'S (NOT SHOWN)

CARD 50 — WATER FLOW

MINIMUM INSTANTANEOUS FLOWS (M^3/SEC) NEEDED FOR HIGH LEVEL OF AQUATIC HABITAT POTENTIAL - COORDINATE ENTRIES WITH MONTANA FWP WATER RESOURCE SECTION

January M^3/sec	February M^3/sec	March M^3/sec	April M^3/sec	May M^3/sec	June M^3/sec	July M^3/sec	August M^3/sec	September M^3/sec	October M^3/sec	November M^3/sec	December M^3/sec	Agreement by Agency	Agency	Water Reserved: Reser. Y or N	Adequ. Y or N	Date Adjustment
150	149	158	1104	306	634	257	175	1116	150	152	159	FWP		Y	Y	X

*SEE INSTRUCTIONS

Figure 1.--Continued.

```
29 OCT 81                          MONTANA INTERAGENCY STREAM FISHERY DATA                                Serial: C4X
Single number in parentheses is the data quality rating (1=low, 9=high). For other codes see instructions for entering data.
---------------------------------------------------------------------------------------------------------------------------

VI  SUPER CREEK                 Code: 23-6132  Reach: 001  Length:    32.2 km (4)  Water type: 01  Hydro unit code: 10070005
     Upper boundary: T09SR14E16A     RAVEN CREEK                       Elevation: 2658.0 m (6)  Av wetted width:   3.0 m (3)
     Lower boundary: T06SR14E12AB    CHARLIE LAKE                      Elevation: 1716.5 m (6)  Av wetted width:  17.7 m (3)
     Trib to: YELLOWSTONE RIVER     Counties: Stillwater  , Park          ,            ,            ,            ,
     Administrative Locations - FWP Region: 5  ,FS Dist: 08-02  ,BLM Dist:     -      ,F&W Ser area:         ,Other:     -
      Mountain range: BTH    Wilderness/primitive area: 131,
---------------------------------------------------------------------------------------------------------------------------

VII FISH PRESENT   (data quality rating for species, abundance & use = 6)
            Species        Abun Use           Species        Abun Use             Species       Abun Use          Species       Abun Use
        Brook trout         R    L        Yellowstone ct      C    L          Mt.whitefish       U    H        Mountain sucker    U    L
        Longnose sucker     R    H        Longnose dace       C    L          Mottled sculpin    R    L
     Standing Crop per 300m      Species            Number    Min length (cm)    Biomass (kg)     Date      Data qual rating
                              Yellowstone ct          35            15                3.9          08/79           4
     Fish biomass is 90% to 100% of potential.     Fish growth rate: fair
     Fish planted regularly?  no
     Habitat rating for fishes of special concern: substantial  for Yellowstone ct  ,                  for                   ,
     Suitability for Yellowstone ct     (1=best, 5=poorest): Residence - 2, Spawning - 1, Rearing - 3
     Fishing pressure     51. man-days/10km/yr (4); std dev =     13.; yr:  1975;  this is  50% to  60% allowable pressure
     Creel census data             Species             Percent    Av length (cm)     Max wt (kg)      Year    Data qual rating
                              Yellowstone ct          89            19                 .3            77           6
                              Brook trout             01            15                 .1            77           6
                              Mt.whitefish            10            28                 .7            77           6
---------------------------------------------------------------------------------------------------------------------------

    OTHER BIOLOGICAL DATA
     Aquatic plants: Non-filamentous algae - not seen,  Filamentous algae - not seen,  Higher plants - not seen
     Aquatic invertebrates: Stoneflies - common  ,  Mayflies - common  ,  Caddisflies - common
      Dragon/damselflies - no obser,  Beetles - no obser,  True flies - common  ,  Aquatic earthworms - no obser
      Snails - not seen,  Fingernail clams - not seen,  Other clams/mussels - not seen
     Aquatic invertebrate species diversity - index name: Shannon-Wiener  ,  index number: 3.25
---------------------------------------------------------------------------------------------------------------------------

    PHYSICAL DATA
     Is reach affected by lake up- or downstream (flow, temperature, movement of plankton or fish, etc.)?  yes
     Stream order: 03
     Flow during 08/19/79 survey:     .85cu  m/sec (3);  water stage: moderate. Normal low:     .42cu m/sec (1)
     Min instant flow needed by fish & wildlife (cu m/sec) - Jan:     .50, Feb:     .49, Mar:     .58, Apr:   1.04, May:   3.06
       Jun:   6.34, Jul:    2.57, Aug:     .75, Sep:    1.16, Oct:     .50, Nov:     .52, Dec:     .59
     Instream flow reserved? yes;  adequate? yes
     Pool-run-pocket water-riffle-ratio:  20%,  30%,     %,  50% (3)                      Av max pool depth:   .4m (3)
     Bottom substrate types - % Hardpan    % Boulders    % Rubble    % Gravel      % Fines
                  Pool (3) -      0            15            45          35            5
                   Run (3) -      0            28            55          17            0
                Riffle (3) -      0            25            55          20            0
     90% of bed material has a diameter smaller then:    5cm (3)
     Gradient:             2.3  (8)        Sinuosity:             1.2  (2)     Side channel occurrence:  nil
     Av channel depth:    .8m (3)        Av riparian width:     35m (2)
     Av valley width:    110m (3)        Av channel width:      11m (3)
     Valley-channel ratio:  10.00
     Pool classes - % class 1,2,3,4,5:  15,  20,  50,  10,   5 (3)  Formation of class 1,2,3 pools:   0% bedrock,  20% debris,
        5% bank scour,  75% bottom scour  (3)
```

Figure 2.--Hypothetical example of printout.

```
29 OCT 81      SUPER CREEK                    Code: 23-6132  Reach: 001  (cont.)                                          Serial: C4X
 Channel stability rating elements - 1:  2, 2:  3, 3:  2, 4:  6, 5:  2, 6:  5, 7:  2, 8:  9, 9:  7, 10:  2, 11:  2, 12:  5,
  13:  8, 14:  7, 15:  2, Total score( <38=excellant, 39-76=good, 77-114=fair, 115+=poor):   64
 Habitat Ratings (4=best, 1=poorest) - Stream cover: 3,  Bank condition: 4,  Bank stability: 4,  Channel stability: 3,
  Streambed sediment: 3,  Combined rating: excellnt,  Bank vegetation type: mixed        ,  Subsurface cover: fair
 Beaver ponds:   0% of reach (3)  Is this a spring creek?  no
 Debris loading: condition - stable excess   ;  Potential - adequate    ;  Imbeddedness - Pool: <25%    , Riffle: <25%
------------------------------------------------------------------------------------------------------------------------------

WATER QUALITY DATA       Normal Low  Normal High   One sample(S), Av(A), or Est(E)
 Total Alkalinity -          10 (4)       22 (4)                  ( )
 Specific Conduct -             ( )          ( )               53 (S)
 Turbidity        -           0 (4)       10 (4)                  ( )
 pH               -         6.8 (4)      8.0 (4)                . ( )
 TDS              -          20 (4)       50 (4)                  ( )
VIII Data also in:           , Mont WQ sys             Normal peak summer water temp: 15C (4)
 Detailed water temperature data available.
------------------------------------------------------------------------------------------------------------------------------

FACTORS LIMITING FISHERY
 temperature          , low nutrients       ,
 steep gradient       , lack undercut bank  ,
 Man-caused pollution:  mining related       ,                    ,                   ,           ,          ,
 Bank encroachment by: mining       ,
------------------------------------------------------------------------------------------------------------------------------

OTHER LIMITING FACTORS (OR MANAGEMENT NEEDS)
------------------------------------------------------------------------------------------------------------------------------

MANAGEMENT NEEDS AND RECOMMENDATIONS
 pollution abatement ,
------------------------------------------------------------------------------------------------------------------------------

OTHER INFORMATION
 Habitat trend: static            Length grazed by livestock: 3220m;  Compatibility (1=low, 5=high): 4
 Ingress rating:  1  (1=public land, 2 & 3=mostly open to public, 4-7=restricted ingress)        Aesthetics:  pristine
 Bank ownership (6) - -FS: 64.4km,
 Access (4): J -  6.4km -     ,   H - 25.8km -rstr,
 Road proximity- <100m:   0%,  100-600m:   0%,  >600m: 100%
 Floatability: not-floatabl
 Non fish use: stock watering  ,
IX Data source & other info: 09/80 MARCUSON FWP. SEE JOHNSON, S. 1977, SUPER CR. FISH POP. DYNAMICS, M.S. THESIS MSU. MOTTL
  ED SCULPIN DISCOVERED 1977; APPARENTLY UNAUTHORIZED INTRODUCTION.
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EXPLANATION OF ABBREVIATIONS AND CODES

Agency and owner codes:
- FWP = Mont. Dept. of Fish, Wildlife & Parks.
- FS or -FS = U.S. Forest Service.
- BLM = Bureau of Land Management.
- F&W Ser = U.S. Fish & Wildlife Service.

Mountain range BTH = Beartooth Range.
Wilderness/
primitive area 131 = Absaroka-Beartooth Wilderness.

Fish abundance:
- C = common.
- U = uncommon.
- R = rare.

Use (by fish):
- L = resident throughout life cycle.
- H = spawning and hatching, young promptly move downstream.

Access:
- J = 4-wheel drive.
- H...restr = horse (use restricted, feed must be carried).

Figure 2.--Continued.

VII. The next section is a summary of fisheries information. Note the single number in parentheses associated with fishing pressure. This is an example of a data quality rating that is assigned to all fisheries and physical data inputs. A rating of one, two, or three indicates a judgement estimate, four to six means the information is based on limited measurements, and a number from seven to nine means extensive, comprehensive measurements were made; nine indicates the highest state of the art. The purpose of data quality ratings is to encourage field people to enter any information they have. We would rather have an educated guess (data quality rating of one) that a stream is 20 meters wide than to have no information at all. From this we can at least get a general idea of the size of the stream; more accurate data can be entered when available. Most data on the printout consist of averages and ranges, not individual items of information.

VIII. "Data also in Mont WQ sys" refers the data-file user to the Montana Water Quality Record System, a computer file of water quality data maintained by the Montana Department of Health and Environmental Sciences. If water quality data for the study reach are also stored in the U.S. Environmental Protection Agency's STORET database, EPA STORET would be referred to.

IX. The month and year of data entry, the name of the investigator, and initials indicating his agency are standard notations. In addition, unlimited space is available for recording references and other information on the stream.

Each agency's data retain their integrity although there are some overlaps. Frequently two agencies have separately entered data on the same stretch of stream but with different emphasis. For example, data collected by the Department of Fish, Wildlife and Parks emphasize fish while the Forest Service and Bureau of Land Management data emphasize habitat. Each agency's data can be retrieved independently. All data are available to everyone with obvious advantages to the user and taxpayer.

The Montana Department of Fish, Wildlife and Parks does all keypunching and editing. Filled-out forms are checked when received and new or revised data are also subjected to a thorough edit by a special computer program.

Presently, the file contains data on 4,110 stream reaches which comprise 57,967 records or cards 80 characters in length. The entry for a single reach includes a minimum of 4 cards, with an average of about 14. Retrieval of information on individual parameters from all reaches is facilitated by the Interactive Database Processor (IDP), a software component of the Honeywell Computer at Montana State University. For example, it is comparatively easy to obtain a listing of all cutthroat trout waters that have pollution problems. Many requests for information retrieval have been received from other agencies and private consulting firms. The Department has accommodated most of these, tailoring listings to meet specific requirements. The Forest Service plans to add the data to its System 2000 database that will make the information available on remote terminals.

The data file has many uses. For example, the Montana Department of Fish, Wildlife and Parks in cooperation with the U.S. Fish and Wildlife Service used the file for the 1980 rating of the fishery values of Montana streams. In this instance a special program was written to scan the file and assign numerical values to various attributes. When special needs arise, the system is expanded to accommodate them. For example, new cards were designed to facilitate entry of Bureau of Land Management riparian data and entry of data required in the detailed trout habitat analyses of the Flathead River Drainage (Fraley and Graham, this publication)

As described above, the information stored is a description of individual stream reaches at any one point in time. In order that changes over time can be documented, it is planned that periodically -- every 2 to 5 years depending upon the amount of stream inventory activity -- a tape containing all the data will be set aside for its historical value and will be maintained unchanged.

In theory our data file can also be used for mapping the distribution of individual fish species, types of pollution, and so forth. However, the streams of the state will have to be digitized before mapping can be implemented. It will be several years before the digitizing is completed. A computerized lake fishery data file, designed along the same lines as the stream file, is in advanced stages of development; data on 400 lakes have already been entered.

Much of the Department of Fish, Wildlife and Parks' effort has been supported with Federal Aid in Fish Restoration (D-J) funds. In addition, financial support has been received from the U.S. Fish and Wildlife Service and the Montana Department of Health and Environmental Sciences -- in each case this was pass-through money from the U.S. Environmental Protection Agency. Similarly, funding was received from the Northern Tier Pipeline Company through the Montana Department of Natural Resources and Conservation. The authors wish to thank Doctors Wayne F. Hadley and Robert G. White for helpful criticisms of the manuscript.

PHYSICAL HABITAT, GEOLOGIC BEDROCK TYPES AND TROUT DENSITIES IN TRIBUTARIES OF THE FLATHEAD RIVER DRAINAGE, MONTANA[1]

John J. Fraley and Patrick J. Graham[2]

Abstract.--Stream habitat and trout population densities were compared on 112 tributary reaches of the North and Middle Forks of the Flathead River during 1979 and 1980. The habitat model that best described age I and older westslope cutthroat (*Salmo clarki lewisi*) and juvenile bull trout (*Salvelinus confluentus*) densities contained measurements of trout cover, D-90 (measurement of bed material) and stream order. The correlation (r) between actual trout densities and predicted densities for 23 new reaches surveyed during 1981 was 0.63 with a least squares fit, and 0.84 when fitted with zero Y intercept. Discriminant analysis produced similar results to those of multiple regression. Trout densities and stream habitat parameters differed significantly between geologic types. Results from this study allowed an integration of fisheries information into the land management decision making process in the Flathead National Forest, Montana.

INTRODUCTION

An assessment of trout habitat and associated densities was recently made in tributaries of the North and Middle Forks of the Flathead River (North and Middle Forks, FHR) as part of a baseline environmental study of the Flathead Lake-River ecosystem in northwest Montana (fig. 1). The study assessed the conditions of the aquatic resource to provide information needed to evaluate potential impacts of large-scale coal development in the Flathead drainage in Canada, and oil, gas, and timber developments in both the U.S. and Canadian portions of the drainage (Graham 1980, Graham et al. 1980).

Tributaries to the Flathead River are in fertile, clear mountain streams dominated by a run-riffle channel configuration. Late summer flows in the tributaries ranged from 0.07 to 1.9 m^3 per second. Trout populations consisted mainly of juveniles resulting from westslope cutthroat and bull trout adults migrating from Flathead Lake and Flathead River, and some resident tributary cutthroat. The tributaries serve as the vital rearing areas for the interconnected Flathead Lake River system.

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[1]Paper presented at the symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information (American Fisheries Society, Western Division, Portland, OR, October 28-30, 1981

[2]Montana Department of Fish, Wildlife and Parks, P.O. Box 67, Kalispell, MT

METHODS

Habitat Measurement

Stream habitat was evaluated on a total of 142 North and Middle Fork Flathead River tributary reaches comprising 675 stream kilometers during 1979 and 1980. This total includes all major tributaries south of the Canadian border in the North Fork drainage and approximately two-thirds of the tributaries

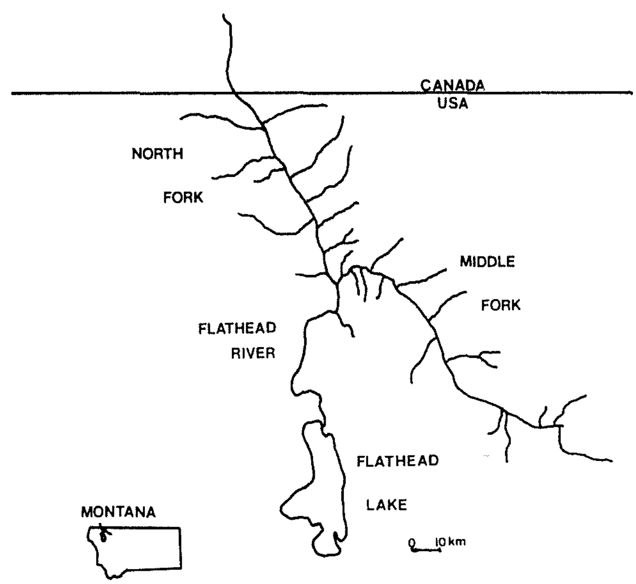

Figure 1. Map of the study area.

in the Middle Fork drainage. Approximately two-thirds of the reaches surveyed are located in wilderness areas or Glacier National Park and have not been impacted by development. One-third of the stream reaches have been impacted to some degree by road building or logging activities.

Stream habitat condition was measured using methods developed by the Aquatic Studies Branch of the British Columbia Ministry of Environment (Chamberlin 1980a, 1980b).

Each study tributary was flown by helicopter and divided into one or more reaches. Reaches were portions of the stream having uniform associations of physical habitat characteristics. Changes in stream gradient resulted in differences in bed material size, stream channel pattern, and channel morphology, and was the major factor used to delineate the reach. Major stream features such as log jams, fish barriers and mass wasted banks were also recorded during helicopter surveys.

Field survey crews measured 30 individual physical habitat parameters for each tributary reach (Chamberlin 1980a, 1980b, Fraley et al. 1981). Major habitat conditions measured were stream hydraulics, channel morphology, bed material, bank material, stream pattern, stream cover, pool class, and pool-riffle-run-pocket water quantities. Log jams, fish barriers, bank and bed stability, and debris were also measured.

Measurements were taken at randomly selected transects in a 0.8 to 2.5 km (0.5-1.5 mi.) portion of each reach, depending on reach length. On a typical 1.6 km (1 mile) section, a total of 40 random transects were selected. At 15 of these transects, measurements were made of bed material compaction, channel particle imbededness, D-90 (substrate size), canopy cover, overhang cover, organic debris, channel width and average stream depth. Stream habitat was classified as to pool, riffle, run or pocket water at all 40 transects and the wetted parameter was measured at 20 of the transects. Bank material, channel substrate and stream channel stability were evaluated for each section (Chamberlin 1980a, 1980b). Instream cover was evaluated for a 150 m (495 feet) section of each reach by snorkeling. Overhang cover was measured for the habitat section and included material such as logs or vegetation extending over the stream at a height of one meter or less. Instream cover was measured in the snorkel section as overhang touching the water surface plus water depth, turbulence, debris and rocks.

Chemical conditions and stream flows were measured once during late summer on the lowermost reach of each major tributary. Alkalinity, conductivity, and flow were measured in the field. The University of Montana Biological Station analyzed nitrate (NO_3-), total phosphorus (TP), total organic carbon (TOC), calcium (CA^{++}), magnesium (Mg^{++}), potassium (K^+) and sodium (Na^+).

The study area was divided into geologic types based on the nature of the underlying bedrock. Physical and chemical characteristics typical of each bedrock type were determined by soil samples of the unweathered soil horizon (Martinson et al. 1982). Stream reaches were then classified into geologic types on the basis of the dominant underlying bedrock type.

Fish Population Estimates

Population estimates of westslope cutthroat and bull trout were made on randomly chosen 100-150 m long sections of each reach. Observers wore a wet suit, diving mask and snorkel, and estimated the number of fish in each age class based on predetermined length frequencies for pools, runs, riffles and pocket water habitats as they pulled themselves upstream.

Snorkeling was preferrable to electrofishing because of the clarity, low conductivity, and inaccessibility of many waters in the Flathead drainage. In wilderness areas and Glacier National Park where regulations restrict the use of electrofishing equipment, snorkeling was an effective and practical method for obtaining fish population estimates. Comparisons of snorkeling and two pass electrofishing estimates for 13 North and Middle Fork FHR tributary reaches indicated no significant difference between the means of the two methods for age I and older cutthroat and bull trout (Fraley et al. 1981). Snorkeling efficiency was lower for juvenile bull trout and estimates for this species were not considered as reliable as those for cutthroat trout (Fraley et al. 1981, Shepard et al. 1982).

Analysis of Habitat and Fish Population Data

Physical-chemical habitat parameters and fish densities measured for each tributary reach were entered on the standard Montana Interagency Stream Fishery Data forms (Fish, Wildlife and Parks, Helena 1980). Data were entered into the statewide data base administered through the Department of Fish, Wildlife and Parks in Helena (Holton and McFarland, this volume). A "dictionary" defining locations of each habitat and fish population variable in the data base was constructed on the Montana State University CP-6 Interactive Data Base Processing System. The dictionary enabled the user to obtain all information available for each stream reach. This information will also be published by the Montana Fish, Wildlife and Parks as an aid to land managers, and will include tabulated data and physical habitat and fish population maps for each drainage (figs. 2 and 3).

A total of 30 physical habitat parameters were tested for their relationships to fish densities in 112 tributary reaches which contained trout through the use of simple linear correlation. Multiple regression (Snedecor and Cochran 1969) was then utilized to identify the most significant combination of habitat variables which affected population densities of age I and older cutthroat and bull trout. All correlations and regressions were calculated with "Mregress", "Sumstat" and "Biplot" computer programs of the Montana State University Statistical Library (Lund 1979). Discriminant analysis was performed using programs in the Statistical Package for the Social Sciences series (Nie et al. 1975). Trout densities and stream habitat conditions in the different geologic types were also analyzed using discriminant analysis.

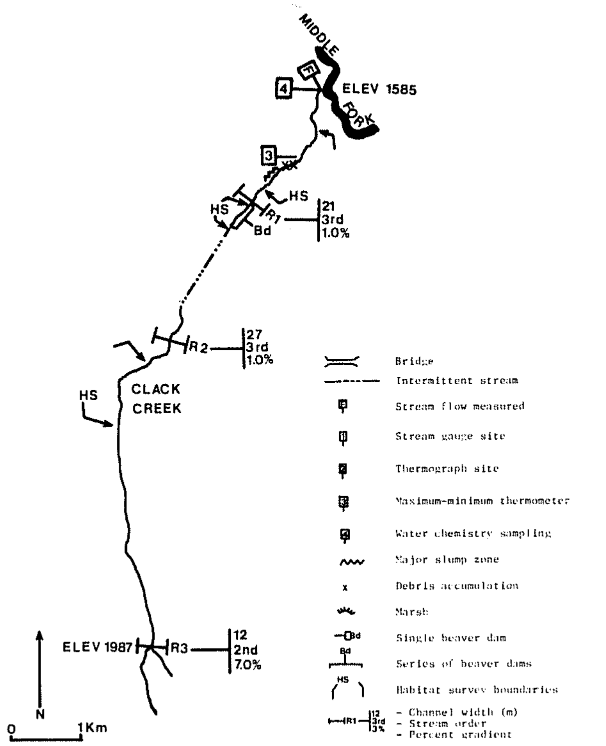

Figure 2. Physical habitat map for Clack Creek (Middle Fork FHR drainage). R indicates a reach break.

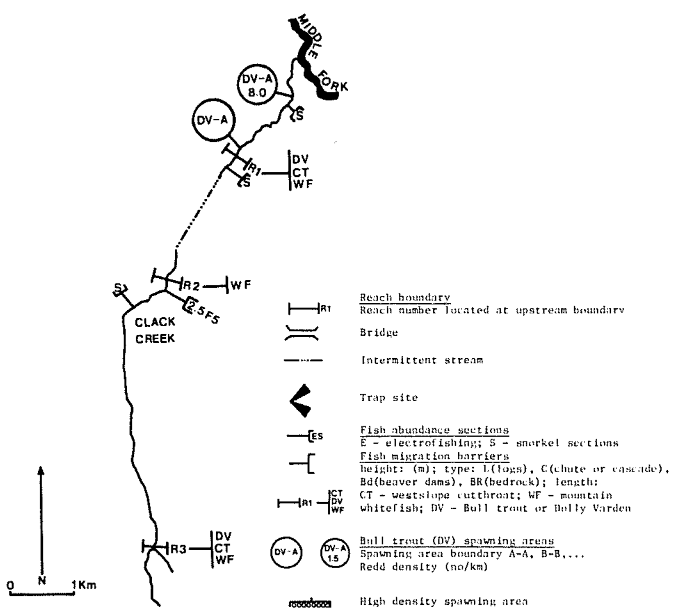

Figure 3. Fish population characteristics map of Clack Creek (Middle Fork FHR drainage).

RESULTS AND DISCUSSION

Habitat-Trout Relationships

Of the 30 physical habitat parameters tested, 10 were found to have significant relationships to trout densities ($p<0.01$). These included six cover variables or variable combinations, substrate size (D-90), wetted perimeter, average depth and stream order.

Variables or variable combinations associated with cover had the highest simple correlation coefficients. All four cover variables tested had significant positive relationships to trout densities. The combination of the variables overhang and instream cover had the best correlation with trout densities ($r=.602$, $p<0.01$). This two variable combination was chosen as best representing trout cover in the tributary reaches. Canopy had the lowest significant correlation of all cover variables tested.

Substrate size (D-90), wetted width, average depth and stream order were all negatively correlated at the 99% level. This indicates that larger measurements of these variables in a reach were associated with lower trout densities. Although water temperature was an important variable affecting trout densities in other studies (Binns and Eiserman 1979), there did not appear to be a strong relationship between measured fish densities and maximum summer water temperatures in North and Middle Fork tributaries in the reaches where temperature data were available.

In the small number of stream reaches where chemical data were available, ion concentrations did not seem to be associated with high fish densities within the range of ion cencentrations sampled. Dissolved ion concentrations were about twice as large in the Middle Fork drainage, but average trout density was only half as large as the density in North Fork tributaries. Nutrient concentrations (phosphorus and nitrate) and total organic carbon were relatively low and varied little in tributaries of both drainages.

Multiple Regression Analysis

Age I and Older Cutthroat and Bull Trout

Trout cover, stream order, and D-90 (substrate size) formed the best variable combination or model ($R=0.64$) describing the relationship between habitat and combined densities of age I and older cutthroat and bull trout (Table 2). Each remaining habitat parameter in the data base was inidividually added and tested, but none increased precision of the model at the 95% level. No multi-collinearity problem existed among the three habitat variables in the model based on tests performed following methods in Cavallaro et al. (1981).

Trout cover had the highest partial correlation coefficient in the model and is probably the single most important habitat variable measured that affected observed variations in trout densities. Binns and Eiserman (1979), Platts (1979b), Harshbarger and Bhattacharyya (1981), Cardinal (1980) and Lewis (1967) reported cover was a critical component of stream habitat affecting trout densities when considered in combination with other habitat variables.

Table 2. Physical habitat variables which formed the best mutual relationship with trout densities (age I and older cutthroat and bull trout) in 134 North and Middle Fork tributary reaches (R=0.64, N=134).

Variable	R-Partial[a/]	Slope[b/]	P-Value[c/]
Trout cover(X_1)	0.50	0.53	0.001
Stream order(X_2)	-0.19	-2.62	0.040
D-90(X_3)	-0.18	-0.082	0.050

a/ Correlation of habitat variable to fish densities while other habitat variables are held constant.

b/ Slope is a measure of the direction and magnitude of a change in fish numbers with an increase in the measurement of a habitat variable by one unit.

c/ Level of significance of the relationship of a habitat variable to fish densities when considered in combination with the other habitat variables.

Stream order is a classification (Platts 1979a) assigned to a reach based on its position in a stream drainage and is roughly indicative of drainage area, discharge, and wetted width. Streams of lower order were associated with larger trout densities in the model. Platts (1979a) also found a negative correlation of stream order with cutthroat and juvenile bull trout densities.

The D-90, or the substrate size which is larger than 90 percent of the remaining streambed material in a reach, also related negatively to trout density in the model, suggesting larger substrate sizes in association with the other habitat variables in the model are associated with lower fish densities in a reach

Age I and Older Cutthroat Trout

The same habitat conditions describing variations in cutthroat and bull trout densities combined also best described variations in cutthroat densities (R=0.61, $p<0.001$). Cutthroat were generally found in much higher densities than bull trout and had dominant influence on the combined species model.

Age I and Older Bull Trout

Juvenile bull trout were closely associated with cover in the North and Middle Fork tributary reaches. Canopy, instream cover and percent of Class 1 pools best explained variations in juvenile bull trout densities (R=0.472, $p<0.05$). Bull trout were found in only about half as many reaches as cutthroat and the smaller sample size limited development of a model.

Predicting Fish Densities Based on Habitat Quality

To test the three variable model, trout densities were predicted based on habitat quality for 23 Middle Fork FHR tributary reaches in Glacier National Park which were surveyed in 1981. The equation used to predict the fish densities was:

$$\hat{Y} = 0.533X_1 - 2.57X_2 - 0.082X_3 + 9.30$$

Where

$\hat{Y}$ = Predicted trout density (age I and older cutthroat and bull trout)

X_1 = Trout cover

X_2 = Stream order

X_3 = D-90

Y intercept - 9.30

Predicted trout densities were much lower than measured densities in several reaches of Ole and Muir creeks (Table 3). This may have been due to underestimation of the instream cover component. Both streams had reaches with very large substrate (D-90) measurements which resulted in a large negative component in the equation for that reach. The instream cover estimates for those reaches did not appear to be as large as expected considering the size of the bed material. A larger measurement for instream cover would have greatly reduced the residual error for those reaches.

Table 3. Measured and predicted trout densities and residual error for 23 tributary reaches surveyed in the Middle Fork FHR drainage, Glacier National Park, during 1981.

Stream	Reach	Measured density Age I+ trout	Predicted density Age I+ trout	Residual error
Park	1	1.5	0.8	-0.7
	2	4.2	7.2	+3.0
	3	5.4	2.8	-2.6
	4	4.3	5.9	+1.6
Coal	1	3.3	1.5	-1.5
	2	7.5	12.6	+5.1
	3	2.7	3.2	+0.2
Ole	1	5.7	1.6	-4.1
	2	6.7	5.0	-1.7
	3	7.8	2.2	-5.6
McDonald	1	0.8	0.1	-0.7
Muir	1	11.7	2.2	-9.5
	2	5.3	6.8	+1.5
	3	19.6	11.4	-8.2
Nyack	1	0.1	1.6	+1.5
	2	0.2	0.1	-0.1
Pinchot	1	5.0	4.8	-0.2
	2	6.1	6.3	+0.2
Walton	1	3.7	8.1	+4.4
	2	14.8	16.1	+1.3
Lincoln	1	1.0	1.0	0
	2	4.7	11.3	+6.6
Harrison	1	0.6	0.1	-0.5

The correlation between predicted and actual fish densities was 0.63 which is significant to the 99.9% level (fig. 4). When fitted with a zero intercept, the correlation coefficient was 0.84. Harshbarger and Bhattacharyya (1981) reported similar correlation coefficient between trout biomass and physical habitat measurements in small North Carolina streams. Binns and Eiserman (1979) obtained a much higher correlation coefficient (0.977) in a model predicting trout densities in Wyoming; however, the model was based on ratings of 11 variables or variable combinations and constructed with only 20 observations. The habitat model developed for the North and Middle Fork FHR tributary reaches consisted of the actual measurements of only three variables which are relatively easy to quantify and was based on 112 observations (reaches). In addition, Binns' model was based on chosen observations from throughout the State of Wyoming, while our model is based on observations from only the Flathead drainage. A much higher correlation coefficient could probably be obtained if streams from other parts of Montana were included in the model, but this would not improve its predictive qualities for the Flathead drainage.

The equation for the final habitat model which includes the 23 Middle Fork reaches surveyed in 1981 was:

$$\hat{Y} = 0.523X_1 - 2.58X_2 - 0.068X_3 + 8.9$$

This model includes all 134 reaches which contained trout in the interconnected North and Middle Fork Flathead River system surveyed from 1979 to 1981.

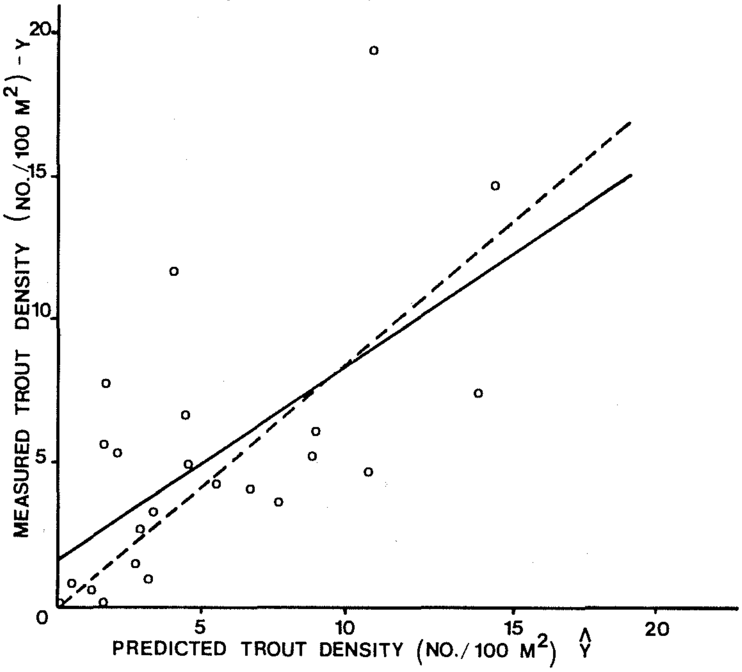

Figure 4. Measured trout densities (Y) and predicted trout densities ($\hat{Y}$) for 23 tributary reaches surveyed in the Middle Fork drainage in 1981. The solid line is the least squares fit ($Y = 1.75 - .67\hat{Y}$, $r = .63$) and the dotted line is fitted with zero intercept ($Y = 0 + .87\hat{Y}$, $r = .84$).

Discriminant Analysis

Discriminant analysis was used as a check for the usefulness of habitat variables to classify stream reaches. Groups of reaches with low (0.1 to 1.9), medium (2.0 - 7.9) and high (8.0+ trout/100m^2) trout densities were compared with 10 habitat variables considered important to trout densities (table 4). The 112 stream reaches surveyed in 1979 and 1980 were used in the initial analysis.

Table 4. Means of physical habitat and trout density measurements for reaches grouped in low, medium and high trout density categories.

Parameter	Trout density categories		
	Low	Medium	High
Number of reaches	37	39	36
Trout density	1.0	4.5	17.7
Stream order	3.1	2.9	2.6
D-90 (cm)	45	42	31
Trout cover (% area)	13	16	22
Wet width (m)	7.1	6.7	4.9
Wet cross-sectional area (m^2)	2.1	1.8	1.2
% run	46	41	45
Gradient	2.7	2.9	2.9
% pool	12	13	10
Average depth (cm)	26	25	20
% cobble	23	24	23

To obtain a significant relationship between fish density and habitat variables ($p<0.005$), the discriminant function analysis used seven of the 10 habitat variables. The three variables which formed the best mutual significant combination in multiple regression analysis, trout cover, substrate size (D-90) and stream order, were three of the top four significant variables used to derive the discriminant function. Average depth, wetted cross-sectional area, percent run habitat and wetted width were also significant in the discriminant function. Gradient, percent cobble and percent pool were not significant and did not enter the discriminant function at the specified level of significance.

Results from discriminant analysis of habitat parameters indicated a highly significant difference between reaches in the low and high trout density categories ($F=4.13$, $p<0.0005$), and between reaches in the medium and high trout density categories ($F=3.14$, $p<0.005$). A less significant difference existed between reaches in the low and medium trout density categories ($F=1.62$, $p<0.07$).

The second portion of the discriminant analysis involves classification of the stream reaches into groups based on habitat parameters. This procedure allows a check of the adequacy of the discriminant function by determining the percent of the original reaches correctly classed into groups by the habitat variables. Based on the habitat parameters utilized, 58 percent of the reaches were correctly classified into three groups (table 5).

Table 5. Classification of reaches based on the discriminant function analysis of habitat parameters for three fish density groups.

Fish density group	Number of reaches	Predicted group membership Low	Medium	High
Low	37	22	5	10
Medium	39	11	21	7
High	36	9	6	21

This classification function was also applied to the 23 Middle Fork tributary reaches surveyed in 1981. Based on the discriminant functions derived from the habitat measurements of the 112 reaches in the original analysis, 14 of these new reaches were correctly classified and nine were incorrectly classified. The results from discriminant analysis were similar and supported the multiple regression analysis. Other workers have recently used discriminant analysis in conjunction with regression analysis in studies of wildlife habitat (Capen 1981).

Geologic Bedrock Associations

The tributary reaches of the Middle and North Forks FHR draining areas where the geology has been mapped were classified according to geologic bedrock type (table 6). The classifications were based on geologic maps in a publication by the Flathead National Forest (1977) adapted from earlier geologic mapping (Johns 1970). Of the 89 reaches classified, only two were type B and were not analyzed. Twenty-one reaches had portions of their drainages composed of both A and C geotype (AC) and were classed as a separate group (table 7). The characteristics of the bedrock of these reaches are functionally similar to group B. Reaches in the D and AC geotypes had the highest trout densities (indicating high fisheries rearing potential) while reaches draining the C geotype had the lowest.

Discriminant analysis was used to determine if trout densities and physical habitat parameters differed between geologic types. To derive two significant ($P<0.002$) discriminant functions, the analysis used nine of the 11 variables. Gradient and average depth were not significant and did not enter the analysis of reaches in the five geologic groups. The discriminant analysis indicated highly significant differences (based on physical habitat and trout densities) between reaches in most of the geologic types (table 8). Discriminant classification functions placed 55% of the reaches correctly into the five geologic groups. Geologic type I was quite distinct from other groups as 76% of the reaches in this geotype were predicted correctly. Platts (1974, 1979a, 1979b) also found correlations between fish populations and selected aquatic and terrestrial geomorphic conditions.

Table 6. Geologic bedrock types in the Flathead National Forest. Physical and chemical characteristics are mean values derived from samples of typical unweathered soil materials (Martinson et al. 1982).

Parameter	Geologic bedrock type A	B	C	D	I
Bedrock nature	Limestone	Calcareous Argillite	Argillite & siltite	Quartzite	Shales, Sandstone and Limestones
Permeability rating 1-10 low high	10	6	4	4	(1-9)
pH	7.8	7.0	6.7	5.7	7.8
Base ion exchange (meq/100g soil)	9.2	5.7	9.8	4.5	20
Ca^{++} (meq/100g soil)	6.2	2.2	4.9	2.5	18.0
Mg^{++}	0.9	1.0	1.5	1.1	3.0
P (mg/l)	1.0	2.0	0.4	1.0	3.0
Soil texture	silty	silty	silty	sandy	sand and clay
% Gravel (% total by weight)	46	39	40	60	30

Table 7. Means of physical habitat parameters and trout densities for 89 reaches grouped in the five geologic types.

Parameter	Mean for geologic type A	C	D	I	AC
Number of reaches	22	16	6	24	21
Trout density (no/100m^2)	5.9	2.4	18.4	5.1	15.3
Stream order	2.9	2.8	2.7	3.0	2.9
D-90 (cm)	48.9	42.8	24.7	35.7	32.7
Trout cover (% area)	17.0	14.3	15.0	15.3	23.9
Wet width (m)	5.7	6.7	7.0	5.6	4.9
Wet cross sectional area (m^2)	1.4	1.7	1.9	1.5	1.3
Gradient	4.3	2.8	2.4	1.8	3.1
% cobble	21.0	23.2	27.8	23.7	19.2
% pool	8.3	9.4	15.2	25.5	7.8
% run	40.0	48.6	42.0	43.6	43.7
Average depth	22.6	23.0	24.7	26.0	20.0

Table 8. Significance of differences between reaches in pairs of geologic groups (from F statistics) based on physical habitat and trout densities.

Group	A	C	D	I
C	.338			
D	.008	.028		
I	.001	.0021	.002	
AC	.146	.003	.023	.0000

Evaluation of Model Performance and Management Implications

Hynes (1972) suggested that the most important environmental factors interacting to affect fish distribution and abundance in streams were temperature, discharge, cover or shelter, and streambed material. He states that these habitat variables are not independent of one another and must be considered in combination.

Platts (1974) has documented multivariate control of fish populations in streams. More recently Binns and Eiserman (1979) developed a model predicting trout densities in Wyoming streams based on 11 stream habitat variables or variable combinations.

Our model is valuable in predicting the existing fisheries potential of a stream reach based on major habitat characteristics. The slope associated with each variable is a measure of the probable increase or decrease in trout densities with a one unit change in the measurement of the habitat variable (assuming a linear relationship). For example, trout cover was associated with a slope of +0.53. This would mean that if trout cover were increased by 10 units in a reach, it should result in an increase in trout density by 5.3 fish per 100 m^2. However, an increase or decrease in trout cover by adding debris to a stream or logging operations in a drainage might also change the bed material size (D-90) by altering the stream hydraulics or channel morphology. Because of this interrelationship of variables, it is difficult to predict the exact nature of the effects of a change in habitat.

Physical habitat components and fish populations are variable and often difficult to measure. It is likely that the precision of our model is limited by the difficulty of obtaining accurate measurements for these variables in a reach of stream. The presence of resident and migratory fish populations in the Flathead drainage create further difficulty in obtaining accurate relationships between trout densities and habitat variables.

It was a basic assumption that the North and Middle Fork FHR tributaries were at carrying capacity for juvenile trout. Burns (1971) reported that juvenile salmonid populations were not always at carrying capacity in small California streams. He suggested carrying capacity of a stream may fluctuate from year to year. Studies conducted by Graham (1977), Sekulich and Bjornn (1981), and Horner (1978) indicated that densities of some age classes of salmonids in several Idaho tributaries may not be at carrying capacity.

Analysis of data from the Flathead drainage demonstrated important relationships among trout populations, physical habitat and geologic bedrock type. Using these relationships, habitat quality in relation to fisheries potential was determined for important rearing areas in the interconnected Flathead Lake-River system. Through cooperation with the Flathead National Forest Office, this information has provided a basis for integrating fisheries into the land management process in the Flathead drainage.

ACKNOWLEDGEMENTS

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USE OF STREAM HABITAT CLASSIFICATIONS TO IDENTIFY BULL TROUT SPAWNING AREAS IN STREAMS[1]

Patrick J. Graham, Bradley B. Shepard
and John J. Fraley[2]

Abstract.--A basin-wide inventory of bull trout spawning areas and habitat parameters was completed in tributaries of the North and Middle Forks of the Flathead River during 1979, 1980 and 1981. Stream order, channel gradient and two channel substrate variables were found to be significantly ($P<0.05$) correlated to bull trout redd frequencies. The combination of stream order and D-90 (diameter of substrate material which was larger than 90 percent of all streambed material) was the best variable combination ($R=0.47$, $P<0.01$). Variables ranked in order of their discriminating ability were stream order, D-90, channel gradient, overhanging bank cover and percent of the substrate in gravel and cobble combined. Two discriminating functions correctly classified 58 percent of the stream reaches into: 1) no-redd; 2) low-redd frequency; and 3) high-redd frequency categories based solely on measurements of habitat parameters. Other factors affecting spawning distributions were side channel development and the influence of ground water. Land managers can use bull trout spawning habitat data to effectively include cumulative impacts on fisheries in long-term planning.

INTRODUCTION

Flathead Lake and the North and Middle Forks of the Flathead River (FHR) (figure 1) support a large adfluvial population of bull trout (*Salvelinus confluentus*). In late spring, mature bull trout 5 or more years of age and 457 mm or more in total length emigrate from Flathead Lake as far as 245 km upstream to spawn in natal tributaries. Spawning occurs in September or October and initiation of spawning activity appears to be cued in part by water temperature (Fraley et al. 1981). Most juveniles rear 2 or 3 years in tributaries before migrating to Flathead Lake where they grow to maturity. A trophy bull trout fishery exists seasonally in the Flathead Lake and River system.

A basin-wide cumulative impact assessment was conducted on the entire North and Middle Fork drain-

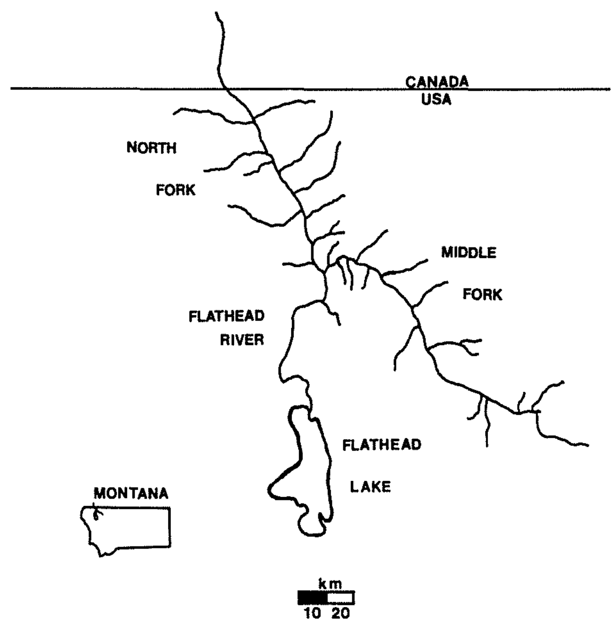

Figure 1. Drainage map of the upper Flathead River Basin.

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ages within the United States to identify potential impacts of proposed coal development in Canada on the Flathead basin fishery. Bull trout spawning areas provided a valuable index of the relative importance of tributaries in the drainage. These spawning areas were easily identified, limited in distribution and site specific (Fraley et al. 1981, Shepard et al. 1982).

In this paper, we discuss the relationships between stream habitat inventory data and the frequency of bull trout redds in stream reaches available to migratory bull trout. These relationships, in combination with site specific data on the quality of spawning gravels, can be used to identify stream reaches important for spawning and monitor long-term changes in habitat quality. Microhabitat and spawning site distribution data also were collected to assess preferred spawning habitat criteria (Graham et al. 1980, Fraley et al. 1981, Shepard et al. 1982).

METHODS

Inventory of Bull Trout Spawning Sites

Bull trout spawning site (redd) inventories were conducted during the fall of 1979, 1980 and 1981 to quantify total numbers of spawning sites in the North and Middle Forks of the Flathead River. Habitat variables and redd frequencies (number of redds/km of stream length) were evaluated in 94 North and Middle Fork tributary reaches. Approximately two-thirds of the reaches available for spawning were located in wilderness areas or Glacier National Park and had not been significantly impacted by development. The remaining reaches have been impacted by roading, logging and other activities. We estimated 750 kilometers of stream were available to bull trout for spawning in the two river systems. Of this total, 270 and 296 kilometers were inventoried during 1980 and 1981, respectively. All areas which contained potential spawning areas were checked for redds during the spawning season. The censuses were concentrated in areas meeting the following criteria: 1) juvenile bull trout were observed by snorkel or electrofishing census (Graham et al. 1980, Fraley et al. 1981); 2) redds were observed in previous years; or 3) suitable spawning habitat was present downstream from any migration barrier.

Redds were identified by the presence of a depression (pit) and associated tailspill area of loosely piled gravel (Reiser and Bjornn 1979). Completed redds were readily identifiable because they were large (1 m x 2 m) and usually covered by "clean", recently disturbed gravel.

Relationship Between Habitat Variables and Redd Frequency

Stream habitat was evaluated using a modification of the system developed by the Aquatic Studies Branch of the British Columbia Ministry of the Environment (Chamberlin 1980a, 1980b). Fraley and Graham (this volume) described the methods used to evaluate habitat parameters. Habitat parameters were measured in areas of concentrated bull trout spawning and in one random 0.8 to 2.5 km portion of each reach.

Correlation Analysis

For each reach, we considered the highest redd frequency recorded during the 3 year study to be a measure of the spawning potential. Thirty physical habitat parameters and parameter combinations were tested for their relationship to redd frequency using simple linear correlation. All but nine parameters were eliminated based on lack of simple correlation.

The nine variables used in the final analyses included channel gradient, stream order, D-90 (diameter of substrate material which was larger than 90 percent of all streambed material), valley-channel ratio, percent of boulder, percent gravel and cobble combined, percent of high quality pools, percent overhanging vegetation (<1 m above the water surface), and percent total cover (streambank and instream cover).

Multiple regression (Snedecor and Cochran 1969) was used to identify the most significant combination of the nine habitat variables which correlated to redd frequencies. All correlations and regressions were calculated using the "Mregress", "Sumstat" and "Biplot" computer programs of the Montana State University Statistical Library (Lund 1979).

Discriminant Analysis

Discriminant analysis was used to determine if the nine habitat variables which best correlated with redd frequency could be used to classify spawning habitat potential. We arbitrarily segregated redd frequencies into three groups: 1) 0.0 redds/km; 2) more than 0.0 but fewer than 3.0 redds/km; and 3) more than or equal to 3.0 redds/km. Discriminant analysis was performed on a CP-6 computer using programs in the Statistical Package for the Social Sciences Series (Nie et al. 1975).

RESULTS AND DISCUSSION

Relationships Between Habitat Variables and Redd Frequencies

Correlation Analysis

During 1980 and 1981, a total of 488 and 562 bull trout redds, respectively, were counted in the U.S. portion of the Flathead River drainage accessible to bull trout. Bull trout spawners utilized less than 28 percent (215 km) of 750 km of stream accessible in the fall.

Channel gradient and stream order were significantly correlated with bull trout redd frequency ($P<0.01$). Two substrate variables, D-90 and percent boulder also were correlated with redd frequency

(P<0.05). Stream order and D-90 were the multiple variable combination that best described the relationship between habitat variables and the frequency of bull trout redds (R=0.47, P<0.01).

Stream order was positively correlated with redd frequency indicating higher stream order was associated with more redds. Stream order has been positively correlated with standing crops of fish, number of species and total eutrophic production (Platts 1979, Naiman and Sedell 1980). Stream order can be used as a single descriptor of several lotic habitat parameters. Bull trout may spawn in higher order stream reaches because: 1) they generally have higher base flows important for maintenance of incubating eggs over winter; 2) large areas of suitable spawning gravels and lower channel gradient are more likely to occur in these reaches; 3) they are the first portion of tributaries adult bull trout encounter when migrating upstream to spawn; and 4) migration barriers are more likely to occur in small, low order streams.

Channel gradient, D-90 and percent boulder were negatively correlated with redd frequency indicating bull trout selected areas with smaller streambed material and low gradient for spawning. D-90 is useful in describing overall substrate composition. Low D-90 measurements indicate the streambed composition is predominated by gravel and finer material. *Salvelinus spp.* generally spawn in areas where substrate material 6 mm to 50 mm predominate (McPhail and Murray 1979, Oliver 1979, Leggett 1969, Blackett 1968). Bull trout in the Flathead spawned in material of similar size (Shepard et al. 1982, Fraley et al. 1981).

McPhail and Murray (1979), Blackett (1968) and Allan (1980) reported that *Salvelinus spp.* selected low gradient areas for spawning. Our field observations indicated that bull trout often spawned immediately downstream from low gradient-high gradient interfaces. This resulted in concentrations of redds in the upstream portion of low gradient reaches.

Discriminant Analysis

Five of the nine habitat variables used in discriminant analysis were significant when applied to the 94 stream reaches available to bull trout for spawning (table 1). Stream order, D-90 and channel gradient were the most significant variables. Overhanging bank cover and percent gravel and cobble were also significant discriminating variables although neither was significant in simple correlation analysis.

Overhanging cover was positively correlated to spawning use. Adult bull trout not actively engaged in spawning were observed closely associated with instream cover (undercut banks, debris jams or deep pools).

The first three discriminating variables (stream order, D-90 and channel gradient) demonstrated a highly significant difference (P<0.0001) existed between sections with no bull trout redds and sections with redd frequencies of 3.0 or more/km. Smaller significant differences were observed between no-redd sections and low redd frequency sections (P<0.025), and between low versus high redd frequency sections (P<0.05).

Table 1. Means of physical habitat parameters for stream reaches grouped as no redds, low redd frequency, and high redd frequency categories.

Parameter	Redd frequency categories None[a/]	Low[b/]	High[c/]
Stream order	3.0	3.1	3.6
D-90	51	37	33
Gradient (percent)	3.2	1.8	1.5
Boulder (percent)	16	12	10
Gravel-Cobble (combined percent)	54	62	62
High quality pool (percent)	5	7	8
Overhang cover (percent)	14	10	11
Valley-channel ratio	10	10	12
Total cover (percent)	16	15	13

a/ Mean frequency of redds was 0.0/km in 34 stream reaches.
b/ Mean frequency of redds was 1.2/km in 29 stream reaches.
c/ Mean frequency of redds was 6.9/km in 31 stream reaches.

Two discriminating functions were derived using the five significant discriminating variables. These discriminating functions correctly placed 62, 52 and 61 percent of the reaches into zero, low or high redd frequency groups, respectively, based only on measurements of habitat parameters (table 2). Overall, 58.5 percent of the reaches were classified correctly.

Table 2. Classification of stream sections based on discriminating functions derived from habitat variables for the three redd frequency groups. The upper number is the number of stream reaches and the lower number is the percent of stream reaches.

Redd frequency group	Number of stream reaches used	Predicted classification None	Low	High
None	34	21	10	3
		62%	29%	9%
Low	29	4	15	10
		14%	52%	34%
High	31	3	9	19
		10%	29%	61%

Other Factors

Stream reaches containing abundant side channel and braided channel areas contained large numbers of bull trout redds. Multiple stream channels are often associated with channel gradient changes and bull trout redds were found more frequently in these low gradient, aggrading reaches of stream characterized by loosely compacted gravels.

Stream reaches continually recharged by ground water provide a more stable environment for developing embryos and are probably more desirable as spawning areas. We observed a concentration of 18 bull trout redds in a 200 m long by 8 m wide spring fed channel draining into Trail Creek, a tributary to the North Fork of the Flathead River. There was evidence of superimposition at two redd sites in the channel. The channel was fed exclusively by a spring having a discharge of approximately 0.2 cms. Other areas of concentrated bull trout spawning may have also been linked to ground water recharge areas. We attempted to correlate redd frequency with geologic type, but were unable to obtain statistically significant results due to our broad geologic groupings. We did observe more bull trout redds in spawning areas located in limestone. We believe one reason for this association was the more permeable nature of the limestone aquifer. Heimer (1965) noted two spring fed areas of a supplemental Dolly Varden spawning channel below Cabinet Gorge Dam in the Clark Fork River, Idaho, had high densities of redds and superimposition occurred. Allan (1980) suggested inland *Salvelinus spp.* in the upper Clearwater River, Alberta spawned in tributaries having stable flows originating from ground water recharge systems.

Cumulative Impact Assessment

Our results illustrate that: 1) bull trout spawning habitat is critically defined; 2) the amount of that habitat is limited; and 3) bull trout recruitment to the Flathead Lake-Upper Flathead River fishery is dependent upon these specific spawning sites.

Criteria are presently being established to identify impacts on fishery resources caused by site specific disturbances. Too often these criteria do not recognize the potential cumulative impacts of long-term resource development. Recently, land management agencies have attempted to evaluate cumulative impacts within river drainages (USDA, Forest Service 1981). The importance of this type of assessment is evident in the Flathead River drainage. A proposed coal mine near Howell and Cabin creeks in Canada could eliminate 10 percent of the spawning sites counted in the combined North and Middle Fork drainages. Based on this total spawning inventory, fecundity rates of 5,000 eggs/female and estimated egg to fry survival of 60% and fry to adult survival of 1%, the loss of Howell Creek would mean a reduction in adult bull trout of approximately 3,000 fish annually. In addition, major timber sales have been proposed in four tributary drainages adjacent to 35 percent of the remaining spawning areas in the Flathead drainage. Potential also exists for extensive oil and gas extraction and micro-hydro development.

The drainage-wide inventory of bull trout spawning sites proved to be a valuable tool when evaluating the relative contribution of tributaries in a river drainage. These inventories identified the limited distribution of spawning areas within and between streams. Incorporating this information into the data base and land classification system used by resource managers helped to insure that bull trout reproduction potential will be considered in planning and decision making processes. This study has also resulted in a cooperative effort between land management and fishery resource agencies to monitor and protect these important spawning areas.

ACKNOWLEDGEMENTS

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COMPUTERIZED INFORMATION MANAGEMENT

IN THE FISHERIES SCIENCES[1]

David L. Mayer[2] and Brian F. Waters[3]

Along with the general scientific community, the present day fisheries scientist is experiencing an information explosion. A revolution is occurring away from the use of hard copy publications to communicate technical information and towards an increasing reliance on computer and telecommunication technologies to manage and distribute new information. This change will require the fisheries scientist to think more in terms of "information storage, retrieval, and use" and less in terms of "publications."

Many information storage and retrieval systems currently available to the fisheries scientist were reviewed with respect to such characteristics as: type of information available; content, scope, and freshness of information; systems relatedness (some are encompassed by others); general availability and accessibility; user costs; user interactiveness; and where appropriate, other characteristics such as optional uses of the systems. The future trends and potentials of computerized information management for the fisheries scientist are discussed.

Future shock and information overloads are no longer subjects of science fiction but are phenomena which are assuming an everyday reality as we approach the 21st century. Our abilities to gather and disseminate information are far in advance of our abilities to catalog and assimilate the information. Electronic instruments gather continuous water quality data on multichannel recordings. Satellites beam meteorological, geological, natural resource, and other information to earth. Data translators feed computer processing facilities that integrate, analyze and store multiple data input streams. Computers supply data summaries and final reports at the push of a button. Data analysis in conducting a classical fisheries research problem which may have required the support of an entire research unit now can be completed by a single individual and a computer. Not only has the population of our research community grown exponentially, but also our quantitative research productivity.

Imagine a large river, representing fishery science information, with two main branches, namely, marine and freshwater research. Each branch is fed by tributaries of governmental, academic and commercial research. Each tributary is composed of information streams from research in applied fisheries biology, fisheries management, environmental assessments and regulation, ecosystem research, modeling and many other topics. The feeder streams of data have grown in number and flow rate (aided by electronics and computers), and have caused a flood in the information mainstream. If fishery scientists can be compared to fish seeking prey (research literature) in the flooding river of information, then we are in danger of being overcome by exhaustion in our search in this overwhelming flow of information and have to seek refuge in the back eddies of the river. To be effective, the researcher and decision maker must leave the river bottom and back eddies and

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swim out into the mainstream of information. Computerized information management systems have been developed to help us find our prey and survive.

Today's explosive growth and development of computerized information management systems are not only providing excellent tools to assist research and decision making, but these automated search systems will be required in order to survive the information flood waters of the next decade.

The field of computerized information management has evolved rapidly in the past decade, beginning with computer storage and retrieval of numerical data. The fisheries scientist quickly recognized the usefulness of the computer to store digital information from field surveys which generated large data matrix combinations of such variables as catch composition, habitat characteristics, ecological inventories, and morphometrics. In fact, the first vacuum tube computer developed at the University of Washington was applied to salmon fisheries catch data.

To foster an awareness of the existing computerized information management capabilities for fishery scientists and to promote their use and ultimate advancement, we will review the highlights and features of this technology, examine some user applications and costs, and make recommendations for the future.

Data or information management systems utilize numerical and alphanumeric classification schemes for information storage and retrieval. Numerical information management systems use index, storage and retrieval techniques that are similar to alphanumeric information management systems. However, there are two primary differences between the two approaches. First, numerical information management systems rarely contain alphabetic data because such data must be transformed or eliminated before mathematical or statistical analyses can be performed. Second, numerical data typically are placed in a fixed-field format which is standardized to conform with assigned fields of particular variables. In practice, the fishery scientist finds numerical information management systems relatively inflexible to changes in sampling designs, measured variables and nonnumerical information content. A common question is how and where to store the field notes written in the margin of the field data keypunch form. Most of these problems can be solved by detailed planning of the data base before the survey, or by revisions of the data formats during the course of the study.

Contrasted to numerical information management systems, alphanumeric information management systems contain information stored as numbers, letters, and words. The information is not normally processed with standard mathematics or statistics. Alphanumeric information systems are typically employed for the storage and retrieval of words organized as text. Applications range from look-up files, such as taxonomic name decoding files, to complete manuscript storage. Manuscript storage and retrieval systems are becoming a very common office facility, replacing the "typing pool" of the last half-century with the "word processing center." The growth of alphanumeric or word information systems has been promoted by the recent advances in computer technology which have reduced the cost of memory and off-line storage. Word information systems are bulky to store and, depending upon the search and retrieval system, they can require large amounts of a computer's central memory.

Various word information systems are developing. One type, developed by TERA Corporation, stores information on microfiche that are indexed by magnetically coded tabs. The fiche, which are stored in a carousel type tray, are searched magnetically by computer control, retrieved, and displayed by micro video camera on remote CRT stations or television monitors. The advantages of this system are the cost of input and the ability to include noncharacter information such as drawings and photographs. The disadvantage of the system is that the computer information search is limited to the information coded in the fiche index tab; the computer cannot search the photographed information on the fiche.

Other word information systems magnetically store all of the information. These systems, of course, require that all of the information is in character format (no drawings or photographs). Word entries to these systems require digital encoding, typically accomplished by a keypunch operator recopying the document onto magnetic tape or disc. The growth of these types of word information systems has been accelerated tremendously by the growing use of computerized office word processing systems. Nearly all publishing companies now compose their journals and books on computer-based word processing systems. This publishing method creates a magnetic record which can be transmitted to the abstracting services and avoids retyping a magnetic record for computer information storage systems. Most scientific abstract services employ computer-based magnetic records and word storage. Once the magnetic file has been created, it can be electronically transferred in standard formats to any other information management system. The bibliographic completeness of computerized scientific information systems has improved tremendously in the past few years due to the proliferation of these computer-based publication techniques. It is important to understand the features and limitations of the present systems to employ them effectively and to foster their advancement and improvement. The following review and summary of these system characteristics focus on the class of computerized bibliographic systems.

Computerized bibliographic search systems vary widely from specialized in-house systems, which are devoted to a particular area of research and to very large national and international systems composed of data bases supplied by outside vendors. The amount and type of information stored in the systems range from simple subject titles to complete documents. The search systems are commonly accessible by a dial-up phone connection and standard remote terminal couplers.

The equipment required to gain access is relatively inexpensive and easily available on a lease or purchase basis. Remote terminal printers with a telephone coupler range from $2,000 to $4,000. The price differences are proportional to printer speed and the necessary coupling equipment. Telephone connections can be made either through direct dial-up on standard lines or through subscription to data transmission networks such as TELENET or TYMSHARE. Many university libraries and agency research branches support the services and communication equipment. Most commercial and governmental data base/information retrieval systems charge a service fee based on the connect time (the amount of time that you are connected to the central computer) and the number of lines printed. On-line connect charges range from $10/hour to $150/hour, and charges for material printed range from no charge to 50¢ per record. In addition, many service systems charge a nominal initiation fee which usually includes user manuals, update literature, and training sessions.

The recent trend in computerized information management/search systems is to combine specialized data bases under a single master search system. Master search programs enable the user to select the most productive data bases for the search subject. An example of one of the largest and most powerful information retrieval services is DIALOG Information Services, a subsidiary of Lockheed Corporation. The system contains more than 160 data bases, which contain in excess of 50,000,000 records. Records, or citation units of information in the system, can range from short directory-type listings to a citation with bibliographic information and an abstract referencing a journal, conference paper, or other original source.

Examples of fisheries related data bases in DIALOG are:

AQUACULTURE, with more than 4,600 records from 1970 to the present. It provides access to information on the growth of marine, brackish, and freshwater organisms. Subjects covered include disease, economics, engineering, food, nutrition, growth, and legal aspects.

Another is BIOSIS Previews, with more than 3,000,000 records from 1969 to the present. It contains citations from Biological Abstracts and constitutes the major English language service providing worldwide coverage of research in the life sciences. Nearly 8,000 primary journals, as well as symposia, reviews, preliminary reports, government reports, semipopular journals, and other secondary sources, provide citations to this data base.

Other relevant data bases, by name, are ENVIROLINE, with more than 91,000 citations since 1971; Environmental Bibliography, with over 170,000 citations since 1974; National Technical Information Service (NTIS), with close to 1,000,000 citations since 1964; Oceanic Abstracts, with more than 120,000 records since 1964; and Water Research Abstracts, with 130,000 records since 1968.

The DIALOG data base most relevant to the fishery scientist is Aquatic Sciences and Fisheries Abstracts (ASFA), which references more than 5,500 national and international journals, as well as other source documents. It presently contains more than 75,000 records from 1978 to the present, and is adding approximately 28,000 records annually. Public access to the ASFA data base is available through information retrieval services in the United States, Canada, and many nations throughout the world.

The ASFA data base attempts to be comprehensive in its coverage. Information sources include journal articles, books, chapters from books, reports, conference papers, maps, sound recordings, motion pictures and other photographic forms. Journal articles account for about 71 percent of the total items in the ASFA data base. Conference papers account for about 21 percent, technical reports about 5 percent, and books and monographs about 3 percent.

While the types of records and their bibliographic elements vary, many elements are common to most records, including:

- a record number,
- a complete citation,
- the aquatic environmental regime,
- the type of document and literary style,
- subject category codes, and
- the language of the publication and that of any abstract or summary published with it.

Accessing and effectively searching a system such as DIALOG requires a moderate amount of initial training and an ongoing program of data base and system awareness in order to keep abreast of the frequent changes and enhancements. Each data base is constructed uniquely, with varying searchable fields. The search techniques of the data bases also vary, from controlled vocabulary to free-text or code searching. The experience of the searcher directly affects the precision/recall rates of a search.

As an example of a combination of free-text and concept code searching, joined with Boolean logic, the BIOSIS Previews data base was searched for literature concerning temperature tolerance or effects on rainbow trout (Figure 1).

The same search performed on the ASFA data base is constructed quite differently (Figure 2). While ASFA does not provide for concept code searching, the data base is most effectively searched using its unique controlled vocabulary. For greater precision, field specificity has also been used in this search.

As skills develop in preparing a search strategy, the cost of searches decreases and results improve. The experienced searcher is adept at tailoring search strategies to information needs and is knowledgeable of data base overlap and subtle variations in subject focus in order to maximize efficiency.

What does all this lead to? First, it is no longer necessary, or even adequate, for us to scan tables of contents in paper copy publications to get the new technical information we need for best job performance. Most of us cannot afford access to all relevant publications. Furthermore, we cannot afford the time it would take to handle them and, even if we could, much of the relevant and timely information is not in peer-reviewed journals.

Let's gaze into the crystal ball afloat the river of fishery science technology. Rising to the forefront are:

- Offices of the near future will be equipped with computer terminals as standard equipment, and will fully support word processing and computerized bibliographic search systems.

- Researchers will publish and electronically review each others' work. Paper copy periodical publications will be very limited or discontinued.

- Publications will eventually include raw data tables, since electronic publication will not be restricted by number of pages or journal size.

- Researchers will standardize many of their methodologies and formats for storing basic aquatic habitat inventory information. With this inclusion into large and accessible computerized data base systems, the information is not only potentially more usable by its originators but also by outside researchers or managers. A user should eventually be able to obtain all available aquatic habitat inventory information by specifying specific stream miles or geographical coordinates.

- Finally, user support and utilization of these systems will result in further advancements. The American Fisheries Society could aid in this effort by working to get more of the gray, or peer-reviewed journal, literature into existing information management systems such as ASFA. The cost of alphanumeric entry on computer-compatible media is decreasing, and many of the universities, agencies, and companies who are producing gray literature are using word processing equipment which produce easily transferrable magnetic records. Therefore, the magnetic records could be easily transferred into such a data base.

So, throw away your 3 x 5 cards and send your bookcases back to the library to make room in your office for a computer terminal -- and be prepared for the information flood. If you don't stay on top of this one, you will sink and be left behind like a spawned-out salmon.

```
? b5
        11Jan82 19:10:49 User4612
```

User logs on system and identifies file 5 for search.

```
  $0.10  0.004 Hrs File1*
```

Cost of file access and title.

```
File5:BIOSIS Previews - 77-82/MAR BA V7302:BA/RRM V2201:(See file 55)
        Set Items Description
        --- ----- -----------
? ss rainbow(w)trout or salmo(w)gairdneri
          1  1381 RAINBOW(W)TROUT
          2  1463 SALMO(W)GAIRDNERI
          3  1826  1 OR 2
.? s temperature(1w)effect?: s temperature(1w)tolera?
          4  1247 TEMPERATURE(1W)EFFECT?
          5   221 TEMPERATURE(1W)TOLERA?
? s cc=10616 or cc=10618 or cc=10614
             30560 CC=10616  EXTERN EFF-COLD
             31156 CC=10618  EXTERN EFF-HOT
             39907 CC=10614  EXTERN EFF-TEMPERATURE
          6 87057  CC=10616 OR CC=10618 OR CC=10614
```

User begins interactive search by specifying search topics. The computer then replies with a count of the number of literature items in each topic Set.

```
? limit 6/maj
          7 19208  6/MAJ
? c3and(4or5or7)
```

User combines trout, Item 3 with topic Sets 4 or 5 or 7.

```
          8   127 3AND(4OR5OR7)
? t8/6/1-127
```

User requests listing of titles and accession numbers Items 1 through 126 in Set 8.

```
8/6/49
69001669
  THERMAL  RESISTANCE OF RAINBOW TROUT FROM A PERMANENTLY HEATED STREAM
AND OF 2 HATCHERY STRAINS

8/6/68
67046805
  TEMPERATURE EFFECTS ON ACCELERATION OF RAINBOW TROUT SALMO-GAIRDNERI
```

Two examples of title listing.

```
8/5/49
```

User requests full record printout of item 68 of Set 8.

```
67046805
  TEMPERATURE EFFECTS ON ACCELERATION OF RAINBOW TROUT SALMO-GAIRDNERI
  WEBB P W
  SCH. NAT. RESOUR., UNIV. MICH., ANN ARBOR, MICH. 48109, USA.
  J FISH RES BOARD CAN   35 (11). 1978.  1417-1422.   Coden: JFRBA
  Language: ENGLISH
  Acceleration performance during and immediately following fast-starts was
measured at 5, 10, 15, 20 and 25.degree. C for rainbow trout (S. gairdneri)
of  mean  mass  23.5 g.  Fast-start responses were initiated by an electric
shock stimulus.  Temperature had little effect  on  fast-start  kinematics.
Response  latency  and  duration  of  propulsion  strokes  decreased  with
temperature.  Latencies decreased from 23 ms at 5.degree.  C  to  6  ms  at
25.degree. C.  Times to complete the first 2 principal acceleration strokes
in a fast-start decreased from 116 ms at 5.degree. C to 65 ms at 25.degree.
C.  Distance traveled in a given time increased with temperature.   For  an
elapsed  time  of 100 ms,  the distance traveled was 3.5 cm at 5.degree.  C
increasing to 11.3 cm at 25.degree. C. Velocity increased with time at each
temperature to reach maximum values by the end of the 3rd propulsive stroke
and thereafter declining.  Maximum velocity increased with temperature from
0.99 m .cntdot. s-1 at 5.degree. C to 1.71 m .cntdot. s-1 at 15.degree.  C.
Maximum velocity was independent  of  temperature  from  15-25.degree.   C.
Similar  trends  were  found  for maximum acceleration rate which increased
from 16 m .cntdot.  s-2 at 5.degree.  C to 41  m  .cntdot.   s-2  over  the
15-25.degree.   C  range.  Temperature effects on acceleration performance
would alter the ability to fish to traverse short areas  of  high  velocity
flow, the effectiveness of predators, and vulnerability of prey fish.
  Descriptors: ELECTRIC SHOCK PREDATION
  Concept  Codes:  ECOLOGY-ANIMAL(*07508),   ECOLOGY-WATR  RESRCH,FISHERY
BIOL(07517), BIOPHYS-BIOENGINEERING(*10511), EXTERN EFF-ELECTR,MAGNET,GRAV-
ITY(*10610),    PHYSIOLOGY-GENERAL   STUDIES(*12002),     MOVEMENT(*12100),
METABOLISM-ENERGY,RESPIRATION(*13003), NUTRITION-GENL,NUTR STATUS,METHS(*1-
3202), NERVOUS SYST-GENL STUDS,METHS(20501), TEMPERATURE-GENL,METHS(23001),
TEMPERATURE-HYPO,HYPERTHERMIA(*23006)
  Biosystematic Codes: OSTEICHTHYES(85206)

? logoff
        11Jan82 19:24:52 User4612
  $5.73  0.117 Hrs File55 11 Descriptors
```

Search time and cost.

```
LOGOFF 19:24:53
```

FIGURE I

AN EXAMPLE OF DIALOG COMPUTER SEARCH OF
BIOSIS ABSTRACTS FOR RAINBOW TROUT
TEMPERATURE EFFECTS AND TOLERANCE LITERATURE

```
b44
        12Jan82 14:31:50 User4612
  $0.31  0.005 Hrs File44
File44:Aquatic Science Abstracts - 78-81/Dec
        Set Items Description
        --- ----- -----------
```

User logs on system and identifies file 44 for search.

Cost of file access and title.

```
? s rainbow(w)trout/ti; s salmo(w)gairdneri/ti; c1or2;
          1    685 RAINBOW(W)TROUT/TI
          2    476 SALMO(W)GAIRDNERI/TI
          3    775 1OR2
? s temperature effects
          4   1681 TEMPERATURE EFFECTS
? s temperature tolerance
          5    209 TEMPERATURE TOLERANCE
? s temperature preference
          6      5 TEMPERATURE PREFERENCE
? s temperature preferences; s temperature requirements
          7     52 TEMPERATURE PREFERENCES
          8      5 TEMPERATURE REQUIREMENTS
```

User begins interactive search by specifying search topics. The computer then replies with a count of the number literature then replies with a count of items in each topic Set.

```
? c4-8/or
          9   1880 4-8/OR
```

The user combines items in topic Sets 4 through 8 and create a new Set 10.

```
? limit 9/maj
         10   1439  9/MAJ
? c3and10
         11     42 3AND10
```

Set 10 is combined with Set 3 (Set 1 and 2).

```
? limit 11/eng
         12     42  11/ENG
```

User limits search to English language titles only.

```
? t12/6/1-42
```

User requests list of titles and DIALOG Accession Numbers for all 42 items in Set 12.

```
1104976  111-04976
  Tolerance of rainbow trout to direct changes in water temperature.

0905776  109-05776
  Temperature effects on acceleration of rainbow trout, Salmo gairdneri.
```

Two examples of title listing.

```
? t12/5/29
```

User requests full record list of Item 29 in Set 12.

```
12/5/29
0905776  109-05776
  Temperature effects on acceleration of rainbow trout, Salmo gairdneri.
  Webb,P.W.
  Sch. Nat. Resour., Univ. Michigan, Ann Arbor, MI 48109, USA
  J. Fish. Res. Board Can., 35(11), 1417-1422, (1978)
  LANGUAGES: English
  SUMMARY LANGUAGES: English ;   French
  Includes bibliography 36 ref.
  DOC TYPE: Bibliography;   Journal Article
  JOURNAL ANNOUNCEMENT: 7904
  Acceleration performance during and immediately following fast-starts was
measured at 5, 10, 15, 20, and 25.degree.C for rainbow trout (Salmo
gairdneri) of mean mass 23.5 g. Fast-start responses were initiated by an
electric shock stimulus. Temperature had little effect on fast-start
kinematics. Response latency and duration of propulsion strokes decreased
with temperature. Latencies decreased from 23 ms at 5.degree.C to 6 ms at
25.degree.C. Times to complete the first two principal acceleration strokes
in a fast-start decreased from 116 ms at 5.degree.C to 65 ms at
25.degree.C. Distance traveled in a given time increased with temperature.
For an elapsed time of 100 ms, the distance traveled was 3.5 cm at
5.degree.C increasing to 11.3 cm at 25.degree.C. Velocity increased with
time at each temperature to reach maximum values by the end of the third
propulsive stroke and thereafter declining. Maximum velocity increased with
temperature from 0.99 m.s.SUP--1. at 5.degree.C to 1.71 m.s.SUP--1. at
15.degree.C. Maximum velocity was independent of temperature from 15 to
25.degree.C. Similar trends were found for maximum acceleration rate which
increased from 16 m.s.SUP--2. at 5.degree.C to 41 m.s.SUP--2. over the
15-25.degree.C range. Temperature effects on acceleration performance would
alter the ability of fish to traverse short areas of high velocity flow,
the effectiveness of predators, and vulnerability of prey fish.
  DESCRIPTORS: temperature effects;   locomotion
  TAXONOMIC DESCRIPTORS: Salmo gairdneri
  IDENTIFIERS: kinesis;   stim;   predation;   thermoregulation
  SECTION HEADING CODES: 1422

? s thermoregulation/id
         13     18 THERMOREGULATION/ID
? c3and13
         14      1 3AND13
? t14/6/1
14/6/1
0905776  109-05776
  Temperature effects on acceleration of rainbow trout, Salmo gairdneri.

? logoff
        12Jan82 14:39:19 User4612
  $7.81  0.126 Hrs File44 10 Descriptors
```

Search time and cost.

```
LOGOFF 14:39:21
"5
```

FIGURE 2

AN EXAMPLE OF DIALOG COMPUTER SEARCH OF AQUATIC SCIENCES AND FISHERIES ABSTRACTS FOR RAINBOW TROUT TEMPERATURE EFFECTS AND TOLERANCE LITERATURE

ASSESSING FLUVIAL TROUT HABITAT IN ONTARIO[1]

Jack Imhof[2]

and

Raymond M. Biette[3]

Abstract -- The standardized assessment of fluvial trout habitat has been initiated in Ontario. Assessment requires a trained two member crew walking the length of the stream during the summer and recording on field maps the selected parameters comprising trout habitat. The parameters include temperature, stream discharge, water velocity, stream width, stream morphology, total dissolved solids, bank stability, stream substrate, stream shading, instream cover, barriers to trout and land use patterns. Simultaneous estimates of trout biomass are made on certain sections of the stream using electrofishing techniques. During the fall and spring the spawning sites are recorded. A description of each component is summarized on maps using coded wheels and tabulated on recording forms for entry onto computer tapes. A mathematical model relating these parameters and trout production will be attempted. This information will be used to develop a long-term plan for protecting and rehabilitating trout habitat.

INTRODUCTION

Over the past several decades the fluvial fisheries resource base in Ontario, Canada, has been steadily declining. Many trout streams have suffered severe degradation because of their proximity to agricultural and industrial locales, and consequently have lost some of their capacity to produce trout. In an attempt to arrest or reverse the downward trend of the fisheries resource, the Ontario Government in 1979 adopted a plan, entitled, Strategic Planning for Ontario Fisheries (Loftus et al. 1978). This plan called for the protection and rehabilitation of fisheries habitat. Implementation of the plan on trout streams required an expanded knowledge base of fluvial trout habitat. While standard inventory data collected during the past 10 years on many Ontario trout streams provided general information of the physical, chemical and biological conditions of the streams (Dodge et al. 1979), it was not comprehensive enough for identifying all the components of trout habitat or to estimate trout production. Hence, it could not be used to develop a long-term plan for protecting and rehabilitating trout habitat. This paper describes how Ontario is now acquiring additional information on the habitat characteristics of its trout streams and trout biomass.

MATERIALS AND METHODS

Assessment of fluvial trout habitat was first undertaken on streams judged to have the greatest potential of contributing to the fisheries resource. Prior to field work, a map of the target stream and watershed was prepared from 1:50,000 topographical maps or aerial photographs. Any major tributary and its branches that flow into the main branch was designated a unit (Fig. 1). Non-branching tributaries entering the main stream were considered as one unit from mouth to headwater. All units were assigned a letter code. Each unit was then enlarged, using an overhead projector, from the original 1:50,000 scale to 1:5,000 and divided into subunits by tributary or branch. Beginning from the uppermost area, each subunit was assigned a number.

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[1]Paper presented at the Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. Portland, Oregon, October 28 - 30, 1981.

[2]Jack Imhof, Fisheries Rehabilitation Biologist, Ontario Ministry of Natural Resources, Central Region, Richmond Hill, Ontario, Canada.

[3]Raymond M. Biette, Habitat Enhancement Biologist, Ontario Ministry of Natural Resources, Fisheries Branch, Queen's Park, Toronto, Ontario, Canada.

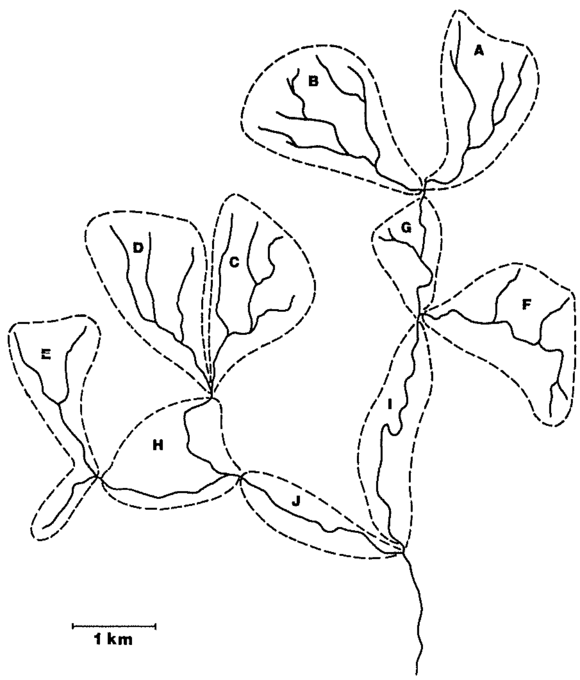

Figure 1 -- An illustration of the division of a hypothetical watershed into various units labelled A to J.

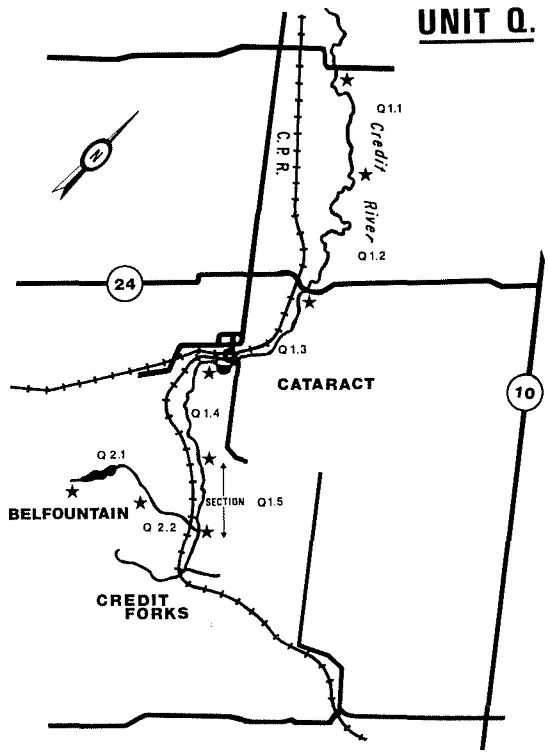

Figure 2 -- An illustration of the division of subunits of Unit Q of the Credit River into various sections approximately 0.4 km in length. Subunit Q1 is divided into sections numbered Q1.1 to Q1.5 and subunit Q2 is divided into sections numbered Q2.1 to Q2.2. Directional features such as roads, railways and names of towns are also shown.

Each subunit was then divided into sections of approximately 0.4 km in length and each section was also numbered beginning at the upstream boundary. An example of this classification is shown for a portion of the Credit River (Lat. x Long. 43° x 79°) on Figure 2. The unit Q was divided into 2 subunits Q1 and Q2, subunit Q2 was divided into two sections Q2.1 and Q2.2, and subunit Q1 was divided into five sections Q1.1 to Q1.5. Directional features such as roads, railways and names of towns were also included on the map (Fig. 2). A 0.4 km section was then enlarged to fit on a 21.5 x 35.5 cm field sheet and used as the field map.

Moving from the upstream and towards the mouth, one person started on each bank identified and recorded on the field map the following: the presence of stable and unstable stream banks, the type of substrate present (on the basis of size), the presence of dense, partly or open stream cover, the presence of instream cover and the presence of riffles, runs, pools and flats. Land use within 10 - 30 m of the stream was also recorded, as well as instream barriers for trout. Symbols, shown in Figure 3, were used to record the observations on the map. An example of a completed field map for a section of the Credit River is shown on Figure 4. Crew members entered the stream only when necessary, so as not to muddy the stream and maintain a better vantage point for observing. At the downstream end of a section, the results for each component were expressed as a percentage of the total area of the section. For each component the average of two percentages, one for each observer, were determined, recorded on standard forms and summarized using coded wheels following the legend indicated in Figure 5. To obtain a rapid overall view of habitat conditions within the stream, the coded wheels were drawn on the maps with a line linking them to the appropriate section. An example of the coded wheels for section Q1.5 of the Credit River is shown in Figure 6. Further, at the end of a section, measurements were taken of average stream width, mean depth, water velocity and water temperature.

For each unit of the stream, measurements of stream discharge were obtained from records of stations operated by other agencies (Conservation Authorities, Ontario Ministry of the Environment, Federal Department of the Environment), or from the standard inventory data base. Measurements of total dissolved

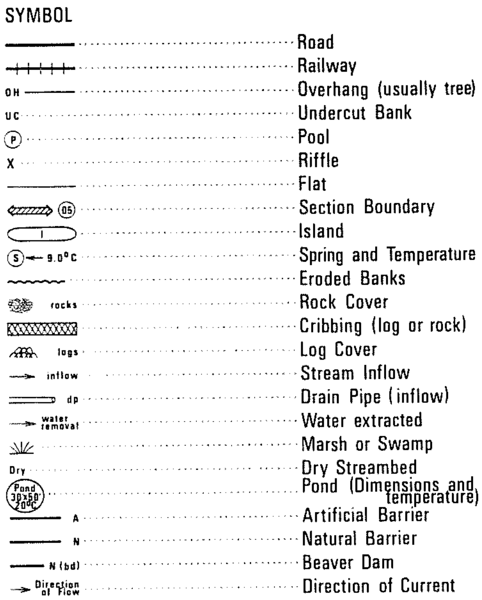

Figure 3 -- A list of symbols used on field maps to designate various components of trout habitat, directional features and other factors.

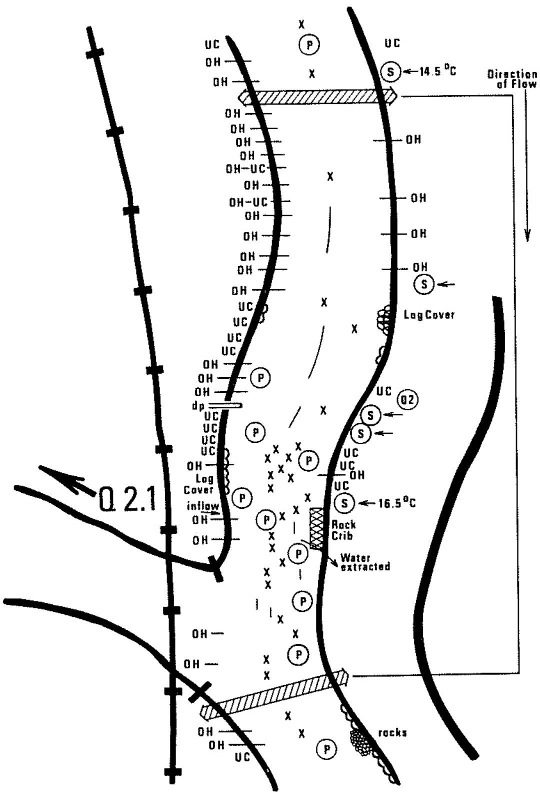

Figure 4 -- An illustration of a field map showing the symbols used to designate the various habitat parameters for a section (Q1.5) of the Credit River.

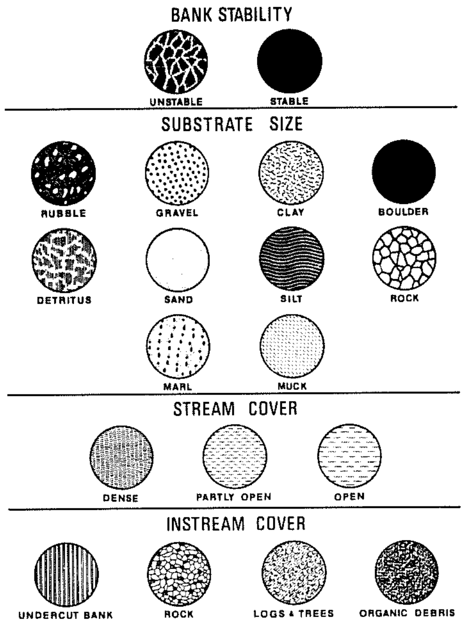

Figure 5 -- Symbols used on coded wheels for summarizing field measurements on bank stability, substrate size, stream cover, and instream cover.

solids were obtained from the standard inventory data base. Estimates of trout biomass were made at sampling stations, representative of the various sections of the stream. At each station, (approximately 40-50 m in length) trout were sampled with electrofishing gear and biomass estimated by the removal method (Zippin 1956). Capture of brown trout *(Salmo trutta)* was aided by using more than one anode. Leslie's estimates (Leslie and Davis 1939) were made also to test for the significance of the regression.

All assessment, except for the description of spawning sites, occurred during the summer when water levels approach base flow, temperatures were highest and clarity of the water was greatest. Assessments performed during summer were biased towards the 'worst case' situations. However, the 'worst case' situations are considered to be limiting to final biomass production in streams and were therefore probably more accurate.

During the autumn and spring information on spawning sites was recorded. Specific times of spawning were determined by spot checking spawning sites to observe when peak spawning activity occurred. Crews of two observers walked the river upstream, located redds, and using polaroid glasses determined relative size and number of fish spawning at specific locations. In addition, observers noted redd locations relative to banks, to spring areas adjacent to the redds, and to riffles. This information

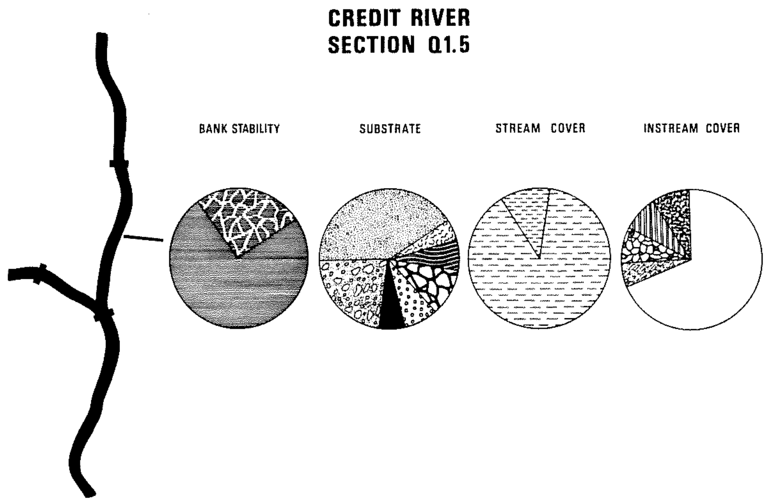

Figure 6 -- Coded summary wheels for the habitat parameters of bank stability, substrate size, stream cover and instream cover for section Q1.5 of the Credit River. At a glance a manager can observe that 75% of the banks are stable, 45% of substrate is comprised of material larger in size than sand, most of the section is open of stream cover and 30% instream cover is present.

was then added to the other habitat information for the appropriate section of stream.

In an effort to achieve common standards in the collection of trout habitat data across the province, all observers, prior to commencing work, were given a one-week lecture and field course. Observers were taught standard methods and definitions and given training in recognition of the various components comprising trout habitat. Observers were taught also to sample trout with electrofishing gear. This involved learning not only the techniques of electrofishing, but also the behaviour of the species being caught.

RESULTS AND DISCUSSION

During the last three years, we have initiated the collection of standardized habitat data on eight trout streams covering over a total of 150 km. Our results showed that following training the values for the various components deviate by 10% or less between observers and that estimates of trout biomass were reliable within 90% confidence limits.

We found that two observers can assess 60 km of stream in approximately 60 days. This includes 5 days for training, 20 days for collecting information on the habitat components (3 km of stream length walked per day), 10 days for estimating trout biomass, 15 days for mapping spawning sites and 10 days for preparing maps and tabulating the information. Hence, to assess, for example, 1200 km of trout streams, we require 20 crews working for one summer and one spring or autumn spawning period; or approximately 10 man years (20 x 2 x ¼ year).

Various public interest groups, such as Trout Unlimited, Federation of Fly Fishers, have assisted with some aspects of assessment, particularly in recording spawning sites. These groups are comprised of highly motivated individuals that through their own interest and keen observation have a good understanding of salmonid streams. Their assistance not only reduces the workload on government personnel but also helps the individuals develop a public stewardship towards the resource.

Information collected from the assessment is already being used by field managers to make more sophisticated decisions regarding the protection and rehabilitation of Ontario trout streams. For example, summary data on the maps (Fig. 6) enables a manager to obtain an understanding of the factors that may limit trout production on a particular stream. Using this information a manager can then develop appropriate tactics such as converting an instream dam to a bottom drawoff, to overcome these limitations. As another example, the documentation of trout habitat helps a manager gain an understanding of the significance for production of certain critical areas in the stream and consequently the need to protect firmly these areas from all other potential users. Knowing this, a manager is able to develop a tactic, such as outright purchase of these areas, to protect them from future degradation.

In the future, the standardized habitat information on trout streams will be placed on computer tapes and added to the computerized Ontario Fisheries Information System (Loftus 1976). This system will enhance the accessibility of the information, allow for the integration with other data bases, such as those for benthic organisms, water quality, and stream discharge and thus provide a sophisticated tool for managing trout fisheries.

The computerized data base will be used also in developing mathematical models which explain trout production. The models could be used for predicting changes in trout production resulting from habitat alterations, whether these alterations occur through degradation or rehabilitation. For instance, these models could be used to demonstrate the gain in trout production that would result from funding projects for controlling erosion and sedimentation. This quantitative information would assist a manager to convince landowners of the merits of a sedimentation control project. The model could also be used to predict the loss in trout biomass that would result from channelizing a section of stream for agricultural drainage. This evaluation would provide for a more readily understood comparison of the costs and benefits of this drainage scheme. An objective evaluation of the trout fishery resource is essential to resolve resource allocations conflicts and consequently protect trout streams from further degradation.

Other workers have used mathematical models to interrelate the various components of trout habitat. Binns and Eiserman (1979) developed a multiple regression model that interrelates nine physical habitat factors (temperature, stream flow, etc.) to predict trout standing crops in high elevation Wyoming trout streams. They have successfully used this model to develop a rationale for protecting the trout resource from potential impacts such as reservoir development and diversions. The Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service used an incremental simulation approach to link various physical habitat factors to construct species habitat suitability curves as a means of explaining trout production (Stalnaker, 1979). Li and Schreck (1981)[4] have pointed out a shortcoming in mathematical models of fish production that account only for physical habitat factors. They have shown that biological factors, such as competition or predation, affect the habitat available for trout and consequently these variables should be included in the model. Although we have not measured these factors directly, we hope that our biomass estimates of the various species present will allow us to account, at least in part, for these variables.

[4] Li, H.W. and C.B. Schreck. 1981. Personal correspondence. Oregon Cooperative Fishery Research Unit, Oregon State University, Corvallis, Oregon.

We hope to develop a preliminary simulation model that interrelates the important variables that influence trout production and to progressively refine it as new information becomes available. For example, in the future, it may be necessary to add other parameters, such as ground water levels, in order to account for trout production on certain streams. However, a detailed description of each component is necessary before we can determine how important the component is to trout production and before trout production can be explained. To date, we are at the descriptive phase of this task.

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PROBLEMS ASSOCIATED WITH HABITAT EVALUATION OF AN ENDANGERED FISH IN HEADWATER ENVIRONMENTS[1]

John N. Rinne[2]

Abstract.--Attempted evaluation of habitat for Gila trout, Salmo gilae Miller, in three headwater tributaries in the Gila National Forest, New Mexico, may have been hampered by small sample size, extreme variability in habitat and fish populations, artificial modification of habitat, stream intermittency, and asynchronous sampling. Prediction of the fish resource (maximum size, number, and biomass) based on physical habitat measurements was more successful in pools than in riffles and more successful for size of trout than for numbers and biomass. However, further developmental testing of methods to evaluate Gila trout habitat is recommended to aid in recovery of this endangered species.

INTRODUCTION

The Gila trout, Salmo gilae Miller, is known to occur naturally in only five streams in the Gila National Forest in southwest New Mexico (Mello and Turner 1980, USDI 1979, Rinne 1980). Because of its rarity and restriction in range, it has been classified as an endangered species since 1967 (USDI 1980). Two major reasons for the decline in population and range of this wild native trout have been its hybridization with rainbow trout and the destruction and loss of habitat (Deacon et al. 1979, USDI 1979).

The habitat of any species can be defined as the sum total of all physical, chemical, and biological factors that surround it. Fish habitat includes the quality and form of water column, flow regimes, living space, food supply, channel substrate composition, and streamside and watershed conditions. These variables interact in time and space and, at any point, one or a combination may have a greater effect on fish populations than others.

Any habitat evaluation technique ideally should examine seasonally all features of the habitat to effectively determine its total condition. Realistically, such a comprehensive approach seldom occurs because of limitations of time, labor, and money. More commonly, only a few habitat factors, which are arbitrarily selected, are measured. Next, their quality and quantity are suggested, and predictions of suitability to the fish resource are made. Variation in selection of those factors which are believed to be most important to a fish species has resulted in a variety of approaches to habitat evaluation.

Recently, considerable interest and research has been directed toward determining components of the stream environment that are indicative of good trout habitat (Rinne 1978, Binns and Eiserman 1979, Chapman and Knudsen 1980, Platts et al. in press). Most studies suggest that the physical factors of the stream are more predictive of suitable trout habitat than are biological or chemical factors (Saunders and Smith 1962, Gunderson 1968, Elser 1968, Wesche 1976). Chemical and biological factors, largely because of inherent variability, rhythms, and often complex interactions have not been successfully correlated with population, size, or biomass of fish. Habitat data that are available pertain to larger (>10 m^3 min^{-1} low flow) streams and, therefore, cannot be reliably extrapolated to conditions in the small (<1 -5 m^3 min^{-1}), headwater tributaries, such as those inhabited by Gila trout. The larger streams may be more stable and less variable physically, chemically, and biologically and, therefore, perhaps lend themselves more readily to accurate evaluation.

This paper discusses problems encountered while attempting to evaluate the habitat of a fish species that is currently found only in extreme headwater streams within its former range.

DESCRIPTION OF STUDY AREA

Habitat evaluation was attempted in 1977 and 1978 in three streams--Main Diamond, South Diamond, and McKnight creeks in the Gila National Forest, New Mexico. Main Diamond and South Diamond creeks are headwater tributaries of the upper Gila River and contain natural populations of Gila trout, the former stream is the type

[1]Paper presented at Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium. (Portland, Oreg., Oct. 28-30, 1981).

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locality of the species. McKnight Creek is a small tributary of the Mimbres River and contains an introduced population of Gila trout from Main Diamond Creek. The three streams are subject to drought and harsh winter weather. Modal flows range between 0.3 and 3.5 $m^3 min^{-1}$, but flooding may increase streamflow 30 to 50 times this rate. Drought periodically may reduce streams to intermittent pools; this occurs annually in South Diamond Creek. Because of this severe limitation of water, log stream improvement structures (Rinne 1981, Rinne 1982) have been installed on Main Diamond and McKnight creeks to improve habitats. None of these structures are present on South Diamond. The three streams support about 80% of the total population of Gila trout.

METHODS

Rationale

Chapman (1966) well stated that space legislates the density of trout populations in streams. Physical factors such as depth and volume of water, overhead cover, and water surface area are less dynamic spacially and temporally in a given riffle or pool of a respective stream. In comparison, pH, water temperature, and aquatic macroinvertebrate populations vary more over time and space. Food, for example, is essential to the survival and well-being of any fish population, but establishing levels that are most suitable to the fish resource is exceedingly more difficult because of the seasonal and dynamic nature of the food resource. Similarly, it is difficult to delimit any aspect of the fish resource at any given time, without information on previous physical habitat conditions, such as flow regimes or prior perturbations of this habitat. Evaluation of physical factors alone, however, is an attempt to alleviate the problem by reducing the number of undefined variables and using ones which are innately less variable in natural systems.

Evaluation Approach

Methodology of collection of fish and habitat data are given in Rinne (1978, 1981), and only are summarized here. Basically, the procedure follows five steps: (1) Block pools and riffles with nets and electrofish three times, (2) record numbers, lengths, weights, and total biomass of fish, (3) compute surface area from measurements of parallel and perpendicular transects of each pool and riffle, (4) estimate pool and riffle volumes and depth statistics from depth measurements on transects, and (5) compute the area of instream and streambank cover from dimension measurements. Study sections normally encompassed 100 m of stream.

The approach to defining the quality of the Gila trout habitat was based upon a hypothesized relationship of the physical habitat to fish resource factors (FRF) comprised of number of trout, biomass, and mean and maximum size. Physical habitat factors (PHF) measured were mean and maximum depths, volume and surface area, and cover and percent cover. The last estimate was the raw cover value expressed as a percentage of the total surface area of the respective pool or riffle. Stream habitat was divided for analyses into pool and riffle components.

Statistical Analyses

Initially, all data were subjected to stepwise multiple linear regression analysis. The data were the four estimates of the FRF's (number, biomass, mean and maximum size of fish) and the six estimates of the PHF's (maximum and mean depths, volume and surface area, and cover and percent cover). Generally low explanation (small r^2 values) of variability occurred in the FRF's by PHF's. A non-parametric correlation test (Spearman Rank) was attempted but failed to improve r^2 values.

To eliminate some of the problems apparently encountered because of natural variability in data, PHF's from pools and riffles were ranked. Spearman Rank analyses provided a listing of all estimates of PHF's and FRF's in increasing order of array. From this list and based on results of stepwise regression analysis, the total range of data for 7 of the 10 variables (3 FRF's, 4 PHF's) were partitioned by inspection into five ranks (Table 1). Rank separation was placed where obvious, natural breaks in the total range (0 to 57) of fish numbers occurred. The remaining six variables were partitioned based on the ranks as defined by fish number. The rationale for this procedure was based on the assumption that an increase in a given PHF (e.g., maximum depth of water) would parallel any increase in a respective FRF (e.g., number or size of fish).

The validity of the ranking technique was tested in two ways. First, an analysis of variance was performed on data groupings of FRF data to determine if means within each of the five ranks were significantly different. Secondly, 10 measured values of maximum pool depth were selected at random from the data array and assigned a rank. Based on this rank, a range of expected maximum size and biomass of fish was predicted for each of the 10 pools. Finally, the actual, measured maximum size and biomass of Gila trout in each of the 10 respective pools was then compared to the predicted range.

To better display the variability in data among the three streams studied and to aid in discussion of factors that precluded effective evaluation of habitat for this endangered fish, data plots and frequency distributions of PHF's and FRF's were compiled.

Table 1.--Ranges in respective ranks of FRF and PHF data for Gila trout habitat evaluation

	Fish resource factors			Physical habitat factors			
Rank	Number of fish	Biomass (g)	Maximum size (mm)	Maximum depth (cm)	Volume (m^3)	Cover (m^2)	Percent cover (m^2/m^2 surf. area)
1	1	25	<100	≤15	≤1.0	≤0.01	≤0.5
2	2- 5	26- 75	101-150	16-20	1.01-1.75	0.02-0.20	0.51-1.00
3	6-10	76-200	151-175	21-30	1.76-3.50	0.21-0.75	1.01-3.00
4	11-20	201-600	176-225	31-50	3.51-10.0	0.76-2.75	3.01-15.0
5	≥21	601	≥226	≥51	≥10	≥2.76	≥16.0

RESULTS

Although stepwise regression did not adequately explain variation (Table 2), analyses did indicate that in pools, depth, and to a lesser extent, volume of water were more consistently related to the Gila trout resource. By comparison, cover and percent cover explained more of the variation in FRF's in riffles. In general, variation in the FRF's was explainable by PHF's more in pools than in riffles. Inherent variability in habitat and fish statistics coupled with small sample size of pools and riffles, therefore, made it impossible to accurately predict any of the FRF's based upon measured physical habitat. However, the PHF's that were more consistently and directly related to FRF's (Table 2) were employed in attempted ranking procedures.

In pool habitat, FRF data groupings formed by ranks of depth and volume and analyzed by analysis of variance were significantly different in all cases but maximum depth rank versus fish numbers (Table 3). This initial test of the reliability of using a 5-rank system of physical habitat to predict FRF's was positive. That is, significance between means suggested that a change in physical habitat was paralleled by a change in FRF's. Intragroup comparisons indicated that data groups might be better partitioned into three, or in a single instance, two ranks (Table 3). In riffle habitat number of fish and biomass data groups formed based on volume and percent cover rankings were not significantly different.

Results of internal, random testing of the ranking technique for Gila trout habitat evaluation are shown in Table 4. Sixty percent of the maximum sizes and biomasses of fish were accurately predicted (within a range) from the 10 randomly selected estimates of maximum pool depth. Of the 10 recorded maximum fish sizes that were outside the predicted ranges, 3 were less than 12% and 25.4 mm (1 inch) in error. Similarly, 3 of the 10 biomasses were only 14% and 25% off, and one measured biomass was only 3 grams from falling within the predicted range. In agreement with analysis of variance results, predictability of FRF's in riffles was much lower. Using the same internal random testing, only 30% of the predictions of number of fish and biomass were correct based on volume and percent cover, respectively.

Combined data plots of FRF's versus PHF's in pools are shown in Figures 1-3. The amount of variation in these plots is evident, with varying trends among plots. The relationships between maximum depth (and to a lesser extent, volume) and maximum size of fish were closer than between these two PHF's and either number or biomass of fish. Analysis of these plots utilizing the ranges of data in each rank (Table 1), revealed that the overall accuracy of prediction of a given FRF by a respective PHF for all three streams combined, ranged between 20% and 40%---much less than that (60%) indicated by earlier cursory analysis utilizing the 10 random maximum pool depths. Frequency distribution plots of FRF's and PHF's in pools and riffles further illustrate the amount of variation among streams in the respective physical habitat and FRF's (Figs. 4-8).

DISCUSSION

High variability in PHF's and FRF's among streams (Figs. 4-8) resulted in overall scatter of plotted data (Figs. 1-3), and, coupled with small sample size, precluded utilizing standard regressional analyses and high probability levels (0.95) to evaluate habitat for Gila trout. Attempted ranking of PHF's to predict FRF's does not appear to be a viable alternative. Random internal examination and testing of such an approach (Table 4) suggested reasonable probabilities (0.60) of predicting maximum size or biomass of fish in pools; however, when all data were treated as a unit, probabilities (0.20-0.40) were much reduced. Further, it is not valid to test a technique based on the same data from which it was developed.

At this point no statistically reliable technique to evaluate Gila trout habitat using

Table 2.--Results of multiple linear regression analyses of physical habitat versus selected fish resource factors (FRF's). Values are the percentage variation (coefficients of determination) in FRF's explained by regression

	N	Number	Biomass	Mean size	Max. size
			Riffles		
McKnight	39	Volume 30	Volume 28	% Cover 23	Volume 14
Main Diamond	11	Cover 45	% Cover 63	% Cover 31	% Cover 58
			Pools		
McKnight	42	Volume 41	Volume 39	Mean Depth 13	Max. Depth 26
Main Diamond	15	Max. Depth 78	Max. Depth 81	------- --	Max. Depth 38
South Diamond	14	Volume 57	Max. Depth 79	Mean Depth 70	Max. Depth 70

physical habitat factors can be offered. However, several plausible reasons which may have led to the failure of this approach should be discussed to aid future efforts of fish habitat evaluation in small headwater tributaries.

Problems in Habitat Evaluation

One problem was restriction of sample size. Because of the endangered status and, therefore, limited populations of Gila trout, sample size (i.e., number of pools and riffles evaluated) had to be appreciably smaller than would be acceptable for other species of salmonids such as brook (*Salvelinus fontinalis*), brown (*Salmo trutta*), and rainbow trout (*S. gairdneri*) which are widespread and normally abundant. The three streams studied support 80% of this total population. The five remaining streams--Gap, Sheep Corral, Spruce, Iron, and McKenna creeks--therefore, do not present a good opportunity to refine attempted methods of evaluating the habitat of this endangered fish.

A second, and perhaps most limiting, factor to success in habitat evaluation of Gila trout was the extreme variability in habitat and the fish populations among streams. Mello and Turner (1980) alluded to the differences between populations of Gila trout in their survey work. Closer examination of frequency plots of data (Figs. 4-8) suggested some plausible reasons for this large amount of variation.

Table 3.--Results of analysis of variance on groupings of FRF's based on habitat rank. Data are from all three creeks containing Gila trout. Similarities within statistically significant groups as predicted by ranks are denoted by underlining of means

Comparison	Significance	DF	F-value	Within-group similarities of mean FRF's				
Pools				1	2	3	4	5
Maximum depth rank-fish biomass (grams)	<.001	60	6.92	26	116	190	364	590
Maximum depth rank-max. fish size (mm)	<.001	61	6.09	126	154	171	201	232
Volume rank-fish biomass	<.0001	66	9.91	130	204	270	547	--
Volume rank-fish numbers	<.0001	66	25.07	8.19	11.5	12.1	20.95	--
Maximum depth rank-fish numbers	.023	63	3.04	7.8	9.8	14.5	11.7	22.8
Riffles								
Volume rank-fish number	.075	57	2.25	5.6	12.9	11.8	--	--
Percent cover-fish biomass	.089	23	2.30	64.6	141.3	176	--	--

Table 4.--Comparison of predictability of maximum size and biomass of fish based on rank of maximum depth in 10 pools in McKnight Creek. Underlined predicted values are those which agreed with actual values. Asterisks indicate correction predictions using the 3-rank system

Pool	Max. depth (cm)	Rank	Predicted maximum fish size (mm) (5-ranks) (3-ranks)	Actual maximum fish size (mm)
1	15	1	< 100	210
2	20	2	101-150	156
3	26	3	151-175	199
4	31	4	176-225	180
5	35	4	" "	216
6	41	4	" "	192
7	47	4	" "	200
8	52	5	> 226	264
9	59	5	"	205
10	65	5	"	270
			Predicted biomass (g)	**Actual biomass (g)**
1	15	1	< 25	20
2	20	2	26- 75	92
3	26	3	76-200	250
4	30	3	76-200	199
5	35	4	201-600	315
6	40	4	" "	282
7	47	4	" "	603
8	52	5	> 601	1,386
9	59	5	"	665
10	70	5	"	517

First, the lack of consistency in relationship between pool depth and fish size suggests that the relative, artifical improvement of habitat in the three streams and the annual drying of South Diamond Creek (Rinne 1982) may have influenced variation.

Second, the large number (>150) of stream improvement structures in Main Diamond Creek may have created such good habitat that Gila trout in this stream are stunted because of overpopulation as was suggested by Mello and Turner (1980). Overpopulation and stunting, therefore, reduced the chances of success of using either a regressional or ranking technique to evaluate Gila trout habitat.

Third, the greater number of fish in pools in South Diamond Creek possibly also results from the annual drought and intermittent nature of this stream, as has been reported elsewhere by Lotrich (1973). Drought conditions in headwater streams (as studied here) generally force smaller fish that normally inhabit riffles into pools. As a result, number of fish increases but mean size of fish decreases (Fig. 4).

Fourth, habitat manipulation in Main Diamond Creek and stream intermittency in South Diamond Creek both contributed to the inability to successfully evaluate habitat in these streams by combining data. The fish population in McKnight Creek is relatively new (introduced in 1970) and may not have reached carrying capacity. Further, although stream improvement has been imposed on this creek, the number of structures was too few to cause overpopulation and stunting.

Fifth, the lack of replicates, and the use of point-in-time, asynchronous sampling did not adequately define natural variation among the three streams. McKnight Creek was sampled in spring and Main and South Diamond creeks in autumn. In contrast to autumn, relatively more and larger, spawning fish would be expected to inhabit riffles in spring resulting in an increase in maximum size of fish in riffles, as was observed in McKnight Creek (Fig. 4). Further, larger fish move into riffles to feed in early morning and late afternoon. Asynchronous sampling on a diel basis, therefore, may increase both maximum size and number of fish in a riffle and by converse reduce these FRF's in pools.

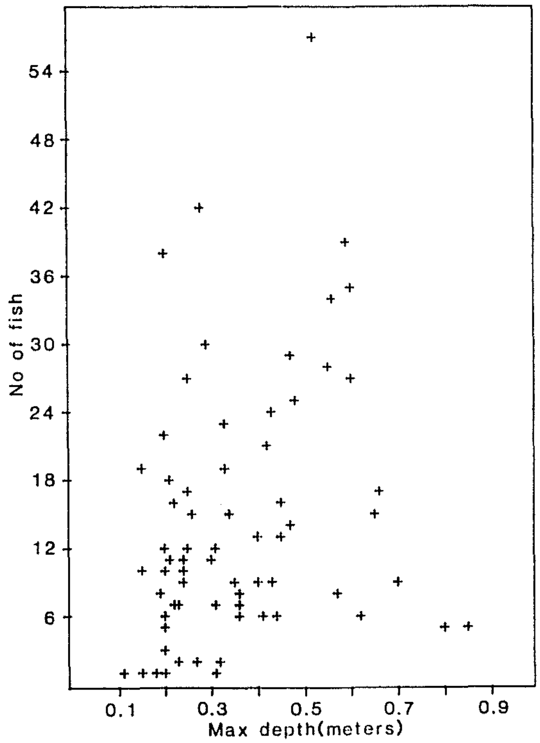

Figure 1.--Data plot maximum depth of water in pools versus number of fish in pools.

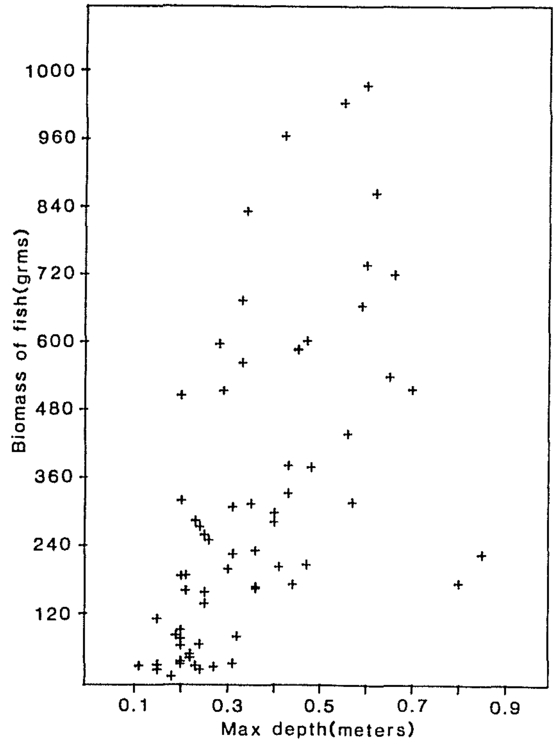

Figure 3.--Data plot maximum depth of water in pools versus biomass of fish in pools.

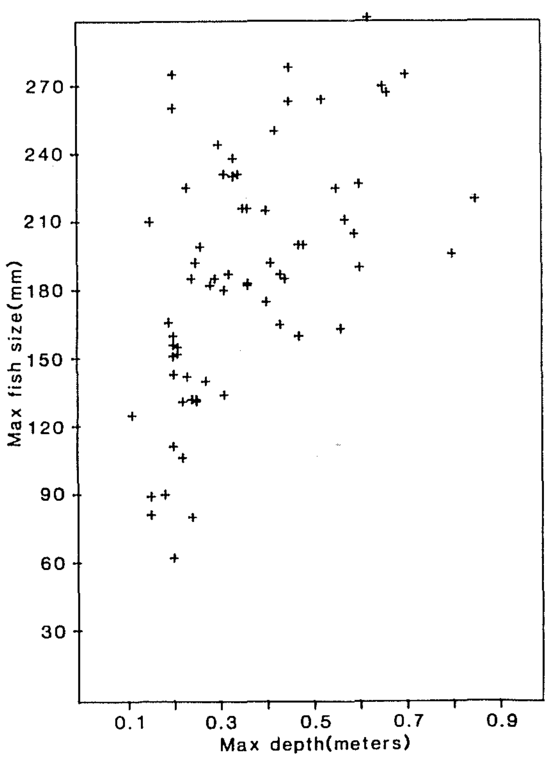

Figure 2.--Data plot maximum depth of water in pools versus maximum size of fish in pools.

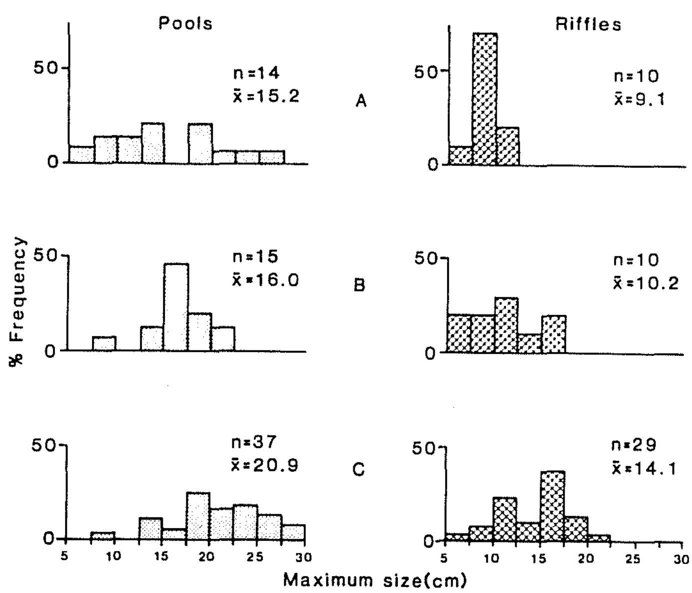

Figure 4.--Percentage frequency of occurrence of maximum size of Gila trout in pool and riffle habitat in South Diamond (A), Main Diamond (B), and McKnight (C) creeks.

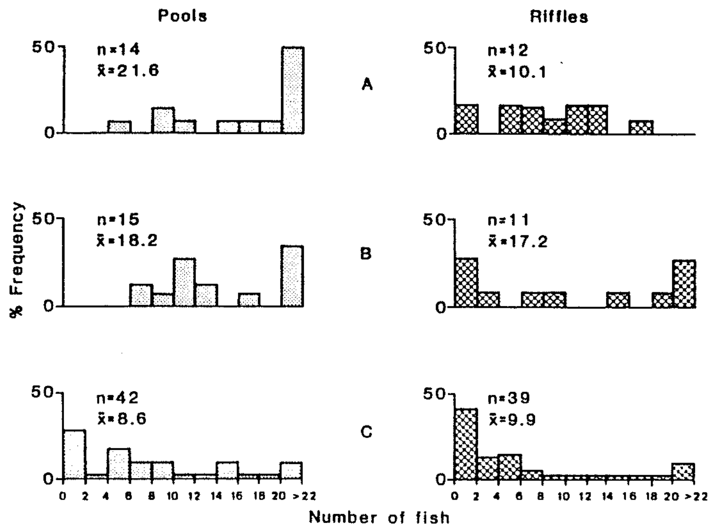

Figure 5.--Percentage frequency of occurrence of number of fish in pool and riffle habitat in South Diamond (A), Main Diamond (B), and McKnight (C) creeks.

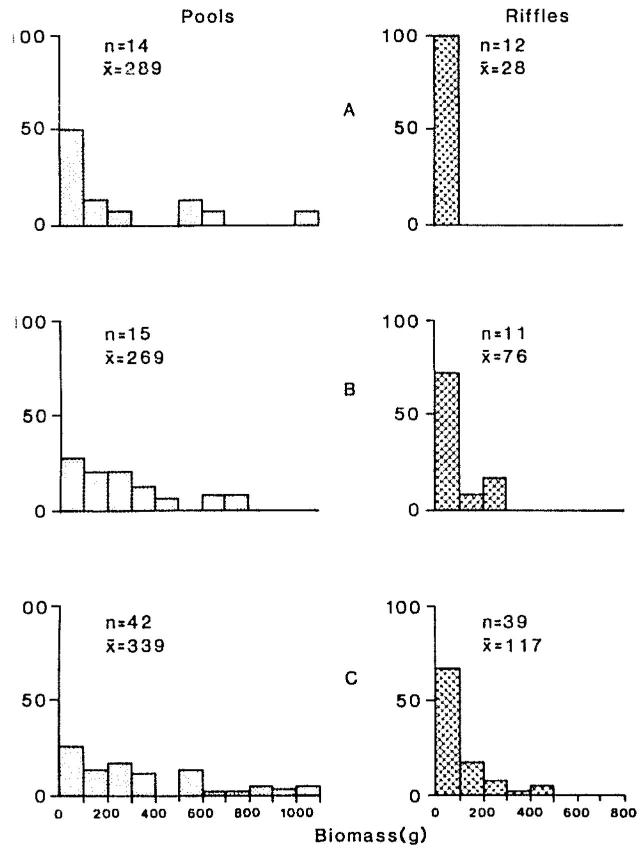

Figure 6.--Percentage frequency of occurrence of biomass in pool and riffle habitat in South Diamond (A), Main Diamond (B), and McKnight (C) creeks.

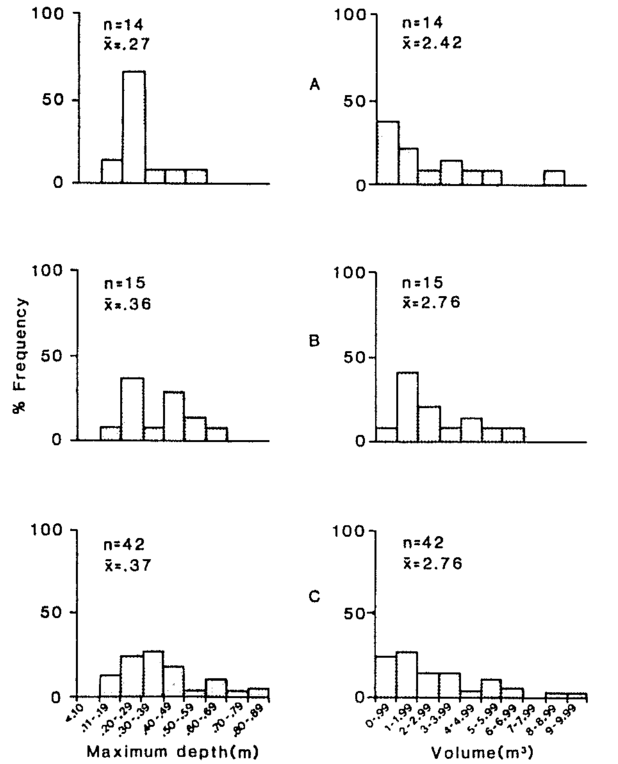

Figure 7.--Percentage frequency of occurrence of maximum depth and volume of water in pool habitat in South Diamond (A), Main Diamond (B), and McKnight (C) creeks.

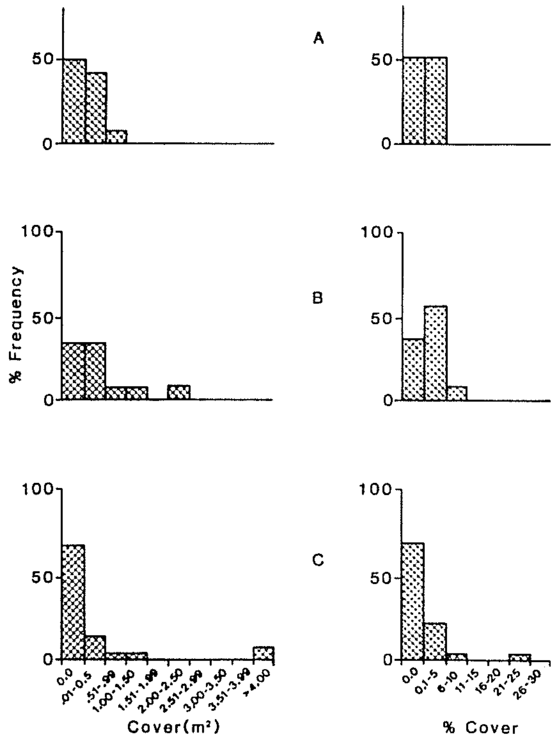

Figure 8.--Percentage frequency of occurrence of cover and percent cover in riffle habitat in South Diamond (A), Main Diamond (B), and McKnight (C) creeks.

Size (width) of stream and size of resident fish have been suggested to be directly related (Smith 1981). Potential maximum size of fish also should parallel greater depth of water. These two factors displayed the most consistent relationship despite problems alluded to above (Table 2, Fig. 2). Number and size of fish are important to an endangered species of fish which has sport potential. Endangered status is based, in part, upon estimated numbers of a species, and it becomes important to be able to validly evaluate habitat to determine potential Gila trout populations that may inhabit a candidate introduction stream.

Recovery of the former range and abundance of Gila trout is a primary goal of the Recovery Team for the species (USDI 1979). At present, this is an active program that plans for duplication of each of the five stream populations of Gila trout. Recovery programs and efforts such as these often cannot afford to wait until some highly refined and tested method of habitat evaluation is available before introduction of the species into "suitable waters" takes place. The ability to quickly survey a candidate stream to determine both quality and quantity of habitat is perhaps an improvement over the present alternative--a "best guess" approach. Unfortunately, no statistically reliable method could be developed to evaluate the habitat of this endangered fish.

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USING THE HISTORICAL RECORD AS AN AID TO SALMONID HABITAT ENHANCEMENT[1]

James R. Sedell and Karen J. Luchessa[2]

Abstract.--Historically, wild anadromous fish stocks evolved with stream systems that were obstructed by fallen trees, beaver dams, and vegetation growing in and beside the channels. River systems as large as 7th order had large numbers of fallen trees in their channels and often were obstructed by drift jams that were up to 1500 m long. The main river channels contained abundant gravels and fine sediments. Habitat complexity was great because of scour around boulders and fallen trees, and the presence of numerous and extensive stable side channels and sloughs. These pristine streams interacted intensively with their flood plains. Historical records document over 100 years of "diligent" stream and river cleanup. Primary activities included removal of boulders, large woody debris, and other obstructions from channels. We believe that historical documentation of the ways unmanaged streams interacted with the streamside forest allows us to know how far we have deviated from the optimum habitat requirements for various salmonids. Until we understand the structure of undisturbed habitats that wild stocks develop within, and the sequence of changes that have occurred in those habitats, our present protection and enhancement efforts will lack both a rational context and effective direction.

INTRODUCTION

Anadromous fish resources in Oregon and Washington streams have declined over the past several decades, prompting calls for intensified protection and enhancement measures. The quality and quantity of habitat available to wild stocks has diminished because of diverse and steadily increasing use of other land-based resources (timber, agriculture, hydropower, ranching). Increased harvest rates threaten the survival of many wild populations of salmonids. Most fishery management as well as land management agencies have some program for habitat enhancement or rehabilitation. The goal in all of these programs is to rehabilitate habitat that has been damaged, or enhance habitat that is naturally low in productive capacity.

A goal of both Oregon and Washington enhancement programs for anadromous fish is maintenance of natural stocks that still exist and preservation of genetic variability wherever possible. Increasing concern about the effects of large-scale hatchery programs on both genetic integrity of wild stocks and carrying capacity of the natural environment may be the strongest argument for improving quality and quantity of stream habitats. Although interspecific differences between the species of salmonids are obvious--such as appearance, size, habitat preference, time of migration, and feeding behavior--equally important differences occur within species, such as coho salmon or steelhead trout. These differences are determined by the nature of their freshwater natal streams and by the location and duration of their ocean rearing. Each stock within a species has developed physical and behavioral characteristics, that are specifically adapted to survival and reproduction in a particular home stream. These traits have a high probability of becoming incorporated into the stock largely because of a strong, genetically controlled homing ability. Because of continuous genetic selection for individuals best suited for

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specific streams, home stream stocks should survive and reproduce better than introduced stocks. Stocks introduced to a new environment usually have lower survival rates than native stocks and often lower the survival of the native stocks through interbreeding or competition (Oregon Department of Fish and Wildlife 1981).

Wild stocks evolved within "natural" stream systems. An understanding of the historical nature of these streams is important if we wish to rehabilitate streams or maintain and enhance wild stocks of fish. We assume that natural selection in freshwater was focused on the structure of these streams and the spawning, rearing, and migration habitats available to endemic salmonids.

We recognize that the best conditions for survival of a species, or stock within a species, are usually found in the center of its range. Much attention is currently being given to Oregon and Washington's geographical location as an important determinant of future potential for several anadromous species (Oregon Department of Fish and Wildlife 1981). It is equally important to identify the historic range and optimum of habitat conditions within a river system. Although important components of stream habitat--such as size of pools, quality of gravels, or pool/riffle ratios--were not historically quantified by early explorers and fur trappers, the general character of the streams and rivers of the Northwest was described. Historical records document how unmanaged stream systems interacted with streamside forests, and provide a comparison between present managed habitats and historic pristine habitats. Without an understanding of pristine streams as a point of reference, our present protection and enhancement efforts may lack an adequate context or conceptual rationale to assure success.

Old cannery records document the relationship of fish abundance to historic habitat conditions. Everman and Meek (1898) estimated about 11,000 chinook salmon and about 87,500 coho salmon were harvested per year from the Siuslaw River in Oregon between 1889 and 1896. If we assume a catch efficiency of 40 percent (Mullen 1981a), runs of chinook and coho salmon in the Siuslaw River in the 1890's would have been about 27,500 and 218,750, respectively. The current Oregon Department of Fish and Wildlife (1981) Coho Salmon Plan has an annual escapement goal of 200,000 to 250,000 wild coho adults to all coastal Oregon streams after habitat rehabilitation. The Siuslaw is one of over 30 major rivers and streams on the Oregon coast. The point is that the habitat available in the early 1890's on the Siuslaw River was able to support large numbers of the chinook and coho salmon. By 1960, virtually no chinook were caught off the mouth of the river and only 7,000 coho were landed (Mullen 1981a). Although fishing pressure has been tremendous over the last 80 years, drastic changes have also been documented in the character and structure of streams and rivers in which salmon spawn and rear. The rehabilitation of wild stocks depends on good habitat and reduced harvests. New habitat will have to be created, damaged habitat restored, and good habitat protected. The historical perspective presented in this paper can help provide a needed rationale for this effort.

EARLY SURVEYS AND DESCRIPTIONS OF NORTHWEST RIVERS

Most early descriptions of Northwest rivers are recorded in British and United States Army journals. They tell of valleys so wet that trails followed "the borders of the mountains." In Oregon and Washington, a common practice in very early times was to travel on the edges of the hills and not along the valley floors (Dicken and Dicken 1979). British Army journals described the Tualatin Valley as "mostly water connected by swamps" (Ogden 1961, p. 122). Much of this flooding was a result of beaver activity and accumulated sediment, fallen trees, and living vegetation in the channels. Because bottom land had accumulated fine silts and organic material of alluvial origin, the land was fertile and the task of draining the land for farming began early in Oregon and Washington.

Oregon State Agricultural College soils scientist I. A. Williams (1914, p. 114) wrote of the condition of Willamette Valley streams in 1910:

"Many of the smaller streams that have their course through these flat sections of the valley flow sluggishly and frequently overflow their banks during periods of heavy winter rainfall. It is found that most of these have sufficient grade to carry even more water than ordinarily comes to them; seldom less than 3, and usually more, feet of fall per mile. The annual overflow is caused from the obstructing of the channel by the growth of trees and the extension of their roots, the dams thrown across the channels by beavers and the consequent accumulation of sediment and other debris, etc. The particular streams in which such a state of affairs has been especially brought to the writer's attention are the Little Muddy and Long Tom Rivers, south of Corvallis in Benton and Lane counties; the Little Pudding River, in Marion County; the Tualatin and its branches in Washington County. It is a common condition, however, and usually all that is necessary is a clearing out and opening up of the clogged channel of the stream to afford entire relief from overflow and the discouraging handicap which it is to the farmer in such a locality."

Descriptions of the Puget Sound lowland streams are similar to those of Willamette Valley streams. Most streams consisted of a network of sloughs, islands, beaver ponds, and drift dams with no main channel. The Skagit River lowlands encompass about 512 km^2 of which over 128 km^2 were beaver marsh, sloughs, and wet grass meadows. Early U.S. Army Corps of Engineer maps for the lower Nooksack, and Snohomish Rivers in Washington show large areas of sloughs, swamps, and grass marshes (Reports of the Secretary of War 1875-1891). All of the coastal valleys in Oregon contained marshy areas and a complex of numerous sloughs. For lowland streams in both States, the area and volume of standing water and interaction of the stream with its flood plain was great before they were cleared and channelized by pioneer farmers (U.S. Congress, House, 1848).

In the rivers and stream channels themselves, the record shows that fast turbulent rivers as well as low-gradient rivers, regardless of alluvial or bedrock control, had large amounts of wood influencing their channels. The lower Siuslaw River and lower North Fork Siuslaw River were so filled with fallen trees that explorer-trappers in 1826 were unable to explore much of these river systems (Ogden 1961). The Willamette River between Corvallis and Eugene flowed in five separate channels in 1870 (Report of the Secretary of War 1875). The Captain of the Portland district reported that the "obstacles were so great above Corvallis" and that the river banks were heavily timbered for a distance of 1/2 mile on either side. In a 10-year period, over 5,500 snags and drift trees were pulled from a 50-mile reach of river, and the river was confined to one channel by engineering activities. These trees ranged between 5 and 9 feet in diameter and from 90 and 120 feet long (Report of the Secretary of War 1875). Table 1 is a partial list of rivers in Oregon and Washington that were completely blocked in their lower main channels by drift wood. The Skagit River drift jam was 3/4 of a mile long and 1/4 mile wide. The Stillaguamish River had six debris-jam closures from the head of tide to river mile 17. Snags were so numerous, large, and deeply imbedded in the bottom that a steam snag boat was required to operate for 6 months to open a channel 100 feet wide on the Stillaguamish (Secretary of War 1881). Another lower gradient stream system, the North River, had 11 drift jams along the main river system (fig. 1).

Drift jams in high-gradient systems often set up where the channel gradient decreased abruptly; the Nooksack River is an example (fig. 2). Of the South Fork Nooksack, Morse (1883) wrote:

"...we came to a place where the river, during freshets had ground sluiced all the earth away from the roots of the trees, and down some 6 feet to the gravel. This covered a region of country a mile in width by five in length. Overgrown yellow fir timber had once covered most of that section. If the river below there was only clear of jams that place would be a paradise of hand loggers. On the gravel lay many million feet of sound fir timber, which only needed to be junked up during the summer and the winter freshets would float the logs down to the sea. Immediately below this place, the jams first extend clear across the river, and for the next 20 miles there is a jam across the river nearly every mile."

These illustrations are important because large woody debris is currently thought to play a minor role in larger rivers. Most large wood is randomly spaced in very small streams (1st and 2d order) because flow volume is insufficient to float and transport large logs downstream. Intermediate-sized streams (3d to 5th order) have lesser amounts of wood. Large wood typically occurs in distinct accumulations where major, immobile logs, channel constrictions, or other conditions provide persistent sites for accumulation of small and intermediate sized debris moved downstream at high flows. The larger streams or rivers (6th to 8th order) generally have most of their debris on the flood plain or on the outsides of bends (Swanson et al. 1976, Swanson and Lienkaemper 1978). The large wood in rivers is about 3 percent of that found in small streams on an area basis (Naiman and Sedell 1979, Franklin et al. 1981). The historical record shows that even in big rivers, large wood contributed significantly to in-channel structure that trapped sediments, ponded water, and created many side channels and sloughs.

Table 1.--Partial list of rivers in Oregon and Washington that had drift jams completely blocking the channels for 100-1500 meters in the mid 1800's (Reports of the Secretary of War 1875-1899).

Oregon	
Tualatin	Wilson
Yamhill	Trask
Luckiamute	Clatskanie
Necanicum	Nestucca
Long Tom	Pudding
Willamette	
Washington	
Nooksack	Puyallup
Stillaguamish	Black River
Skagit	Chehalis
Samish	Satsop
Snohomish	North
East Fork Quinalt	Quilicene
Most Gray's Harbor Rivers	Duwamish
Most Willapa Bay Rivers	Nisqually

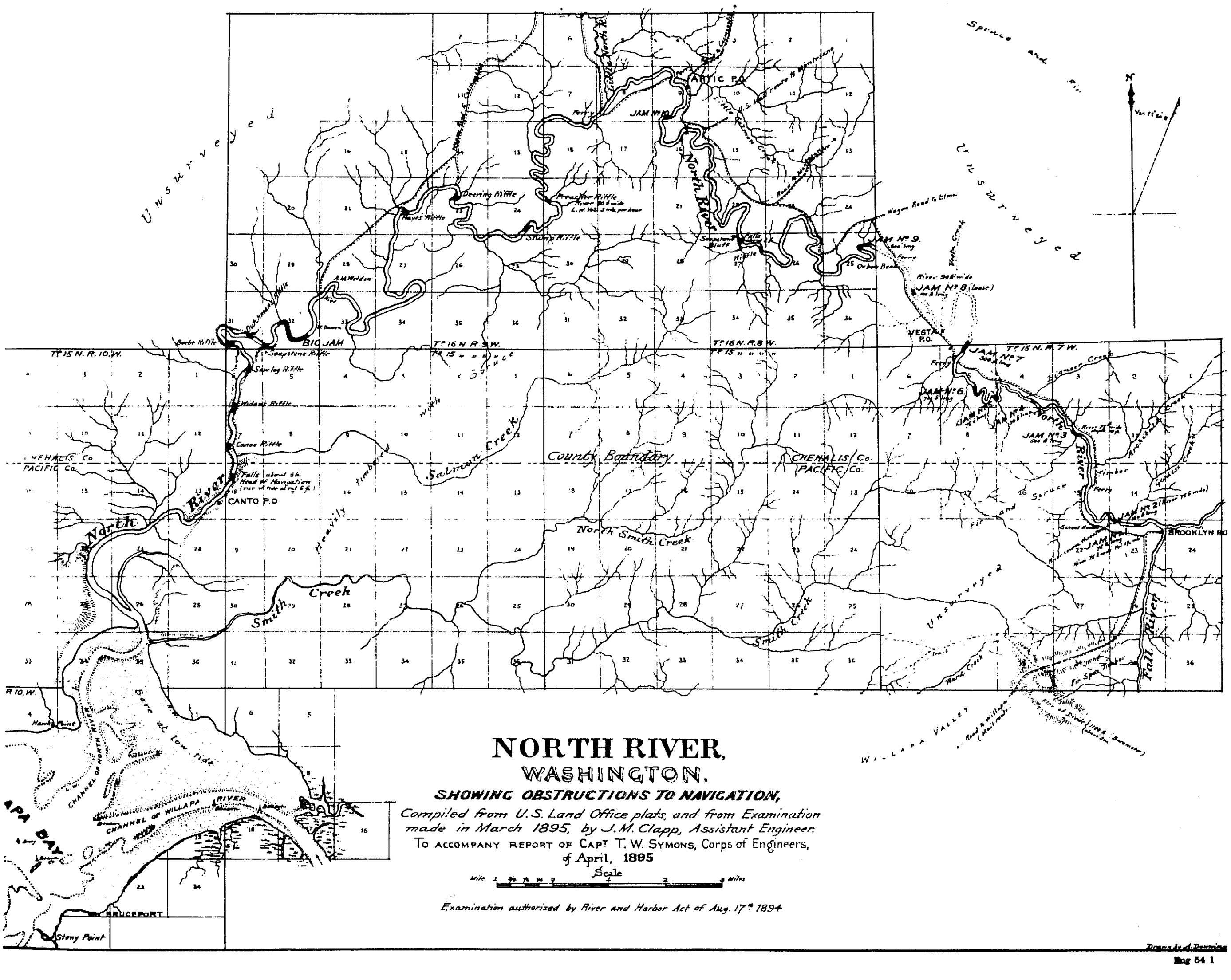

Figure 1.--Map of North River, Washington, showing 10 drift jams in the upper part of the basin. Before logs could be driven on the North River in 1896, these drift jams had to be removed. They were removed by 1898 (Reports of the Secretary of War 1896, 1899).

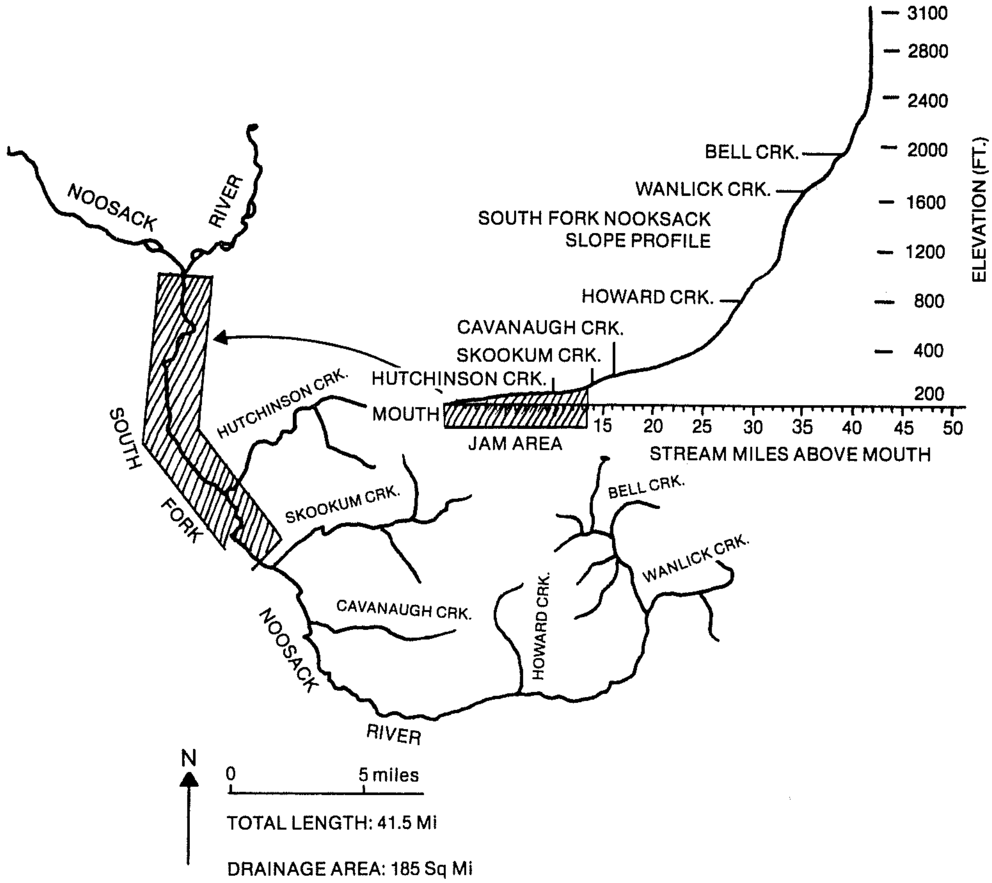

Figure 2.--Location of drift jams on the South Fork Nooksack River, Washington. Area prone to drift jams was reported by E. Morse (1883). When the gradient of the river decreased, the drift jams formed. The Nooksack represents a typical high-gradient river in the Pacific Northwest.

MANAGEMENT ACTIVITIES AFFECTING LARGE ORGANIC DEBRIS IN OREGON AND WASHINGTON STREAMS

The Pacific Northwest has a 150-year history of cleaning woody debris and boulders out of streams. The sequencing of various activities is illustrated in table 2. Farming and initial removal of drift jams were the first order of business in the mid-1800's. Rivers were the only highways for transporting goods and supplies in and out of the interior from the seaports. During this time, many rivers in Washington and Oregon were not only cleaned of woody debris, but the pulled snags were used to dike off sloughs and side channels to consolidate the main channel. Thus, supply boats could use the rivers for longer periods during the low-flow season.

Recent research has shown that side channels are the most productive habitats for salmonids in large rivers (Sedell et al. 1980, Yuska et al. in press). In the pristine South Fork Hoh River, they found that the greatest standing crop of salmonids occurred in side channels and spring-fed flood-plain tributaries. The main river channel, despite the large surface area, has the lowest salmonid densities and biomasses. Yuska et al. (in press) found that these side-channel and terrace-tributary habitats accounted for 6 percent of the total salmonid habitat available on the South Fork Hoh and reared about 70 percent of the potential smolts from the basin. For the Upper Queets River system, side channels and terrace tributaries accounted for about 23 percent of the available fish habitat and 54 percent of the potential coho salmon smolts. Both Sedell et al. (1980) and Yuska et al. (in press) reported that large woody debris was important in creating, stabilizing, and providing excellent cover in these productive habitats.

Table 2.--Chrono-sequence of disturbance to fish habitat in the Northwest.

- Early settlers in Willamette Valley and Puget Sound - 1848-80: snagging and millponds, small-scale localized clearing on lower rivers and main rivers for transportation.
- Corps of Engineers and timber companies "river and stream improvement for navigation" - 1880-1905: Very intensive and extensive:
  - Bowlder (sic) blasting
  - Debris removal
  - Splash damming and sluicing
- Ditching and draining - 1870-1920.
- Logging into streams - 1920-50's: Road building along streams.
- Diking and WPA snag and brush removal - 1930's-40's.
- Road building mid-slope and ridge tops - 1940-present: Road failures increased. Smaller tributaries in headwaters adversely affected by sluicing and large debris jams.
- Forest Practices Act Oregon - 1972, and Washington - 1976:
  - A. Overzealous debris cleanup in 1st-and 2d-order streams, as well as intermediate-sized streams.
  - B. Leave strips salvaged as quickly as they are undercut or blown down.
  - C. Debris-jam removal as the primary fisheries habitat improvement activity.

Log Drives and Splash Dams

The timber industry was well underway by the 1860's as the California gold rush provided an economic demand for timber. The State of Washington, with excellent ports in large estuaries (Grays Harbor, Willapa Bay, Puget Sound), was the first to initiate its timber industry. By 1880 the land along the western banks of Puget Sound and all around Hood Canal had been cleared of trees for 2 miles inland and up to 7 miles around the major streams and rivers (Buchanan 1936).

Log driving is simply the process of transporting logs by floating them in loose aggregations in water with the motive power supplied by the natural or flushed streamflow. First, all timber within easy access of the stream was cut and floated down the adjacent river. If timber was too far to be profitably hauled by oxen to the mill or stream, the logger moved to another location. Gradually, loggers had to go greater distances for the timber, which introduced the use of river landings, log yards, log driving, rafting, towing, and booming. Still later, the more distant timber required the use of splash dams and sluiceways, expensive stream improvements, canals, tramways, trestles, log chutes and slides, trucking, and railroads for floating and driving.

Streams of all sizes had to be "improved" before a log drive could begin. Principal forms of stream improvement were as follows (Brown 1936):

- Blocking off sloughs, swamps, low meadows, and banks along wider parts of the streams by log cribbing, to keep the logs and water in the main stream channel.
- Boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind in the main bed had to be blasted out or removed during periods of low flows. Obstructions or accumulations of debris--such as floating trees, brush, and rocks--often caused serious and expensive log jams during the driving seasons. Frequently, small low-gradient streams were substantially widened during log driving, as a result of the frequent flushing of the stream by splash dams and by the impact of the logs along the streambank.

The records of stream cleanup and improvement in the Northwest come from pioneer interviews, county court records, State court records, and U.S. Army Corps of Engineers reports. An example is from the Samish River, Washington, 1880, as told by E. E. Watkinson: "Since two logs had never been driven down the Samish River before, E. E. and Milbourne Watkinson began the backbreaking task of cleaning out the river which was then a network of sloughs, islands and jams with no main channel. For the purpose several indians were hired. Islands were cleared of brush which was towed ashore on a slab raft and burned. During this campaign the river was cleared from about 2 miles above Allen to saltwater" (Jordon 1962). The length of river was just a few miles and took 4 months to clear.

Court records also give good accounts of activities to clear obstructions on different rivers and streams. East Hoquiam Boom and Logging Company vs. Charles Nelson (1898) describe the continued improvement of the stream "by removing fallen trees, snags, roots, jams of logs and other obstructions" from the "narrow, crooked streams varying in width from forty to a hundred and fifty feet and containing numerous shallows and sandbars" (p. 143). "It also appears that the annual expense of keeping the streams clear of obstructions, so as to enable the logs to be floated, thereon, between plaintiffs upper dam and tide water, amounts to hundreds of dollars" (p. 145).

By 1900, over 130 incorporated river and stream improvement companies were operating in Washington. The distribution of major splash dams in western Washington and western Oregon is illustrated in figures 3 and 4. Over 150 major dams existed in coastal Washington rivers and over 160 splash dams were used on coastal and Columbia River tributaries in Oregon. The splash dams shown represent only the main dams that operated for several seasons. On many smaller tributaries, temporary dams were used seasonally, but no record was kept. Wendler and Deschamps (1955) were mainly concerned with these dams as obstacles to fish migration. Many were actually barriers, but the long-term damage was probably caused by the stream improvement before the drive and the scouring, widening, and unloading of main-channel gravels during the drive.

Small streams were heavily impacted by cedar logging, which occurred many years before clearcut harvest. Because cedar was used for shingles and not just lumber like Douglas-fir, it could be cut up into small bolts (< 1 m lengths). They could then be driven down very small streams. "By taking out shingle bolts from inaccessible localities far from the mills and driving them down streams impossible for logs, it is possible to utilize overmature cedar that would deteriorate before general logging on the tract was possible" (West Coast Lumberman 1914). Much of the best and most plentiful cedar timber occurred along streams in Puget Sound and in rich, moist, coastal valleys; it was exploited more rapidly than Douglas-fir. Even for driving cedar bolts, small streams had to be cleared of fallen trees, big boulders, and rooted vegetation in the channels. Streams were maintained clear of obstructions until the cedar logging in the drainage was completed.

Snag boats operated on Puget Sound streams from 1890-1978 and generally averaged 3,000 snags a year for a total of 200 miles of snagging in the Skagit, Nooksack, Snohomish, Stillaguamish, and Duwamish Rivers. The Coquille River system in Oregon started a county snagging operation in 1890, which continued to operate until the early 1970's.

During the 1930's when the WPA was active, most of our lowland streams were cleared of brush, particularly in agricultural areas. After every major flood, and particularly after the Federal Flood Control Act of 1936, funds were made available to clean almost any size stream in any locale.

Clearing of streams and rivers for passage of boats and logs has reduced the interaction of the stream system with its flood-plain vegetation. Draining, ditching, and diking of valley bottoms and lowlands has also reduced terrestrial-aquatic interaction. Flood-control levees have insured that complex sloughs and side channels, which are valuable rearing areas (Sedell et al. 1980), are reduced or eliminated.

Removal of Fish Barriers and Debris Jams

Stream cleanup of debris jams to benefit fisheries was initiated on a major scale in the late 1940's and early 1950's in Oregon and Washington. In the late 1950's and early 1960's, the California Department of Fish and Game conducted a program to remove old log jams on nearly every major coastal river that supported anadromous fish (cited in Hall and Baker in press).

During this period, log and debris jams and loose aggregations of debris with the potential to form jams were cleared. This was a period of timber harvest abuses and excess of unstable slash in streams. The result of the programs for debris-jam removal, however, was to put fishery biologists into the position of being river engineers, a role they were not fully equipped to carry out. In general, debris in streams was negatively viewed, as:

- An accumulation that would either hamper fish passage upstream or downstream, or block it altogether;
- A potential source of material for the consolidation of larger jams (with the same results as above); or

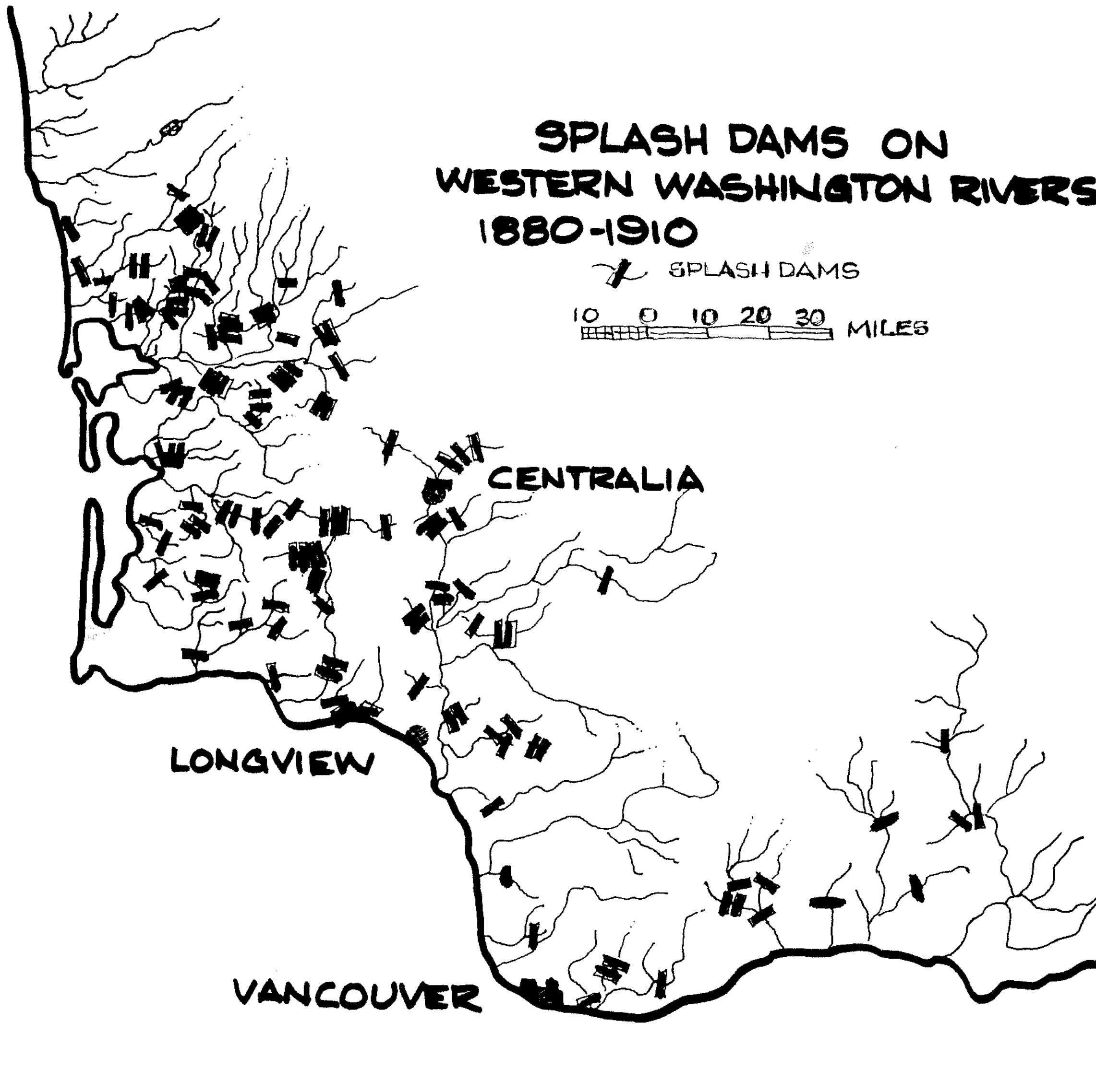

Figure 3.--Splash dams operating on western Washington rivers from 1880 through 1910. Data derived from Wendler and Deschamps (1955); Bryant (1949), and U.S. Army Corps of Engineers reports on file at Portland District Office.

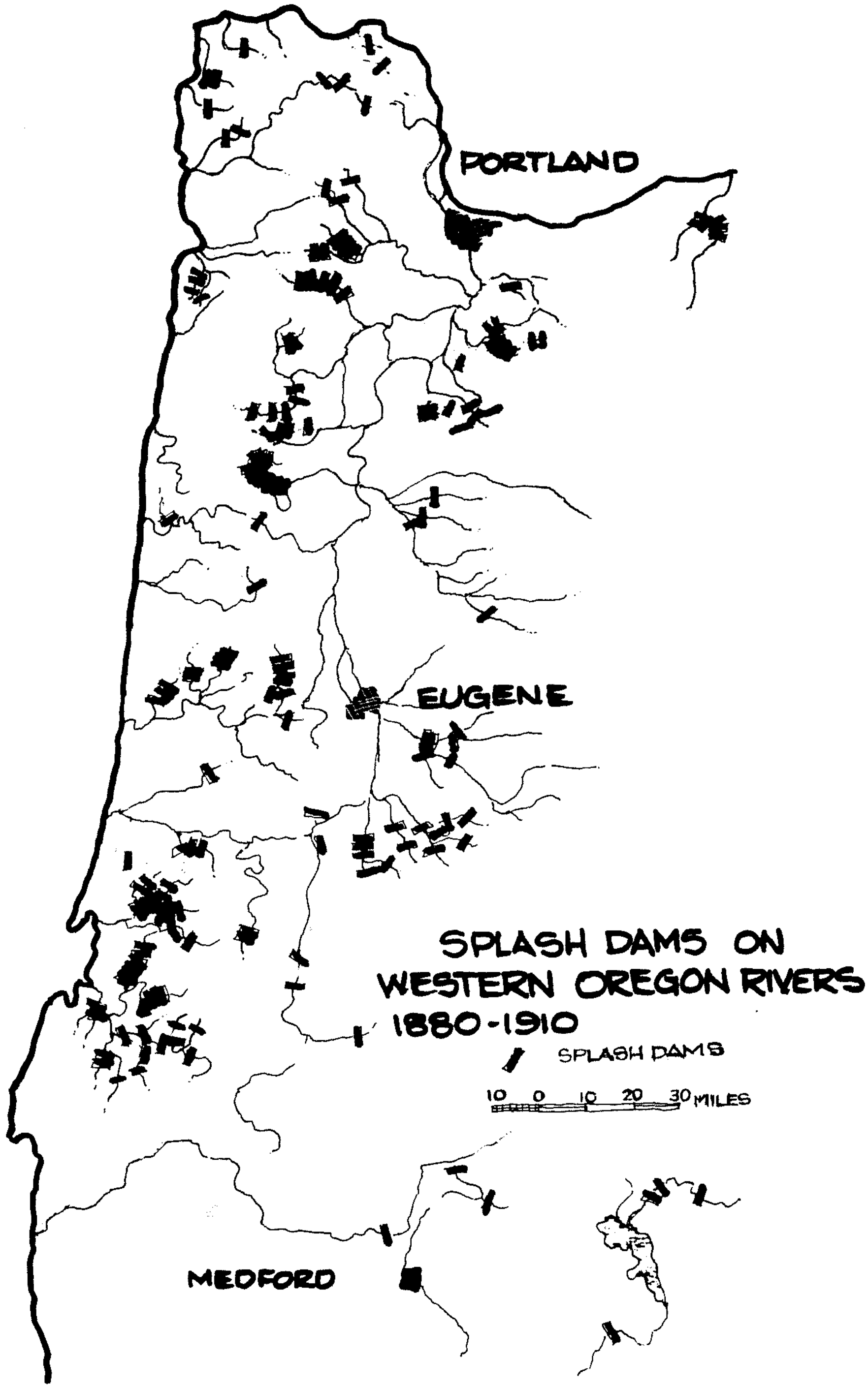

Figure 4.--Splash dams operating on western Oregon rivers from 1880-1910 (some on the Coos Bay rivers operated until the mid-1950's). Data were derived from research and reports by Dr. James E. Farnell of the Division of State Lands, Salem, Oregon.

- A potential source of channel destruction by scour resulting from jam failure during a storm event.

In the extreme cases during the 1940's and 50's, all of the above fears were well founded (McKernan et al. 1950, Gharrett and Hodges 1950).

Determining the historic magnitude of the debris jam problem or the historic distribution and abundance of jams in a basin is difficult. We studied old stream-survey records from the Oregon Fish Commission dating from the late 1940's and early 50's (Gharrett and Hodges 1950) for the Tillamook Bay rivers and the Coquille River system. In the Coquille River system, about 28 percent of the length of potential fish-producing streams was inaccessible to migrating fish. Natural bedrock blocks accounted for a little more than 16 percent of the total, and debris jams accounted for 12 percent. For all of the tributaries of Tillamook Bay, 26 percent of the length of fish-producing streams were blocked. Blocks from natural bedrock falls accounted for 6 percent of the total and debris jams, 20 percent. Many blocks in tributaries to Tillamook Bay resulted from salvage operations related to the Tillamook Burn of 1933.

Using USDA Forest Service low-flow stream surveys in the late 1970's from the Mapleton District in the Siuslaw National Forest in western Oregon, we calculated length of fishbearing streams ($<$ 10-percent gradient) blocked by over 200 jams (table 3). Only 5.5 percent of the total miles of streams were blocked, and nearly all of the blocked area was in small streams at gradients between 5 and 10 percent. In coastal Oregon and Washington, very little rearing and spawning occurs in such high-gradient systems.

Fishery-management agencies have used explosives and heavy equipment to remove thousands of jams over a 40-year period. Land management agencies have also made removal of debris jams the focus of their programs for enhancing fish habitat. Until recently, up to 90 percent of the funds for fish-habitat work went for removal of debris jams. Little thought was given to rearing-habitat requirements of salmonids, or the impacts of releasing sediments downstream in large pulses. Full or partial barriers were thought to be such obvious negative factors that their actual role in stream ecology was not adequately defined or investigated. As a result of debris jam removal and the addition of fish ladders, more miles of streams in western Oregon and Washington are probably now available to migrating fish than were available 100 years ago. We question whether the bulk of funds for fish-habitat improvement should continue to be spent on improving 5 to 20 percent of the mileage in high-gradient streams of the upper watersheds, when 80 to 95 percent of the stream mileage at lower gradients within the basin is available to migrating fish, and is lacking in habitat complexity necessary to rear many salmonids.

Table 3.--Length of stream blocked by log jams in different-sized basins in the Mapleton District of the Siuslaw National Forest, western Oregon (data provided by M. Parsons, Siuslaw National Forest).

Basin size (km^2)	Mean basin area (km^2)	No. of streams	Mean stream length (km)	Mean stream blocked (km)	Percent blocked
5	4.6	7	5.2	1.1	22
6-12	9.1	12	9.2	2.1	22
13-25	17.5	8	12.7	0.5	4
26-100	38.0	7	31.4	1.6	5
100	129.5	1	27.0	0	0

LARGE WOODY DEBRIS AND FISH HABITAT

The important role large woody debris plays in creating and maintaining spawning and rearing habitat has been recognized and documented by researchers only within the last 10 years. In streams of the Idaho Panhandle National Forests, large wood forms 80 percent of the pools found in streams between 1-and 6-percent gradient (R. Rainville, Coeur D'Alene, Idaho, personal communication). The earliest descriptions of the role of big wood in streams came from Swanson et al. (1976) and Swanson and Lienkaemper (1978), who recorded amounts of wood in streams and documented that debris torrents tended to set up when the stream gradient flattened to 3 to 4 percent.

Bisson and Sedell (in press) examined several streams in western Washington to compare population biomass in streams flowing through old-growth forests with those in recently clearcut areas. Although total salmonid biomass increased, species shifted from a mix of salmonid species to a predominately aged 0+ steelhead population. Coho salmon and 1+ and 2+ cutthroat trout were proportionately less abundant in the clearcuts. These authors related the shifts in composition of species and age group to habitat changes that accompanied timber harvest and debris removal from the channel. They found the frequency of large, stable debris had declined and unstable debris had increased after passage of the 1976 Washington Forest Practices Act, which mandated immediate debris removal after logging. Pool volumes appeared to decrease and riffle volumes to increase after clearcutting and channel clearance. The frequency (number per kilometer) of both pools and riffles appeared to decline in clearcuts, thus suggesting that normally stepped stream profiles had been altered to a more even gradient.

Pool volume has been documented by Nickelson et al. (1979) as being directly related to coho biomass in Oregon coast streams. Bustard and Narver (1975b), Everest and Meehan (1981), and Bisson et al. (this volume) found dammed pools and backwaters to be used by coho and large cutthroat trout.

Wood debris as a preferred cover for salmonids is thoroughly covered by Bisson et al. (this volume). Bustard and Narver (1975a) documented the preference of yearling steelhead for large debris, and both Osborn (1981) and June (1981) have shown that older cutthroat trout rely heavily on large wood debris for cover. The association of coho salmon with wood debris has been previously demonstrated by Lister and Genoe (1979), Bustard and Narver (1975a, b), and Toews and Moore (1982). The important role of large wood in large, high-gradient river systems, such as the South Fork Hoh River, was mentioned previously (Sedell et al. 1980, 1982).

Mullen (1981a, b) estimated coho salmon escapements to be nearly 1 million fish in the early 1900's and remained around 3/4 million in the 1930's. Coastal coho spawning escapements were believed to be less than 100,000 in 1977 and 1978 (Oregon Department of Fish and Wildlife 1981). The exact cause of the decline cannot be determined because concurrent influences are operating. Three primary influences, habitat alterations from timber harvest, commercial fishing, and ocean upwelling patterns, could have caused the large drop in escapements in the last 20 years (McKernan et al. 1950, Oregon Department of Fish and Wildlife 1981). We can reduce fish harvest and improve habitat, but not much can be done at present about improving coastal upwelling. Recent research and historical descriptions of rivers and streams that correlated with large anadromous fish runs strongly suggest that large wood in streams was an important habitat component in all sizes of streams; we can still manage streamsides to provide trees and large woody debris to the stream.

DISCUSSION AND CONCLUSIONS

What does the documentation of historical characteristics of streams and the history of channel cleanup mean to fisheries managers today? One, the historical record indicates many boulders, fallen trees, sloughs, and in-channel vegetation, and large numbers of fallen trees in river channels. Two, abundant salmonid populations were associated with these pristine rivers, from which we infer complex habitat resulted from these in-channel structures. Three, managers have been preoccupied with removal of debris jams in the upper parts of basins where the gradient is steep. Such activities effectively channelize streams right up to the headwalls. The 70 to 90 percent of basin stream lengths available to migrating fish are areas where anadromous fish can be increased significantly, but habitat improvment in these areas has been underemphasized.

Improving fish habitat using large wood will not be easy because the long-term stability of woody debris in many streams cannot be accurately predicted. Many hydrologists and fishery biologists will continue to recommend removal of potential jams and big merchantable trees because of risk to downstream bridges or culverts and not because of fish habitat. Leaving debris in place has a high probability of enhancing rearing and spawning habitat for salmonids--if not in the original location, then maybe around the bend after a storm. Rivers are dynamic, and fish evolve within their physical and chemical constraints. Predicting with certainty the stability of debris at a point in space will only occur if the stream is "trained" throughout its entire length. Dam construction, bank revetments and levees, and channelization efforts have shown the obvious: whenever you tinker with a stream, it makes an adjustment to the new change. These natural adjustments may not be compatible with basin-wide efforts at habitat improvement. Deciding to remove upper-basin debris dams should be made with great care and thought. The potential for sluicing downstream habitat must be weighed against the potential release of large pulses of sediments to downstream areas after removal. When in doubt, leave jams in, because in time they could well become a source for downstream habitat complexity.

Emphasis should be placed on restoring habitat complexity to channels of 4th to 7th-order streams. Bigger fish rear in these waters as compared to small streams (Skeesick 1970; Yuska et al. in press; Fred Everest, Corvallis, Oregon, personal communication). Over 70 percent of productive stream lengths are available to migrating fish, yet very little money or effort has been expended to restore or improve these rearing and spawning habitats. At the same time, we must renew efforts to improve road building, landing locations, road maintenance, and good land stewardship to protect existing habitat in small streams.

We cannot expect to restore wild stocks of salmonids when present habitats appear to be so unlike their historic conditions. Until we incorporate the structure of undisturbed habitats, like those where wild stocks developed, and understand the sequence of changes that have occurred in those habitats, our present protection and enhancement efforts will continue to lack both a rational context and effective direction.

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SESSION 4A

Moderator: Christopher Estes
Alaska Fish and Game

VALIDATION OF TWO FISH HABITAT SURVEY METHODS IN SOUTHEAST ALASKA[1]

Willard E. Barber,

Mark W. Oswood

and

Stephen J. Deschermeier[2]

Abstract.--Two stream survey techniques, the Transect Method and a new technique based on diagrammatic mapping, were evaluated. Measurements of stream habitat features were made at 76 stations in southeast Alaska. At each station, estimates of numerical abundance were obtained for five fish groups (coho salmon age classes 0 and 1+, trout, Dolly Varden and sculpin). For the Diagrammatic Mapping Method, habitat features measured included combinations of water velocity and depth, fish cover (forest debris, undercut banks, riparian vegetation), spawning substrate, stream gradient and season (time-related fish mortality and movement). Multiple regression analyses of stream features and fish abundance of the five fish groups resulted in correlation coefficients ranging from R=0.66 to R=0.87. Predictive habitat features varied between fish groups. Multiple regression analyses of stream features (as percent of total area) and fish density (number/m^2) showed that variables entering the equations were generally quite different from equations predicting abundance (number/station) based on absolute area (m^2) of stream features.

For the Transect Method nine habitat characteristics were measured or evaluated. These characteristics were: channel and water widths, average stream depth, riffle and pool widths, pool rating, bank environment, bank stability and stream bottom (substrate) type. Multiple regression analyses of stream characteristics and fish abundance showed that derived indices of pool quality and overall habitat quality had little relation to fish abundance. However, multiple regression equations were reasonably predictive of fish abundance (R=0.60 to R=0.77 for the five fish groups).

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[1]Paper presented at the Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium, held at Portland, on 28-30 October, 1981.

[2]Willard E. Barber, Assistant Professor of Fisheries, Mark W. Oswood, Assistant Professor of Aquatic Biology, and Stephen J. Deschermeier, student, Wildlife and Fisheries Program, and Institute of Arctic Biology, University of Alaska, Fairbanks, Alaska.

INTRODUCTION

Increasing demands for wood products, mineral resources, water development, etc., make adequate inventory/evaluation of streams essential to fisheries management. Stream habitat analyses are generally aimed at estimating habitat quality (i.e., potential fish production) or habitat vulnerability to other resource uses (e.g., logging) or, in southeast Alaska, to determine potential for stream habitat improvement (Bryce Rickel, personal communication, U.S. Forest Service). A habitat analysis technique should provide data highly predictive of fish habitat quality or habitat vulnerability and allow managers to protect critical or vulnerable stream habitats.

The forests of southeast Alaska are managed jointly by several management agencies following the multiple use concept (Sullivan 1980). The principal activity having potential impacts on freshwater habitats in southeast Alaska is harvesting of timber. To minimize the impacts of forest harvesting practices, managers realized the need for stream survey data. The method of Dunham and Collotzi (1975), hereafter referred to as the Transect Method, was used but it had not been validated for use in southeast Alaska. Because of this and the perceived need for an additional technique, a new method was developed based on diagrammatic mapping of stream features, hereafter referred to as the Diagrammatic Mapping Method (Oswood and Barber, in press). The ultimate test of a technique resides in its capability to predict fish abundance. This paper summarizes a statistical evaluation of the predictive capabilities of each method in terms of numerical standing crop of stream fishes.

METHODS AND MATERIALS

Data on fish habitats and population estimates were obtained from 76 stations established in eleven streams on Prince of Wales Island and one (Black Bear Creek) on Cleveland Peninsula, southeastern Alaska. Sampling occurred from mid-June to late August (1979) and mid-June to early September (1980). The ranges of the stream characteristics are presented in Table 1. General information on the region can be found in Harris et al. (1974).

Data were generally obtained in the following sequence: (1) preliminary observations of the stream and establishment of stations, (2) fish capture and population estimation, and finally (3) measurement of stream characteristics. Stations were located about 100 to 150 m apart.

For the Transect Method (Dunham and Collotzi, 1975) stations 60 m long were delineated, within which five transects were established, each 15 m apart. At each transect nine habitat characteristics were measured or evaluated: channel width, water width, average stream

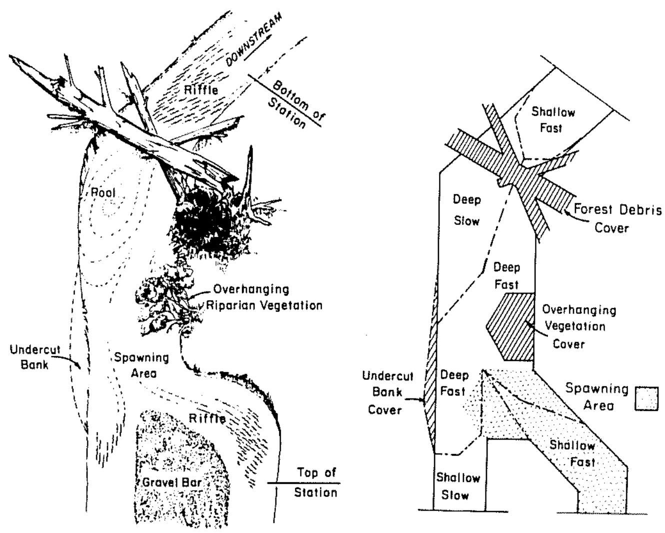

Figure 1. Pictoral representation of a stream section and resultant diagrammatic map following application of Area Method techniques. Areas of each stream feature are determined planimetrically or using a computerized image analysis system from the map. From Oswood and Barber, in press.

Table 1. The means and ranges (in parentheses) of general characteristics of study streams. Data based on 76 stations established on 12 streams located in southeastern Alaska. The number of stations/stream varied from 2 to 12. Stream order is based upon the Horton-Strahler method (Wetzel and Likens 1979).

Width (m)	Depth (cm)	Gradient %	Stream Order	pH	Total Alkalinity (mg/l)
8.0	16.1	3.2	-	7.0	38.8
(0.8-23)	(4.6-35)	(0.0-14.5)	1-3 and Lake Source	(6.3-9.0)	(17-51)

Table 2. List of predictor variables used for the Diagrammatic Mapping Method and a short definition of each. Abbreviations are given in parentheses and are used in following tables. All measurements of these variables, unless indicated, are in m^2.

Predictor Variable	Definition
Total Area (T.A.):	The total m^2 within the sampling station.
Shallow Slow (S.S.):	Area of water less than 50 cm deep and water velocity less than 30 cm/sec.
Shallow Fast (S.F.):	Area of water less than 50 cm deep and water velocity more than 30 cm/sec.
Deep Slow (D.S.):	Area of water deeper than 50 cm and water velocity less than 30 cm/sec.
Deep Fast (D.F.):	Area of water deeper than 50 cm and water velocity more than 30 cm/sec.
Forest Debris Total (F.D.):	Area of fallen trees and large limbs in the stream.
Forest Debris In Riffle (F.D.R.):	Area of forest debris in stream where water velocity is greater than 30 cm/sec.
Forest Debris In Pool (F.D.P.):	Area of forest debris in stream where water velocity is less than 30 cm/sec.
Undercut Banks Total (U.B.):	Area of eroded, overhanging stream banks which offer overhead cover for fish.
Undercut Banks In Riffle (U.B.R.):	Area of undercut bankswhere water velocity is greater than 30 cm/sec.
Undercut Banks In Pool (U.B.P.):	Area of undercut banks where water velocity is less than 30 cm/sec.
Riparian Vegetation Total (R.V.):	Area of overhanging vegetation along stream banks (fish cover).
Riparian Vegetation In Riffle (R.V.R.):	Area of overhanging vegetation where water velocity is greater than 30 cm/sec.
Riparian Vegetation In Pool (R.V.P.):	Area of overhanging vegetation where water velocity is less than 30 cm/sec.
Available Spawning Area (A.S.A.):	Area of stream substrate materials with diameters between 8 mm and 256 mm.
Gradient (G.):	Change in stream elevation from upper to lower section boundaries (e.g., slope).
Season (S.):	The time elapsed from the first day of sampling during the field season: an attempt to account for seasonal mortality and movement.

depth, riffle width, pool width (if present), pool rating, bank environment, bank stability and stream bottom type. See Dunham and Collotzi (1975) for a description of these characteristics.

For the Diagrammatic Mapping Method (Oswood and Barber, in press), 30 m long stations were established, within stations established for the Transect Method. Diagrammatic maps of stream habitat features were then constructed (to scale). Stream features measured and sketched are listed and defined in Table 2. Figure 1 is an example of a stream section with the resulting map.

A standard Petersen mark and recapture experiment (Ricker 1975) was conducted at each station to estimate fish abundance. Following Robson and Regier (1964), we attempted the experiments with a 25% deviation from the true mean. To lessen possible fish size or species selectivity (Ricker 1975), three collecting techniques were used: baited minnow traps, seine and electro-shocker. At each station, six or more standard minnow traps (3.2 mm mesh wire covering) were baited with salmon roe and allowed to fish for several hours to overnight. Following trap recovery, additional collections were made with a 2.4 m long X 1.6 m wide, 3.2 mm mesh minnow seine and a 125 volt DC backpack electro-shocker (Coffelt BP-3). Such factors as stream depth, amount of debris and obstructions of various types determined which of these latter two techniques was emphasized. Captured fish were anesthetized with MS-222 (tricaine methanesulfonate), identified and part of the anal or caudal fin clipped for the salmonids (pectoral fin for sculpin). A representative sample of each group was measured (fork length) to the nearest millimeter. Fish were allowed to recover in stream water and then returned to the general area of capture. Debilitated fish were not used in population estimation.

Fish were again collected by the same methods after a minimum of 24 hours. Numbers of marked and unmarked fish were enumerated by species and size group. Age class 0 coho salmon (Oncorhynchus kisutch) were enumerated separately from 1+ and older age classes. Age class 0 of other fish species were not distinguished from 1+ and older age classes. These species were: cutthroat trout (*Salmo clarki*), rainbow trout (*S. gairdneri*), Dolly Varden (*Salvelinus malma*) and coastrange sculpin (*Cottus aleuticus*). A few individuals of prickly sculpin (*C. asper*) were encountered at one study site and are included in analyses of sculpin abundance. Because normal taxonomic characters (such as color patterns) used in current references to distinguish between young cutthroat and rainbow trout are not reliable in Alaska (Morrow 1980, Behnke 1979, R.H. Armstrong, personal communication, Alaska Department of Fish and Game), we could not confidently distinguish between the two species in the field. Therefore, we present the results as *Salmo* spp.

Dunham and Collotzi (1975) do not state specifically how the data should be analyzed for the Transect Method. We averaged data from the five transects for each station. For channel width, water width and average stream depth, means were calculated by summing the linear values of the five transects and dividing by 5. For average pool width and pool rating, all pools were summed and divided by the number of pools in the five transects. Average riffle width was obtained by subtracting average pool width from average water width. Average bottom (substrate) type (weighted mean) was calculated by summing the linear distance of each bottom type, multiplying by the code for each bottom type and then dividing by the total linear distance of the transects. For bank stability, the environmental stability ratings were summed for all five transects and divided by 10 (both banks at each transect are rated). To determine pool measure, pool structure, stream environment, stream bottom and habitat optimum, Dunham and Collotzi (1975) were followed.

Statistical analyses were carried out for both abundance (number of fish within the station) and density (number of fish/m^2) data. Univariate correlations between fish abundance ($\log_{10}$ transformed) and predictor variables (untransformed and $\log_{10}$ transformed) were obtained using BMDP5D (Dixon and Brown 1979). Since abundance and distribution of organisms are seldom determined by a single factor, forward stepwise multiple regression analyses were also carried out (Draper and Smith 1966) using program BMDP2R (Dixon and Brown 1979). Predictor variables were added to equations until addition of a variable resulted in <1 percent increase in predictive capability (R^2). Backward stepwise regression analyses were performed on a subset of the data. Interpretation of results from stepwise multiple regression techniques is difficult if the predictor variables are correlated among themselves (Green 1979). Therefore, stepwise multiple regression analyses were also carried out on standardized predictor variables transformed by principal component analyses (P.C.A.) (BMDP4R, Dixon and Brown 1979). P.C.A. transforms the predictor variables (many of which are correlated) into a set of uncorrelated principal components, each of which is a linear combination of the original predictor variables (Marriott 1974). These principal components may be used as predictor variables in stepwise multiple regression analyses (Green 1979).

RESULTS

Diagrammatic Mapping

Fish Abundance

Univariate correlation analyses[1] between untransformed and $\log_{10}$ transformed abundance of each fish group and habitat variables showed that the most common significant ($P \leq 0.05$) correlations were with Gradient (negative for all fish except Dolly Varden), Available Spawning Area (all positive except for Dolly Varden), Total Area (all positive except for Dolly Varden), Shallow Slow and Deep Slow. The habitat variables which showed significantly higher correlation coefficients when $\log_{10}$ transformed than when untransformed were used as transformed variables in the stepwise regression analyses.

[1] Copies of data analyses may be obtained from the authors upon request.

Table 3. Predictive equations for $\log_{10}$ transformed abundance (number of fish/30 m station) of each fish group resulting from stepwise regression analyses. Final R and R^2 values are given. Coho 0 is coho age class 0 and coho 1 is coho age classes 1+ and older. See Table 2 for a key to abbreviations and definitions. n=76.

Fish	R	R^2	Predictive Equation
Coho 0	0.87	0.76	$\log_{10}Y$ = 0.871+1.011 log A.S.A.+0.010 R.V.-0.009 S.
Coho 1	0.70	0.49	$\log_{10}Y$ = 0.249-0.073 G.+0.416 log S.S.+0.006 R.V.+0.260 log U.B.
Dolly Varden	0.70	0.49	$\log_{10}Y$ = 3.223-1.110 log T.A.+0.344 log F.D.R.
Trout	0.66	0.43	$\log_{10}Y$ = 0.703+0.419 log F.D.R.+0.284 log D.F.+0.006 F.D.P.+0.226 log R.V.R.
Sculpin	0.77	0.60	$\log_{10}Y$ = -1.208+0.483 log S.S.+0.531 log A.S.A.+0.334 log D.S.+0.009 S.

Table 3 summarizes the results of the forward stepwise regression analyses. The highest multiple correlation coefficient (R) was 0.87 for coho 0 with three variables entering the equation. The lowest R was 0.66 for trout with four variables entering the equation. Predictor variables entering the equations were usually different for each fish group. For example, Riparian Vegetation was the only common variable among the six entering the equations for coho 0 and coho 1. Similarly, comparing coho 1 and Dolly Varden, there were no common variables of the six entering the equations.

Results from regression analyses on principal components showed that variables which contributed substantially (relatively large regression coefficients) to the regression equations were generally the same as those present in the stepwise regression equations (Table 3)[1] and, therefore, confirm these analyses. Likewise, backward stepwise regression analyses (of a portion of the data) were similar to results from forward stepwise regression analyses.

Fish Density

Fish density (numbers/m^2) and stream features expressed as a percent of total stream area may also be used to examine the relationships between fish and stream features. Similar to the abundance approach, univariate correlation analyses[1] were carried out between $\log_{10}$ transformed fish density and arcsine transformed percent stream features (Sokal and Rohlf 1981). There were few significant ($P \leq 0.05$) correlations as compared to the univariate analyses of fish abundance and absolute area of stream features (m^2). As an example, for coho 1 there were 11 significant univariate correlations between coho 1 abundance and $\log_{10}$ stream features but only five significant correlations between fish density and arcsine transformed percent stream features.

Table 4 shows the results of stepwise regression of $\log_{10}$ transformed fish densities against percent stream features (arcsine transformed). The differences are striking when results are compared with those of Table 3 where the stream features were expressed in an absolute area (m^2) basis. In the fish density/percent stream feature approach, multiple correlation coefficients are much lower and different variables generally entered the predictive equations as compared to the relationship of fish abundance and stream features.

Table 5. Univariate correlation coefficients between $\log_{10}$ transformed fish density (number of fish/m^2) and Pool Rating and Habitat Optimum of the Transect Method. Pool Rating is a measure of pool quality and Habitat Optimum is an overall measure of habitat quality. Coho 0 is age class 0 and coho 1 is age classes 1+ and older. n=76. *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.

	Pool Rating	Habitat Optimum
Coho 0	-0.31**	0.08
Coho 1	-0.51***	-0.14
Trout	0.16	0.36**
Dolly Varden	0.26*	-0.03
Sculpin	-0.30**	-0.07

Transect Method

Univariate correlation analyses carried out between $\log_{10}$ transformed fish abundance and stream habitat characteristics from the Transect Method showed that the majority (21 of 37) of significant ($P \leq 0.05$) correlations were associated with stream size variables (channel width, water width, pool and riffle widths, and pool depth)[1]. Variables which reflected habitat quality or complexity (i.e., Pool Rating and Habitat Optimum) revealed contradictory relationships. Pool Rating (quality of pools in terms of depth and cover) was significantly ($P \leq 0.05$)

Table 4. Predictive equations of $\log_{10}$ transformed density (number/m^2) for each fish group resulting from stepwise regression analyses. Stream features were converted to percent of total stream area (arcsine transformation) prior to analyses. See Table 2 for explanation of definitions. Final R and R^2 values are given. Coho 0 is coho age class 0 and coho 1 is age classes 1+ and older. n=76. See Table 2 for a key to abbreviations and definitions.

Fish	R	R^2	Predictive Equation
Coho 0	0.72	0.51	$\log_{10}Y$ = 0.473+0.421 A.S.A.-0.004 S.-0.013 G.
Coho 1	0.55	0.30	$\log_{10}Y$ = 0.049+0.102 R.V.P.-0.004 G.
Trout	0.56	0.32	$\log_{10}Y$ = 0.609-0.075 S.S.-0.100 log S.-0.100 D.S.-0.047 pH
Dolly Varden	0.59	0.34	$\log_{10}Y$ = 0.064+0.113 R.V.+1.158 U.B.R.-0.094 A.S.A.
Sculpin	0.49	0.24	$\log_{10}Y$ = -0.102+0.079 S.S.+0.002 S.+0.165 A.S.A.

Table 6. Predictive equations of $\log_{10}$ transformed abundance for each fish group resulting from stepwise regression analyses of Transect Method. R and R^2 values are also given. Coho 0 is coho age class 0 and coho 1 is age classes 1+ and older. n=76.

Fish	R	R^2	Predictive Equation*
Coho 0	0.77	0.59	$\log_{10} Y = 2.305+1.236 \log_{10} P.W.-2.164 \log_{10} B.T.+0.031 C.W.$
Coho 1	0.60	0.36	$\log_{10} Y = 1.774+0.725 \log_{10} P.W.-2.219 \log_{10} P.R.$
Trout	0.75	0.56	$\log_{10} Y = -46.930+8.774 B.S.+2.939 C.W.$
Dolly Varden	0.74	0.54	$\log_{10} Y = 1.905-1.317 \log_{10} P.W.-0.300 \log_{10} R.W.$
Sculpin	0.77	0.59	$\log_{10} Y = -0.340+2.253 \log_{10} P.W.$

* Predictor Variables: P.W. = Pool Width; B.T. = Bottom Type; C.W. = Channel Width; P.R. = Pool Rating; B.S. = Bank Stability; R.W. = Riffle Width. See Dunham & Collotzi (1975) for predictor variable definitions.

related to fish abundance for four of the five fish groups but only Dolly Varden showed the expected positive relationship (Table 5). Habitat Optimum (a composite variable which includes Pool Measure, Pool Structure, Stream Bottom and Stream Environment) reflects the overall quality of the area to support fish, but only trout showed a positive significant ($P \leq 0.05$; Table 5) relationship. These results were unexpected.

Table 6 summarizes the results of stepwise regression analyses for the Transect Method. The highest R value was 0.77 for two groups, coho 0 and sculpin. Of Pool Rating and Habitat Optimum, only Pool Rating entered a predictive equation (coho 1) and with a negative regression coefficient. These results were also unanticipated.

DISCUSSION

Prediction of fish habitat quality in streams involves two types of predictor variables. The first includes easily measured features (e.g. stream morphology). The second type (e.g. benthic invertebrates, seasonal water temperatures, water chemistry data) requires substantial analytical effort or time series data. We achieved considerable success using the first type, with R^2 values ranging from 0.43 to 0.76 (Table 3). Additional predictive capabilities would undoubtedly have been gained by including the second more costly or time-consuming type in our approach. However, much of the variation unaccounted for in predicting fish abundance is undoubtedly due to the large variations in estimates of fish abundance. Confidence limits (95%) for estimates of fish abundance at each station were generally large (Deschermeier, unpublished data). We believe that substantially increased predictive capabilities would have resulted from absolute determinations of fish abundance (e.g. by use of explosives).

Substantial differences in opinion exist among investigators as to what features are important in predicting fish numbers and how survey data should be analyzed. These differences may arise from different methods of data analysis or in the differential responses to habitat features by fish in various regions. Fish densities and percent habitat features are ratio variables in which both numerator and denominator may vary independently of one another. Green (1979) points out that such ratio variables generally involve substantial interpretational difficulties. Perhaps fish habitat requirements are crudely analogous to human housing needs. A kitchen area representing 10 percent of a large house (e.g., 150 m^2) may be adequate while the same percentage of a very small house (e.g., 15 m^2) yields a kitchen of ridiculously small proportions. Perhaps fish likewise respond to actual, rather than relative, habitat requirements. Thus, our analyses using the fish abundance approach and absolute area (m^2) of habitat features (Table 3) are more predictive than analyses using fish densities and relative sizes of habitat features (Table 4).

Although the Transect Method (Dunham and Collotzi 1975) may be a valuable tool for evaluating fish habitat in the Pacific Northwest, the results of this study indicate that it must be modified for use in southeast Alaska. Habitat Optimum is a composite variable reflecting overall quality of the area to support fish. Only trout showed a positive significant ($P \leq 0.05$) relationship (Table 5) in univariate analyses. Additionally, Habitat Optimum did not enter the multiple regression equations (Table 6). This suggests that this composite variable is not adequately measuring stream quality for the fish species present in the southeast Alaska study streams. Another variable which may not be adequately measuring habitat quality is Pool Rating, which takes into consideration depth and width of the pools, as well as the amount of cover, in determining how "good" a pool is in terms of fish habitat. Pool Rating showed significant ($P \leq 0.05$) negative correlations with three fish groups (Table 5) and only one positive (Dolly Varden). Additionally, Pool Rating entered the multiple regression equation for coho 1 as a negative variable.

Survey techniques rely on the fact that fish use environmental heterogeneity (spacial and temporal patchiness) for ecological segregation. For example, Gorman and Karr (1978), Mendelsen (1975) and Zaret and Rand (1971) showed that fishes tended to specialize on specific habitat types. Our approach has been to develop predictive equations based on the morphological characteristics of streams and to determine fish segregation in terms of these characteristics (Tables 1, 3 and 4). Coho 0 are remaining closely associated with spawning areas (as defined here, stream substrate material having a diameter between 8 mm and 256 mm), using riparian vegetation for cover and, because of mortality, show a decreasing population size as the season progresses. Coho 1+ are in streams of relatively low gradient, occurring in shallow slow areas where there is cover (riparian vegetation and undercut banks). Dolly Varden are inhabiting steeper gradient streams than those occupied by coho 1 and using forest debris as cover. Recall that stations were a constant 30 m long and stream size is reflected in Total Area. Trout are using different habitats than coho and Dolly Varden, i.e., fast water with cover of forest debris and riparian vegetation. Sculpin use both deep and shallow areas with slow current where there is spawning size gravel (8 to 256 mm).

Surveys can serve as a valuable source of data in stream fish ecology. Such information might include habitat preferences, fish community structure, zoogeographical patterns, etc. Given the immense effort and costs associated with stream surveys, and declining availability of research funding, "multiple-use data" may become a necessity.

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USING TIME SERIES STREAMFLOW DATA
TO DETERMINE PROJECT EFFECTS
ON PHYSICAL HABITAT FOR SPAWNING AND
INCUBATING PINK SALMON[1]

E. Woody Trihey[2]

Abstract.--The incremental method of instream flow assessment was applied to identify effects of a proposed hydroelectric project on pink salmon in the Terror River, Kodiak, Alaska. Time series streamflow data are used to compare spawning and incubation conditions for 27 years of simulated pre- and postproject streamflows. This paper demonstrates that an evaluation of project effects based only on a comparison of long-term average monthly streamflows overlooks the dynamic nature of riverine habitat and is likely to have lead the analysts to erroneous conclusions regarding effects of the proposed project streamflows on spawning and incubating pink salmon.

INTRODUCTION

Traditionally, instream flow assessments have arrived at a single valued streamflow requirement to protect the fishery resource -- "a minimum flow." Such an instream flow recommendation, often determined solely from cursory review of streamflow records, overlooks the seasonal and annual variability of instream habitat conditions and provides limited opportunity for negotiation. Furthermore, such an approach promotes the mistaken assumption that only streamflows below this "minimum" are detrimental to instream use and/or resources.

As a result of the inflexibility and fallacies associated with such traditional approaches, a new methodology is emerging, capable of displaying the dynamic response of instream habitat conditions to seasonal and annual changes in streamflow, yet also compatible with the decision-making processes of water planners and managers. This methodology utilizes time series streamflow data in association with physical habitat simulation modeling. The U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group (IFG), Fort Collins, Colorado was instrumental in pioneering and promoting the Incremental Methodology (Bovee and Milhous 1978, Stalnaker 1978, Trihey 1979).

The incremental methodology is based on the theory that the availability and relative value of riverine habitat conditions can be estimated by evaluating the behavioral response of a species/life stage to such streamflow-dependent variables as depth, velocity, water temperature, and channel structure. Thus, this methodology is intended for use in situations where the streamflow regime and channel structure are the principal factors controlling the fishery resource and where field conditions are compatible with the underpinning theories and assumptions of the methodology. This methodology is particularly well suited for displaying effects of proposed water developments or streamflow alterations on riverine fish habitat.

The primary purpose for using hydraulic simulation modeling is to make the most efficient use of limited field data to describe the occurrence of depths and velocities with respect to stream temperature and substrate conditions over a broad range of unobserved streamflows. The availability and quality of fish habitat are reflected as changes in a habitat index value called weighted usable area (WUA). Calculation of WUA does not totally describe the actual quantity or quality of available fish habitat. It does, however, provide a structured analytical approach for using streamflow-dependent variables to

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describe selected physical aspects of fish habitat in riverine environments. Thus, a change in the WUA index can generally be accepted as a good indicator of the effect a change in streamflow would have on the availability of riverine habitat for the species/life stage being evaluated.

This modeling process, utilizing the incremental method, was applied by the Arctic Environmental Information and Data Center (AEIDC) to quantify effects of the proposed Terror Lake Hydroelectric Project on existing fishery resources in the Terror and Kizhuyak Rivers, Kodiak Island, Alaska (Wilson, et al. 1981). For the purposes of this paper, the discussion will be limited to the "Terror Gage" study reach.

This 560-ft study reach was established to characterize project effects on pink salmon spawning habitat in the lower Terror River. Transects 1 through 3 crossed a relatively deep, high-velocity run, and transects 4 through 7 were placed across an upstream pool area. Depth, velocity, and substrate measurements were made approximately every 2 feet along each transect at three streamflow levels (94, 251, and 425 cfs). Both right- and left-bank water surface elevations were surveyed at each transect for each of the three streamflows. Water surface elevation and depth-velocity data were used to calibrate hydraulic models, which were then used to predict depth and velocity values for discharges between 50 and 120 cfs.

A comparison between total surface area and weighted usable area for pink salmon spawning habitat was developed for a range of streamflows from 50 to 1200 cfs (Figure 1). This plot

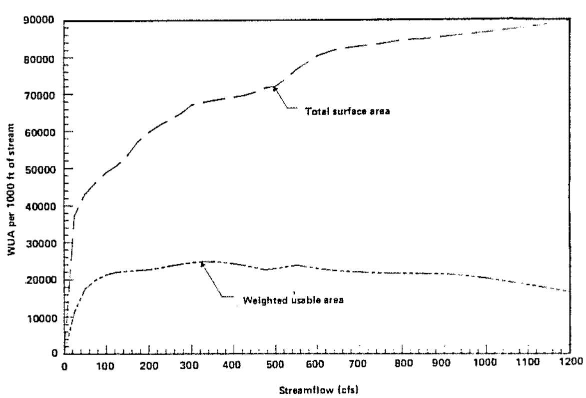

Figure 1.--Total surface area and weighted usable area as a function of streamflow at the Terror Gage study site.

illustrates the reach specific response of total surface area and WUA to incremental changes in streamflow. These curves were used throughout the remainder of the analysis as the primary description of the availability of pink salmon spawning habitat in the lower Terror River as a function of streamflow.

A comparison was made between WUA indices for simulated long-term average monthly pre- and postproject streamflows for the pink salmon spawning period (Table 1). From late July through early September, streamflows would be decreased by approximately 30%. WUA for spawning pink salmon would increase approximately 7% in July while decreasing 3 to 4% during August and September. Overall this represents less than a 5% net change in WUA for the pink salmon spawning period.

Table 1.--Comparison of long-term average monthly pre- and postproject streamflows and corresponding WUA indices throughout the pink salmon spawning period.

Month	Preproject		Postproject	
	cfs	WUA	cfs	WUA
July	579	23,280	346	24,800
August	374	24,610	261	23,850
September	375	24,610	245	23,530
Average	--	24,610	--	24,060

The project sponsor proposed to stabilize Terror River winter flows near 60 cfs. Thus, the simulated long-term average monthly December streamflow would decrease from 80 to 66 cfs, while March flows would increase from 50 to 62 cfs. Changes of this magnitude imply that the proposed postproject streamflows would have a negligible effect on altering preproject levels of redd dewatering and the associated overwinter survival of incubating eggs and alevins.

Solely by comparing simulated long-term average monthly streamflows and corresponding WUA indices, one would conclude that project effects on the availability of spawning habitat for adult pink salmon and the dewatering of incubating eggs and alevins are inconsequential. However, extremes in seasonal and annual streamflow conditions resulting from regional weather patterns cause notable fluctuations in Terror River fish stocks. Fall storms cause high streamflows, which scour eggs and alevins from streambed gravels. Low streamflows during August and September concentrate spawners into confined areas and cause redd superimposition. Low streamflows during winter months often dewater redds and contribute to the freezing of exposed streambed gravels and the developing embryos buried therein.

Therefore, a more rigorous examination would be required of project effects on the annual and seasonal variability of streamflow and the associated WUA indices before project effects on spawning pink salmon could be objectively discussed with any degree of confidence.

STREAMFLOW ANALYSIS

A flow frequency analysis was undertaken to determine the validity of using average monthly streamflow values as a basis for evaluating project effects on fish habitat. These analyses were based on 6 years of average daily streamflow record at the Terror Lake outlet gage (USGS No. 15295600) and 4 years of average daily data at the Terror River gage (USGS No. 15295700).

The 1-, 7- and 30-day high and low flows were determined for each year of record. The ratios of the 1-day to 30-day and 7-day to 30-day flows were also determined to provide an indication of how well monthly streamflow values might represent extremes in seasonal and annual habitat conditions. It was determined that the 30-day low flow closely approximates the average daily low flow (Table 2) while the high-flow statistics indicate that peak daily flows are often two to three times greater than the 30-day high flow (Table 3).

Low-flow statistics (Table 2) indicate that the 1-, 7-, and 30-day low flows are relatively constant. Thus, a reasonably accurate evaluation of project effects on overwintering habitat would result from a comparison of 30-day (monthly) streamflow values. A comparison of 7-day pre- and postproject streamflow values would provide a better portrayal of project effects on the natural stress to which incubating eggs and alevins are being subjected. However, in the case of the Terror River project, insufficient data were available on 7-day pre- or postproject streamflows to justify using anything shorter than a 30-day time step in the analysis, particularly when it was evident that 7-day low flows of record did not differ appreciably from the monthly values.

Midwinter streamflow records were also reviewed to determine months that are most critical to incubation success. Low streamflows occur between January and March but are most prevalent during late February and early March. During this 4- to 5-week period, the mean monthly streamflow was found to be a reasonable indicator of natur-

Table 2.--Low-flow statistics for the Terror River drainage.

TERROR LAKE OUTLET
USGS Gage 15295600

Water Year	Annual low flow in cfs 1-DAY	7-DAY	30-DAY	Min. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1963	18.	19.3	23.4	23.4	.77	.82
1964	11.	11.7	12.4	12.5	.89	.94
1965	10.	10.1	11.1	11.3	.90	.91
1966	8.	8.	9.1	9.2	.88	.88
1967	9.	9.	11.5	11.7	.78	.78
1968	14.	14.6	19.5	26.2	.72	.75
MEAN	11.7	12.1	14.5	15.7	.81	.83

TERROR RIVER GAGE
USGS Gage 15295700

Water Year	Annual low flow in cfs 1-DAY	7-DAY	30-DAY	Min. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1965	28.0	29.1	32.5	33.6	.86	.90
1966	23.0	23.0	26.9	27.4	.86	.86
1967	19.0	20.4	26.6	27.1	.71	.77
1968	38.0	40.3	54.8	75.7	.69	.74
MEAN	25.2	28.2	35.2	41.0	.72	.80

Table 3.--High-flow statistics for the Terror River drainage.

TERROR LAKE OUTLET
USGS Gage 15295600

Water Year	Annual high flow in cfs 1-DAY	7-DAY	30-DAY	Max. Month for Year	Ratio 1-DAY / 30-DAY	7-DAY / 30-DAY
1963	3250	1168	452	270	7.2	2.6
1964	904	554	454	449	2.0	1.2
1965	1490	681	389	362	3.8	1.8
1966	1800	693	564	533	3.2	1.2
1967	1130	587	378	349	3.0	1.6
1968	1560	666	418	371	3.7	1.6
MEAN	1689	725	442	389	3.8	1.6

TERROR RIVER GAGE
USGS Gage 15295700

Water Year	Annual high flow in cfs 1-DAY	7-DAY	30-DAY	Max. Month for Year	Ratio 1-DAY / 30-DAY	7-DAY / 30-DAY
1965	1490	806	692	625	2.2	1.2
1966	2600	1416	1090	1066	2.4	1.3
1967	1780	1232	708	708	2.5	1.7
1968	2000	968	797	660	2.5	1.2
MEAN	1968	1105	822	765	2.4	1.3

ally occurring low-flow conditions in two of three winters for which continuous streamflow data were available. However, simulated preproject monthly midwinter flows were found to differ markedly from observed monthly streamflows. It was also determined that naturally occurring monthly low flows throughout the 3-year period of record were considerably less than the simulated long-term average monthly streamflows. Therefore, it is reasonable to assume that incubating eggs and alevins are subjected to a greater amount of dewatering and subsequent desiccation and freezing than the simulated long-term average monthly preproject streamflows indicate.

High-flow statistics (Table 3) indicate peak daily streamflows for the year often exceed the 30-day high flow by a factor of 2.5. Thus evaluation of project effects on pink salmon spawning habitat based only on monthly streamflows would cause the potentially detrimental effects of these naturally occurring peak streamflows on spawning success to be overlooked.

Further review of the U.S. Geological Survey (USGS) streamflow records for the Terror River gage indicates that maximum mean monthly streamflows are normally associated with the June-July snowmelt period, while maximum daily streamflows occur between late August and early October as the result of intense rainstorms. Considerable variation was observed among the monthly streamflow values of record. It was also determined that peak daily flows range from 4.75 to 9.45 times greater than the long-term average monthly streamflow for the months in which they occur. Hence pink salmon that spawn in the Terror River are subjected to a wide range of naturally occurring streamflow conditions which, at times, can be detrimental.

SPAWNING

Monthly Streamflows

To visualize the effects that the proposed project flows might have on the natural variability of habitat conditions on the lower Terror River during the pink salmon spawning period, WUA indices were determined utilizing time series streamflow data. The 27 years of simulated monthly pre- and postproject streamflows used by the engineering firm to determine reservoir operational characteristics formed the basis for this analysis. WUA indices were determined for corresponding monthly streamflow values during the pink salmon spawning period for the 27 years of simulated streamflows (Figures 2a and b).

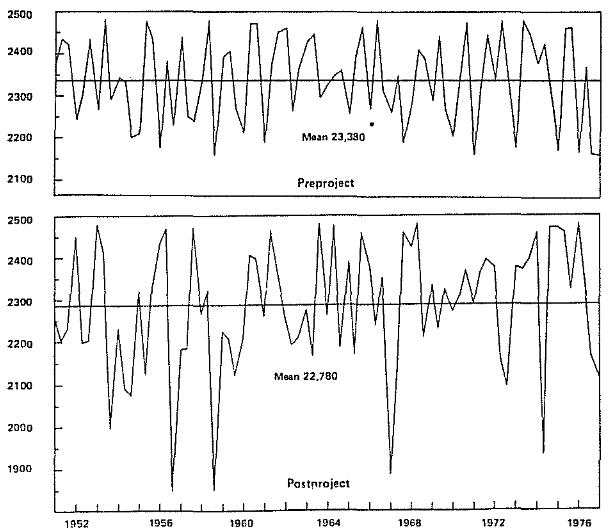

Figure 2.--Composition of time series WUA indices for spawning pink salmon in the lower Terror River for average monthly pre- and post-project streamflows during the spawning season.

The long-term pre- and postproject average WUA indices for the 27 years of simulated values are 23,380 and 22,780, respectively. A comparison between these two averages indicates a net reduction in WUA of 2.6 percent, a relatively insignificant project impact. However, it is quite apparent from a comparison of the time series analyses that the proposed postproject streamflows would notably reduce the WUA index in 8 of the 27 years. This is attributable to the proposed withdrawal of water from the Terror River for power production during naturally occurring low-flow periods without regard for spawning requirements. Such a practice, if allowed, would amplify an already stressed situation and probably cause losses beyond those that would have occurred under natural conditions.

Daily Streamflows

Figures 3a and 3b illustrate the relationship between average daily streamflows and their respective WUA indices for spawning pink salmon. August 1968 was chosen for this analysis because the range of daily streamflows that occurred during that month encompass a broad spectrum of flow conditions that spawning pink salmon are likely to encounter. The average monthly streamflow of 407 cfs is within 10% of the simulated long-term average monthly flow of 374 cfs. Daily flows vary between 129 and 2,000 cfs.

Peak flow events, which occurred on August 10 and 13, were associated with intense rainstorms which frequent Kodiak Island during late summer and fall. The 1,060 cfs streamflow which occurred on August 13 reduced the WUA index for that day, but only about one-eighth as much as the 2,000 cfs event that occurred 3 days earlier. WUA values peaked out between August 19 and 21, when streamflows were in the range of 300 cfs.

Construction of the proposed Terror Lake reservoir is expected to reduce peak daily streamflows at the mouth of the Terror River during August by approximately one-third. Thus, for purposes of illustrating the general effect of the project on the availability of spawning habitat on a daily basis, it was assumed that daily streamflows for August 1968 would have been reduced by 30 percent and the corresponding daily WUA indices plotted (Figure 3c). WUA indices during the

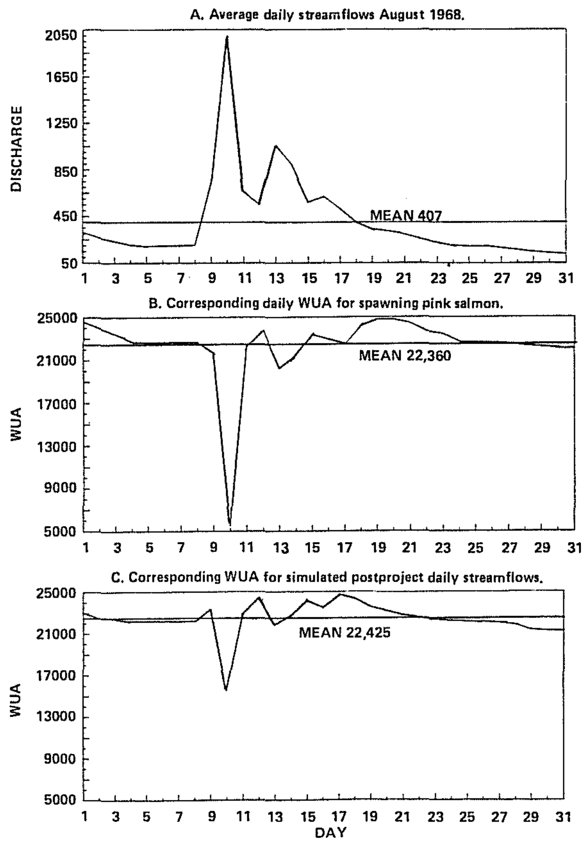

Figure 3.--Average daily streamflows and corresponding pre- and postproject WUA indices for spawning pink salmon in the lower Terror River.

latter part of the month are depressed as a result of the proposed streamflow withdrawals during the low-flow period. The severity of adverse effects from the peak daily flows are greatly diminished. Such a change in daily WUA indices must be interpreted within the proper context. A marked 1- or 2-day change in the WUA index such as discussed here is far more important in alerting the analyst to the biological (reduction of scour), rather than the arithmetic significance of the change in the monthly WUA index.

INCUBATION

In the Terror River, fertilized pink salmon eggs incubate among streambed gravels from their time of deposition through early April. High streamflows during the August-October period are a recurrent cause of streambed scour and associated mortalities. Another major cause of incubation mortality, redd dewatering, persistently occurs during the January-March period. Therefore, to adequately evaluate the effects of postproject streamflows on the existing pink salmon resource of the lower Terror River, a comparison must also be made between the "survivability" of eggs under pre- and postproject streamflow conditions.[3]

Streambed Scour

The following discussion is not intended to serve as an analysis of stream channel stability, but simply to provide a general understanding of the probable effects that postproject streamflows are likely to have on the potential for scouring spawning areas in the lower mainstem of the Terror River.

Streambed scour is principally a function of channel gradient, discharge, and substrate particle size. Particle size is also an important influence on the suitability of streambed materials for spawning. Hence, to evaluate the potential for spawning areas to be scoured, it is necessary to know both the predominant sizes of particles used by spawners and at what discharge rate specific particle sizes are likely to begin moving.

Particles used by spawning pink salmon in the lower Terror River range from medium gravels to cobbles (1 to 8 in). But the predominant particles found in most spawning areas are coarse gravels and small cobbles (2 to 4 in). Threshold velocities required to move the various sized substrate particles found in the lower Terror River were determined through hydraulic analyses. Mean column velocities in the range of 7 to 8 feet per second were required before spawning areas in the lower Terror River were likely to be scoured (Simons et al. 1980).

Simulated mean column velocities at selected transects within the Terror Gage study reach were obtained for a range of streamflows between 400 and 1200 cfs directly from the hydraulic model (Tables 4 and 5). Comparisons between these simulated mean column velocities and the threshold velocity required to move the predominant substrate material at the Terror Gage study reach

Table 4.--Simulated mean column velocities for selected streamflows at designated points along transect 2 (within a riffle/run) at the Terror Gage study reach.

Horiz.	Velocity (fps)			
Dist.	Q=400cfs	Q=600cfs	Q=800cfs	Q=1200cfs
3.5	*	0.00	0.00	0.00
5.0	0.00	.23	.38	.57
6.0	.16	.19	.21	.24
7.4	.34	.48	.60	.83
7.5	.34	.48	.60	.83
8.0	.50	.65	.77	.99
10.0	1.82	2.87	3.96	6.21
12.0	2.46	3.51	4.51	6.40
14.0	3.71	5.10	6.39	8.74**
16.0	3.84	4.99	6.01	7.78**
18.0	4.17	5.25	6.18	7.74**
20.0	4.51	5.52	6.35	7.71**
22.0	4.99	6.27	7.37**	9.23**
24.0	4.85	5.88	6.72	8.11**
26.0	4.78	6.09	7.22**	9.15**
28.0	4.64	5.92	7.03**	8.94**
30.0	4.40	5.65	6.73	8.60**
32.0	3.45	4.15	4.72	5.63
34.0	3.34	4.14	4.80	5.91
36.0	3.16	3.94	4.60	5.70
38.0	3.18	4.19	5.09	6.67
40.0	3.16	4.20	5.12	6.77
42.0	2.87	3.35	3.74	4.34
44.0	2.35	2.73	3.03	3.51
47.0	2.14	2.60	2.58	3.60
50.0	1.68	2.59	3.52	5.41
52.0	1.48	2.10	2.53	3.16
55.4	.99	1.56	1.96	2.51
58.0	0.00	.34	.57	.86
69.0	0.00	0.00	0.00	0.00
90.0	0.00	0.00	0.00	0.00
97.0	0.00	0.00	0.00	0.00
107.5	.19	.33	.42	.54
113.5	.11	.27	.37	.50
119.8	0.00	.14	.23	.34
120.0	*	0.00	0.00	0.00

* No Flow
** Scour Likely

[3]Thermal effects associated with the altered flow regime are also recognized as an essential component of incubation and were evaluated in the Terror Lake study. However, presentation of that assessment is outside of the scope of this paper.

Table 5.--Simulated mean column velocities for selected streamflows at designated points along transect 5 (within a pool) at the Terror Gage study reach.

Horiz. Dist.	Velocity (fps) Q=400cfs	Q=600cfs	Q=800cfs	Q=1200cfs
8.0	0.00	0.00	0.00	0.00
10.5	.43	.68	.85	1.11
12.0	1.06	1.29	1.48	1.76
12.5	1.55	1.81	2.04	2.41
15.0	2.18	2.38	2.54	2.79
18.0	2.43	2.66	2.84	3.13
21.0	2.46	2.65	2.80	3.04
24.0	2.53	2.69	2.82	3.03
28.0	2.41	2.55	2.66	2.84
31.0	2.94	3.29	3.56	4.01
34.0	2.96	3.31	3.58	4.03
37.0	2.77	2.92	3.04	3.23
40.0	3.16	3.59	3.94	4.52
43.0	3.06	3.36	3.60	3.98
46.0	2.88	3.06	3.21	3.45
50.0	3.23	3.71	4.10	4.74
53.0	2.94	3.43	3.84	4.53
56.0	2.89	3.52	4.07	5.02
59.0	2.83	3.25	3.59	4.15
62.0	2.49	3.29	4.02	5.36
65.0	2.47	3.36	4.19	5.76
67.0	1.99	2.81	3.61	5.16
70.0	1.75	1.93	2.07	2.29
73.0	1.83	2.08	2.29	2.63
76.0	1.62	1.98	2.28	2.81
78.0	1.45	1.72	1.96	2.34
82.0	1.63	2.19	2.60	3.21
85.0	1.50	2.01	2.39	2.96
88.0	1.27	1.75	2.11	2.63
91.0	1.37	1.84	2.18	2.70
94.0	1.17	1.67	2.03	2.57
97.0	.95	1.50	1.88	2.43
100.0	.83	1.41	1.80	2.36
103.0	.71	1.32	1.72	2.30
107.5	.59	1.10	1.43	1.91
108.0	0.00	.37	.78	1.27
112.0	*	0.00	0.00	.16
115.5	*	*	*	0.00

* No Flow

indicate that streambed scour is unlikely to occur in pool areas, but local scour probably would occur in runs and riffles when streamflows approach 1,000 cfs. Scour probably would occur in spawning areas throughout the lower mainstem whenever streamflows exceed 1,500 cfs.

Knowledge of the seasonal occurrence and frequency of such flows is of particular importance for evaluating the survivability of deposited eggs. During 1965-1968 period of record at the USGS Terror River gage (15295700), 12 daily streamflows greater than 1,500 cfs and 47 greater than 1,000 cfs were recorded. Ten flows greater than the former and 20 above the latter discharge occurred between mid-July and early October. Annual peak daily flows of record have always occurred in association with rainstorms during late summer and early fall. These peak streamflows are normally of short duration and represent relatively small volumes of water. For example, the September 10, 1965 discharge of 1,490 cfs was preceded by more than a week of average daily streamflows of between 150 and 250 cfs. The September 18-19 and September 26-29, 1966, peak flow periods of 1,000 to 2,200 cfs occurred within a 15-day period when ambient streamflows were between 200 and 450 cfs (USGS 1965 and 1966).

As a result of the project, the storage capacity of Terror Lake would increase from 16,000 to 94,000 acre-feet, providing 78,000 acre-feet of active storage (R.W. Retherford and International Engineering Company, Inc. 1978, 1979). The September 26-29, 1966, runoff (13,500 acre-feet) is the largest volume of water attributable to a fall storm during the 1965-1968 period of record. The Terror Lake drainage area comprises 15.1 mi^2 of the 46 mi^2 upstream of the Terror River gage. If the rainstorm that caused this 4-day peak flow event had been uniformly distributed over the Terror River basin, approximately one-third of the 13,500 acre-feet of runoff or 4,400 acre-feet would have originated above the proposed Terror Lake dam. Seldom would the proposed reservoir with 850 surface acres and 78,000 acre-feet of active storage be so full that it could not temporarily store all the upper basin runoff from such a storm.

Were peak daily streamflows in the lower Terror River reduced by 30% as might result from the proposed dam, only two streamflow events above 1,500 cfs and 11 above 1,000 cfs would have occurred between the mid-July and early October period. This contrasts with 10 flows above 1,500 cfs and 20 above 1,000 cfs for the 1965-68 period of record. Thus, it may be concluded that the frequency at which lower mainstem spawning areas are scoured would be notably reduced but not eliminated as a result of the project.

Dewatering of Redds

Another major factor influencing the survival of fertilized pink salmon eggs is the potential of low winter streamflows to dewater redds. Streamflows during the spawning season provide salmon easy access to spawning habitat along the streambed margins and in riffle areas. However, midwinter water surface elevations often drop appreciably below those present in these areas during the spawning season. As a result, spawning habitat along the stream margins and in riffle areas can become dewatered, and flow through the streambed gravels may be substantially reduced.

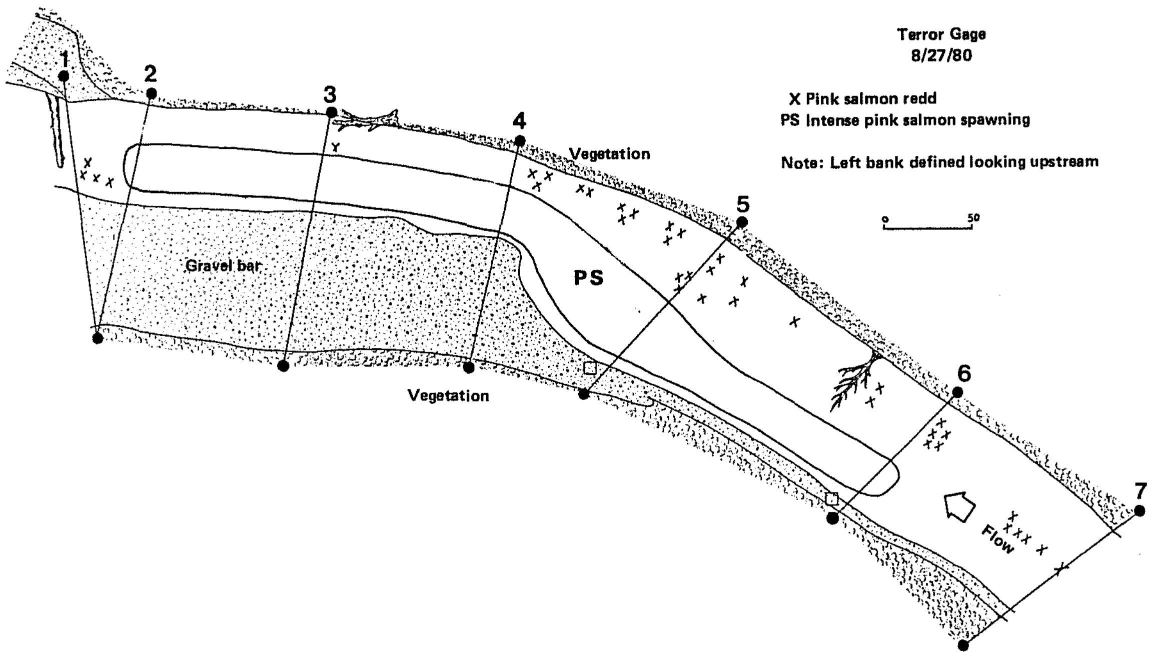

Figure 4.--Redd map of the Terror Gage study reach, August 1980.

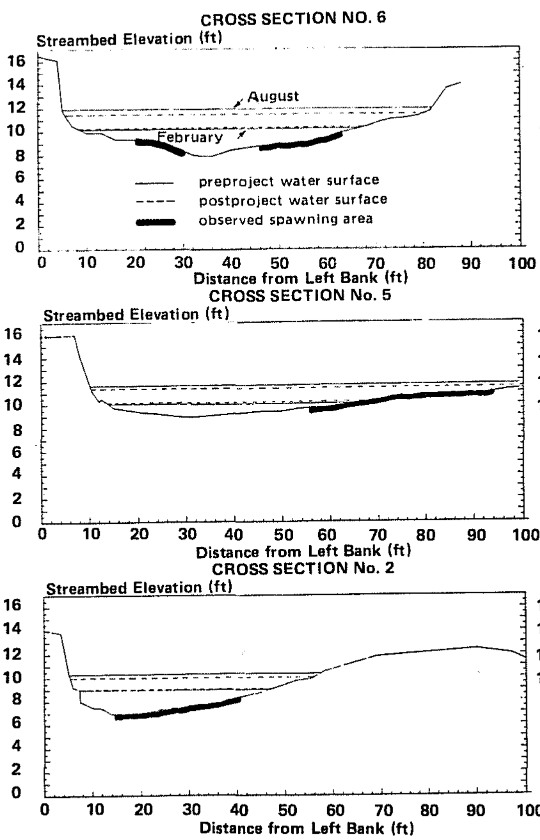

Figure 5.--Comparison of long-term average monthly water surface elevations during August and February in the lower Terror River.

Figures 4 and 5 present a redd map (field sketch) and scale drawing of respective cross sections denoting the locations of pink salmon redds observed during August 1980. Transects 2, 5, and 6 collectively represent typical stream channel cross sections for the study reach, hence the remainder of the transects were deleted from the analysis. To expedite analysis of project effects on redd dewatering, August and February were selected as index months. Figure 5 provides a comparison between pre- and postproject water surface elevations for long-term average August and February streamflows. Postproject streamflows would reduce the magnitude of the change between average monthly water surface elevations for the index months by approximately 0.5 ft. The long-term average postproject winter water surface elevation would be approximately 0.1 ft higher, while during the spawning season it would be approximately 0.4 ft lower.

The 27 years of simulated monthly streamflows during the midwinter incubation period were reviewed and the lowest monthly flow and corresponding water surface elevation for each winter identified. A comparison was then made between these water surface elevations and the water surface elevation associated with a controlled winter release of 60 cfs (Figure 6).

The low-flow statistics obtained in the flow variability analysis indicate that the simulated monthly midwinter streamflows are substantially greater than the lowest daily flows. Therefore, it must be remembered that incubating eggs and alevins are being stressed to a greater extent than the simulated monthly streamflows would

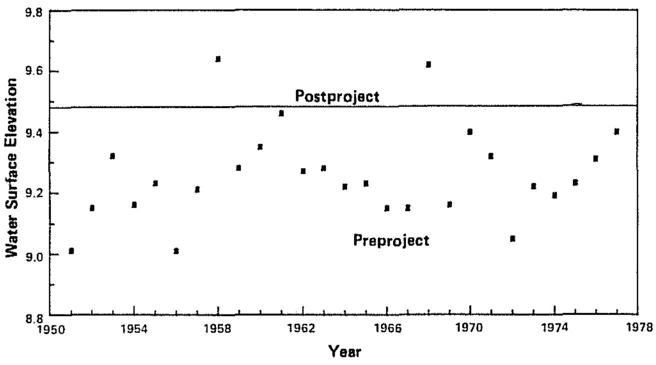

Figure 6.--Comparison of average monthly pre- and postproject water surface elevations for 27 years of simulated streamflows during the incubation season.

imply. Hence, postproject flow regulation near 60 cfs throughout the winter months should do more to protect incubating redds from dewatering than this comparison of average monthly pre- and postproject water surface elevations indicates.

Natural mortality would continue to occur in the lower Terror River as a result of redd dewatering but losses would not be as severe or as frequent as under preproject conditions. Reduction of water surface elevations during the spawning period should encourage adults to spawn closer to midchannel where their redds are not as vulnerable to dewatering. With reference to scour, the proposed project would reduce the magnitude and frequency of flood peaks, thereby improving the potential survival of incubating salmonid eggs in the lower Terror River.

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AN INTERAGENCY STREAMFLOW RECOMMENDATION ANALYSIS FOR A PROPOSED ALASKAN HYDROELECTRIC PROJECT[1]

William J. Wilson[2]

Abstract.--During 1980-81 an incremental instream flow assessment was performed for the proposed 20 megawatt Terror Lake Hydroelectric Project on northern Kodiak Island, Alaska. This development would reduce average annual discharge by 35 percent near the mouth of the Terror River and augment streamflow by 30 percent in the lower Kizhuyak River, affecting the pink, chum, and coho salmon and anadromous Dolly Varden populations of these rivers. Physical habitat simulation models and fish habitat preference criteria were integrated to arrive at habitat availability indices for various streamflows. Correction factors were applied to these data to assure results portrayed observed field conditions. The final report was utilized by permitting and regulatory agencies in a workshop having an objective of protection or enhancement of the existing fishery resources of the project area while concurrently optimizing hydroelectric power production. The instream flow incremental methodology facilitated arriving at a streamflow regime mutually satisfactory to the regulatory agencies and the electric utility.

INTRODUCTION

Since World War II the City of Kodiak, a large fishing port on Kodiak Island, Alaska, has sought alternative methods for generating electrical power. Electrical energy was, and currently still is, generated by diesel-fired turbines. In the 1950's potential hydroelectric power sites were investigated by Kodiak Electric Association, Inc. (KEA), and one site, Terror Lake, was found only approximately 32 km from the City of Kodiak. A development for the Terror Lake project site was designed in the early 1960's. The project would involve enlarging an existing 109 hectare lake, tapping the newly created 344 hectare reservoir through a power tunnel, thereby diverting water from the Terror River watershed into the Kizhuyak River watershed where a powerhouse would be located. Although the original scheme for development was deemed too costly for the times, in the late 1970's KEA again asked its consulting engineers to evaluate the Terror Lake project in light of markedly increased diesel costs.

Some engineering refinements were made, and an Application for License to the Federal Energy Regulatory Commission (FERC) was prepared in late 1978. FERC rejected this initial application because of several deficiencies, specifically in the environmental assessment area. KEA contracted with the University of Alaska's Arctic Environmental Information and Data Center (AEIDC) to gather the required additional data to complete a satisfactory environmental assessment.

AEIDC undertook preliminary reconnaissance studies in 1979 (Wilson et al. 1979), during which time several specific fish and wildlife information needs were fulfilled and preliminary groundwork was laid for responding to a more involved question: what would be the quantitative change in fish habitat resulting from streamflow changes in both the Terror River and Kizhuyak River drainages? As a result of our reconnaissance field efforts, and during further scoping discussions with state and federal agencies as well as FERC, the instream flow incremental methodology (IFIM) was specifically requested by agencies for an instream flow assessment for the Terror Lake project. This methodology was selected specifically because of (1) its capability to assess quantitative change in fish habitat from both decreased and increased streamflows, and (2) FERC environmental staff had determined this method would withstand scrutiny under legal hearing if that were to become necessary. The latter issue was particularly important to this study since the project was to be built on the Kodiak National Wildlife Refuge and interven-

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tion in the FERC licensing process by conservation or other concerned organizations was likely.

FISHERY RESOURCES IN THE PROJECT AREA

The fishery resources of concern in the Terror Lake project area consist of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and coho salmon (*O. kisutch*) and anadromous Dolly Varden (*Salvelinus malma*). From the standpoint of their economic importance as well as their contribution to the food resources of the Kodiak brown bear, pink and chum salmon are the primary resources of the drainages. Adult pink and chum salmon return to both drainages to spawn in mid to late summer. In the Terror River an average of approximately 40,000 pink and 5,000 chum salmon return to spawn each year, while in the Kiżhuyak drainage approximately 5,000 pink and nearly 10,000 chum salmon escape local commercial fishing gear to return each year. Pinks and chums spawn in the lower segments of both rivers; pink salmon prefer intertidal żones while chums seek areas of upwelling intragravel water flow above the intertidal żone. Of all species, pink salmon are the most important commercial species, sought after by purse seine and gillnet fisheries around the perimeter of Kodiak Island.

Coho salmon are far less abundant, although reliable estimates of adult escapement to both systems are unavailable because of lack of reconnaissance effort by management over the past few years due to persistently poor weather conditions for aerial surveys as well as their sparse distribution in these systems. Perhaps only a few hundred coho escape to each river annually. Anadromous Dolly Varden, on the other hand, are fairly abundant in both systems but only during the summer and fall months. Hundreds, maybe thousands, forage in both drainages throughout the summer, but only a few hundred mature adults will actually spawn in either system during late fall and early winter months. These char feed on drifting pink and chum salmon eggs as well as rearing fry and juvenile coho salmon and Dolly Varden. Anadromous Dolly Varden spawn principally in spring-fed areas, tributaries to the mainstem, or far upriver mainstem segments.

Incubating embryos of all species are present in stream gravels throughout winter months, and fry emergence occurs during late winter and spring. Fry and smolt outmigration occurs during the months of April and May (pink and chum salmon) through June or July (Dolly Varden and coho salmon). The large outmigrating population of pink and chum salmon fry generally peaks during the month of May.

Juvenile Dolly Varden and coho salmon are found in a wide range of habitat types throughout the year in both river systems. During winter they tend to congregate in deeper mainstem areas or in segments of tributaries or backwater areas fed by springflow throughout the ice covered period. During spring and summer juvenile fish are distributed more widely throughout the systems, preferring eddies and pools, side channels and sloughs, and tributaries. Pools created by eddies behind uprooted trees and jams of other debris in the mainstem of both rivers are common mainstem rearing areas.

THE TERROR LAKE DEVELOPMENT SCENARIO

KEA had proposed a minimum postproject flow regime for both rivers based upon recommendations provided by the U.S. Bureau of Commercial Fisheries in the mid-1960's. The project would result in permanent reduction in streamflow in the lower 12.9 km of the Terror River and augmentation in the lower 6.4 km of the Kiżhuyak River (Table 1). The Terror Lake hydroelectric project would provide baseload generation of 15 to 20 megawatts for the City of Kodiak, Alaska and surrounding areas. An estimated 76,000 acre-feet of water originating in the Terror River basin would be diverted through an 8 km long tunnel and discharged through a powerhouse located in the Kiżhuyak River basin (Figure 1). An additional 42,000 acre-feet of water originating

Table 1--Effects of the Terror Lake hydroelectric project on average monthly streamflow near the mouths of the Terror and Kizhuyak Rivers.

	Terror River Average Monthly Streamflow (cfs)			Kizhuyak River Average Monthly Streamflow (cfs)		
Month	Preproject	Postproject	% Change	Preproject	Postproject	% Change
January	69	62	-10	50	150	200
February	56	65	16	40	150	275
March	50	62	24	40	150	275
April	99	124	25	45	150	233
May	403	239	-41	300	370	23
June	822	417	-49	600	580	-3
July	579	346	-40	500	510	2
August	374	261	-30	450	490	9
September	375	245	-35	225	290	29
October	275	170	-38	160	230	44
November	170	109	-36	70	160	129
December	80	66	-18	50	150	200
Average	279	181	-35	211	282	34

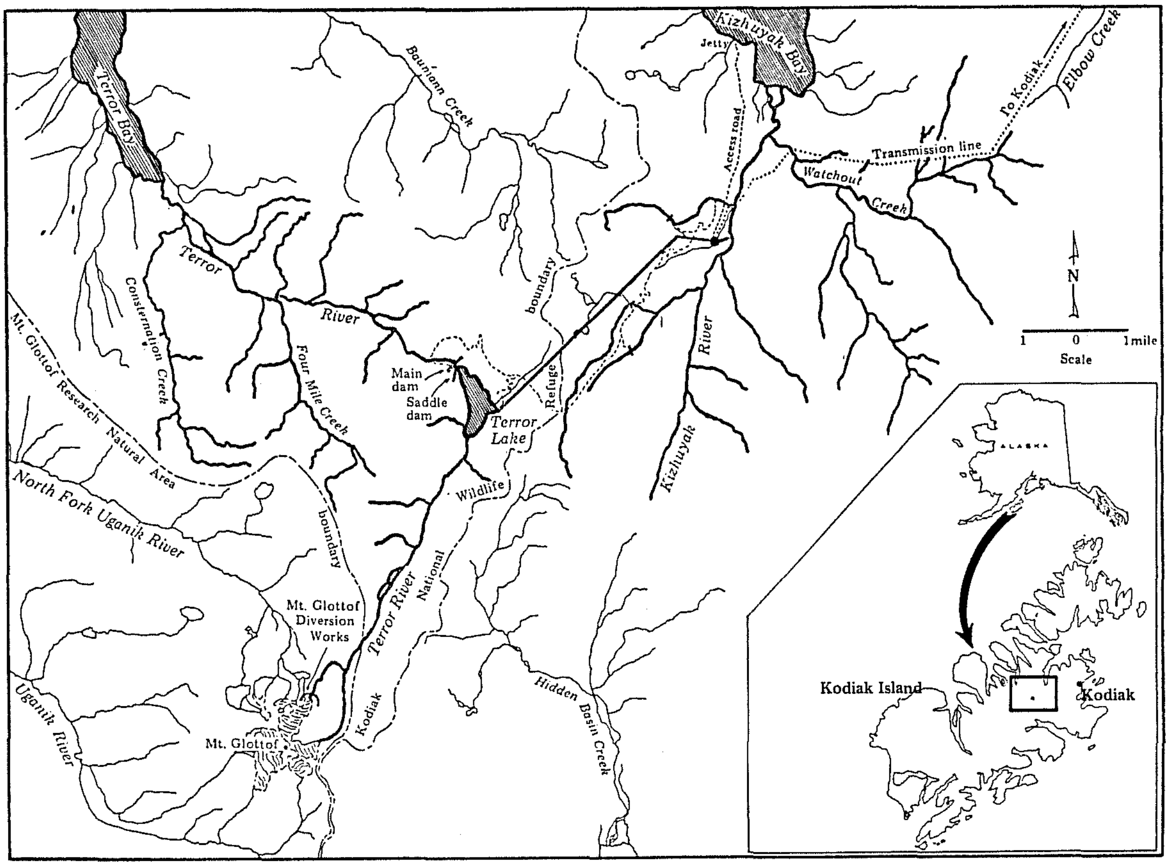


Figure 1--Location of the Terror Lake project area.

in the Kizhuyak basin would be diverted to the powerhouse from three tributary streams to augment the Terror basin diversion. This development would decrease the mean annual discharge in the Terror River basin by 34.7 percent at the river mouth, and would increase that for the Kizhuyak River at its mouth by approximately 30 percent.

INSTREAM FLOW STUDY METHODS

The IFIM makes extensive use of fish habitat suitability criteria and the concept of Weighted Usable Area (WUA). As used in this study, WUA is a quantitative index of the availability of fish habitat at a given streamflow. Extensive hydraulic simulation, as described in Milhous, Wegner and Waddle (1981) yielded stream models capable of predicting physical habitat available under a wide range of streamflow regimes. Descriptions of the methodology are available in several publications (Bovee and Milhous 1978; Trihey 1979, 1980; Stalnaker 1980; Trihey and Wegner 1981; Bovee 1982). While very data-intensive, the incremental method in my opinion is unsurpassed in its capability to examine a multitude of hydro project operation scenarios where river flow will be changed. It enables quantification of fish habitat available at almost any streamflow, thus permitting resource managers or other decision-makers to optimize electric power generation from a hydroelectric production facility while at the same time view trade-offs (or enhancement) in fish habitat.

Aquatic habitat for specified stream discharges was determined principally on the basis of three physical parameters: depth, velocity, and substrate. Application of the incremental methodology is comprised of several steps: (1) field observation and consultation with experts to determine fish species composition and distribution by life history stage within the stream; (2) study site selection using either a critical reach or representative reach approach; (3) field measurement of hydraulic and stream channel characteristics using a multiple transect approach; (4) field observations and measurements to validate or develop habitat suitability criteria (i.e., species preference or tolerance for physical parameters); (5) hydraulic simulation to determine the frequency and spatial distribution of depth-velocity combinations with respect to substrate for unobserved streamflows; and (6) calculation of Weighted Usable Area based upon the results of steps 4 and 5. Trihey (1982) and Baldrige and Amos (1982) provide additional more detailed information on the methodologies utilized in this study.

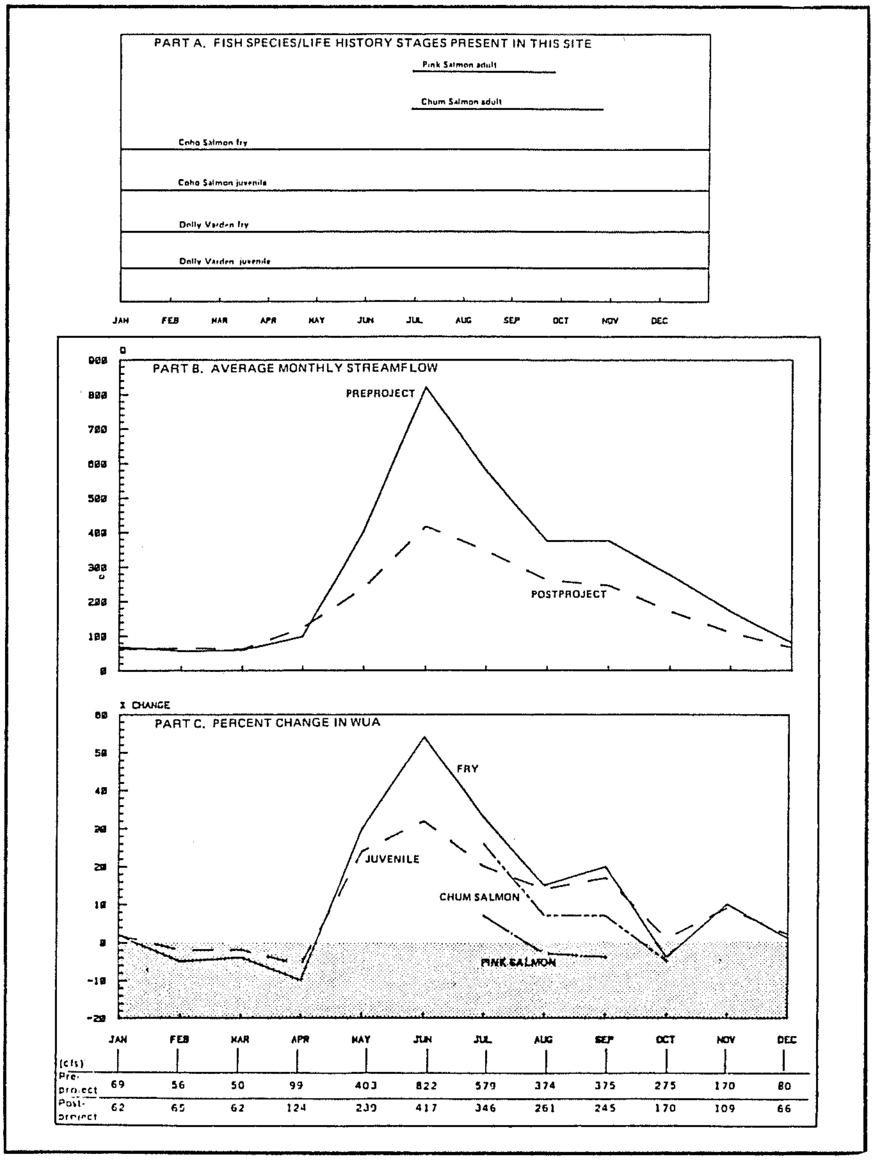
RESULTS

Because streamflows in the Terror River would be significantly and permanently reduced and streamflows in the Kizhuyak River increased, flow regime was the one aspect of riverine fish habitat which would be most affected by the proposed development. This paper, therefore, focuses on flow regime versus fish habitat considerations. The process through which instream flow information was used to help regulatory agencies, the utility, and intervenors to the FERC licensing process attain a mutually acceptable streamflow regime was comprised of three steps: (1) facilitating the decision-making process by design of appropriate display methods for data from the instream flow analysis, (2) critical evaluation of the predicted effects of anticipated changes in flow regime on fish habitat in both drainages, and (3) enhancing the prospects of arriving at a postproject flow regime acceptable to agencies and the utility.

Data Display Formats

The electric utility proposed to deliver a minimum of 1.68 cu m/sec (60 cfs) average monthly streamflow to the Terror River mouth except in April and May, when 2.80 cu m/sec (100 cfs) would be delivered for smolt outmigration. The effects of this altered flow regime on the riverine fishery resources in the project area were evaluated by hydraulic and fish habitat modeling, and the results were displayed in a variety of formats to facilitate ease of interpretation by the individuals we anticipated would review this report. Extensive use was made of graphics to illustrate differences between pre- and postproject situations. Charts were prepared which illustrated pre- and postproject average monthly streamflows and the percent change in fishery habitat--Weighted Usable Area--by species and life history stage (Figure 2). Pre- and postproject Weighted Usable Area data for each month for each species were contrasted and Weighted Usable Area as a percent of stream surface area for each month also was

Figure 2--Summary of project effects on monthly streamflows and Weighted Usable Area at the Terror Gage study reach.



portrayed. A graphic portrayal of the study reach was provided with accompanying illustrations of the stream channel cross sections at all study reaches. The calibration discharges were plotted on the stream channel cross sections to permit visual comparison of low, medium, and high flows in terms of top width or wetted perimeter. Summary tables were also prepared illustrating at each study reach the pre- and postproject Weighted Usable Area for each species and life history stage. These tables also included extrapolation factors to expand the predictions at a specific study site to the entire segment of river that that study site represented (Table 2). By summing river segment Weighted Usable Areas, a comprehensive view of project effects upon all life history segments of each fish species in each river system could be realized (Table 3).

Evaluation of Effects Predicted by Models

The second part of the analytical process involved relating study results to actual field conditions. An essential component of any aquatic/fishery modeling study should be the careful interpretation of modeling results by experienced field biologists. In this study, we felt it extremely important to critically evaluate all data generated by the hydraulic and fish habitat models. Actual field conditions are not always well duplicated by mathematical or other models, if at all. Thus, we asked ourselves: do we believe the results, and if not, what are the possible explanations for any apparently anomalous model predictions. We felt, therefore, that some subjective interpretation of habitat data generated by the incremental method models was in order.
The following conditions were subjectively factored into the overall instream flow assessment report.

Groundwater Contribution to Surface Runoff

Changes in fish habitat resulting from project-induced streamflow alteration can be moderated, or exacerbated, by the influence of springflow or groundwater seepage. During periods of low surface flow, springs can maintain water flow through streambed gravels and, therefore, favorable dissolved oxygen and thermal regimes. These areas may not be significantly influenced by surface streamflow change resulting from project operation and, therefore, would act as a reservoir of fish habitat remaining even under the more adverse postproject situations.

Actual Habitat Use by Spawning Salmon

Weighted Usable Area indices calculated for a specific species and life history stage in a given river segment are a function of habitat criteria and physical conditions. This index does not imply that that specific river segment was used to capacity by that species. For example, the availability of 1,000 Weighted Usable Area units in the upper drainage of the Terror River system could not be assumed to be as important to spawning pink salmon as 1,000 Weighted Usable Area units in the lower 1.6 km. In this lower, intertidal reach of the Terror River, our field crews observed pink salmon spawning in nearly all available habitat. Pink salmon made noticeably less use of habitat for spawning in the middle and upper river segments, even though habitat was available in considerable quantity (in terms of depth, velocity, and substrate characteristics). Distances between redds were consistently greater at upstream spawning areas than in the lower river. Clearly, a higher redd density per unit of Weighted Usable Area existed in the lower km of the Terror River (and also in the Kizhuyak River) than at any upstream location.

Table 2--Summary of project effect on fish habitat of the Terror Gage Study reach and the Terror River Segment that it represents.

Month	Spawning WUA						Fry Rearing WUA						Juvenile Rearing WUA					
	Pink Salmon			Chum Salmon			Coho Salmon			Dolly Varden			Coho Salmon			Dolly Varden		
	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%/.
January							11,636	11,795	1	17,779	18,215	2	23,440	23,997	2	23,495	24,043	2
February							12,115	11,615	-4	18,797	17,937	-5	24,216	23,703	-2	24,248	23,754	-2
March							12,186	11,795	-3	19,200	18,215	-5	24,450	23,997	-2	24,471	24,043	-2
April							10,631	9,357	-12	16,455	15,047	-9	22,058	20,813	-6	22,161	20,930	-6
May							7,580	10,067	33	12,262	15,456	26	16,724	20,748	24	16,961	20,983	24
June							4,618	7,340	59	8,014	11,565	49	12,440	16,322	31	12,533	16,560	32
July	23,276	24,802	7	14,795	18,600	26	6,000	8,819	47	11,825	13,935	18	15,683	18,722	19	15,869	18,959	19
August	24,613	23,854	-3	18,334	19,544	7	8,183	9,510	16	13,042	14,853	14	17,667	20,072	14	17,903	20,333	14
September	24,605	23,530	-4	18,326	19,618	7	8,160	9,943	22	13,012	15,299	18	17,629	20,636	17	17,864	20,881	17
October				19,453	18,576	-5	9,467	8,733	-8	14,729	14,704	-.2	19,653	19,790	.7	19,919	19,931	.1
November							8,733	9,948	14	14,704	15,650	6	19,790	21,521	9	19,931	21,634	9
December							11,706	11,612	-.8	17,460	17,889	2	23,180	23,627	2	23,251	23,679	2
ΣWUA[1]	72,490	72,190	-.4	70,910	76,340	8	111,020	120,530	9	177,280	189,170	7	236,930	253,950	7	238,610	255,730	7
Avg. Mo., WUA	24,160	24,060		17,730	19,090		9,250	10,040		14,770	15,760		19,740	21,160		19,880	21,310	
Extrapolation[2] Factor	6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3	
R. Segment ΣWUA	456,700	454,800	-.4	446,700	480,900	8	699,400	759,300	9	1,116,900	1,191,800	7	1,492,700	1,599,900	7	1,503,200	1,611,100	7
R. Segment Avg. Mo. WUA	152,200	151,600		111,700	120,300		58,300	63,300		93,100	99,300		124,400	133,300		125,200	134,300	

River segment represented by Terror Gage = 1.2 mi.

1. Accumulative WUA is the summation of monthly WUA values for the time period that the designated species/life stage is occupying the representative reach; 12 months rearing, July - September pink spawning, and July - October chum spawning.

2. Extrapolation factor is the multiplier used to apply WUA values to the entire river segment represented by the study reach. It is simply the length of the river segment being represented by the study reach in feet, divided by 1,000.

River Segment	Flow Regime	Spawning WUA								
		Pink Salmon			Chum Salmon			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre	278,200						278,200		
	Post	365,000	86,800	31.2	-	-	-	365,000	86,800	31.2
Bear Meadow	Pre	121,000			82,700			203,700		
	Post	170,400	49,400	40.8	114,000	31,300	37.8	284,400	80,700	39.6
Log Jam	Pre	521,400			529,700			1,051,100		
	Post	403,500	-117,900	-22.6	420,100	-109,600	-20.7	823,600	-227,500	-21.6
Terror Gage	Pre	456,700			446,700			903,400		
	Post	454,800	-1,900	-0.4	480,900	34,200	7.7	935,700	32,300	3.6
Mainstem Total	Pre	1,377,300			1,059,100			2,436,400		
	Post	1,393,700	16,400	1.2	1,015,000	-44,100	-4.2	2,408,700	-27,700	-1.1

River Segment	Flow Regime	Fry Rearing WUA								
		Coho Salmon			Dolly Varden			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre				1,875,700			1,875,700		
	Post	-	-	-	2,044,700	169,000	9.0	2,044,700	169,000	9.0
Bear Meadow	Pre	538,600			879,600			1,418,200		
	Post	565,100	26,500	4.9	965,800	86,200	9.8	1,530,900	112,700	7.9
Log Jam	Pre	1,731,900			2,524,300			4,256,200		
	Post	1,816,800	84,900	4.9	2,669,500	145,200	5.8	4,486,300	230,100	5.4
Terror Gage	Pre	699,400			1,116,900			1,816,300		
	Post	759,300	59,900	8.6	1,191,800	74,900	6.7	1,951,100	134,800	7.4
Mainstem Total	Pre	2,969,900			6,396,500			9,366,400		
	Post	3,141,200	171,300	5.8	6,871,800	475,300	7.4	10,013,000	646,600	6.9

River Segment	Flow Regime	Juvenile Rearing WUA								
		Coho Salmon			Dolly Varden			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre				2,392,100			2,392,100		
	Post	-	-	-	2,654,700	262,600	11.0	2,654,700	262,600	11.0
Bear Meadow	Pre	1,145,800			1,151,000			2,296,800		
	Post	1,292,500	146,700	12.8	1,298,800	147,800	12.8	2,591,300	294,500	12.8
Log Jam	Pre	3,022,700			3,073,200			6,095,900		
	Post	3,174,700	152,000	5.0	3,229,200	156,000	5.1	6,403,900	308,000	5.1
Terror Gage	Pre	1,492,700			1,503,200			2,995,900		
	Post	1,599,900	107,200	7.2	1,611,100	107,900	7.2	3,211,000	215,100	7.2
Mainstem Total	Pre	5,661,200			8,119,500			13,780,700		
	Post	6,067,100	405,900	7.2	8,793,800	674,300	8.3	14,860,900	1,080,200	7.8

Table 3--Summary of project effects on WUA in the Terror River basin.

Flood-flows and Scour vs Low Flow and Dessication

The change in basin-wide Weighted Usable Area indices from pre- and postproject situations were representative only of average-year streamflows. During periods of abnormally high or low flow, project operation could have different effects on spawning pink salmon. In order to better visualize the natural variability of habitat conditions in the Terror and Kizhuyak rivers and the effects that project operation might have on these phenomena, Weighted Usable Area indices were determined specifically for pre- and postproject wet and dry years. In other words, during dry periods project withdrawals from the Terror River system may greatly exacerbate an already stressed situation for adult spawners by reducing streamflows even further, crowding spawners and perhaps causing redd superimposition. In this situation, habitat for spawning salmon would be expected to be reduced significantly during low-flow periods. During high-flow periods, however, the proposed streamflow withdrawals during spawning months could be beneficial, both from the standpoint of increasing Weighted Usable Area (primarily attributed to the reduction in mean column velocities) and reducing the potential for streambed scour and the resultant high egg or alevin mortality.

Other Adjustments to Model Predictions

In addition to the above factors, other aspects of our computer model output was scrutinized in light of preference by spawning chum salmon for intragravel water upwelling and the effects of the project on habitat conditions during winter incubation of salmonid eggs. AEIDC's instream flow assessment team initially evaluated the results from the hydraulic and fish habitat models in light of their field experience. Factors such as intragravel water upwelling, cover, water temperature, river channel scour, backwater effects, and springflow were considered in association with the WUA indices. Thus, conclusions in our final report were derived from the instream flow model output adjusted (or, in most cases, bolstered) by these unmodelled but biologically significant factors.

Report Conclusions

AEIDC's final report (Wilson et al. 1981) was prepared and distributed by KEA to FERC and the many state and federal agencies responsible for granting permits or permit review. The results of the incremental instream flow assessment provided a working document with which a negotiated settlement of a potential controversy was expeditiously reached. During low-flow periods, the postproject streamflows would reduce spawning habitat in the Terror River drainage, but would not affect fishery habitat in the Kizhuyak River system. During high-flows the Terror Lake reservoir would reduce the intensity of peak daily streamflows, thereby reducing the severity and frequency of streambed scour in spawning areas in the lower mainstem Terror River. The project would have an insignificant effect on peak flows in the Kizhuyak River. The bottom line was that postproject flows would have little effect on fish.

The reason for this conclusion was that in almost all years, wet, dry, or average, the utility would affect only the upper one-third of the Terror watershed. Recurring, persistent, and extensive precipitation on Kodiak Island would maintain streamflows in the lower watershed where the entire fishery resource is located. Even though KEA would guarantee 1.68 cu m/sec (60 cfs) in the lower river for spawning, far in excess of that amount would flow merely from runoff in the lower two-thirds of the basin. In the Kizhuyak River, a continuous 4.90 cu m/sec (175 cfs) over and above natural streamflows would be discharged from the powerhouse, having no consequence to fish in that river. The principal question still remaining for resource managers: what is the absolute minimum acceptable streamflow regime for the Terror River? We know 1.68 cu m/sec (60 cfs) is far too low for spawning, and we also know that climatic conditions would probably preclude that situation in most years. Nevertheless, what minimum flow regime should be recommended to FERC for licensing? That question led our study team to the third step in the recommendation process.

FINAL RECOMMENDATIONS: AN INTERAGENCY WORKSHOP

So you have a report--now what? The instream flow study completed by AEIDC for KEA was a product containing extensive numerical and interpretive material. Our work generated a complex set of results which, in order to be understood by someone other than a member of the study team, had to be examined carefully. It appeared to us unlikely that agency personnel would either have the time or the background to adequately comprehend the study or to prepare comments for FERC regarding the adequacy or inadequacy of the electric utility's instream flow study. Similar sentiments were voiced by many agency representatives; we, therefore, suggested that a task group be convened so that the assigned review staff of concerned agencies could together become well versed with the instream flow assessment methodology employed and the types and significance of data generated from the study. This forum also would provide an opportunity for agencies to interact to arrive at a mutually satisfactory streamflow regime which protected fishery habitats in both systems yet did not compromise power production desired by KEA.

Attending the four-day session were representatives of several agencies as well as staff scientists from AEIDC (hydraulic engineering, fishery biology) to interpret data or to explain results. Invited by the USF&WS were individuals from the Cooperative Instream Flow Service Group (IFG) to provide additional analytical support and comment. The principal goal of the working session was to arrive at an agency consensus on an acceptable minimum postproject streamflow regime--at least at the biological staff level. The interagency group felt that various alternatives to the streamflow regime originally proposed by the utility should be examined, and a concensus streamflow regime forwarded to the utility and to FERC. KEA was not present at this workshop, but the power production tradeoffs from various alternative streamflows were known by the workshop participants, and the utility's contracting engineers were consulted periodically throughout the workshop for various input. Also, the utility paid for the original study and already were well-versed on the results and their implications.

Several limitations and assumptions were agreed to by all at the beginning of the workshop. It was determined that because of its economic importance and the large size of runs in both drainages, pink salmon were selected to be the indicator species for review of alternative streamflow regimes. Also, a single study site was selected to be representative of the overall hydraulic and habitat characteristics of the Terror River system: the Terror Gage study site. This study site contained representative spawning and rearing conditions found in the entire drainage and included a prime pink salmon spawning area. The Kizhuyak Gage study site was similarly selected for that drainage. Thus, by limiting discussions to a single study site and a single species, the interagency group could complete an analysis of alternative streamflow regimes for both rivers in a timely yet biologically satisfactory manner.

Various tools were made available to the workshop team. Initially the graphs and charts prepared by AEIDC were reviewed and the procedures for adjusting model output were presented. In order to simplify the presentation of the long-term consequences of postproject streamflow regime alternatives, the IFG staff transformed the AEIDC habitat data into time series analyses of project effects based on a 27-year synthetic streamflow record for both river drainages. Pre- and postproject hydrographs for the 27 years of synthetic and measured streamflow record for the Terror Gage and Kizhuyak Gage study sites were reviewed. These graphs showed the natural state in the Terror River and the long-term consequences of this project on the existing streamflow patterns. Using the 27 year period of record, the IFG staff graphically displayed the long-term consequences of augmented streamflows on pink salmon spawning habitat in the Kizhuyak drainage. Trihey (1982) explains the technique utilized to generate these time series Weighted Usable Area data.

No long-term detrimental effects were noticed for the Kizhuyak system. A similar data portrayal for the Terror River system illustrated the long-term effects of the postproject 1.68 cu m/sec (60 cfs) minimum as well as the consequences of establishing a different minimum flow. Four time series analyses of pink salmon spawning Weighted Usable Area contrasted preproject, proposed post-project, and a series of alternative postproject minimum streamflow regimes: 7.00 cu m/sec (250 cfs), 5.60 cu m/sec (200 cfs), 4.20 cu m/sec (150 cfs), and 2.80 cu m/sec (100 cfs). The interagency workshop group felt that the long-term consequences of the proposed postproject regime of 1.68 cu m/sec (60 cfs) minimum would reduce pink salmon production to an unacceptable level. Similarly, the establishment of a 2.80 cu m/sec (100 cfs) minimum would result in a Weighted Usable Area (WUA) low threshold judged to be unsatisfactorily low when compared with the preproject WUA mean. The group felt that the long-term low threshold resulting from a 4.20 cu m/sec (150 cfs) minimum would be an acceptable minimum streamflow regime.

The point I wish to make is this: the incremental method quantifies fish habitat available for any streamflow (within the extrapolation limits of the hydraulic models employed). Thus, a variety of alternatives can be explored and compared quantitatively. The method enables a decision-maker to readily appraise the consequences of streamflow changes and render a decision in a minimal amount of time.

The consequences of a reduced streamflow regime in the Terror River were also evaluated for salmonid egg incubation. Fertilized embryos of all four species of salmonid incubate in streambed gravels throughout the period July-April. AEIDC staff biologists familiar with available literature on these species as well as site-specific field conditions developed criteria for pink salmon egg incubation. The IFG staff then transformed this data into a 27 year time series of incubation WUA for pre- and postproject streamflow regimes. Readily visible were the recurrent low WUA values during winter under preproject conditions and the benefits accrued to incubating eggs by a 1.68 cu m/sec (60 cfs) minimum flow. The 27 years of simulated pre- and postproject streamflow data readily illustrated the number of times that mid-winter streamflows would drop below the proposed minimum streamflow value. This indicated that considerable overall benefit, in terms of egg incubation, would result from stabilizing mid-winter streamflows near 1.68 cu m/sec (60 cfs).

Spawning and egg incubation are events in a fish's life cycle which are intimately related. How could we be assured that the fertilized eggs deposited at a certain <u>spawning</u> streamflow would have sufficient water at a lesser <u>incubation</u> streamflow? The concept "Surviving Weighted Usable Area" was examined by the interagency group. This is discussed as effective spawning area by Milhous (1982). Both high flow (scour) and low flow (dewatering) situations were portrayed for each of four spawning streamflows: 1.68 cu m/sec (60 cfs), 2.80 cu m/sec (100 cfs), 4.90 cu m/sec (175 cfs), and 7.00 cu m/sec (250 cfs). WUA which would "survive" from these spawning flows were then generated from various incubation streamflows. Data were generated using the egg incubation habitat criteria previously mentioned over the 27 year period of synthetic record.

The interagency group analyzed the four situations and concluded that, although flows of 7.00 cu m/sec (250 cfs) would maintain preproject spawning conditions, an incubation flow of 4.48 cu m/sec (160 cfs) would be required in order to maximize survivability. Or, in other words, if salmon spawn at a streamflow of 7.00 cu m/sec (250 cfs), any subsequent flow of less than 160 cfs would result in egg mortality from redd dewatering, thereby negating the production from the 7.00 cu m/sec (250 cfs) spawn. The group concluded that a spawning flow in the range of 4.90 cu m/sec (175 cfs) would complement an incubation flow of 1.68 cu m/sec (60 cfs).

The interagency group's final instream flow recommendation for the Terror River system appeared to be biologically sound for the maintenance of the existing fishery resources, particularly during low-flow conditions: spawning flows should be 4.20-4.90 cu m/sec (150-175 cfs) winter flows 1.68 cu m/sec (60 cfs), and spring smolt outmigration flows 2.80 cu m/sec (100 cfs). While there appeared to be room for small increment streamflow trade-offs in either direction during the spawning period, any streamflow regime significantly less than that concluded by the discussion group would be unacceptable. Thus, it was felt that this minimum regime would be palatable to all agencies concerned with this project, was realistic and attainable, and would not compromise the health of fish stocks in the Terror and Kizhuyak River drainages.

Having arrived at a consensus amongst themselves, state and federal agencies were able to transmit to FERC that, in terms of instream flow, the Terror Lake project was fully evaluated and no mitigation, other than the consensus streamflow regime, would be required for aquatic/fishery impacts. Because of KEA's acceptance of the study as well as the interagency recommendation regarding downstream releases, a negotiated settlement was rather quickly reached between the applicant and the Alaskan resource agencies. Thus, the recommended streamflow regime (Table 4) was made part of an overall agreement between the utility, the U.S. Department of the Interior, the State of

Alaska, and several other intervenors was presented to FERC for attachment to the final environmental impact statement (EIS). The final EIS was circulated, and a license to construct was granted by FERC on September 29, 1981. The project is underway, and a monitoring agreement has been implemented, satisfying the agency mandated follow-up study and monitoring requirements.

The instream flow incremental methodology provided an excellent and widely acceptable tool for quantitatively evaluating the effects of streamflow change relating to the Terror Lake Hydroelectric Project on Kodiak Island. The data products from this instream flow assessment permitted sound and orderly decision-making by those concerned with the environmental effects of this project. Future users of this method in Alaska should understand its limitations, and the need for creative use and adaptation to each specific circumstance. Quantitative modeling of aquatic habitats should never entirely take the place of the judgement of experienced fishery biologists, but rather these techniques are excellent complementary tools which can be constructively used by fishery biologists in improving their skills of predicting the effects of streamflow or channel change on fish habitat.

An instream flow assessment must be a team effort, involving at least those disciplines of fishery biology, open channel hydraulics, and perhaps such capabilities as sediment transport or thermal modeling. In Alaska, where many river systems are ungaged, where climate stations are often widely dispersed or completely nonexistent, and where often only limited knowledge of fishery resources is available, the difficulty of the task of the instream flow assessment team is compounded due to lack of necessary background data. In such cases, I judge it necessary to spend sufficient time gathering these kinds of baseline data before undertaking the instream flow study itself. Also, such assessments must usually involve the employment of capable streamflow pattern modeling expertise to develop synthetic hydrographs or other hydrologic data of key importance to the successful completion of hydraulic modeling. Whether the assessment is a simple, one study site evaluation or a more complex study such as that conducted for the Terror Lake project, the instream flow incremental methodology, in my opinion, is unsurpassed in its utility as a decision-making tool for the comprehensive and wise evaluation of environmental effects of streamflow change on fish habitat.

ACKNOWLEDGEMENTS

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To protect existing pink and chum salmon resources of the Terror River, Kodiak Electric Association, Inc. will make the necessary releases from Terror Lake reservoir to ensure that instantaneous streamflows at the Terror Gage No. 15295700 do not fall below the following values during reservoir filling and thereafter during project operation:

Month	Minimum Streamflow	Biological Justification
January	60 cfs	Incubation
February	60 cfs	Incubation
March	60 cfs	Incubation
April	100 cfs	Outmigration
May	150 cfs	Outmigration
June	150 cfs	Outmigration
July	150 cfs	Spawning pink salmon, chum salmon
August	150 cfs	Spawning pink salmon, chum salmon
September	150 cfs	Spawning pink salmon, chum salmon, coho salmon, Dolly Varden
October	150 cfs	Spawning pink salmon, chum salmon, coho salmon, Dolly Varden
November 1-15	100 cfs	Spawning coho salmon, Dolly Varden
November 16-30	60 cfs	Incubation
December	60 cfs	Incubation

Natural streamflows in the Terror and Kizhuyak Rivers will be maintained during project construction.

Table 4--Final consensus streamflow regime for the Terror River.

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A TECHNIQUE FOR DETERMINING FISH HABITAT SUITABILITY CRITERIA: A COMPARISON BETWEEN HABITAT UTILIZATION AND AVAILABILITY.[1]

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Abstract.--We developed habitat suitability criteria (used with the Cooperative Instream Flow Service Group [IFG] incremental method) from field data by comparing frequency analyses of utilized and available habitat. Using hydraulic simulation models and point measurements of depth, velocity, and substrate at active pink salmon (Oncorhynchus gorbuscha) redds, we determined the degree of utilization and availability of one habitat attribute--flow depth. Habitat suitability functions which account for habitat availability can be markedly different from those developed only from utilized habitat.

INTRODUCTION

Increased competition for existing water resources requires careful decisions on water allocations from Alaskan rivers and streams. Efforts to meet our energy requirements are focusing on the development of hydroelectric power, which can significantly alter natural streamflow regimes. To determine effects of altered flow regimes on fish habitat, scientists must understand relationships between streamflow and fish habitat. The incremental methodology of instream flow assessment is one method that allows for quantification of the relationships between streamflow and various characteristics of fish habitat. Effects of proposed changes in streamflows on fish habitat can be predicted through a field data collection and computer modeling process. For this methodology, criteria that characterize the relationship between physical habitat and fish behavior are called habitat suitability criteria.

In evaluating effects on fish habitat of changes in streamflow, the analysis focuses on those habitat characteristics most likely to be affected. The incremental method has been most widely used to describe effects of streamflow alterations on riverine fishery habitat. Flow alterations most directly affect streamflow dependent attributes associated with flow regime and channel structure. These attributes include flow depth, velocity, water temperature, substrate, and cover. Most research in Alaska and the western states has focused on these attributes.

Habitat suitability criteria are used to translate predicted changes in the physical stream environment into predicted changes in usability of a particular type of fish habitat. This usability is described through a habitat index called weighted usable area (WUA), which combines the quantity and quality of the habitat. It is derived from the total amount of habitat at the study site and the suitability of that habitat to a particular fish species/life stage (i.e. pink salmon spawners). By plotting WUA indices against streamflow, usability of fish habitat can be presented as a function of incremental changes in streamflow.

In this paper we discuss one procedure for developing habitat suitability criteria from field measurements. The technique presented here considers not only the habitat associated with the fish but also the habitat available in the vicinity. Using hydraulic simulation models and point measurements at fish locations, suitability of a particular habitat attribute was determined. We applied this method to data collected for spawning pink salmon (Oncorhynchus gorbuscha) in the Terror River, Alaska. This paper examines the application of this procedure to one habitat attribute--flow depth. Suitability criteria for other streamflow dependent habitat attributes or species/life stages can be developed in a similar manner.

Terminology

In presenting this method we use specific terminology. Our definitions and use of several terms may differ slightly from those in previous papers. In order to avoid confusion, we provide the following definitions or examples of this terminology.

1. Attribute refers to a specific habitat characteristic, such as depth, velocity or temperature.

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2. Value refers to the magnitude of an attribute in a specific habitat. For example, flow depth (attribute) may have a value of 0.2 ft deep, 1.5 ft deep, 3.0 ft deep, etc.

3. Availability of an attribute value is determined from its prevalence in the habitat, which is adjusted to eliminate areas where other attribute values are beyond the tolerance range of the species/life stage of interest. Thus, availability is a function of the habitat present and the range of acceptable attribute values.

4. Suitability represents a relative preference for an attribute value by a particular species/life stage.

5. A utilization function is developed from attribute values utilized by the fish species/life stage. This function represents what the fish finds suitable, biased by what was available.

6. In developing a suitability function, it is necessary to account for (a) the attribute values which were utilized by the fish species/life stage and (b) the availability of the attribute values in the habitat.

Data Base

Data used in this analysis were obtained during the instream flow assessment for the Terror Lake Hydroelectric Project, Kodiak, Alaska. We selected data sets from two study sites on the Terror River which described pink salmon spawning areas. Each data set consisted of point measurements of depth, velocity, and substrate at active redds collected during a single discharge, as well as simulated hydraulic conditions and substrate measurements present in the study area during that discharge. Physical attributes of 338 active redds were evaluated to establish suitability and 815 measurements of redds were reviewed to establish the ranges of acceptable conditions. The highest and lowest 5% of the values measured were eliminated to establish acceptable ranges of each habitat attribute considered. Field techniques, data reduction, and model calibration are described in other publications and will not be presented here (Trihey 1980a and 1980b, Wilson et al, 1981, and Bovee in press).

ANALYSIS FRAMEWORK

Habitat suitability criteria are used to assess utility of a particular area as habitat for a fish species/life stage. Riverine fish habitat can be viewed as consisting of four basic components: streamflow, channel structure, water quality and food-web relationships (fig. 1). Each of these components in turn consists of several habitat attributes, which interact within and among components to produce various quantities and qualities of fish habitat in the stream environment. Understanding the relationship between fish behavior and habitat attributes is fundamental to forecasting effects that changes in one or several of these attributes may have on fish habitat.

RIVERINE FISH HABITAT COMPONENTS

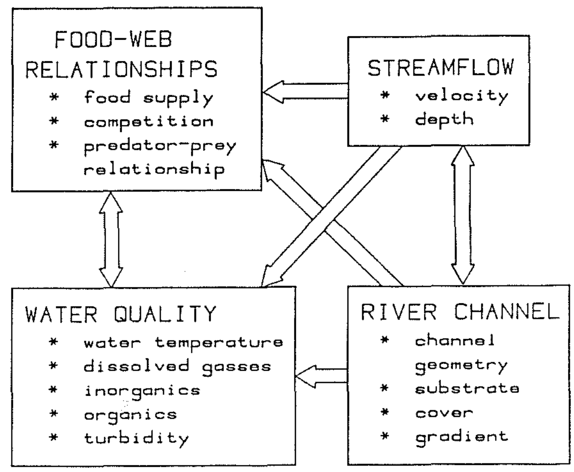


Figure 1.--Major components of riverine fish habitat are interrelated and each influences the habitat attributes of other components.

Habitat quality can be determined by assessing the values of its individual attributes. We assume that fish either occupy or avoid a particular habitat in response to the suitability of specific attributes of that habitat. Suitability of a particular value is determined from the frequency of fish occupancy and from the prevalence of that value in the available habitat.

Habitat suitability criteria are based on several assumptions:

1. Individual fish tend to select the most favorable habitat from within the total range of available habitat. They use less favorable habitat with lesser frequency and eventually leave the area, if possible, before microhabitat conditions become lethal.

2. Individual fish are most frequently observed in their most preferred habitat conditions; therefore, frequency of observation can be accepted as an indication of habitat utilization and frequency of observation weighted by habitat availability can be accepted as an indication of suitability.

3. Individual fish select values of one habitat attribute independently of the other habitat attributes as long as all these other attributes are within the

tolerance range of the target species/ lifestage.[4]

4. Field data represent conditions necessary to provide for the life requirements of the particular species/life stage being studied.

EVOLUTION OF HABITAT CRITERIA

Although the incremental method is considered to be state-of-the-art, the concept of using suitability criteria for evaluating fishery habitat is not new. For years, biologists have been investigating the relationship between fish behavior and the physical characteristics of their environment. In the 1950s early investigators described the characteristics of typical salmon spawning areas in the Pacific Northwest. Burner (1951) was one of the first biologists to develop spawning criteria. These criteria were used to evaluate replacement spawning habitat in the Columbia River basin. Chambers, Allen, and Pressey (1955) developed physical habitat criteria for use in designing artificial spawning channels.

In the 1960s Rantz (1964) used these criteria to develop a relationship between streamflow and the amount of spawning habitat present. The habitat attributes he considered were depth, velocity, and substrate, and he determined habitat to be either usable or nonusable. Collings, Smith, and Higgins (1968) conducted similar investigations but limited the range of acceptable depth and velocity to optimum habitat values. Values considered less than optimum were rated zero. The Oregon State Game Commission applied this technique to some Oregon rivers and in the process developed spawning habitat criteria for more salmonids (Smith 1973).

A significant change in habitat criteria came in the mid-1970s. Waters (1976) developed habitat criteria that addressed quality as well as quantity. He used weighting factors to describe the utility of individual values of three habitat attributes (depth, velocity, and substrate) to a particular species and life stage.

Major advancements came rapidly following development of this concept. The incremental method was developed by the U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group (IFG). It combines habitat criteria with simulated hydraulic streamflow. Through simulation, effects of incremental changes in streamflow and the resultant habitat can be evaluated for a wide range of streamflows.

Bovee and Cochnauer (1977) developed a technique for formulating habitat criteria using clustered frequency analyses to create a smooth curvilinear function. Point measurements of selected habitat attributes associated with capture or observation locations of fish were used to generate independent functions for each attribute. Voos (1981) developed a technique to determine suitability functions using exponential polynomial probability density functions. Voos's technique uses the observed values of two attributes while accounting for the relative abundance of those attributes within the habitat. This mathematically sophisticated procedure considers the degree of correlation or interdependency that may exist between attributes.

CURVE DEVELOPMENT

Habitat Utilization Function

A habitat utilization function represents the attribute values occupied by spawning pink salmon. We developed utilization functions for each data set from frequency analyses of point measurements for flow depth at fish locations. To reduce variance, adjacent values were grouped (Bovee and Cochnauer 1977). Given the difficulty of precisely locating fish within the stream environment, the accuracy of the field measurements is probably plus or minus 0.1 ft. For example, fish recorded as occupying a flow depth of 2.0 ft could have been actually occupying water between 1.9 and 2.1 ft deep. By combining adjacent values, we reduced localized fluctuations and the variability of our data. We felt that combining four adjacent values was the largest grouping that reduced variability yet maintained the integrity of our data.

We evaluated histograms developed from groups of two, three, and four values. Grouping by "N's" implies "N" possible starting values. For example, if groups of two were considered, groups began with either the first or second value, each yielding a unique histogram. Some of these histograms developed from the same data set were relatively similar visually and mathematically, while others were surprisingly different. Figure 2 contains histograms of depths utilized by spawning pink salmon both as originally recorded (ungrouped), and as combined in groups of four. All resultant histograms were evaluated and one was selected for further curve development.

Several criteria were used to determine the best grouping. Variance is one measure for the range or variability of observations. If grouping adjacent observations reduces the magnitude of fluctuations, the variance is lower.

[4]This assumption must be carefully considered for the species/life stage of interest. Dependency refers to one attribute influencing the utilization of another attribute. Minor dependencies exist between habitat attributes for spawning salmon. For example, salmon can use larger substrate in higher velocities. The velocity aids the fish in moving the substrate particles. Thus, we would say that a dependency exists between these two attributes (velocity and substrate). For spawning salmon most of these dependencies exist near the tolerance limits of the fish. By eliminating habitat with any attribute value beyond the tolerance limits, interdependency is generally reduced. A correlation analysis of the point measurements by the IFG showed that these minor dependencies were not statistically significant and had little effect on the suitability assigned to a particular attribute value.

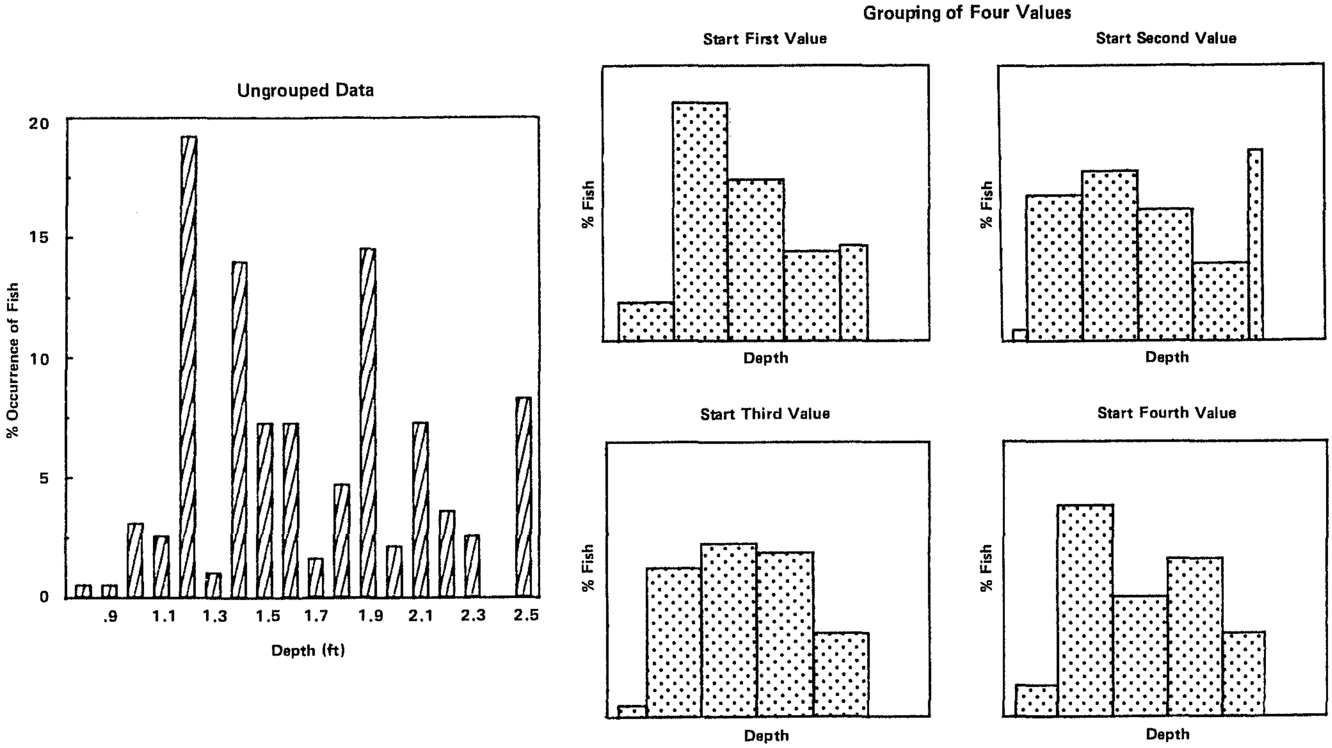


Figure 2.--Histograms of depths occupied by spawning pink salmon at the Terror Gage site, presented both as originally measured (ungrouped) and as combined in groups of four adjacent classes, have different shapes.

A standard F ratio (larger variance/smaller variance) revealed any statistically significant differences between these variances. A grouping yielding a significantly higher variance than another grouping was undesirable. Another measure of data variability is the coefficient of variation (standard deviation/mean * 100). It indicates the relationship between a standard deviation and its mean. Ideally, a set of grouped values would have a low variance and coefficient of variation relative to other groupings of this set of depth data. No irregular fluctuations should be present, meaning grouped values should continually increase to the maximum grouped value, then continually decrease. However, several groupings may fit some of these requirements while no single group fulfills all requirements. For example, the grouping of four containing the (not statistically significant) lowest variance and coefficient of variation also had irregular fluctuations (fig. 2). In the following table the variances of ungrouped data are compared with those data grouped in fours.

Starting Class	Mean	Variance	Coefficient of Variation
ungrouped	5.57	30.14	98.6%
1	5.43	11.27	61.9%
2	5.28	8.29	54.6%
3	5.06	8.86	58.8%
4	5.26	8.98	57.0%

If irregular fluctuations were present in grouped data, the following variables were examined.

1. Number of irregular fluctuations (number of times grouped values decreased prior to the maximum value and increased after the maximum);

2. Total magnitude of irregular fluctuations:

$$\sum_{i=2}^{\text{maximum value}} [\text{group}_{(i-1)} - \text{group}_{(i)}]^* \quad +$$

$$\sum_{i\,=\,\text{maximum value}+1}^{\text{last group}} [\text{group}_{(i)} - \text{group}_{(i-1)}]^*$$

*only when this difference is greater than 0.

3. Maximum individual irregular fluctuation (largest difference computed in No. 2 above prior to any summing);

4. Average fluctuation (total magnitude of irregular fluctuations/number of irregular fluctuations).

When irregular fluctuations were present, the preferable grouping contained the fewest number, lowest total magnitude, smallest maximum, and lowest average fluctuation. These variables as calculated for each grouping of four adjacent classes of the Terror Gage depth data are presented below:

Starting	Irregular Fluctuations			
Class	Number	Sum	Maximum	Average
1	1	0.25	0.25	0.25
2	2	4.02	2.35	2.01
3	0	0.00	0.00	0.00
4	1	1.65	1.65	1.65

In spite of the various methods presented for determining the best grouping, no single grouping may fit all criteria. Mathematically, several groupings may yield equally good distributions. Then the biologist determined which grouping to use based on familiarity with the study site, requirements of spawning pink salmon, and information from other studies.

Once the grouping was determined, values were standardized in order to develop a habitat utilization curve. To standardize, each group value was divided by the maximum grouped value, yielding a standardized step function. Though grouping minimized or eliminated irregular fluctuations, the step curve was still a crude approximation of habitat use. Depth, a continuous attribute, was forced into discrete classes. It was unreasonable to assume these fish did not use water to depths of 0.29 ft, but did use water 0.3 ft deep. These abrupt jumps were graduated by using midpoints of the physical measurement classes except at the optimum group (fig. 3).

Habitat Availability Function

A habitat availability function displays the amounts of various attribute values which were available to spawners. Hydraulic simulation models (IFG-4) were used to predict the hydraulic conditions present in the study site during fish observations. Total area overestimates the amount of habitat which can be utilized by spawning pink salmon. For example, water depth may be too shallow, velocity too great, or substrate too large. Local areas within the study site containing intolerable values must be eliminated from the data file because they are unavailable to spawners.

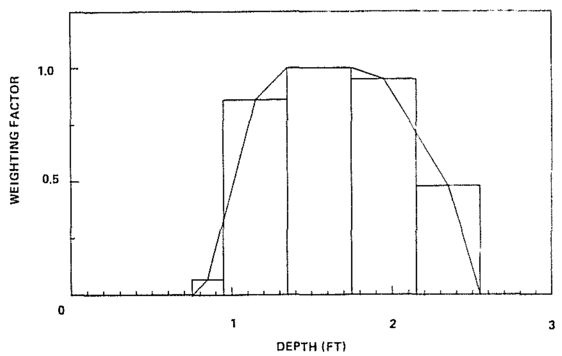


Figure 3.--A step function which silhouettes a standardized histogram was developed into a utilization function by enveloping the optimum class and connecting the midpoints of the remaining classes.

In order to establish availability, the attributes of an area must be tested to ensure that all the values are within the tolerance ranges of spawning pink salmon. We determined the range of acceptable values from frequency analyses of all point measurements of pink salmon observations in the entire study area (815 observations). Pink salmon were observed spawning in flow depths of from 0.3 to 3.5 ft. These values then became the cutoff points for flow depth. Bounds were similarly obtained for velocity (0.1 to 4.0 ft/sec) and substrate (3.5 to 6.0 Wentworth scale as modified by Wilson et al. 1981)[5]. Areas were unavailable to spawners because of extreme values of at least one physical characteristic, even though other attributes of this habitat were within tolerable bounds. For example, usable water depths over good spawning substrate were not available if the velocities were too swift. Areas with any attribute outside these bounds were deleted from the total area present regardless of the value of the other attributes. The remaining area was termed "available area" (fig. 4).

AVAILABILITY = (Set of values present) - (Set of values beyond the tolerance limits)

Unlike the habitat utilization function, habitat availability is not necessarily expected to be a curvilinear function. Attributes occur in various quantities of different values. Since irregular fluctuations are indicative of the available habitat, use of one grouping over another cannot be defended. Since this histogram is developed for comparison to a utilization function, we selected the same grouping chosen for the corresponding utilization function. Areas associated with attribute values were calculated according to IFG methods (Trihey 1980b).

Habitat Suitability Function

Since habitat suitability depends on both fish preference and habitat availability, suitability curves were developed from a ratio between habitat utilization function and habitat availability. If an equal amount of habitat were available for each depth/velocity/substrate combination, we would not need to correct for area. However, physical habitat is available in various quantities. Relatively scarce available habitat that fish heavily utilize should be weighted more than abundant habitat that few fish lightly utilize. To account for area in curve development, percent occurrence of fish observed for a particular value was divided by the corresponding percent occurrence of the available area of that characteristic value in the habitat.

$$\text{SUITABILITY} = \frac{\text{utilization}}{\text{availability}}$$

The above ratio was developed from histograms of utilized and available values. When

[5]3.5 = 0.5 in. to 1.3 in. mean particle size
6.0 = 2.5 in. to 5.0 in. mean particle size

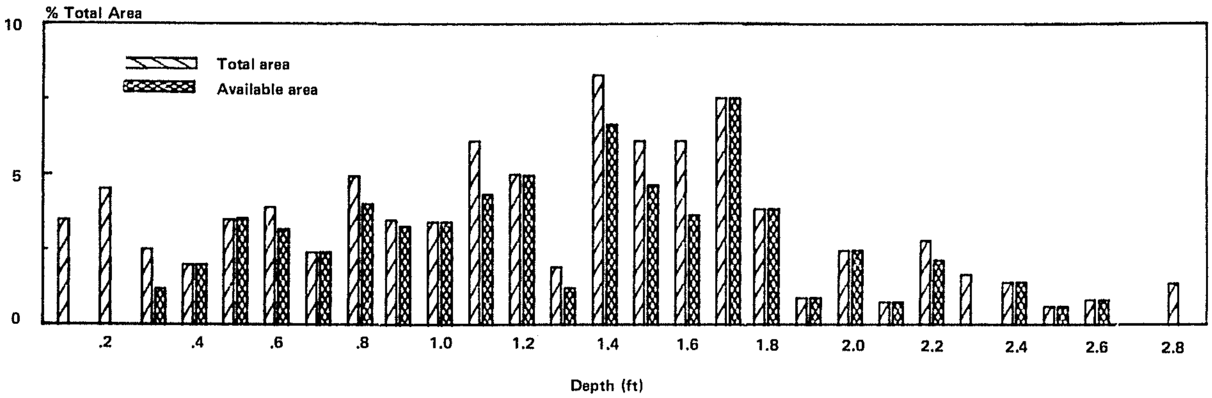


Figure 4.--Available area excludes cells having unacceptable depths or acceptable depths coupled with either unacceptable velocities or substrate.

combining two or more adjacent classes of physical habitat attributes, the percent of fish observed for those classes were summed and divided by the percent of total area available for those classes. The best histogram was selected according to requirements presented earlier and a curve was formed as described for the utilization function.

At this point we critically examined the endpoints of the suitability curve. Available area, not total area present, was once again scrutinized, because the range of available habitat defined the range of the habitat suitability curve. In the particular data set from which the curve was derived, water depths greater than 2.8 ft were not present, much less available, to spawners. Available depths did not exceed 2.6 ft. Since no area was available, the shape of the suitability curve beyond 2.6 ft is unknown. If the curve must be extended beyond the last measured available value, more data are required. Another data set from a nearby area where greater depths are available could be analyzed to provide information on the suitability of deeper areas. If this is not feasible, a poor alternative would be to review studies of the target species/life stage from similar areas to determine use of this habitat type.

DISCUSSION

Frequency of utilization for a particular attribute value depends on its suitability to the fish and availability within the environment. Analyses of point data from fish locations reflect only the values utilized by fish. It is equally important to identify the values that were available to the fish at the time point measurements were collected. Then the values utilized can be evaluated within the context of the total range available, and the bias removed, to give a more accurate indication of suitability.

Utility of a particular area as fish habitat is determined by the combination of habitat attributes--depth, velocity, and substrate, in this study. In order for an area to be usable as spawning habitat, each of these habitat attributes must be within the tolerance limits of the fish. Therefore, simply because a value is present does not imply that it is available to the fish. If the value of one of the habitat attributes is unacceptable, the fish cannot use the habitat for spawning. In fact, the values of the other habitat attributes associated with that habitat become unavailable to spawners even if they are with the tolerance limits. To verify availability of one value, it must be determined that the other attributes are within the range utilized by the fish. Using these data we can determine if fish distribution with respect to any one habitat attribute is influenced (limited) by the unacceptability of another attribute.

For example, in our study we compared data sets from two sites, Bear Meadow and Terror Gage. These data described habitat utilization of pink salmon spawners and habitat availability for two sites. Both sites had similar ranges of water depths, from 0.0 to 2.5 ft, but very different habitat utilization by pink salmon. These data were collected two days apart during the peak of spawning activity, while streamflow levels remained constant. In Bear Meadow, fish occupied flow depths from 0.3 to 1.7 ft, while at Terror Gage they occupied flow depths from 0.8 to 2.5 ft. Best-fit curves generated from a frequency analysis of depth observations from these two data sets have different optimum values and different total ranges (fig. 5).

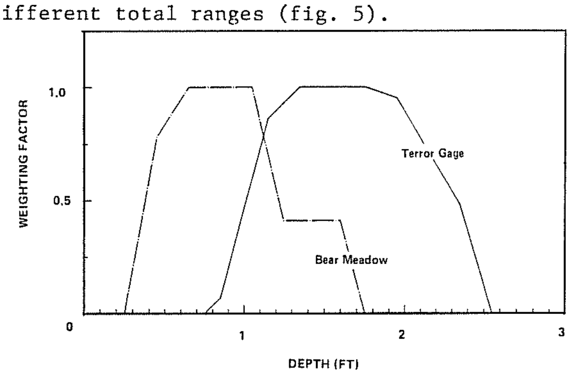


Figure 5.--Utilization function of depth in which pink salmon were observed from two sites yielded very different curves.

We speculated that fish distribution in one or both of these sites could have been influenced by attributes other than depth. Scatter plots of the velocities and substrates associated with depth values allowed us to determine if other attributes were affecting spawner distribution with respect to depth. Figure 6 presents a scatter plot of depth, velocity, and substrate values present at each of two sites. Substrate was originally recorded as a particular value according to mean particle size, but for this plot these values were later combined into two groups (acceptable and unacceptable). Amount of habitat present for each is not discernible from the plot.

This figure illustrates that at Bear Meadow, substrate was indeed influencing the availability of deeper water. Most depths greater than 1.7 ft were associated with unsuitable substrate, which precluded their use by spawners. The total range of depth available to fish was limited between 0.3 ft and 1.7 ft, even though depths in the study area ranged from 0.0 to 2.5 ft.

At Terror Gage fish were not observed in water depths less than 0.8 ft. In this case, the scatter plot demonstrated that shallow areas were available to spawners, as suitable velocities and substrates were associated with water depths less than 0.8 ft (fig. 6). Even though shallower water was available to pink salmon spawners, they did not use it. This lack of utilization indicates that spawning pink salmon prefer water depths of 0.8 ft and greater.

In addition to the range of values available to the fish, the occurrence or area associated with a particular habitat attribute value must be evaluated to identify the suitability of physical habitat attributes. If a preferred value of an attribute were available in limited quantities, few fish would be observed in association with that value, even if it were totally occupied. A frequency of utilization comparison between the preferred value and a lesser utilized but more plentiful value would mistakenly rate the preferred value low. Conversely, the partially occupied but exceedingly prevalent value would probably have a high frequency of utilization, causing the suitability of that value to be falsely elevated. Thus, in order to determine whether fish actually prefer certain values of a given habitat attribute or merely utilize values that are available, the prevalence of those areas associated with each value must be determined.

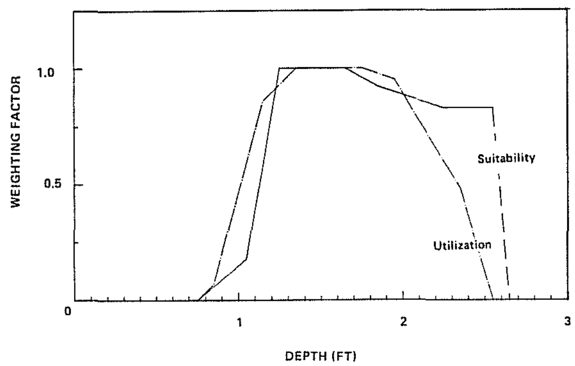
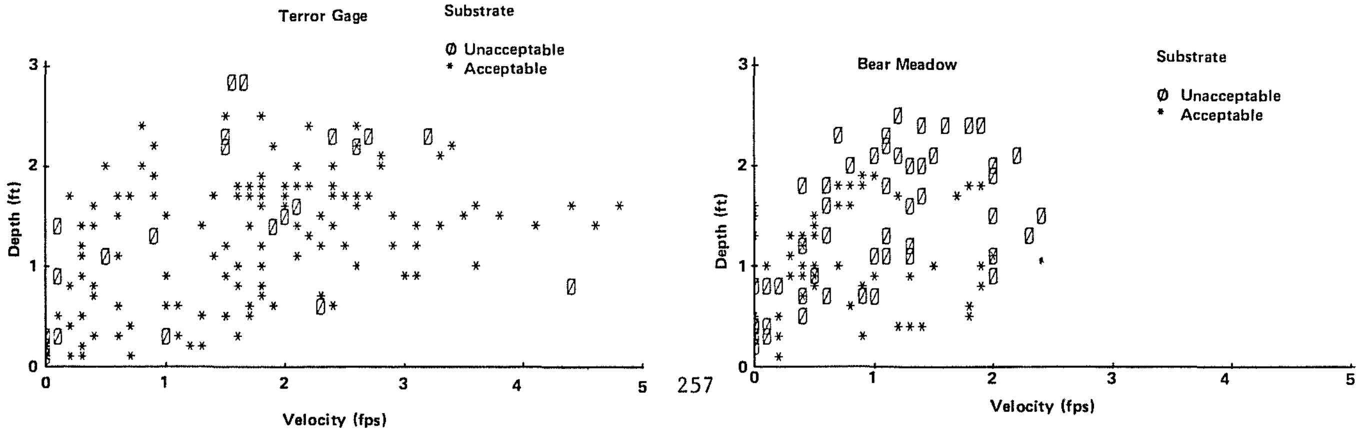


Figure 7.--Utilization and suitability functions were developed from data measured at the Terror Gage site, resulting in markedly different weighting factors in deeper water.

At Terror Gage we noted a high ratio between utilization and availability of 2.5-ft depths. Few fish were observed at this value as suitable spawning habitat at this depth was extremely limited in the study area. Thus, a higher proportion of spawners used this value than its availability would warrant under random selection.

Figure 7 compares the utilization function and suitability function developed from the same data set. The significance of availability is apparent in the discrepancy between the weighting factors assigned to deeper water. Water 2.5 ft deep is assigned a much lower value on the utilization function than on the suitability function. Even though this depth is heavily utilized, fewer fish were observed there due to its limited availability in this site. The suitability function corrects for availability. The dashed line on the descending limb of the suitability function represents the fact that the availability is limiting utilization. Since no depths greater than 2.6 ft were available, the

Figure 6.--Scatter plots of depth, velocity, and substrate values present at two sites illustrate the differences in habitat available. Note that deeper water is associated with unacceptable substrates in Bear Meadow.



suitability of these depths cannot be determined from this data set.

SUMMARY

Most habitat criteria have been developed from frequency analyses of habitat attributes measured at fish capture or observation locations (Bovee and Cochnauer 1977, Waters 1976, Smith 1973, and Graybill et al. 1979). However, habitat utilization depends on both fish preference and habitat availability. Definition of suitability criteria solely on the basis of independent analyses of attributes may lead to erroneous conclusions if habitat availability is ignored.

We developed habitat suitability functions from field measurements using a three-step process. First, we developed habitat utilization functions from a frequency analysis of point measurements associated with fish locations. Then, we used hydraulic simulation models to generate depth and velocity values for the total area. Some of this area was unusable to these fish and was eliminated, yielding available habitat in the local environment. We developed suitability by comparing utilized to available habitat. To a degree, this process addresses the influence availability has on utilization and provides a more accurate estimation of suitability than do other processes. However, the range of the available habitat defines the range of the suitability function (unless the entire tolerance range of the species/life stage is available). Therefore, no suitability can be assigned to values beyond the range of the available habitat.

ACKNOWLEDGMENTS

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ORGANIC DEBRIS IN SALMONID HABITAT IN SOUTHEAST ALASKA: MEASUREMENT AND EFFECTS[1]

Mason D. Bryant[2]

Abstract.--Woody debris is an important part of the stream habitat used by juvenile salmonids. As part of an examination of the effects of logging debris and its removal, this study examined some methods for measuring the amount and effects. Several indices of channel morphology were developed from stream cross-section measurements. Some differences were detected. Differences in debris loading following removal were observed, but the patchy distribution of debris and changes in stream channel boundaries masked some differences. Stream maps revealed year-to-year bank changes and changes in debris orientation following debris removal. Coho populations appeared to respond to debris removal with fewer numbers in cleared stream sections.

INTRODUCTION

Woody debris is a natural additive to forest streams. As such, it plays an important role in the structure and function of stream ecosystems. It influences channel shape, provides a colonization habitat and food source for micro- and macro-invertebrates, and provides cover for salmonids. Timber harvest frequently increases the rate and amount of organic debris added to streams. Although the material is natural, the amount of the material in the stream is not. At this point, management of debris becomes a problem; and methods to measure, analyze, and treat organic debris are necessary.

This paper presents some of the techniques that have been used to measure organic debris and its effect on channel morphology and on fish populations. I will discuss the methods used in a specific study of logging debris and its removal in two small salmonid nursery streams. The techniques provide a method to measure the effect of organic debris and its removal on salmonid nursery streams. The results illustrate the effectiveness of the methods and some of the problems in application. The emphasis is on the methods rather than the specific results.

The studies were done on two small streams in the Staney Creek drainage on Prince of Wales Island. The two study streams were small, first and second order, low gradient (less than 5%) streams flowing through areas logged in the late 1960's. Both streams had populations of coho salmon (Oncorhynchus kisutch (Walbaum)) and Dolly Varden (Salvelinus malma (Walbaum)). Lower numbers of cutthroat trout (Salmo clarki Richardson), rainbow trout (Salmo gairdneri Richardson), and coastrange sculpin (Cottus aleuticus Gilbert) were also present. Both streams had heavy concentrations of logging debris.

A number of studies discuss the effect, function, and physical aspects of wood debris in streams, for example, Swanson et al. (1976), Keller and Swanson (1979), Keller and Talley (1979), and Bilby and Likens (1980). Marzolf (1978) discusses the effects of removing large debris in streams. The importance of fine and coarse organic debris to the stream biota is reviewed by Cummins et al. (1973), Triska and Sedell (1975), and Anderson et al. (1978). Various studies, primarily of natural organic material, show that large debris is extensively used by juvenile salmonids as cover (for example Hartman 1965, Mundie 1969, Hall and Baker 1975).

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Bustard and Narver (1975) provided direct evidence of use of debris by juvenile coho during winter. Elliott (1976), Lestelle (1978), and Baker (1979) studied effects of various types of debris removal on salmonid populations.

Throughout these studies, a number of different methods were used to measure physical habitat and fish populations. In many cases only visual estimates of debris loading, such as estimated percent of stream covered, were made; elsewhere, detailed measurements of debris volume by scaling and counting were made. Methods to determine effects of debris on stream channel morphology include cross-section profiles, detailed sketch maps, and photography. Estimates of fish populations range from none at all to intensive population estimates over several seasons.

The studies conducted on Prince of Wales Island used relatively intensive survey techniques which may be too time consuming for long stream reaches, but the methods can be used on selected shorter sections of a stream. Sections can be selected either purposely or randomly depending upon the objectives of the study and the characteristics of the stream. In either case, the methods can be used by field personnel to monitor the effects of a treatment on a stream.

METHODS

Both study sections in Tye and Toad Creeks were bounded either by a road and culvert or by the edge of a cutting unit and were isolated by two-way fish traps. The section on Tye Creek was 170 m long; the section on Toad Creek was 320 m long. The forest around the streams was cut in the late 1960's using free falling and high-lead yarding methods. No precautions were taken to protect the streams. Debris was removed in 1979 using the guidelines given in appendix I.

The streams were mapped in 1977 and in 1978 with a fiber tape, stadia rod, and compass. Both streams were remapped in 1981 after treatment in 1979. The tape was stretched along the stream, and the direction and length were drawn on graph paper. Stream bank, water edge, rocks, and logs were recorded by perpendicular distance from the tape measured along the stadia rod. The scale of the map was determined by the size of the squares on the graph paper. For this study, one square on the graph paper with 4 squares to the inch represented one foot. Distances of measurements with the stadia along the tape were determined by the complexity of the stream. Where greater detail was required, shorter distances were used.

Cross-sectional profiles were made at 10-m intervals at marked locations along the stream. Distance from a level tape stretched across the stream was measured to the stream bottom at 30-cm intervals along the tape from bank to bank. Where water was present, depths were recorded. The profiles were drawn from the measurements to give a graphic representation of the stream.

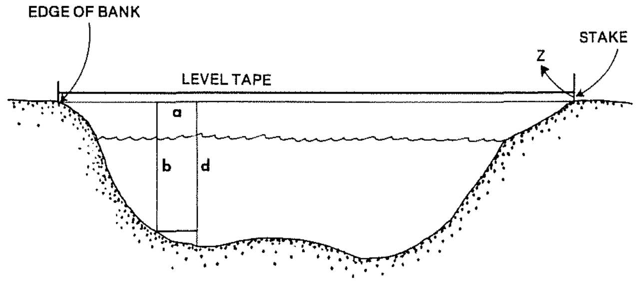


Figure 1.--Stream cross-section profile showing measurements.

Cross-sectional area (A) was calculated from the following equation:

$$A = \Sigma\ 1/2\ (ad+ab) \qquad \text{(see fig. 1)}$$

Cross-section perimeter (W) was calculated by:

$$W = \Sigma \sqrt{a^2+(d-b)^2} \qquad \text{(see fig. 1)}$$

"Average depth" (A/L) at each cross section was calculated by dividing area (A) by the length of the transect (L). Similarly "average perimeter" (P/L) was calculated by dividing cross-section perimeter by the length of the transect. Measurements were made from bank to bank based on summer flow.

Debris volume measurements were made according to the methods described by Froehlich et al. (1972) and Lammel (1972). The method divides organic debris into fine debris less than 10-cm diameter and large debris into material greater than 10-cm diameter. Fine debris is further divided into three classes; less than 1 cm, 1-3 cm, and 3-10 cm. Volume of fine debris per square meter of stream surface (V) was estimated by:

$$V = \frac{\pi^2 \cdot \Sigma(n-d)^2}{8L}$$

Where: n = number of pieces intersecting the transect line,
d = mean diameter, and
L = length of the transect

(Van Wagner 1968). Average diameters for each size group were 0.423, 1.792, and 5.049 cm (Froehlich et al. 1972).

Pieces greater than 10 cm in diameter were individually scaled by measuring top diameter (d_2) and bottom diameter (d_1) and length of each piece in the stream (Froehlich et al. 1972). If part of a log was in the stream, only the part in the stream was measured. Mass (Kg) was estimated by multiplying volume (V) calculated by the following equation:

$$V = \frac{\pi(d_1^2 + d_2^2)L}{8}$$

by 0.5, the estimated specific gravity of softwood.

Salmonid population estimates were made periodically from June through September using between 12 and 20 sections in each creek which were saturated with minnow traps baited with salmon eggs. A Peterson mark-recapture estimate was made during each sampling period. Because the streams were blocked by weirs and because sampling periods were less than 10 days, the population was considered to be closed with no immigration or emigration.

RESULTS AND DISCUSSION

Debris Loading

The quantity of fine debris (less than 10-cm diameter) and coarse debris (greater than 10-cm diameter) was estimated in 1977 and in 1981 after debris removal in 1979. Fine debris, estimated from piece counts, shows considerable change in the intervening period. Changes were also observed in coarse debris loading for both streams.

Table 1.--Fine debris (less than 10-cm diameter) for Tye Creek and Toad Creek, 1977 and 1981 (kg/m^2).

	1977	1981	% Reduction
Tye Creek:			
Untreated	41.5	12.85	69
Treated	49.2	1.83	96
Toad Creek:			
Untreated	14.6	2.76	81
Treated	14.3	6.22 (2.29)*	84*

*After removal of a single high transect.

Fine debris estimates in 1981 were substantially lower than those in 1977 for both streams. The estimate for the cleaned section of Tye Creek in 1981 was about 14 percent of that in the untreated section (table 1). The fine debris density in Toad Creek was lower in 1981 than in 1977. A single transect in the treated section of Toad Creek increased the total loading estimate to 6.22 kg/m^2 (table 1). Removal of this transect in the estimate brings the average density for the treated section of Toad Creek to 2.29 kg/m^2, slightly lower than the estimate for the treated section. A similar point occurs in Tye Creek, but it occurs in the untreated section where greater debris loading was expected and the effect is less dramatic.

Throughout the study a wide range in quantities of fine debris was observed. Tye Creek values for individual transects ranged from 0.061 to 80.5 kg/m^2; Toad Creek values ranged from 0.512 to 41.63 kg/m^2. This reflects the patchy distribution of fine debris in these streams. Throughout the streams, fine debris frequently occurred as clumps held by larger pieces forming dams or breaks in velocity. In between, riffle and pool areas were relatively clear of material, particularly in the treated sections.

The loading estimates for coarse debris in kilograms per square meter do not follow an expected pattern of decrease with time and lower densities in the treated section. In fact, Tye Creek shows an increase in density from 1977 to 1981, but a lower density in the treated section (table 2). Toad Creek shows a decrease in density from 1977 to 1981 in the treated section, which could be expected (table 2). Differences may arise from the methods used to compute channel area and in observer differences between the two sample periods. At Tye Creek, however, shifts

Table 2.--Coarse debris (greater than 10-cm diameter) for Tye Creek and Toad Creek, 1977 and 1981 (kg/m^2).

	1977		1981	
	Potential	Instream	Potential	Instream
Tye Creek:				
Untreated area (m^2)--		595.		243.1
Debris loading (kg/m^2)	1.4	17.0	7.4	31.7
Treated area (m^2)--		512.		272.4
Debris loading (kg/m^2)	4.3	12.1	2.7	21.6
Toad Creek:				
Untreated area (m^2)--		1/191		3/320
Debris loading (kg/m^2)	12.2	40.3	8.5	40.4
Treated area (m^2)--		2/141		4/373
Debris loading (kg/m^2)	19.1	82.6	5/	46.3

1/Area from 200 - 300 meters along the stream.
2/Area from 50 - 150 meters along the stream.
3/Area from 170 - 310 meters along the stream.
4/Area from 0 - 170 meters along the stream.
5/Not estimated.

in the stream channel may account for part of the increase. For example, a large log at 60 m was in the off-channel area in 1977. By 1981, the stream had cut around the log and it was included in the instream estimate (fig. 2).

Loading estimates were recomputed on the basis of total volume (square meters) for each stream to remove the area differences (table 3). The 1981 estimates show lower volumes in the treated sections; however, the 1981 estimates for Toad Creek are greater than those for 1977; but in 1981, a longer section of the stream was surveyed. Because of these difficulties, year to year comparisons are tenuous, but within year comparisons are reasonable.

The individual estimates of coarse debris for each 10-m section varied considerably. For example, in the untreated section of Toad Creek between 270-280 m, the estimate was 26.1 m^3; and for the section between 220-230 m, the estimate was 0.67 m^3. For Tye Creek, volume estimates ranged between 0.15 and 5.63 m^3.

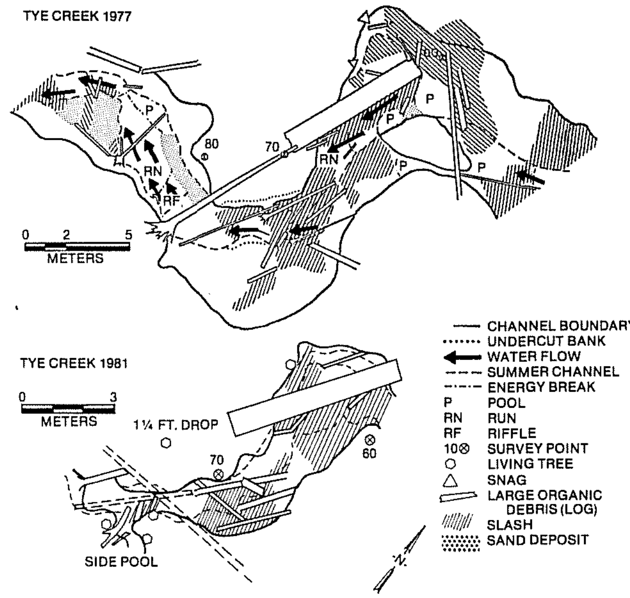


Figure 2.--A section of Tye Creek in 1977 before and in 1981 after debris removal.

Table 3.--Large debris (greater than 10-cm diameter) loading by volume (m^3) for Tye Creek and Toad Creek, 1977 and 1981.

	1977				1981			
	Stream length (L)	Pieces	Debris volume		Stream length (L)	Pieces	Debris volume	
	m	n	m^3	m^3/L	m	n	m^3	m^3/L
Tye Creek:								
Treated	100	48	20.91	.209	100	48	12.28	.123
Untreated	70	85	19.97	.285	70	72	12.44	.178
Toad Creek:								
Treated	50	29	13.68	.274	40	35	13.58	.339
Untreated	70	29	14.48	.207	70	42	82.4	1.177

The methods and the data provide one means of evaluating the intensity of debris loading in streams. The definition of the stream channel boundary must be explicit in both the method to evaluate fine debris and the method to evaluate coarse debris. The calculation of area in the density estimate is incorporated in the method for determining fine debris, but the limits of the transect are not--these are determined by the observer's perception of where the bank ends. The same is true of the coarse debris estimates except that area is derived independently. Again, channel boundaries must be defined to determine which pieces should be included and how much of a piece should be scaled.

The point estimates do not reflect the orientation of the coarse debris, nor do they show the effect on stream channel morphology. In the case of logs, the position of the material will have a greater effect on the stream than size or amount. To determine distribution of the material, the point estimates must be dissected and the point estimates along the stream must be considered. Orientation and distribution of organic material are more explicitly studied from stream maps constructed to show specific instream features.

Stream channel morphology

Because the method of debris removal prescribed that stable large material be left in place, changes in the log-sized material in the two treated sections were relatively small. Accumulations of large material were distributed throughout both streams in both years. In many cases, the larger material remained in place with little movement, for example the large log at 60 m on Tye Creek (fig. 2) and the log at 130 m on Pond Creek (fig. 3). Movement of smaller pieces has occurred, however; and in many cases, particularly in Tye Creek, pieces have been moved so that they are now parallel to the streamflow. In other cases, accumulations forming small dams have broken down following debris removal. One example of this is found in Toad Creek at 140 m (fig. 3) where the accumulation has opened into a chute. For the most part, the active channel in the treated sections is clear of most smaller debris, limbs and branches, whereas in 1977, extensive areas were covered.

In several instances large material remained essentially unchanged from 1977 to 1981. For example, in Toad Creek the large logs at 210 m and to some extent those at 200 m are in about the same place. The evidence on the maps is reinforced by on-site inspection. The channel has incorporated the larger pieces, whereas the smaller material has been moved out of the "summer" channel shown in the maps.

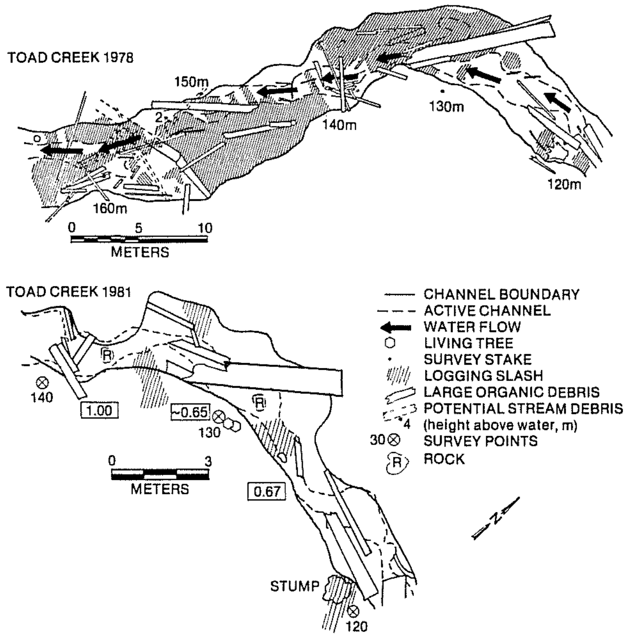


Figure 3.--Stream map sections of Toad Creek before debris removal (1978) and after (1981).

In several instances substantial changes in the stream channel are shown on the maps, the most apparent being in the untreated section above 70 m in Tye Creek. In general, the Tye Creek channel was less well defined than the Toad Creek channel which flows through a V-notch from about 40 m to 200 m.

Stream channel cross-sections were taken in 1977 to document possible changes in channel profile through debris removal. These were translated into numerical measures to reflect the cross-section perimeter and cross-section area.

Table 4 summarizes cross-section perimeters and areas, and average depths and perimeters for 1977 and for 2 years following treatment. Cross-section perimeter and cross-section area show no trends. The average depth for both streams is consistently less in the treated section than in the untreated section for all years. Average perimeter (the ratio of perimeter to cross-section width) decreases following removal in both streams.

This likely reflects removal of irregularities in the channel caused by either individual pieces of debris or of accumulations of debris which were removed during treatment.

Table 4.--Means for cross-section perimeters (P), cross-section area (A), "average depths" (A/L), and "average perimeter" (P/L).

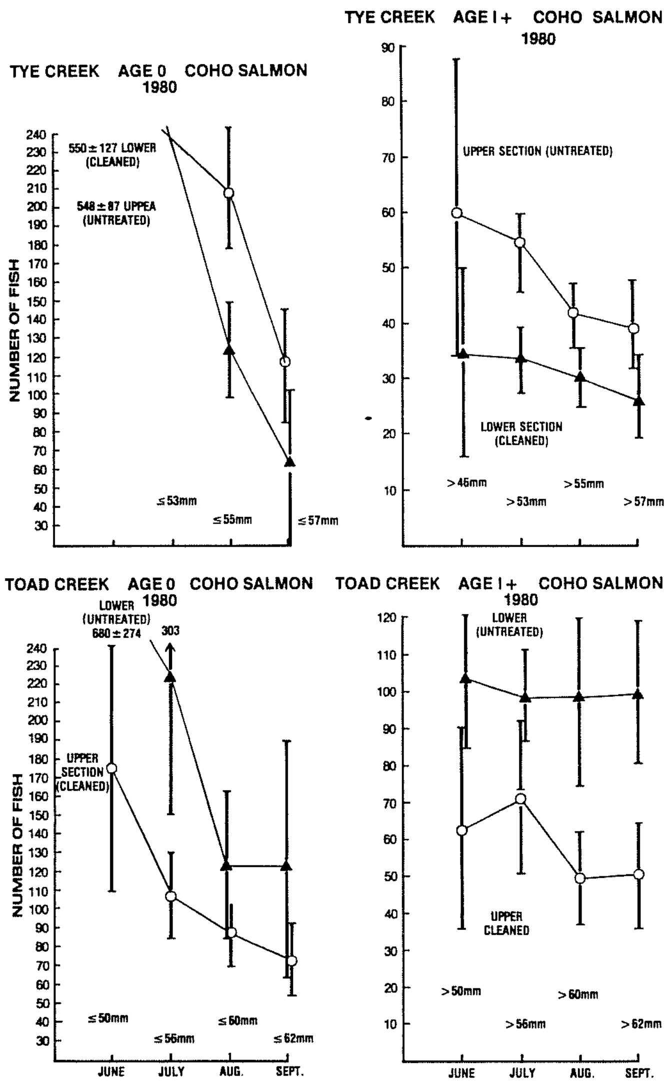
	Section	P	A	A/L	P/L
	m	m	m^2	m	m
Tye Creek:					
	1977				
Untreated	(0-70)	2.43	.286	.167	1.19
Treated	(80-170)	2.79	.266	.110	1.30
	1979				
Untreated	(0-70)	2.89	.51	.181	1.10
Treated	(80-170)	2.79	.41	.133	1.08
	1981				
Untreated	(0-70)	2.64	.34	.153	1.15
Treated	(80-170)	2.90	.35	.131	1.06
Toad Creek:					
	1977				
Treated	(0-170)	3.27	.29	.178	2.33
Untreated	(180-320)	2.77	.30	.208	1.43
	1980				
Treated	(20-160)	2.33	.25	.121	1.05
Untreated	(233-300)	1.72	.28	.163	1.05
	1981				
Treated	(30-160)	1.89	.25	.129	1.04
Untreated	(180-320)	2.42	.38	.162	1.07

The lack of difference shown in the average depth measures is not surprising because cross-section measurements were not stratified with respect to channel type (i.e. pool or riffle). Further analysis from more intensive transect data may show a reduction in average depth in the treated areas, although the present data do not reflect this result. Both area and perimeter are affected by the size of the system and location of the measurement along the system; "average depth" and "average perimeter" are not as likely to be affected within a stream section because the width of the transect is included.

Fish Populations

Coho and Dolly Varden densities (numbers per square meter) in 1977 and 1978 were about the same for upper and lower sections of both streams. Differences among sampling stations were attributed to specific habitat features. In Tye Creek, densities of coho and smaller Dolly Varden were positively correlated to density of fine and coarse debris. A similar trend did not appear in Toad Creek with the exception of 0-age coho. Cardinal (1980) suggested that the extensive streamside shrub vegetation in Toad Creek masked any relationships between fish densities and debris density. Tye Creek was more exposed and did not have the extensive shrub growth along its banks; therefore, debris was more likely to provide cover.

Figure 4 shows the population levels for coho in both streams following debris removal. In all cases, the treated sections supported smaller numbers of coho than the untreated sections. Survival rates for the summer of 1980 for coho and Dolly Varden do not show any marked differences between treated and untreated sections. On the basis of studies by Bustard and Narver (1975), greater differences in mortality rates might be expected during winter than in summer. In both streams, population levels of age 1+ coho in untreated sections are nearly twice those in the treated sections.



(fish≤50,≤56 mm etc. were considered as age 0)

Figure 4.--Monthly population estimates and 75% confidence intervals for age 0 and age 1+ coho salmon for Toad and Tye Creeks.

CONCLUSIONS

1. Instream variation of fine debris accumulations and the patchy distribution of material is likely to mask treatment differences when fine debris is scaled with cross-section transects. An overall index of debris loading of a system can be obtained.

2. Large debris estimates are affected by differences in stream area determinations and determinations of channel boundaries by different observers. Seasonal changes in the stream channel may influence year-to-year comparisons.

3. Numerical indices of debris loading do not reflect the effect of debris on stream channel morphology, but may be described with stream channel maps, showing stream course, debris orientation, and locations and extent of accumulations.

4. Absolute measurements of cross-section areas and cross-section perimeters may be influenced by observer perception of stream bank boundaries. Average depths and average perimeter include more consistent year-to-year comparison of cross-section length and yield.

5. There is an apparent reduction of coho population levels following debris removal.

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APPENDIX I

Criteria for Debris Removal Treatment for Toad and Tye Creeks 1979

(1) All debris less than 60-mm diameter removed.

(2) Larger material, greater than 60-mm diameter removed if it is:
   (a) loose and not firmly embedded,
   (b) completely across the channel blocking flow and is not firmly embedded in the channel or in the bank, and
   (c) part of an extensive debris dam obstructing the channel.

(3) Trailing branches on larger instream material removed.

(4) No material removed in the control sections.

LOCATING CHINOOK SALMON SPAWNING SITES IN THE KENAI RIVER WITH RADIO TELEMETRY

Carl V. Burger[1]

Abstract. From 1979 to 1981, 139 adult chinook salmon (Oncorhynchus tshawytscha) were tagged with low frequency, radio transmitters to locate spawning areas in the Kenai River, southcentral Alaska. Of those, 107 were tracked to destinations in the mainstem river or its tributaries. Chinook salmon tagged during May through late June chose tributaries while fish tagged from late June through early August chose the mainstem Kenai River. Radio telemetry was a useful tool for studying salmon behavior in a glacial environment.

INTRODUCTION

Methods that depend upon direct, visual observation to identify spawning areas of anadromous fish are inadequate for many silt-laden, glacial streams in Alaska. Because there is an urgent need to identify these areas in the Kenai River and its tributaries for land-use planning, investigators at the National Fishery Research Center (U.S. Fish and Wildlife Service) in Anchorage initiated a project to meet this need by tracking radio-tagged chinook salmon (Oncorhynchus tshawytscha) during their migration in the river. This report describes the general methods used in a three-year investigation (1979-1981) to obtain baseline data on the locations of spawning areas in the Kenai River. This paper also presents some conclusions from a preliminary analysis of the results concerning the feasibility of this technology for locating important components of salmon habitat when direct observation is impossible.

MATERIALS AND METHODS

Electrofishing proved to be an unsatisfactory method for sampling adult salmon, therefore, they were captured in the lower 20 km of the Kenai River by drifting a small mesh (13 cm stretch mesh) gill-net (18.0 m by 2.4 m). Fish encountering this net were entangled by their teeth and jaws. Thus netted, a fish was quickly retrieved and transferred to a holding tank on the river shore for anaesthetization.

The anaesthetized fish was held with its ventral side to the surface and with its lower jaw raised, while a glycerin-coated transmitter was slid into the anterior portion of the stomach through plexiglass tubing (method modified from Monan and Liscom 1975). The body of the transmitter was no longer visible since it was now posterior to the esophageal sphincter. The external antenna extended into the mouth where it was attached to the upper jaw with a stainless steel fishhook. Fish then were transferred to near shore water for recovery and hand held until they could forcefully swim away.

We used low frequency (40 MHz) radio telemetry equipment developed by Smith-Root Inc., Vancouver, Washington. Two types of receivers were used in addition to direction sensitive, loop antennas. The encapsulated transmitters used on chinook salmon were cylindrical (9.6 cm long by 1.8 cm diameter) with external antennas (18 cm long). Transmitters were designed to operate for 80 to 90 days on lithium batteries. Different frequencies (40.600-40.740 MHz) and pulse rates were used to distinguish tagged fish.

We attempted to track radio tagged fish from boats or airplanes at least every two days. From boats, it was possible to determine the strongest and weakest (null) signal from the transmitter. We could locate, with two or more of these measurements, the exact position of each fish by triangulation. Based on tests, locations of transmitters made from a boat were accurate to ±3 m. Signal range of a given transmitter was over 0.8 km while tracking from a boat and over 1.6 km from an airplane.

[1]Carl V. Burger is a Project Leader, U.S. Fish and Wildlife Service, National Fishery Research Center, Anchorage, Alaska.

RESULTS AND DISCUSSION

From 1979 to 1981, 139 chinook salmon were captured and radio tagged in the lower 20 km of the Kenai River. Of these, 107 were tracked to destinations in the river or its tributaries, 16 were captured by anglers, 11 returned to the ocean (Cook Inlet), and 5 were unaccountably lost. Fish were presumed to have spawned when they were repeatedly located in the same area of the mainstem or tributary for a minimum of 8 days. About 70 of the tagged salmon met this arbitrary criterion while the remainder were assigned to general reaches of the mainstem or tributary, only.

Other areas investigated were migration rates of tagged salmon (maximum rate recorded was 3.0 km per hour), diel movements, and characteristics of spawning areas (low flow surveys). With triangulations made from boats, depths and velocities were estimated in holding areas used during upstream migrations of tagged fish. Of over 50 measurements made in 1981, the most frequent depths ranged from 1.20 to 2.40 m, while the most frequent velocities near the river bottom ranged from 0.45 to 1.05 m/s.

Preliminary conclusions from the data are:

1. Two runs, early and late, of chinook salmon occur in the Kenai River. The early run occurs from May through June, and the late run occurs from late June through August. Peak spawning times (mid-July for early run chinook; mid-August for late run fish) are bimodal.

2. Early-run fish spawn in tributaries while late run fish spawn in the mainstem from river kilometer 16 to 122.

3. Radio-tagging did not appear to have any impact on fish behavior that would negate the value of the results. There was no uniform response to tagging. Radio-tagged fish in clear water tributaries were observed to be present in association with spawning, untagged fish.

4. Spawning locations in the mainstem tended to occur in low gradient sections of the Kenai River (kilometer 64 to 80, and 16 to 33) - often immediately upstream from vegetated islands where loose, aggrading gravels were found during low flow periods.

In general, I am satisfied that we obtained new, valid information concerning the important areas used by chinook salmon for spawning during the study period, and concerning important behavioral differences in early and late-run fish. Accumulation of these data was made possible by the availability of radio tagging and tracking technology.

ACKNOWLEDGEMENTS

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TECHNIQUES FOR STUDYING THE HABITAT USE OF JUVENILE[1] CHINOOK SALMON IN THE KENAI RIVER, ALASKA

David B. Wangaard[2]

Abstract. SCUBA diving and fish collection techniques (electrofishing, minnow trapping, seining) were used to document habitat use by juvenile chinook salmon (Oncorhynchus tshawytscha) in the Kenai River. The facing water-column velocity which included the highest occurrence of capture or observation of chinook salmon (55-85 mm) was 9 cm/sec. This optimum water velocity was compared with habitat available downstream from a jetty.

INTRODUCTION

Juvenile chinook salmon (Oncorhynchus tshawytscha) were studied in the glacial Kenai River in 1979-81. The primary study objective was to analyze riverbank alterations and their impacts on chinook salmon rearing habitat. The intent of this paper is to review some of the techniques used during this study. Use of habitat in relation to riverbank alterations is described as an example of the information obtained by using the study techniques.

Fishing pressure on adult chinook salmon increased on the Kenai River to an estimated 98,000 man-days in 1979 (Hammarstrom 1980). This represented an approximate 300% increase from 1974, when harvest statistics were first recorded. Most of the successful fishermen used a drift fishing technique that required a boat and outboard motor. The increased recreational fishery resulted in an increase in riverbank development (e.g. construction of boat basins and jetties by private landowners).

Under Section 404 of the Clean Water Act, the U.S. Corps of Engineers (with professional recommendations by federal and state resource agencies) is required to provide permits for dredge-and-fill activities such as boat basin and jetty construction. However, resource agencies lacked sufficient baseline hydraulic and biological information to make sound decisions. The techniques described here were used to obtain some of this information as it related to juvenile chinook.

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MATERIALS AND METHODS

Sampling sites were established at about 3-km intervals in the lower 72 km of the Kenai River and visited once each month from April through October. Additionally, selected sites that included various riverbank alterations were also visited during field surveys.

Sampling techniques used to collect juvenile chinook salmon included the use of electrofishers, traps, and seines. Observations were also made by SCUBA divers. During all sampling, data were recorded on various river characteristics (components of the habitat of juvenile chinook salmon) associated with the location of fish capture or observation. Water velocity, river depth, cover availability, and substrate composition were among the variables measured and correlated with the number and total length of salmon collected or observed. This information was then used in the construction of habitat-use curves (Bovee and Cochnauer 1977), which described the range of chinook salmon occurrence in relation to specific habitat components. River characteristics were also recorded at sampling points where juvenile chinook were not encountered.

Electrofishing with a Coffelt BP3 backpack electrofisher was the primary method of capturing fish in habitat with specific characteristics. The low conductivity (40-80 µmhos/cm) of the Kenai River necessitated the use of voltages greater than 300 V during electrofishing surveys. The electrofisher produced about 1.0 to 1.5 amperes at a 500-V setting. Although few mortalities were noted during electrofishing, an unrecorded percent of live fish developed a discoloration along their caudal peduncle which may have been a result of internal hemorrhaging. Most of these fish swam away normally when they were released, but their survival remained in doubt. Fish captured with baited 3.2-mm-mesh minnow traps and habitat characteristics noted at trap locations were also recorded. Information collected during minnow trapping was included in the construction of habitat-use curves only when there was no detectable water velocity around the traps, and the traps were set more than 30 m from flowing water. These criteria were invoked to control sampling bias. Water flowing through traps dispersed the bait odor and was observed to attract chinook salmon from surrounding areas. Baited traps that attracted fish from large areas were not useful in documenting discrete habitat use. A seine 12-m-long with netting of 3.2-mm-mesh was also used to collect juvenile fish within specific habitat zones.

Water-column velocities were measured with a Marsh-McBirney direct readout flowmeter. Mean water-column velocities were measured according to Instream Flow Guidelines (Bovee and Cochnauer 1977). Facing velocities (those that fish experienced) were measured at point locations that fish occupied for at least 5 minutes. Most facing-velocity measurements were recorded during SCUBA surveys.

SCUBA was used to collect data on fish behavior and habitat use in water that was too deep or flowing too fast to permit effective electrofishing, trapping, or seining. A diver wearing a drysuit moved into the river channel, using a weighted "creeper" (Gale and Thompson 1974). The creeper enabled the diver to maintain a position in the river and move along the river bottom. The diver began observations at the riverbank and then proceeded 90° from the bank to a point in the river where no more juvenile chinook salmon were observed. A standard dive required 30 to 40 minutes underwater.

Underwater communication equipment manufactured by Micro Communications Inc., Costa Mesa, California, was used in 1979. The "wet phones" enabled a diver and surface observer to remain in voice communication during SCUBA surveys.

SCUBA diver surveys were aided by the use of the wet-phone communications system and the weighted creeper. The use of the wet phones allowed more data to be recorded and required less diver exertion during dives into deeper water. This system also added a significant element of safety to the river-diving program. Additionally, the weighted creeper was a relatively safe anchoring device as it was used during river channel surveys. The diver was not mechanically attached to the creeper, and could release from it immediately if surfacing was required.

Observations during SCUBA surveys and fish collection with traps, seines, and electrofishers contributed data to an analysis of Kenai River bank alterations. Those data were then compared with the habitat-use curves for juvenile chinook salmon. Habitat zones created by riverbank alterations were thus evaluated for juvenile chinook salmon use. One description of a riverbank alteration is provided below as an example of the results .

RESULTS AND DISCUSSION

The weighted creeper enabled divers to move upstream against most water velocities and over most of the substrates in the Kenai River. However, limitations in mobility were encountered where substrate diameters were larger than 200 mm or smaller than 30 mm. It was difficult to pivot the device over large rubble, and the gravels under 30 mm in diameter were too small to anchor the creeper. While the diver and creeper were over the smaller gravels, they were displaced downstream in facing velocities greater than 60 cm/sec. When the creeper could be well anchored and pivoted, divers were able to move upriver in facing velocities up to 91 cm/sec. Substantial exertion was required for the diver to achieve upstream progress in water velocities greater than 91 cm/sec. A fixed position was maintained in facing velocities up to 122 cm/sec. Downstream approaches were not often used because they were observed to alter fish behavior (chinook salmon were attracted to the diver); behavior did not seem to be altered when the diver moved upstream toward fish and avoided making rapid movements.

Visibility in the Kenai River ranged from 5 cm to about 1.2 m. When visibility was less than 20 cm, underwater observations were discontinued because they were unproductive. The best underwater visibilities occurred during late summer and early autumn.

The wet-phone system was successfully used in 1979. When the wet-phone antennas were maintained in a line of sight orientation, a diver could relay observations directly to a technician at the surface up to 46 m away. However, to use the wet phone, the diver was required to wear a full-face mask. Although the underwater communication capability was useful, the full-face mask was not always the most effective gear for shallow-depth SCUBA surveys of short duration. Air supplies and time were conserved during multiple short-duration surveys, when the diver used a standard small-volume mask and regulator.

Habitat-use curves were developed with mean water-column and facing water-column velocity data and substrate data for Kenai River juvenile chinook salmon. Observations were also made on the water depths and cover types at the points of fish capture. Data collected for facing water velocities of chinook salmon are presented here.

Juvenile chinook salmon longer than 50 mm remained along the river margins throughout the summer. As the Kenai River discharge increased in July and August, the river channel inundated vegetated riverbanks. Along those banks, large numbers of juveniles were observed in current eddies. The largest number of chinook salmon were along the riverbanks where the facing water-column

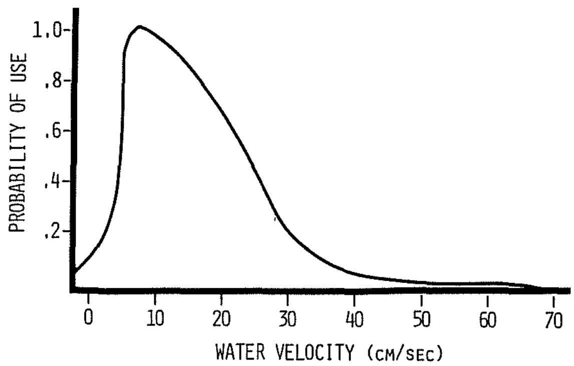

Figure 1. Facing water velocity and probability of use for juvenile chinook salmon (55-85 mm) as determined by SCUBA observations in the Kenai River, 1981. The probability of 1.0 is assigned to the water velocities that included the largest percent of chinook occurrence.

velocity was 9 cm/sec (fig. 1). In addition, 75% of all chinook salmon were in areas where facing water velocities did not exceed 18 cm/sec. Fish in water velocities of 3 to 15 cm/sec were generally in schools. Numbers of fish were highest at the upstream end of eddies. Fish in water velocities of 15 to 60 cm/sec did not exhibit schooling behavior. As water velocities increased beyond 15 cm/sec, chinook salmon moved closer to the river bottom. None were observed in facing water-column velocities greater than 67 cm/sec.

Jetties that extend out into the river channel are present at various locations in the study area. They are generally constructed to prevent erosion of the downstream riverbank and provide pools in which people could fish for adult salmon or moor boats. Jetties can be permeable to river flows when made of large unconsolidated boulders, or nonpermeable when filled with soil or cement.

A typical nonpermeable jetty is perpendicular to the riverbank and causes a pool to be formed above and below it. These pools eliminate flows that otherwise pass numerous small bank indentations. The lengths of these pools along the riverbank are variable and depend on the length of the jetty, the angle of the jetty into the river, and the relation of the jetty to the river's thalweg and meander. Some pools extend 6.5 times the length of the jetty downstream, and up to 4 times its length upstream.

One nonpermeable jetty was observed to form a pool with no measurable water velocity at its downstream base (fig. 2). The highest concentrations of chinook salmon were observed immediately below the jetty in the water-velocities previously shown to provide usable habitat (table 1). On the downstream side of the jetty, the numbers of fish decreased rapidly as the diver moved away from the upstream mixing zones and toward the zero-velocity zone. No fish were observed in the zero-velocity zone at the heel of this particular jetty and for some 6 m along the downstream bank. Fish at points 2 and 3 (fig. 2) were observed to be feeding actively on drift material within the water column.

Juvenile chinook salmon occupied a narrow range of river habitat that is typically described by pools along the margins of riffles or current

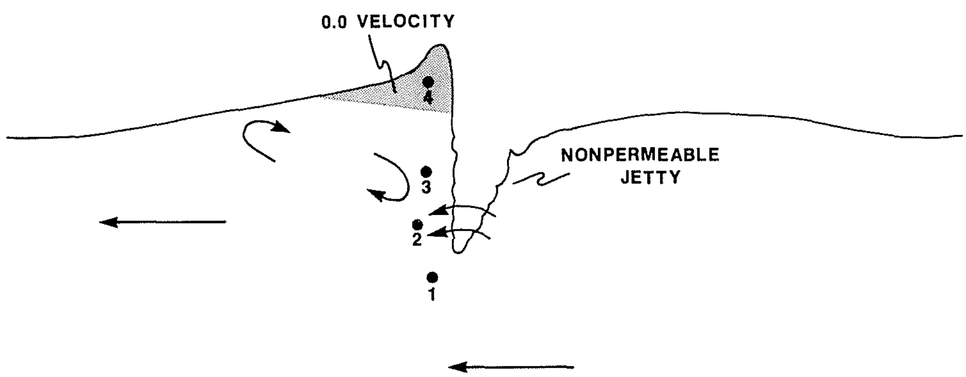

Figure 2. Top view of a nonpermeable jetty with some overflow in September 1981, along the Kenai River; arrows represent flow patterns and dots (1-4) represent points of data collection.

Table 1. Data collected during a SCUBA survey downstream of a nonpermeable jetty in the Kenai River, 1981.

Sampling Point	No. Chinook Salmon Seen (55-85 mm)	Facing Water Velocity (cm/sec)	Distance From Bottom (cm)	Water Depth (m)	Mean Water-Column Velocity (cm/sec)
1	0	45.7	9.1	2.0	51.8
2	8-10	24.4	6.1	1.0	73.2
3	24-30	9.1	9.1	1.9	21.3
4	0	0.0	-	0.6-1.8	0.0

[1] See figure 2 for location.

eddies (Stein et al. 1972; Kissner 1976; Platts and Partridge 1978). Other reports have also noted the absence of chinook salmon from pool and bog areas without riffles (Waite 1979) and river sections where water velocities exceeded 60 cm/sec (Everest and Chapman 1972).

The large numbers of juvenile chinook salmon in habitat with low-water velocities indicate the importance of irregular bank profiles along the Kenai River. Bank irregularities form small pools and current eddies. Optimum water-velocity zones are created downstream from these bank irregularities.

Nonpermeable jetties directly alter the available habitat of juvenile chinook salmon. The numerous small pools found along irregular banks are replaced by larger pools upstream and downstream of the structure. While evaluating pool habitat used by salmon and trout, Glova (1978) noted heavy use of the upstream part of pools and lighter use of the downstream area. This observation was similar to ours and those of other researchers (Miller 1970; Everest and Chapman 1972). Thus, biomass of juvenile chinook salmon may decrease along banks where river structures eliminate numerous small pools and create fewer and larger pools.

SCUBA diving provides a practical methodology for direct observation of the use of the habitat by juvenile chinook salmon in the Kenai River. Combining SCUBA techniques with the data collection guidelines described by Bovee and Cochnauer (1977) resulted in the development of chinook salmon habitat-use curves. This analysis technique facilitates the evaluation of riverbank alterations and their impacts on the rearing habitat of chinook salmon.

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SESSION 4B

Moderator: Robert House
Bureau of Land Management
Salem, Oregon

The Following Not Included in Proceedings:

James R. Johnson and James W. Ericson, Rio Blanco Oil Shale Company.
Baseline Evaluation, Assessment and Monitoring of the Aquatic Ecosystem near Federal Prototype Oil Shale Lease Tract C-a.

Rimmon C. Fay, Marine Review Committee, Inc.
Aquatic Habitat Inventory Information at a Coastally Sited Nuclear Power Plant.

METHODS IN ANALYZING FISH HABITAT UTILIZATION FROM TELEMETRY DATA

Jimmy D. Winter[1] and Marvin Jon Ross[2]

Abstract.--Telemetric methods to follow fish movements can generate large amounts of information on habitat utilization by individual fish. Simple methods are discussed to quantitatively analyze fish habitat utilization and habitat selection from telemetry data. A distinction is made between habitat use and habitat selection which is a comparison of use to habitat availability. We have found that modified convex polygons are useful to define the maximum home ranges of fish and to circumscribe the available habitat. The utilized home range can be analyzed by grid-square methods which give intensity of habitat use per grid-square or habitat type.

INTRODUCTION

Identifying the unique set of habitat features required by a given fish population is essential to the management and protection of this species. Implicit in the study of animal habitat use and the resulting management efforts is the concept that most animals survive, grow and reproduce at higher rates in their preferred habitats. Complex and dynamic aquatic ecosystems contain a large variety of factors which affect resident fish populations. Prominent among the variables often monitored in aquatic habitats are temperature, dissolved oxygen, current, light intensity, bottom type and vegetation. Perturbations (Christie 1972) or manipulations (Johnson and Stein 1979, Everhart and Youngs 1981) of these variables usually alter fish population dynamics or species composition. If the basic habitat requirements of a species are known, the effects of habitat alterations can be more effectively predicted.

Most current knowledge of fish habitat utilization is inferred from angling and netting data. As valuable as netting and angling studies have been, they have several potential shortcomings in assessing habitat utilization. Angling and fishery assessment gear are not equally effective in all habitat types and they are sometimes fished where it is easy to use the gear and not necessarily where fish are most abundant. Habitat studies can be biased because fishing gear are generally size selective. Since most fishing gear are more effective during certain times of the day, a biased view of the temporal distribution of fish may be obtained. Angling may give an inaccurate view of habitat utilization because a species may not exhibit a feeding or strike response while in certain habitats. Finally capturing a species in a particular area at a point in time does not exclude their presence elsewhere. In addition to harvest data, mark-recapture studies have been used to determine habitat utilization but they often have an insufficient number of locations to make good conclusions.

Telemetry studies can augment and answer many of the assumptions associated with conventional fishery methods used in habitat studies. Conventional netting studies usually generate a relatively small amount of data on a large sample of individuals. In contrast, telemetry studies can generate a large amount of data on relatively few individuals and can have a minimal influence on the fishes' behavior.

Many fish telemetry studies to date have been largely descriptive. Investigators have produced large numbers of maps of individuals' movements and a narrative of what they believed the behavior illustrated. This reflects problems in processing large amounts of telemetry data and in quantitatively handling the data so meaningful statistical comparisons can be made. Computers and spatial models are useful in handling these problems. The purpose of our paper is to present some simple methods to analyze fish habitat utilization from telemetry data. We will concentrate on methods for structural aspects of habitat such as vegetation, bottom type or bathymetry.

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METHODS AND RESULTS

Fish locations are usually determined by taking bearings (via compass, sextant, Loran C) from the fish to landmarks or from fixed-shore stations and landmarks (via compass) to the transmitter signal. These bearings are then plotted on maps and a scattergram is produced of each fish's movements.

The first step in quantitatively dealing with telemetry data often is to construct a plot board which is a Cartesian coordinate system drawn on a map that has an accurate representation of the shoreline. From a plot board, each fish location is given X and Y coordinate values. These coordinates can be entered into a computer along with information on the fish's identification number, date, time, weather conditions, water characteristics, habitat type and any environmental or physiological parameters monitored by the transmitter on the fish.

The next step is to compile habitat information. The habitat type occupied by an individual is often determined by either recording the habitat characteristics each time a fish is located or from transparent maps of habitat types overlaid on maps of radio locations. Grid-squares on a map can also be given habitat codes and a computer can print out the number of fixes in each habitat type (Nicholls and Warner 1972). For studies involving thousands of fixes, Gilmer et al. (1973) used a digitizer to convert habitat maps into digital form on magnetic computer tape. When radio fixes were inputed into the computer, a listing of the number and percentage of fixes in each habitat type was produced.

Another step in determining fish habitat utilization is to delimit the home range or the approximate area that the fish uses. This is important in establishing what habitats are available to the fish and in determining what is being used by the fish. There are numerous methods of analyzing home ranges each with certain advantages and drawbacks (Sanderson 1966, van Winkle 1975, Voigt and Tinline 1980, Macdonald et al. 1980). Most early analyses were concerned with the size and shape of home ranges (Voigt and Tinline 1980). However, the size and shape of home ranges may have little or no significance in themselves (Sanderson 1966). Methods of delimiting home ranges fall into three general categories: bivariate circular or elliptical normal models; convex polygons; and grid-square methods.

In bivariate normal models, the home range is calculated as the area of a circle or ellipse with the length of the axes a specified percentage of the variance of the X and Y coordinates (Jennrich and Turner 1969, Sokal and Rohlf 1969) (Fig. 1). Confidence ellipses or circles are computed from probability distributions and enclose a chosen proportion 1-α (e.g. 95%) of the animal's activity or fixes. Bivariate normal models are attractive because with increasing numbers of locations the estimate of home range size changes little and the statistical error decreases. This allows for good statistical comparisons of individual home ranges. Bivariate normal models are also not greatly affected by peripheral locations because the boundary is calculated from all locations, not a few peripheral fixes. On the other hand, few animal movements have been shown to be bivariate normally distributed in space (Macdonald et al. 1980). In addition, these models include areas of water not frequented by the fish or areas of land when the fish is near shore or is occupying a lake with an irregular shoreline. Most of these models are not well suited for animals in heterogeneous habitats (van Winkle 1975, Macdonald 1980) and thus, appear to be of limited value for habitat studies in lakes.

One of the simplest and most widely used methods (Fig. 1 and 2) of delimiting home ranges is the convex polygon method (Mohr 1947, Odum and Kuenzler 1955). The extreme outermost fish locations are connected so that the smallest possible convex polygon encloses the other locations. Only one polygon fits this description for a given set of data. When a polygon side cuts across land on a map of a lake with an irregular shoreline, the shoreline can be used as a boundary (Winter 1977). A similar modification can be made with bivariate normal models but this reduces the advantages of mathematically constructing home range boundaries. The convex polygon method produces a minimum home range area for mark-recapture studies because the number of recaptures is usually small. Since telemetry yields a larger number of locations, convex polygons often represent the maximum home range size.

There are several limitations of convex polygons. Foremost is a sample size bias due to an increase in polygon size with increasing numbers of locations. This makes it statistically difficult to compare sizes of home ranges among individuals or during seasons. The problem can be alleviated by comparing individuals with a similar number of fixes and by using Odum and Kuenzler's (1955) observation area curve. This a plot of the cumulative increase in home range size against time. Odum and Kuenzler (1955) recommended that home range size be determined at that point where each additional fix produces a 1% maximum increase in area. However, they used this method on visual locations of territorial birds where the boundaries were well defined. From our experience, this 1% rule is a restriction that is seldom achieved in most telemetry studies of home ranges and we recommend a higher level such as 5% or 10%. Another shortcoming of the convex polygon method is that it is sensitive to fish movements near the periphery of the range, which often represent wanderings and not utilization of habitat. As a result, a polygon may enclose areas that a fish does not frequent; however, this can be useful in analyzing habitat selection as we will discuss later. In spite of these problems, convex polygons are a quick method to obtain approximate estimates of home range sizes and to determine home range boundaries.

Another method of delimiting a home range involves using grid-squares (Fig. 2) (Siniff and

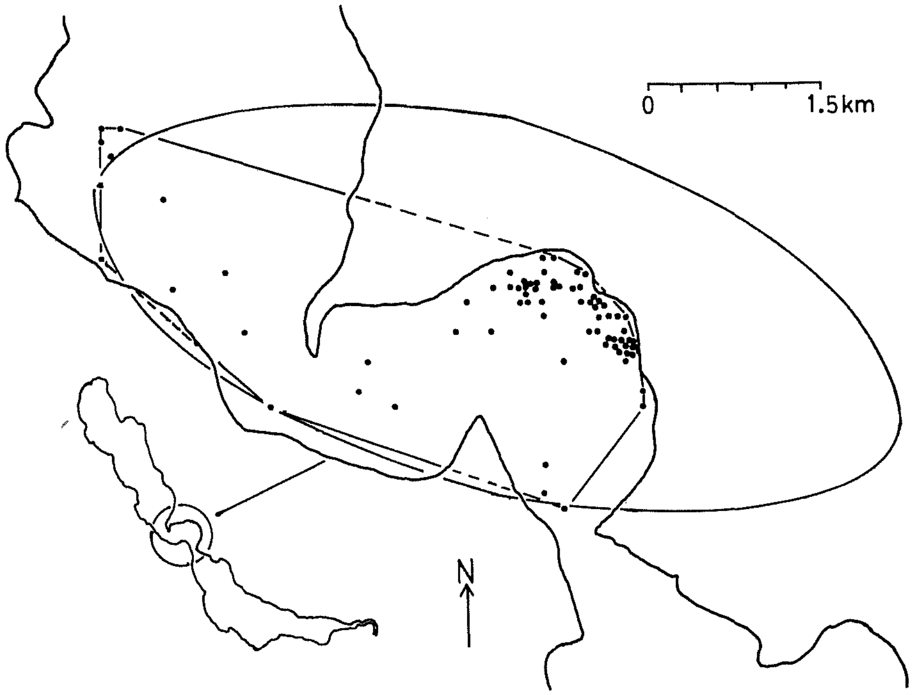

Figure 1.--A comparison of the (95%) probability ellipse and the modified convex polygon methods for determining home range boundaries of a walleye (#1369) in Chautauqua Lake, New York. The shoreline was used as a boundary when sides of the convex polygon crossed land (dashed line).

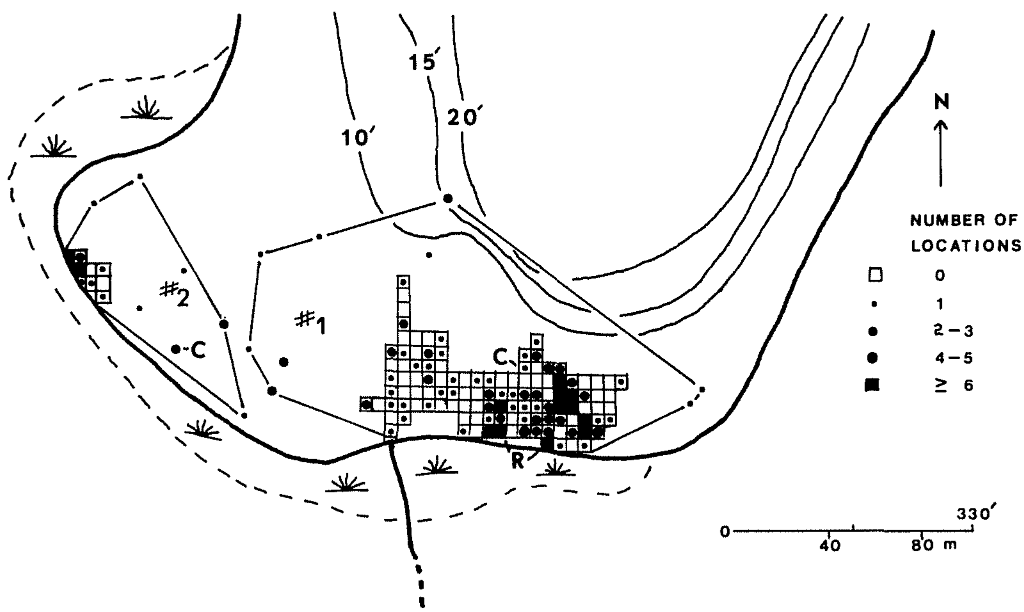

Figure 2.--Summer home range and intensity of habitat use for two largemouth bass. Maximum range is enclosed by convex polygons. Intensity of use is illustrated by the number of locations per grid-square. The point of capture is indicated by C and mid-day resting areas are designated by R (Winter 1976).

Tester 1965, Winter 1977, Macdonald et al. 1980). The study area is partitioned into squares the size of which is chosen to be no smaller than the accuracy of the locations. A computer can sort fixes into the appropriate squares and the area of the home range can be computed by summing the number of squares with fixes. Since fixes that may have been part of the same trip can be separated by empty squares, squares within a specified distance of a square containing locations are often included in the home range (Winter 1977, Einhouse 1981). Squares along a probable travel path can also be recorded as utilized squares (Voigt and Tinline 1980). These procedures are often termed the 'fill factor'.

Grid-square methods are greatly influenced by the size of the squares chosen and by the number of empty squares assumed to be part of the range. Both are somewhat arbitrarily chosen by the investigator. Since the number of squares influences the frequency distribution of location data, there is a bias in comparing home ranges of greatly different sizes. Voigt and Tinline (1980) solved this problem by choosing square sizes that are a fixed proportion of the total range size. Another bias is that a whole square is included in the home range when a fix may occur only in a corner. Grid-square methods are extremely valuable in that the number of fixes in each square reveals the intensity of habitat utilization.

Habitat use or utilization is a descriptive concept. It is usually expressed as the number or percent of radio locations in a particular habitat type for an individual or a group. Winter (1977) described depth utilization of largemouth bass by reporting that 94.2% of the locations were less then 3 m deep (Fig. 2). Ross and Winter (1981) presented a frequency table (Table 1) of depth use to show interspecific differences among four radio-tagged fish species. Differences in walleye mean depth utilization, distances from shore and home range sizes were related by Einhouse (1981) using ANOVA to differences in walleye length among three behavioral groups. Most walleye used areas near the edge of the macrophyte zone. Although it is difficult to map fish home ranges for vegetation or bottom types, utilization of each type can be categorized similar to methods used for other vertebrates (Gilmer et al. 1975, Fritzell 1978).

Table 1.--Depth Utilization by Four Fish Species in a Minnesota Lake (Ross and Winter 1981).

	Percent of total radio locations			
Depth (m)	Yellow Perch	Northern Pike	Largemouth Bass	Walleye
0-1.5	69	78	96	24
1.5-3.0	16	17	3	17
3.0-7.0	15	6	1	59
mean depth (m)	1.6	1.2	0.8	3.5

Habitat selection refers to the disproportionate use of a habitat type with respect to its occurrence in the study area. This suggests some preference or avoidance by the fish. Generally, selection is determined by comparing the number of locations in a particular habitat to the proportion of that habitat available. The key question that must be answered prior to choosing an analysis scheme is what habitats were really available to the animal observed. It may occasionally be appropriate to assume that an entire lake is available to a fish species. Einhouse (1981) assumed that all the habitats in a basin were potentially available to a walleye. This was fairly realistic for his study because some individuals roamed almost an entire basin and most areas of the basin were occupied by one of the three walleye behavioral groups (Fig. 3). Quite often large areas are not available to a species such as the warm, shallow areas for lake trout or deep, oxygen deficient areas for largemouth bass (Winter 1977). Thus, the area considered as available to fish species must fall within the physiological limits of the species.

Another approach to habitat selection is to assume that the available habitat is that contained within an animal's home range. Gilmer et al. (1975) used the convex polygon method to circumscribe the available habitat types for ducks. The advantage of using the home range is that large amounts of uninhabitable areas are omitted that would otherwise obscure statistical inferences on the relative importance of utilizable habitat types. An extension of this method would be to compare the amounts and types of habitats found within a home range to the amounts and types of habitat present outside of a home range. This method presupposes that areas outside of the home range are available to an animal and the areas fall within acceptable physiological limits for the animal.

Several indexes have been used to show the amount of habitat utilization or the degree of habitat selection. Gilmer et al. (1975) calculated a habitat use index by dividing the number of animals using (having fixes in) a habitat type by the number of home ranges containing that habitat type. Contingency tables were used to examine variation among individuals in the usage of habitat types during the day or night. Habitat selection was determined by using a Wilcoxon matched-pairs signed-rank test to compare the proportions of fixes in a habitat type to the proportions of a habitat type in the home ranges. We have calculated a Habitat Selection Index (HSI) by dividing the percent of total fixes occurring in a habitat type by the percent of that habitat type in the study area (Table 2). The strength of preference or avoidance is indicated by the degree of deviation from a value of one. Fritzell (1978) adapted Ivlev's Index as an Index of Habitat Electivity: $E = (r - p)/(r + p)$ where r was the percent of radio locations in a particular habitat and p was the percent of that habitat within the animal's home range (Table 2). The magnitude of the value and its sign indicate the strength and degree of selection/rejection, respectively. Although these indexes

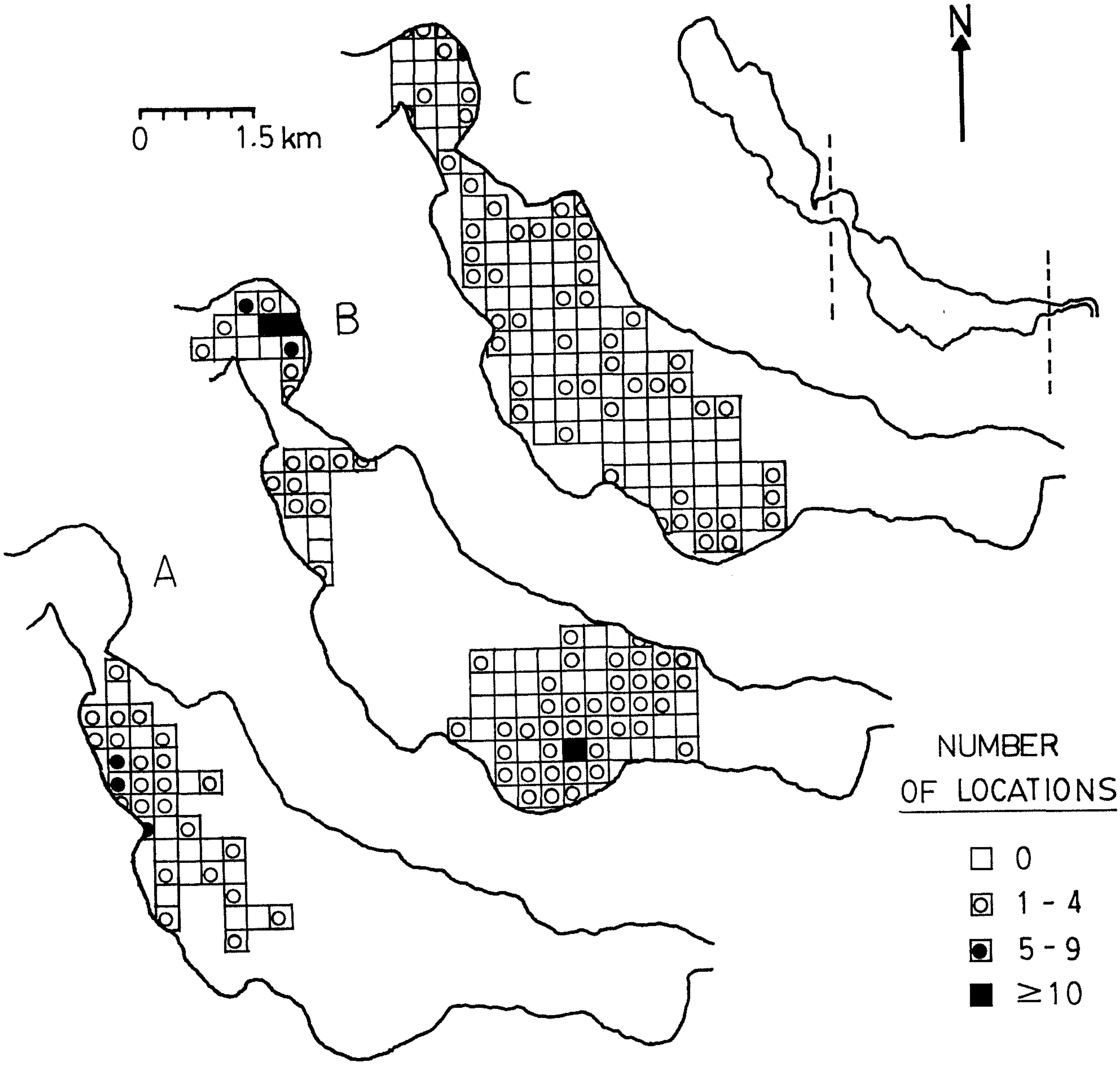

Figure 3.--Three main patterns of habitat utilization exhibited by walleye in Chautauqua Lake, New York. (adapted from Einhouse 1981)

	Mean Depth (m)	Mean Walleye length (mm)
A. Single Activity Area	3.8	535
B. Multiple Activity Areas	3.7	613
C. No Activity Areas, Nomadic	6.8	614
	$p<0.005$	$p<0.005$

give a general picture of habitat selection, they may produce false conclusions due to the investigator's method of deciding what constitutes available habitat. Johnson (1980) has developed a method of ranking habitat types by usage and by availability that provides statistically comparable results whether a questionable habitat type is included or excluded from analysis.

DISCUSSION

Comparisons of habitat utilization among telemetry studies are often difficult because of differences in the time the studies were conducted, geographic areas, methodology and terminology. The following should be reported in fish telemetry papers: number of instrumented fish used for analysis, length of the monitoring period per individual,

Table 2.--Selection of water depth in the summer and fall by walleye in Chautauqua Lake, New York (Einhouse and Winter, unpublished). Habitat Selection Index (HSI) = % locations in habitat type ÷ % habitat type available. Index of Habitat Electivity (E) = (r - p) ÷ r + p). Data include 3824 locations on 80 walleyes.

Depth (m)	% Area(p)	% Fixes(r)	HSI	E
0- 1.9	17.0	6.2	0.4	-0.5
2- 3.9	18.5	52.4[1]	2.8	0.5
4- 5.9	28.1	28.0	1.0	0.0
6- 7.9	7.6	8.5	1.1	0.1
8- 9.9	7.4	1.4	0.2	-0.7
10-11.9	12.1	2.6	0.2	-0.6
12-15.9	8.4	0.7	0.1	-0.8
16-19.9	0.8	0.2	0.2	-0.6
20-23.9	0.1	0.0	0.0	-1.0

[1]Significantly different (χ^2) at p <.005

sampling interval, season, fish size and condition, transmitter size and attachment method, habitat description and location, and analysis methods. To facilitate comparisons between studies, it is important to define movement data with respect to some time frame (Winter 1977). Fish may change their patterns of habitat use greatly during particular times of the year. It is also important to use standard terminology or methods that are in the literature so that people will have a better understanding of what was observed. To obtain a good perspective on fish habitat utilization, we suggest combining the usual method of obtaining a few locations on an individual per day(s) with occasional closely spaced locations over 24-hour periods.

We recommend measuring the maximum area over which a fish travels, and that portion of the maximum area that is utilized (Odum and Kuenzler 1955, Winter 1977). Macdonald et al. (1980) warn that the more mathematically complicated models used to analyze animal location data do not necessarily give greater biological insight. We have found that the modified convex polygon method (Winter 1977), in spite of its statistical weakness, is useful for defining the maximum home ranges of fish and for circumscribing areas of potentially available habitat. The convex polygon method is quick, simple, reproducible and widely used. We have also found that grid-square methods are useful for comparing intensity of fish habitat use per grid-square to habitat types. As this paper was going to press, Anderson (1982) proposed a nonparametric method that may be valuable in defining home ranges and habitat selection.

We also recommend calculating indexes of habitat use or habitat selection. They are useful for understanding what habitat types are important to the fish and in making comparisons between species or lakes. It is important to distinguish between the terms habitat use and habitat selection. Gilmer et al. (1973) pointed out that selection cannot be determined until habitat use is compared to habitat availability.

Investigators should recognize that there is a great amount of individual variation within a species. They should avoid referring to patterns of behavior as if all members of a species invariably exhibit the same pattern or patterns unless they have evidence to confirm it. Einhouse (1981) found that there were three main behavior groups of walleyes in Chautauqua Lake, New York based on differences in their patterns of habitat utilization. This suggests that regulations or policies in managing aquatic ecosystems should recognize that subpopulations of a species may have different habitat requirements. Since patterns of habitat utilization usually have been categorized subjectively by visually examining maps of fish locations, it is difficult to compare patterns within or between studies. Methods need to be developed to objectively classify patterns of habitat utilization such as using the truncated negative binomial distribution similar to Siniff and Jessen (1969).

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A NON-ANALYTICAL COMPUTER PROGRAM FOR ANSWERING WIDE-RANGING PHYSICAL, BIOLOGICAL AND ADMINISTRATIVE QUESTIONS

Clee Sealing[1]

Abstract--A time sharing computer program being used to store and retrieve physical, biological, and political information on the lakes and streams in a Colorado Division of Wildlife administrative region is described. The program was developed after several of the "canned" storage and retrieval programs were found unsatisfactory. The program was tailored to the needs of the State Wildlife Agency Fishery Administrator. Types of data input and the reasons for their selection are discussed. The program can answer questions concerning any of the input factors in any combination. Examples of the various types of uses for this program, advantages of and problems with the system and plans to incorporate these experiences into a new system for use on in-house microcomputer are offered.

INTRODUCTION

By 1978, the Colorado Division of Wildlife's northwest regional fish management office was being flooded with requests for aquatic baseline information, as a result of intensive energy exploration. To handle these requests for information, it was decided to explore the feasibility of computerizing the existing fishery information using a non-analytical data storage and retrieval approach.

There were several reasons for using a non-analytical approach. First, it was clear that responses from the fish management office did not require any analysis of data and most of the requests were for simple baseline data. At this same time, several analytical programs to evaluate, mitigate or project wildlife losses were being developed by Federal agencies and any similar work by the Division would have been a duplication of effort.

After the decision was made to develop a computerized data storage and retrieval system, several action items had to be accomplished concurrently. A computer programming consultant was hired to review existing commercial data storage and retrieval systems, and review our data base and the types of reports that would be needed. During this phase, other state and Federal agencies were contacted to determine if they could provide any useable information. Very little data was found.

After all the information was considered, a final selection of input items for the data base was made. Selection was based on historic demands for certain types of data; i.e., area, depth, fish species, stream flows, etc.

Concurrently, an evaluation report from the consultant indicated that commercially available data storage and retrieval programs were either too small and inflexible to handle the volume of data we had or the programs were too large and expensive to operate. The Division decided to develop a program that was customized to our needs.

DISCUSSION

Several possible designs for a custom non-analytical data storage and retrieval system was evaluated. The "best" system design from a user's standpoint would have been a totally interactive data storage and retrieval program with all files on active status for immediate use. This option, however, was prohibitively expensive. At the other end of the scale was a system that operated totally from punch cards and required remote entry and retrieval of all information. This was equally unattractive.

The first operational design used two magnetic tapes for the storage and retrieval of data. The data base could be accessed by requesting that a tape be mounted either to add new information or to generate a report. This method of having all information on tape was very cost effective but created long delays in updating or querying the data base.

The program was later modified so that the operating programs and data base were placed in active file storage in the computer. The updating or querying is then performed on active files which greatly improved response time. If no update to the data base was performed, the entire system could be purged from the active files. If an update was performed, a program was run that added the new information to the tapes and the users could then purge the system.

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The data base contains four types of information about each water and specific detail is listed in Appendix A. Each water in the file has an initial entry that contains most of the political and geographic location information. People requesting information are usually interested in locating waters within a geographic or political area for report generation purposes.

The second type of information is the physical, chemical, and biological field survey data. Items in this section are again based upon most frequently requested information for the widest use.

The third type of information is stocking data. This information starts in 1973 and is updated annually. Information is coded by water and includes species, sizes, numbers and dates.

The last type of information is creel survey information. This information begins with 1973 and is updated annually. Included in this entry, by water, is number of anglers, hours fished, total fish caught, catch per man-hour, percent of each species in the creel and average size. These four major types of information for each water give a well rounded description of that water and usually satisfies most information requests.

Appendix A, contains a complete list of input items in the data base plus a list of commands for generating reports. In general, questions about the data can be conditioned by almost any or all of the input items so long as it makes logical sense to do so. For example, one might want a list of the names of the lakes within the White River National Forest. Further, the question can be conditioned to list only those lakes in the White River National Forest above 10,000 feet in elevation that contain only cutthroat trout. A list of names along with stocking records can be printed. This type of data base and report generation has been well received by biologists looking for general baseline data and by administrators needing to answer politically-oriented questions such as how many fish a certain area receives.

When this system became operational in 1978, it provided a quantum leap in the ability of fish management section to respond to demands for information spurred by energy development. Time, effort, and cost to create this system have been more than recouped in the time and effort saved in searching files and preparing reports from field data.

However, situations and demands change over time as well as equipment. Jobs become more demanding and responses need to be faster and more flex flexible. Programming delays, long distance communications to the computer, tape handling problems, periodic overloading of the system all create a less productive work situation. As this condition developed, a new alternative was explored.

At the beginning of this project in 1978, the only practical computer solution for our situation was the use of a large time share system typical of the Cyber CDC 6400 located at several of the larger universities. Computing time and file storage could be purchased within budget constraints. Minicomputers were also in existence and had the capability of handling the project but were far too expensive ($20,000.).

By 1981, however, microcomputer technology had made major advancements in computing speed and ability to store and retrieve large volumes of data. The combination of improvements in hard disk and diskette data storage and retrieval and an initial investment of less than $13,000, made the microcomputer a viable alternative to the time share system.

Before any decision was made to purchase an in-house microcomputer system, an in-depth evaluation of available equipment was made by a consultant. This evaluation included a literature review of current equipment, and interviews with experts in the field of microcomputer technology. It was not possible to find an expert consensus as to the "best" equipment for our project. This lack of concensus was due to the way different manufacturers use standard parts to build computers that operated differently and the fact that the microcomputer industry is in a state of rapid technological development.

The consultant was then to develop a list of brands that appeared suitable, based upon its own literature and our criteria and were within budget limits.

The criteria used to make a final selection were:

1. Computer must have at least 64,000 bytes random access memory.
2. Must have at least 20 megabytes of hard disk storage space.
3. Must have two eight inch diskette units for backup and small program storage.
4. Must have option for multi users.
5. Must have option for remote on/off operation.
6. Must have real time clock and calendar for file control.
7. Must have RS-232 port for acoustic coupler, display screen terminal and printer.
8. The system must have a bidirection, 165 character per second, dot matrix printer.
9. System must have good user satisfaction from units now in operation.
10. System must have good dealer support.

Once suitable brand names had been identified, current users were contacted for their opinion of the equipment and company services. After this evaluation work was completed, there was really no clear single choice and several brands would have been acceptable. Through the state bidding process, the final section was a Ohio Scientific C3C computer with two eight inch diskettes, a 23 megabyte hard disk, a Visual 200 display terminal and an Anadex printer. This system has been in operation about one year without any equipment failures.

RECOMMENDATIONS TO PROSPECTIVE MICROCOMPUTER PURCHASERS

1. List all the jobs the microcomputer is expected to perform, including report generation and letter writing. The latter is important because the printer may need to produce letter quality type.

2. Size your programs and data files to determine the amount of computing and data storage space needed. It may be necessary to hire an expert to do this but it will prevent trouble later on.

3. Many of the specialized needs of wildlife people cannot be met with existing general purpose programs. Discussions with several reputable programmers familiar with microcomputer will provide estimate of the time and expense necessary to develop and operate a system.

4. Selecting equipment can be frustrating as anything built today can be obsolete tomorrow. Program size, data file size, brand availability and budget constraints will help determine selection.

5. Spend time actually working with several brands of equipment. How the user feels about the equipment plays a significant role in how much benefit is finally realized from the acquisition.

Microcomputers are a viable option to large time share computer systems, but care needs to be taken in selecting the equipment and the programming so the job will be done correctly.

APPENDIX A

Input Items to Inventory Data Base Items Entered for Both Lakes and Streams

1. Code Number
2. Name of Water
3. Location
4. County
5. National Forest Name
6. Wilderness Area Name
7. Conservation Officer District Number
8. Is it owned by the Division of Wildlife?
9. Is it managed by the Bureau of Reclamation?
10. Is it privately owned?
11. In what inventory unit is it located?
12. Does the Bureau of Land Management own any of it?
13. Has it been surveyed?

Input Items Used for Lakes

1. Code Number
2. Elevation
3. Surface Acreage
4. Maximum Depth
5. Storage in Acre/feet
6. Lake type (natural or artificial)
7. Type of dam (natural, earthen, concrete)
8. Length of dam in feet
9. Height of dam in feet
10. Type of outlet (stream, spillway, gate, combination)
11. Date lake was built
12. Date of water filing
13. U. S. Forest Service special use permit number
14. Date of conditional water rights
15. Acre/feet of storage in water filing
16. Date filing became absolute
17. Water will be used for (industrial, agricultural, domestic, nonconsumptive)
18. Name of water right holder
19. Are fish present?

20-29. List fish species in descending order of abundance and average length

30. Type of management used on lake (natural population, creel size stocking, subcatchable stocking or combination)
31. Method used to stock lake (airplane, packed in or by tank truck)
32. Type of shore vegetation (alpine tundra to desert)
33. pH
34. Conductivity
35. Access to lake (foot, car, four-wheel drive)
36. Reschedule schedule. Should this water be resurveyed each year, every five years or every ten years.
37. Man-days needed to carry out survey for budget purposes.

*38. Date lake was last surveyed

*39. Mean Depth

*40. Shoreline development factor

Input Items Used for Streams

1. Code Number

2-5. A single stream may flow through four counties.

6. Type of management applied to this stream (natural, creel size stocking, subcatchable, stocking or combination).

7.-10. Used to list four factors that limit this stream's full potential for trout production.

11. Number of miles on Bureau of Land Management lands.

12. Number of miles on U. S. Forest Service lands
13. Number of miles on state land board lands
14. Number of miles on National Park lands
15. Number of miles on Division of Wildlife lands
16. Number of miles on private lands
17. Drainage area in square miles
18. Resurvey schedule either one, five, ten years
19. Number of man-days to conduct survey
20. Date of last survey

From this point on, a stream or stream section can have four subsections to record the following data:

21. The recommended minimum stream flow for that reach.
22. Conductivity (4)
23. Species of fish (16)
24. Average length (16)
25. Average width of section
26. Actual measured flow in cfs
27. A description of the section or subsection

* Will be added to revised data base.

The following is a list of the items that are entered from creel census and stocking records:

1. Year fish are stocked
2. Species stocked
3. Number of fish stocked
4. Average size of fish stocked
5. Year that creel census was taken
6. Number of anglers censused
7. Total hours fished
8. Species of fish caught
9. Number of fish by species caught
10. Average size of fish by species caught

The following is a list of logic commands:

1. and
2. then
3. find
4. or
5. initialize
6. reset
7. count
8. sum
9. list
10. print
11. report
12. equal to
13. not equal to
14. greater than
15. equal to or greater than
16. equal to or less than

MISSOURI'S SYSTEM FOR STORAGE RETRIEVAL

AND ANALYSIS OF STREAM RESOURCE DATA[1]

William L. Pflieger,[2] Pamela S. Haverland,[3]

and M. Anthony Schene, Jr.[4]

Abstract.--A computerized system is being developed for storage, retrieval, and analysis of a large quantity of stream resource data that has heretofore been largely inaccessible to resource planners. The central feature of this system is a hierarchical series of stream codes that permits the retrieval of data from any combination of 5,139 drainage areas and stream segments. These stream codes are a common denominator for interphasing separate files being developed for several subject classes of stream resource data. Files are under development or are planned for the following data classes: fishes, benthic invertebrates, physical and chemical characteristics, alteration by channelization and impoundment, pollution, habitat quantity by type and condition, and recreational use.

When fully developed this system will have application in assessing the impacts of proposed water resource development projects, and will provide a basis for improved research and management of Missouri streams.

INTRODUCTION

The loss or alteration of stream habitat in Missouri began with the arrival of the first settlers, but the rate of change has accelerated in recent decades. Examples of activities that have brought about these changes include stream impoundment and channelization, replacement of native vegetation with erosion-promoting crops, and the release of toxic substances into streams as by-products of agriculture, mining, industrialization, and urbanization.

A substantial body of information is available for evaluating the effects of these activities on the habitat and biota of Missouri streams. However, this information has not been fully utilized because of its bulk and the lack of uniformity in the way it is organized and stored.

In July 1975 we began developing a computerized system to improve capacity for storage, retrieval and analysis of Missouri stream resource data. In this report the system is briefly described, examples of the kinds of data to be included are provided, and potential applications for the system are indicated.

This system is being developed primarily from information already in our files, but will be updated and refined as new or revised information becomes available. Therefore, the collection and assimilation of information into the system will continue indefinitely.

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[1]Paper presented at the symposium on Acquisition and Utilization of Aquatic Inventory Information (Portland, Oregon, October 28-30, 1981).
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METHODS AND MATERIALS

Data entry into the system is primarily by computer cards punched from forms developed for each subject class of data. An Amdahl 470 computer on the Columbia Campus of the University of Missouri provides direct-access disc storage for the data files being developed. These files are transferred to computer tapes for long-term storage. A Tektronix 4052 minicomputer functions as a remote terminal, as well as a stand-alone computer, and is coupled with an interactive digital plotter and a hard copy unit for displaying and analyzing data subsets. Programs for managing the data are written in BASIC, SAS, FORTRAN, AND PL/1. The statistical packages NT-SYS (Rohlf, Kishpaugh, and Kirk 1972) and SAS (Helwig and Council 1979) are used for data analysis.

Separate computer files are being developed for each subject class of stream resource data. These files are designed to provide maximum flexibility in the way they can be interphased for producing output of the data in the member files. Files are under development or are planned for the following stream resource data classes: stream biota, physical and chemical characteristics, alteration by channelization and impoundment, pollution, habitat quantity by type and condition, and recreational use. Other files may be developed as the need for them becomes apparent.

A file of data on the fish fauna of Missouri streams will be described in some detail to exemplify our system. The application of the fish faunal file in the development of a classification of stream habitats is the subject of another paper in this symposium (See Pflieger, Schene and Haverland).

STREAM CODES

The central feature of our system is a hierarchical series of stream codes that permits the retrieval of data from any combination of 5,139 drainage areas and stream segments. These stream codes are a common denominator for interphasing separate subject files as mentioned in the preceding section.

In developing these codes we found by trial and error that all Missouri streams except the smallest could be accommodated by an 8-digit code. The state has been divided into 6 primary divisions, which are numbered at the highest level in the classification (Fig. 1). These drainages are each divided into 1-9 areas that are numbered at the next level in the classification. These areas are further subdivided at succeeding levels into smaller and smaller areas down to the level of drainages or streams which in most cases have only intermittent flow.

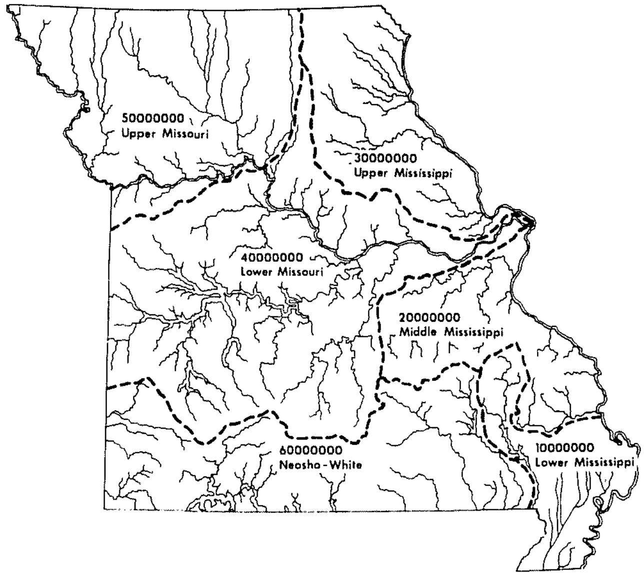

Figure 1.--Primary divisions of the Missouri stream coding system.

The Strahler (1952) modification of the stream order system proposed by Horton (1945) provided the basis for deciding which streams would be assigned codes. In this system, unbranched ultimate headwater streams are designated as Order 1. Two Order 1 streams join to form an Order 2 stream, and the order continues to increase by one each time two streams of the same order join. For our determinations of stream order, streams shown on topographic maps on a scale of 1:24,000 and 1:62,500 were used.

We assigned a number code to all Missouri streams of Order 4 or higher. Smaller streams were numbered whenever they could be accomodated by the 8-digit code. Thus, the majority of Order 3 and many Order 2 streams were numbered. We also numbered Missouri springs listed by Vineyard and Feder (1974) as having an average flow in excess of 1 cfs (cubic foot per second). Springs were arbitrarily designated as Order 15 to distinguish them from headwater surface streams. The man-made drainage ditches of southeastern Missouri did not fit the stream order system because they are artificial and some of them interconnect. Therefore, most ditches were coded. These ditches are designated as missing values in the stream order field of the stream code file.

The Osage River is Order 8, and thus has the highest order for any Missouri stream except the Missouri and Mississippi rivers. The order of the latter two streams was not determined, and they were arbitrarily designated as Order 12.

The stream code system can be exemplified by listing the eight levels of subdivision used in assigning a code to Chesapeake Spring (Table 1). In this table, each of the streams is tributary to the one above which is numbered at the next highest level. Notice that the Sac River and Turnback Creek have been divided into numbered segments. Most large streams were divided into segments, with the length of these segments being adjusted to accomodate no more than 8 direct tributaries that were to be numbered at the next lower level in the classification. The digit 9 at the level corresponding to these tributaries was a collective category reserved for other small direct tributaries at the same level. Streams were assigned to this collective category only if data were available from them. Since all are small and many do not support a permanent aquatic biota, we have had little need as yet for this collective category.

Table 1. The eight levels of subdivision required to assign a code to Chesapeake Spring, using the Missouri stream coding system.

Code	Stream	County	TRS
40000000	L. Missouri R.	St. Charles	47N,07E,·
44000000	Osage R.	Osage	44N,09W,05
44700000	Sac R.	St. Clair	38N,25W,31
44720000	Sac R. S4	Cedar	34N,26W,11
44727000	Turnback Cr.	Dade	31N,26W,02
44727300	Turnback Cr. S3	Lawrence	29N,26W,03
44727370	Goose Cr.	Lawrence	29N,25W,29
44727372	Chesapeake Sp.	Lawrence	28N,25W,21

For each numbered stream drainage or segment, the stream code file includes the code number, the stream name (abbreviated to occupy no more than 15 spaces), the location of the stream mouth or lower end of the stream segment (county, township, range, and section), the stream order, and the number of the topographic map on which the stream mouth or lower end of the stream segment is located. This number refers to a numbered set of topographic maps that we maintain at the Fish and Wildlife Research Center.

Some stream names in the computerized data bank are marked by one of two symbols. Streams in the special collective category referred to above are designated by the symbol (#) to alert the user to the fact that data from other streams may also be cataloged under this number. The other symbol used is (*), and it indicates that this stream name is a synonym for another stream name. Since some Missouri streams are known by several names, we selected one as the preferred name and listed others as synonyms. In actual use, data were cataloged only under the preferred name. Computer printouts, arranged numerically by stream code and alphabetically by stream name, provide a reference for users of the stream codes.

THE FISH FAUNA OF MISSOURI STREAMS

Our first application of these stream codes was in the development of a computer file for fish collection data acquired over a period of more than 50 years, as part of a continuing general survey of the Missouri fish fauna. This file is complete, except for periodic updating, and presently contains 2,608 collections made at 1,933 localities between the years 1923 and 1980.

Data entry into the file is by standard 80-space punch cards encoded from data processing forms. Eleven cards, designated Card A - Card K, are required to encode the data from each collection. The first 55 spaces on Card A are reserved for geographic information (Fig. 2). The locality is designated by a 4-digit number that is unique for the collection location, followed by a letter of the alphabet that corresponds to one of three time periods in which collections were made: A for collections made prior to 1950, B for collections made between 1950 and 1973, and C for collections made since 1973. The stream name and code are from the stream code file. The county is also represented by a code. The stream mile is the distance from the stream mouth to the collection site. The Universal Transverse Mercator (UTM) Grid Coordinates express the location of the collection site as X and Y coordinates to the nearest 100 meters. The map number refers to a set of United States Geographic Survey topographic maps on which we have marked the location of the collecting site.

Certain physical data, intended for use in the development of a classification of stream habitats, is recorded on the remainder of Card A. Our intention here is not to describe the habitat in great detail, but rather to provide a set of general physical parameters that can be used to judge the plausibility of classifications that result from applying various classification techniques to the species composition of collections. No additional fieldwork is anticipated, and these habitat parameters can be obtained from maps and other published sources.

The locality number is repeated on Card B and all subsequent cards as an identifier (Fig. 2). The first part of Card B is reserved for certain information about the collection, including an assessment of sample adequacy, sampling methods, sampling dates, the sampling effort, and a number that associates the computer record with the original collection records that were used in compiling it.

The intention of the sample adequacy field is to promote consistency in the data used for certain types of analysis. The collections at our disposal vary greatly in the precision with which they reflect the composition of the fish fauna at the time

LOCALITY:	0263A (1-5)	STREAM ORDER:	12 (56-57)
STREAM NAME:	MISSRLMIDDLE) __ (6-20)	ORDER OF RECEIVING STREAM:	· · (58-59)
COUNTY:	075 (21-23)	ELEVATION:	0330 (60-63)
DRAINAGE:	20000000 (24-31)	LOCAL RELIEF:	190 (64-66)
STREAM MILE:	078 (32-34)	GRADIENT:	001 (67-69)
TOWNSHIP:	34N (35-37)	MILES TO HEADWATER:	3070 (70-73)
RANGE:	14E (38-40)	PHYSIOGRAPHIC REGION:	4 (74)
SECTION:	06 (41-42)	BEDROCK:	01 (75-76)
UTM GRID COORDINATES:	X 8081 Y 41675 (43-51)	SOILS:	07 (77-78)
MAP NUMBER:	0877 (52-55)	CARD:	A (80)

LOCALITY: 02634 (1-5)		ICHTHYOMYZON UNICUSPIS	__ __ (37-38)
SAMPLE ADEQUACY		ICHTHYOMYZON CASTANEUS	__ __ __ (39-41)
SPECIES		ACIPENSER FULVESCENS	__ __ (42-43)
LARGE FISHES:	1 (6)	SCAPHIRHYNCHUS PLATORYNCHUS	__ __ __ (44-46)
NEKTONIC FISHES:	1 (7)	SCAPHIRHYNCHUS ALBUS	__ __ (47-48)
BENTHIC FISHES:	1 (8)	POLYODON SPATHULA	001 (49-51)
NUMBER OF SPECIMENS		ATRACTOSTEUS SPATULA	02 (52-53)
LARGE FISHES:	1 (9)	LEPISOSTEUS PLATOSTAOMUS	268 (54-56)
NEKTONIC FISHES:	3 (10)	LEPISOSTEUS OCULATUS	__ __ __ (57-59)
BENTHIC FISHES:	2 (11)	LEPISOSTEUS OSSEUS	008 (60-62)
		AMIA CALVA	023 (63-65)
SAMPLING METHODS:	__ __ 1 __ __ 1 1 1 1 __ __ (12-22)	ANGUILLA ROSTRATA	__ __ (66-67)
COLLECTION DATE(s):	310544 (23-28)	ALOSA CHRYSOCHLORIS	__ __ __ (68-70)
SAMPLING EFFORT (HOURS):	025 (29-31)	ALOSA ALABAMAE	__ __ (71-72)
COLLECTION NUMBER:	08934 (32-36)	DOROSOMA CEPEDIANUM	0017 (73-76)
		CARD:	B (80)

LOCALITY: 02634 (1-5)			
PERCINA COPELANDI	__ __ __ (6-8)	PERCINA SCIERA	__ __ __ (25-27)
PERCINA CYMATOTAENIA	__ __ (9-10)	PERCINA SHUMARDI	002 (28-30)
PERCINA EVIDES	__ __ __ (11-13)	PERCINA URANIDEA	__ __ __ (31-33)
PERCINA MACULATA	__ __ __ (14-16)	COTTUS BAIRDI	__ __ __ (34-36)
PERCINA NASUTA	__ __ (17-18)	COTTUS CAROLINAE	__ __ __ (37-39)
PERCINA OUACHITAE	__ __ __ (19-21)	COTTUS HYPSELURUS	__ __ __ (40-42)
PERCINA PHOXOCEPHALA	__ __ __ (22-24)		

HYBRIDS	CODE	NO.
Notropis lutrensis X Notropis spilopterus	__ __	01 (43-46)
	__ __	__ __ (47-50)
	__ __	__ __ (51-54)
	__ __	__ __ (55-58)
	__ __	__ __ (59-62)
CARD:		K (80)

Figure 2. Selected forms used in compiling data on the fish fauna of Missouri streams.

Figure 2. Selected forms used in compiling data on the fish fauna of Missouri streams.

the collections were made. This is due to such factors as the objectives of the collector, the type of collecting gear and the manner in which it was used, and the amount of sampling effort. The sample adequacy field is divided into two sections, referring respectively to species and number of specimens. Collections judged to adequately indicate the species composition of the fauna sampled are given a "1" in the species field. Those considered marginal in that respect are given a "2," and those judged inadequate are given a "3". The "number of specimens" field is similarly used to indicate the adequacy of the sample in reflecting the relative abundance of the species present at the collection site. Adequacy judgements are based on an evaluation of sampling gear, effort, and the objectives of the collectors.

For rating sampling adequacy the species are divided into three groups: "Large Fishes," "Nektonic Fishes," and "Benthic Fishes." These categories are to some extent ecological as their names imply, but the primary consideration in establishing them was the selectivity of various sampling gear and sampling techniques for collecting fishes of the three groupings. "Large Fishes" are defined for our purposes as those species in which the adults commonly exceed 150 mm in length. "Nektonic Fishes" are those smaller species such as minnows and killifishes that actively swim above the substrate, often in schools. Benthic fishes such as darters and madtom catfishes live on or in the bottom and typically are solitary.

Three principal methods were used in obtaining most of the collections at our disposal: electrofishing, drag seining, and kick seining. Differences are evident in both composition and relative abundance of fishes obtained by these three methods. Species in the "Large Fishes" category typically predominate in the electrofishing samples. This is due in part to selectivity of the large boat-mounted electrofishing gear typically employed, and in part to the fact that fishes less than 100 mm total length were often not recorded. Drag seining appeared to be less selective than the other two methods, and often resulted in the largest number of species. However, this method is clearly selective for "Nektonic Fishes," since large fast-swimming species and small bottom-dwelling species were not well represented in drag-seine samples from most habitats. Kick-seining provided the largest samples of "Benthic Fishes" such as madtom catfishes that burrowed in the substrate, but was inadequate for sampling the other two groups.

On the remainder of Card B and the following 9 cards space is provided for recording the number of specimens of any of the 221 species and subspecies of fishes that have been recorded in the collections available to us. We avoided assigning species codes by adopting a "fixed field" approach, reserving a specific field on the data processing cards for recording the number of specimens of each species. The size of the field reserved varied with the species, based on the number of specimens expected for a given species at a single locality. By eliminating species codes and varying the field reserved for number of specimens, a substantial reduction in the number of data processing cards required was realized.

Space is provided on Card K (Fig. 2) for coding and recording the number of specimens of any of 61 hybrid combinations of fishes that have been identified in our collections. We coded hybrids rather than employing the "fixed field" approach used for species, because of uncertainty about the hybrid combinations we might encounter, and also because hybrid combinations are mostly of less frequent occurrence.

Computer programs were written to organize and print the data in this file by locality or by species. For the locality option, all of the data are printed for specified localities. The localities of interest can be specified in a number of ways, but most often are specified for a range of stream codes so that all of the data are obtained for a particular stream system or segment. The segment option can be made more precise by specifying a range of stream miles. Locality data can also be retrieved for one or more counties, for all streams of a particular order, etc. For the species option, a listing can be obtained for all the localities of occurrence for the species of interest, along with the number of specimens and any other data in the file. The species option can be made more restrictive by specifying a range of drainage codes, etc., as for the locality option.

Certain additional information that was not a part of the original input is generated when data are printed for either the locality or species option. This includes an indication of the status of species listed as rare (RA), endangered (EN) or extirpated (EX) on an official state list of rare and endangered species. The relative abundance of each species is indicated by expressing the number of specimens of the species as a percent of the total number of specimens in its group. This computation is made only for collections of a certain specified adequacy in the number of specimens field of sampling adequacy. The total number of species and specimens is also computed for each group and for all groups combined. Two commonly used measures of diversity, the Shannon and Margalef Diversity Indices, are also computed.

The Universal Transverse Mercator Grid Coordinates that are a part of this file can be used to map the data. To accomplish this we transfer data from the Amdahl 470 disc files to the Tektronix 4052 minicomputer disc files. Certain other files that are used for mapping are stored on the minicomputer disc. These include boundaries of the state, the counties, physiographic regions, and principal drainages. To exemplify these files, we have plotted the distribution of the northern hog sucker (Hypentelium nigricans) in relation to the physiographic boundaries that seem important in explaining its distribution (Fig. 3).

STREAM ALTERATION FILE

Another computer file developed by Otto Fajen of our staff provides information on stream loss or alteration by channelization and impoundment. The original and present mileage of stream channels were measured on United States Geologic Survey topographic maps. An examination of aerial photographs provided by the United States Agricultural Stabilization and Conservation Service revealed additional losses not evident on the topographic maps. This information, along with the stream code and stream order, were recorded on data processing forms. The mileage of all Missouri streams of Order 2 or higher have been measured.

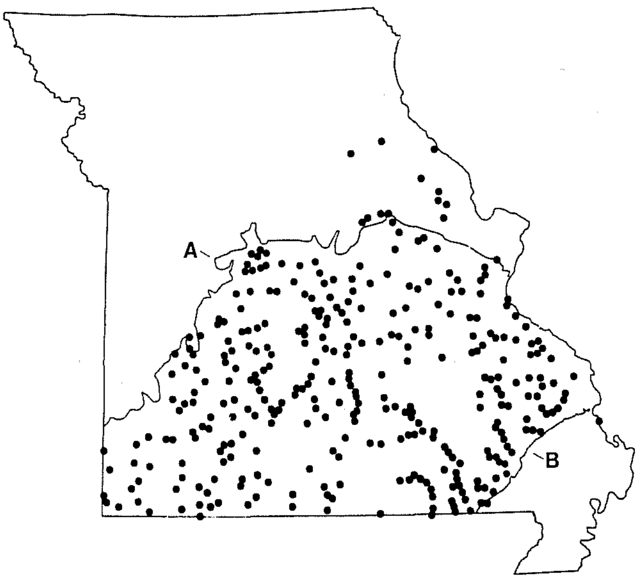

Figure 3. Distribution of the northern hog sucker (Hypentelium nigricans) in relation to Physiographic boundaries of the Ozark Uplands (A & B = boundaries).

To exemplify this file we have listed stream loss and alteration by channelization or impoundment in a short section of the Osage River (Table 2). The original stream channel length of 91 miles has been reduced to 27 miles, of which 14 miles are affected by periodic inundation from a reservoir.

Table 2. Loss or alteration of stream habitat by channelization and impoundment in a portion of the Osage River, Missouri.

Stream Code[1]	Orig. Miles	Miles Channe-lized	Miles Impounded Permanent	Miles Impounded Periodic	Present Miles[2]
44810000	19	0	19	0	0
44820000	14	0	10	0	4
44830000	15	9	0	6	6
44910000	21	13	0	8	8
44920000	22	13	0	0	9
Totals	91	35	29	14	27

[1]Each code denotes a stream segment
[2]Includes miles periodically impounded.

GRADIENT PROFILES OF MISSOURI STREAMS

As part of an inventory of the physical characteristics of Missouri streams, we are compiling data on stream gradients. The gradient profiles of all streams of Order 5 and larger have been determined. The gradient profiles of streams less than Order 5 from which we have fish faunal data are also being determined. The elevation of each contour interval and the distance between contour intervals along the stream channel are determined from United States Geologic Survey topographic maps. This information, along with the stream order and stream code, comprise the data base for this file. In Figure 4, gradient profiles are plotted for two streams of similar length to exemplify the file. These streams occupy different physiographic subdivisions of Missouri and support fish faunas of widely divergent composition.

We will explore techniques for quantitatively comparing the gradient profiles of different streams. We hope this analysis will provide additional insight into the relationship between stream gradient and faunal composition, as well as physical parameters of the habitat, such as riffle-pool development and substrate composition.

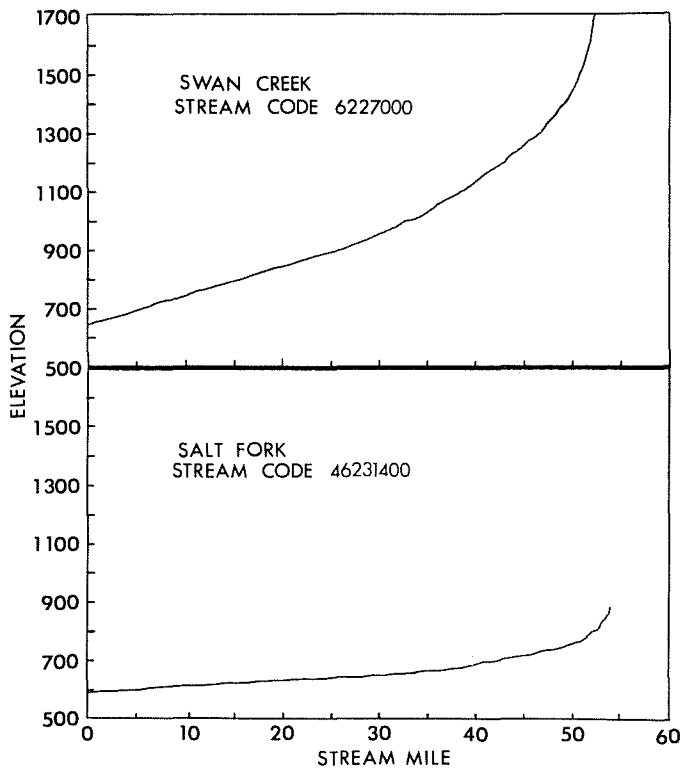

Figure 4. Gradient profiles of Swan Creek and Salt Fork, two streams with markedly different physical and biological attributes.

DISCUSSION

This system is still under development, and it will be some time before its full potential as a tool in resource planning will be realized. However, we are using these files in a preliminary way to provide information for environmental assessments. Fish faunal data in a format comparable to that previously described are being provided to users on request. In a recent 12-month period we responded to 31 requests for data, for areas ranging in size from a small watershed to an entire county. Most requests have come from resource planners in state or local government, and private consulting firms doing EIS work.

We are using these data to develop a stream habitat classification (See paper by Pflieger, Schene, and Haverland in this symposium). Other types of analysis envisioned for these data include the documentation of changes in the fish fauna and habitat over the period of time for which collections are available, and the development of a species depletion index for defining more objectively the status of each species of fish within Missouri.

When these analyses are completed we should be able to provide the following information for any area of the state:

1. Site-specific data on the fish fauna for each locality where collections have been made and an improved capacity to predict the fauna of localities from which no collections are available.

2. A more realistic assessment of the uniqueness of the fish fauna and the status of rare and endangered species.

3. A listing of stream habitat types, the amount of each, and the condition of these habitats in terms of man-induced disturbance.

4. Maps depicting the distribution of species and habitats.

Since the perception of resource planning needs and the data base for meeting these needs may vary from one geographic area to another, the system we are developing could not be adopted elsewhere without some modification. We hope the ideas presented here will be useful to other natural resource agencies in the development of a system to meet their particular stream resource planning needs.

The system can be used to assess the impacts of proposed water development projects, and to mitigate stream losses as a result of these projects. It will put these losses in perspective by providing the most accurate and current figures available on the amount of stream habitat of various types and its condition with respect to man-caused disturbance. It will reveal gaps in present knowledge, and will serve as a basis for improved research and management of Missouri streams.

ACKNOWLEDGEMENTS

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GENERAL AQUATIC WILDLIFE SYSTEM[1] (GAWS)

Donald A. Duff[2]

The General Aquatic Wildlife System (GAWS) contains the basic Intermountain Region (R-4) survey elements necessary to inventory, describe, monitor, predict habitat condition, and vulnerability to impacts of aquatic habitat.

A computer system known as WILD RAM (Wildlife Resource Allocation Model) has been developed to store, retrieve, and analyze fish and wildlife data on the 19 National Forests within the 31-million acre, six-state area of Region 4. GAWS is the aquatic component within the WILD RAM system.

Included within GAWS are procedural methods for conducting (1) stream habitat surveys, (2) lake-reservoir habitat surveys, (3) macroinvertebrate surveys, and (4) instream flow (minimum flow) determinations.

GENERAL AQUATIC WILDLIFE SYSTEM

Stream Habitat Surveys. The basic survey method for stream habitat is referred to as the transect method. Habitat stations are selected on a stream based on the stream's physical hydrogeomorphic characteristics. Each stream station consists of 5 transects, spaced at regular intervals, i.e., 50 meters, above each other in ascending order from the station point. At each transect, physical features are measured which include channel and stream width, streambank channel soil stability, and vegetative cover ratings, streambed material composition, and pool riffle class and quality. At present, a computer program called GAWS HABITAT provides outputs of this habitat data.

This present GAWS HABITAT program is being modified and in the near future will be capable of producing outputs at four different survey levels. These levels will also apply to the lake survey procedure. These levels are based on the assumption that different intensities of data collection are required to cope with varying levels of planning and management activities. Accomplishment of a Level I survey is required on every known stream. With Level I as a foundation, the survey process can proceed to Level II or III, or even to Level IV.

Level I is an identification level inventory providing the most general description of the aquatic habitat. It presents gross measurements of aquatic habitats within large geographical areas. It is an office method and uses primarily all past file material available for a stream from the state wildlife agency, Forest offices, etc.

Level II is a reconnaissance level inventory providing basic information about aquatic habitat (i.e., spawning, rearing, vulnerability, improvement potential). This level of inventory is used only where time factors and priorities do not allow for more intensive surveys. Random reaches or the entire stream can be surveyed extensively at this level.

Level III is a prescriptive planning level inventory. This is the physical habitat transect survey providing information necessary to make land management prescription recommendations.

Level IV is an implementation/monitoring/evaluation level inventory. This level is also the transect survey procedure accomplished with a larger number of physical transects to meet a desired statistical reliability. A more intense variety of stream habitat characteristics

[1] Presented at Symposium - Acquisition and Utilization of Aquatic Habitat Inventory Information, Portland, Oregon, Hilton Hotel, October 28-30, 1981.

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are measured. Information from this aquatic habitat survey level is used to coordinate final project and site-specific prescriptions and to improve the implementation of similar land management prescription activities in the future.

Lake Habitat Survey. Lake-reservoir surveys are done to characterize the ecosystem of these standing waters. Physical habitat parameters will be measured according to the four levels prescribed under stream habitat surveys. At present, this survey is not operational for input/output in the GAWS program. Habitat components and field forms are under development now and will be ready for field use in 1982.

Macroinvertebrate Surveys. The macroinvertebrate survey portion of GAWS is a program which addresses in detail the aspects of both abiotic and biotic characteristics of instream and riparian habitat in aquatic ecosystems. Macroinvertebrate samples are collected by selected personnel on Forests throughout the western United States. These field technicians are trained to select stations and sample sites and 3 stratified random samples are taken at each station on a given sampling date. Quantitative samples are taken with a modified Surber net. The foot-square frame is placed over rubble substrate (3-12" rocks) and rocks and underlying substrate are scrubbed until the aquatic insects from the square foot of streambottom are in the net. Saturated salt water in aluminum pans is used to flat the aquatic insects at streamside. This eliminates sand and rocks from the sample.

Samples are processed in the laboratory by technicians trained in identification and quantification techniques. An 8-pan subsampler is used to reduce samples to workable size. Technicians also run a dominance and taxa diversity index (DAT) and record dry weight biomass for each sample. Data is fed into the computer, which provides printout lists of (1) a species analysis list, listing names from class to species along with the mean number of species per square meter, mean grams per species per square meter, and logorithemic functions; and (2) total sample statistics, which contain 11 columns of statistical computations for the total sample of species, including mean numbers of species per square meter per station, confidence limits, standard deviations, etc.

One of the most significant measures of habitat quality and water quality is the Biotic Condition Index (BCI) which compares a stream's condition to its own potential based upon the natural physical and chemical characteristics of the ecosystem.

The BCI is computed using the samples' statistical data and the DAT. The BCI is helpful to evaluate stream conditions based on its own potential and to define management strategies for that stream.

Instream Flow Method. This method is part of GAWS for the measurement and evaluation of aquatic habitat. This methodology is based on a habitat-discharge relationship evaluation to estimate a low streamflow. Since any flow reduction or manipulation affects the aquatic habitat, the basic approach is to determine discharge-habitat relationships and establish a reference from which further flow reductions could be related to retention or loss of aquatic habitat.

GAWS is used to predict habitat retention at low level streamflows on cold-water mountain trout streams that range from 1-45 meters (3-150 feet) in width. The instream flow hydraulic parameters can be measured separately or included within single or multiple transects of the GAWS stream habitat transect survey method. Hydraulic parameters measured across the transect at the index or reference flow include depth, width, gradient, and velocity. Aquatic habitat features which can be measured to assist the biologist in evaluations of the instream flow data include subjective streambank cover and stability evaluations, pool-riffle area and quality, and streambottom composition. A computer program, GAWS HABITAT, is used separately from the GAWS Instream Flow Program, to calculate and summarize aquatic habitat transect features. Hydraulic parameter outputs for the GAWS INSTREAM FLOW method include three primary output groups, as follows:

1. Stream Channel Profile. A display of the vertical cross section (measured at right angles to the direction of flow) of a given transect. It shows the Index Flow as it relates to the channel profile and additional levels desired by the user (the program is designed to print out seven levels below and five levels about the Index Flow).

2. Aquatic Habitat Flow Table. A computer tabulation printout of hydraulic features at the Index Flow and the desired water levels of the user. Hydraulic features include wetted perimeter, surface width, maximum depth, cross-sectional area, velocity, and discharge. Each tabular column has two figures. The figure on the left is the parameter value and the figure on the right is the percent of the parameter retained when compared to the Index Flow. In addition, the table contains stream location/identification data such as stream name, state, Forest, date, Forest catalog number, station and transect number, as well as a summary of selected habitat transect data, i.e., gradient, riffle width, channel width, mean depth, and pool quality ratings.

3. Aquatic Habitat Flow Graph. A computer display of hydraulic features in the aquatic habitat flow table in graphic form plotted against measured and predicted discharges. The graph shows visually the intervals between discharge estimates and the hydraulic features. The measured field values are the base point indicated as 100 percent of retention of the Index Flow. The graph shows what percent retention (vertical axis) of the hydraulic feature exists as a result of a measured and predicted discharge (horizontal axis).

The R-4 GAWS Instream Flow method has been in use within the six-state Region 4 area since 1975 and has maintained its credibility in water adjudication court cases.

Flow recommendations for habitat preservation fisheries, and water adjudications require interpretive analysis and judgment by the biologists.

The method is not as time-consuming and expensive as the Fish and Wildlife Service IFG3 or IFG4 methods. It needs only one flow measurement for a simple minimum flow recommendation and provides an array of predicted flows and habitat values at low flows.

SUMMARY

The GAWS program provides biologists and administrators in Region 4 of the Forest Service a ready reference and catalog for storing and retrieving aquatic habitat data. Each water on every National Forest in Region 4 has an identifying catalog number to establish positive identification of individual waters for computer data files and for storage of survey data for later retrieval and manipulation into output programs. A sequential numbering system using two-digit and three-digit series is used for streams, and alphanumeric combinations are used for lakes. Accompanying these catalog numbers are also the state wildlife agency code number for the water surveyed and the national watershed numbering code so that easy and efficient retrieval of data can be assured by In-Service and Out-Service users.

At the present time, the GAWS computer system is operational for data input/output for stream habitat, instream flow, and macroinvertebrate survey elements. Analysis of these three survey elements within GAWS provides a habitat condition index (HCI) for stream habitat, a biotic condition index (BCI) for macroinvertebrate-water quality relationships, and 12 predicted levels of instream flows based on single or multiple instream flow transects. Portions of the GAWS program became computer operational in 1975. Full operational status for the entire GAWS program is expected by the mid-1980's.

Additional information on GAWS can be obtained by calling or writing the author on the Wildlife Management Staff, Intermountain Region: telephone (801) 625-5662 or FTS 586-5662.

AN APPROACH FOR EVALUATING THE POTENTIAL SIGNIFICANCE OF CHEMICAL CONTAMINANTS IN AQUATIC HABITAT ASSESSMENT[1]

G. Fred Lee[2] and R. Anne Jones[3]

Abstract.--Recent changes in the critical concentrations of chemicals which may affect the numbers, types, and growth of aquatic organisms, especially fish, necessitates that those doing fish physical habitat assessment ascertain whether chemical impacts are adversely affecting their assessment. Guidance is provided on how to determine whether trace concentrations of chemicals are adversely affecting the numbers and types of fish present at a particular location in a stream.

INTRODUCTION

The refinement of instream flow methodology for determining the numbers and types of fish that could be present at a particular location requires that greater attention be paid to the relative roles of physical habitat characteristics such as bottom type, water depth, velocity, etc., and chemical factors such as nutrients, toxicants, etc., in influencing fish populations at a specific location within a river or stream. It is known that even "trace" amounts of certain chemicals (sometimes at levels below those readily measurable) derived from even natural sources, can, in certain instances, adversely affect fish populations. Therefore, aquatic habitat assessment work should include site-specific evaluations of the potential role that contaminants present in the water could have on the fish populations found in a particular location. This paper addresses this topic and provides guidance on how chemical factor considerations should be incorporated into aquatic habitat assessment.

IMPACT OF CHEMICALS ON FISH POPULATIONS

Chemicals can generally affect fish populations in one of two ways. Certain chemicals can act to stimulate or sustain the production of fish. Others can impair fish growth, reproduction, health, or presence in a particular place either directly by affecting the fish or indirectly by affecting fish food organisms.

Impact of Aquatic Plant Nutrients

Aquatic plant nutrients, principally nitrogen and phosphorus in certain forms and within certain concentration ranges, stimulate and sustain the overall primary production - fish food biomass in a water and thus allow the development of a certain amount of fish. While, as discussed below, the relationships between the nutrient (especially phosphorus) loads to or concentrations in a lake or impoundment and trophic status characteristics (including fish yield) have, in general, been quantified, they have not been quantified for rivers and streams. It is obvious, however, that as in lakes and reservoirs, within certain limits, increasing the input of certain nitrogen and/or phosphorus compounds will increase the productivity of the water as may be manifested as increased attached and planktonic algae, and attached and floating aquatic macrophytes, and hence, increased amounts of zooplankton and fish. More apparent in flowing water systems, however, is the complicating factor of allochthonous detrital organic matter serving as a food source for zooplankton, small fish, etc. Although apparently not quantitatively studied to any significant extent, it appears that the detrital food web in general plays a greater role in streams with lower primary production.

Before it will be possible to develop quantitative relationships between the concentration or load of nitrogen and phosphorus compounds, and trophic status characteristics in the riverine environment, it will be necessary to understand the roles that specific forms and concentrations of various nitrogen and phosphorus compounds play in controlling planktonic and attached algal growth. It is important to recognize in conducting or reviewing any work that is done on the impact of

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[1]Paper presented at American Fisheries Society symposium, "Acquisition and Utilization of Aquatic Habitat Inventory Information," (Portland, OR, October 1981).

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nutrients on aquatic plant growth or fish populations that only certain forms of nitrogen and phosphorus are available to support algal growth. Soluble orthophosphate, nitrate, and ammonia are the principal compounds of concern. Particulate and organic forms of phosphorus and nitrogen are, in general, not immediately available to support algal growth and, therefore, probably play limited roles in governing algal growth at the point in a stream or river where measurements are made. Algal growth at any particular point is determined by the readily available forms at that point. Lee et al. (1980a) provide a summary and discussion of the current information on the available forms of phosphorus, and methods for their assessment. They concluded that available phosphorus in rivers draining into the US-Canadian Great Lakes could be estimated by the sum of the soluble orthophosphate concentration and about 20% of the particulate phosphorus concentration. If these results are typical, what this translates into in terms of the riverine environment is that the soluble orthophosphate at the point of sample collection is available for algal growth there, and 20% of the particulate phosphate at that point will likely be available at some point downstream.

One of the first steps that should be undertaken in the investigation of nutrient - fish relationships is a study of the relationships between nutrient concentrations in rivers and streams, and the primary production of the algae and other aquatic plants present in the stream. The diel dissolved oxygen method of estimating primary production, such as that outlined by APHA et al. (1981) Section 1003 D.4, would likely be suitable for this purpose. As far as the nutrient portion of these investigations is concerned, it would be important to evaluate which nutrient, if any, is limiting the growth of algae and other aquatic plants in the stream segment of concern. While relatively simple relationships have been developed for determining limiting nutrients in lakes and reservoirs (see Lee and Jones, 1981a), similar relationships have not been developed for flowing waters. One of the problems which would greatly complicate developing such relationships for rivers and streams is the fact that in flowing waters, the concentrations of nutrients, like those of other chemicals, may be highly variable.

Once these areas have been understood, then work can proceed on determining the relative roles of attached and planktonic algae in influencing zooplankton populations in various types of streams, and to understand the relationships between the abundance and type of zooplankton and fish. With the reductions in funding for research that have occurred in the past and that will continue in the future, it is likely to be a very long time before the above-mentioned relationships will be understood to a sufficient extent to enable reliable predictions to be made of the change in the numbers and types of fish present in a particular stream or river having a particular set of physical habitat characteristics, that may result from a change in the aquatic plant nutrient concentrations in the water. While this may never be adequately done, as a start, work should be done on the deterministic modeling of nutrient-aquatic plant-zooplankton-fish couplings in rivers. In addition, statistical, correlative-type studies should be undertaken to define, in a general way, the expected fish populations as a function of the nutrient content of the water.

As part of the modeling effort, in situ experimental systems should be set up to attempt to define some of these relationships. Such experiments should be begun with the monitoring of fish populations in areas having defined physical habitat characteristics, and be continued for several years. Then two reaches having the same physical habitat and fish characteristics should be singled out; one should receive nutrient additions for several years and the other, not, in order to determine what, if any, changes in fish populations occur.

Load - Response Relationships

The ultimate objective of the nutrient concentration - aquatic plant growth - fish yield work for streams should be the development of relationships such as that between phosphorus load to a lake or reservoir and the biomass of fish produced in the waterbody shown in figure 1. The development of figure 1, as described by Lee and Jones (1979a) was based on the results of the US OECD eutrophication study program.

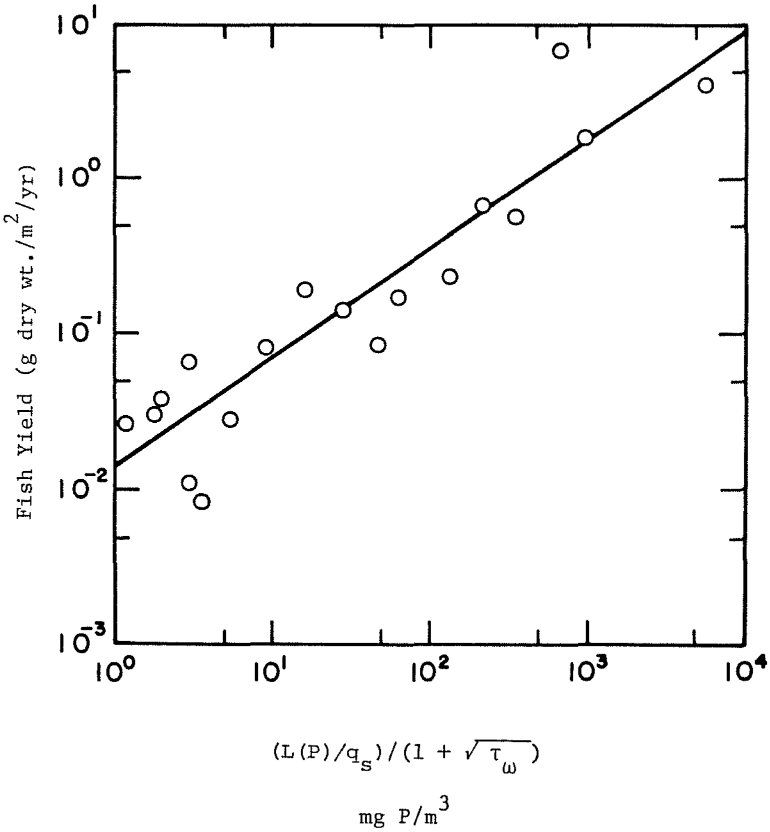


Figure 1.--Relationship between phosphorus load and fish yield (after Lee and Jones, 1979a) (see figure 2 for explanation of terms).

In the early 1970's, 22 member countries of the Organization for Economic Cooperation and Development (OECD) initiated a five-year study on 200 waterbodies (lakes and impoundments) located in Western Europe, North America, Japan, and Australia to define relationships between nutrient load and eutrophication-related waterbody characteristics. The concepts for the work progressed from Vollenweider (1975, 1976) who developed for a group of waterbodies, a statistical relationship between the phosphorus loads normalized by the waterbodies' mean depths and hydraulic residence times, and the waterbodies' planktonic algal growth as measured by the average chlorophyll concentrations. The normalized phosphorus loads were thus empirically related to the average phosphorus concentration of the waterbody. As part of the US part of the OECD study program, Rast and Lee (1978) determined analogous relationships for the approximately 40 US waterbodies included in the program, between normalized P load and planktonic algal chlorophyll, Secchi depth (water clarity), and hypolimnetic oxygen depletion rate, all factors that reflect the amount of planktonic algal production in the waterbody.

Lee et al. (1978) summarized the results of the US OECD work which was completed in the mid-1970's. Since that time, the authors have continued to examine and evaluate the applicability of the US OECD load - response relationships and have found that the additional 40 or so waterbodies (lakes and impoundments) they have since evaluated, follow the same general load - response couplings found for the US OECD waterbodies. Using their entire US waterbody data base, Jones and Lee (1982) developed the correlations shown in figure 2. The work of Rast et al. (1981) has shown that by knowing the magnitude of change in the phosphorus load to a waterbody, this approach can be used to make reliable estimates of the change in chlorophyll and Secchi depth that will result. Through the lines of best fit shown and with information from the literature, Lee and Jones (1979a) developed the normalized phosphorus load - fish yield relationship shown in figure 1.

Ultimately, through load - response studies of the type conducted as part of, and subsequent to the US OECD eutrophication study program, it should be possible to formulate similar types of relationships between phosphorus concentration, primary production, and fish yield in rivers. The normalizing factor for phosphorus load to rivers and certain nearshore areas would undoubtedly, however, have to be different from those for lakes and reservoirs. The variable concentrations of nutrients in a lotic system would likely need to be included, perhaps through a water velocity component to account for the time that a certain parcel of water is in the vicinity of attached algae or other attached aquatic plants. Further the Vollenweider-OECD-Rast-Lee-Jones load - response relations are only applicable to planktonic algal growth. Additional factors would likely have to be included to account for nutrient uptake by mechanisms peculiar to attached algae and aquatic macrophytes.

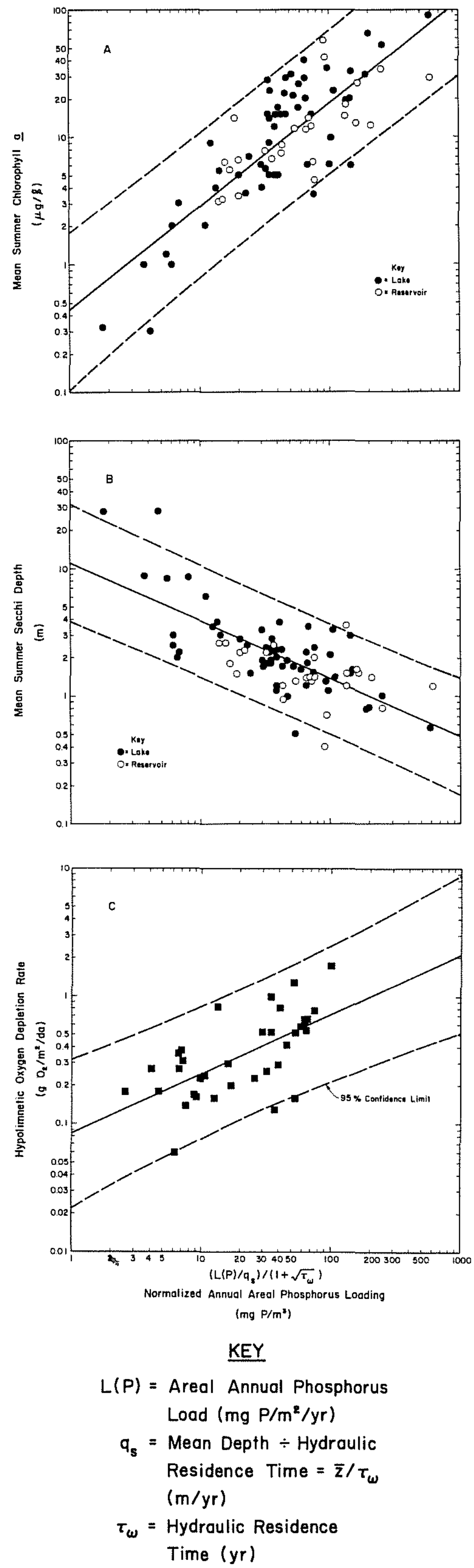


Figure 2.--Relationships between phosphorus load and eutrophication-related water quality characteristics (after Jones and Lee, 1982).

Impact of Toxicants

By far the greatest attention regarding chemical effects in physical habitat assessment studies should be directed toward toxicants that could be adverse to fish or fish food organisms. Since the mid-1960's, international, federal, and state pollution control agencies and others have devoted a considerable amount of attention to determining "critical" or maximum safe concentrations of chemicals for fish and some other forms of aquatic life. Two publications compiled much of this early information: the McKee and Wolf (1963) Water Quality Criteria, and the Federal Water Pollution Control Administration (FWPCA) (1968) Water Quality Criteria, also known as the "Green Book." The former was a noncritical compilation of the literature available as of the early 1960's on the concentrations of chemicals that can impact aquatic life and other beneficial uses of water. The FWPCA (1968) document, prepared by the National Technical Advisory Committee of the FWPCA, was the first critical compilation of this type, giving consideration not only to the data but also to their validity as assessed by the laboratory methods used and other factors that could affect the results of the testing. Primary emphasis was given in the Green Book to the concentrations of chemicals that were acutely toxic to aquatic life. In the water quality management field "acute toxicity" is generally described by the 96-hr LC_{50} value, i.e., the concentration of a contaminant that will kill 50% of the test organisms in 96 hours.

Prior to the mid-1970's water quality criteria and standards were generally based on the 96-hr LC_{50} and a safety factor multiplier, usually 0.1. By the early 1970's, it was becoming clear that some chemicals, when present at concentrations at or below one one-hundredth of the 96-hr LC_{50} could have adverse effects on aquatic organisms that were exposed to these concentrations throughout their lifetimes. Hence, it was clear that such a criteria and standards approach did not afford sufficient protection for such "chronic exposure" situations.

In the early 1970's, the US EPA commissioned the National Academies of Science and Engineering (NAS and NAE) to perform a critical review of the literature on the impacts of chemicals and other agents, on the beneficial uses of water. This resulted in the publication of the Water Quality Criteria 1972 (NAS-NAE, 1973) known in the field as the "Blue Book." The emphasis of the Blue Book was significantly different from that in the Green Book. Whereas the Green Book focused on acute toxicity in defining "critical" concentrations, the Blue Book focused on chronic toxicity; critical concentrations were estimated based on the concentration that would be safe to aquatic life under conditions of lifetime exposure. It also began to take into account that characteristics of a water other than the concentration of the toxicant of concern could impact the toxicity of the chemical. The National Academies' committee prescribed that as part of establishing a "critical" concentration of a chemical, the 96-hr LC_{50} should be determined for the chemical in the particular water of concern. This value was to be translated into a chronic safe level using an application factor of 0.01 which had been found appropriate for this purpose for many chemicals. Since then, application factors generally between 0.1 and 0.001 have been found for various chemicals.

With the passage of PL-500 in 1972, the US EPA was required to develop water quality criteria which were to be used as a basis for state water quality standards. These criteria were released in July 1976 in what has become known as the "Red Book" Quality Criteria for Water (US EPA, 1976). The US EPA Red Book was developed "in-house" without substantial review by the technical community. The American Fisheries Society (AFS, 1979) subsequently conducted a critical review of these criteria and updated the information presented on the toxicity of many chemicals to aquatic life. This review also pointed out a number of important problems with the criteria and the way in which the US EPA developed them for some contaminants.

PL 92-500 also required that the US EPA develop a separate list of "toxic chemicals" and promulgate criteria for these chemicals. When the US EPA failed to meet its deadline for developing this list, several environmental activist groups filed suit against the agency to force it to comply with this section of the regulation. This suit was settled by a court decree which forced the development of such a list. This list developed by the US EPA and the environmental activist group involved in the suit, albeit without proper technical review, has become known as "the list of 65," since 65 chemicals or groups of chemicals were included. In actuality, there were 130 individual chemicals included in this list. The US EPA, in November 1980, released the water quality criteria for 129 of these "toxic" chemicals (US EPA, 1980). A number of these chemicals had been included in the US EPA July 1976 Red Book; the November 1980 release represented an update of the information on the toxicity of these particular chemicals to aquatic life. The US EPA is scheduled to release updated criteria information in about January 1982 for a number of the chemicals listed in the Red Book which were not updated in November 1980.

A number of significant changes were made by the US EPA in its approach to the development of the November 1980 criteria compared to that used previously. One of the most important was the discontinuance of the application factor approach in favor of a single-value, numeric standard approach. Further, the US EPA has assumed a zero threshold model for those chemicals which are known or suspected of causing cancer in man or animals. In some cases adopting this approach has decreased the 1976 criterion value by a factor of 10^3. For example, the Red Book criterion value for DDT was 1 ng/l; one of the November 1980 criterion options for this chemical was 0.0034 ng/l. Supposedly DDT in water at this concentration could bioconcentrate in fish to a sufficient extent to cause in the United States one additional cancer in 10,000,000 people when these fish are used extensively as human food. From a fish habitat assessment point of view, the concentrations of carcinogenic chemicals that bioconcentrate in fish are of little concern since these concentrations are, in general, far less than the concentrations that are adverse to the aquatic organisms themselves. It is, therefore, important in physical habitat assessment work, to carefully screen the chemical water quality criteria information and select only those values which have been developed based on impact on aquatic life.

The best source of information today on the critical concentrations of chemicals to aquatic life are the NAS-NAE Blue Book; the US EPA July 1976 and November 1980 criteria, as well as those planned for release in January 1982; the supporting documents for these criteria; and the AFS critique of the US EPA Red Book. Because new information is currently being developed in this field, and because these criteria and supporting documents are frequently several years behind the new information, it is important to keep abreast of new literature in the field. This can usually be most readily done through the Journal of the Water Pollution Control Federation annual reviews of the water quality management literature, which are published each year in the journal. A word of caution should be given to those not familiar with this field, concerning acceptance of "new" information as being more reliable than previously-developed information. Frequently, minor changes in procedures used in toxicity testing will significantly affect the results of the test. Even if an investigator claims that he followed "Standard Methods procedures" one should not automatically assume that the work is reliable. Procedures in Standard Methods (APHA et al., 1981 and previous editions) allow considerable latitude in the experimental approaches that may be used in toxicity testing. In general, the authors have found that the toxicity testing procedures developed by the American Society for Testing and Materials (ASTM) Committee E-47 tend to produce more reliable and reproducible results than those found in the APHA et al. Standard Methods.

Another potential source of data on the toxicity of chemicals to aquatic life are the state water quality standards and any supporting documentation. According to PL 92-500, each state must develop water quality standards which are to be legally enforceable limits on the concentrations of chemicals present in the state's waters. Generally, these standards are designed to protect certain beneficial uses, such as fish and aquatic life, domestic water supplies, irrigation waters, etc. While for the most part, because of US EPA policy, states have adopted the numeric values of the US EPA criteria as standards, in November 1980 the US EPA abandoned its policy of presumptive applicability of its criteria and thereby potentially provides for much greater flexibility in implementing US EPA criteria into state water quality standards. Some states, such as Colorado, are beginning to conduct toxicity testing in order to evaluate the critical concentrations of chemicals to aquatic life or other beneficial uses of water in their region. This kind of evaluation may in some situations be more appropriate for defining critical or safe concentrations of some chemicals for aquatic life than the US EPA criteria. Again, caution should be exercised in suggesting that a state standard is necessarily more reliable or less reliable than a federal criterion. It is best for those who work in the fish habitat area but are not familiar with aquatic toxicology to obtain the assistance of an expert in this area to assist in the selection of "critical" concentrations of chemicals to aquatic life for a particular waterbody.

Problems in Using US EPA Criteria and State Water Quality Standards

The US EPA water quality criteria were deliberately designed to be worst-case criteria, to be chronic - lifetime exposure safe concentrations for the available forms of the contaminants. There are many situations in natural waters in which the total concentration of a contaminant can be considerably above the US EPA criterion, without adverse effects on aquatic life residing in these waters. As shown in figure 3, there is a relationship between the concentrations of the available forms of contaminants and the duration of exposure that an aquatic organism may experience without being adversely affected. Relatively high concentrations of chemicals can be tolerated for short periods of time. But as the duration of exposure is increased, the concentration of the contaminant that can be tolerated without adverse impact concomitantly decreases. The horizontal line in figure 3 is representative of the chronic exposure, worst-case criteria developed by the US EPA. An organism can be exposed to this concentration for its entire lifetime without adverse impact.

In most natural water systems the concentrations of the available forms of a contaminant are highly variable, with changes in concentration on the order of a factor of ten or so within a few hours not uncommon. Factors such as variable contaminant loads, variable stream discharge, and natural diel processes all tend to cause the concentrations of contaminants to vary substantially in many aquatic systems thus altering the duration of organism exposure. It is therefore important that anyone doing fish habitat assessment work determine the variability of the concentrations of the various contaminants of potential concern as a function of factors that could influence these concentrations, such as time of day, day of week, season, and stream and contaminant discharges in order to get a more realistic estimate of duration and pattern of exposure of organisms.

Figure 4 illustrates many potential duration of exposure situations not uncommon in natural water systems. In the vicinity of the point of a contaminant discharge there is an area in which the discharge is physically mixed and diluted with the receiving waters, i.e., the zone of physical mixing. Depending on the situation, the contaminant concentrations within this zone, or within part of

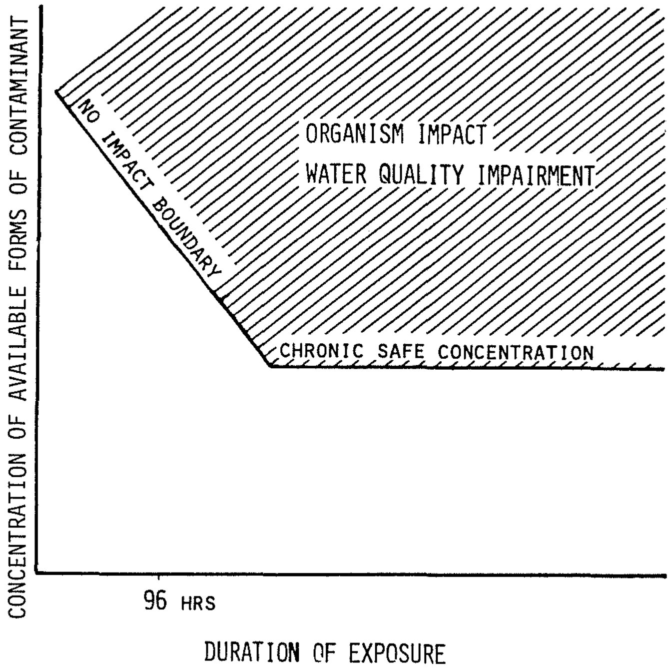
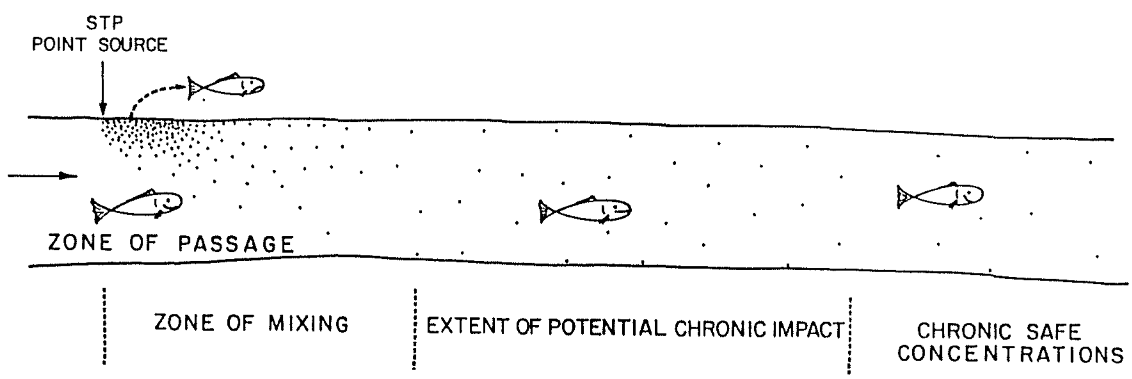


Figure 3.--General concentration of available forms - duration of exposure relationship (after Lee et al. 1980b)

this zone (or under more rare circumstance, beyond this zone) may be sufficient to cause acute lethal toxicity to fish forced to stay in the area for days. Certain fish, however, are known to exhibit an avoidance behavior when the concentrations of certain chemicals are elevated, thus affecting the likelihood of their being exposed for potentially dangerous durations. Further, for some contaminants if their discharge were steady and of reasonably constant concentration, fish tend to become acclimated to the elevated levels, and are thereby able to withstand higher concentrations than fish that had not previously been exposed. There is often, associated with discharges, a "zone of passage" past the area of potential acute lethal toxicity in which a fish could reside without impact. As shown in figure 4, there is associated with many discharges, also a zone of potential chronic toxicity. This zone extends to the location downstream at which the concentrations of all contaminants are less than the US EPA criteria. This distance can be less than a few hundred meters or as great as tens of kilometers downstream of the point source discharge. Below the zone of potential chronic toxicity, the numbers and types of fish present should be controlled exclusively by the physical habitat characteristics and the biological interactions between the organisms living in the area. Within the zone of potential chronic toxicity, however, the role of chemical contaminants must be



DOMINANT CHARACTERISTICS		
·High concentrations ·Short duration of exposure ·Potential acute lethal toxicity ·Avoidance	·Potential chronic impact based on US EPA Red Book criteria (chronic safe levels) ·Longer duration of exposure ·Acclimatization	·Safe concentrations based on US EPA Red Book criteria (chronic safe levels)

FISHERIES-RELATED BENEFICIAL USE OF REACH OF RIVER CONTROLLED BY:		
·Habitat characteristics ·Possible acute lethal toxicity of contaminant	·Habitat characteristics ·Potential chronic toxicity or other impairment due to contaminant	·Habitat characteristics

Figure 4.--Schematic representation of potential impact of non-persistent chemicals discharged in wastewater effluent (after Lee et al. 1980b)

considered as a factor influencing the numbers and types of fish present. The "effective" duration of exposure depends on how much time an organism spends in any of these zones, the pattern of exposure, etc.

For many waters the most important factor causing chemicals at total concentrations above US EPA criteria values to not adversely affect aquatic life is the fact that many chemical contaminants exist in natural waters in a variety of forms, only some of which are "available" to adversely affect aquatic life. There are few contaminants for which the total concentration is a reliable indicator of potential water quality impact. It is important in any habitat assessment work to determine the availability of the forms present and the factors influencing their availability. A prime example of the importance of aquatic chemistry in determining aquatic toxicity is provided by the US EPA 1980 criterion for cadmium. For soft water systems, a criterion value of 0.012 μg/l has been established by the US EPA. There are very few waters anywhere with total cadmium levels below this amount. It is evident that substantial parts of the total cadmium levels present in many aquatic systems are in forms that are not available to aquatic life.

Aqueous environmental chemistry has been one of the most neglected areas in the assessment of the potential impact of chemicals on beneficial uses of water. Lee (1973) and Lee and Jones (1980, 1981b) discuss the importance of considering aquatic chemistry in such evaluations and provide insights into how this can and should be accomplished.

Another problem with trying to use the US EPA water quality criteria directly for evaluating potential chemical impacts in physical habitat assessment is that a number of the criterion values are below the concentrations that can be readily measured with normally-used analytical procedures. While in most cases it is possible, through the use of special-purpose analytical techniques, to measure contaminants at or near criterion values, it requires working with individuals who are familiar with the latest developments in the area of analytical techniques for natural water systems. Further, when working with these concentration ranges, great care must be taken to avoid contamination and analytical interference.

APPROACH FOR EVALUATING THE SIGNIFICANCE OF CONTAMINANTS IN AFFECTING NUMBERS AND TYPES OF FISH PRESENT

It is suggested that a "hazard assessment" approach be used to evaluate whether chemical contaminants could be playing a significant role in determining the numbers and types of fish in a particular area.

Elements of Hazard Assessment

Hazard assessment, as it is becoming known today in the water quality management field, is the combined integrated evaluation of the aquatic toxicity and environmental chemistry-fate of the contaminant or combination of contaminants present in an environment. The objective is to define expected contaminant levels and the impact of them on designated beneficial uses of the particular water of concern based on a given set of site-specific conditions, by describing a concentration - duration of exposure - impact relationship such as that shown in figure 3. For cost-effectiveness, this evaluation is made in tiers. Early tiers prescribe more simply screening tests to identify the highly hazardous and essentially innocuous contaminants in the situation being evaluated. The higher tiers directing more sophisticated and expensive testing, can be reserved for those contaminants and situations for which the potential hazard is not readily definable. The use of this approach for evaluating the impact of discharges on beneficial uses of water has been described by Lee et al. 1980b and Newbry et al. 1981.

Hazard Assessment in Physical Habitat Assessment

It is first assumed that these evaluations are being conducted in conjunction with a physical habitat assessment study. In the first tier of the chemical evaluation, a general understanding of the setting and pertinent conditions at the specific site should be obtained. This would include determining potentially influencing point and nonpoint discharges, land use, and flow. The literature should be examined and if necessary electroshocking or other fish census work should be conducted to determine the numbers and types of fish inhabiting the area of concern and areas having similar habitat but different potential chemical influences, ideally in a more "pristine" area. A word of caution is offered, however, when labeling an area "pristine" since as indicated above, trace contaminants from "natural" sources can also affect fish. If it can be clearly established that these areas of similar habitat have similar fish populations, then it might be assumed that the chemicals present are not having a major impact on fish populations in the reach of concern. If the populations are not the same or if such an assessment cannot be made, testing should continue.

If a point or nonpoint source of contaminants is suspected of influencing the area of concern, the constituents of the discharge should be defined as well as possible. If discrete contaminants can be identified (for example, ammonia, nitrite, and chlorine in a domestic wastewater treatment plant effluent), their concentrations should be measured in the water of concern. If the area of concern is within the direct influence of a discharge, a more detailed assessment of mixing, chemical transformation, etc. would have to be made as described by Lee et al. (1980b) and Newbry et al. (1981). No attempt should be made at this stage to quantify trace amounts of every potential toxicant present, but rather, only grossly contaminating substances.

The next step would be to place instream fish toxicity testing cages with sensitive test fish, in the area of concern and in the vicinity of the point or nonpoint contaminant source(s) immediately upstream of the area of concern. The primary objective of this testing would be to define what would be analogous to an LC^{50}, for the combination of contaminants and forms of contaminants at the site of concern and near the offending discharge. It is desired to determine the point at which 50% of the test organisms die within a 96-hr exposure. Then, in a manner analogous to using the 96-hr LC_{50} and an application factor to determine a chronic exposure safe concentration, the point at which the site waters should be chronically safe for fish can be determined by computing at what point below the "96-hr LC_{50}" test cage, 100-fold dilution (i.e., an "application factor" of 0.01) would have occurred. Beyond this point, until the next chemical input, chemicals should not be impacting fish populations; above this point, they could. This approach would be conservative in terms of environmental protection since it assumes that the only factor responsible for decreasing contaminant concentrations is dilution; in reality, many contaminants undergo physical and chemical transformations which decrease the concentrations of their available or toxic forms.

If desired, the "hazard assessment" could be continued to determine chemical transformation and to determine more precisely the area actually being "impacted" by contaminants. Heinemann et al. (1981) describe how such an assessment can be made using the example of domestic wastewater treatment plant chlorine.

The most reliable procedure for determining whether chemical contaminants are having an adverse effect on numbers and types of fish present involves the use of chronic bioassays, in which sensitive aquatic organisms are exposed to waters of the region for sufficient periods of time to detect not only acute toxicity potential but also chronic effects such as lethal and sublethal impairment of reproduction, altered growth rates, etc. Tests of the types described above involving the use of Daphnia (Mount and Norberg, 1981) appear to be well-suited to this purpose. If toxicity is found with tests of this type and there are questions about the cause of this toxicity, a standard additions technique of the type described by Lee and Jones (1979b) could be used to determine whether a particular chemical is responsible for the toxicity observed.

CONCLUSIONS

Recent changes in what are perceived to be "critical" concentrations of contaminants for aquatic life necessitate that those doing habitat assessment - fish population studies consider the possible influence of chemical contaminants on the numbers and types of fish present at any location. Since the "critical" concentrations of some contaminants for fish and other aquatic life are less than the total concentrations often present in natural waters, the aqueous environmental chemistry and expected exposure durations must be considered in these evaluations. The US EPA water quality criteria provide a convenient, worst-case starting point for assessing whether contaminants present in a particular water could be adversely affecting fish populations. A hazard assessment approach should be used to evaluate whether the presence of a contaminant at concentrations above the US EPA criterion represents adverse conditions for fish or other aquatic life in a particular waterbody.

While significant advances have been made through the use of the US OECD study results to relate nitrogen and phosphorus loads to the fish yield of a lake or impoundment and to a lesser extent to the types of fish present, little is known today about the impacts of nitrogen and phosphorus in stimulating fish populations in streams and rivers. This is an area that needs attention as part of physical fish habitat assessment work.

It is clear that as instream flow methodology and similar physical habitat assessment techniques move from the "pristine" remote areas to those areas more heavily impacted by man, much greater emphasis will have to be given to the impact of chemicals on the numbers and types of fish present in a particular waterbody.

ACKNOWLEDGMENTS

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SESSION 5A

Moderator: Dave Heller
U.S. Forest Service
Portland, Oregon

The Following Not Included in Proceedings:

C. Jeff Cederholm, Washington State Department of Natural Resources.
Observations of Winter Movements of Juvenile Sculpins and Speckled Dace in Tributaries of the Clearwater River, Washington.

Robert Tuck, Yakima Indian Nation.
Yakima River Study.

AQUATIC HABITAT INVENTORY -

THE ONTARIO APPROACH TO LAKE SURVEYS[1]

G.A. Goodchild and G.E. Gale[2]

Abstract -- Ontario's aquatic habitat inventory program for lakes, its background, survey approach, data storage and retrieval system and some practical applications for management are discussed. Since 1968, 10,000 of the province's 250,000 lakes have been surveyed. Standard biological, chemical and physical data have been obtained and stored on line for rapid retrieval and analyses using System 2000.

INTRODUCTION

The province of Ontario is approximately 363,000 square miles in area or almost one and a half times the size of Texas. Over one quarter of a million inland lakes in the province comprise 10% of the surface area, an area approximately half the size of Oregon.

Much of the province is inaccessible except by float plane; in fact half of the province has yet to be surveyed and organized into townships. A great majority of the lakes are in these remote areas. They are typically fragile, unproductive and oligotrophic, especially those in the Precambrian shield, and many are ice covered for up to 6 months of the year.

Lake surveys completed prior to 1968 are usually insufficient by today's standards and have been criticized for being "poorly done, poorly documented and seldom (providing) a sufficient basis for diagnosing a lake problem" (Loftus 1976). Equipment and techniques used were primitive and irregular at best, with much of the focus on collecting fishes and little consideration given to other facets of the aquatic habitat. Surveys were often completed on an ad hoc, management-by-crisis basis, usually on easily accessible lakes, and data collected were seldom standardized within the Ontario Ministry of Natural Resources organization (presently 47 districts, 8 regions, and over 20 assessment and research units).

We now know that during this period in the 1950's and 60's uncontrolled fish harvest, degradation of environmental quality and conflicts among users of natural resources were becoming serious problems. A standardized program of aquatic habitat inventory was essential to initiate proper lake management.

PROGRAM DESCRIPTION

In 1968 a program was initiated to standardize the collection of lake inventory data throughout the province. These inventory surveys were not intended to answer complex questions nor solve problems for long-term management but were to provide the "first good look" at a body of water, i.e. basic knowledge upon which further management can be based. Since 1968, over 10,000 selected lakes have been inventoried, the lakes being chosen according to a pre-determined set of criteria (Table 1).

It should be emphasized that inventory surveys are point-in-time data collections as lakes are usually visited once and once only. Time series data collection on lakes is a function of several fisheries assessment units (Anon. 1978).

Inventory surveys are usually conducted by university students and recent graduates. Each spring, after ice out in late May, as many as 150 surveyors are instructed in the techniques and procedures of surveying lakes at a central training course. Both classroom and field work are incorporated into this 10 day training program which complements the Manual of Instructions -

[1]Paper presented at the Symposium on the Acquisition and Utilization of Aquatic Habitat Inventory Information. (Oregon Hilton, Portland, Oregon, October 28 - 30, 1981.)

[2]Co-authors Gareth A. Goodchild and George E. Gale are respectively Aquatic Habitat Inventory Biologist and Data Systems and Laboratory Specialist, both with Fisheries Branch, Ontario Ministry of Natural Resources, Queen's Park, Toronto, Ontario, Canada.

Table 1. -- Aquatic habitat inventory surveys: criteria for lake selection (unpriorized).

1. "Type" Lakes	-	4 representative lakes from each watershed unit.
2. "Lake Trout" Lakes	-	Lakes having known or expected presence of lake trout *Salvelinus namaycush* or potential for introduction.
3. "Stressed" Lakes	-	Over-exploited fisheries, degraded habitat, multi-use and acid sensitive lakes.
4. "Stocked" Lakes	-	All stocked lakes and lakes proposed to be stocked.
5. Lakes "Under Development"	-	Lakes under development or in areas planned to be developed (e.g. cottage and resort development, new roads, etc.)
6. Old or Incomplete Surveys	-	Older surveys of important lakes or incomplete surveys.
7. Other	-	Locally important lakes (e.g. brook trout *Salvelinus fontinalis* lakes, walleye *Stizostedion vitreum vitreum* lakes, meromictic lakes).

Aquatic Habitat Inventory Surveys (Dodge et al. 1981). Examinations are also an integral part of the course. The program is quite flexible in that new ideas are regularly incorporated but all surveys must contain at least the minimal amount of detail as outlined in the manual.

As well as the training program, quality control and standardization of the data is also maintained by a field audit, controlled centrally, followed by a detailed office audit of the completed data before filing. In addition, the small fish collected are preserved in the field and later identified at a central lab. These are later utilized by museums and universities for further study and reference collections. Copies of the final survey summaries are stored in a central paper file as well as a computer storage and retrieval system.

Survey Details

Each survey has three separate parts: (1) pre-field, (2) field, and (3) post-field activities.

Pre-field Activities

Preparation before the field survey consists of examining topographic maps, air photos and watershed maps to properly identify the lake location. Next, preparatory map work is completed, including the enlarging and drawing of work size field maps and the measurement of lake surface areas and shoreline lengths. Many lakes surveyed are quite remote, therefore crews usually of 2 are often air-lifted to the site by float plane or helicopter. Generally, 20 days are spent at a time in the field at a lake or group of lakes. Crews are moved around by air and supplies and equipment are delivered when requested by radio.

Field Activities

The field work is in turn divided into 4 main categories: (1) bathymetric mapping, (2) fish sampling and collecting, (3) physical and chemical water parameter measurements, and (4) shoreline cruise or habitat mapping.

Echo sounding is the most time-consuming activity of a lake survey. Using set criteria, transects are run in straight lines from shore to shore and at a constant speed. Recorded depths from the sounding tapes are then later transcribed onto a map to produce a bathymetric chart (Fig. 1). These are not navigation quality charts, but instead describe the bottom contours and shape of a lake, enabling an accurate mean depth to be calculated.

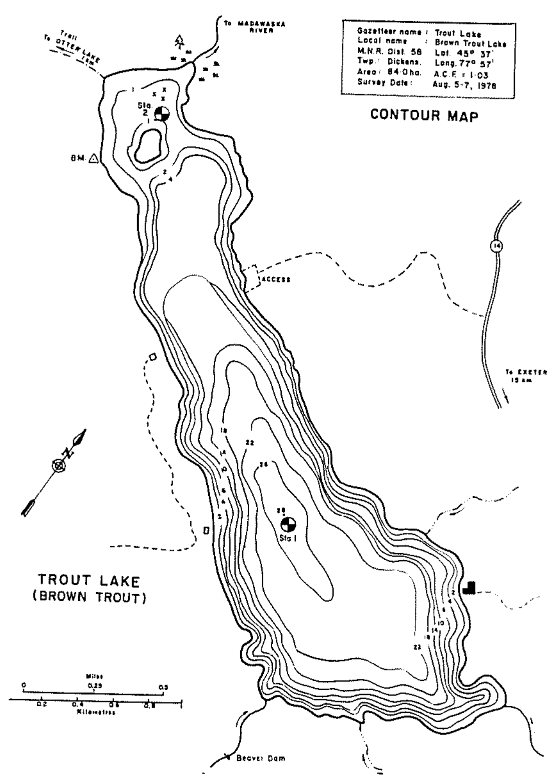


Figure 1. -- Lake survey contour map.

Incidentally, one of the spin-offs from the program is to produce fishing maps. To date over 500 different contour maps with descriptive text have been produced and printed on waterproof paper for sale to the public.

Once the profile of the lake bottom is determined, gill nets are set to sample the larger species of fish while other procedures are carried out. As well as gill nets, seines, small trap nets, dip nets and piscicides are used to collect fishes. The purpose is to collect from as many different habitat types as possible. Sampling is strictly qualitative, not quantitative.

Physical and chemical parameters of the lake water are measured at each basin of the lake. Water temperature profiles dictate at which depths samples are collected and routine Hach kit tests are carried out on these samples. A minimum of three samples are always collected - surface, mid-depth or mid-thermocline, and 2 m above the bottom. As well as dissolved oxygen, pH and alkalinity, specific conductance is also measured and used for the calculation of standard conductance[3] (@ 25°C), total dissolved solids[4] (TDS) and morphoedaphic index[5] (MEI) (Ryder 1965).

The standard secchi, surface conditions and colour are also taken. Water samples are collected by means of a Kemmerer or Van Dorn bottle.

Habitat mapping is the last function performed by the field crew at the lake site (Fig. 2). Surveyors cruise the shoreline of the lake recording substrate type, aquatic macrophytes, terrain features, water levels, inflow and outflow discharge measurements, potential spawning sites, shoreline soil types, timber stands, and possible pollution sources. Cottage counts are also recorded as are potential sites for remote fishing camps.

As well as being plotted on the physical feature map, all quantifiable data collected are recorded on the standardized form 1422 (Fig. 3) while in the field.

In recent years selected crews working in areas potentially susceptible to acidic precipitation have been performing more accurate pH and alkalinity tests (Dillon et al. 1978;

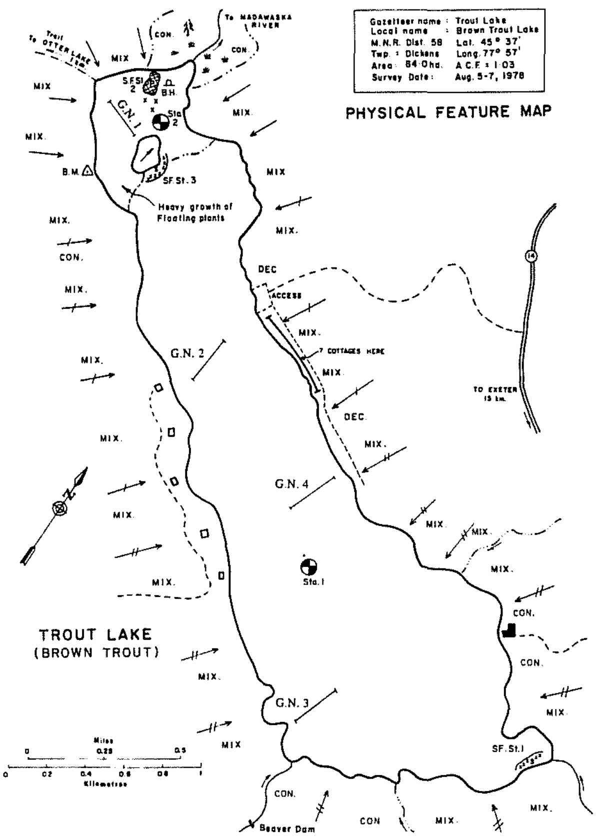


Figure 2. -- Lake survey physical feature map.

Anon. 1979). A field kit for Gran alkalinity titrations has enabled the sampling of hundreds of lakes in this way (Goodchild et al. 1981). Previously remoteness of these lakes precluded collection, shipment and laboratory analyses. These field analyses, however, have proven to be quite accurate by laboratory standards. Since 1979, approximately 3,000 samples have been tested from more than 1,800 lakes. All field data are recorded on standardized forms and a separate computer storage and retrieval system is utilized to analyse, summarize and store the data.

Another piece of equipment found useful is the Hydrolab/Nera Model 4 water quality monitor.[6] This instrument has enabled many water chemistry updates to be conducted from aircraft. As many as 40 remote lakes per day have been sampled by taking measurements directly from the aircraft pontoons. An array of probes is lowered to different depths where pH, temperature, dissolved

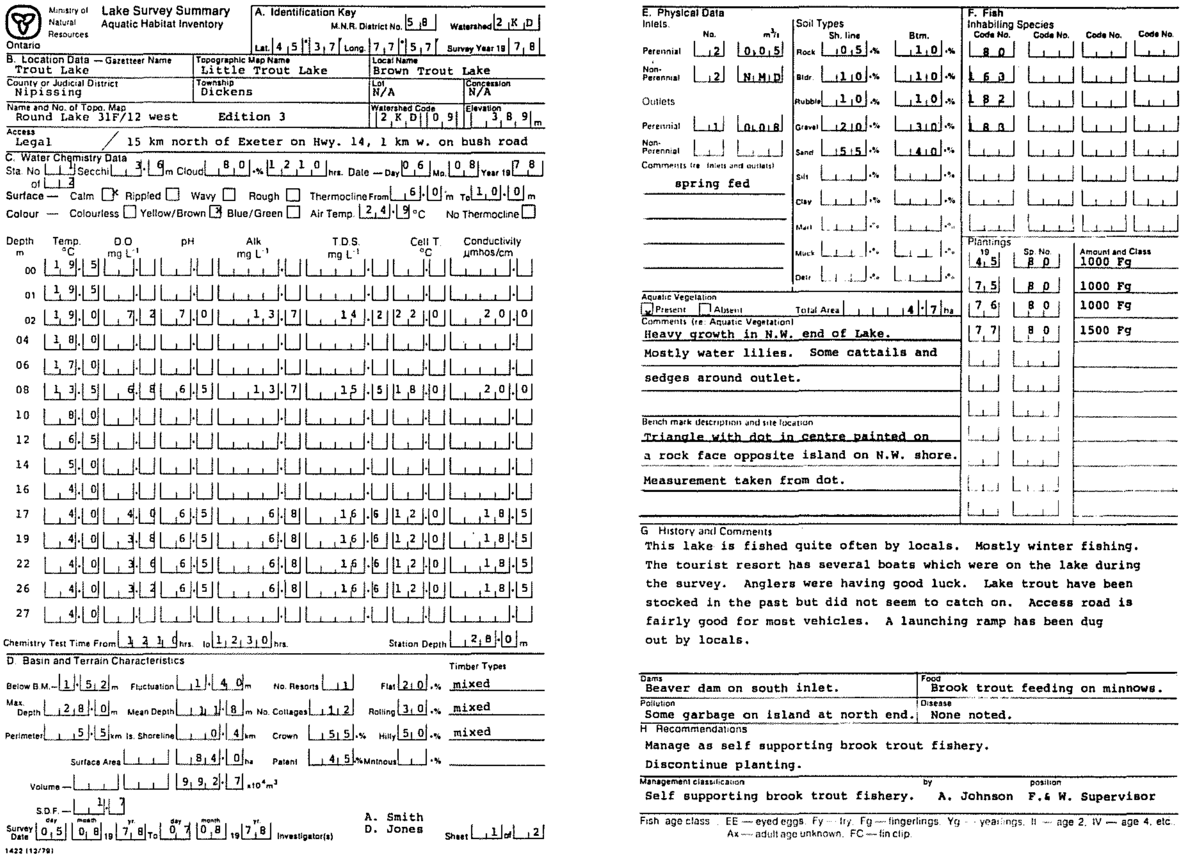
---

[3] Standard Conductance (@ 25°C) = $\frac{\text{(Specific Conductance µmhos/cm)}}{1 + (0.02(\text{cell temp. } ^\circ C - 25^\circ C))}$

[4] TDS = (Standard Conductance (@ 25°C) x 0.666 (Sharma and Gale 1982).

[5] $\text{MEI} = \frac{\text{TDS}}{\text{Mean depth (m)}}$

[6] Information regarding commercial products or companies may not be used for advertising or promotional purposes and it is not to be construed as endorsement of any product or company by the Ontario Ministry of Natural Resources.



Ministry of Natural Resources — Ontario

Lake Survey Summary — Aquatic Habitat Inventory

A. Identification Key — M.N.R. District No. 58 — Watershed 2KD — Lat. 45°37′ — Long. 77°57′ — Survey Year 1978

B. Location Data — Gazetteer Name: Trout Lake — Topographic Map Name: Little Trout Lake — Local Name: Brown Trout Lake

County or Judicial District: Nipissing — Township: Dickens — Lot: N/A — Concession: N/A

Name and No. of Topo. Map: Round Lake 31F/12 west Edition 3 — Watershed Code: 2KD 09 — Elevation: 389 m

Access: Legal / 15 km north of Exeter on Hwy. 14, 1 km w. on bush road

C. Water Chemistry Data — Sta. No 1 of 2 — Secchi 3.6 m — Cloud 80 % — 1210 hrs. — Date — Day 06 Mo. 08 Year 1978

Surface — Calm [x] Rippled [ ] Wavy [ ] Rough [ ] — Thermocline From 6.0 m To 10.0 m

Colour — Colourless [ ] Yellow/Brown [x] Blue/Green [ ] — Air Temp. 24.9 °C — No Thermocline [ ]

Depth m	Temp. °C	D.O. mg L⁻¹	pH	Alk mg L⁻¹	T.D.S. mg L⁻¹	Cell T. °C	Conductivity µmhos/cm
00	19.5						
01	19.5						
02	19.0	7.2	7.0	13.7	14.2	22.0	20.0
04	18.0						
06	17.0						
08	13.5	6.8	6.5	13.7	15.5	18.0	20.0
10	8.0						
12	6.5						
14	5.0						
16	4.0						
17	4.0	4.0	6.5	6.8	16.6	12.0	18.5
19	4.0	3.8	6.5	6.8	16.6	12.0	18.5
22	4.0	3.6	6.5	6.8	16.6	12.0	18.5
26	4.0	3.2	6.5	6.8	16.6	12.0	18.5
27	4.0						

Chemistry Test Time From 1210 hrs. to 1230 hrs. — Station Depth 28.0 m

D. Basin and Terrain Characteristics

Below B.M. — 1.52 m — Fluctuation 1.40 m — No. Resorts 1 — Flat 20 % — Timber Types: mixed

Max. Depth 28.0 m — Mean Depth 11.8 m — No. Cottages 12 — Rolling 30 % — mixed

Perimeter 5.5 km — Is. Shoreline 0.4 km — Crown 55 % — Hilly 50 % — mixed

Surface Area 84.0 ha — Patent 45 % — Mntnous . %

Volume — 992.7 x10⁴m³

S.D.F. — 1.7

Survey Date 05 08 1978 To 07 08 1978 — Investigator(s) A. Smith, D. Jones — Sheet 1 of 2

1422 (12/79)

E. Physical Data

Inlets	No.	m³/s
Perennial	2	0.05
Non-Perennial	2	N.M.D
Outlets		
Perennial	1	0.08
Non-Perennial		

Comments (re: inlets and outlets): spring fed

Soil Types	Sh. line	Btm.
Rock	05 %	10 %
Bldr.	10 %	10 %
Rubble	10 %	10 %
Gravel	20 %	30 %
Sand	55 %	40 %
Silt	%	%
Clay	%	%
Marl	%	%
Muck	%	%
Detr.	%	%

Aquatic Vegetation — Present [x] Absent [ ] — Total Area 4.7 ha

Comments (re: Aquatic Vegetation): Heavy growth in N.W. end of Lake. Mostly water lilies. Some cattails and sedges around outlet.

Bench mark description and site location: Triangle with dot in centre painted on a rock face opposite island on N.W. shore. Measurement taken from dot.

F. Fish — Inhabiting Species — Code No.: 80, 163, 182, 180

Plantings

19	Sp. No.	Amount and Class
45	80	1000 Fg
75	80	1000 Fg
76	80	1000 Fg
77	80	1500 Fg

G. History and Comments

This lake is fished quite often by locals. Mostly winter fishing. The tourist resort has several boats which were on the lake during the survey. Anglers were having good luck. Lake trout have been stocked in the past but did not seem to catch on. Access road is fairly good for most vehicles. A launching ramp has been dug out by locals.

Dams: Beaver dam on south inlet. — Food: Brook trout feeding on minnows.

Pollution: Some garbage on island at north end. — Disease: None noted.

H. Recommendations

Manage as self supporting brook trout fishery. Discontinue planting.

Management classification: Self supporting brook trout fishery. — by A. Johnson — position F.& W. Supervisor

Fish age class: EE — eyed eggs, Fy — fry, Fg — fingerlings, Yg — yearlings, II — age 2, IV — age 4, etc., Ax — adult age unknown, FC — fin clip.

Figure 3. -- Lake survey summary form (no. 1422).

oxygen, conductivity, oxidation reduction potential and depth data are obtained and transferred onto magnetic tape automatically. Playback, transcription and analyses can occur at any later date. In addition, depth information can be determined on previously unsurveyed lakes by running 2 or 3 echo sounding transects across the lake with a transducer attached to the pontoons. In this way an estimated maximum depth and volume can be derived and mean depth and MEI calculated. Several hundred lakes have been surveyed in this manner.

Post-field Activities

Following field activities, data are reviewed and collated into a final report. Survey summary forms (Fig. 3) are completed and final maps drawn. Contour map (Fig. 1) preparation which can be a time-consuming process is completed, area measurements are made and mean depth and volumes determined. Completed reports are filed at the local district office, while copies of forms and maps are sent to the main office in Toronto for audit, filing and computer storage.

Data Storage And Retrieval System

Historically summary paper files have been and shall continue to be maintained for all lake inventory information. However, the volume and extent of the information presented a formidable task to anyone wishing to refer to any more than a few of the lakes at one time. Increased need for review, integration, and assessment of these data continue to be more frequent exercises performed by all of Ontario's management units - Districts, Regions, Assessment and Research Units, as well as the Main Office in Toronto. A rapid and flexible information storage and retrieval system was a necessity and has proved to be invaluable to fisheries managers since its inception in the early 1970's.

Fortunately, most lake survey data can easily be digitally encoded and stored, with only a few site-specific comments, recommendations and historical notes excluded. Aquatic habitat inventory data standards including site name conventions and specific biological, chemical and physical survey information, have for the most part, remained uniform in an electronic data processing sense. Furthermore, a natural data organization by site (i.e. lake name) was evident and could be used to key all other information. To date almost 8 million

```
SYSTEM RELEASE NUMBER  2.90
DATA BASE NAME IS      LAKEINVENTORY
DEFINITION NUMBER            3
DATA BASE CYCLE NUMBER      6434
     1*  LAKE NAME (CHAR X(20))
     2*  WATERSHED (CHAR X(5) WITH  FEW FUTURE OCCURRENCES )
     3*  LAT (INTEGER NUMBER 9999)
     4*  LONG (INTEGER NUMBER 9999)
     5*  MNR DIST (INTEGER NUMBER 99 WITH  FEW FUTURE OCCURRENCES )
     6*  TOWNSHIP (NON-KEY CHAR X(15))
     7*  LAKE AREA (NON-KEY DECIMAL NUMBER 9(7).9)
     8*  PERIMETER (NON-KEY DECIMAL NUMBER 9(5).9)
     9*  ISLAND SHORELINE (NON-KEY DECIMAL NUMBER 9(5).9)
    10*  MAXDEPTH (NON-KEY DECIMAL NUMBER 999.9)
    11*  MEAN DEPTH (NON-KEY DECIMAL NUMBER 999.9)
    12*  LITTORAL ZONE (NON-KEY INTEGER NUMBER 999)
    13*  ELEVATION (NON-KEY INTEGER NUMBER 9999)
    14*  MEI (NON-KEY DECIMAL NUMBER 9999.9)
    15*  PROJECT (CHAR X(6))
    16*  YR (NON-KEY INTEGER NUMBER 99)
    17*  CROWN (NON-KEY INTEGER NUMBER 999)
    18*  RESORTS (NON-KEY INTEGER NUMBER 9999)
    19*  COTTAGES (NON-KEY INTEGER NUMBER 9999)
   100*  STATION (RECORD)
     101*  STN NO (NON-KEY INTEGER NUMBER 99 IN 100)
     102*  STN DATE (NON-KEY DATE IN 100)
     103*  TIME (NON-KEY INTEGER NUMBER 9999 IN 100)
     104*  SECCHI (NON-KEY DECIMAL NUMBER 99.9 IN 100)
     105*  CLOUD (NON-KEY INTEGER NUMBER 999 IN 100)
     106*  SURFACE (NON-KEY INTEGER NUMBER 9 IN 100)
     107*  COLOUR (NON-KEY INTEGER NUMBER 9 IN 100)
     108*  AIR TEMP (NON-KEY DECIMAL NUMBER 99.9 IN 100)
     125*  TEMP PROFILE (RECORD IN 100)
       126*  DEPTH (NON-KEY DECIMAL NUMBER 999.9 IN 125)
       127*  TEMP (NON-KEY DECIMAL NUMBER 99.9 IN 125)
       150*  CHEM PROFILE (RECORD IN 125)
         151*  DO2 (NON-KEY DECIMAL NUMBER 99.9 IN 150)
         152*  PH (NON-KEY DECIMAL NUMBER 99.9 IN 150)
         153*  ALK (NON-KEY DECIMAL NUMBER 9999.9 IN 150)
         154*  CELL (NON-KEY DECIMAL NUMBER 99.9 IN 150)
         155*  COND (NON-KEY DECIMAL NUMBER 9999.9 IN 150)
   200*  CONTOUR (RECORD)
     201*  CONTOUR DEPTH (NON-KEY DECIMAL NUMBER 999.9 IN 200)
     202*  CONTOUR AREA (NON-KEY DECIMAL NUMBER 9(7).9 IN 200)
   300*  FISH SPECIES (RECORD)
     301*  FISH (INTEGER NUMBER 999 IN 300)

2000*  DISTRICT TABLE (RECORD)
  2001*  DISTRICT CODE (NON-KEY INTEGER NUMBER 99 IN 2000)
  2002*  DISTRICT NAME (NON-KEY CHAR X(12) IN 2000)
2100*  FISH SPECIES TABLE (RECORD)
  2101*  FISH SPECIES CODE (NON-KEY INTEGER NUMBER 999 IN 2100)
  2102*  SCIENTIFIC NAME (NON-KEY CHAR X(24) IN 2100)
  2103*  COMMON NAME (NON-KEY CHAR X(18) IN 2100)

 STRINGS

4000*  TALLY (STRING (*C4001**C4002**C4003**C4004*))
4001*  TALWH1 (STRING (COMPOSE:FOR REPORT TALWH:PHYSICAL PAGE IS 72 BY
       O:DE INT   VAL=(!):DE INT UNIQ=RCNT OF VAL:DE INT OCCR=RCNT OF V
       AL:DE INT TAL=RCNT OF VAL: OB *1*:PR (1)$************************
       *************$:))
4002*  TALWH2 (STRING (PR (2)$TALLY WHERE$:PR (1)$*******************$:
                 PR (1)$ FREQUENCY VALUES$:PR (1)$-------------------$
       :AT END, PR                 (1)$-------------$:PR R(1,Z(07)9)UNIQ
       , (11)$UNIQUE VALUES$:))
4003*  TALWH3 (STRING (PR (1)$----------------------$:PR (1,Z(07)9)OCCR
                 (11)$OCCURRENCES$:PR (1)$-------------------$:FOR *1*
       , AT END, IF *1* EXISTS    THEN PR R(1,Z(07)9BBB)TAL, *1* ELSE P
       R R(1,Z(07)9BBB)TAL, (15)$-NULL-$:))
4004*  TALWH4 (STRING (COMPUTE UNIQ:FOR RECORD,COMPUTE TAL,OCCR:
                              END REPORT: GENERATE TALWH))
4005*  SURVEYED LAKES (STRING (LI/REPEAT SUPPRESS,TITLE D(25)SURVEYED L
       AKES,        L(50)LAKE NAME, L(12)TOWNSHIP, R(4)LAT, R(4)LONG, R(
       2)YR/BY ENTRY, C1, C6, C3, C4, C16, OB C1 WH C5 EQ *1*:))
4006*  SPECIES (STRING (LI/TITLE D(30)*1) LAKES,L(50)LAKE NAME/C1,
                              BY ENTRY, MIN C152, MIN C151, C12, C11 W
       H ENTRY HAS                            C301 EQ *2* AND C5 EQ *3
       *:))
4007*  TDS (STRING (LI/REPEAT SUPPRESS, TITLE L(50)LAKE NAME,R(4)LAT, R
       (4)LONG,   R(25)TOWNSHIP, T.D.A. + MG'L,CELL T+  C, COND  +UMHOS
       'CM/C1, C3, C4, C6,               (0.666*(C155/(1+(0.02*(C154-25)
       )))),  C154, C155, OB C6, C1))

 FUNCTIONS

4050*  TDS (DECIMAL FUNCTION ((0.666*(C155/(1+(0.02*(C154-25))))))
4051*  COND25 (DECIMAL FUNCTION ((C155/(1+(0.02*(C154-25))))))
```

Figure 4. -- Lake inventory data base description.

characters or bytes of data, current to 1981, have been loaded into the Lake Inventory Data Base (Fig. 4), utilizing a commercially available data base management system, System 2000.

S2K, as it is sometimes called, has its own structure and English-like or "end-user friendly" language. The structure is hierarchical or tree-like in the sense of an inverted family tree, with the "root" node at the top representing the lake name (Fig. 5)

From the trunk down, locational and physical data, chemical profiles and fish species information are stored. Branch and sub-branch nodes occur where multiple entries for the same element are required, permitting data to be stored for more than one station and many depths. Other "repeating groups", as they are often referred to, were constructed for contour depths with areas, and transcription tables of District numbers and fish species codes and taxonomy. These last two permit decoding of the 55 District/Regional codes and 142 fish species to full common and/or scientific names.

As noted above, S2K has high level, end-user query and report generating languages. These features are essential to the Lake Inventory system as biologists, not only systems specialists, will eventually perform their own enquiries, reports and data updates. Primarily, on-line terminals, using a local or remote time sharing facility such as TSO, will be used as they presently are. However, terminal or card submitted batch jobs could also be initiated, again primarily by biologists, not systems analysts.

The Lake Inventory System using System 2000 is not perfect. Distinct limitations include awkward facilities for data base redefinition (especially considering changing levels of accuracy required by certain parameters) and realignment of data for more efficient storage. Nevertheless, in reviewing James Martin's (1977) primary objectives of good data base organization, most if not all of the objectives as noted below have been fulfilled or are expected to be in the near future (Table 2).

The Ontario Ministry of Natural Resources presently supplies most output through facilities in Toronto, especially where complex reports or extensive printing is required. This situation is likely to change in the future as field facilities improve, and full integration of OFIS (The Ontario Fisheries Information System) is implemented. OFIS consists of data bases and files other than those for lake surveys. The fish culture and commercial fish data bases, contaminant information system and acid precipitation/lake sensitivity data are some of the prominent ones. These are analysed and reported on separately but with the

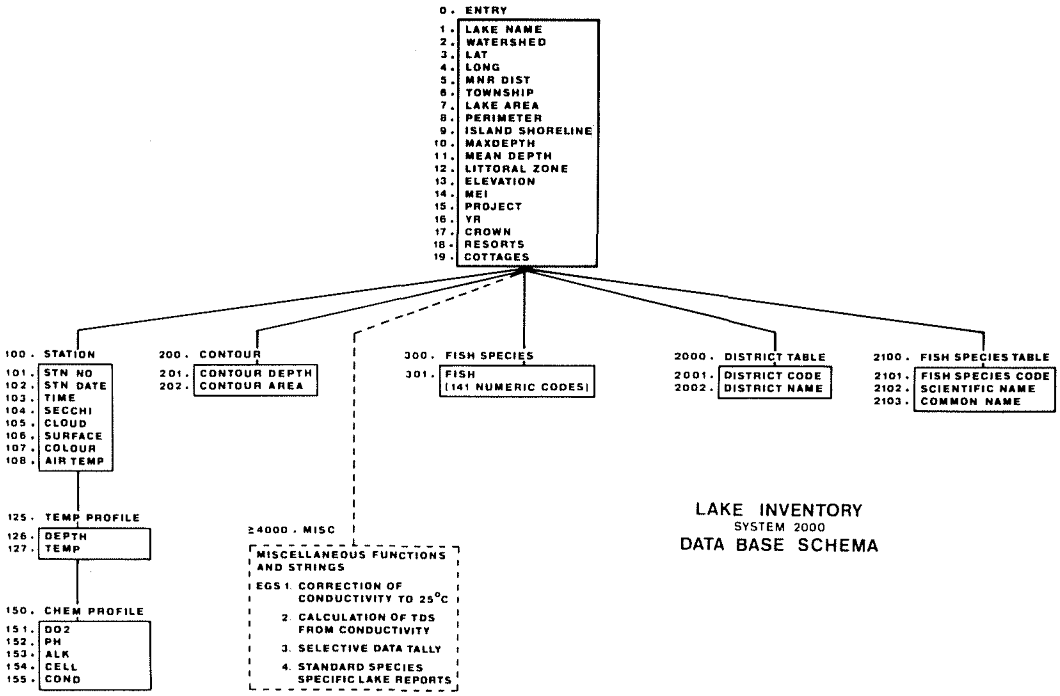


Figure 5. -- Lake inventory data base schema showing S2K tree structure.

flexible nature of S2K, compatible output files can easily be produced for merging, further processing, and reporting.

Table 2. -- Objectives of the lake inventory data base (Adapted from Martin, 1977).

1.	A foundation for easier, cheaper, faster, and more flexible application development.
2.	Should handle multiple uses and users at reasonable cost.
3.	Should have clear, rapidly available, easy to use and change, independent data.
4.	Quick handling of unanticipated or ad hoc user requests.
5.	Growth and change of data should not impact previously established uses and should show little or no unnecessary redundancy or proliferation.
6.	Data privacy and security systems should be in place with protection from loss or damage through back-up and restoration procedures.

Data Systems Applications

Presently, most lake inventory report requests are needed for District fisheries management plans, strategic land use planning and special assessments of lake groups or fish community types. Detailed printouts can easily be generated in as little as 10 minutes.

Simple statistics are often included in reports. Minimums, maximums, means and standard deviations of particular parameters are all directly available and do not require special programming. Where necessary though, repetitive calculations and special or particularly complex enquires can be stored as S2K strings and functions. These show up in the data base definition and can be treated as a user would treat almost any element. In the lake inventory system, for example, strings and functions exist to correct specific conductivity to standard conductivity at 25°C, to calculate total dissolved solids, to selectively tally parameter values and to provide species-specific lake reports. The potential and versatility are completely user definable.

Two particularly interesting applications of the data base have saved extensive manual effort, the first probably in terms of many man-months. Ontario's fisheries managers wanted to develop the fisheries assessment unit concept of long-term, trend-through-time studies on type lakes. The lake inventory data base was used to select, locate and regionalize the lakes containing the six primary species (brook trout *Salvelinus fontinalis*, lake trout *Salvelinus namaycush*, lake whitefish *Coregonus clupeaformis*, northern pike *Esox lucius*, smallmouth bass *Micropterus dolomieui*, walleye *Stizostedion vitreum vitreum*) making up 63 possible fish community types (Anon. 1978). Twenty-four communities were subsequently judged to be sufficiently prevalent or important enough to warrant secondary selection. From the inventory list of 4,618 lakes, field staff proposed 911 candidate lakes representing fish communities and stresses in their areas. The data base was again used to select a final 172 lakes based on numerical and areal importance, representative "stresses (exploitation, entrophication, acidification, water level, physical alterations, introductions) and inherent properties (area, mean depth, oxygen, temperature, total dissolved solids)" (Anon. 1978). These lakes were logistically grouped into 28 fisheries assessment units and are to date represented by 10 inland and 5 Great Lakes units.

The second application of the system again involved lake selection. Cultural eutrophication appears to have seriously threatened the traditional lake trout *Salvelinus namaycush* and lake whitefish *Coregonus clupeaformis* stocks of a major Ontario inland lake, Lake Simcoe. Processing lake inventory data enabled managers to pre-select suitable "surrogate" or "refuge" lakes in which to introduce and preserve genetic stocks of these species. Field investigations followed and confirmed these selections. With enough time and effort the water quality in Lake Simcoe may be sufficiently restored to return the fish to their native habitat (Olver et al. 1979).

Further uses of the lake inventory data base have been made by many individuals and institutions outside the Ontario Ministry of Natural Resources. The provincial Ministry of Housing, for instance, requested data for their Lakeshore Capacity Study investigating particular resort/cottage areas for lake-side land use potential and development. The process of acidification has brought researchers and university professors in pursuit of data from as far away as Great Britain. As well, researchers from both the Royal Ontario Museum and National Museum of Canada have indicated their interest in fish distributional information from our nearly 80,000 point-in-time fish species occurrence records. Finally, consultants preparing a wide variety of reports including environmental impact and assessment studies are frequent data users.

Future System Applications

Many future applications have been envisioned for the lake inventory data system with some already under feasibility study or development. A direct automated cartographic system capable of plotting contour maps and calculating contour areas and lake volumes has been tried and proven feasible. Production development problems have arisen, however, and will require additional work before this system can be considered viable. Another automated mapping system is also being considered. This one would draft parameter distributions according to latitude/longitude coordinates (e.g. fish distribution) and could overlay other parameters, year classes of information or management unit boundaries. This would greatly alleviate the present problems our fisheries managers face in assessing complex parameter trends over very large areas of the province.

More importantly, though, Ontario is made up of a substantial number of highly productive streams and large rivers. In fact, large rivers can represent the majority of productive fisheries habitat in some ares of the province, particularly in the north. It is essential that for a fully informative Ontario Fisheries Information System, the lake inventory system must be complemented by systems for streams and rivers. Much of the field inventory work has already been completed for streams, but large river surveys in Ontario have just passed the first stages of feasibility. A considerable number of years still remain before these surveys will reach the level of efficacy exhibited by the Lake Inventory Program in Ontario.

ACKNOWLEDGEMENTS

The support of Dr. D.P. Dodge and his valuable assistance in reviewing the manuscript is gratefully acknowledged. We also thank K.H. Loftus for his critical review. Funds to attend this symposium were provided by the Ontario Ministry of Natural Resources.

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REMOTE-SENSING INVENTORY OF ALASKAN LAKES[1]

Jack Mellor[2]

Abstract.--Water depth is a major factor in predicting resources associated with tens-of-thousands of uninventoried Alaskan arctic lakes. Radar images are used to determine lake depths. Computer manipulation of digital satellite data provides for lake identification and lake data management. This knowledge coupled with the two remote-sensing tools add to our ability for regional inventory, classification, and management of arctic lake resources.

INTRODUCTION

The Alaskan Arctic Coastal Plain is covered with tens-of-thousands of lakes and ponds. A few, primarily those near the Naval Arctic Research Laboratory (NARL) and Point Barrow, have been studied extensively (Hobbie 1973 and 1980); however, exiguous regional inventory across the Arctic Coastal Plain is the reason that no lake-specific data are available for the vast majority of the Arctic Coastal Plain lakes.

The Bureau of Land Management is responsible for managing aquatic resources within the National Petroleum Reserve-Alaska (NPR-A), which is centered in the Alaskan Arctic (fig. 1). The studies reported in this paper are being conducted within the 95,000 km^2 Reserve. The northern half of NPR-A may contain as many as 40,000 water bodies that are as large as 0.5 ha or larger. The need for a data base that is adequate for making timely assessments and minimizing conflicts among aquatic resource uses is increasing as human populations and petroleum exploration and development expand.

This report is an overview of remote-sensing tools and limnological data being investigated concurrently to determine the feasibility of accomplishing economical regional inventories of Alaskan Arctic Coastal Plain Lakes. The study (Mellor 1982) is composed of three parts: (1) development of a remote-sensing technique for water-depth data acquisition, (2) limnological surveys of lake constituents by depth, and (3) development of a data storage and retrieval system by computer manipulation of satellite data. The remote-sensing tools used were Side-Looking Airborne Radar (SLAR) from fixed-wing aircraft and Multi-spectral Scanner data from a satellite. The limnological surveys completed included physical, chemical, and biological measurements.

Several studies relating to regional water availability and approaches to water and aquatic resources management have been completed for the

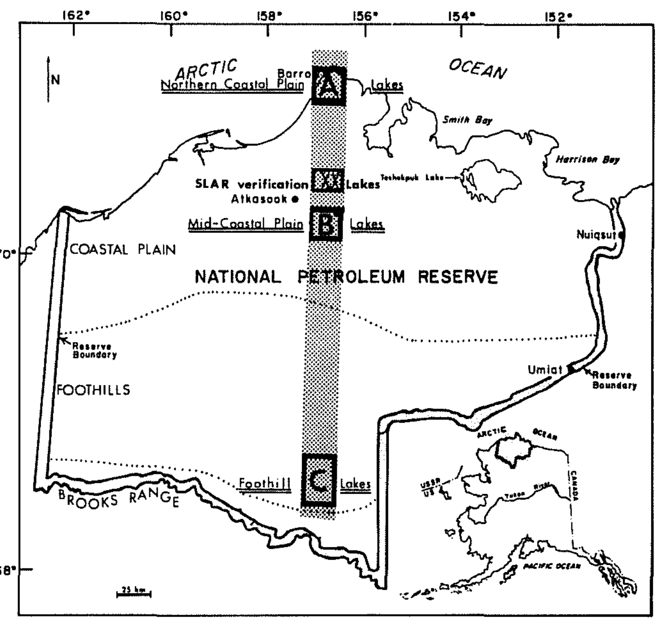

Figure 1.--Rectangular study areas shown within transect used for acquisition of lake and SLAR data.

[1]Paper presented at the symposium on acquisition and utilization of aquatic habitat inventory information (American Fisheries Society, Portland, Oregon, October 28-30, 1981).

[2]Jack C. Mellor is a Limnologist for the Bureau of Land Management, National Petroleum Reserve in Alaska, Fairbanks, Alaska.

Alaskan Arctic (e.g., Greenwood and Murphy 1972, Wilson et al. 1977). Each study suggested that gaps exist in our information about water use conflicts (i.e., among fish, wildlife, human inhabitants, and industry) and about water availability (e.g., where and how much water may be used without adversely affecting the environment). Greenwood and Murphy suggested that large-scale ecological studies aimed at establishing areas important for preservation could provide "ecologican evaluation maps." The maps would be useful to planners for choosing one site or community over another for alteration. The aquatic ecosystems must be defined and inventoried before the "maps" are made. The studies reported here investigate methods that define, relate, and inventory aquatic ecosystem components that might aid the production of economical regional "ecological evaluation maps."

REGIONAL WATER DEPTHS FROM SLAR IMAGE ANALYSIS

Side-Looking Airborne Radar (SLAR) images were used in conjunction with ice-thickness and lake-depth data to determine what the uniquely bright SLAR images of arctic lakes portray. Bright areas occurred on images of lakes that had fresh water beneath the ice, and dark areas occurred on images of lakes that were frozen to bottom (Weeks et al. 1978 and Mellor 1982). A change in intensity of SLAR return of a lake defines the zone at which ice cover contacts the lake bottom. A method is illustrated for acquiring 0.5 m lake depth contours down to maximum winter ice depth, utilizing estimated ice thickness in conjunction with SLAR imagery.

This study was designed to provide sufficient lake-bathymetry, ice-thickness, and SLAR data to investigate an application for lake depth contouring. From studying winter SLAR imagery over arctic lakes, Sellmann et al. (1975) concluded that fresh-water lakes with weak SLAR returns were frozen to the bottom, while lakes with strong return were not. Nine study lakes were sampled (Mellor 1982) for ice thickness coincident with sequential SLAR imaging of the study transect (fig. 1) during ice growth and decay through the winter and spring 1978-79. SLAR-imagery and ice-thickness data were acquired to compile sufficient empirical data to verify the hypothesis first developed by Sellmann et al., to look for mechanisms that would explain the unusual

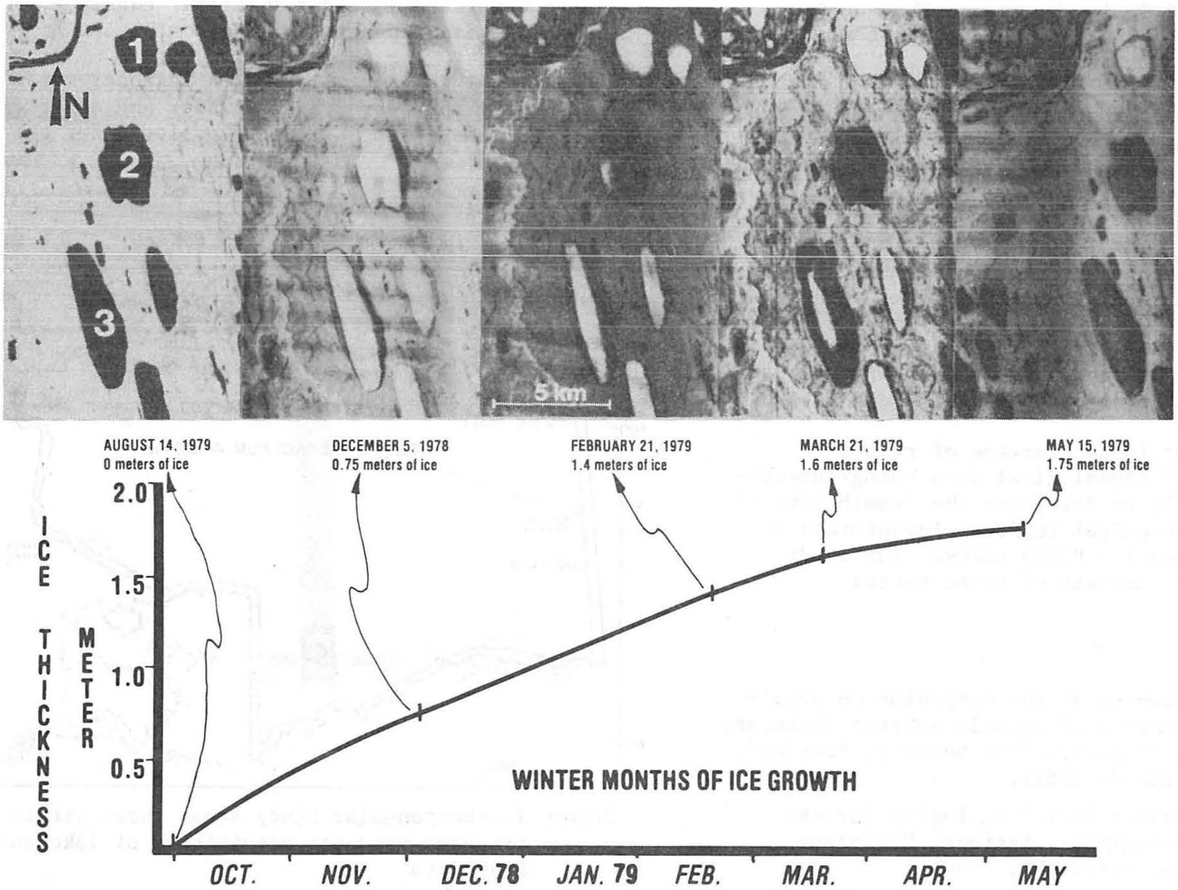

Figure 2.--Sequential SLAR images of Lakes SLAR 1, 2, and 3(top), correlated with ice thickness (bottom).

SLAR returns for arctic lakes and to investigate a technique for utilizing these data to provide lake depth contour information.

Figure 2 illustrates a series of sequential SLAR images of Arctic Coastal Plain Lakes SLAR 1, 2, and 3 (fig. 1) relative to winter 1978-79 ice thickness. The SLAR images are in order of increasing ice thickness with a summer (14 August 1979) image on the left, representing the ice-free condition, and successive images with thickening ice cover during the winter of 1978-79.

The 14 August 1979 image shows the lake numbers SLAR 1, 2, and 3, superimposed on a black lake surface image. The lakes were free of ice; therefore, the radar energy was absorbed or was spectrally reflected away from the SLAR imaging aircraft by the water at the lake surface. The second image (5 December 1978) was acquired when the ice was about 0.75 m thick. The image shows most of the surface on each lake as white because of high radar signal reflectance back to the aircraft. The shallow shelves on the eastern sides of Lakes 2 and 3 are black where the ice is frozen to the lake bottom. The third image (2 February 1979) was acquired when the ice was 1.4 m thick. The image of most of Lake 2 is black, indicating that ice was frozen to the bottom of 80 percent of the lake area. By 21 March 1979, when the ice was 1.6 m thick, Lake 2 was completely frozen to the bottom. Lake 3 had an elongate area in the middle that still had water beneath the ice. That area is white in the March image. The Lake 1 image is still almost totally white but has a small black area where the lake is frozen to the bottom on the eastern shore. The last image (15 May 1979) depicts both Lakes 2 and 3 as black and totally frozen to the bottom, with a 1.75 m ice thickness. The areas in Lakes 2 and 3 that were more than 1.75 m deep were too small to show significantly on the 15 May 1979 image. However, the SLAR image of freshwater Lake 3 shows a subtle brightening near the lake center. A thin layer of brackish water ($\gtrsim$ 2 parts per thousand) may still have existed between a brine-contaminated ice layer and the lake bottom. The layer, resulting from salt rejection and concentration, could have caused most of the SLAR signal to attenuate rather than reflect. The Lake 1 image has a black perimeter where the lake is frozen to the bottom, surrounding the deeper white midbasin that is more than 1.75 m deep.

Nearly 200 holes were drilled in the lakes' winter ice during this study to verify SLAR findings. In every case, where a SLAR image had a bright return from a lake, water was found below the ice cover. Similarly, the lakes with bright centers and dark perimeters were found to be frozen to the bottom along the perimeter.

Lake 3 has been selected to illustrate the use of sequential SLAR images for contouring lake depths (fig. 3). The first four SLAR images shown

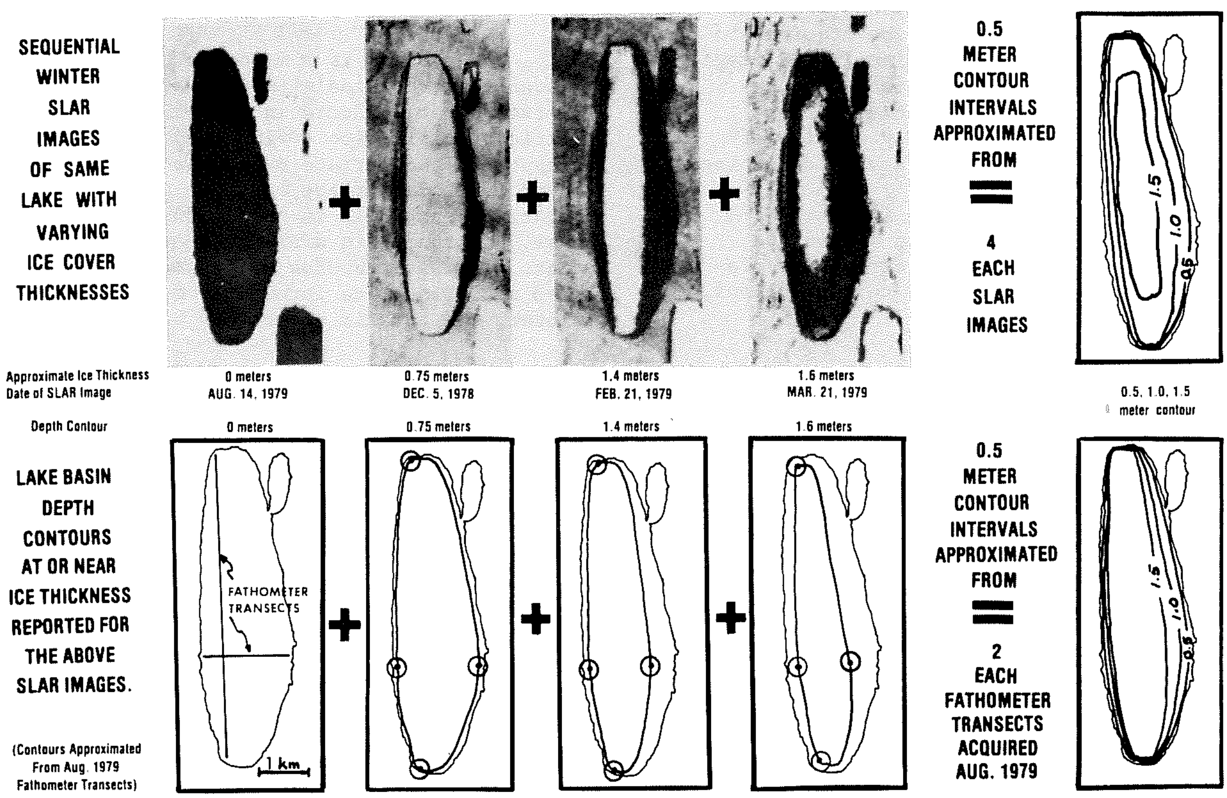

Figure 3.--Lake depth contour determination by two methods: (top) four sequential SLAR images with empirically derived ice thickness; (bottom) two summer fathomater transects.

in Figure 2 were enlarged and cropped, leaving only Lake 3 in Figure 3 (top). A zoom transfer scope was used to overlay each image on a shoreline map of the lake. The 0.0 m (shore), 0.75 m, 1.4 m, and 1.6 m ice/substrate contact zone contours provided by the SLAR images were interpolated to obtain the 0.5 m, 1.0 m, and 1.5 m depth contours shown on the upper right. Fathometer profile data acquired on two summer (August 1979) fathometer transects were used to compare depth data with SLAR image interpretation. The fathometer transects made are shown on the 0.0 m or shoreline map (fig. 3, lower left). Each transect crossed a depth interval twice, providing only four points on the two transects from which a contour could be approximated. The four points were plotted, and the extrapolation of these points was used to estimate each contour. Contour estimates are shown for the depths (0.75 m, 1.4 m, and 1.6 m) corresponding to ice thickness in the above images. The final 0.5 m, 1.0 m, and 1.5 m contours estimated from the two fathometer transects are shown in the lower right in Figure 3.

The two methods provide slightly different re results; however, both provide acceptable data for practical approximations of lake bathymetry and/or calculations of lake water volume. Both methods have some inherent error, but in this study more error undoubtedly exists in the fathometer transects than in the SLAR-image interpretation. The largest margin for error for fathometer data is the few data points used to estimate a contour around an entire basin; however, with sufficient time and money, more transects can be acquired to reduce this error. The two-dimensional SLAR image eliminated this problem. Other potential fathometer data errors exist in transect position identification accuracy, consistency of aircraft speed across a transect, and accuracy of obtaining fathometer depths (± 10 cm).

The SLAR image interpretation method for obtaining lake depth contours had errors associated with accuracy of ice-thickness determinations, horizontal resolution of the SLAR imagery (30 m), accuracy of contour placement utilizing zoom transfer scope overlays, and interpolation of desired contour intervals from the ice/lake-bottom contact zones shown on SLAR images acquired on specific dates.

The advantage of the SLAR method over the fathometer transect method is that SLAR enables us to use remote-sensing imagery, with relatively few ground verification measurements of ice thickness, to obtain regional lake depth information. The major drawback of this method is that it is useful for obtaining depth contour information only to the maximum winter ice thicknesses achieved (≈ 2 m) and only for freshwater lakes. An additional factor learned during this study, however, may allow interpretation of the 4 m isobath from SLAR images. Because most Arctic Coastal Plain thaw lake depths range from 0 to 2 m, these methods have practical utility for assessing and/or inventorying lake depths when repetitive radar coverage of the area becomes economical. This may be imminent because use of Synthetic Aperature Radar (SAR) systems on Space Shuttle and/or future satellites has been proposed. The imagery from the Seasat satellites has been proposed. The imagery from the Seasat satellite SAR would have provided a good test had the system remained operational into the winter months.

ARCTIC LAKE-DEPTH/AQUATIC RESOURCE ASSOCIATIONS

Water depth is a major factor in predicting resources associated with Alaskan arctic lakes. Surface water collects in the Arctic when the little precipitation (≈10 cm annually) becomes trapped at the surface by a nonporous permafrost layer. Little surface water is lost through evaporation because it is frozen for 9 months of the year, and runoff is minimal because the terrain is flat. The water bodies are typically shallow (2-3 m). Since ice forms to 2 m thickness by midwinter, the aquatic nature and biotic function of

Table 1.--Arctic lake/pond characteristics associated with six categories of water depth.

RANGES OF WATER DEPTH		LAKE CONSTITUENTS								LAKE RESOURCES						
		Potential for Primary Production		Summer Light Extinction & Suspended Sediments Loads	Salinity Concentration at Lake Bottom	Potential for Winter Depletion of Dissolved Oxygen	Potential for Extreme Water Temperatures							Aircraft Usage (Months)		Light Aircraft and Off-Road Vehicle Use of Ice Cover (Months)
Category	(m)	Water Column	Benthic		Mid-Winter		High in Summer	Low in Winter	Ice Cover Comments	Free Water Available (Months)	Potential for Fishery Over-wintering	Potential for Emergent Vascular Vegetation	Waterfowl Usage (Months)	Floats	Hercules Ice Strip 1.2 m of ice	
1	0 to .5	M to H	L to H	H	H	Total (ice)	H	H (ice)	Freezes to the bottom by December and melts first in spring; used by early spring waterfowl	June thru Sept.	N	H	June to Sept.	N	Dec. to late Sept.	Nov. to late Apr.
2	.5 to 1.0	H	M to H	H	H	Total (ice)	M	H (ice)	Freezes to the bottom by February and melts soon after the 0-.5 m Ice	Late June thru Nov.	N	M to L	June to Sept.	Early July to Sept.	Jan. to May	Nov. to May
3	1.0 to 1.5	H	H	M	H	Total (ice)	M	H (ice)	Freezes to the bottom by April usually	July thru Jan.	N	Very L	July to Sept.	July to Sept.	Feb. into May	Nov. to May
4	1.5 to 2.0	H	H	M to L	H to M	H	M	M	May not freeze to the bottom entirely, melt may last well into July	July thru Mar.	Very L	N	July to Sept.	July to Sept.	Late Feb. into May	Nov. to May
5	2.0 to 4	M to H	M to H	L	M	M	M	M	Does not freeze to bottom; may last into late July	All year	L to M	N	July to Sept.	Late July to Sept.	Late Feb. into May	Nov. to May
6	>4	M to L	H to L	Very L	L	L	L	L	Never freezes to the bottom; very late melt and breakup which may last into late July or early August	All year	H	N	July to Sept.	Late July to Sept.	Late Feb. into May	Nov. to May

Key: H = High; M = Medium; L = Low; N = None these basins are influenced by ice growth throughout all or most of each of these basins. The fact that aquatic resources are limited to shallow depths and are influenced by ice that reaches to or near the lake bottom led me to consider how extensively lake resources, properties, and/or constituents might be associated with lake bathymetry. Physical, chemical, and biological resources related with water depth were studied in three specific areas (A, B and C - see fig. 1) along a north/south transect extending from Point Barrow on the Arctic Ocean to the Foothills of the Brooks Range.

Limnological surveys showed that wind and marine influence had significant effects on the lakes studies. Increasing salinities, suspended sediment loads, and light attenuation were observed in lakes toward the seaward end of the study area (fig. 1). The maximum depths of study lakes were deeper in the middle (12 m) and at the southern (7 m) end of the transect than at the northern end (3 m). Variations in algal biomass, summer and winter temperatures, winter dissolved oxygen, and ice cover measurements were also related to changes in climate across the study area (Mellor 1982).

Constituents and resources that changed with water depth were sampled. Many of these varied because of physical factors, such as wind-generated waves and ice accretion, that affect shallow (<3 m) lake environments. Wind-generated wave mixing in shallow water causes sorting of benthic substrate materials, changes in water column suspended sediments and light attenuation, possible nutrient replenishment from resuspended sediments, and quantitative shifts in benthic versus water column chlorophyll *a* and primary production measurements. Shallow basins and/or shoals within deep basins are the most severely affected by wave action.

Ice accretion causes a percentage reduction in free water volume that is inversely proportional to lake depth. In shallow lakes, ice accretion causes rapid increases in specific conductance, freezing of shallow substrates and their benthic inhabitants, increases in columnar gas bubbles in ice cover, depletion of dissolved oxygen, limited fish and zooplankton habitats and near freezing water temperatures. Ice limits the lake depth range of benthic invertebrate species intolerant of frozen habitat. Overwintering fish require lake depths greater than maximum ice thickness and are rarely found in lakes < 3 m deep. Most of the summer's heat is used to melt thick ice cover, leaving little to warm the water column of deep lakes. Ice on shallow basins melts early, allowing sediment and water to attain very warm (17°C) summer temperatures. Emergent vascular plant species are limited to specific shallow ranges in water depth. Waterfowl utilize aquatic resources that occur in specific ranges of water depth; hence, water depth information can be used to help define waterfowl habitat (Bergman et al. 1977). Water depth information can also be used to help identify lakes for winter water supplied and/or surface uses such as airstrips or other vehicle travel.

These results show that bathymetry is a major factor in predicting aquatic resources associated with Alaskan arctic lakes and indicate that bathymetry is the best single parameter that can be used to classify and define the resource potential of all arctic lake habitat.

In order to evaluate the validity of using SLAR-determined water depth contours to inventory or assess aquatic resources, ranges of depth that might be assessed with SLAR were selected and compared with aquatic constituents and resources associated with arctic lakes and wetlands (Table 1). Water depth categories that could reasonably be distinguished using SLAR-image interpretations are: 0-0.5 m, 0.5-1.0 m, 1.0-1.5 m, 1.5-2.0 m, 2.0-4.0 m, and >4.0 m. Water within these depth ranges is affected differently by winter ice formation and by summer winds and light penetration. The first three shallow categories (0-1.5 m) have winter ice growth to the lake bottom and summer vascular aquatic vegetation, and are affected by the severest summer and winter environmental extremes. In the 1.5 to 2.0 m category, depending upon latitude and winter severity, ice forms to, or very close to, the lake bottom. Lake basins 2.0 to 4 m deep are in a marginal environment, where midwinter conditions may be extreme, yet some water remains unfrozen throughout the winter. These lake basins always have some free water within the basin that is available for use by industry, the public, and/or the flora and fauna of the natural habitat, but water volumes required to sustain fauna may limit water withdrawal. However, basins with water depths 4 m may have sufficient water column to sustain both fauna and water withdrawal. Deeper basins have less severe winter conditions and therefore a greater chance to sustain a year-round fish population. Most of the water in Arctic Coastal Plain Lakes is turned to ice by midwinter; thus, resources associated with water depth are controlled or limited. Ice, however, is not the only control. Turbidity and light penetration, bottom substrate, available nutrients, watershed, basin morphology, specific conductance, and other factors can affect resources associated with any water body. Table 1 is used to relate the selected water depth categories with aquatic constituents and resources associated with arctic lakes and wetlands.

Results from this study, in addition to the literature, were used to describe fish and emergent vascular plant associations with water depth, while other resource associations (i.e., water availability, fish overwintering, and aircraft or off-road vehicle usage) have been inferred from ice-thickness data (Mellor 1982). Waterfowl usage was determined from Bergman et al. (1977).

COMPUTER GENERATION OF A REGIONAL LAKE DATA FILE FROM LANDSAT DIGITAL DATA

A computer lake system was developed that uses computer-compatible Landsat data to create a regional lake information file in which each lake in the file is uniquely characterized. The system is being developed because of the potential for a substantial increase in the data base for Alaskan arctic lakes and the need for consolidating this information into a single organized source. Once lake depths and resources within thousands of lake basins are defined, the data must be organized so that they may be retrieved for future application, such as resource management and resource identification.

The computer program being tested manipulates Landsat satellite digital data and compiles a master file of lakes and their computer-calculated surface features (i.e., area, perimeter, crenulation, and centroid). The master file uniquely identifies each computer-identified lake by latitude and longitude and stores its calculated features in a data file. Computer retrieval of this lake data can then be accomplished within a specified geographic area. The record for each identified lake also has storage space for lake resource data collected by means other than computer generation.

The objectives for developing this system were threefold. The first objective was that each computer-generated lake identity would be unique and data for each lake would be retrievable on a geographic basis. The second objective was to combine this geographic identity and the computer-calculated surface characteristics into a file with sufficient storage space allocated for each lake to accept data acquired outside this computer system. The final objective was to enable computer manipulation of this file to retrieve lake listings specific to a restricted geographic area and/or lake characteristic(s) defined by a user. This gives the user the ability to efficiently sort and filter large amounts of lake data for selective classification and reporting.

Retrieval of lake information on file can be accomplished through sorting and sieving (filtering) functions defined by parameters of interest and values limited by comparators (>, =, and <). When a geographic area containing lakes of interest is specified, the user-defined area is calculated and printed at the end of the listing. The sum of all lake surface areas in the listing is also printed for comparison with the geographic area in which they exist.

The ability to use Landsat multispectral scanner data to discriminate between water and terrestrial environments has been evident to users since Landsat data became available. From Landsat data, lakes have been identified, defined, and classified (Tarnocai and Kristof 1975, Work and Gilmer 1976, Best and Moore 1979).

Two major differences between the system reported here and others documented in the literature should be emphasized. First, this computer program produces a file that uniquely identifies lakes by geographic location (latitude and longitude) for permanent storage and retrieval of a multitude of lake-specific data. Second, the system uses off-the-shelf Landsat data to compute accurate map projection lake center positions from Landsat scene coordinates. Only recently has Ground Control Point (GCP) geometric correction been available for Landsat scenes delivered by EROS Data Center in Sioux Falls, South Dakota. Although system capability exists, operational capability is still lacking. The system described here was the first operating user computer program that required the use of this operational capability for Landsat data. The nonavailability of GCP-corrected data has limited the testing of this system for accuracy.

This system has several potential applications. It could be used to consolidate aquatic *data* with readily retrievable *access*. This can supplement or replace conventional means of lake data management and analysis. The system provides the capability for *rapid survey* of lakes in relatively flat terrain and for monitoring their changes in time. Finally, it provides the capability for *lake classification* through sorting and filtering functions applied to the various lake parameters on file.

SUMMARY

Some of the data acquired during this study are still being analyzed and verified, and some are being incorporated into resource management applications. Aquatic resource/depth associations are being used to help assess resource use conflicts (e.g., winter water withdrawal versus overwintering fish use). April 1980 SLAR data that were acquired over 90 percent of the National Petroleum Reserve-Alaska are being used for office identification of winter water sources and aquatic resource use conflicts. Additional SLAR acquisition and study will improve the application of SLAR data for regional inventory of lake depths. The computer generation of a lake file from Landsat digital data requires further testing and verification before it will become operational.

These remote-sensing tools and the knowledge of aquatic resources associated with bathymetry can add to our ability for regional inventory, classification, and management of arctic lake resources.

ACKNOWLEDGMENTS

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COST-EFFICIENT BIOPHYSICAL STREAM SURVEYS: A PROVEN APPROACH[1]

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E.A Harding[3]

Biophysical stream surveys were conducted on 40 000 km^2 of remote wilderness in northeastern British Columbia at a total cost of $56/km of channel surveyed. An eight-member crew gathered extensive data on the channel characteristics and fish populations of the area at the rate of 200 km^2 per air hour. The data was organized with a computer-oriented data base and recorded on 1:50 000 topographic maps.

INTRODUCTION

The following paper summarizes an extensive inventory using a reconnaissance aquatic systems survey methodology developed by a study team in British Columbia as described by Chamberlin (1980a). Some details of the methodology have since been modified but the basics remain unchanged. The discussion illustrates how pre-planning a study's logistics can minimize survey and data handling costs.

The study area is in relative wilderness in northeast British Columbia (fig. 1). The Northeast Coal Project was set up to collect background biophysical data on some 40 000 km^2, primarily in response to proposed large-scale coal developments.

Some of the anticipated impacts to the area include construction of a highway and railroad and development of an 80 hectare townsite with a proposed population of 5-10 000 residents. A provincial park is also proposed for the area. Some 9 companies are undertaking exploration work on 13 major coal lease areas with development proceeding on at least four open pit coal mines. There is an existing minor forestry operation in part of the project area.

The aquatic survey group was part of a multidiscipline task force that conducted biophysical surveys on the area's climate, soils, vegetation, wildlife, visual aesthetics, archaeology, recreation, and aquatic resources. Little information existed on the area's aquatic resources, its fisheries values, population dynamics, channel characteristics or hydrology prior to this inventory.

[1] Paper presented at the Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. (Portland, Oregon, 28-30 October, 1981).

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STUDY AREA

The study area for the Northeast Coal Project encompasses approximately 40 000 km^2 (fig. 1) in northeastern British Columbia. It is a complex area of diverse climate, topography, and surficial materials with attendant variety of channel morphology, hydrology and habitat characteristics.

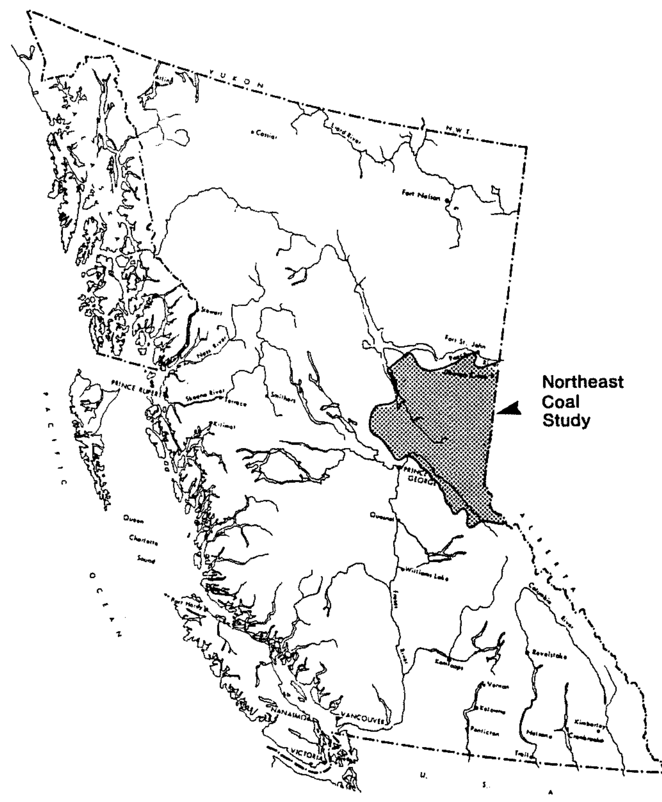

Figure 1.--Study area location

Split into Arctic and Pacific drainages by the continental divide, the study area includes portions of five main physiographic regions (Holland, 1964). These range from the gently rolling Alberta Plateau to the steep, often glacial, Rocky Mountains. River types range from low gradient meandering channels to steep, entrenched channels. Harding (1979) discusses the general biophysical relationships of each of these physiographic regions to the aquatic resource.

Ground access within the study area is nearly non-existent. Some road and trail access is possible due to coal and gas exploration and from the forestry operation. However, most of the area is wilderness.

PROJECT DESIGN

The Aquatic Studies Branch recognizes four levels of detail of aquatic surveys as summarized in Table 1. The "reconnaissance" level of survey detail was used for the Northeast Coal Project. This survey level enables comparisons between basins and between reaches of a channel. It is used for planning at a regional level and effectively "flags" areas sensitive to disturbance or of high value that may require a more detailed assessment (e.g. a channel stability problem area).

The steps in designing the project are: study area designation; airphoto interpretation; field surveys; map and card edits; drafting and data entry; summary and interpretation of results. These are discussed more fully in the following sections and in Chamberlin (1980a).

LOGISTICS

Experience has shown that, although apparently more expensive, use of helicopter access for reconnaissance inventories is less expensive overall and yields better quality data than does ground access. The helicopter is not used just to transport the sampling crew to the site, but to fly up and down the channels of the study area to collect reach information (table 2). Using this approach, it is possible to collect data at 8-12 sample sites (table 3) and survey 230 km of channel per day. i.e. Surveying only the significant channels, this is equivalent to a 900 km^2 mapsheet (1:50 000) per flying day of five air hours.

To achieve this rate of coverage requires thorough preplanning. The "observer", who handles minute-to-minute organization of the day's surveys as described later, must be closely involved with the organization and preparation for the survey. The planning steps preceding the field survey are: definition of

Table 1.--Levels of Aquatic Surveys

Level	Objectives	Sampling	Ground Samples
I Broad Overview	REGIONAL comparisons 1:100 000 to 1:500 000 Provincial planning	REMOTE Sensing Existing data only to satellite imagery and some 80 ch. aerial photos	NONE
II Reconnaissance	BASIN comparisons 1:50 000 Reaches defined Obstructions located Fish sp. presence/absence Regional or Strategic planning	AERIAL observation Reach parameter estimates Few point samples 10-80 ch. aerial photos	FEW
III Detailed Inventory	MANAGEMENT 1:10 000 to 1:20 000 Habitat types described Population sizes measured Sub-regional or Operational planning	GROUND transects Reaches subsampled Detailed aerial photos	MANY
IV Intensive Studies	SITE SPECIFIC Engineering design Population ecology Time functions established Productivity estimates Project design	REPETITIVE sampling Experimental work	VERY MANY

after Chamberlin (1980a)

study area, initial aerial photo interpretation, and development of a preliminary flight plan. Definition of a study area is done in consultation with the data requestor. This dialogue establishes what level of detail (table 1) and which interpretations are necessary to satisfy the purpose of the survey without gathering excessively detailed information.

Initial air photo interpretation (pretyping) determines areas requiring special investigation such as anticipated problem areas, channel features, preselection of sample points and probable landing sites.

A preliminary flight plan is developed to estimate flying distance/time, fuel requirements, suitable fuel dump locations and the most efficient sequence of point sites. This preliminary plan is especially important. An accurate prediction of time requirements allows placing the total season's helicopter requirements out for bids by the various helicopter contractors. By using contracts instead of casual hire, it is frequently possible to save $100.00 per hour in helicopter rentals. To forecast requirements we use the following guidelines: observing (reach mapping 95 km/h; ferrying speed 160 km/h; 95 l/hr fuel consumption; 2.5 hours fuel capacity. Further, a 40-60 litre reserve must be left in the fuel tank of turbine helicopters at all times as a safety measure, thus reducing their operating range by some half hour from the theoretical maximum. Because of British Columbia's mountainous terrain and unpredictable weather, it is also necessary to allow enough time for low-level valley-bottom flying for all access rather than shorter distance straight-line flying.

A Bell 206B Jet Ranger helicopter or a machine of equivalent size and power is used for most surveys. Smaller helicopters, such as a Hughes 500 do not have enough cargo and personnel space for the job. Besides the pilot, the survey crew consists of an "observer" and one or two ground crews of two or three people each. The helicopter thus carrys up to five people in total plus equipment (usually an electro-shocker and batteries, seine net, water sample bottles, etc.) in the cargo hatch. Exterior baskets are seldom used.

During the aerial surveys the observer is responsible for general minute-to-minute organization as outlined below, while the ground crew collects data at the sample sites.

The observer flies up the designated channels recording reach parameters onto a tape recorder, takes example photographs, records channel features onto a 1:50 000 topographic map, places the ground crews at suitable sample sites and keeps track of their elapsed ground time. The ground crew must have sufficient time to complete a point sample (usually 45 minutes to an hour) but be moved onto the next site as soon as possible. The observer also keeps a rough idea of the location of the next fuel stop relative to the active working area to minimize long non-productive ferrying trips. When using two ground crews (the most efficient method for large areas) the helicopter "leap-frogs" them throughout the study area.

As is apparent, the observer's job is enormous. It requires long periods of intense concentration. Therefore, it is not advisable to have any one person do more than about three hours of actual channel reach observing per day and to transcribe the notes made about the reaches as soon as possible after doing the flight, particularly before participating in another flight. The number of errors versus air time on any one day is nearly expotential after about three hours of observing. Thus, it is a good idea to rotate the crew members on a daily basis. All spare equipment, crew and pilot accommodation, etc. must be pre-arranged.

The ground crew consists of two or three people which take the sample point and fish population sample measurements. Fish sampling is done by a combination of electro-shocking, seining, angling and observations made while snorkelling.

The data are entered onto field cards which, once checked for errors, are keyed directly onto magnetic tape for storage on computer. Transcribing field notes onto coding forms is an unnecessary expense and introduces error.

Channel features are electronically digitized from the original topographic map. The map features are then drafted onto a mylar topographic base map for subsequent black and white reproduction upon request (the Aquatic Biophsical map). No colour maps are currently produced.

Many of the steps act as edits and checks against one another. These edit steps plus minimizing the number of times any data bit is handled before being entered into the data bank helps reduce both costs and the frequency of introduced errors.

Finally, many of the "reports" are computer-written summaries and tables (B.C. Aquatic Data Base) which minimize staff preparation time. This is one of the greatest economies of all.

RESULTS

The Northeast Coal project aquatic resources program was concerned primarily with generating information related to fish populations, biophysical lake and stream characteristics, water quality, and hydrology.

The data bank is multilevel, with files organized according to watersheds, reaches, points, and fish samples. All data is organized and stored by its watershed code. The watershed code methodology is outlined in Shera and Grant (1980).

Reach measurements (table 2) are generalities and average values for a relatively homogenous length of channel. Gross summaries of the fish, channel characteristics and bed material composition are also included on the map for each reach described.

Channel features (such as falls, slumps, and known spawning areas) are part of the reach file. Channel features are mapped onto 1:50 000 topographic base maps and georeferenced in the data bank by latitude/longitude and distance upstream from the stream mouth.

The point file contains the biophysical sample site data (table 3) collected by the ground crews. A point is a subsample of a reach. The fish file contains all the fish sampling information relative to a point. The parameters for the various files are defined by Chamberlin (1980b).

The resulting data is stored in the computerized British Columbia Aquatic Data Base, on hard copy file, and on 1:50 000 topographic base maps. Some 1000 reaches, 500 points and 70 mapsheets were generated for the 40 000 km^2 study area. From the data bank, tables of values and summaries can be generated by running selective sorts of the information. For example, fish can be sorted by species (i.e. "where are the whitefish") or by location (i.e. "what fish are present 20 km upstream?").

Table 2.--Reach parameters collected during reconnaissance aquatic biophysical inventories

Reach documentation: survey date; reach length; elevation; gradient; reach location by distance to mouth, latitude and longitude, and map no; other sampling (points, fish); survey agency; access; weather; surveyor; aerial photograph no. date and scale.
Valley process: avalanches, slumps, slides, etc.
Bars: quantified by seven types
Islands
Lateral stability evidence
Degree of Confinement
Meander pattern
Riparian and channel overhang cover by type and quantity of each
Substrate characteristics
Vertical stability
Flow character, flooding evidence, turbidity
Debris amount and stability

Three basic types of maps can be produced. The Aquatic Biophysical map provides much of the basic data; derivative maps are the map representation of a selective sort of the data (e.g. a fish distribution map); and interpretive maps are those for which the data must be modelled and new values created for the reaches (e.g. a fisheries "sensitivity" map).

The reconnaissance survey data from the Northeast Coal project has been used to: summarize fish distribution (ELUSC, 1977); evaluate the anticipated impact of transportation corridors (Sigma, 1981; ELUSC, 1977); establish background suspended sediment levels; assess aquatic impacts by the various proposed coal mines (ELUSC, 1977); provide a basis for general management and priorization of that region's aquatic resources. Other aquatic surveys from the Northeast Coal project (Miles and Harding, 1980) have been used to highlight areas of concern regarding flooding and fisheries impacts associated with the proposed townsite and evaluate channel stability.

This relatively new approach has been used for about 165 000 km^2 of British Columbia since 1975. It is also being used in the Yukon, parts of Northern Alberta (Sekerak and Walder, 1980), and southern Quebec.

Table 3.--Point parameters measured at sample sites during reconnaissance aquatic biophysical inventories

Point documentation: date and time; location by reach no., distance from mouth, latitude and longitude, and map no.; survey; agency; access; weather; site photo documentation; weather; presence of other samples (water, fish, aquatic biota).
Bank: genetic materials; stability; shape; texture composition
Substrate: texture composition; evidence of ice scouring; imbrication; lag deposits; by size class
Debris: amount and stability
Biota: aquatic veg and algae, invertebrates and fish abundance and species; fish sizes and collecting effort
Riparian veg and overhang: by type and quantity of each for each bank
Channel hydraulics: width of valley flat, channel, water; channel slope at point; maximum and average depth; velocity; flow volume and character; evidence and height of flooding; ice scouring; presence of side channels; valley-to-channel ratio
Water quality: temp., turbidity; TDS; dissolved oxygen; pH

COSTS

The 40 354 km^2 study area cost a total of \$589,786 ('81 Canadian dollars). Figure 2 breaks down the relative amounts of the total project costs into survey costs and ancillary office costs or support services. The considerable cost of equipment was arbitrarily assigned to support services because of its re-usable nature on other projects. In reality, probably 30% of the equipment was of disposable nature and not re-usable (e.g. repair and maintenance supplies and film). With equipment assigned to support services the cost of surveys and cost of support is 50:50.

The actual cost of the surveys at the time they were conducted (1976-1978) was about 5.3¢/hectare. However, when the support services were added and the total converted to 1981 dollars, the cost today would be about 14.6¢/hectare. Therefore, it is possible to plan, perform reconnaissance surveys, and interpret the data for all the principal channels of a project area for about 14.6¢/hectare or \$13,000 per 1:50 000 mapsheet (roughly 900 km^2 per mapsheet in Northeast Coal project area latitudes). Approximately 230 km of channel (range 202 to 256 km) was surveyed for each mapsheet, an average of \$56 per km.

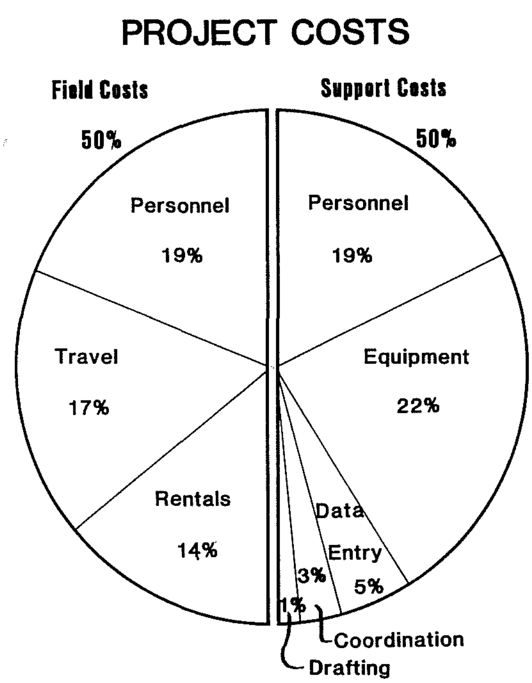

Figure 2.--Northeast Coal Project: proportionate costs of 1:50 000 Aquatic Biophysical mapping

It should be noted that the actual field time to do the stream inventory totalled 5 weeks over the two year project. The bulk of the two field seasons were actually spent doing life history, habitat preference, some small streams and discharge and water quality studies. Also, a good portion of this time was used training a seven-man crew in using this Aquatic Studies Branch methodology. Therefore, if a trained crew had been available and the fish biology of the region understood, these inventory costs would have been further reduced.

By way of comparison, a 1981 Aquatic Studies Branch Slocan River reconnaissance survey cost 17¢ per hectare (J. Balkwill[1]) which compares closely to the projected 1981 costs of the Northeast Coal Study. The Slocan survey used a non-contract (higher priced) helicopter but a reduced field effort and pretrained field crew (lower cost).

More detailed aquatic surveys increase costs exponentially. For example, an intensive scale (1:1 000) engineering design survey (anon. 1980) of some 15 km of British Columbia's Fording River cost some \$88,000 (81 dollars) (R. Berdusco[2]). This emphasizes the importance of choosing the appropriate survey scale for the study requirements. Aquatic system surveys can be done economically only if they are carefully pre-planned and coordinated.

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[1] Balkwill, J. 1981. Pers. comm. Aquatic Studies Branch, Ministry of Environment, Victoria, British Columbia.

[2] Berdusco, R. 1981. Pers. comm. Reclamation Department, Fording Coal Ltd. Elkford, British Columbia.

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NEW PERSPECTIVES ON SAMPLING, ANALYSIS, AND

INTERPRETATION OF SPAWNING GRAVEL QUALITY[1]

F. H. Everest, F. B. Lotspeich, W. R. Meehan[2]

Abstract.--Methods of sampling salmonid spawning gravels and interpreting their quality have improved in recent years. Multiple probe freeze-core samplers allow vertical subsampling of gravel cores and provide an improved understanding of the textural composition of gravels. Vertical subsampling of cores has shown that textural composition of gravels varies with depth below the substrate surface and is changed by the hydraulic forces exerted by spawning fish. These findings have important management implications.

INTRODUCTION

The amount and condition of streambed gravels available to spawning salmonids has been a perennial concern of fishery managers. Biologists conducting habitat inventories routinely record quantities of gravel available to spawning salmonids and estimate the quality of gravels based on surface appearance. Resource managers often sample streambed gravels to monitor changes in textural composition and quality resulting from land management activities or changes in streamflow regimen caused by water development projects. Monitoring is also conducted to assess changes in substrate composition resulting from watershed rehabilitation projects. Finally, gravel sampling is frequently used to determine the success of salmonid habitat enhancement projects designed to increase the quantity and quality of spawning areas.

Gravels containing a low proportion of fine sediments have long been recognized (Harrison 1923) as a critical requirement for successful salmonid reproduction. Significant advances in equipment and techniques for quantitative sampling of gravels, however, have been made only within the past few years. New methods for assessing gravel quality have also been developed recently. The new equipment, procedures, and techniques have shown that the textural composition of streambed gravels changes with depth below the substrate surface (Everest et al. 1980, Scrivener and Brownlee 1981). The new insights on vertical textural variations of spawning gravels have several important management implications. Our objective is to describe the recent advances in gravel sampling and analysis techniques and their implications for management, and to recommend current state-of-the-art procedures for assessing gravel quality.

GRAVEL SAMPLING

Sampling Equipment

Two basic types of gravel samplers are presently in use, the "McNeil" type sampler and the freeze-core sampler. Both devices have advantages and disadvantages that are described below.

McNeil Sampler

The first attempts at quantitative samplers for general use consisted of metal tubes, open at both ends, that were manually forced into the substrate. Sedimentary material encased by the tubes was removed by hand for analysis. A variety of samplers using this principle have been developed, but one described by McNeil and Ahnell (1960) has become widely accepted for sampling streambed sediments.

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[1]Paper presented at the Symposium on Aquisition and Utilization of Aquatic Habitat Inventory Information. [Portland, Oregon, October 1981].

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The McNeil sampler is usually constructed of stainless steel and can be modified to fit most sampling situations. It is lightweight and portable and can be used in remote locations if necessary. Disadvantages of the sampler are:

(1) Core materials are completely mixed upon removal so no interpretation can be made of vertical or horizontal differences in particle size distribution within a core, (2) sampling depth is limited by such factors as water depth and length of the collector's arm, (3) the core tube often pushes larger particle sizes out of the collecting area, (4) suspended sediments in the core are lost, (5) sediment particle sizes larger than the core tube cannot be collected, and (6) often the sampler can not be inserted to the required depth if sediment particles are large or if the substrate is compacted.

Regardless of the many limitations of this sampler, when time and costs are considered, it is probably the most economical method available for establishing rough estimates of substrate particle size distribution.

Freeze-Core Samplers

In the last decade scientists have been experimenting with cryogenic devices to obtain sediment samples. These devices, generally referred to as "freeze-core" samplers, consist of a hollow probe driven into the streambed and cooled with a cryogenic medium. After a prescribed time of cooling, the probe and a frozen core of sediment adhering to it are extracted. Liquid nitrogen, liquid oxygen, solidified carbon dioxide ("dry ice") and acetone, dry ice and alcohol, and liquid carbon dioxide (CO_2) have been used experimentally as freezing media. Several years of development produced a reliable single-probe sampler (Walkotten 1976) that uses liquid CO_2.

The accuracy and precision of the single probe freeze-core and McNeil sampler have been compared in laboratory experiments.[3] Samples collected by both devices were found to be representative of a known sediment mixture, but the freeze-core sampler was more accurate (Walkotten 1976). An important advantage of cryogenic samplers is that frozen cores can be vertically subsampled. Freeze-core samplers are also more versatile, functioning under a wider variety of weather and water conditions.

Cryogenic samplers also suffer several disadvantages. It is difficult to drive probes into substrate containing many particles over 10 cm in diameter, and the freeze-core technique is equipment intensive, requiring CO_2 bottles, hoses, manifolds, probes and a sample extractor. Also, since it is necessary to vertically subsample cores by depth for accurate interpretation of gravel quality (Everest et al. 1980), it is often necessary to collect more massive cores than can be easily obtained by the single-probe technique. For example, Adams (1980) used a single-probe device to extensively sample stream substrates in the Oregon Coast Ranges. He was able to extract up to six cores of sediment averaging about 1.6 kg/core per 9-kg (20-pound) tank of CO_2. Individual cores of such size are minimal for vertical subsampling. Skaugset (1980), on the other hand, collected cores exceeding 20 kg with a single-probe device using 10 liters of liquid nitrogen per sample. Skaugset's samples were large enough for representative subsampling, but liquid nitrogen is more expensive, difficult to obtain, store, and use than liquid CO_2.

To alleviate problems caused by the small size of sediment cores obtained by single-probe samplers using CO_2, and to avoid use of liquid nitrogen as a cooling medium, Lotspeich and Reid (1980) and Everest et al. (1980) have modified the single-probe device. The modified freeze-core sampler uses a triangular array of three probes driven into the substrate through a template that keeps the probes in fixed relationship to each other. The "tri-tube" sampler (fig. 1) retains all the advantages of the single-probe freeze-core sampler, but extracts larger cores--often more than 20 kg per 9-kg (20-pound) tank of CO_2--which are more representative of substrate composition than small cores obtained by the single-probe sampler, or cores obtained with McNeil samplers.

We recommend use of the multiprobe procedure if an analysis of horizontal and vertical stratification of sediments is required. We suggest use of the tri-tube sampler described by Lotspeich and Reid (1980) and Everest et al. (1980) when numerous cores must be collected, and the Platts-Penton (1980) sampler when only a few large cores are needed.

The freeze methods allow collection of eggs and alevins in a redd at any stage of development, will function at most air or water temperatures or stream depths, and allow analysis of horizontal and vertical location of the eggs and alevins. Because these techniques require several pieces of equipment, they are most conveniently used in accessible areas.

SAMPLING LOCATION AND DEPTH

Selection of spawning sites by salmonids is a nonrandom activity. Adult salmonids seeking locations to spawn respond to environmental variables such as water depth and velocity, substrate composition, and proximity to cover. Because both sediment particle-size distribution and redd site selection are nonrandom events, the location from which samples are drawn to

[3]Koski, K. Victor, and William J. Walkotten, unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oregon.

characterize spawning gravels should be identified by an experienced fishery biologist. Samples should only be drawn from locations that meet the known spawning requirements of a species. The suitability of each sampling site should be determined by quantitative measurements of water depth and velocity. The depth at which the sample is extracted is also critical to the analysis. Samples should be taken only as deep as the average depth of egg deposition for the species being studied. Since there is substantial stratification in stream gravels, sampling above or below the level of egg deposition might yield an inaccurate estimate of the size and distribution of particles within a redd. If prediction of survival to emergence of salmonid fry is desired, all samples should be collected from redds just prior to onset of emergence. Otherwise, temporal variations in gravel composition (Adams and Beschta 1980) might lead to inaccurate assessments of gravel quality at the onset of emergence.

GRAVEL ANALYSIS

Analysis of substrate samples is accomplished by sorting sediments through a series of sieves, determining the fraction of each pre-specified size group of sediment in the sample, and making an inference about the quality, or changes in quality, of the substrate for salmonid reproduction.

Sorting Gravels

Two primary methods for sorting sediments are the "wet" method and the "dry" method. The wet method can be done in the field but is the least accurate because water is retained in pore spaces of the sediments. The wet method uses a water flushing technique with some hand shaking to sort sediment through sieves. The trapped sediment on each screen is allowed to drain and is poured into a graduated water-filled container. The amount of water displaced determines the volume of that size fraction plus the volume of water retained in the pore spaces of the sediment. A correction factor (see Shirazi et al. 1981) must be applied to each size fraction of sediment to account for retained water.

For more exacting results, samples should be analyzed by the dry method. Samples are transported to the laboratory, oven or air dried, and sorted through sieves with a mechanical shaker. The proportion of individual size fractions in a sample is then determined gravimetrically. We recommend the Wentworth sieve series which is a geometric progression of 12 size-classes ranging from 0.062 to 100 mm (0.002 to 3.94 in). The upper limit might seem arbitrary, but it approximates the largest size particles in which most salmonids will spawn. Consequently, few grains larger than 100 mm are present in preferred spawning areas.

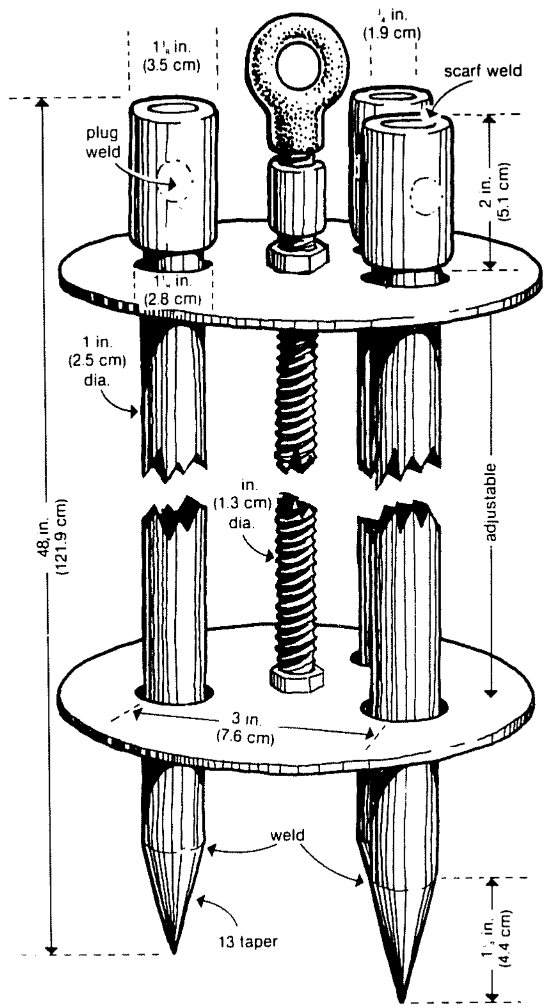

Figure 1.--Schematic diagram of the tri-tube cryogenic gravel sampler.

SELECTION AND USE OF QUALITY INDICES

The quality of gravels for salmonid reproduction has traditionally been estimated by determining the percentage of fine grains (less than some specified diameter) in samples collected from spawning areas. Field data have often been compared to results of laboratory studies (e.g. Phillips et al. 1975) to estimate survival to emergence of various species of salmonids. While an inverse relationship between percent fines and survival of salmonid fry has been demonstrated by several researchers, beginning with Harrison (1923), use of percent fines alone to estimate gravel quality has a major disadvantage. Use of only fine grains of sediments to characterize the quality of a sample ignores the textural composition of the remaining particles which can have a mitigating effect on survival. For example, imagine two samples each containing 20-percent by weight fine sediment particles less than 1-mm diameter, but the average diameter of larger particles is 10 mm in one sample and 25 mm in the other. Interstitial voids in the smaller diameter material would be more completely filled by a given quantity of fine sediment than voids in the larger material and the subsequent effect on survival of salmonid fry would be very different. Percent fines is a reasonable index of gravel quality but has serious limitations because it ignores the textural composition of the remainder of the sample.

Other quality indices have recently been developed in an attempt to improve upon the percent fines method. Platts et al. (1979) used the geometric mean diameter (d_g) of sediment particles in a sample as an index of salmonid incubation success. This has advantages over the commonly used percent fines method in that (1) it is a conventional statistical measure used by several disciplines to represent sediment composition, (2) d_g relates to the permeabililty and porosity of channel sediments and to embryo survival as well as or better than percent fines, and (3) d_g is estimated from the total sediment composition. Despite these advantages, d_g has been shown by Beschta (1981) to be rather insensitive to changes in stream substrate composition caused by sediment from roads in a Washington watershed. Also, Lotspeich and Everest (1981) have shown that use of d_g alone can lead to erroneous conclusions concerning gravel quality. Because of these problems, Beschta (1981) has raised serious questions regarding the utility of geometric mean diameter as a quality index when used as the sole criterion.

Tappel (1981) offers another approach which is a modification of the d_g method and uses a linear curve to depict particle size distribution by assigning the points 0.8 mm (0.03 inches) and 9.5 mm (0.37 inches) for determining a line. According to Tappel the slope of the line gives a truer picture of fine sediment classes detrimental to incubation. A major drawback of this procedure, as with percent fines, is that it ignores the larger particles in a sample and might, consequently, suffer the same limitations.

A quality index which appears to overcome limitations of percent fines and geometric mean has been reported by Lotspeich and Everest (1981). Their procedure uses a measure of the central tendency of the distribution of sediment particle sizes in a sample and the dispersion of particles in relation to the central value to characterize the suitability of gravels for incubation and emergence of salmonids. These two parameters are combined to derive a quality index called the "fredle index," which provides an indicator of sediment permeability and of pore size. The measure of central tendency used is the geometric mean (d_g). In addition to d_g, the size distribution of sediment particles in a sample is a useful descriptor of a gravel's reproductive potential for salmonids. To quantify the distribution of grain sizes in gravels, Lotspeich and Everest (1981) have used the sorting coefficient (S_o) described by Krumbein and Pettijohn (1938). S_o is derived by taking the square root of the quotient of the grain size at the 75th percentile divided by that at the 25th percentile. Permeability and pore size, which control movement of water and alevins through gravel, are determined largely by the size distribution of grains in a sample. These two substrate parameters are the primary legislators of survival-to-emergence of salmonid embryos.

The Fredle index (f) is calculated by the following method:

$$f = \frac{d_g}{S_o};$$

where, $d_g = (d_1^{w_1} \times d_2^{w_2} \times \dots\dots\dots d_n^{w_n})$,

d_n = mid-point diameter of particles retained on the nth sieve,

w_n = decimal fraction by weight of particles retained on the nth sieve, and

$S_o = \sqrt{\frac{d_{75}}{d_{25}}}$ = sorting coefficient--

d_{75} and d_{25} = particle size diameters at which 75 and 25 percent, respectively, of the sample is finer on a weight basis.

Fredle numbers for sediment with a single grain size will be equal to the geometric mean because S_o is then 1. Sediments with the same d_g will have f numbers less than the geometric mean as S_o increases. Sediments with small d_g values are less permeable than those with larger means because pores are small and intragravel flow and movement of alevins is impeded even though S_o might be 1. Also sediments with large d_g might be slowly permeable when S_o is large because pore spaces are occupied with smaller grains that impede interstitial flow and movement. Thus, the magnitude of the Fredle index numbers is a measure of both pore size and relative permeability, both of which increase as the index number becomes larger.

The Need to Subsample Substrate Cores by Depth

Use of freeze-core samplers has clearly demonstrated that particle size distribution of gravels can vary with depth below the substrate surface (Everest et al. 1980, Scrivener and Brownlee 1981). Our research has shown that the quality of gravels for incubation of salmonid eggs and emergence of alevins generally decreases with depth below the surface of the substrate. The difference between quality of surface layers and subsurface layers appears to be directly related to the load of fine sediment transported by the stream.

In 1978 and 1979 we collected substrate samples from salmonid spawning areas on four streams in the Rogue River basin of southwest Oregon. Two streams support large populations of fall chinook salmon (*Oncorhynchus tshawytscha* (Walbaum)) and two support large runs of summer steelhead (*Salmo gairdneri* Richardson). Each pair of streams was selected because one member of the pair carried a much higher load of fine sediment during freshets than the other. Samples collected from the streams utilized by chinook were analyzed by 10-cm increments from the surface to a depth of 30 cm. Samples from spawning areas of steelhead were analyzed by 7.5-cm increments to a depth of 30 cm. The results of this analysis (tables 1 and 2) demonstrate that the quality of gravel for salmonid reproduction often decreases substantially with depth below the substrate surface. Such knowledge indicates that accurate inferences of gravel quality can only be made from samples that have been partitioned and analyzed by depth increments.

How to Subsample Substrate Cores by Depth

A major advantage of the freeze-core sampler is that it provides opportunity for vertical subsampling of substrate cores. Everest et al. (1980) have developed a subsampler consisting of a series of open-topped boxes made of 26-gage galvanized sheet metal (fig. 2). A core is laid horizontally on the boxes of the subsampler and thawed with a blow-torch. Sediments freed from the core drop directly into the boxes below. Individual subsamples can then be dried, sorted, and analyzed for textural composition and quality.

EFFECTS OF NATURAL GRAVEL STRATIFICATION ON INTERPRETATION OF GRAVEL QUALITY

Our investigation of the characteristics of spawning gravels using the tri-tube freeze-core sampler and vertical core subsampler have yielded some important implications for future analyses of stream substrates and interpretation of past work. Three major implications are apparent:

1. Surface appearance of gravels is an inadequate and often misleading indicator of gravel quality for salmonid reproduction although stream surveyors often estimate the quantity and quality of available spawning gravels by visual

Table 1.--Changes in textural composition and quality of gravels in chinook salmon spawning areas as related to depth below the substrate surface, Evans Creek and Slate Creek, Rogue River basin, Oregon, 1979.

Stream	Sample depth (cm)	Geometric mean (mm)	Percent fines <1 mm	Fredle index
Evans Creek,	0-10	11.2	12.1	3.6
high sediment	10-20	7.6	22.0	1.5
stream (n=5)	20-30	2.5	42.5	0.4
Slate Creek,	0-10	13.8	6.5	5.7
low sediment	10-20	13.0	7.5	5.1
stream (n=5)	20-30	12.7	12.5	4.4

Table 2.--Changes in textural composition and quality of gravels in steelhead spawning areas as related to depth below the substrate surface in Foots Creek and Sams Creek, Rogue River basin, 1979.

Stream	Sample depth (cm)	Geometric mean (mm)	Percent fines <1 mm	Fredle index
Sams Creek,	0-7.5	9.4	12.3	3.8
high sediment	7.5-15	7.3	16.4	2.7
stream (n=6)	15-22.5	9.1	14.0	2.9
	22.5-30	9.6	13.1	3.2
Foots Creek,	0-7.5	14.5	6.9	9.4
low sediment	7.5-15	10.8	10.8	3.1
stream (n=6)	15-22.5	11.6	12.1	3.1
	22.5-30	13.3	11.2	5.2

appearance of the substrate surface. In addition to the visual assessment, a boot heel is often ground into the substrate to test the compaction or concretion of gravels as an index to quality. Neither method, however, adequately describes gravel quality because gravel quality cannot be assessed at the 20-to 30-cm depth where spawning salmonids usually deposit eggs.

Our research has shown that streambed gravels with similar surface properties and appearance can have very different properties a few centimeters below the surface. For example, surface appearance of gravels in Foots Creek and Evans Creek in the Rogue River basin, Oregon, are very similar and would be classified "good" by visual inspection. Geometric mean particle diameter, sorting coefficient, Fredle quality index, and percent fines <1-mm diameter are also very similar within the top 10-cm layer of gravel in each stream (table 3). The physical characteristics of gravels, however, diverge markedly in the 10-to 20 and 20-to 30-cm strata (table 3). If salmonid fry were forced to emerge through the 20-to 30-cm strata on Evans Creek which contained 41.5 percent fines <1-mm diameter and a Fredle index of 0.4, low survival would be expected. Foots Creek, on the other hand, contained only 11.5 percent fines <1-mm diameter and had a Fredle index of 3.6 in the 20-to 30-cm depth strata. More than 50-percent survival to emergence would be expected under the latter conditions.

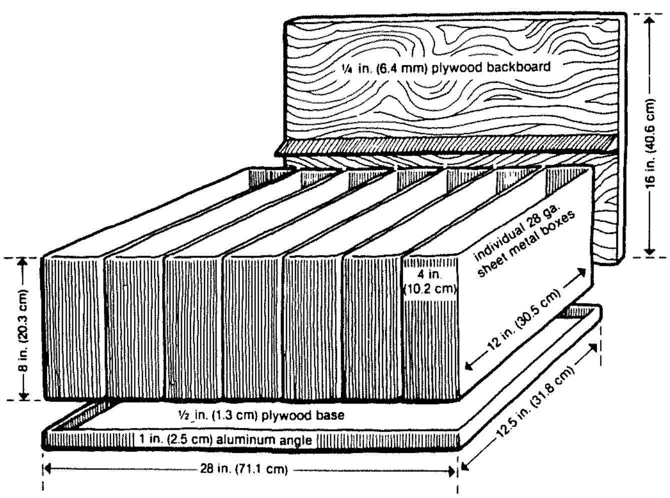

Figure 2.--Diagram of freeze-core subsampler.

2. Failure to stratify cores vertically into subsamples can also misrepresent quality of gravels for salmonid reproduction. Gravel sampling equipment that mixes the contents of a gravel core during extraction, for example, the McNeil sampler, can result in quality estimates either higher or lower than conditions actually faced by emerging fry. For example, if chinook salmon on Evans Creek deposit eggs 30 cm below the substrate surface and 30-cm-deep cores, mixed during extraction, are removed from redds and analyzed, the predicted quality of gravels in the redd exceeds actual conditions faced by fry during emergence (table 4). Data from mixed cores yield an average estimate of 7.6 percent fines <1-mm diameter and a Fredle index of 6.0 in chinook redds. Data from samples taken by freeze-core and stratified into 10-cm increments indicate a Fredle quality index of 3.3-and 10.8-percent fines <1-mm diameter are located between 20 and 30 cm below the substrate surface. The latter are the actual conditions fry must traverse during emergence, not the conditions calculated after mixing the contents of the core.

The quality of gravels in redds can also be underestimated by failing to vertically subsample cores. If core samples collected from redds include a layer of gravel and fine sediment below the level of salmonid eggs and the contents of the core are mixed during extraction, the result is usually an underestimation of gravel quality when compared to samples that include only gravels above egg level. Our research has shown that spawning can remove 20 percent or more of the fine sediments <1-mm diameter in redds. Eggs are deposited at the lowest level of the "cleaned" gravels. If, for example, chinook salmon deposit eggs about 30 cm below the substrate surface, then cores collected with McNeil samplers should not exceed the 30-cm depth. Collection of 40-cm deep gravel cores that include 10 cm of uncleaned gravel below the eggs result in depressed estimates of gravel quality within a redd. Samples collected from Evans Creek in the Rogue River basin illustrate this point. Forty-cm-deep samples were collected with freeze-core equipment and analyzed by 10-cm-depth strata. Strata in individual cores were then combined to compare gravel quality in 30-and 40-cm columns of the same cores (table 5). When samples were mixed and 10-cm of gravel below egg level was included, there was an apparent decrease in gravel quality within the redds. Neither 30-nor 40-cm mixed cores, however, provide an accurate estimate of conditions that fry must actually penetrate during emergence. The actual gravel quality between the 20-and 30-cm depth (table 5) was substantially lower than estimates from combined strata in a 30-cm core, but was in this example coincidentally similar to combined strata for a 40-cm core.

Table 3.--Comparison of gravel composition and quality in surface and subsurface layers in spawning areas of Evans Creek and Foots Creek, Rogue River basin, Oregon.

	Evans Creek Sample depth (cm)			Foots Creek Sample depth (cm)		
Parameter	0-10[1]	10-20	20-30	0-10[1]	10-20	20-30
Geometric mean (mm)	15.7	5.6	2.6	16.9	9.3	11.8
Percent fines <1 mm	6.2	23.1	41.5	5.4	10.6	11.5
Fredle index	8.0	1.3	0.4	8.4	3.0	3.6

[1] Characteristics of surface layers are very similar and look alike.

Table 4.--Comparison of gravel texture and quality in samples (n=6) taken from chinook redds and analyzed first by depth strata and then mixed and analyzed as a unit, Evans Creek, Rogue River basin, Oregon.

	Sample depth (cm)			
Parameter	0-10	10-20	20-30[1]	0-30 mixed
Geometric mean (mm)	25.1	10.7	9.0	13.3
Percent fines <1 mm	1.9	8.7	10.8	7.6
Fredle index	16.3	4.3	3.3	6.0

[1] Fry must actually traverse these conditions to emerge rather than conditions indicated by the 0-to 30-cm mixed core.

Table 5.--Comparison of gravel texture and quality in samples (n=6) including materials from above egg level (0-30 cm) in chinook redds, and below (30-40 cm), Evans Creek, Rogue River basin, Oregon.

	Sample depth (cm)					
	Above eggs			Below eggs		
Parameter	0-10	10-20	20-30	30-40	0-30 mixed	0-40 mixed
Geometric mean (mm)	25.1	10.7	9.0	5.0	13.3	9.3
Percent fines <1 mm	1.9	8.7	10.8	31.1	7.6	13.4
Fredle index	16.3	4.3	3.3	1.7	6.0	3.3

3. Laboratory studies of survival to emergence of salmonid fry utilizing artificial gravel mixtures are not very useful for predicting survival to emergence in the field. Gravel mixtures produced in the laboratory often contain only a few graded sediment particle sizes both for convenience and to allow standardization of mixes. Gravels with such simple textural composition are usually not found in the field. Secondly, eyed eggs are usually planted at a specified depth (e.g. 25 cm) in the homogeneous lab mixtures. Since our studies indicate that the texture of stream gravels usually changes with depth, it is difficult to make direct comparisons of emergence success between lab and field studies. In a study of the effects of sand on emergence of coho salmon (O. kisutch (Walbaum)) and steelhead trout, Phillips et al. (1975) used an artificial control gravel mixture of six particle size groups ranging from 32 to 3 mm with some intermediate size groups missing. Varying amounts of 1-to 3-mm-diameter sand were added to the control mixture; no particles less than 1-mm diameter were added. Eyed eggs were planted at a depth of 25-cm in each homogeneous mixture and survival to emergence was monitored. Survival was inversely related to the amount of sand in the mixtures.

Examining the results from just one of the mixes (20 percent sand) used by Phillips et al. (1975) will illustrate the problems associated with inferring lab data to the field. One group of alevins was forced to emerge through a 25-cm-thick mixture of homogeneous gravel containing 20 percent sand. No such homogeneous columns 25-cm-deep have been observed in our field studies, although samples mixed during removal often contain an average of 20 percent 1-to 3-mm sand. Field samples containing an average of 20 percent 1-to 3-mm sand when subsampled, however, revealed that textural composition was changing rapidly with depth. A field sample containing 20 percent sand mixed during extraction might seem similar in character to the 20-percent-sand lab mix unless the sample is subdivided by depth for analysis (fig. 3). Subsampling, however, might reveal that fry actually must traverse a layer of gravel containing more than 40 percent sand at the 20-to 30-cm depth, while the 0-to 10-cm depth might contain less than 10 percent sand.

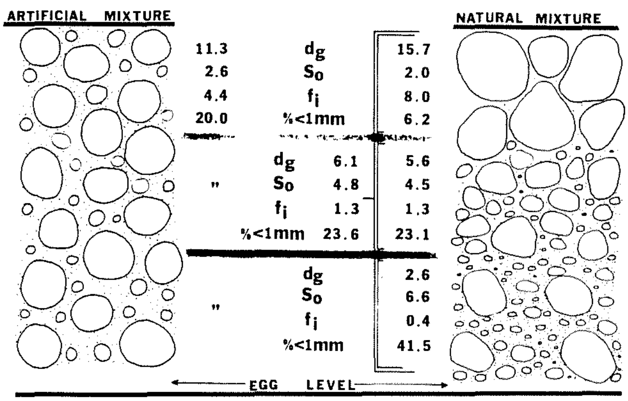

Figure 3.--Diagramatic comparison of the characteristics of artificial and natural gravel mixtures. Because most lab mixtures fail to simulate natural gravels, caution must be used when applying results of lab survival studies to the field.

The general inverse relationship between survival to emergence and fine sediment is valid, but only vertical subsampling of gravel cores from natural environments will show the actual conditions fry must face during emergence.

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SESSION 5B

MODELING AQUATIC INSECT HABITAT[1]

Steven F. Railsback[2]

Edwin E. Herricks[3]

Vahid Alavian[4]

Abstract.--A boundary-layer Reynolds number is proposed as an index of habitat quality for aquatic insects. This Reynolds number can be easily evaluated by field measurements or mathematical models. A laboratory experiment was performed in which the Reynolds number was shown to be linearly related to measured benthic velocities throughout a variety of substrate types.

INTRODUCTION

Aquatic insect habitat has been poorly quantified in stream inventories because microhabitat conditions are extremely complex, precluding easy selection and measurement of critical factors. Habitat inventories have generally taken the form of substrate size class analyses or water column depth and velocity measurements. However, hydraulic parameters interact in a complicated fashion to determine the benthic microhabitat flow conditions. Previous researchers have acknowledged this interaction (Erickson, 1966; Gore, 1978; Rabeni and Minshall, 1977) but have been unable to combine these macrohabitat parameters in a hydraulically and biologically meaningful way.

We have developed a hydraulic parameter suitable for use as a measure of benthic microhabitat velocity. We have also developed a velocity probe small enough to accurately measure benthic velocities in order to demonstrate the usefulness of the hydraulic parameter. The hydraulic parameter may prove a practical means of modeling aquatic insect habitat.

[1]Paper presented at the Symposium on acquisition and utilization of aquatic habitat inventory information, Portland, Oregon, October 28-30, 1981.

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DEVELOPMENT OF A HYDRAULIC PARAMETER

The physical habitat parameters depth, mean column velocity, and substrate type interact to determine flow conditions within the benthic region. The description of hydraulic conditions at the water-substrate interface has been the subject of sediment transport research. Sediment transport theory suggests that a particle's potential for being moved is a function of the boundary shear stress (Simons and Senturk, 1977). Shear stress is the drag force parallel to the surface exerted on sediment particles, per unit area of bed surface. Shear stress is often quantified not as an absolute value with units of force per area, but as a dimensionless ratio of turbulent shear stress to viscous shear stress; this ratio is known as the Reynolds number. For substrate particles the Reynolds number is evaluated as

$$R^* = \frac{U^* \, Ds}{v}$$

where R* is the boundary layer Reynolds number, U* is the boundary shear velocity, Ds is the particle diameter, and v is the kinetic viscosity. A common approximation for U* is

$$U^* = \quad g \, R \, S$$

where g is the gravitational acceleration, R is the hydraulic radius, and S is the bed slope. The hydraulic radius is defined as the channel's cross-sectional area divided by its wetter perimeter, and is approximated by the depth for wide, shallow streams. Substituting for U*, the Reynolds number becomes:

$$R^* = \frac{Ds \quad g \, R \, S}{v}$$

This parameter has the following desired qualities for a measure of benthic velocity:

1. R* increases as particle diameter increases, causing higher interstitial flow;
2. R* increases as mean column velocity increases;
3. R* increases as depth decreases and the boundary layer is reduced in thickness;
4. R* increases as bed roughness increases and more drag is exerted on the substrate;
5. R* increases as viscosity decreases, viscosity being an inverse function of temperature.

Assumptions involved with the use of this parameter are that particles are round in shape and of a uniform size for each substrate type. In cases where the substrate is significantly out-of-round, a sphericity value between zero and one can be applied to estimate an effective diameter (Fair, Geyer, and Okun, 1968). In cases where more than one particle size exists at a point in the benthos, a dominant particle size must be determined.

Table 1 demonstrates the broad response of R* to various habitat conditions.

EXPERIMENTAL METHODS

To verify the usefulness of R* as a habitat indicator, an experiment was performed to measure benthic velocities through gravel beds in a laboratory flume and compare them to R*.

Velocities were measured using an electronic water velocity probe which uses thermistors, measuring velocity indirectly at the rate at which heat is lost from the probe (Alavian, 1979). The thermistor probe provides the capability to measure local velocities at points in the benthos which are important to aquatic insects, the diameter being only .18 cm (.070 in). This was done in three different substrate types: large cobble with mean diameter 10 cm (3.9 in), medium gravel 5.4 cm (2.1 in) in diameter, and small gravel 2.5 cm (1 in) in diameter. In each substrate type two different microhabitats were measured: very near the surface and slightly above the surface; the surface measurement was made by holding the probe against the rock such that the sensing element on the tip of the probe was half the diameter or .09 cm (.035 in) above the rock surface, in the range where many insects would have their gills. The measurement above the surface was made at 0.7 cm (0.3 in), an approximation of where a net-spinning caddisfly might have its net.

A bed of each substrate type was made in a laboratory flume which has dimensions 49 m (161 ft) long, 1.8 m (6 ft) wide, and 1.2 m (4 ft) high. The flume could provide flow rates up to a .19 cubic meters per second (6.7 cfs) and by varying the flow rate and tailgate elevation, a variety of depths and velocities were created. Benthic velocities were measured in four market spots for each substrate type and the value over the four points was averaged. The hydraulic radius, slope, and temperature were measured in order to calculate the value of R*.

RESULTS

When R* and the corresponding benthic velocities had been measured, they were plotted against each other on a log-log scale (Figures 1 and 2). There is scatter shown in the lower range of R* but correlation at higher values. A possible explanation for the scatter is suggested by the observation that it develops when R* falls below about 100. According to Shields (1936) the transition from turbulent to laminar flow occurs when R* falls below around 70, so it may be that the scatter may be due to this transition.

TABLE 1. SENSITIVITY ANALYSIS FOR R*

Case	Ds m(ft)	R(depth) m(ft)	Velocity m/sec (ft/sec)	n	Temp. oC	R*
A	$10^{-4}(3.3\times10^{-4})$	1.5(4.9)	.10(.33)	.030	20	1
B	.02(.07)	.50(1.6)	.20(.80)	.035	20	440
C	.05(.16)	.20(.66)	.50(1.6)	.040	20	3100
D	.10(.33)	.20(.66)	.75(2.5)	.045	15	9300
E	.15(.49)	.20(.66)	1.0(3.3)	.050	10	18000

Case A is typical of a large river or pool habitat: the water is deep and slow, with a fine sand bottom.
Case C is typical of a riffle in a midwestern stream: the water is shallow, moderately fast, with a gravel substrate.
Case E represents a mountain torrential stream: it is shallow, very fast, cold, and with large cobble substrate.
Cases B and D represent intermediates between the extreme cases.

It may also arise from the difficulty of measuring very low slopes. For velocities measured at .09 cm above the surface all velocities below 3.0 were not analyzed.

Because the slopes of the log-log plots are very close to one, linear regression was done for both velocity measured at .09 cm and at .7 cm above the rock surface. For benthic velocities measured at .09 cm (very near the surface) the equation found was

$$V = .075\ R^* - 3.9$$

where V is the measured benthic velocity, the coefficient of correlation was .95. For velocity measured at .7 cm (above the surface) the equation was

$$V = .093\ R^* + 2.7$$

and the coefficient of correlation was also .95. These equations demonstrate the close relationship between the boundary layer Reynolds number and the actual benthic microhabitat conditions when R* is above a threshold of about 100. As can be seen from Table 1, most riffle habitats have a Reynolds number considerably above 100.

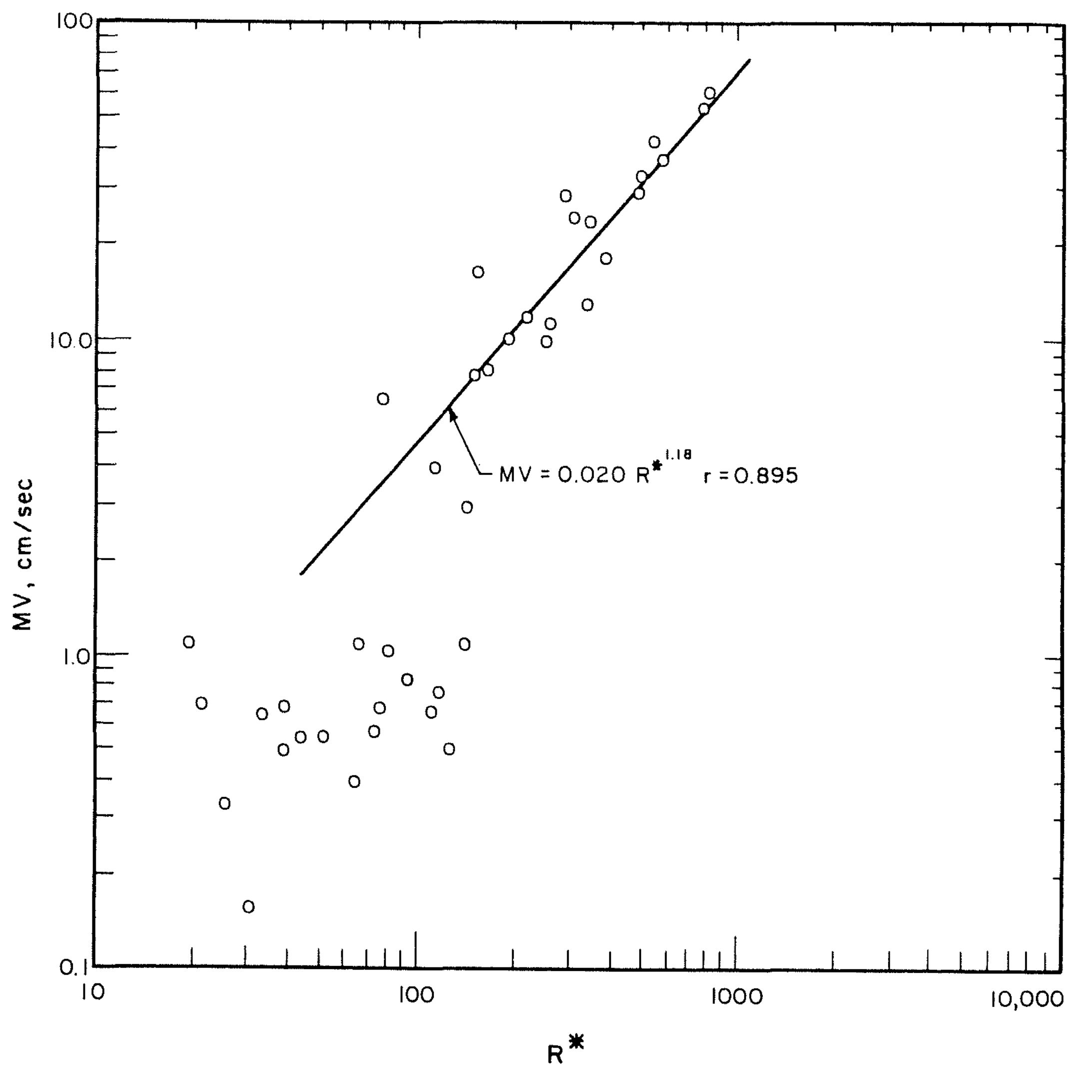

Fig. 1: MICROVELOCITY AT .09 CM VS R*

CONCLUSIONS

The boundary layer Reynolds number has been shown to be a good indicator of benthic micro-habitat flow conditions. The variables needed to evaluate R* (substrate size, viscosity, hydraulic radius or depth, and slope) can easily be determined by models which are already adapted for habitat inventory and instream flow analysis (Stalkner, 1979).

Further research needs to be done to determine if and how benthic organisms respond to R*. If it can be shown that benthic animals do show preferences for defined ranges of the boundary number and if these ranges can be quantified for specific taxa, the use of R* can become an easily applied and meaningful index of habitat quality for aquatic insects and other benthic species.

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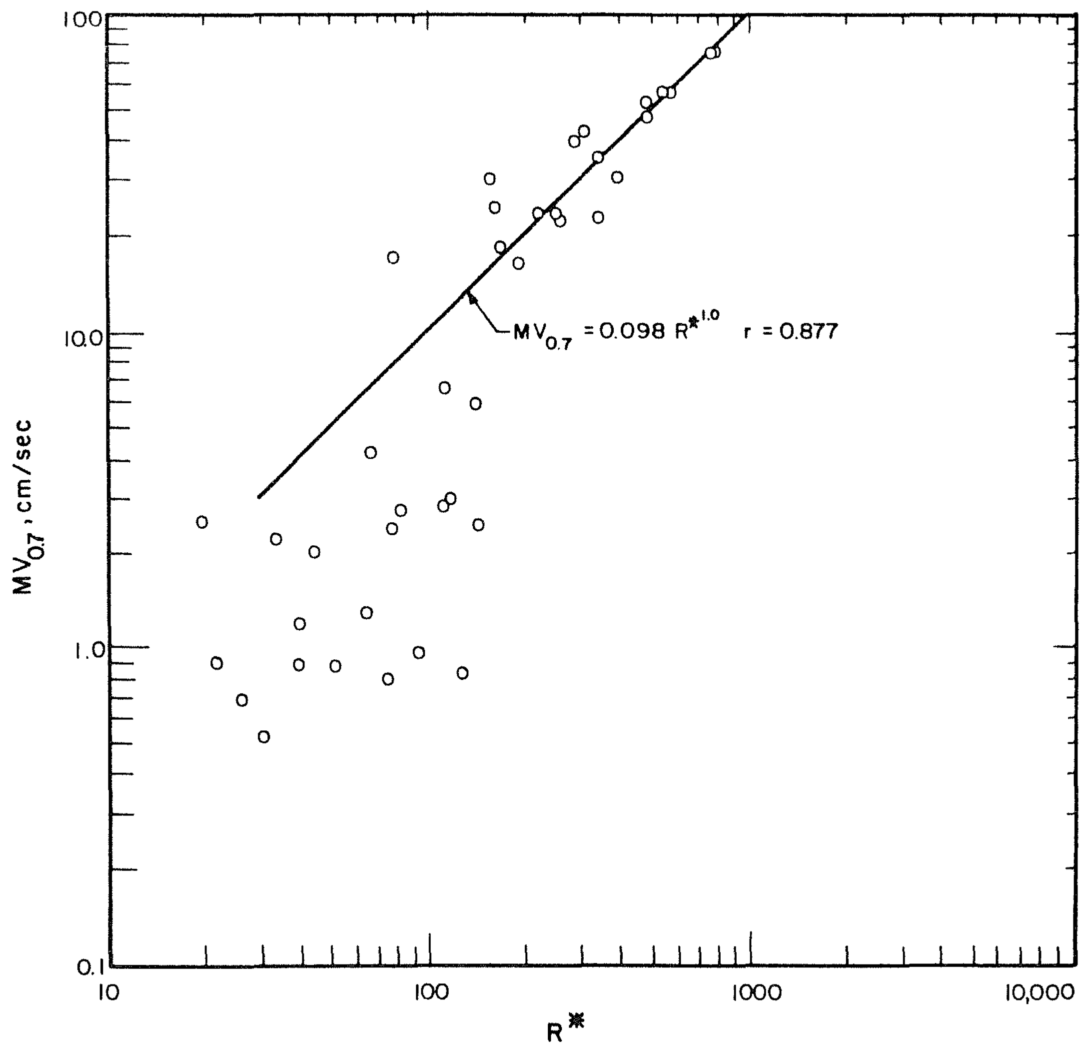

Fig 2: MICROVELOCITY AT .7 CM VS R*

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FREQUENCY ANALYSIS OF AQUATIC HABITAT:

A PROCEDURE FOR DETERMINING INSTREAM FLOW NEEDS[1]

Michael J. Sale[2], Steven F. Railsback[3], and Edwin E. Herricks[3]

Abstract.--Minimum flow recommendations can be improved by analyzing the natural habitat variability in lotic environments. Habitat modeling techniques such as the Incremental Methodology can be combined with stream flow records to generate habitat frequency curves that are useful in determining instream flow needs.

INTRODUCTION

Conservation of stream flows to protect lotic ecosystems has become an increasingly significant environmental issue in all types of water resource planning, including water quality maintenance and the development of hydropower, synthetic fuels, irrigation, and public water supplies. Habitat evalution models are often used for estimating the minimum flow requirements of aquatic biota. Of these assessment techniques, the Incremental Methodology and its physical habitat simulation (PHABSIM) system developed by the U. S. Fish and Wildlife Service (USFWS) are the most advanced and most frequently used (Stalnaker 1979a, 1981; Milhous et al. 1981).

The development of these sophisticated modeling techniques unfortunately has not resolved the controversy involved with selecting appropriate management objectives, strategies, or tactics for determination of instream flow needs (IFN). Too often, the application of habitat models seems to be the end, rather than the means, of an IFN study. More attention needs to be paid (1) to defining aquatic resource management objectives before applying complex modeling techniques such as PHABSIM, and (2) to the use of habitat data after they are generated.

This paper examines the ways in which information derived from habitat evaluation models can be used to make minimum flow recommendations. Current uses and misuses of habitat indices are discussed. A new technique called habitat frequency analysis is presented that explicitly recognizes the stochastic nature of lotic environments, allowing minimum flows to be based on the frequency of occurrence of habitat conditions. This frequency analysis approach and the conservation criterion associated with it are suggested as improvements over more deterministic techniques currently in use for defining IFN. Although this discussion concentrates on PHABSIM, the analysis technique is applicable to other environmental indices as well. The reader is assumed to have some familiarity with habitat evaluation models, including PHABSIM.

BACKGROUND

Multi-transect habitat evaluation models such as PHABSIM calculate composite indices of habitat condition that combine the suitability (i.e., quality) and availability (i.e., quantity) of physical parameters within a specified stream reach that are of importance to an evaluation species (an evaluation species is a specific life stage of a target species or species guild). Weighted Usable Area (WUA; units of ha/km) is the habitat index calculated by PHABSIM (Milhous et al. 1981). WUA is determined by the surface area of the stream reach and weighting functions that represent the behavioral preferences of the evaluation species for parameters such as depth, velocity, bottom

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substrate, cover, and temperature. Although several different habitat-rating methods are available (Stalnaker and Arnette 1976; Wesche and Rechard 1980; Loar and Sale 1981; other papers in these proceedings), the USFWS's Incremental Methodology is unique in its combination of hydraulic modeling and habitat suitability data. Through the use of computerized simulation techniques, WUA can be predicted for a wide range of stream flows and for any number of different evaluation species. The habitat response curves (WUA vs discharge) produced by PHABSIM are used as the information base to determine IFN. These curves are often highly nonlinear (e.g., Fig. 1).

Most applications of WUA data to produce minimum flow recommendations select a point on the habitat response curve that corresponds to a low-flow threshold below which unacceptable habitat degradation is judged to occur. Although several different criteria have been suggested for selecting these threshold points, very few baseline hydrologic data are incorporated into the determination. Orth and Maughan (1981) established their minimum flow recommendations at the so-called "inflection" point in the habitat response curve (location of a sharp change in slope) without reference to baseline stream flows or to how often the habitat conditions at the inflection point occurred naturally. Stalnaker (1979a) recommended that the minimum flow be set at the lowest flow

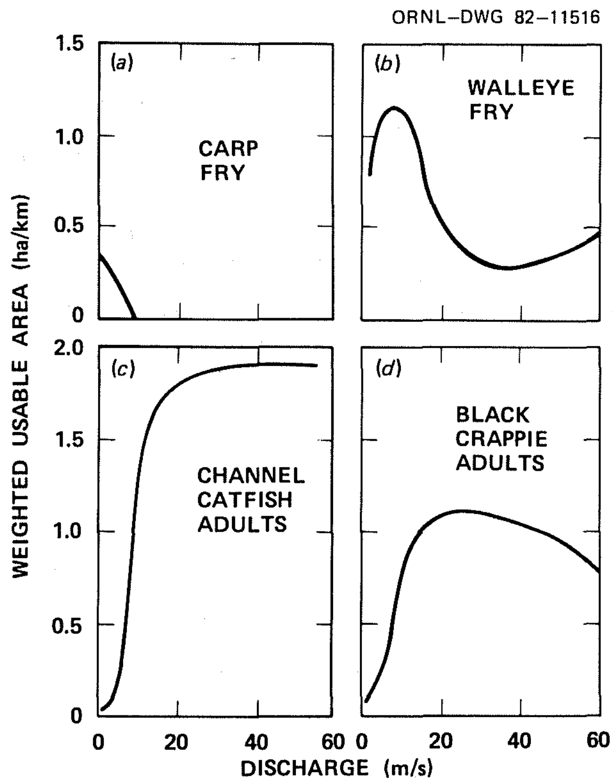

Figure 1.--Selected examples of habitat response curves from the Kaskaskia River near Shelbyville, Illinois.

Table 1.--Example of the optimization approach to calculate a minimum flow recommendation.

Flow	Species A Fry	Species A Adult	Species B Fry	Species B Adult	Mean	Minimum
(m^3/s)	------(% of optimal habitat value)------					
3	88	20	75	42	56	20
6	80	49	100	55	71	49
9	71	63	98	69	75	63
[1]12	69	100	80	82	[1]83	[1]69
15	50	100	66	89	76	50

[1]Minimum flow recommendation based on either the mean or minimum summary statistic.

that could provide the same WUA value produced by the average monthly flow. The application of either criterion is very sensitive to the shape of a particular habitat-response curve.

The Cooperative Instream Flow Service Group of the USFWS recommends an "optimization" approach to minimum flow selection in which the threshold point is set at the flow between the average monthly flow and the 1-in-10-year low flow that produces the greatest WUA value.[4] A similar analysis procedure has been used by the USFWS in Texas.[5] Flow requirements for more than one evaluation species are accounted for by combining the single-species results into a tabular or matrix format (Table 1). For each analysis period, the table contains one column for each evaluation species present during the specified time period. The rows of the table represent different stream flows to be considered. The elements in the table are the percent of the maximum attainable WUA value for each evaluation species at each specified stream flow. A summary statistic, such as the mean or minimum of these percentage values, is calculated for each row, and the overall minimum flow recommendation is set at the flow (row) with the highest summary statistic.

These three approaches are all oriented toward maximizing WUA values without considering the actual needs of individual species or the stochastic habitat conditions normally experienced within the stream reach. The strategy of using optimum points on a habitat response curve may be justified if the management objective is to enhance single-species fishery potential. However, when habitat conservation or mitigation of low-flow impacts is the instream flow issue, or when multiple species with very different habitat requirements must be accounted for, the use of optimum points to estimate minimum flow

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[5]Butler, D. 1979. Stream evaluation project, phase II. Unpublished draft report. U. S. Fish and Wildlife Service, Fort Worth, Texas.

requirements is inappropriate. For example, if the optimum rarely exists under natural flow regimes, why should it be maintained by a minimum flow requirement?

The nonlinear shapes of habitat response curves (e.g., Fig. 1) can have some very important implications when these data are used to determine IFN. The implications are rather nonintuitive and can lead to misuse of WUA data. For example, an important misstatement that is often made is that the average habitat condition (h_{ave}) occurs at the average flow (q_{ave}). This is in fact rarely the case; it would only be true with monotonically increasing response curves. Two examples in which $h_{ave} = h(q_{ave})$ are: (1) a uni-modal, concave response curve (e.g., Fig. 1d) with its maximum less than q_{ave}, and (2) an asymptotically increasing response curve (e.g., Fig. 1c) with q_{ave} to the left of the shoulder of the curve. It can be shown that in the first case, h_{ave} is less than $h(q_{ave})$ and that in the second case, h_{ave} is greater than $h(q_{ave})$. Because all types of shapes are possible in the habitat response curves, each must be analyzed separately.

Nonlinear habitat response curves, with different shapes for different evaluation species, also result in the fact that unequal protection of the habitat of different species occurs whenever a discrete minimum flow requirement is selected. For example, in the Kaskaskia River in Illinois, the Montana method (Tennant 1976) was initially used to estimate the minimum flow requirements (q_{min}) below two large mainstem reservoirs operated by the U. S. Army Corps of Engineers. By this method,

$$q_{min} = 0.30 \times q_{ave} = 0.30 \times 7.6 \text{ m/s} = 2.3 \text{ m/s} ,$$

where q_{ave} is the mean annual flow.

After calibrating PHABSIM and calculating habitat frequencies that would have occurred under the historical, pre-project flow regimes (procedure described below), it was found that the minimum flow based on Tennant's method protected the habitat values for channel catfish adults that had been equaled or exceed 99% of the time before dam operations began. On the other hand, this q_{min} only protected the habitat of juvenile bluegills that had been equaled or exceeded 22% of the time. Without explicitly examining the natural variability of habitat indices for individual evaluation species, it is very difficult to anticipate which species will be overprotected and which will be underprotected by deterministic minimum flow recommendations such as Tennant's method. Without knowing which species or life stages are least protected, there can be no assurance that fisheries management objectives will be satisfied.

ANALYSIS OF STOCHASTIC HABITAT CONDITION

Environmental variability is a natural component of lotic ecosystems. Fish and other aquatic biota are adapted to these variations in their habitat and have evolved behavior or reproductive strategies that allow them to recover from the degraded conditions that occur infrequently during drought or flood events (Larimore et al. 1959; Elwood and Waters 1969). Furthermore, the range in magnitude and frequency of stream flows occurring at a specific site play a strong role in determining the structure and composition of fish commumities (Horwitz 1978). Any water project that alters either of these flow parameters can cause changes in downstream aquatic habitat that may ultimately affect aquatic biota.

In lotic environments, habitat condition and values of WUA, or any other indices used to quantify habitat, are stochastic variables; they are determined by stream flows which are also random events (Milhous and Bovee 1978). Therefore, stochastic habitat values (H) can be described in terms of probability density functions (Fig. 2) using the same procedures employed in descriptive hydrology (e.g., Chow 1964). Over a given period of time (e.g., an annual cycle or a specified month of the year), each discrete value (h) of a habitat index will have a unique frequency of occurrence [f(h)]. The information contained in this probability density function (Fig. 2a) can also be represented in terms of a cumulative probability function (Fig. 2b), also called a habitat frequency curve. In the latter case, the probability of exceedance function,

$$F(h) = \text{Prob}[H \geq h] = \int_{H=h}^{\infty} f(h)\, dh ,$$

represents the proportion of stochastic events (e.g., daily habitat values) that is equal to or greater than the specified value (the shaded area in Fig. 2a). These cumulative probability levels are called exceedance values. Flow duration curves (i.e., frequency curves) that are cumulative probability density functions of stream flow events are widely used in designing dams and other hydraulic control structures where IFN is an issue. Habitat frequency curves can be used as an analogous tool for IFN determinations and can provide an excellent measure of baseline, pre-project environmental variability. Although annual habitat frequency curves can be calculated, the seasonal changes in habitat requirements of most evaluation species dictates that a seasonal approach to habitat frequency analysis is necessary.

If habitat condition is quantified in terms of WUA and a habitat response curve is available from the application of PHABSIM, then a simple, two-step procedure can be used to calculate habitat frequency curves (Fig. 3). Given an historical flow record (stream flows over a fixed period of time), the first step (subroutine HCALC in Fig. 3 or program HABT in the current version of PHABSIM) is to use the habitat response curve to generate a synthetic habitat record by converting each discrete flow event (e.g., daily average discharge) into its corresponding WUA value. The second step (subroutine FCALC) is to calculate habitat exceedance values from the synthetic habitat record. To do this, the easiest approach is to rank the values in the habitat record by sorting from largest to smallest, and then to use the following formula:

$$F(h) = 100 \cdot [r(h)/(n+1)] ,$$

where F(h) is the frequency at which habitat value h is equaled or exceeded, r(h) is the rank of habitat value h, and n is the number of events in the record.

A FORTRAN computer program has been developed at the University of Illinois at Urbana-Champaign (UIUC) and is currently available on the CDC-CYBER

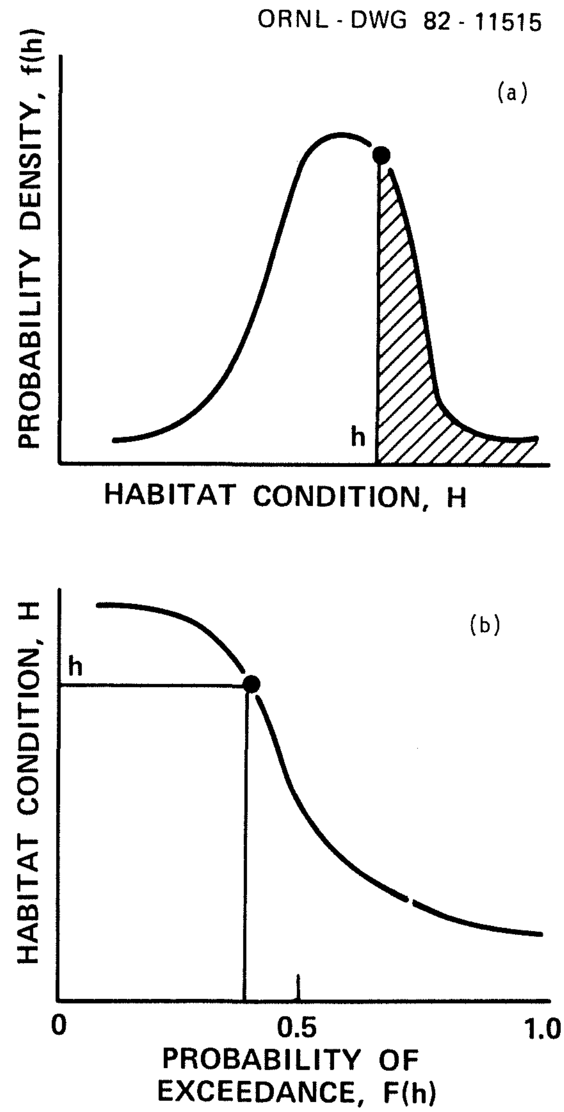

Figure 2.--Probability density function for a habitat value index (a) and its cumulative form (b).

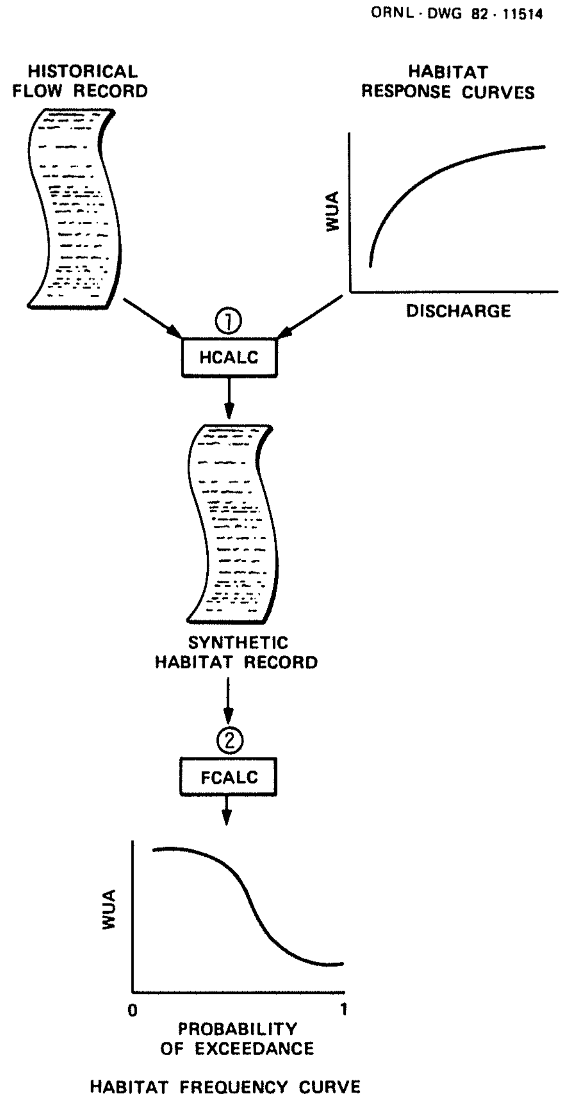

Figure 3.--General structure of a computer program for calculating habitat frequency curves.

175 at UIUC along with all other PHABSIM software.[6] The UIUC program for habitat frequency analysis reads in daily flow records from a USGS tape, calculates monthly or weekly mean flows, and then generates a habitat value for either the weekly or monthly average flow. Alternatively, the habitat value for each daily flow can be calculated, then these daily values can be averaged. This second approach may produce more realistic habitat frequency curves, but it involves much more computer time. The generalized

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calculation procedure can be used for any desired time period, for synthesized flow records from ungaged watersheds or alternative operating rules for upstream reservoirs, or for any number of evaluation species for which habitat response curves are available.

MINIMUM FLOW RECOMMENDATIONS

Habitat frequency curves can provide the basis for IFN determinations that consider both the magnitude of WUA values produced by minimum flows and the frequency at which those values are achieved under natural conditions. The management objective implicit in this approach is that a certain proportion of the stochastic habitat condition, as measured by the WUA index, should be protected by the minimum flow recommendation. The strategy for achieving this objective is to identify a habitat exceedance value that would have occurred under the original flow regime (i.e., a WUA value that is equaled or exceeded by a specified percent of the values in a habitat record) and to assure that flows at or above the q_{min} will always provide habitat values equal to or greater than the habitat exceedance value. The percentile level used in this definition can be called a conservation criterion; it defines the amount of habitat that will be preserved at the minimum flow.

A simple nomograph for calculating this type of q_{min} can be constructed by plotting the habitat response curves and the habitat frequency curves on the same set of axes (Fig. 4). Using this approach, a minimum flow recommendation is obtained by (1) selecting the habitat exceedance level to be protected (in Fig. 4 the WUA value equaled or exceeded 80% of the time was selected), (2) dropping vertically to the point on the habitat frequency curve that corresponds to the desired exceedance level, (3) moving horizontally to the

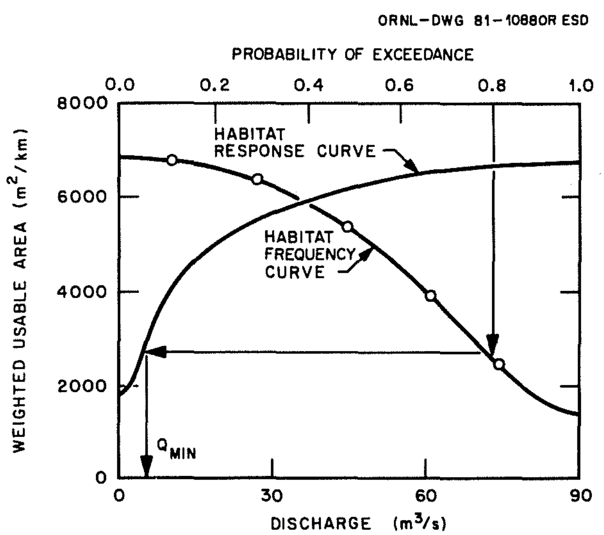

Figure 4.--Nomograph for calculating a minimum flow recommendation using habitat response and habitat frequency data.

Table 2.--Tabular format for determining minimum flow recommendations from habitat frequency data (h_{70} is the habitat value that is equaled or exceeded 70% of the time) and flows required to produce those habitat values [$q(h_{70})$]. N/P means not present during this time period.

Habitat type	May h_{70} (WUA)	May $q(h_{70})$ (m^3/s)	October h_{70} (WUA)	October $q(h_{70})$ (m^3/s)
Channel catfish:				
Juvenile	8,910	224	171	8
Adult	45,300	[1]486	491	[1]9
Spawning	17,467	303	N/P	N/P
White bass:				
Juvenile	76,703	334	3,246	[2]122
Adult	71,262	[1]583	1	0
Spawning	40,292	220	N/P	N/P
Largemouth bass:				
Juvenile	32,018	118	14,545	11
Adult	28,342	[2]637	1,155	[1]34
Spawning	N/P	N/P	N/P	N/P
Walleye:				
Juvenile	6,159	134	1,976	[1]26
Adult	16,342	[1]490	1	0
Spawning	586	69	N/P	N/P
Bluegill:				
Juvenile	5,121	0	1,747	0
Adult	2,971	38	1,879	0
Spawning	6,511	[1]66	N/P	N/P

[1]Recommended flow for individual species.
[2]Recommended flow for multispecies analysis.

habitat response curve to the lowest discharge that produces the desired WUA value, and (4) moving vertically down to the discharge axis to find the stream flow to be used as the minimum flow recommendation. This nomograph procedure is applicable for one evaluation species at one time period. Additional nomographs can be constructed for each time period or evaluation species to be considered.

Habitat frequency analysis can also be presented in a tabular format similar to the deterministic, optimization approach shown in Table 1. In Table 2, an example is presented of a multispecies assessment of the minimum flows needed to protect 70% habitat exceedance levels for two different time periods. For each time period analyzed (May and October in this example), two columns are presented: (1) the WUA values equaled or exceeded 70% of the time during the specified time period (h_{70}), and (2) the lowest flow required to produce that habitat value [$q(h_{70})$]. These columns are then examined for the highest flow within each species to find the most sensitive life stages or for an overall minimum flow for the entire time period. In this procedure, species with habitat response curves that decrease monotonically with increasing flow will have q_{min} = 0, are not limited by low flows, and drop out of the analysis for q_{min}. Only those life stages that are present in each time period are examined. Computer programs can again be used to generate these types of data presentations for different time periods or habitat exceedance levels. Essentially the same data are used to generate the nomograph and tabular data.

DISCUSSION

Application of PHABSIM or any other habitat evaluation model to an IFN problem must always be accompanied by the proper qualifications. Because WUA is an index of a limited number of physical parameters, it cannot account for all the factors that determine production in lotic ecosystems (e.g., water quality or food supplies). The limitations of PHABSIM are recognized by its developers (Milhous et al. 1981) and have been critiqued elsewhere (Patten 1979). It is the responsibility of the user to ensure that physical habitat models are not applied to management situations in which they are not applicable.

The proposed frequency analysis procedures also involve several assumptions whose validity must be examined on a site-specific basis. The generation of a synthetic habitat record from historical flow data should not be perceived as a representation of historical habitat conditions. Channel morphology and substrate at any stream reach cannot be assumed constant over the period of record of stream flow events. Therefore, the synthetic habitat record and the habitat frequency data produced from it, should be considered as the habitat conditions likely to occur in the near future under a flow regime similar to the historical flow regime. The assumptions are then that morphology and substrate are relatively constant over the short term and that the stream reach modeled by PHABSIM remains representative of a larger section affected by regulated flows. Better predictive capabilities will be possible only when the dynamics of fluvial morphology are included in these habitat models.

The generation of a synthetic habitat record often requires extrapolation of the habitat response curve to flows and WUA values outside of the prediction limits of the PHABSIM hydraulic simulation models. This is an area where the professional judgment of the fisheries biologist must come into play. Based on experience, the habitat condition that would likely exist at extremely high or low flows is often obvious from examining the trends in the WUA data sets. However, any assumptions about the direction of response curves must be carefully documented. Instead of making assumptions about the response curve shapes, an alternative approach is to eliminate from the historical record all flow events (e.g., out of bank flows) that are outside the prediction limits and to then analyze only a partial record of habitat events.

Finally, it is important to note that any single minimum flow requirement, whether it is generated by the frequency analysis approach or some other procedure, cannot duplicate all of the natural habitat variability present before flow regulation. If a minimum flow is strictly enforced, it will cause the habitat values produced by the q_{min} to be equalled or exceeded 100% of the time (i.e., more frequently than before regulation!). A hierarchy of q_{min}'s for dry, normal, and wet years is still the most realistic stream management strategy (Stalnaker 1979b, 1981). Also, flushing flows (infrequent high flows simulating flood events) are essential for maintenance of channel morphometry and substrate characteristics. These high flows should be incorporated into regulated flow regimes whenever possible.

CONCLUSIONS

The analysis procedures described in this paper are an improvement over more deterministic approaches for determining minimum flow requirements. Although certain simplifying assumptions are involved in using habitat evaluation models such as PHABSIM, these procedures are useful for describing the environmental conditions that support lotic ecosystems and for understanding how those conditions are influenced by stream flow regulation. The frequency analysis approaches that have been discussed are not only applicable to PHABSIM and WUA data, but can also be equally useful in analyzing other physical habitat indices such as wetted perimeter or weighted usable width (Stalnaker and Arnette 1976; Loar and Sale 1981).

As with any quantitative assessment technique, the proposed frequency analysis procedures can benefit from further refinement and field validation. The question of what habitat exceedance value should be used to determine a q_{min} is unresolved. However, negotiations over this question should be more relevant to the real effects of stream flow regulation than attempts to defend the use of "optimal" WUA values, especially in the case of conservation-related management objectives. Procedures such as these that capitalize on the experience and techniques of hydrologists (also see the paper by E. W. Trihey in these proceedings) can help to solidify the scientific basis for IFN recommendations.

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USING AQUATIC INSECTS

FOR THE EVALUATION OF FRESHWATER COMMUNITIES[1]

Ronald A. Hellenthal[2]

Abstract.—A computerized evaluation and prediction system for aquatic habitats contains environmental and pollution tolerances for 3,503 aquatic insect taxa. The system can identify organisms with specific tolerances to environmental conditions as indicators of aquatic conditions and can determine the taxonomic level required for accurate environmental assessment. Where information was obtained from more than one source environmental tolerance of a taxon may differ. In most cases specific identification is necessary to reliably indicate environmental conditions.

INTRODUCTION

Aquatic organisms have long been recognized as potentially useful indicators of habitat conditions and water quality. This is due to their ability to reflect conditions through time, to demonstrate the effects of disturbances even after the environment has returned to apparently normal physical and chemical conditions, to integrate the effects of many different environmental factors and their interactions simultaneously, and to provide a living context for considerations of environmental quality.

According to Sladecek (1973), the study and use of organisms as indicators of water quality began in Europe in 1848 with investigations on environmental relationships of Trichoptera by F. A. Kolenati. While much of the early investigation of aquatic indicator organisms concentrated on microorganisms, aquatic insects possess attributes which make them particularly well suited as indicators of environmental conditions. Many have life spans and generation lengths which are ideal for use in environmental assessment: long enough to reflect intermittent or occassional disturbances and short enough so that sensitive life stages may be subjected to adverse environmental conditions. Most have excellent dispersal mechanisms which permit them to find and rapidly colonize suitable environments. Insects are found in great abundance and diversity in most aquatic environments and possess the greatest range of habitats and habitat requirements of the macroscopic freshwater biota. They are critical elements in the trophic structure of aquatic communities, important as accumulators and concentrators of toxic substances, and may be involved in the release of toxic materials and essential nutrients from aquatic sediments. Aquatic insects, therefore, have great potential in evaluation of aquatic habitats and in recognition of changes in aquatic conditions due to environmental stress.

The association between certain aquatic insect taxa and aquatic conditions has been known for a long time. The syrphid fly genus Eristalis has been associated with conditions of profound organic enrichment since ancient Greece (Clausen, 1954). Anglers have associated aquatic insects with habitats of game fish for hundreds of years (Schwiebert 1973). Environmental classification schemes using chironomids and other aquatic insects, such as those reviewed by Brinkhurst (1974), have been available for at least 50 years. Discussions of the use of invertebrates as indicators of river and stream pollution are provided by Gaufin and Tarzwell (1952), Hynes (1958), and Goodnight (1973).

Given this association and the knowledge that aquatic insects and other macroinvertebrates have been a fundamental component of aquatic habitat surveys, why are these organisms not more effectively used in aquatic assessment? One factor may be the difficulties often encountered in comparing and summarizing information obtained by different researchers. This may be due to differences in organism identifications made by inexperienced personnel, or to inconsistent methods of data collection, analysis or presentation. A second factor may be the many diverse outlets for publication of these data. They often appear only in

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progress and summary reports, receive little dissemination, and are frequently omitted from standard abstracting and indexing publications. Another factor is the great difficulty in developing quality control procedures for organism identifications. This has resulted in great variation in the quality and reliability of published associations between organisms and specific environmental conditions.

Investigators who compile data on aquatic organisms from more than one source have often found variation in pollution tolerance and environmental requirements information at both the genus and species levels. For example, in reviewing tolerances to decomposable organic wastes published in the U.S. Environmental Protection Agency Biological Field and Laboratory Methods manual (Weber 1973), Resh and Unzicker (1975) noted that 61 of the 89 genera known from more than one species had differing tolerance information for the different species. While justifiably concluding that generic identification was wholly inadequate for water quality evaluation, they left unanswered the question of how useful available data are at the species level.

Environmental data and reports vary widely in quality and reliability. Standardized methods for data acquisition and analysis, and quality control procedures are reasonably well established for most biological, chemical and physical environmental data. However, the association of specific organisms with these parameters rests on the reliability of species identifications performed by investigators of varying backgrounds, experience, expertise, and motives. At present, the primary quality assurance mechanism for organism identifications is the competence and dedication of individual researchers. While independent verification of voucher specimens by taxonomic experts is possible, this is a procedure which, even on a small scale, is time consuming and costly and, on a large scale, would significantly exceed our present resource of taxonomic experts (Irwin et al. 1973; Barr 1974; Edwards and Grotta 1975).

Publications providing summary information on the environmental relationships and tolerances of aquatic organisms are extremely useful in identifying potential indicator organisms and in establishing levels of tolerance of organisms to specific environmental factors. However, unless the reference publication survey is extremely exhaustive or very selective, it may be difficult to establish useful trends among the vast amounts of often contradictory information reviewed.

Some publications providing useful summary information on the environmental requirements and pollution tolerances of aquatic organisms are: Proceedings of the Third Seminar on Biological Problems in Water Pollution (Tarzwell 1965) which includes discussions of environmental requirements of freshwater algae, protozoa, crustacea, annelids, insects, and fish; a manual on biological field and laboratory methods (Weber 1973) published by the U.S. Environmental Protection Agency which includes summaries of the tolerances of freshwater invertebrates to decomposable organic wastes; the appendix of Sladecek's (1973) water quality system monograph which includes many tables of tolerances of aquatic species to a variety of environmental conditions; a book on the pollution ecology of freshwater invertebrates (Hart and Fuller 1974) which includes information on environmental requirements for a number of invertebrate groups; general treatments of biological methods for water quality assessment (e.g., Cairns and Dickson 1973; James and Evison 1979) and a series of U.S. Environmental Protection Agency Environmental Monitoring and Support Laboratory (Cincinnati) water quality profiles for diatoms (Lowe 1974), Chironomidae (Beck 1977), Ephemeroptera (Hubbard and Peters 1978), Plecoptera (Surdick and Gaufin 1978), and Trichoptera (Harris and Lawrence 1978).

While these reports have helped to make environmental information on aquatic organisms more accessible to biologists, much of the potential of even this accumulated information still remains unexploited. This may be due to the taxonomic organization and fixed tabular format of these publications which limit the ways in which their data can be used. For example, since most of these publications are organized by taxa rather than by environmental factors they are difficult to use to predict organisms likely to occur in an environment with particular characteristics. Also, it is often difficult to determine which environmental requirements are consistent within a genus or higher taxonomic level and which environmental inconsistencies at the specific level could be due to errors in data collection or identification.

Computerization of these data would greatly enhance their usefulness by allowing queries based on taxonomic association, environmental parameters, or a combination of these factors. If the data for various taxonomic groups were standardized, it would be possible to answer questions concerning biological communities and their environments. In addition to being able to ask a variety of questions about requirements of organisms and environmental conditions, a major application of this system would be the development of lists of taxa associated with specific environmental conditions which could serve as reference communities for environmental scientists. This system also could be used as a device for scrutinizing environmental data by comparing the known tolerances of organisms reported in monitoring and impact studies with the physical and chemical characteristics of the habitats from which they were collected. Discrepancies encountered in these comparisons would be flagged as potential errors in data collection or specimen identification. Another quality control device possible with these data would be comparison of the known ecological parameters associated with combinations of taxa reported to be collected together at individual sites. Inconsistencies in the environmental requirements of these taxa would also be flagged as potential errors in identification.

It is my purpose here to describe one computerized system which is being developed to perfom these operations, and to consider some preliminary evaluations of several groups of insects as indicators of water quality conditions in aquatic habitats.

PROGRAM AND DATA BASE DESCRIPTIONS

An integrated system of computer programs for the storage, retrieval, and manipulation of environmental requirements and pollution tolerance information on aquatic organisms, called ERAPT, is being developed for use on an IBM 370/168 computer system at the University of Notre Dame. Most ERAPT computer programs are written in Fortran, but some assembly language routines are used for data manipulation and evaluation. Data are stored and manipulated as hierarchically related environmental requirements and pollution tolerance categories representing tolerance ranges to specific pollutants or environmental conditions, geographic locations, general or specific habitat characteristics, and periods of appearance, emergence or greatest abundance. At present the system uses 15 heading categories (stage, pH, salinity, nutrients, degradable organics, oxygen, temperature, turbidity, current, general habitat, specific habitat, seasonal distribution, feeding behavior, geographic distribution, and water chemistry), divided into 103 specific parameters. These categories and parameters were taken from those recommended by the Aquatic Biology Section, Environmental Monitoring and Support Laboratory of the U.S. Environmental Protection Agency (Cincinnati, Ohio) for use with macroinvertebrates and diatoms (Lowe 1974; Beck 1977). However, the capacity of the system is more than 320 headings and parameters, with up to 64 parameters permitted within each heading category.

Data for ERAPT are encoded on tabular forms which may be produced by the system. On these forms, rows correspond to specific parameters such as stage, feeding behavior or tolerance to environmental conditions, and columns represent different sources of information for the same species. Data are coded on the forms by marking those environmental categories applicable to a particular species and environmental site or study. The ERAPT system reads the tabular forms as digitized X-Y coordinate values corresponding to each mark on a form. The computer then determines the relative location of each mark with respect to the form and stores this information with a list of environmental codes which identify the various parameters (rows). Location tolerance values are used to indicate ambiguous mark positions and these are fit by the program into the most probable category and flagged for subsequent rechecking.

The digitized data are then standardized for the ERAPT system. Since data entry forms may contain any subset of the environmental categories included in the data base, the category codes stored with the digitized data are used to create a translation table which transforms the data to correspond with the full environmental category table used by the ERAPT system. During this process both direct and hierarchical correspondences between categories are established. For example, one set of data entry forms may contain the environmental category Mesosaprobic, whereas another may divide this category into alpha and beta ranges. During this step these parameters are hierarchically associated so that a parameter shown at a lower level of the environmental category hierarchy is included at all upper levels. There is no limit to the number of levels in a hierarchy and no requirement that the number of levels be consistent among parameters. For example, the heading salinity is divided into 5 categories with the categories Mesohalobous and Oligohalobous further subdivided into 2 and 3 parameters, respectively. This structure permits the ERAPT system to store, manipulate and use environmental information differing in precision without sacrificing the most reliable data.

During the standardization process the data are packed into computer memory locations as 1-bit word subsegments. This allows data to be stored in about 3% of the computer memory that would be required if this information were stored as individual integer numbers. It also permits comparisons of up to 32 different factors simultaneously by the computer using Boolean algebra functions. This greatly reduces processing costs, increases the amount of information which can be processed, and simplifies analysis and retrieval of the data.

The next procedure is the creation of a searchable data base. At this point the various components of the system are linked. The taxonomic categories are hierarchically connected in a manner similar to that described previously for environmental headings and parameters. This enables queries at any level of the taxonomic hierarchy. The linking operation involves the association and storage of memory addresses for the taxonomic names, environmental headings and parameters plus their definitions, author citations and references, report page numbers, environmental data, and a series of 2- and 4-character abbreviations which are used in the query and information retrieval process. The lowest taxonomic level directly addressable by the system is species. However, data from individual sources are available to the system as an external file.

The data normally used by the system consist of two summaries of the information contained in the various reference sources for each taxon. They are stored as strings of binary digits which correspond to bit by bit iterative Boolean sums (logical OR) and products (logical AND) of parameter fields for each non-zero heading category for each taxon. Boolean sums include all environmental parameters given by any source for each taxon in the system. For example, if one investigator reported that a species occurs in streams and another reported that the same species occurs in both lakes and streams, the Boolean sum for the general habitat heading category for that species would include both lakes and streams. The Boolean product summary includes only those parameters indicated by all sources containing environmental requirements or pollution tolerance information within each heading category for a taxon. Therefore, each product summary consists of those environmental parameters which are consistently associated with a taxon in the system. For the general habitat example given above, the product summary would show only lakes, since it was the only parameter indicated by all sources of information for the taxon. A summary of inconsistencies among investigators reporting information about any heading category for a taxon may be obtained by calculating the Boolean difference (exclusive OR) between the sum and product summaries. In this case parameters are only included in the summary if there is inconsistent information for that taxon within the data base. In the general habitat example, streams would be considered an inconsistent parameter since one source used the parameter and the other did not. For taxonomic categories above species, similar data summaries are maintained based on Boolean sums of the information for all lower taxonomic levels. The system also maintains the number of data sources which were summarized for each taxon and environmental heading category.

The query and information retrieval process is accomplished by using an additional program which is still being developed. At present this program can examine the various taxonomic levels within a data base for consistency of environmental information among different data sources and can produce lists of potential indicator organisms which show full agreement among environmental parameters obtained from different sources within each heading category. Consistency evaluations and searches for indicator taxa may be performed independently for any geographic region or for all regions defined within the data base. At present U.S. Environmental Protection Agency regions are defined within the data bases, but states or other geographic regions could easily be used. Data screening and reference community prediction capabilities of the system currently are being developed.

At present ERAPT data bases contain 22,647 parameter values for 3,503 aquatic insect taxa in the orders Ephemeroptera and Plecoptera and in the Dipteran family Chironomidae. This represents a mean of 6.5 environmental parameters per data source for each species, with 3.5 data sources per species and 4.3 species per genus. An additional data base contains 5,510 parameter values for 341 diatom taxa. The diatom data base was included for comparison with data bases for the aquatic insect groups. Most of these data have been obtained from U.S. Environmental Protection Agency water quality profiles (Lowe 1974; Beck 1977; Hubbard and Peters 1978; Surdick and Gaufin 1978).

DATA BASE EVALUATION

Each ERAPT data base has been evaluated for internal consistency among the environmental parameter data obtained from different sources for each species and among the species for each genus represented. Both the number of species and genera which showed consistent environmental information and corresponding percentages of the total number of taxa evaluated for each of 12 environmental parameter headings for the 3 insect groups and diatoms are given in Table 1. For data representing all geographic regions the median numbers and proportions of consistent taxa for all environmental headings were: 140 species (69%) and 54 genera (62%) in the Chironomidae; 102 species (80%) and 19 genera (49%) in the Ephemeroptera; 82 species (76%) and 36 genera (68%) in the Plecoptera; and 100 species (77%) and 16 genera (43%) in the diatoms.

Unfortunately these data present an unrealistically optimistic picture of the number of potentially reliable indicator taxa for both species and genera. Any species in the data base which has been characterized from only a single data source is inherently incapable of showing inconsistencies among environmental parameters and is included in both the counts of potential indicator organisms and calculated percentages. Likewise, any generic summary based on a single species is incapable of showing inconsistencies. This bias may be reduced by considering only those species for which environmental information is included in the data base from multiple sources and only those genera for which information exists for multiple species. The ERAPT system permits the minimum number of data sources per species and species per genus to be specified in the evaluation process. Taxonomic summaries based on less than this minimum number of sources or species are not listed as potential environmental indicators even though the data shows no inconsistencies among the environmental parameters within any heading category.

A typical data source contains information for only about half the environmental headings in a data base. Therefore, the number of data sources and species containing information for a heading category is usually substantially less than the mean of 3.5 per species and 4.3 per genus indicated for the data bases and varies greatly among environmental headings. The results of consistency evaluations for the environmental data bases with the requirement that only species summaries based on 2 or more sources and generic summaries based on 2 or more species for each environmental category are considered are given in Table 2. For data representing all geographic regions the median numbers and proportions of consistent taxa of those evaluated for all environmental headings were: 16.5 species (34%) and 7.5 genera (21%) in the Chironomidae; 16 species (28%)

Table 1. Number and percentage of taxa showing agreement in environmental parameters for each of 12 heading categories. Evaluation is based on data from all geographic regions for all species and genera.

Parameters	Chironomidae		Ephemeroptera		Plecoptera		Diatoms	
	Species	Genera	Species	Genera	Species	Genera	Species	Genera
pH	137 (63%)	51 (58%)	92 (71%)	9 (32%)	82 (64%)	36 (64%)	105 (40%)	20 (43%)
Salinity	231 (100%)	85 (96%)	-- (---)	-- (---)	-- (---)	-- (---)	62 (23%)	14 (30%)
Nutrients	140 (62%)	45 (52%)	49 (82%)	24 (50%)	9 (100%)	7 (88%)	78 (87%)	25 (78%)
Organics	153 (75%)	54 (63%)	92 (83%)	18 (54%)	35 (80%)	15 (68%)	100 (63%)	16 (41%)
Oxygen	173 (75%)	61 (68%)	98 (84%)	18 (58%)	79 (78%)	41 (80%)	-- (---)	-- (---)
Temperature	131 (58%)	48 (55%)	122 (61%)	24 (50%)	108 (57%)	40 (56%)	44 (88%)	12 (52%)
Turbidity	140 (72%)	57 (68%)	102 (80%)	19 (49%)	42 (84%)	15 (68%)	-- (---)	-- (---)
Current	160 (69%)	56 (63%)	124 (63%)	19 (41%)	11 (83%)	38 (68%)	145 (77%)	14 (38%)
General habitat	131 (57%)	49 (55%)	209 (58%)	20 (35%)	174 (54%)	45 (57%)	123 (76%)	14 (37%)
Specific habitat	150 (68%)	55 (63%)	112 (62%)	16 (36%)	57 (76%)	30 (81%)	149 (85%)	28 (68%)
Season	125 (57%)	46 (54%)	213 (67%)	20 (36%)	161 (46%)	46 (55%)	46 (81%)	18 (62%)
Feeding	120 (84%)	53 (73%)	54 (83%)	15 (58%)	76 (73%)	34 (68%)	-- (---)	-- (---)

Table 2. Number and percentage of taxa showing agreement in environmental parameters for each of 12 heading categories. Evaluation is based on data from all geographic regions for species with 2 or more reference sources and for genera with environmental information for 2 or more species.

Parameters	Chironomidae		Ephemeroptera		Plecoptera		Diatoms	
	Species	Genera	Species	Genera	Species	Genera	Species	Genera
pH	20 (20%)	6 (14%)	16 (30%)	0 (0%)	14 (23%)	7 (26%)	65 (29%)	2 (7%)
Salinity	108 (99%)	41 (91%)	-- (---)	-- (---)	-- (---)	-- (---)	30 (13%)	0 (0%)
Nutrients	12 (12%)	3 (7%)	1 (8%)	2 (14%)	-- (---)	0 (0%)	10 (46%)	6 (46%)
Organics	28 (35%)	11 (26%)	5 (21%)	4 (21%)	5 (36%)	1 (12%)	15 (20%)	2 (8%)
Oxygen	47 (45%)	17 (38%)	20 (51%)	6 (32%)	19 (46%)	12 (54%)	-- (---)	-- (---)
Temperature	10 (9%)	4 (9%)	13 (14%)	3 (11%)	9 (10%)	4 (11%)	2 (25%)	0 (0%)
Turbidity	13 (36%)	9 (25%)	14 (36%)	4 (17%)	4 (33%)	1 (12%)	-- (---)	-- (---)
Current	37 (34%)	12 (27%)	36 (33%)	2 (7%)	26 (53%)	6 (25%)	94 (68%)	2 (8%)
General habitat	11 (10%)	5 (11%)	58 (28%)	4 (10%)	68 (31%)	11 (24%)	12 (29%)	0 (0%)
Specific habitat	29 (30%)	7 (18%)	18 (20%)	2 (7%)	14 (44%)	8 (53%)	56 (68%)	14 (52%)
Season	6 (6%)	4 (9%)	45 (30%)	3 (8%)	43 (19%)	8 (17%)	2 (15%)	2 (15%)
Feeding	13 (36%)	8 (39%)	3 (21%)	2 (15%)	23 (45%)	6 (27%)	-- (---)	-- (---)

and 3 genera (11%) in the Ephemeroptera; 16.5 species (34%) and 6.5 genera (24%) in the Plecoptera; and 15 species (29%) and 2 genera (8%) in the diatoms.

Evaluating environmental consistency of taxa for all of North America may also provide misleading results, particularly at the generic level. Ecotypic variation among widely separated populations of species may result in differences in environmental characteristics. However, within a region or locality these organisms may serve as reliable indicators of environmental conditions. Environmental tolerances within a genus may reflect parallel or similar evolutionary forces on related species or they may represent the diversity of their ecological relationships. Therefore, large and widely distributed genera may show more variation among environmental characteristics than do smaller genera or those with geographically restricted distributions. To establish the potential for using organisms for environmental evaluation on a regional basis, each group of organisms was evaluated for environmental consistency within each of the 10 U.S. Environmental Protection Agency regions plus two additional regions representing eastern and western Canada. The results of these consistency evaluations for species with 2 or more data sources and for genera including 2 or more species are given in Table 3. The median numbers and proportions of consistent taxa for all environmental headings were: 42 species (42%) and 27.5 genera (36%) in the Chironomidae; 33 species (33%) and 9 genera (25%) in the Ephemeroptera; and 20 species (45%) and 15 genera (42%) in the Plecoptera.

DISCUSSION

The results of the data base evaluations support the use of aquatic insects as indicators of environmental conditions, but they also suggest that careful selection of indicators is essential for reliable environmental assessment. Only by considering a large number of different organisms and data sources will it be possible to establish limits for reliable biological environmental assessment. The evaluations also suggest that aquatic insects are at least as reliable biological indicators as diatoms, and capable of evaluating a broader range of environmental conditions. The utility of using organisms identified to genus for environmental assessment remains questionable. While it does appear that in some cases environmental tolerances are reasonably consistent among the species within a genus, in only a few genera are environmental data available from enough species to establish a clear pattern of generic tolerance.

Use of environmental indicator organsims on a regional basis appears to be particularly promising. Assessment systems based on a sound knowledge of a local fauna, such as that developed for Wisconsin by Hilsenhoff (1977), would seem to have the greatest probability for success.

One of the most exciting capabilities of environmental data evaluation systems such as ERAPT is their potential for screening environmental data. The ability to automatically detect apparent inconsistencies among the environmental tolerances of different organisms said to be collected together at a given site could be used both to flag errors in data collection and organism identifications and to evaluate the reliability of environmental data bases. For example, it eventually may be possible to require that taxonomic experts confirm the identifications of organisms found to have inconsistent environmental information. This would provide a cost effective means of evaluating the quality of biological information. Where new environmental associations of organisms are found the data bases can be expanded, thereby eliminating future error flags for the taxa involved. It may even become possible to use environmental characteristics as characters in taxonomic keys for organism identification. These are probably most applicable to computer based identification systems which permit users to skip missing or uncertain key characters such as the AUTOKEY taxonomic identification system for aquatic organisms (Hellenthal 1978).

Sources of environmental information within the data bases can also be evaluated. For example, it is possible to identify authors who have provided environmental information which frequently contradicts that supplied by other workers for the same organisms.

Obviously, more enviromental data needs to be collected and compiled on more organisms before a system such as ERAPT can realize its full potential in environmental evaluation and prediction. However, given the massive amount and great diversity of the biologically significant environmental information being collected, it seems certain that this kind of approach will yield substantial benefits for environmental scientists.

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Table 3. Number and percentage of taxa showing agreement in environmental parameters for each of 12 heading categories. Evaluation is based on data from individual geographic regions for species with 2 or more reference sources and for genera with environmental information for 2 or more species.

Parameters	Chironomidae		Ephemeroptera		Plecoptera	
	Species	Genera	Species	Genera	Species	Genera
pH	43 (37%)	29 (36%)	11 (37%)	7 (25%)	10 (34%)	13 (52%)
Salinity	132 (98%)	84 (94%)	-- (---)	-- (---)	-- (---)	-- (---)
Nutrients	22 (24%)	29 (36%)	2 (33%)	3 (30%)	-- (---)	-- (---)
Organics	34 (42%)	25 (36%)	7 (27%)	10 (30%)	3 (75%)	10 (91%)
Oxygen	66 (56%)	46 (60%)	7 (58%)	11 (55%)	9 (41%)	16 (76%)
Temperature	28 (22%)	26 (29%)	19 (23%)	9 (17%)	2 (5%)	15 (37%)
Turbidity	45 (56%)	47 (64%)	16 (57%)	10 (28%)	5 (50%)	1 (10%)
Current	59 (44%)	26 (29%)	37 (33%)	7 (11%)	21 (54%)	15 (40%)
General habitat	41 (31%)	25 (31%)	79 (31%)	23 (20%)	110 (42%)	46 (38%)
Specific habitat	46 (44%)	37 (44%)	24 (26%)	7 (12%)	10 (48%)	12 (43%)
Season	12 (11%)	24 (30%)	54 (36%)	13 (14%)	135 (38%)	29 (23%)
Feeding	11 (42%)	25 (53%)	3 (75%)	7 (64%)	17 (49%)	16 (53%)

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UTILIZING THE SAS COMPUTER SYSTEM FOR MODELING HABITAT SUITABILITY FOR WARMWATER FISHES IN STREAMS

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Abstract.--Relations were determined between physical and chemical characters of prairie streams and occurrence of eight warmwater fish species: largemouth bass, *Micropterus salmoides*; spotted bass, *M. punctulatus*; white crappie, *Poxomis annularis*; channel catfish, *Ictalurus punctatus*; green sunfish, *Lepomis cyanellus*; slenderhead darter, *Percina phoxocephala*; orangethroat darter, *Etheostoma spectabile*; and central stoneroller, *Campostoma anomalum*. We used T-tests to relate physical and chemical stream characteristics to presence and absence of each fish species. Variables that significantly differed between where the species was present and where it was absent were used in a discriminate analysis procedure. The procedure was designed to predict the probability of presence or absence, given a measure of physical and chemical factors and subsequently a criterion that would support removal of zero standing crop estimates from regression analysis. Functions relating individual physical and chemical variables to the estimates of standing crop were linearly indexed. Models designed to predict standing crops based on index values were then developed by a step-wise multiple regression.

The models closely predicted presence or absence and standing crop for species with moderate environmental limits, such as spotted bass and the slenderhead darter; however, predictability was much less precise for species with broad environmental tolerances, such as green sunfish. The probability of accurate prediction for other species lay between these two extremes. Models predicting standing crops do not explain all of the variation. They do, however, explain a significant portion of the variation and may be useful in assessing impacts of habitat changes on a given species.

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Introduction

The ever increasing scarcity of water resources has resulted in conflicts between resource development and habitat protection (Project Evaluation Team 1979). Legislative mandates at all levels of government have forced various agencies to deal with habitat protection. A major portion of the protection of habitats involves assessing the impact of man's activities on aquatic communities. Because many conflicting methodologies have been advanced to assess such impacts, recommendations for mitigation are often not unanimous, and lack of unanimity can result in a loss of credibility (Lockard 1979). In recent years much effort has been made toward standardizing methodologies. Most of the methodologies attempt to relate fish biomass or occurrence with physical characteristics that are descriptive of stream segments. The basic assumption is that once these relations are developed a knowledge of physical changes associated with some activity can be used to predict changes in fish distribution, occurrence, or biomass. Of course we make these additional assumptions: (1) that populations are responsive to physical and chemical characteristics of streams; (2) that the relations between fish occurrence or biomass and physical factors can be evaluated; and (3) changes in physical or chemical attributes of a stream due to man-induced impacts can be predicted.

Some work supports the assumption that species occurrence or biomass can be predicted by physical stream characteristics. For example, Binns and Eiserman (1979) explained 96% of the variation in trout standing crops in Wyoming streams with nine habitat attributes, and Lessenden (1976) was able to relate presence and absence of fish species in Kansas with physical and chemical stream attributes. Lessenden (1976) also found that only three variables were sufficient to define habitat types.

The assumption that changes in physical or chemical attributes of a stream due to man-induced impacts can be predicted is far from reality for many variables, although it is possible to predict the factors directly related to physical hydrological phenomena such as flow levels, depths, and velocities. The relations between these variables and standing crops of fishes have not been completely worked out, but several methodologies exist to determine instream flow needs for various fish species (Orth 1980). These methods have been used extensively only for cold water species and involve only a few variables such as depth, velocity, and substrate. Although these characteristics may be adequate to predict impacts in species-poor environments, other types of habitat seem to require more extensive models to predict changes in fish communities (Patten et al. 1979; Orth 1980). In spite of this apparent need, models involving other variables have not yet been developed.

The need for more complex models requires a larger data base. Many state and federal agencies accumulate large quantities of data on streams. The immensity of the resulting data sets often preclude detailed analysis. However, it is just such data sets that are needed to develop models of biomass and physical characteristics. In the absence of large sets of data reliance must be placed on existing literature, which often is based on laboratory investigations of narrow scope. The approach or methodology presented here is directed toward use of these large data sets, with the goal of furthering our knowledge of the relations between the occurrence of individual fish species and their abiotic environment.

Methodology and Application

The data set for our study was obtained from the Kansas Fish and Game Commission, and was originally used in the development of a technical report by Layher et al. (1978). The data set contained 420 observations (stream locations) with measurements of biotic and abiotic variables (table 1). The data set used in the present analysis was incorporated into a Statistical Analyses System (SAS) data set and all statistical analyses followed that system of Blair et al. (1979).

Eight species of adult fishes were investigated with respect to environmental variables: largemouth bass, *Micropterus salmoides*; spotted bass, *M. punctulatus*; white crappie, *Poxomis annularis*; channel catfish, *Ictalurus punctatus*; green sunfish, *Lepomis cyanellus*; slenderhead darter, *Percina phoxocephala*; orangethroat darter, *Etheostoma spectabile*; and central stoneroller, *Compostoma anomalum*.

In investigating the relations of habitat characteristics to fish occurrence or standing crop one must revert to theoretical concepts relating to such phenomena. Most of these concepts are deeply rooted in niche theory. While an adequate and universal definition does not exist, the aquatic resource manager generally uses the constrained hypervolume (realized niche) of Hutchison (1957). In this conceptualization the factors in the environment define the resource space in which a population occurs. Increased populations can be obtained by modifying one or more factors (limiting factors) that define the niche of that population, so that useable space expands. Conversely, the reciprocal approach can lead to a decrease in the resource space occupied. For the current model, we have assumed that physical rather than biological factors provide the limitation to this space. For southern Great Plains streams this assumption seems to be supported by field observations (Jones and Maughan 1980; Orth and Maughan 1980).

Our approach to developing a model for depicting some aspects of the niche of adult fishes involves two basic ideas: First, habitat conditions control whether a species occurs or does not

Table 1.--Variables included in the Kansas stream survey data set for each sampling station.

Descriptive variables	Physical variables	Chemical variables
Stream (number)	Riffle (%)	Total dissolved solids (mg/l)
County (number)	Pool (%)	Turbidity (JTU's)
Basin (number)	Run (%)	Total alkalinity (mg/l)
Station (number)	Total length of site (m)	Hydroxide alkalinity (mg/l)
Date	Mean width (m)	Calcium hardness (mg/l)
Month	Maximum width (m)	Magnesium hardness (mg/l)
Day	Minimum width (m)	Sulfates (mg/l)
Year	Mean depth (m)	Phosphates (mg/l)
Sampling method	Surface area (ha)	Nitrates (mg/l)
Segment	Volume of flow (m^3/sec)	pH
	Velocity (m/sec)	Conductivity(μmhos/cm)
	Gradient (m/km)	Chlorides (mg/l)
	Riffle depth (m)	
	Secchi disc (m)	
	Water temperature (°C)	
	Air temperature (°C)	
	Growing season (frost-free days)	

Biological variables:

(1) standing crop estimates for approximately 100 fish species;

(2) Presence-absence (0 or 1) for each fish species.

occur at a stream site (tolerance limits). Second, another set of characteristics, some of these controlling species occurrence included, at least partly determine the amount of fish in a stream segment (standing crop). Our methodology includes both of these concepts.

Presence-Absence Models

To evaluate the conditions that determine whether a given species occurs at a location, we attempted to determine which variables are most important or exert the most influence on presence or absence. In niche theory parlance, these would be limiting factors. To obtain the information we made T-tests for each variable measured using presence or absence of a species to designate groups. From the data set the SAS computes an F value to test the null hypothesis that variances were equal among the groups. However, T-tests were computed under the assumption of both equal and unequal variances. Which of the T-tests (whether for equal or for unequal variances) were used in further analysis depended on the result of the F test. Those parameters which showed statistically significant differences between presence and absence groups for a given species were then used in a discriminant function analysis to develop a predictive model for occurrence of the species being investigated.

However, as an example of the approach used, those variables found to show significant differences between where spotted bass occurred and where they did not were then utilized in a discriminant function alysis to relate how well these groups (presence and absence) could be predicted based on only these physical and chemical parameters. Using the PROC DISCRIM procedure misclassifications were then printed out on hard copy and an ID option used to identify each observation (in our case, a variable was created which identified the river basin, stream, and sampling station). After observations were identified by the ID option we ascertained sample location and recorded it on a map of the sample area. This graphic presentation enables a better analysis of why misclassifications may have occurred. For example nine of the locations where spotted bass were predicted to occur but didn't lie outside of the natural range of spotted bass. In these locations habitat may be suitable for the species but spotted bass have not had evolutionary access to the area. It is interesting to note that spotted bass have recently appeared in this area (Brunson 1981). This introduction supports the validity of the model prediction that suitable habitat existed in this area. Ten sites were misclassified from absence to presence within the species' native range. There are many possible biological explanations for such misclassifications (table 2).

However, although these reasons regarding misclassifications appear reasonable there is another reasonable non-biological explanation: differential sampling efficiency. In the Kansas project, eight sampling techniques were used. Figure 1 shows mean standing crop values for sites located within the native range of spotted bass by collection method. The data for Figure 1 were obtained by categorizing data by sample method and using a PROC MEANS to obtain the average values for standing crop of spotted bass obtained with each sampling method. We also programmed our discriminant function analysis misclassification printout to provide information on sampling methods used in each inappropriate observation. All sites misclassified from absence to presence within the native range of spotted bass were found to have been sampled by seining (sample method 2 in fig. 1). In addition, the average standing crop found at stream sites by this method of collection was considerably lower than that obtained by other collection methods. We conclude that seining is a poor collection method for determining the presence of spotted bass. However, it is also possible that seining was used only in poor spotted bass habitat.

The presence-absence model based on physical factors seemed to work reasonably well for the Kansas stream data, however, the assumption that

Table 2.--Possible biological reasons for misclassifications at stream sites by a discriminant function analysis utilized to predict occurrence or nonoccurrence of designated species of fishes (adult life stage).

1. All variables important in determining species occurrence may not have been measured.

2. Exogenous entities (pollution) in the stream may have eliminated the species prior to sampling.

3. Pulses in environmental characteristics may have ensured that the parameter measurements were not representative of "normal" stream characteristics.

4. Requisites for nonadult life stages of the species being considered may not exist in close proximity to the sample location.

the discriminant function analysis will work well on other stream sites sampled does not necessarily follow. The model should be tested on another data set to determine its feasibility. If another data set exists containing similarly measured variables as the original data set, the original can be used as a calibration set and be conveniently stored on tape or disc to be used at the researcher's discretion. Blair et al. (1979, p.185) described a simple SAS procedure for testing a second data set by using the original for calibration data values.

Standing Crop Predictive Models

The procedure so far outlined deal only with whether a species occurred or did not occur. Obviously, it would be useful to develop ways to predict graduations of habitat quality. One approach to this problem is to relate changes in standing crop to changes in physical or chemical variables. Using the SAS PROC PLOT procedure, we attempted to graph species' standing crops against measurements of physical and chemical variables. When large data sets are used, such plots can be

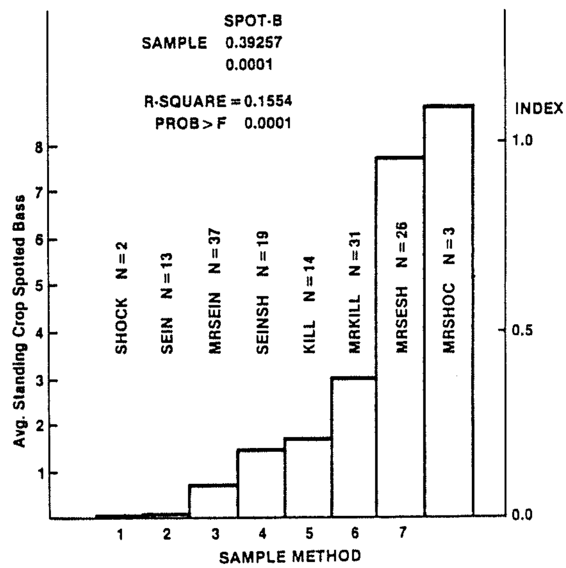

Figure 1. Average standing crops (kg/ha) for spotted bass collected by various sampling techniques. All sites represented by this figure were located within the native range of spotted bass. Sample method codes; shock=shocking; sein=seining; mrsein=mark and recapture using seining; seinsh=seining and shocking; kill=rotenone; mrkill=rotenone with mark and recapture; mrsesh=seining and shocking with mark and recapture; and mrshoc=shocking with mark and recapture.

very confusing. Many data points with similar variable measurements result in observations being hidden on the plot. In addition, extreme variation in standing crop values exist for locations with similar variable values. Often the relation developed for this data is nonlinear and requires complex polynomial equations to fit a relation. Conversion of this polynomial equation to a linear relation would increase tremendously the number of data points needed to fit a multivariate function.

In an attempt to overcome these problems, we drew suitability curves relating standing crop of fish species to each variable measured. Each range of each parameter investigated was then divided into increments and mean standing crop values were calculated within each increment. (See table 3 for an explanation of SAS computer procedures used.) If possible, curves were then drawn to pass through these means. The number of observations within each increment enabled us to estimate the validity of the results. If an observation yielded a high estimate of standing crop at a point where the major portion of the data indicated standing crop should have been low and the standing crop value was based on only a few samples, the curve was drawn to conform with the major body of data. An example of this situation is shown in figure 2.

The highest mean standing crop value represented by a large proportion of the observations was usually assigned the highest suitability value, a value of one. Habitat suitability values were then assigned proportionally to segments of the curve passing through any given increment of a physical or chemical variable. The effect of this procedure was an attempt to linearize the f(x) = standing crop, where x is one of the physical or chemical variables. Figure 3 shows the theoretical effect of this procedure.

From the Kansas data we devoloped curves for most of the 30 physical and chemical parameters measured in the field for each of the eight fish species. Each observation in the data set was then assigned suitability values ranging from 0 to 1 based on the habitat suitability curves for each variable for a given species. Stepwise multiple regression runs were then utilized (SAS PROC STEPWISE) to identify variables which explained the variation of standing crop by species.

In this data set, as mentioned previously, we found differences relating to sample method and therefore split the data on this basis. From these procedures we developed models to estimate standing crop at a given location based on measurements of the physical habitat. It should be remembered that (1) the regressions were performed on suitability index values and not on empirical data; (2) the resulting equations can not be used to evaluate variable importance or relationships by looking at coefficients because different scales of measure were used for each variable; and (3) the model is a combined estimator of standing crop; therefore the entire model must be used. As with presence-absence predictive models, standing crop models should be tested with another data set for verification. Where large data sets are available an alternate approach would be to block by geographic area or variable increments and assign observations within blocks randomly to

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Table 3. SAS procedures utilized to develop a habitat suitability curve for the physical variable mean stream width (MEAN_WID) for the species spotted bass (SPOT_B). For other variables substitute variable code for MEAN_WID. For other species substitute new species identifier for SPOT_B.

STEP

A. PROC PLOT; SPOT_B *MEAN_WID;

B. MEAN_WID=INT (MEAN_WID/10)* 10;

C. PROC MEANS; VAR SPOT_B

D. PROC CHART; VBAR MEAN_WID/TYPE=MEAN SUMVAR=SPOT_B DISCRETE;

E. PROC SORT; BY MEAN_WID;

F. PROC MEANS; BY MEAN_WID; VAR SPOT_B

RESULTS BY STEP

A. A plot of spotted bass standing crops on the ordinate and mean width on the abscissa.

B. Has the effect or producing intervals of mean width in groups of 10 meters (0 ≤ MEAN_WID < 10; 10 ≤ MEAN_WID < 20, etc.).

C. Computes mean for spotted bass standing crop estimates with N value and other descriptive statistics.

D. Produces a bar chart of mean standing crop for each interval of mean width.

E. Sorts the data set by mean width which now has an interval value (0 for 0 ≤ MEAN_WID < 10; 10 for 10 ≤ MEAN_WID < 20, etc.).

F. Produces a table with interval values for mean width. Includes the actual mean value for spotted bass for each interval as well as the range, standard deviation, maximum and minimum values, and N.

NOTE: The bar graph in conjunction with data printed out unter step F are used to develop the habitat suitability curve.

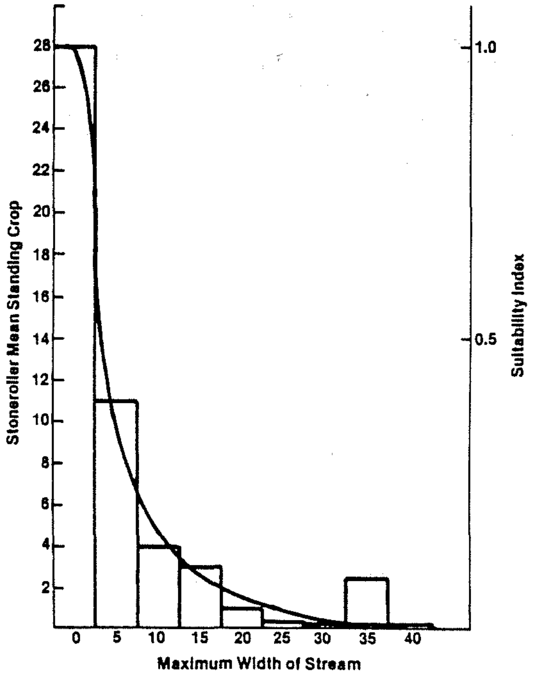

Figure 2. Plot of stoneroller mean standing crop (kg/ha) vs. maximum stream width; mean mean standing crop value for the width interval, 35 meters to 40 meters, does not fit the curve. N for this interval is 2. See text for discussion.

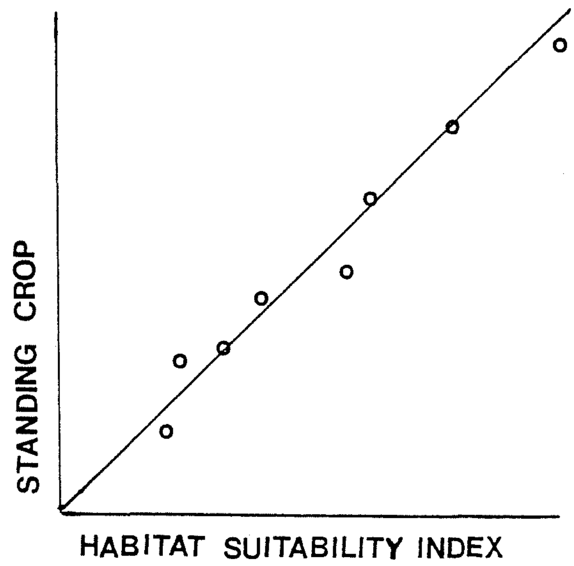

Figure 3. Theoretical response of standing crop for a hypothetical species plotted against a habitat suitability index for a single variable.

each of two data sets. One data set could then be used for model building and the other for testing.

SUMMARY AND CONCLUSIONS

The presence-absence models appear to work well to predict areas where a species can exist. These models may be of value in situations where loss of a species from a habitat due to man-induced alterations is a possibility and where later effects can be predicted. We believe that if presence-absence models were available for other life stages, the number of misclassifications would probably be significantly reduced.

Sampling technique appeared to greatly affect data interpretation when predictive models for standing crop were evaluated. When all sites where the species occurred were used in the analysis, no significant regressions were obtained, however, if the data set was split by sample method, the correlations were significant. Although we developed no criteria for the selection of a sampling method, it appeared that mark and recapture and killing methods gave more useful data than did seining.

Possibly some of the variation in the complete data set was the result of matching sampling technique with particular habitats. Such an approach would have unintentionally divided sampling sites into relatively homogeneous clusters. Such clustering may explain why different variables assume importance when different sampling techniques are used. It might then follow that different variables are limiting in different habitat types. The significant and often high R^2 values relating standing crop with a particular type of population sampling indicates a reduction in the variability, and also a reduction in the chance for more variables to be limiting. However, in spite of the forgoing argument, it seems reasonable that some sampling techniques are superior to others.

Our failure to model the complete data set would suggest that modeling habitat suitability for large geographic areas with a multiplicity of sampling techniques may be unattainable by conventional methods of regression analysis. However, our success within sampling techniques would suggest that if data sets are reduced to represent a limited geographic area or homogeneous habitats, quantitative modeling may be attainable.

Our data also show that it is easier to model habitat suitability for species with restricted habitat requirements. For these species, even though they may be found over a relatively wide geographic area, habitats may be similar enough so that relatively few variables determine suitability. Spotted bass and slenderhead darters are two examples of this type. Some of the other species investigated; channel catfish, white crappie, largemouth bass and green sunfish, are fish with broader physical and chemical tolerances. Consequently, the number of limiting factors in aggregate that exist at various localities for each of the species is much greater than those for species with narrower requirements. This hypothesis must be further tested; and a way to determine overall niche breadth of species along multiple dimensions on a comparative basis is needed. Consequently, our approach of quantitatively modeling habitat suitability will produce good results for some species and poor results for others.

Our data show a new approach to developing suitability curves but no way to develop actual numerical models for all species. We still believe that suitability curves based on quantitative data may be a strong aid in determining impacts. In as much as limiting factors vary from one location to the next (as noted for species with broad niches), the best approach may be one of evaluating suitability curves for as many variables as possible and intuitively predicting the impact due to changes in all the parameters.

The major limitation of our approach is lack of field verification. We have sampled 50 stream locations in approximately 45 streams across the northern one-half of Oklahoma between 10 June 1981 and 12 August 1981. Physical and chemical parameters were measured at all of these sites and estimates of standing crops of all fish species obtained. We will use these data to evaluate our models for each of the eight species we are investigating.

ACKNOWLEDGMENTS

We thank the Kansas Fish and Game Commission, especially Robert Hartmen and Ken Brunson, and the Kansas Department of Health and Environment for their generous permission to use the Kansas stream survey data set in our analysis of habitat evaluation procedures; Gail Tompkins for aiding in computer programming and card punching; the approximate 100 private land owners contacted in Oklahoma for permission to cross their lands and sample streams; the Oklahoma Department of Wildlife Conservation and the U.S. Army Corps of Engineers for similar assistance; and, the U.S. Fish and Wildlife Service, Office of Biological Services for providing funds; Ken Collins, Ron Eby, Patti Harjo, Ken Williams, Frances Grant, and David Latham for aiding in data collection on Oklahoma streams; and Michael Clady for direction in sampling fish populations.

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TECHNIQUES FOR THE CLASSIFICATION OF STREAM HABITATS, WITH EXAMPLES OF THEIR APPLICATION IN DEFINING THE STREAM HABITATS OF MISSOURI[1]

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and Pamela S. Haverland[4]

Abstract.--We are using the general composition of the fish fauna and a few readily quantifiable physical attributes at 1608 localities to delimit the habitats of Missouri streams.

Cluster analysis, coupled with a truncation procedure, was used to obtain a preliminary definition of habitat regions. A procedure called species composition analysis was developed to determine the species that characterize these regions, and to further refine the classification. Topographic patterning and the conformity of physical attributes to the locality groups defined by faunal analysis provided criteria for judging the plausibility of the classifications obtained.

The techniques being developed should be applicable for classifying stream habitats in any area from which general collections of fishes or other elements of the stream biota are available for study.

INTRODUCTION

A system for describing and assessing stream habitat in terms of relative scarcity and condition is being developed in Missouri (Fry and Pflieger 1977). To implement this system it is essential to know the types of stream habitats in the state, the amount of each type, and the condition of these habitats with respect to man-caused disturbance.

No generally applicable classification of stream habitats exists for the USA. The literature on stream classification has been reviewed by Hynes (1970) and Hawkes (1975). Pennak (1977) discussed the difficulties of stream classification and recognized seven distinctive lotic categories for the USA. All other kinds of lotic habitats, which would include the majority of those found in Missouri, he grouped together as "indistinctive habitats" because "they defy practical classification". It is our belief that some further subdivision of stream habitats is possible. Here we describe the techniques we are using to define these subdivisions, and demonstrate the application of these techniques in defining the major habitat regions of Missouri.

We are using the general composition of the fish fauna and a few readily quantifiable physical attributes to delimit stream habitat types. The utility of fish collections for defining broad fish faunal regions has been demonstrated (Pflieger 1971). That these faunal regions also comprise broad aquatic habitat regions is suggested by the correspondence between the regions and the occurrence of certain physical attributes such as bedrock type and topographic relief. In the present analysis we are using multivariate computer techniques to better define these regions, and to define further habitat subdivisions within the regions.

The data base for our analysis is a computerized file of 2,608 fish collections from 1,933 localities. Repeat collections from the same locality were combined to compile species lists for 1,608 localities from which collections were deemed adequate for analysis. Also included in this file were a locality number and drainage

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code for retrieving data, Universal Transverse Mercator Grid Coordinates for mapping data, and 10 physical attributes of the locality (stream order, order of receiving stream, miles to headwater, stream mile, elevation, local relief, gradient, bedrock type, soil, and physiographic region). This file was described in greater detail in another paper of this symposium (see Pflieger, Haverland, and Schene).

The sequence of steps we used in defining habitat regions was as follows: cluster data subsets ⟶ truncate data-subset phenograms to form locality groups ⟶ compile composite lists of species to represent locality groups ⟶ cluster composite lists to obtain a preliminary definition of habitat regions ⟶ compute constancy-fidelity indices for species ⟶ use species composition analysis to further refine the classification. For judging the plausibility of the classifications resulting from application of cluster analysis and species composition analysis we relied on two types of criteria proposed by Clifford and Stephenson (1975). One of these criteria was topographic patterning. The other was the extent to which the physical attributes of localities (extrinsic data) conformed to classifications derived using faunal composition (intrinsic data). By these criteria, the "best" classification was the one that produced the most highly coherent topographic grouping of localities and the highest degree of conformity of physical attributes to locality groups. In the sections that follow, each of the topics introduced above will be discussed in greater detail.

CLUSTER ANALYSIS AND THE DEVELOPMENT OF A TRUNCATION PROCEDURE

Cluster analysis was used to obtain a preliminary definition of habitat regions. The initial step in this procedure was the computation of a matrix of values (similarity coefficients) which expressed the degree of faunal similarity between all possible pairs of the localities used in the analysis. The localities were then grouped, or clustered according to their faunal affinities, and the results were expressed as a phenogram. Clifford and Stephenson (1975) and other general texts provide a more complete exposition of this procedure. We used the NT-SYS statistical package (Rohlf, Kishpaugh, and Kirk 1972) for cluster analysis. From the several coefficients of similarity and clustering algorithms offered by NT-SYS we selected the Kulzynski Second presence-absence coefficient and the unweighted pair-group clustering procedure for use in the analysis of our data.

For this phase of the analysis we used faunal lists from 1,540 localities. However, the largest number of lists that we found practical to cluster as a single group was about 250. We developed a truncation procedure to reduce the number of entities to be clustered: eight data subsets corresponding to major drainage subdivisions of Missouri were clustered independently; the resulting phenograms were truncated at a uniform level to form locality groups; faunal lists (composite records) were compiled to represent the localities in each group; and the composite records from the eight data subsets were combined into a single data set and reclustered to define the habitat regions.

A simple phenogram is shown in Figure 1 to demonstrate the truncation procedure. The data for this cluster analysis consisted of species lists for 9 localities in the drainage of a small stream, Big Tavern Creek. These localities are identified in the column just to the right of the phenogram, and in the adjacent column the levels at which the localities were linked in the phenogram are expressed as a number ranging between 0 and 1. These levels are also indicated by the horizontal scale along the upper and lower margins of the phenogram. Two arbitrarily selected truncation levels (0.50 and 0.65) have been drawn vertically across the phenogram. Truncation at the 0.50 level results in the formation of two locality groups, while truncation at the 0.65 level results in three locality groups.

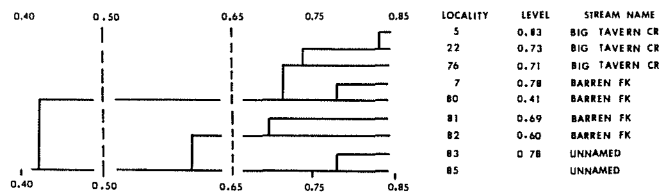

Figure 1. Phenogram based on a cluster analysis of localities in the Big Tavern Creek drainage. Dashed lines represent arbitrarily selected truncation levels.

In truncating the phenograms resulting from cluster analysis of our 8 data subsets we were operating within the following constraints. We had to stay far enough to the right (higher levels of similarity) to avoid the formation of locality groups including more than one habitat type. On the other hand, we had to stay far enough to the left (lower levels of similarity) to form locality groups of a size and number to sufficiently reduce the number of entities to be clustered.

To estimate the truncation level that would meet the above criteria, we analyzed the frequency distribution of linkage positions in the phenograms (Table 1). We found that the linkage positions in our phenograms were normally distributed, exhibiting a more or less bell-shaped frequency distribution. We reasoned that the part of the frequency distribution where numerous linkages occurred might represent within-habitat variation, while the part on the left of the phenogram where fewer linkage positions occurred might represent between-habitat variation. We decided that we should truncate about one standard deviation from the mean, since that would approximate the point where within-habitat variation gave way to between-habitat variation. In 5 phenograms that we analyzed, one standard deviation to the left of the mean ranged from 50.2 to 58.6. We selected a truncation level of .60. At that level truncation of 8 data subsets reduced the number of entities to be clustered from 1,540 to 94.

Table 1. Frequency of linkage positions in phenograms produced by cluster analysis of five data subsets.

		Linkage Frequency		
Data Subset	Number of Localities	$\bar{X}$	SD	$\bar{X}$-SD
Osage Basin	220	71.4	13.0	58.4
Middle Mississippi	263	72.1	13.5	58.6
Lower Missouri	122	68.9	13.8	55.1
Neosho-White	134	69.5	12.1	57.4
Lower Mississippi	156	64.9	14.7	50.2

In compiling composite species lists to represent the locality groups formed by cluster analysis we concluded that only commonly occurring species should be included, and used the concept of constancy to eliminate the less frequently occurring species. For purposes of our analysis, constancy is defined as "the consistency with which a species occurred in a locality group defined by cluster analysis". The quantitative expression of constancy that we used was the number of occurrences for the species in the locality group as a percent of the total number of localities in that group.

We theorized that a composite list might best represent a locality group if the number of species in the list approximately equalled the average number of species per locality in the group. In Table 2, the consequences of forming composite lists at various levels of constancy are examined. In these three locality groups the number of species in the composite lists at the 50% constancy level were approximately equal to the average number of species per locality, thus favoring the use of this level of constancy in compiling the composites.

Table 2. Number of species in composite lists representing three groups of localities at four constancy levels.

		Number of Species in Composite as a percent of $\bar{X}$ Number/Locality			
No. of Locs. in Group	$\bar{X}$ No. of Species/ Locality	Full List	25% Constancy	50% Constancy	75% Constancy
19	26.1	172.4	128.1	99.6	72.8
14	35.1	173.8	122.5	99.7	82.6
5	52.1	142.8	119.3	104.2	83.3

As a further test of this conclusion we clustered species lists for 220 localities, truncated the resulting phenogram at the .60 level, and computed a Kulzynski Second Coefficient that compared the species lists for each of the 220 localities with the composite species lists formed at various levels of constancy. We found that some localities exhibited their highest coefficient with a composite other than the one in which they were placed by cluster analysis, and reasoned that the number of such localities was a measure of the distortion that the selected constancy level engendered in the relationships expressed by the cluster analysis. The number of localities exhibiting a higher coefficient with a composite other than the one in which they were placed by cluster analysis was: 31 for the full species list, 9 for 25% constancy, 5 for 50% constancy, and 19 for 75% constancy. These results suggest that the 50% level of constancy gave the least distortion.

We defined a "composite" so as to exclude locality groups that included fewer than four localities. This was done because in a 3-locality group at 50% constancy a species would have to occur in two of the three localities (67% constancy), and the composite record for a 2-locality group at 50% constancy would be equivalent to a full list. Groups of three or fewer localities were therefore excluded from the cluster analysis of composite records, but were brought back into the classification procedure by species composition analysis. Using the above criteria, 295 of the 1,540 localities did not join composites.

Truncation of the eight data subsets at the .60 level resulted in the formation of 94 composite records representing 1,245 localities. Cluster analysis of these 94 composites produced four principal locality groups: a "lowland" group of 55 localities and a "river" group of 63 localities that linked to other groups in the phenogram at the .16 level of similarity, and an "Ozark" group of 492 localities and a "prairie" group of 635 localities that separated from each other at the .24 level of similarity.

CRITERIA FOR JUDGING THE PLAUSIBILITY OF CLASSIFICATIONS

In this section we will use conformity analysis and topographic patterning (see Introduction for definitions) to demonstrate that the four principal locality groups defined above correspond to major habitat subdivisions of Missouri. We determined the conformity of 10 physical attributes to the four principal locality groups, and found that most attributes exhibited a high degree of conformity. In Figure 2, conformity of the attribute stream order to the locality groups is demonstrated. Frequencies were weighted to account for differences in the number of localities sampled in streams of various orders. Localities in the lowland cluster group were mostly from man-made ditches and natural lentic habitats, while those in the river cluster group were mostly from the Missouri and Mississippi rivers. Localities in the Ozark and prairie cluster groups included a broad representation of streams of order 1-8.

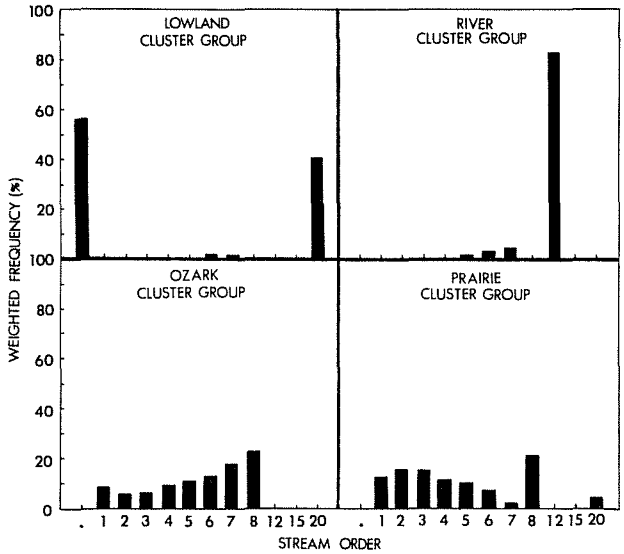

Figure 2. Conformity of the attribute stream order to locality groups formed by cluster analysis of 94 composite records. Stream order was not determined for: •=man-made ditches, 12=Missouri and Mississippi rivers, 15=springs, 20=natural lentic habitats.

Conformity of the attribute physiographic region to the four principal locality groups (Fig. 3) reflects the response of the fish fauna to a complex of physical attributes including bedrock and soil types, topographic relief, and stream gradient. The reader is referred to Pflieger (1971) for a map and discussion of Missouri's physiographic regions. All localities in the lowland cluster group were from the Southeastern Lowlands. Most of the localities in the Ozark cluster group were from the Salem Plateau, Springfield Plateau and St. Francis Mountains, which together comprise a major physiographic subdivision of Missouri known as the Ozark Uplands. Localities in the prairie cluster group were mostly from the Dissected Till Plains and Osage Plains, but with some representation of other regions.

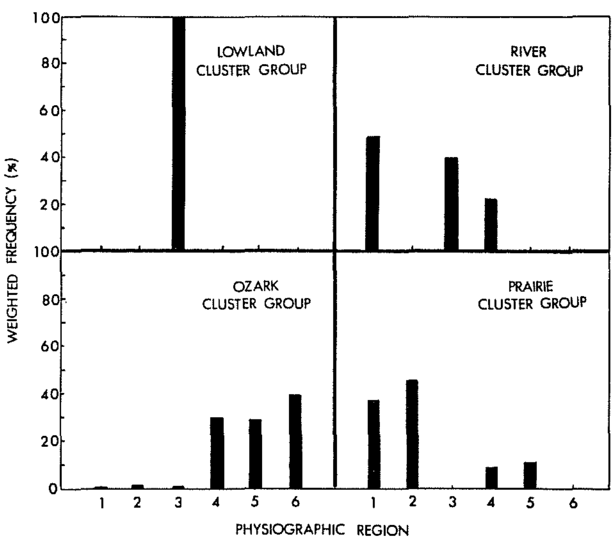

Figure 3. Conformity of the attribute physiographic region to locality groups formed by cluster analysis of 94 composite records. The physiographic regions represented by the numbers are: 1=Dissected Till Plains, 2=Osage Plains, 3=Southeastern Lowlands, 4=Salem Plateau, 5=Springfield Plateau, 6=St. Francis Mountains.

Topographic patterning in the cluster groups and the relationship of these patterns to principal physiographic boundaries, are indicated in Figure 4. The largely complimentary distribution of localities in the four cluster groups is evident.

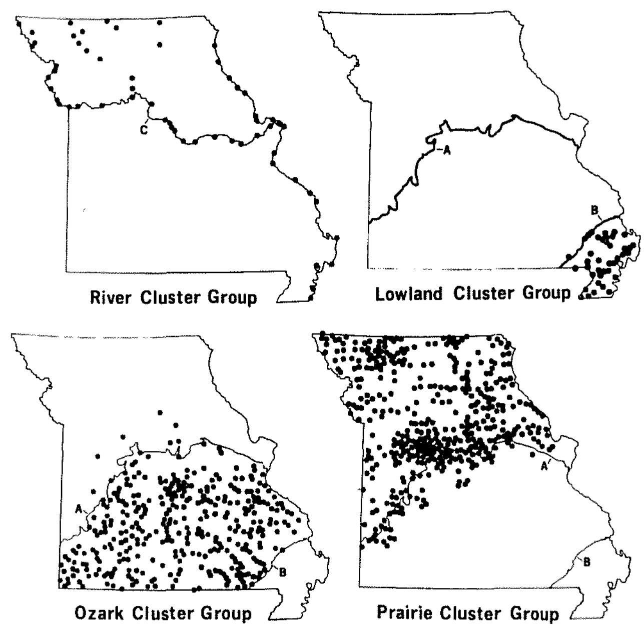

Figure 4. Distribution of locality groups formed by cluster analysis of 94 composite records. A & B=physiographic boundaries of Ozark Uplands; C=Missouri River.

SPECIES COMPOSITION ANALYSIS

In this section we use a procedure for which we propose the name "species composition analysis" to accomplish three principal objectives: 1) to characterize the locality groups defined by cluster analysis in terms of their fish fauna, 2) to explore a supplemental method of classification as a tool to further refine the classification, and 3) to establish criteria that could be used to place additional localities in the classification without repeating the entire analysis.

Species composition analysis is a further refinement of a procedure used previously in defining the major fish faunal regions of Missouri (Pflieger 1971). In the quantitative application of species composition analysis we used the concepts of constancy (see preceding section for a definition) and fidelity. Fidelity is defined as "the number of occurrences for a species in a locality group in relation to its number of occurrences in all the locality groups under consideration". The quantitative expression of fidelity that we used was the number of occurrences for the species in a locality group as a percent of its total occurrences in all the locality groups under consideration. In the context of the present discussion, the locality groups used in computing constancy and fidelity were the four principal locality groups defined by cluster analysis, as described in the preceding section.

Constancy and fidelity measure different aspects of a species distribution: a common, generally distributed species may exhibit high constancy but low fidelity for all locality groups, while a rare species of localized occurrence may exhibit high fidelity for one locality group and low constancy for all groups. Some species are of frequent occurrence but confined to a single locality group, thus exhibiting high constancy and high fidelity for only that locality group. We combined constancy and fidelity into a single index by summing them and dividing by two. This index, called the constancy-fidelity index, ranges from 0-100, as is true also for constancy and fidelity.

We computed the constancy, fidelity, and constancy-fidelity index of each species in the four principal locality groups, and sorted the species into four groups, based on their highest index value. The results for constancy, fidelity, and the constancy-fidelity index are summarized in Table 3. Comparison of the number of species sorted into groups corresponding to the principal locality groups by the three indices revealed a group-size effect on constancy and fidelity.

Table 3. Number of species sorted into four cluster-group categories, using the highest value for constancy, fidelity, and the constancy-fidelity index.

Cluster-group Category	No. of Localities	Number of Species: Constancy	Fidelity	C-F Index
Lowland	55	52	29	36
River	63	56	33	45
Ozark	492	78	97	91
Prairie	635	21	48	35

Constancy appeared to favor the allocation of larger numbers of species to groups corresponding to locality groups having the smallest number of localities (lowland and river). Fidelity, on the other hand, favored the allocation of larger numbers of species to groups corresponding to locality groups having the largest number of localities (Ozark and prairie). The constancy-fidelity index gave intermediate results, suggesting that this group-size effect was at least partly nullified by combining constancy and fidelity into a single measure of species distribution.

We devoted considerable time and effort to exploring the properties of constancy, fidelity, and the constancy-fidelity index, particularly with respect to the group-size phenomenon. We tried several transformations of constancy and fidelity that were intended to minimize the group-size effect. We concluded from this work that the results obtained by application of the simple constancy-fidelity index were equal or superior to those resulting from any of the transformations that we tried.

Species composition analysis involved the application of the species constancy-fidelity indices to the species listed for each locality, as exemplified in Table 4. The constancy-fidelity indices for all the species occurring at the locality were summed and averaged down the columns corresponding to the lowland, river, Ozark, and prairie indices. The relative values of these index averages were interpreted as an indication of the faunal or habitat affinities of the locality. The locality used in the example exhibited a much higher average index for "Ozark" than for other cluster group categories.

Table 4. Computation of the locality constancy-fidelity indices. The data used in this example was from Locality 0349 in Indian Creek, a tributary of the Meramec River.

Species	Constancy-Fidelity Index: Lowland	River	Ozark	Prairie
Ambloplites rupestris	0.0	0.0	56.7	0.0
Lepomis megalotis	47.1	1.8	75.6	17.2
Campostoma oligolepis	1.0	0.9	79.8	6.2
Notropis greenei	0.0	0.0	60.8	1.5
Notropis rubellus	0.0	1.9	60.6	18.4
Notropis zonatus	0.0	0.0	78.7	4.8
Fundulus olivaceus	49.0	0.9	68.2	8.0
Etheostoma caeruleum	0.0	0.9	83.9	1.1
Etheostoma tetrazonum	0.0	0.0	50.7	9.2
Index Averages	10.8	0.7	68.3	7.4

Average constancy-fidelity index values were similarly computed for each of the 1,245 localities used in the cluster analysis, and the localities were sorted into habitat categories (lowland, river, Ozark, and prairie), based on their highest average index value. Comparison of the locality composition of the habitat categories obtained by species composition analysis with that obtained by cluster analysis revealed that they were similar. However, 86 (6.9%) of the localities were allocated to a different group by the two analyses. The largest of the "reallocated" categories consisted of 57 localities placed in the prairie group by cluster analysis and in the Ozark group by species composition analysis. Topographic patterning is evident in the distribution of these localities; they are concentrated along the physiographic boundary between the Ozark Uplands and the plains regions to the north and west (Fig. 5). Seventeen localities were reallocated from the Ozark to the prairie group, and these were mostly in small headwater creeks. Eleven localities reallocated from the river to the prairie group were mostly in large streams of the Dissected Till Plains.

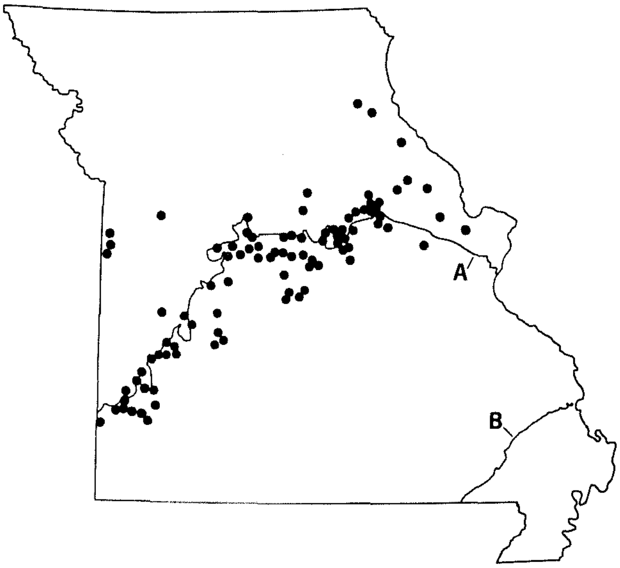

Figure 5. Distribution of localities allocated to the prairie group by cluster analysis, and to the Ozark group by species composition analysis. A and B=physiographic boundaries of Ozark Uplands.

We considered these "reallocated" localities to be transitional. To determine if other transitional localities might be represented in our data, we applied an unpaired T-test to the average index values for all 1,245 localities to test whether the highest average, (that is, the one responsible for group allocation of the locality) was significantly different from the other averages at the .05 level of confidence. This procedure is exemplified for the average constancy-fidelity indices of five localities allocated by species composition analysis to the Ozark group (Table 5). The Ozark averages for two of these localities (0718 and 0488) did not test as significantly different than one or more of the other averages for the locality. At the .05 level of confidence, 282 (22.7%) of the localities included in our analysis did not test as significant. However, of the 86 localities allocated to a different group by species composition analysis than by cluster analysis, 70 (81.4%) did not test as significant. This disproportionate representation of "reallocated" localities lends support to the conclusion that they are transitional. In any case, removal of the 282 localities that did not test as significant resulted in a sharpening of the distinctions between the four habitat groups (Fig. 4 vs. Fig. 6).

Table 5. Application of an unpaired T-test to the average constancy-fidelity index of selected localities allocated to the Ozark group by species composition analysis. Asterisks indicate Ozark averages that were not significantly higher than other averages (P>.05).

		Average Constancy-Fidelity Index			
Locality		Lowland	River	Ozark	Prairie
1482	Pine Valley Cr.	7.2	1.5	72.9	11.3
1428	Black R.	12.9	4.5	62.0	15.2
0718	Pickle Cr.	23.3	10.7	59.1*	40.6
1742	Current R.	10.4	10.1	48.6	14.4
0488	Gasconade R.	5.6	26.2	27.8*	25.5

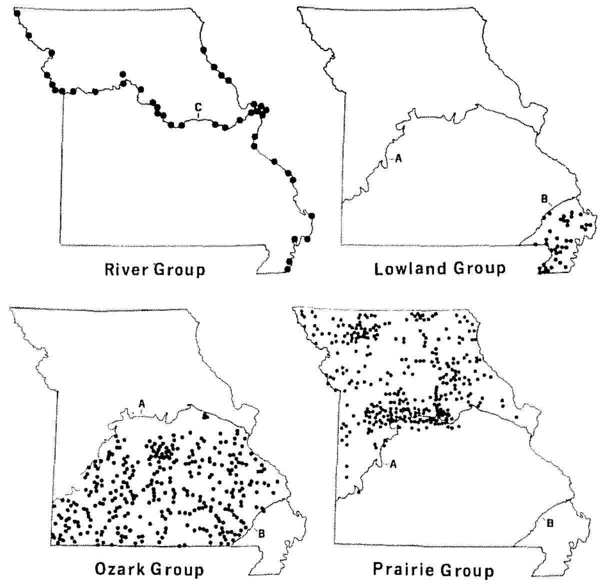

Figure 6. Distribution of localities allocated to four groups by species composition analysis. Only localities used in the preliminary cluster analysis are shown. A & B=physiographic boundaries of Ozark Uplands; C=Missouri River.

We tested the utility of species composition analysis to assign localities that were not a part of the original cluster analysis. The localities used for this test included the 295 that were not assigned to locality groups when the original eight phenograms were truncated to cluster the composite records. Also included were 68 newly-acquired localities. We applied the previously computed constancy-fidelity indices to these 363 localities and tested the means with an unpaired T-test as before. By this procedure, we allocated an additional 180 localities to the four habitat regions (Fig. 7). The localities exhibited the same high conformity to physiographic boundaries as did the original cluster localities.

From a total of 1,608 localities available to us for analysis, we allocated 1,208 (75.1%) to one of four habitat regions, using species composition analysis coupled with the T-test for significance. We suspected that the remaining 400 localities represented habitats that were transitional between the primary habitat regions, and reclustered them in an effort to define these transitional categories. By this procedure we recognized three principal transitional categor-

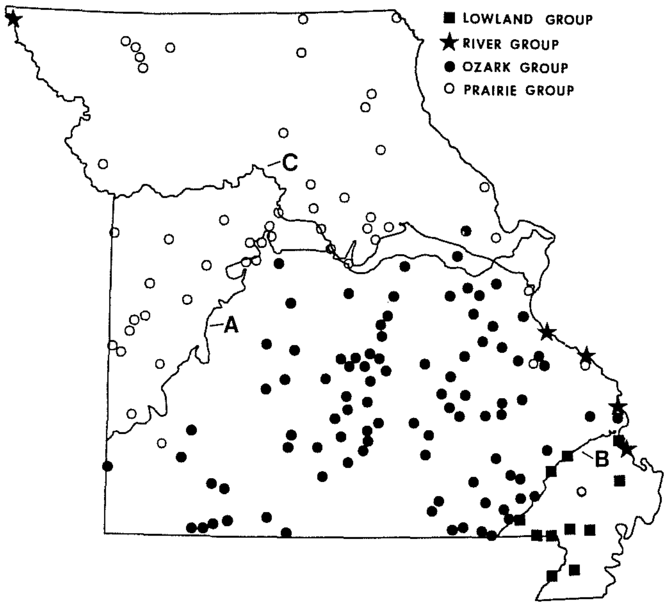

Figure 7. Distribution of localities allocated to four groups by species composition analysis. These localities were not used in the preliminary cluster analysis.

ies (Fig. 8). These included an Ozark-prairie transitional group supporting a mixture of Ozark and prairie fish species, a prairie-river transitional group supporting a mixture of prairie and large-river species, and a group of extreme headwater localities in the Ozarks that supported a limited fish fauna. A number of other smaller special habitat categories were recognized, including an Ozark-lowland transitional group, and a category consisting of natural lakes.

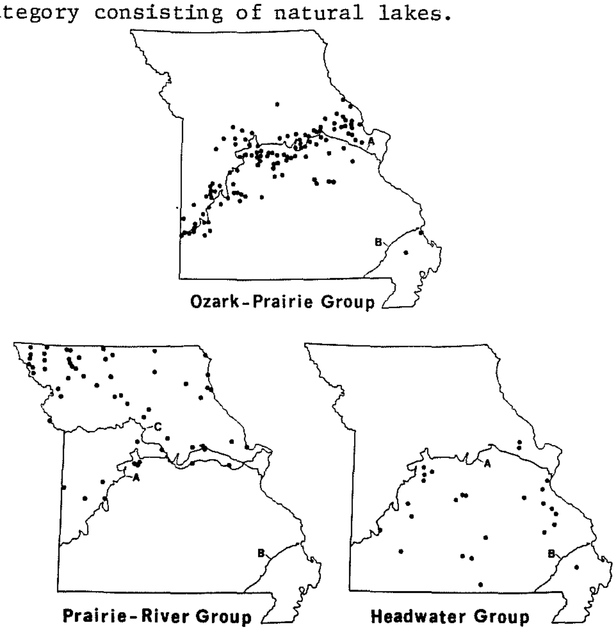

Figure 8. Distribution of localities allocated to three groups by cluster analysis. These localities were not allocated to groups during species composition analysis because the index averages responsible for group allocation were not significantly different (P>.05) than other index averages for the locality.

CONCLUSIONS

By these techniques we successfully defined four principal habitat regions and some transitional habitats. The techniques we have discussed will be used to further subdivide the major regions into subregions until a level is reached in which the streams are of a similar type. We will then use other techniques such as ordination to define habitat zones along the length of streams within each region.

The various techniques we are using for habitat classification are still under development, and will probably be further refined as our study progresses.

We have demonstrated sufficient local differentiation in stream habitats to suggest that our stream habitat classification will have application only to Missouri and perhaps portions of adjoining states. However, we hope the techniques for habitat classification that we are developing can be applied with appropriate modifications to other geographic areas from which general collections of fishes or other elements of the stream biota are available for study.

ACKNOWLEDGEMENTS

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EVALUATING COMMUNITY SIMILARITY:

AN EXPLORATORY MULTIVARIATE ANALYSIS[1]

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David A. Rundstrom[4]

Abstract.--Traditional studies of community fisheries data are often analyzed with a series of pairwise comparisons on correlation coefficients or diversity indices. Although some information can be gained from these kinds of analyses, often erroneous or inappropriate conclusions are drawn. Several multivariate analysis techniques, which avoid many of the pitfalls of the traditional analyses, are available. This paper details the application of two of these techniques: Principal Component Analysis (PCA) and cluster analysis.

A PCA followed by a cluster analysis on the orthogonal (statistically independent) components was performed on trawl catches of 32 fish taxa (variables) taken from 11 sites along the southern California coast. This process filters the variables, which are often highly correlated and allows the investigator to determine which communities are similar and which fish taxa influence these similarities. Emphasis is placed on the benefits and insights which can be gained by applying these types of exploratory techniques.

INTRODUCTION

One of the primary objectives of aquatic monitoring programs is to evaluate the status of fish-invertebrate communities in habitats subject to proposed or extant pollutant perturbations. Owing to fiscal and temporal restraints on experimentally oriented research, aquatic habitat information is acquired to gain basic information on distribution and abundance patterns or population dynamics of selected taxa. Although much information is gained regarding the taxa, the investigator often faces a problem when evaluating the status of the community based upon data which were collected without the community analysis in mind.

The technique presented here provides the investigator with a tool to evaluate community level questions using select species population information. The example selected for this particular analysis deals solely with abundance data. However, the technique can and should include physical-chemical information where possible.

A principal component analysis (PCA) followed by a cluster analysis are the techniques discussed in this paper. This paper does not deal with the mathematical aspects of PCA and cluster analysis techniques, but rather with approaches, benefits and insights which can be gained from their application.

APPROACH

The initial impetus for the application of these techniques arose because we wanted to quantitatively compare marine fish communities near several power generating stations in the Southern California Bight with respect to the relative abundance of select species populations (fig. 1). The primary objective was to determine if nearshore fish communities differed with regard to abundance of 32 commonly occurring fish taxa. Observations of the fish taxa were made at 11 sites (10 offshore power generating stations and one offshore

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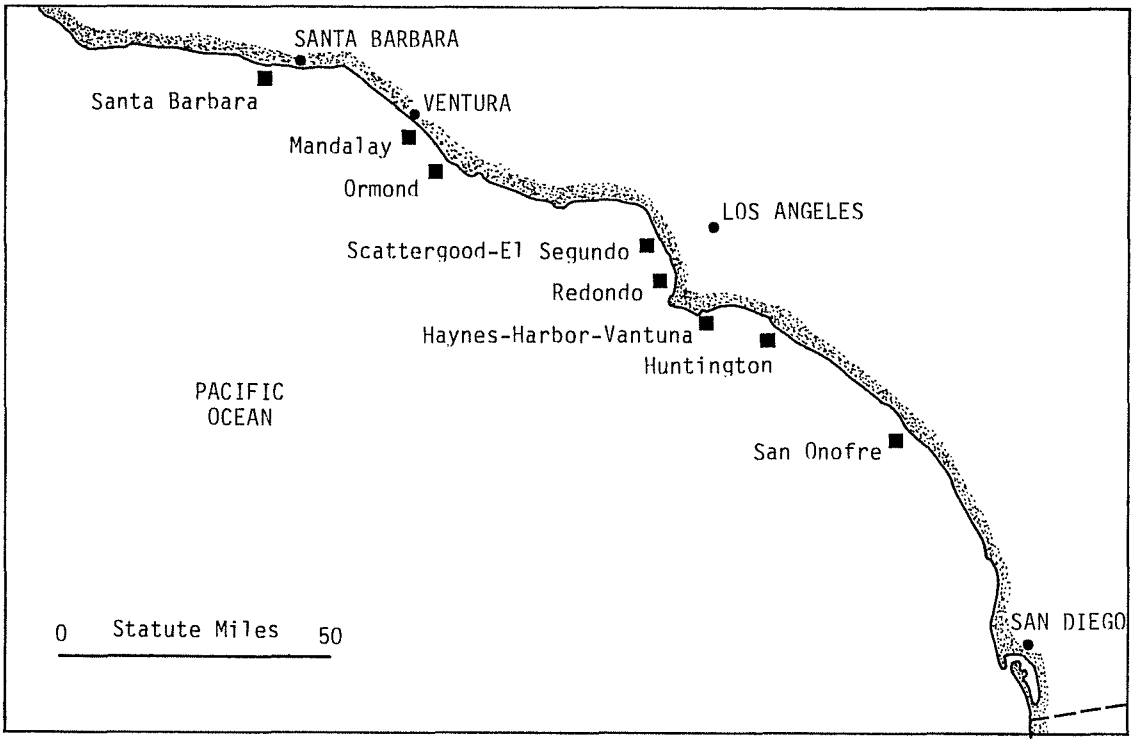

Figure 1.--Sampling locations within the Southern California Bight for data collected from 1978 to 1980.

site not situated near a power generating station) over a three-year period. We used PCA followed by cluster analysis to identify patterns in community structure based on the 32 fish taxa sampled. In this way groups or clusters of similar communities were isolated and identified.

We chose PCA methodology because the acquisition of aquatic habitat inventory information is seldom designed to answer experimentally-oriented questions but rather to gain basic information on distribution and abundance patterns or population dynamics of certain taxa of interest. In many cases (at least where multi-species assemblages of fishes in the nearshore marine habitat are studied) information on physical parameters of the habitat are lacking; or alternatively, the causal stimuli (in terms of physical-chemical processes) for an observable pattern (response) are perhaps unknown. At best, many of the variables measured for the purpose of evaluating cause and effect relationships are often highly correlated, resulting in apparent relationships which may be misleading or even meaningless. Thus, the investigator finds that a large site species data matrix exists which may be of little or no use regarding large scale (geographic) comparisons among faunal assemblages within a similar habitat, because of the lack of an interpretive technique.

Traditionally, data matrices of this type are partitioned into pairwise comparisons for use in rank correlation significance tests (table 1) (Talbot et al. 1978) or tests on diversity indices. Although some information can be gained from these kinds of analyses, the null hypotheses on which the test is based may be incorrect, (Jumars 1980) casting the results and interpretations of the tests into serious doubt. Correlation coefficients are measures of the linear relationship between two variables, however, when taken individually the coefficients do not allow the investigator to determine what underlying physical and biological relationships caused any two particular variables to take on a particular coefficient. For each pair of taxa the influence of the underlying relationships may change. Intercorrelations result when the underlying relationships themselves are also correlated. Unless the investigator can evaluate all possible pairwise correlation coefficients simultaneously, the nature of the underlying relationships must remain unknown. Using PCA alleviates the intercorrelation problem, enables the investigator to make broad geographic comparisons among faunal assemblages, and provides a means of generating new hypotheses (fig. 2).

PCA is one of a family of factor analyses. The primary objective of PCA is to disclose independent patterns of variation in terms of variables which are independent (orthogonal) of one another (Frey and Pimentel 1978). Aside from reducing confounding intercorrelations, the orthogonal variables (i.e., principal components) are also fewer in number than the original data set and represent some underlying (hypothetical or non-observeable) factors responsible for the observed patterns.

Table 1.--A portion of the original 32 species correlation matrix. This information is used by the Principal Components Analysis.

	R. PRODUCTUS	M. UNDULATUS	P. NEBULIFER	U. RONCADOR	SYNGNATHUS	U. HALLERI
RHINOBATUS PRODUCTUS	1.00	0.89	0.77	0.73	0.75	0.86
MENTICIRRHUS UNDULATUS	0.89	1.00	0.81	0.86	0.85	0.78
PARALABRAX NEBULIFER	0.77	0.81	1.00	0.83	0.66	0.47
UMBRINA RONCADOR	0.73	0.86	0.83	1.00	0.55	0.48
SYNGNATHUS SP.	0.75	0.85	0.66	0.55	1.00	0.78
UROLOPHUS HALLERI	0.86	0.78	0.47	0.48	0.78	1.00

The PCA operates on the matrix of product-moment correlation coefficients among the independent variables (species) (table 1), and is a mathematical process which attempts to explain as much of the variability found in the original data with as few principal components as possible. As part of this process, each variable or taxon receives a weighting coefficient or loading for each principal component. These coefficients and principal components can be combined with the original data to form the component (or factor) scores. These scores are the estimates of an underlying relationship or factor inherent in the original data that was not sampled directly. Each site has a score for each component (table 2) and each taxon contributes to each of those scores (table 3). The factor scores represent estimates of what the investigator might have expected to observe had he been able to sample for the component directly. The cluster analysis operates on these component scores to create the clusters (fig. 3) of similar fish assemblages.

Each taxon or independent variable contributes to the component score at each site. The size of the contribution of each taxon depends on the data itself and the loading assigned to that taxon. These contributions are hard to calculate by hand, but, they can be programmed for the computer and are very useful to an investigator who needs to determine why a particular component score received the value it did. The investigator may then explore a community in terms of individual taxon contributions (table 3), thereby aiding in the determination of what underlying phenomena each component is actually measuring.

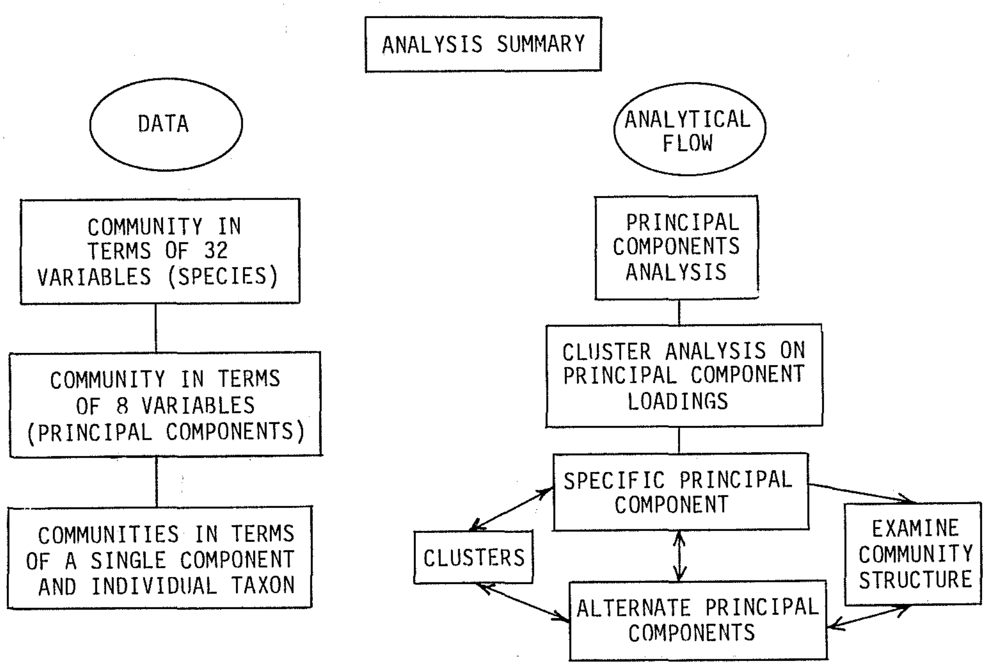

Figure 2.--Summary of the analytical processes involved in the reduction of the data from the population information of 32 species to fish assemblages.

Table 2.--The site component scores for the first principal component are the estimates of an underlying and potentially unsampled relationship between sites and species.

LOCATION		COMPONENT 1
A	SONGS 1980	18.018
C	SONGS 1978	13.529
B	SONGS 1979	10.476
E	SCATTERGOOD-EL SEGUNDO	3.530
F	HAYNES	0.009
D	HUNTINGTON	- 1.471
M	SCATTERGOOD 1980	- 2.378
I	MANDALAY	- 2.878
H	ORMOND	- 5.891
G	VANTUNA	- 6.338
J	REDONDO	- 7.253
K	LA HARBOR	- 8.478
L	SANTA BARBARA	-10.875

Because of our interest in the similarity or dissimilarity of fish communities among sites within a defined habitat, we performed a cluster analysis on the component scores resolved by PCA. The cluster analysis is designed to help identify clusters of observations that have similar attributes. For this application this analysis grouped sites on the basis of dissimilarities associated with the principal components generated in the PCA. The technique, which is based on an algorithm outlined by Johnson (1976), begins by forming one cluster for each site. The two closest clusters are combined into one cluster, then the two closest of the new set of clusters are combined into a single cluster, and so on (Goodnight et al. 1979). Using the component scores in the clustering program reduces the intercorrelation problem thereby providing a more biologically meaningful grouping of sites (clusters). This particular approach of clustering on the principal components is not unique (Bartko et al. 1971), however its application to fishery studies has been quite limited.

Table 3.--Species contributions to the component score for SONGS 1980 (18.0175) shown in Table 2. Each site component score is the sum of the contributions of each of the taxa. Each contribution is a function of the abundance of that taxon and its loading.

TAXA	CONTRIBUTION COMPONENT 1
RHINOBATUS PRODUCTUS	2.2804
MENTICIRRHUS UNDULATUS	2.1651
PARALABRAX NEBULIFER	2.0559
UMBRINA RONCADOR	1.7309
SYNGNATHUS SP.	1.2223
UROLOPHUS HALLERI	1.2183
SERIPHUS POLITUS	.9639
ANCHOA COMPRESSA	.9226
PARALICHTHYS CALIFORNICUS	.8470
PEPRILUS SIMILLIMUS	.7708
(OTHERS) [1]	(3.8403)
	18.0175

[1]The remaining taxa were combined into this category.

In this application, the cluster analysis is to the PCA what a multiple range test is to Analysis of Variance (ANOVA). The cluster analysis in this example groups power plant sites with similar fish communities together (fig. 3).

The cluster diagram (fig. 3) and site cluster plots (fig. 4) provide graphical displays of the relationships of sites to one another and of sites relative to their principal components. The number of clusters decreases as the similarity decreases (fig. 3). Often it is useful to examine the cluster diagram for various levels of similarity. The number of clusters examined in detail and plotted as in figure 4 is fairly arbitrary and depends to a large extent on the application. Everitt (1980) gives some useful guidelines for this determination.

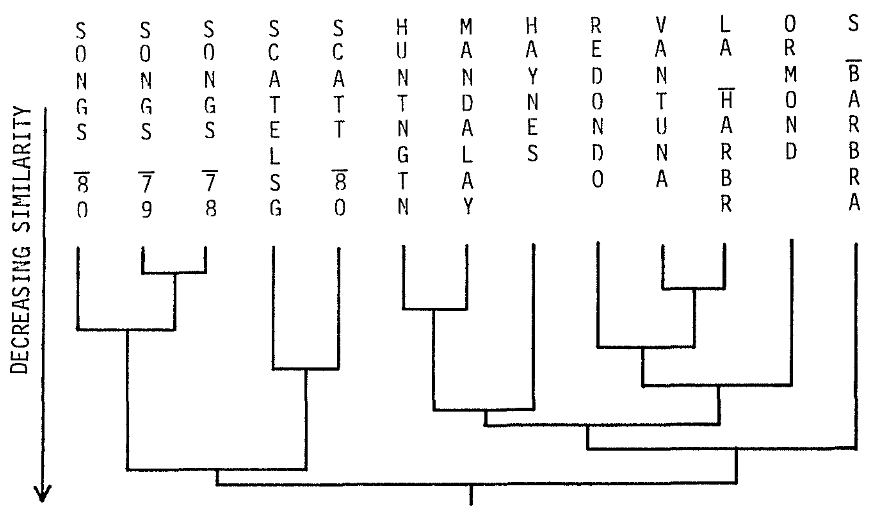

Figure 3.--Dendogram of site similarities based on a cluster analysis performed on the orthogonal component scores resolved by the Principal Component Analysis.

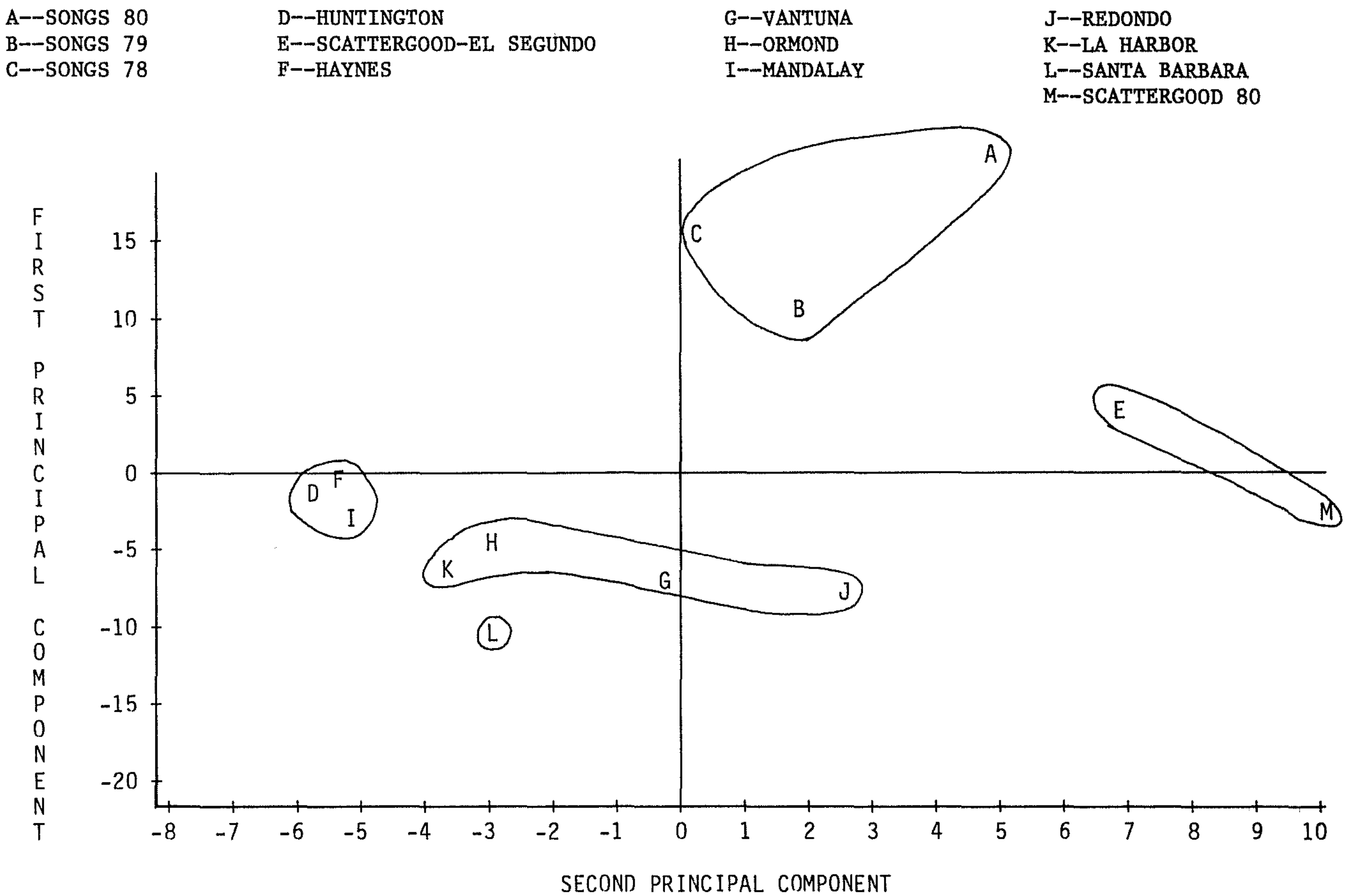

Figure 4.--Site cluster groupings based on the cluster analysis and plotted against the first and second principal component scores.

The principal components themselves often provide the investigator with a great deal of information concerning the variables or taxa which influence the formation of site clusters. Each principal component accounts for a portion of the variability within the entire data set, and represents an underlying factor inherent in the data (i.e., abundance of each fish taxon). The relationship between the underlying factor and the fish taxa is often very valuable to the investigator. Determining the nature of this relationship is not always possible; insights can often be gained, however, by considering the contributions of the individual taxon.

The overall influence or loadings of a particular taxon or variable can be graphically represented as in figure 5. Plots of various combinations of components allow the investigator to determine which taxa tend to have the greater weight or influence. Taxa with larger loadings (influence) occur furthest from the origin of the principal component axes. These loadings are used as coefficients in the calculation of the contributions. Often taxa which have low (close to zero) influence or weight in all components are eliminated and the analysis rerun without them.

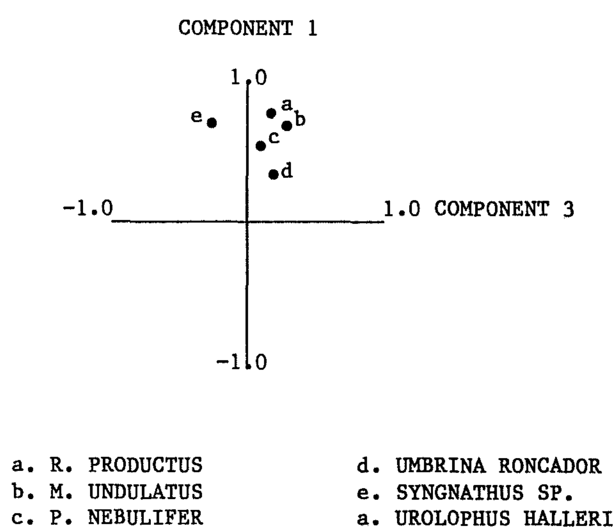

Figure 5.--A portion of the plot of the taxa weighting coefficients (loadings) for the first and third principal components. Taxa with larger coefficients usually have large contributions to the component score (table 3).

RESULTS AND SUMMARY

The objective of this study was to provide a method, via PCA, for determining whether fish assemblages from several southern California sites were similar in regard to species composition and abundances and to identify the underlying reasons for the similarity. This section presents the steps an investigator would take to explore the results of the PCA and cluster analysis.

PCA and cluster analysis generate an overwhelming number of pages of output. This large amount of information can be most easily organized and interpreted by starting with the cluster diagram and then working backwards through the PCA itself. These steps are outlined below and in figure 2.

The cluster map contains not only the most concise summary of the data, but also serves as the starting point for the investigator's exploration into the relationships hidden within the data. This diagram indicates which fish assemblages are similar or dissimilar to each other. For convenience, each of these assemblages has been labeled by the power generating station closest to it. The cluster map for this example figure 3 indicates, for example, that SONGS (1978) and SONGS (1979) are quite similar while Santa Barbara has a much lower degree of similarity.

Another graphical representation of these clusters of similar generating stations can be made by plotting the principal component scores of each fish assemblage for the first two or three components (fig. 4). This gives a multidimensional view of the clusters and puts them in perspective to one another. The principal component scores determine the site locations on each principal component axis while the cluster analysis determines site similarities.

The component scores for sites on the first principal component are shown in table 2. These scores are the values we might have expected to observe if the sampling effort had been directed at the phenomena explained by this component. Usually the investigator will want to determine why a particular site score takes on the value it does. For this example SONGS (1980) was selected. Its score of 18.018 is the sum of the contributions of the various taxa (table 3) sampled at SONGS in 1980. Examination of these contributions allows the investigator to determine which species have the largest influence in the component scores for a particular site.

The contributions of each species to the various component scores is determined in part by the loading coefficient. Most computer programs print either the coefficients or a plot of them (fig. 5). Those taxa with low coefficients usually will tend to have less influence overall than those with larger coefficients. It is possible though, for a species with small coefficients to have a large contribution if it is very abundant.

Although it is often useful to determine what underlying function a given component is estimating, this is not always possible. However, by examining the component loadings (table 2), the contributions by the various species (table 3) and the coefficients (fig. 5), an interpretation can usually be found. This is especially true for the first two or three components. The number of interpretable components is often a function of the number of observations and the number of taxa involved.

The application of PCA to this type of analysis is not without problems (Green 1979). The PCA utilizes euclidean distances; therefore species which are quite important to the community, in terms of relative abundance, may not be singled out and indeed may receive quite low loadings (Sprules 1981). This technique does not necessarily determine the taxa which are dominant or even which have the most influence in a community. Rather the technique minimizes variability by keying on taxa which are the most variable among sites. Because they show no trend in abundance among sites, ubiquitous species often receive low loading coefficients.

Interpretation of the components themselves may be made more difficult by low sample size (Barcikowski, in press), by nonlinear relationships between some of the independent variables, or by correlations among the underlying factors themselves. The analysis will however point out species which do contribute to the scores for each component. These species can be considered important when clustering sites and when determining similarities in fish asemblages.

The Principal Components Analysis followed by a clustering technique has been shown to be an effective tool in the process of discriminating between fish assemblages. The techniques outlined in this paper allow the investigator to determine not only similarities between sampling locations but also which species have the most influence in determining those similarities.

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POSTER SESSION

Gregg Tichacek, Illinois Department of Conservation, Springfield, Illinois.
Illinois Comprehensive Stream Inventory Project.

James M. Omernik, Robert M. Hughes and Mostafa A. Shirazi, EPA, Corvallis, Oregon.
An Approach for Differentiation of Regionalized Patterns in Aquatic Ecosystems.

Gareth A. Goodchild, Ontario, Canada.
Ontario's Lake Survey Program.

Jack C. Mellor, U.S. Bureau of Land Management, Fairbanks, Alaska.
Remote Sensing Methods for Regional Inventory of Alaskan Arctic Lakes.