SCIENTISTS' REPORT

NATIONAL SYMPOSIUM ON WETLANDS
Lake Buena Vista, Florida
November 6 to 9, 1978

Submitted to:
The U.S. Water Resources Council and U.S. Army Corps of Engineers; Environmental Protection Agency; Federal Insurance Administration; U.S. Fish and Wildlife Service; U.S. Geological Survey; National Marine Fisheries Service, NOAA; Office of Coastal Zone Management, NOAA; U.S. Soil Conservation Service.

By the
National Wetlands Technical Council

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Edited by

John Clark

and

Judith Clark

Submitted to

U.S. Water Resources Council

and

U.S. Army Corps of Engineers
Environmental Protection Agency
Federal Insurance Administration
U.S. Fish and Wildlife Service
U.S. Geological Survey
National Marine Fisheries Service, NOAA
Office of Coastal Zone Management, NOAA
U.S. Soil Conservation Service

by

National Wetlands Technical Council

Washington, D.C.
April 12, 1979

NATIONAL WETLANDS TECHNICAL COUNCIL

The National Wetlands Technical Council was formed in April, 1977, to provide a forum of prominent experts to represent wetlands science at the national level in advising federal institutions on technical aspects of wetlands policy and on research priorities. Staff and administrative support for the Council is provided by The Conservation Foundation in Washington, D.C. Council members are:

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U.S. Soil Conservation Service

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Virginia Carter, U.S. Geological Survey
Robert H. Kadlec, University of Michigan
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Milton W. Weller, University of Minnesota
William A. Niering, Connecticut College

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Finally, we wish to thank John Clark and Judith Clark for their splendid job in editing this report.

Joseph S. Larson
Executive Chairman

COVER: The montage drawing is from Alan Carroll's "Developer's Handbook" (State of Connecticut, Department of Environmental Protection).

OVERVIEW

This report describes the status of scientific knowledge about the functions and values of the nation's wetlands in 1978 resulting from a structured "dialog" between Federal agency representatives and wetlands scientists. The content is a record of a workshop held at Lake Buena Vista, Florida, on November 10, 1978, the day following the National Symposium on Wetlands.

At the workshop scientists met in six concurrent panels to address the wetlands information needs of the Federal sponsoring agencies as indicated in questions submitted by the agencies two months in advance of the Symposium and circulated to scientists participating in the Symposium. The process was a mutual learning experience. On the one hand, the scientists learned what kinds of information gaps are most critical to management agencies and how the agencies think about information problems. On the other hand, the agencies learned something about the present state of scientific knowledge about wetlands. The participating scientists were able to provide in depth answers to only a small proportion of the 233 questions, partly because of time limitations. However, all questions were reviewed and some response was provided by the panels for most of them. Based upon this experience science will be able to more effectively plan research to meet federal management needs as they exist in the field.

The question responses can be categorized in three general groups: (1) questions to which detailed answers were possible (numerical answers were possible for but a few of them); (2) questions which could not be answered in detail but for which broad guidance was given and, often, the state of knowledge considered; and (3) questions which could not be answered at all for one reason or another. Questions submitted that were not directly relevant to wetland values and functions were not considered.

The six panels that gathered to consider the agency questions were for the most part the same scientists who wrote the papers and formed the discussion panels for the Symposium. To an extent their papers responded to the agencies' needs because they had received the list of questions while preparing their papers some two and a half months before the Symposium (questions deemed relevant to their panels were specifically identified). Also the authors all had the opportunity to revise their papers in light of the panel discussions at the followup workshop. In this way, the Symposium papers themselves respond to the agencies' questions. Therefore, these papers to be published as the Proceedings of the Symposium will address the subjects of the questions in additional detail.

From analysis of the questions we can discern general categories of agency concern and some specific high priority needs for scientific information. While it was not possible to treat the responses to all 233 questions in a brief summary, the comments below give some of the highlights.

Field Techniques: There is apparently a strong need for "quick-and-dirty" methods of field evaluation to be used in permit review activities. This indicates a priority need for research and development of simple field evaluation methods that can be used by field agents of the regulatory agencies. The following were among the specific needs for simple techniques: (1) primary productivity potential, (2) carrying capacity potential, (3) plant and/or spoil indicators of pollution effects (i.e., overload thresholds)

Boundaries: Many questions were concerned with practicable means for determining boundaries, indicating another high priority management research subject. Where does the wetland end? For management purposes, can an upper boundary be determined vegetatively? by soils? by seasonal surface water? by ground water? How is the lower (often submerged) boundary defined? Can these factors be used to delineate transition areas or buffer areas? It seems that even the concepts necessary for delimiting wetlands are vague. What ecological functions are the agencies trying to optimize when they set the boundaries? How far should we go in this?

Physical Factors: Because the visual attributes are those of most relevance for site visits in the field, there were many questions about physical factors. On this high priority item, much could be accomplished by development of methods for analysis and interpretation of present data, although much more basic research must be added for the long term. Is there a minimum size below which wetlands are not worth saving? How do different regional types of wetlands compare in value? How long do artificially constructed wetlands have to mature to provide "full" value? Are certain parts of wetlands more important than others (for nurseries, wildlife habitat, pollution uptake, etc.)? How do component wetland units act to multiply the values of a larger wetland system?

Processes: There is much interest in gaining a better understanding of wetland natural processes that indicates a need for more research, both interpretative and basic. The mode and rate of biochemical cycling of nutrients was one such subject. Another was the water regime and the effects of such variables as: various water levels and durations; flow-through rates; periods of drought and flood; and of different soil types, slopes, plants, and configurations. A third priority subject was water quality relationships, particularly uptake rates for heavy metals and dissolved organics as modified by types of plants and soils.

Wildlife: Many concerns were related to wildlife. Which species have an absolute dependence upon wetlands, that is, are largely obligate users for breeding, resting, or feeding? What dependence do various facultative terrestrial species have on wetlands? What factors are involved in governing carrying capacity for various species?

INTRODUCTION

The National Symposium on Wetlands was sponsored by the U.S. Water Resources Council and eight other Federal agencies. It was organized by the National Wetlands Technical Council and the American Water Resources Association in cooperation with The Conservation Foundation and the Environmental Law Institute. It was held in conjunction with the Fourteenth Annual Water Resources Conference of the American Water Resources Association.

The Symposium was the core of a project designed to assist Federal agencies in evaluating current knowledge about wetlands and improving the regulation of land and water uses that affect wetlands. A particular purpose of the Symposium was to provide a forum for scientists to review the state of knowledge on values of wetlands, both inland and coastal, in the United States and to consider research needs to provide better information for use by regulatory agencies in managing wetlands. This report which discusses results of the Workshop is one product of the Symposium. The major product is the proceedings, a collection of 50 individual papers presented at the Symposium (November 6-9, 1978) which will be published by the American Water Resources Association.*

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* The full proceedings of the Symposium is being published by the American Water Resources Association. Copies of the Proceedings will be available from the Association at the following address:

American Water Resources Association
St. Anthony Falls Hydraulic Laboratory
Mississippi River at Third Avenue, S.E.
Minneapolis, MN 55414

A campaign of advance preparation for scientists and agency representatives preceded the Symposium and a retrospective evaluation Workshop of scientists followed it. In order to focus the Symposium on the information needs of regulatory agencies, the National Wetlands Technical Council staff held two organizing meetings with the sponsoring Federal agencies and arranged for them to submit written lists of questions on wetlands values which the agencies considered relevant to their operations. Council staff seaparated the 233 questions that came forth into several subject areas, corresponding to the different panels around which the symposium was structured. Subject areas were: (1) wetlands-based food chains, (2) habitat values of wetlands, (3) hydrologic and hydraulic values of wetlands, (4) water quality maintenance values of wetlands, (5) harvest values of wetlands, and (6) heritage values of wetlands (the latter two were later combined into a single list). The list of questions appropriate to each panel was mailed to each member of that panel two and a half months in advance of the Symposium for use in preparing his or her symposium paper.

The National Symposium on Wetlands was structured to culminate in the Workshops where the scientists would attempt to reach general agreement on the state of knowledge of wetlands values. Preparations were extensive and were structured according to the "Coordinate System" of management information transfer developed by the Conservation Foundation. The Workshops included 56 scientists, organized into six working panels that met on November 10th to discuss the agency questions and to prepare responses. By having the questions in advance, the scientists could prepare themselves for dialog at the follow-up workshop and could ensure that their Symposium papers were relevant to the agencies' needs for information.

Workshop sessions organized according to the Coordinate System are an efficient way to bring a wide spectrum of technical talent to bear upon technical information needs of managers. The success of the workshop approach is conditioned upon a number of operating requirements. The following are among the most important of these: (1) the technical experts must have demonstrated experience in their fields of expertise; (2) they must review literature in the area prior to the workshop and have reported in writing on their findings and tentative conclusions; (3) they must be prepared for decision sessions by receiving, in advance, complete instructions, background materials, and drafts of colleagues' reports; (4) as a team, they must represent a spectrum of disciplines and personal and professional advocacies; and (5) the method of consensusing must simulate the scientific/academic milieu as closely as possible.

The Council spent ten months organizing for the Symposium and Workshop, contacting the participants frequently by mail, by telephone, and in person. The Council sent them detailed subject lists and region/subject coverage matrices after the preliminary papers were received. The following instructions were sent in August:

> The purpose of the Symposium is to provide for assessment and consensus on: (1) state-of-the-art knowledge of wetlands values, and (2) critical needs for research. ...Our goal is to cover all values, of all wetland types in all regions of the U.S. We want to come as close to achieving this goal as possible. It will be difficult. Most difficult will be the request for you to extend beyond your own research area and consider the subject in a broadened perspective and from a national (or in some instances, regional) point of view.
>
> We realize that the four-day period of involvement in November is a heavy drain on your time. However, we feel it is the minimum needed for effective accomplishment. We, in wetlands science, bear a strong responsibility to our federal sponsors to guide the nation's wetlands management and research policies and programs. Also, this will be a landmark experience in wetlands science from which you should personally benefit in many ways.

Since the agencies are expecting practical results, we begin the Symposium on Tuesday, November 7, with a day of discussion on wetlands evaluation, regulation, and orientation. We then run through a series of comprehensive review papers on the second day (Wednesday) to create a pattern for our detailed panel discussions on the next day (Thursday). Finally, we have set up Friday for private panel workshops (the six panels meet separately) wherein we can argue points as needed to reach agreement where possible. For the Friday workshop it would be most helpful if you could bring key items of literature, data, bibliographies. and so forth.

Because all of our earlier sessions are in the company of audiences of varying size and because most of the time will be spent on presentation, there will be virtually no opportunity for thoughtful intra-panel discussions to resolve differences of opinion on important issues that surface during the presentations. We must have (the Friday) discussions in order to present a consensus state-of-the-art and research priority report to the Water Resources Council and the other eight federal agencies supporting the Symposium.

The method of dealing with the 233 agency questions was to allocate each to one of the six panels of experts. Like questions were combined to facilitate the task. The chairman of each panel then led the group through the list assigned to that panel. Some panels disaggregated at a mid-point so that individuals could write up detailed answers once the sense of the group was clear. A draft of the completed work was then consolidated by the Council staff, edited, and circulated to all participants for review and correction (see Table 1 for a list of participants).

The system worked as well as could be expected under the circumstances and the pressures created by shortness of time. The surprisingly good results from so short a session suggests that a future concerted effort to bring scientists together for extensive structured dialog could produce results of great value to Federal agencies from the existing fund of wetlands knowledge.

The National Wetlands Technical Council believes that: the Federal agencies should sponsor a continuing process for review and reporting on scientific knowledge on wetlands functions, values, and conservation. (See Appendix for details.)

TABLE I. Participants in Wetlands Symposium Workshops

Food Chains Panel

Robert J. Livingston (Convenor), Florida State University
John H. Crow, Rutgers University
Armando de la Cruz, Mississippi State University
Rezneat M. Darnell, Texas A&M University
Robert Friedman, University of Wisconsin
Calvin DeWitt, University of Wisconsin
Curtis J. Richardson, Duke University
Eville Gorham, University of Minnesota
Ariel Lugo, Council on Environmental Quality
Robert W. Holmes, University of California-Santa Barbara
James Gosselink, Louisiana State University
Daniel E. Willard, Indiana University

Pete Kirby, Recorder

Habitat Panel

Milton W. Weller (Convenor), University of Minnesota
Leigh H. Fredrickson, University of Missouri
William E. Odum, University of Virginia
Gordon Thayer, Beaufort Marine Lab, NMFS
Robert D. Ohmart, Arizona State University
Frank Schitoskey, S.Dakota State University
Lester Flake, S. Dakota State University
Donald E. Kroodsma, Rockefeller University
Donald L. Tilton, University of Michigan
Judith Clark, NWTC
Theodore R. Merrell, Jr., NMFS-Alaska

Kristin Johnson, Recorder

Heritage Panel

William A. Niering (Convenor), Connecticut College
Peter A. Fritzell, Lawrence University
Richard Smardon, University of California-Berkeley
James H. Zimmerman, University of Wisconsin
Robert J. Reimold, Georgia Dept. of Nat. Resources
Michael Hardisky, Georgia Dept. of Nat. Resources
Eugene Jaworski, Eastern Michigan University
Patrick T. Gannon, Sr., NOAA
Joseph S. Larson, University of Massachusetts

Cindy Van Duyne, Recorder

Table I - Continued

Hydrology Panel

Virginia Carter (Convenor) U.S. Geological Survey
Richard P. Novitzki, U.S. Geological Survey
Arthur F. Doyle, Corps of Engineers
Richard F. Dworsky, New England River Basins Comm.
Hollis H. Allen, Corps of Engineers
Elon S. Verry, U.S. Forest Service
M.S. Bedinger, U.S. Geological Survey
John M. Hill, Louisiana State University
William O. Wilen, U.S. Fish & Wildlife Service
Michael Deuver, National Audubon Society

Dinesh Sharma, Recorder

Water Quality Panel

Robert H. Kadlec (Convener), University of Michigan
Ivan Valiela, Woods Hole Marine Laboratory
Bill Wilcox, Environmental Quality Labs., Port Charlotte, FL.
Steve Graham, University of Florida
Dennis Whigham, Chesapeake Bay Center for Env. Studies
Arnold van der Valk, Iowa State University
John D. Lunz, Corps of Engineers
John Cairns, Jr. Virginia Polytechnic Institute

Kevin Erwin, Recorder

Harvest Panel

A. William Palmisano (Convenor), U.S. Fish & Wildlife Service
J. Henry Sather, Western Illinois University
Theodore R. Rice, Beaufort Marine Lab. NMFS
Rouse S. Farnham, University of Minnesota
Robert Johnson, U.S. Forest Service
Raymond I. Dideriksen, Soil Conservation Service

Jeffrey A. Zinn, Recorder

1. FOOD CHAIN VALUES

Panel Convenor: Dr. Robert J. Livingston

In wetlands, as in all ecosystems, plants convert solar energy to chemical energy, producing organic material as plant tissue. Some of the tissue is consumed by herbivores as it grows and some is consumed after it dies and decays and becomes "detritus." The energy trapped by plants may thus be passed on to either herbivore-based or detrital food chains. Wetlands--part water and part land--may have either type of food chain in an aquatic or terrestrial version. The food chain value of a wetland depends partly on how effective it is in trapping energy and passing it on to these food chains and partly on how effective the wetland is in "biogeochemical cycling"--tapping reservoirs of elements available in the biosphere and making those elements available to the biota. Because nutrients, such as nitrate, can be exported from many wetlands via water outflow, a wetland can contribute to food chains downstream as well as within the wetland.

The subject of food chain values is complex, involving a large number of biological and physical processes. Some of the issues addressed in the questions and answers below are: the relative productivity of different types of wetlands; the amount of primary production available to terrestrial vs. aquatic, and to herbivore-based vs. detrital, food chains; the amount of primary production exported from the wetland as detritus; the amount that supports specific animal species or groups (e.g., oysters, commercial fish); the factors controlling wetland productivity; the importance of water regime to food chain values; the importance of the "successional stage" of wetland plant communities to food chain value; the dependence of wetland productivity on imported nutrients or organic material; and the role of wetlands in cycling elements essential to life.

Summary

Terms such as "productivity" and "production", which are used in several disciplines, have specific meanings in the context of food chain values. To clarify the usage of such terms here, a few definitions are given below:

production: the quantity of organic material produced (may be expressed as g/m^2, lb/acre, etc.).

productivity: the rate of organic production per unit of time (may be expressed as the amount (usually weight or mass) produced per hour, day, year, etc., e.g., $g/m^2/yr.$).

primary production: the quantity of plant material produced through photosynthesis.

secondary production: the quantity of organic material produced by organisms that do not photosynthesize. Includes production of all animals as well as most bacteria and fungi.

habitat: the environment within which an organism lives.

habitat type: one of the major recognizable environmental types, such as marsh, mudflat, submerged grass bed, etc.

Productivity, energy flow, and food webs of wetland systems have all received considerable study, but the subject of food chain values is a complicated one requiring further research. Measurements of primary productivity, taken by themselves, are not indicators of wetland health nor do they adequately represent food chain values. Both the quality and the quantity of organic production are important; in many cases the quality of energy stored by photosynthesis is high though the rate of energy storage (productivity) is low. Food chain value depends not only on the amount and type of organic material produced by wetland plants, but also on the availability of this plant material to detrital and herbivore-based food webs. Thus Alaskan coastal wetlands, whose primary productivity appears to be relatively low, may have relatively high food chain value to estuarine and marine fish because they export proportionately large amounts of palatable organic material to nearby waters.

Nevertheless, most of the existing data on food chain values consists of measurements of primary productivity, particularly phytoplankton productivity and the productivity of the above-ground portions of macrophyte vegetation. Saltwater wetlands along the Atlantic and Gulf coasts have been studied most extensively; little work has been done on wetlands along the Pacific Coast. Studies on two estuaries in southern California have found marsh productivity on a per-unit-area basis to be lower there than in Atlantic and Gulf coast systems, but the food value of the largely succulent flora of the California marshes is also different from the food value of East and Gulf coast marsh plants. Productivity work on freshwater wetlands is scattered.

Secondary productivity, the rate of organic matter production by all non-photosynthetic organisms, covers such a wide variety of organisms that it is extremely difficult to measure. Some studies of invertebrate productivity, fish recruitment, and waterfowl productivity of wetlands exist, but there is virtually nothing on total secondary productivity and few studies quantitatively linking wetland primary productivity to secondary productivity. Quantitative research on the importance of wetlands to the productivity of such animals as shrimp and crabs is badly needed. Qualitative research in the Great Lakes area and along the Atlantic, Gulf, and north Pacific coasts has already established the critical importance of shoreline wetlands to fish and shellfish populations in associated waters. Southern California wetlands seem to be less important than other coastal wetlands in maintaining marine fish populations.

On the food chain value of various habitat types within wetlands (e.g., mudflats, submerged grassbeds, emergent marsh vegetation) there is an abundance of site-specific data on primary productivity (particularly for coastal wetlands) but little on the relative contributions of these wetland subsystems to overall wetland productivity, or on their relative importance to the support of animal populations. These questions are under study now on both the East and West coasts. Broad systems studies are needed on inland wetlands and on a wider variety of coastal wetlands.

Wetland productivity depends heavily on inputs of organic matter and nutrients; wetland systems in turn export organic matter and nutrients. Most wetlands seem to act as nutrient traps, at least during the growing season, but annual or longer-term nutrient budgets are lacking for many wetland systems. Over long periods of time large amounts of organic matter and nutrients accumulate in the peat and woody biomass of certain wetlands. Rapid release of these stored materials through human activities (e.g., ditching or dredging peatlands) can upset regional biochemical cycles and have disastrous effects on downstream or estuarine areas. The relative contributions of organic matter and nutrients by various interior wetland types to downstream systems are not known. This is a priority area for future research, focusing on the import-export concept.

Hydrologic factors (timing and duration of flooding, speed of water flow) are the main determinants of wetland structure and function, including the chemical and physical conditions of the soils, the vigor of plants, and net primary productivity. Changes in water regime have immediate and usually adverse effects on wetland productivity. Artificial stabilization of the water regime tends to reduce habitat, and thus species, diversity, and to hasten the loss of the wetland through succession to terrestrial climax.

Wetland systems are subject to cyclical change--for example, flooding and drydown occurring annually or every few years. Not only do productivity and food chain values change with these cycles, but the maintenance of these values over the long term seems to depend on the maintenance of such periodic pulsing. It is especially important, therefore, that future research on productivity and food chain values of wetlands include long-term studies.

Question: Is measurement of primary productivity a valid indicator of health?

"Health" refers to the optimum functioning of the wetland system as a whole (1), or to the "normal" state of the wetland, as determined by climate, soil parent material, and topography, in the absence of human disturbance. In their normal state, some wetlands (e.g., *Sphagnum* bogs) are unproductive, others (e.g., cattail marshes) highly productive. Moreover, in some cases, plants which are usually quite productive (e.g., *Phragmites*) may maintain dominance at low productivity. For example, in marginal fens around pine bogs in Finland and Scandinavia, *Phragmites* maintains itself in a sterile and unproductive phase against competitors which might seem more adapted to the infertile nature of the site. Presumably the dense mat of reed roots and rhizomes prevents establishment of other species, even though the site has gradually become infertile and unsuitable for seed colonization by *Phragmites*.

Asking whether primary productivity is a valid indicator of wetland health is thus like asking if increase in weight is a valid indicator of human health. The answer is that primary productivity is one of a series of indicators which could be used, but it should, in any case, be applied with some judgment, and certainly not used to compare the health of dissimilar wetlands. Species composition is another indication. Species diversity is yet another. In general, one should beware of using only a single indicator of the condition of a complex system.

Indicators of Wetland Value

Question: What are some indicators that can be used to assess (by field observation, not detailed research) the general level of productivity of a particular salt marsh or freshwater wetland, as well as its contribution to aquatic and terrestrial ecosystems?

Only a partial answer can be given. In general, to assess the productivity of a wetland and its contribution to aquatic ecosystems, one should consider the productivity of the dominant macrophyte and the hydrologic character of the area (2). In marshes dominated by a single species or a few similar species of reeds, sedges, or grasses (e.g., cattail stands, sedge meadows, Phragmites stands), the general level of standing crop, with which primary productivity is correlated, can be roughly estimated by multiplying mean shoot height by mean shoot density.

Productivity Values of Specific Wetlands

Questions: What are some specific productivity values applicable to wetlands in the Pacific Northwest? To what extent can productivity data from Atlantic and Gulf Coast marshes be applied to Pacific Coast marshes? Are Pacific Coast estuarine salt marshes as important (on a per-unit-area basis) in their contribution to estuarine ecosystem integrity and animal production as Gulf and Atlantic Coast marshes seem to be?

Geographic, climatic, hydrologic and other factors greatly affect the character and functions of wetlands. As a result, the transference of characteristics (values) of one wetland watershed to another must be done cautiously, giving due consideration to environmental and ecological differences. To establish the limits of commonality in wetland characteristics and processes, additional research is needed in wetlands in representative areas characterized by diverse climatic and hydrologic regimes.

At present the data base is inadequate to generate a list of productivity values applicable to Pacific Northwest wetlands. It is likely that significant differences in value exist among the wetlands in this region. Wetlands in California, Oregon, Washington, and Alaska certainly differ from those in southern California and probably differ among themselves with respect to the quantity and quality of organic matter production. Data presently available from two southern California wetlands, Mugu Lagoon and Tijuana Estuary, reveal lower marsh primary productivity per unit area than that found in East Coast marshes at similar latitudes; however the quality of organic matter is of extreme importance in wetland food chains, and the mixed succulent flora of these two wetlands may have quite a different food value from the *Spartina*-dominated flora of the East Coast marshes. There is some doubt that the Tijuana and Mugu productivity values will prove to be typical for southern California coastal salt marshes since many of these are located in lagoons which differ from Tijuana and Mugu in that they lack water exchange with the adjacent ocean for most of the year.

Colorado Lagoon, Mugu Lagoon, and Elkhorn Slough do not seem to serve as important nursery areas for coastal finfish of commercial or recreational value. To the north the situation is probably different. Estuarine salt marshes along the Alaska Pacific coast appear to be critical or very important to the production of many animal species, providing spawning grounds for fish, nursery areas for an assortment of larval stages, and food for a host of adults--waterfowl, fish, bivalves, crustaceans, and other animals (3,4,5,6,7,8,9).

Productivity Values of Wetland Subsystems

Question: What type of inland wetland vegetation has the highest primary productivity?

Richardson (2) gives primary productivity data for a variety of freshwater wetland habitats. Cattail marshes receiving abundant nutrients by silting are highly productive; southern swamp forests may also be very productive. It should be noted, however, that high primary productivity does not necessarily indicate high food chain value, which depends not only on the quantity of plant material produced but on its food value and availablity to consumers.

Question: In freshwater marshes and swamps, what portion of primary productivity is contributed by algae?

In freshwater marshes and swamps, algae have small standing crops in comparison with those of macrophytes; however, algae produce much faster because of their smaller size. In addition, algae are immediately available as food for consumers. Much of the macrophyte production, on the other hand, is not available to be consumed until the macrophytes have died and decomposed, so that this year's production is not consumed until next year. Algae also tend to be consumed locally, whereas macrophyte production may be buried (becoming unavailable) or transported some distance downstream from the wetland where it originated.

Question: What is the nutrient value of Phragmites australis (common reed), and what role does it play in the estuarine ecosystem?

De la Cruz (10) gives data on the nutrient content of *Phragmites communis*, but information on the complex ecologic role of this plant is not readily available.

Questions: What are the values of various types of intertidal substrates to the aquatic productivity of an estuary? How does an unvegetated intertidal area compare in productivity to vegetated wetland? What is the food chain value of a mudflat in relation to a marsh? Are the mudflat and the marsh parts of the same system?

All wetlands include a series of sub-habitat types, and each of these contributes its own processes to the balanced functioning of the overall system. Within the estuary, most of the primary production takes place in the marsh. A large share of the decomposition takes place on and in the mudflat. Different processes are emphasized in the two sub-habitats, and different species make use of them. Both are quite important. On an acre-for-acre basis, however, the marsh is most important, because of its higher rate of production and because it is used by species most important to society.

Questions: In Pacific Coast estuaries, what is the relative primary production, on an annual basis, of salt marshes, eelgrass beds, benthic algae, and phytoplankton? How important are each of these sources of organic material to the various estuarine food chains?

The productivity data base for California estuaries is meager, and it is extremely doubtful that the existing data can be generalized to estuaries which have not yet been studied. Even in those estuaries studied in some detail, such as Mugu Lagoon and Tijuana Estuary, the annual primary productivity of all wetland primary producers is not known, nor is there adequate information on the relative importance of these sources of organic matter to the various estuarine food chains.

In Mugu Lagoon and Tijuana Estuary, phytoplankton primary productivity is very low, epibenthic productivity (diatoms and other micro-algae) is intermediate, and low and middle marsh productivity is highest. Adequate measurements of macro-algae and eelgrass productivity in Mugu Lagoon have not been made yet.

For Alaskan salt marshes, there appear to be no published data pertaining to primary productivity except for Crow and Koppen (11). There are virtually no data on the relative contributions of various habitat types within an estuary. There are, however, several papers linking marshes and other habitat types to estuarine food chains (3,4,5,6,7,8, and 9). In addition, Crow and Koppen (11) present some evidence that considerable differences exist among plant communities as to their impact on estuarine food webs. Factors include net primary production, amount and rate of organic matter export to the estuary, and food value. For example, some habitats may have relatively low primary productivity values but readily export a significant share of what is produced.

Question: In estuarine ecosystems, what percent of primary productivity is contributed by salt marshes, seagrass beds, and mangroves, versus phytoplankton using detritus from floodplain wetland systems above the estuary?

This is a complex question and one in which the answer varies geographically. In south Florida, the mangrovces are clearly important. In Louisiana, the salt marshes are the important areas. In Georgia, it may be the open water areas.

Question: What are the quantitative contributions of Salicornia virginica

Spartina foliosa, freshwater marshes, freshwater swamps, and freshwater ponds to primary productivity in San Francisco Bay?

Some data on primary production in San Francisco Bay salt marshes are available, but the data have never been put together for the Bay as as a whole. It is unlikely that an adequate sythesis could be made with the existing data, since they show a high degree of geographic variability within the Bay.

Relationship between Primary and Secondary Productivity

Questions: For any given wetland, what is the relationship between primary production and secondary production? To what degree are measures of primary productivity reliable indicators of productivity at higher trophic levels? For each wetland type, how much net primary production is transported and available for aquatic secondary production?

The quantity, quality, and food chain value of primary production are often significantly different. High primary productivity may not be translated into high secondary productivity because of the accumulation of organic matter in place and/or the breakdown of organic matter. In the first case, very little matter may be exported to consumers; in the second case, considerable loss of organic matter is asssociated with the metabolism of each decomposer level. The consequent reduction in the amount of organic matter ultimately available to consumers may or may not be offset by the "upgrading" of organic matter (increase in nutritional value due, for example, to increased nitrogen or protein content) as it passes from one trophic level to another.

Some relatively low-productivity habitat types may readily export a major portion of their organic matter to consumers. This makes their "effective" production high in spite of low primary production.

Another factor to consider in evaluating the "effective" production of a wetland habitat is the inherent nutritional value and palatability of the plant material produced. Algae, graminoids, succulents, and woody plants differ in their value to both direct consumers and detrital food webs.

Factors such as net primary production, food value, and amount and rate of organic matter export may be quantitatively related to wetland community structure and the numbers of consumers and decomposers in wetland food webs.

Food Chain Connections between Systems

Questions: Since most wetlands are associated with moving-water systems (creeks, rivers, etc.), how do inflowing nutrients and the associated productivity relate to resident productivity, and how do both influence the outflow of nutrients and productivity? How do interior wetlands contribute to the estuarine food chain? What are the nutrient contributions of salt marshes and freshwater wetlands to estuaries or river systems? Are freshwater swamps often a significant source of detritus for estuaries?

The high primary productivity of some wetland ecosystems, when compared to upland systems, is the result of those wetlands being subsidized with inputs of water, energy, and nutrients from the adjacent watershed, and their dominant plants being adapted to such conditions.

The productivity and, in turn, nutrient dynamics of these systems change naturally with fluctuations in input levels and disturbances in the systems themselves. Changes in material storage are related to increases and decreases in the net primary productivity of the dominant species and in decomposition rates.

In small headwater streams, aquatic production depends upon both instream and floodplain production. In larger streams which annually overflow their banks, the floodplain is also important for stream production. Leaves of floodplain vegetation decompose and are used by inhabitants of pools and riffles. The contribution that floodplain and upstream systems make to downstream production depends greatly on local flow rates, flooding, and other factors. Quantitative information is not available.

Streams draining the uplands bring to estuaries organic and inorganic nutrients in both dissolved and particulate form (see reference 12). Most of this material precipitates and remains within the estuary for a long period of time (generally, years). No one has ever attempted to partition the incoming nutrients on the basis of their upstream sources. In any event, the contributions made by different sources vary quantitatively in relation to local and upstream conditions as well as in relation to hydrographic conditions.

Questions: How much primary and secondary productivity is used in situ within a wetland system, and how much is available for export? How can the nutrient/energy input entering the aquatic food chain from the wetland vegetation be evaluated?

The availability of wetland production for export, and the timing of export, depend upon wetland size, process rates (decomposition, cycling, and production), and structural characteristics of the wetland storage system (slopes, substrates, vegetation form, etc.). Many wetlands are merely pass-through systems, in which production is almost immediately available for downstream use. Other wetlands (e.g., peatlands) however, store inputs and production, so that the nutrients and organic materials received or produced by the wetland are not immediately transported downstream.

Storage periods range from the ephemeral (e.g., as a result of absorption processes) to the long-term, in which materials may be held for hundreds or thousands of years.

The coupling of wetlands with other wetlands and bodies of water implies that productivity research should focus on the concept of import-export (of water, nutrients, and other materials). In order to relate inland systems quantitatively to downstream wetlands, the hydrologic boundaries and processes of wetlands should be precisely characterized. This will allow standardized studies of productivity (endemic and allochthonous) and respiration, decomposition and utilization of produced materials, and transport of residual energy and nutrients.

Flow of Energy and Nutrients

Questions: What role do wetlands play in biogeochemical recycling, storage and transport of nutrients? How do biogeochemical recycling processes affect productivity, ecosystem resiliency and stability?

The role of wetlands in biogeochemical recycling is a subject that cannot be adequately addressed in a short essay. For more comprehensive discussions, see Moore and Bellamy (13), Good et al. (14), Tilton (15), Reid and Wood (16), Hynes (17), and Darnell (18).

Briefly, most nutrients are water-soluble. Water moves downhill as a result of gravity, and it takes with it both dissolved nutrients and particulate organic material derived from uplands and floodplains. Eventually, many of the organic and inorganic materials enter the sea. However, in their downhill and downstream movements, these materials become involved in many functional processes of wetland systems, the exact nature of which depends upon local circumstances.

Many wetlands function as "nutrient traps", i.e., they sequester and hold onto nutrients which enter them. This is a storage function, and it has been used for tertiary treatment of human sewage. Some of the nutrients may eventually be passed from one part of the wetland system to another. In this case there is a release and subsequent downstream transport of nutrients.

Without wetlands, there would be a very rapid downstream transport of nutrients to the sea. Therefore, wetlands tend to retard the biogeochemical cycles and to retain nutrients for local production and partial local recycling. Since the local recycling is not 100 percent efficient, some of the nutrients are lost at each annual recycling. By and large, lakes, ponds, marshes, swamps, and estuaries tend to retain nutrients and to recycle them locally for long periods of time. Streams also carry out some local recycling, but in this case there is greater leakage and faster downstream transport.

In making management and planning decisions on wetland systems, the following points should be recognized:

(1) The output of a wetland system is an output of energy-rich and nutrient-rich material which can be used by various organisms and which has positive effects on downstream production. How people view such increased production varies with the situation. If the wetland output contributes substantially to stream or lake eutrophication, it may be viewed negatively, whereas if it results in enhancement of detritus-based commercial fisheries, it is likely to be viewed positively.

(2) Management or planning decisions can exert a major impact upon the productivity of a wetland by altering the "input side" of the wetland storage equation. For example, such decisions can result in increased or decreased nutrient input from adjacent uplands. Or they may result in changing biotic community structure (microbial, plant, and animal) from a higher to a lower level of productivity.

(3) Management or planning decisions can exert a major impact upon the storage characteristics of a wetland. For example, such decisions can result in increasing the rate at which nutrients are stored. More often, such decisions result in opening up a storage reservoir, making the materials outflow of the wetland system greater than the inflow. In cases where such storage has accumulated over hundreds or thousands of years, it is possible for nutrient output to exceed input by a factor of 100 or more--an input/output relationship which can persist for decades or centuries.

Effect of Water Regime on Productivity

Question: In West Coast salt marshes, what affects production and reduction (detritus formation) more--the extent of tidal inundation or the diversity of plant species?

It is not known which factors are most important in controlling production and detritus formation in West Coast salt marshes, although salt marsh succulents as a group (which characterize California marshes) appear to lose organic matter rapidly. It is almost certain that generalizations cannot be made for the entire Pacific Coast of the United States (19,20). It should be noted that, for Alaska at least, the extent of tidal inundation and the diversity of salt marsh plant species are strongly related to each other (21).

Questions: How much productivity loss is associated with reduced flooding of wetlands? In terms of energy transfer and benefits to an estuary, what are the differences between an unobstructed freshwater system and a freshwater system that has one or numerous dams in its watershed? How does water level management in streams and reservoirs influence the biological productivity of wetlands in those systems? At what level of lowered frequency of flooding of hardwood bottom type wetlands is productivity significantly affected?

Hydrologic factors (timing of flooding, length of flooding, and speed of water flow) are major determinants of wetland structure and function. These factors affect the chemical and physical conditions of wetland soils, and thus the vigor and net primary productivity of wetland plants. They also affect the quality of the water, since stagnant water systems tend to accumulate nutrients and other chemicals, while moving water systems import and export great quantities of organic and inorganic substances.

Given the importance of hydrologic factors and water quality, and given the sensitivity of plants and animals to these factors, it follows that alterations in flooding regime, rates of water flow, water quality, and so on will result in rapid changes and responses in the wetland ecosystem. For example, permanent flooding of wetlands due to impoundment prevents seed germination and eventually results in complete tree mortality. Channelization decouples wetlands from waterways and thus blocks import and export of materials to and from wetlands; primary and secondary productivity consequently decrease. Lowering of water tables similarly decreases primary productivity over the long term, and also increases fire frequencies, allowing the invasion of non-wetland species into the wetland habitat. Deceleration of water flow contributes to a decrease in net primary productivity by increasing stress associated with low oxygen levels in soils and by allowing sediment accumulation. Acceleration of water flow may raise the net primary productivity of still-water wetlands, but if too great may cause erosion of wetland soils and reduction of habitat diversity. Blockage of water inputs into wetlands causes a sharp decline in productivity by eliminating nutrient inputs and root ventilation by flowing water. It also disrupts life history patterns of animal species which require several habitats to complete their life histories.

Upstream impoundment adversely influences downstream wetland environments in numerous ways, but the details and especially the quantitative aspects are locally specific. Among the adverse effects are the following:

-- Floodplain wetlands:

reduced recharge

reduced restocking

reduced sediment enrichment

-- Streams:

reduced flow rates, especially peak flows

reduced flushing, hence increased sedimentation

reduced enrichment by leaf litter from the floodplain

-- Estuaries:

reduced flushing

increased shoaling

increased salinity

sharpening of salinity gradients

reduced nutrient inflow

increased invasion of marine species (including predators, parasites, and diseases)

-- Nearshore coastal areas:

reduced beach nourishment

increased beach erosion

Artificial stabilization of wetland hydrologic processes tends to reduce habitat, and hence species, diversity. It eliminates the periodic pulses of nutrient input. It tends to select for a few species groups at the expense of others and thus reduces species diversity. It may eliminate or reduce populations of those species which depend upon a specific type of hydrologic regime for successful breeding or migration.

Hydrologic stabilization hastens the loss of the wetland through succession to terrestrial climax.

Change in Food Chain Values Over Time

Question: What effects do seasonal changes exert in typical wetland environments in terms of productivity?

The effects of seasonal change are considerable but locally variable. See Jervis (22) and Good et al. (23) for a fuller discussion.

Questions: What seral stages of wetlands provide the most productivity? To what extent do newly established marshes function similarly to old marshes in terms of their contribution to the food chain? At what age does the productivity of various marsh types reach a peak, and how long does it maintain this peak?

See Livingston and Loucks (24) for a general review of the relationship between wetland productivity and temporal change. The successional stage at which productivity peaks varies to some extent with the region and the particular wetland. One wetland sere which occurs commonly in northern temperate areas proceeds from reedswamp to sedge fen to *Sphagnum* bog. In this sere, primary productivity is highest in the early, reedswamp stage, and declines markedly as succession transforms a silted, minerotrophic site to an ombrotrophic site dependent upon direct precipitation for its nutrient supply.

Questions: How do wetland food chain values change with time? How do transition communities contribute to the integrity of the overall wetland?

Processes occurring in wetlands are the sum of ecosystem dynamics that occur at many different time scales. The most commonly considered diurnal and seasonal changes cannot be taken out of context of ecosystem dynamics which occur at decade, century, or longer time scales. Wetland dynamics are a function of both external and internal variables acting cyclically and randomly at many time scales. Change is inherent in wetland systems; however, there is a limit to the amount of change that a wetland system can take and still remain in a particular condition. Human activities which either increase or decrease the natural variability may have unpredictable consequences.

All temporal stages are necessary to the integrity of an ecosystem. People, however, attach more value to some stages than to others, and attempt to manage wetlands for what is considered to be the most valuable stage (what produces the most ducks, cleans the water best, etc.). Thus we sacrifice one function for another or, in a temporal sense, we sacrific future for present values. In natural systems it appears that when one wetland is changing from state A to state B, another is changing from B to A; if we look at a large enough area, we should find a relatively constant level of the functions of A. Historically, we have rarely taken the large view, however. When a wetland changed from A to B, and B didn't produce anything we valued as far as we knew, we converted the wetland from B to something else totally different and denied it the alternative of returning to A some day. When a wetland in condition A began to change, the property owner tried to stop the process, to maintain his property values. Finally we created and accelerated the mechanisms driving change.

Clearly, for better wetland management, enough wetlands should be controlled to allow each one to oscillate naturally in time. Daily, monthly, annual, and longer-term changes should be maintained. As far as research is concerned, we must have long-term studies in a wide variety of wetland types: some studies on big wetlands, some with large interdisciplinary teams, but many more small-scale projects done for a long time at widely scattered localities.

2. HABITAT VALUES

Panel Convenor: Dr. Milton Weller

Wetlands provide living space for a variety of plants and animals. For animals, wetlands may provide food, breeding grounds, nesting materials or sites, moulting grounds, resting areas, protection from weather, or escape from predators. Some animals depend on wetlands in order to carry out all their life functions; others use wetlands for only one or two functions. Some animals are resident in a particular wetland throughout their life; some are residents only during a particular life cycle stage or season of the year; others use the wetland throughout their life (e.g., for feeding) but reside primarily in deeper water or in upland areas. The variety of life patterns in animals that use wetlands complicates the business of identifying the species dependent on each wetland type and determining the parameters of dependence. Other difficult issues in determining the habitat value of wetlands include the species diversity and carrying capacity of different types and sizes of wetlands, the effect of surrounding land uses on wetland habitat values, and the effect of natural temporal changes on habitat value.

Summary

Habitat is one of the more studied functional values of wetlands. Many factors influence the value of a particular wetland as animal habitat, but wetland research has repeatedly stressed the importance of the following: size and spatial arrangement of habitat, vegetative structure, water regime (especially fluctuations in water level), and energy flow between systems.

The data base on wetland habitat values is geographically broad, although freshwater tidal wetlands, as a group, and saltwater wetlands along the Pacific coast have not had sufficient depth of study. Nor have certain animal groups--micro-biota, many macroinvertebrates, amphibians, reptiles, small mammals, and in freshwater wetlands, fish--been studied intensively, in spite of their importance to the wetland ecosystem.

Regarding habitat for fish, the value of Atlantic, and Gulf coast wetlands is well established. Information is lacking for much of the Pacific coast; however, the lagoon and estuary systems in southern California are probably not very important to marine fish populations. Data on freshwater wetlands are spotty, and concentrated on game species of the Great Lakes coastal wetlands. Vegetated wetlands of all types seem to be valuable as nursery areas for fish in adjacent waters. The value of coastal high marsh to fish needs further study. During extreme high waters, fish can move into high marsh areas to feed or find cover, and detritus can be carried out of the marsh into deeper water, to be utilized by organisms later eaten by fish. More importantly, high marsh areas may also be indirectly valuable to fish by trapping nutrients and releasing them slowly to lower marsh and water areas. Little is known of the optimum balance between wetland and open water areas; this is a valuable area for further research.

Many species are specialized to use wetlands for only a part of their life cycle or to use more than one type of wetland or wetland habitat during their life cycle, and in addition are unable to shift to other habitats when the appropriate wetlands are unavailable. To maintain populations of these species and the habitat value of any given wetland, it is necessary to maintain a diversity of wetland habitats and types.

Diversity and abundance of most wetland animal groups (data are particularly good for birds and invertebrates) increase with increasing structural diversity of habitat, i.e., the greater the habitat zonation (vertical and horizontal) and the greater the amount of edge between zones, the more different kinds of animals will be able to use the wetland. Location is also important: isolation tends to reduce the habitat value of a wetland. There is evidence that migratory birds and mammals use complexes of wetlands. Studies of dugout ponds show that isolated dugouts are used by fewer numbers and species of waterfowl than dugouts near natural wetlands. Diversity of nearby habitat is clearly important to wetland species diversity, but appropriate buffer widths for maintaining the habitat value of wetlands for various species require a lot of further study. Comparison of the species diversity (and carrying capacity) of wetlands and non-wetland systems (e.g., bottomland hardwood forests) have never been made.

The issue of carrying capacity is extremely complex, encompassing virtually all the current issues in wetland ecology. No single species or small cluster of species can serve as an infallible indicator of wetland carrying capacity: community-level measures, such as species richness or structural diversity, might be used but these techniques need study. Natural wetland habitats appear to be already "crowded"--that is, there are no known cases where elimination of wetland habitat has resulted in a population shift to remaining wetland habitat without impact on the total population. Since vacant ecological niches are few or non-existent in wetland communities, the introduction of exotic species should be discouraged.

Although individuals of each wetland species require a certain amount of living space, wetland size is not an overriding factor determining habitat value. There is no minimum size below which wetlands have no habitat value. Again, location is of considerable importance. The value to ducks of small prairie marshes belonging to wetland complexes has been demonstrated recently. Small wetlands in urban areas may have limited species diversity and abundance but the visibility of the fauna to urban residents makes the habitat functions of such wetlands significant.

Wetland habitat values are not constant over time. Habitat conditions change daily (e.g., with the tides), with the seasons, over periods of several years, and with long-term succession. Adaptations of wetland species to periodic changes have been well studied and the value of ephemeral or seasonally-flooded wetlands to wildlife fairly well documented. The course of natural succession in wetlands has also been studied repeatedly but, with some new evidence of long-term cyclical change, is now under debate.
The secondary successional patterns in various wetlands (e.g., the pattern and rate of colonization of both newly created and existing natural wetlands by benthic aquatic species), the rates of change associated with natural evolution of wetlands, the effect of such rates on habitat values, and the factors and time periods

necessary to return disturbed wetlands to "climax" stages are all important questions for research.

Habitat Values of Specific Wetland Types or Sub-Areas

Question: What are the values of Type I (seasonally flooded), VI (shrub swamp), VII (wooded swamp), and VIII (bog) wetlands as wildlife habitat? For which wildlife?

Type I ephemeral wetlands are regarded as especially valuable to pre-breeding waterfowl, which depend on the rich invertebrate resources found there to obtain the protein essential to egg laying (25). When such areas are dry or less wet, they are used by pheasants and songbirds (26). See Stewart and Kantrud (27) and Kantrud and Stewart (28) for lists of birds using Type I wetlands.

Type VI shrub wetlands are valuable as nesting areas for redwings, flycatchers and other passerines, and as roosting cover for wood ducks in some areas. They can be excellent waterfowl hunting areas--for wood ducks, mallards, and ringnecks. See Linder and Schitoskey (26) on the use of these wetlands by upland wildlife.

For wildlife habitat values of Types VII and VIII wetlands, see Fredrickson (29) and Aldrich (30), respectively.

Questions: What parts of the various types of wetlands provide significant nursery habitat for fishes? How important are mudflats in comparison to vegetated flats as nursery grounds for larval and juvenile fish?

All parts of the wetland normally accessible to adjacent open waters provide significant nursery habitat for fishes. Some plant cover capable of providing shelter and food is essential. This may include submergents, emergents, floating-leaved plants, or even free-floating plants that create shade. Northern pike is an example of a freshwater species whose spawning requirements are closely tied to freshwater marshes (31). Structurally similar plants occur in freshwater marshes, marine coastal marshes, stream-estuary interfaces, and wooded swamps. Of particular importance is the production of detritus, part of which is used within the habitat and part of which is exported to adjacent waters (see 32,33, and 34).

Mudflats do not offer the same protection to larval stages as vegetated wetlands, and, in freshwater systems, apparently have lower invertebrate populations (35), but may still serve as important feeding grounds for larval and juvenile fish (32,33,36). Research on the optimum balance among mudflat, marsh, and open water areas in coastal systems is in progress and should also be carried out in freshwater systems.

Questions: What parts of the various types of wetlands and adjacent uplands provide nutrient base for fish? What is the nature and extent of the importance of high marshes (above mean high water) to the well-being of living marine resources?

Considerable amounts of nutrients enter major water bodies via stream inflow. Nutrients from high marsh and adjacent terrestrial areas are also carried into open water areas by periodic flooding or extreme high tides in freshwater marsh, swamp, or coastal wetlands. High marshes seem to act as natural nutrient sinks which slowly release nutrients to lower marshes and estuaries (37). The fact that high marshes are inundated infrequently results in a longer period of *in situ* degradation of detrital material than occurs in low marshes. The material flushed from high marsh areas tends to be "fine" detritus, as opposed to the coarser material exported from low marshes. The periodic flushing of such detritus from high marshes may serve as a buffer to the seasonality in phytoplankton production.

High marshes may also trap pollutants. At storm tides, such habitat provides cover and food for fish and other animals normally associated with lower tidal wetlands or open waters.

Species and Habitat Diversity

Question: What is the optimum community structure for maximizing wetland species diversity?

Wetland species diversity usually increases with the structural diversity of the habitat and the amount of edge between sub-habitats (ecotone effect). For birds, maximal species diversity is associated with maximal cover-water or cover-cover interface; for aquatic invertebrates, maximal species diversity may be associated with maximal leafy area of submersed vegetation; for other aquatic organisms, maximal cover-water complexity is probably important. However, the conditions producing maximal species diversity probably differ among major animal groups; certainly the conditions which are optimal for one species are not optimal for all others. In the absence of species-specific information, a general principle to follow in managing wetlands for maximal species diversity is to aim for maximal structural zonation and layering (above or below water) within individual wetlands and diversity of wetland types within wetland complexes (32, 33, 38).

Questions: What is the relative faunal diversity of various wetland ecotones in relation to the wetland itself? At what point in the ecotone does wetland become upland, and how can this point be quantitatively identified?

There is evidence that structural edges or ecotones (e.g., cover-water or cover-cover interfaces) can induce a concentration of nesting birds (39), flying insects, or aquatic invertebrates. Based on what little research data are available, however, it appears that not all species respond in this way.

The wetland edge is often dynamic (depending on geomorphology). Though it can generally be determined at a single point in time from avian and plant communities as well as soil structure, it changes seasonally, annually, and over longer time periods, and cannot be identified permanently. See Cowardin et al. (40) for definition of hydrophytes and plant-animal community descriptions, which can be used to define boundaries of various regional wetland types. Stewart and Kantrud (41) include good lists of hydrophytes for prairie potholes.

Question: How do the species diversity and population capacity of wetlands (swamps, bogs, etc.) compare with those of non-wetland mixed hardwood forests?

Data are not readily available. Comparison of such structurally different areas is difficult, and may be impossible. However, measures such as species richness are likely to be more valuable than species diversity indices.

Question: What regional bottomland forest patterns are optimal for diverse bird life?

Information is not available for bottomland forests thoughout the United States. For information on riparian forest types which are optimal for wildlife in the Southwest, see U.S. Forest Service (42).

Habitat for Non-Resident or Specialized Species

Question: To what extent are terrestrial animal species inhabiting land bordering a wetland dependent upon the condition of the wetland?

Terrestrial animals normally use wetlands only when the wetland area is relatively dry or, in northern areas, when it is frozen. Pheasants and deer use marshes in open country (26), mink in southeast Alaska come down to shorelands to feed in winter, turkeys wade to reach pin oak areas (26), moose feed on submergent plants (see 38), and eagles nest in old trees by water (43). For breeding use of wetlands by primarily terrestrial species, see Weller (38) or Weller and Fredricksen (44).

Question: What permanent or temporary resident species utilize wetlands for narrow, specialized functions which are extremely important to life cycle or food chain?

There are many specialized animal species that cannot exist in the absence of some wetland, even if they are mobile or migratory. Some examples are: dragonflies that have two- or three-year life cycles; frogs and salamanders that move into wetlands only to breed; marsh birds that are restricted to feeding on aquatic organisms (grebes on fish and aquatic invertebrates, Yuma Clapper Rail on crayfish, Limpkin on certain snails); Bald Eagles, which require large old trees on shorelines for perching and nesting; Snow Geese and Canada Geese, which are restricted to certain marsh types for feeding and nesting; Northern Pike, which spawn in shallow sedge marshes or in cattail marshes adjacent to lakes; Pacific Herring, which spawn in shallow subtidal waters where their eggs become attached to submerged grasses; and American alligators.

Question: What is the value of wetlands to the life cycle of anadromous species?

Anadromous salmonids pass through wetlands at least twice: as adults moving to spawning grounds and as juveniles en route to the sea. One or two species are known to spawn in wetlands at the stream/estuary ecotone, but most species spawn upstream. Wetlands in this ecotone are an important source of amphipods, isopods, and other invertebrate foods for juvenile salmonids. See Merrell and Koski (36). For information on non-salmonid anadromous fish, see Odum et al. (33) and Thayer et al. (32).

Questions: Which wetlands comprise the main corridors or migratory routes for migratory bird species? Which wetlands are preferred resting, breeding, or nesting areas?

The bulk of this information can be found in Bellrose (45). Information on the value of various wetland types within migratory corridors is available only by general region (e.g., prairie pothole marshes, northern bogs, etc.). Ohmart and Anderson (46) give data on corridors in the Southwest.

Connections Between Wetlands and Surrounding Areas

Question: Many coastal delta ecosystems consist of a combination of plant communities or habitat types (e.g., wooded bottomland, cypress swamp, coastal prairie, fresh marsh, brackish marsh, and high marsh). What are the interrelationships among contiguous habitats in wetland ecosystems, and how do these interrelationships affect animal populations?

This is an important, relatively unstudied, but very complex issue. Work on prairie marshes (47) suggests that populations of ducks are more seriously affected by the loss of small, dispersed wetlands than was formerly recognized. Movements of birds, reptiles, amphibians, and mammals between areas for feeding or other life functions at various ages and times of year suggest that no one wetland answers all needs. Habitat diversity and increased edge clearly enhance species richness (48,36,32,33,38). In both isolated and contiguous units, free water flow and natural fluctuations in water levels seem to be important to the maintenance of animal populations.

Question: Vast stretches of saline flatlands, consisting primarily of succulent halophytes, occur adjacent to tidal wetlands and at inland saline depressions along the Texas coast. What is the ecological importance of these areas, and how valuable are they to adjacent wetlands?

Such seasonally-flooded wetlands are no less important than prairie potholes, wooded swamps, or other "impermanent" wetlands. They allow seasonal nutrient shifting (via water) among wetlands or between wetlands and terrestrial systems, and provide feeding sites for aquatic birds which move from place to place seasonally or to meet physiological needs.

Questions: What patterns and classes of land near wetlands will enhance the faunal component of those wetlands? What is the value of buffer zones around wetlands? How wide should buffer zones be?

Vegetated uplands near wetlands generally contribute to wetland species diversity; pavement or plowed fields contribute less in the way of food resources, wind and flood protection, or other benefits to wetland fauna. Diverse nearby vegetation may provide nest sites (for herons, terns, certain waterfowl, and other birds), denning sites (for raccoons, otters, and other mammals), travel lanes between wetlands (for frogs, turtles, salamanders, and other vertebrates), food (such as willows for beaver), protection from weather or predators, and so on.

The appropriate width of buffer zone around wetland depends on the purpose for which it is established--e.g., to avoid human disturbance of nesting waterbirds, to maintain the riparian vegetation which provides insect food for fish, to provide a refuge for certain amphibians during periods of extreme high water, to protect upland development from extreme high waters, to prevent pollution or siltation of wetland habitat due to construction, agriculture, waste disposal, or other development activities in upland areas. To take a relatively simple case, if the goal is to provide nesting sites for teal, the appropriate width of buffer zone can be based on the average distance between teal nests and water in areas where nesting is unrestricted. In many cases, however, data are not available on the normal spatial use patterns of various species, on their tolerance to various human impacts, or on the size of area likely to be affected by various human activities in areas around wetlands.

Question: What is the importance of the "canopy effect" on the waterways and animal life associated with freshwater swamps?

The tree or shrub canopy in freshwater swamps reduces the amount of sunlight reaching the water below, which in turn reduces the growth of aquatic algae and probably submergent vascular plants. The reduced light intensity also means that only shade-tolerant plants regenerate. The canopy lowers water temperatures during the summer, favoring cool-temperature aquatic species such as trout, and creates warm air pockets during the winter, which provide protection for many species (e.g., deer in white cedar swamps) in the northern United States (26). The litter produced by the forest canopy is an important source of nutrients and detrital food for aquatic organisms. The canopy also provides living space, food, or temporary refuges for birds, insects, tree frogs, and arboreal mammals.

Carrying Capacity

Questions: What is the carrying capacity of various wetland communities for populations of game and non-game animals? What intrinsic and extrinsic factors affect the carrying capacity of species inhabiting wetland ecosystems?

These questions are impossible to answer fully, as they encompass many, if not all, of the current issues in wetland ecology. Such diverse factors as the formation of social systems in animals (e.g., blackbirds) concentrated for nesting and/or food, the territoriality of solitary-nesting species, the conditions in wintering areas of migrants, climatic influences and disasters, the nutrient/productivity base, the structural components of the wetland units in question--all (and more) contribute to carrying capacity. Some data are available for certain species and certain sites, but they have not been (and perhaps cannot be) compared in a logical manner to answer these questions.

Questions: What species could serve as indicator organisms for each type of wetland to provide an indirect measure of wetland value? What is the carrying capacity of each type of wetland for selected indicator or key species?

No single species or even small cluster of species can serve as an infallible indicator of wetland habitat value or carrying capacity. A community approach is essential in assessing habitat value or carrying capacity. Possible approaches include the measurement of species richness (number of species present), structural diversity of plants, and water regime.

Questions: Relative to animal behavior, what types of wetland habitats can be crowded and to what extent, without significantly (statistically) affecting the normal seasonal population (aquatic, terrestrial, and avian)? Following destruction of habitat, what is the interaction effect between displaced individuals and remaining populations in the unaffected portion of the habitat?

Crowding in fish and aquatic invertebrates may be predator-controlled and thus possible to manipulate to some extent. Our general understanding of social systems in wetland birds, however, suggests that these species have evolved high levels of social tolerance already due to the restrictive nature of the habitat, and that little additional crowding is possible or should be encouraged. If the habitat diversity is not optimal, increased edge from pools, cover-water or cover-cover interfaces may increase the carrying capacity of the habitat to the level of social tolerance. Habitat modification or management leading to reduced species richness (or diversity) is not recommended.

We know of no cases where elimination of habitat has resulted in a population shift without impact on the total population. The most dramatic demonstration of the results of habitat destruction may be what happened with the loss of eelgrass along the Atlantic Coast in the 1930's. The decline in eelgrass resulted in a widespread decline of faunal populations at all trophic levels, from small epifauna and infauna to fishes and waterfowl (49,50). Loss of this wetland habitat had a particularly severe impact on populations of Black Brant (51,52,53), a bird whose primary food is eelgrass. The issue of wetland habitat loss is both complex and serious, since entire populations of certain species may be displaced, and community structure is so refined in temperate latitudes that few (if any) vacant ecological niches exist.

Question: What are the ecological and economic impacts of nutria on marshlands of Texas?

Nutria seem to favor fresh water and may have displaced muskrats from fresher-water marshes in both Texas and Lousiana (54). See also Chabreck (55) and work by Palmisano, cited in Chabreck.

Questions: What plant species can be successfully introduced to improve existing wetland habitat? In what ways do introduced aquatic species affect wetland ecology, particularly the quality of habitat for endangered waterbirds?

Introduction of exotic plant species rarely, if ever, "improves" wetland habitat (56,57,58). In general, natural invasion eventually occurs, even in long-dry basins; planting and seeding have been costly and unsuccessful for the most part because of the factors limiting natural invasion (pollution, sedimentation, wave action, etc.).

The effect of introduced aquatic plants on wetland ecology depends partly on whether the alien plants are emergent, floating (or floating-leaved), or submerged aquatics. For example, introduction of hybrid cattail (*Typha glauca*) into freshwater wetlands can lead to the displacement of shorter emergent species and may cause eventual senescence if colonies are extensive. Swamp loosestrife, or water willow (Lythrum salicaria), colonizes the edge of the emergent vegetation along streams, reducing animal and detrital interchange between the emergent and open-water components of the wetland system. Floating, or floating-leaved, plants, such as water hyacinth (Eichhornia crassipes) and alligator weed (Alternanthera philoxeroides), have colonized the entire open-water surface of some slowly moving water bodies in the southeastern United States, thereby causing light extinction, reducing anaerobic conditions, and greatly lowered secondary productivity in the water system. Dense duckweed (e.g., Lemna minor) colonies are common throughout much of the United States, but wind and water circulation tend to reduce the extent and permanence of the floating cover. Introduction of certain submerged aquatic plants--notably Eurasian watermilfoil (Myriophyllum exalbescens or M. spicatum), waterweed (Elodea canadensis), and coontail (Ceratophyllum demersum)--may have a very significant impact on wetland ecology. These plants generally tolerate siltation and/or nutrient loading, and provide less preferred seeds, vegetative material, or tubers/rootstalks than the native plants. Many submerged aquatic invaders (e.g., coontail) float near the water surface; hence light extinction and silt accumulation combine to reduce the habitat for benthic organisms.

In general, introduced plant species reduce the extent of open water, increase the density of some emergent communities, and alter the species composition of wetland communities, especially submersed communities, which, in turn, reduces the food availability for ducks and other waterbirds.

Questions: How critical is wetland size (acres) in terms of providing significant habitat values? What may be considered the smallest area of wetland to be valuable as wetland habitat? What is the minimum size of wetland below which no contribution to living space for fauna is made? How can small, isolated, stressed wetlands in highly urbanized areas contribute to real habitat values?

There is no minimum size of wetland below which the area has no habitat value. The space required by various wetland species ranges from minute (a crayfish hole for a mosquito) to vast (hundreds of acres for swans and geese). Depending on their location, smaller wetlands (less than an acre in size) may have extremely high habitat value for certain animals, as small ephemeral prairie potholes have for nesting ducks (47). If stressed, small wetlands in urban areas may not have diverse or abundant animal populations, but the educational and aesthetic values of such wetlands probably far outweigh any shortcomings in fish and wildlife production. The salmon stream running through a town, or the small marsh in the city which attracts a pair of mallards or redwings may bring pleasure, beauty, and personal satisfaction to large numbers of people.

Change In Habitat Value Over Time

Questions: What rates of change are associated with the natural evolution of wetlands, and how are values affected thereby? What are the secondary successional patterns that occur in various types of wetland habitats? If disturbances occur in wetland habitats, what factors and time periods are required for these regions to return to "climax" successional stages?

This is an extremely important area. It warrants intensive review by wetland ecologists and considerable further research. Typical textbook descriptions of wetland succession are not holding up very well under scrutiny. Long-term changes in wetlands do not all follow the familiar lake-to-bog or marsh-to-upland successional patterns. Some wetlands are long-lived, dynamic, and self-perpetuating, if not expanding systems. For discussions of the natural evolution of specific wetlands, see Heinselman (59,60) on bogs, Weller and Fredrickson (44) on prairie marshes, Thayer et al. (32) on seagrass systems, and Thorsteinson et al. (61) and Goldthwait et al. (62) on Alaskan coastal wetlands. In Alaska, coastal wetlands subjected to rapid susidence or uplift (to 12 m.) during earthquakes have suffered drastic physical change, as well as reduced productivity. Other Alaska wetlands are also uplifting, but less rapidly, as a result of glacial melting.

Although considerable study of the relationship between wetland developmental patterns and environmental gradients is underway in some wetland systems (e.g., seagrass beds), little background data are available in most systems to document changes following disturbances of wetlands. Disturbances apparently may have long-lasting effects, however, as in the case of seagrass losses on the East Coast.

Question: What factors affect the pattern and rate of colonization of newly created wetlands by benthic aquatic species?

Colonization by benthic species is a successional process influenced by the character of the sediments, pH, nutrients, organic matter, and other factors. To determine the factors controlling the development of the benthic faunal community of coastal wetlands in North Carolina, Cammen (63) studied several sites: a dredge spoil island planted with Spartina alterniflora, spoil left bare, and two sites in a nearby natural marsh. He concluded that at least five factors may control the development of benthic fauna on planted spoil: similarity of the spoil to natural marsh in elevation and sediment particle size; sedimentation rate of the area; proximity of the spoil to natural marsh; and relative maturity of the natural marsh faunal community. Work similar to Cammen's has been done on dredge spoil banks and new artificial Spartina marshes at the Corps of Engineers' Waterways Experiment Station (64).

Question: What are the effects of fire on the various types of wetlands?

Fires can be used to deepen northern bogs and create diversity. In midwestern fens, on the other hand, fires combined with drainage produce monotypic stands of nettles, reed canary grass, giant ragweed, or quaking aspen. In the Everglades, fires (which occur naturally) deter dominance by woody vegetation Fire is used in management of some coastal marshes, to induce the growth of various sedges used by geese and muskrats. Studies of the use of fire and the effects of fire, particularly on nutrient turnover, are still relatively few, however, and more work will be needed before fire can be generally recommended as a management tool.

3. HYDROLOGIC AND HYDRAULIC VALUES

Panel Convenor: Virginia Carter

Water enters wetlands as precipitation, surface flow (runoff or tidal flow), or groundwater discharge, and leaves wetlands as evapotranspiration, surface flow, or groundwater recharge. The existence and pattern of water movement through wetlands--the pathways by which water moves, the amount of water moving along each pathway, and the timing of water movement--are basic to the functioning of wetlands in terms of producing organic material, cycling nutrients, altering water quality, providing distinctive habitat, and so on. Hydrologic and hydraulic properties of wetlands are thus important determinants of food chain, water quality maintenance, and habitat values, as well as harvest and heritage values. Hydrologic functions also have their own value: some wetlands control floods, some stabilize shorelines or absorb the destructive energy of storm waves, and some may recharge groundwater, thereby contributing to base flows in stream channels.

Issues to consider in assessing hydrologic value are the extent to which different wetlands carry out these valuable hydrologic functions, and the factors controlling these functions. Major questions addressed below relate to: the hydrologic characteristics of different types of wetlands; the hydrologic conditions necessary to maintain different wetlands, and the effects of hydrologic change on wetland biota; the processes by which wetlands can control floods, recharge groundwater, contribute to base flow, or control shoreline erosion;

the relative effectiveness of different wetland types, and of wetlands versus other types of land, in carrying out these functions; the effects of wetland size and location on hydrologic and hydraulic functions; and the effects of wetland plants and soils on these functions.

Summary

All natural wetland functions are closely linked to wetland hydrology. Wetland primary productivity, nutrient cycling, wildlife habitat, harvest, and even aesthetics are unquestionably tied to the presence, movement, quality and quantity of water in the wetland. An understanding of the pattern of water movement through individual wetlands, wetland complexes, and drainage basins containing wetlands is essential for a good understanding of wetland functions and the values related to those functions. Research on wetland hydrology is thus a key to understanding wetland values.

The hydrologic and hydraulic properties of wetlands are not yet well understood. This is partly due to the difficulty of studying wetlands with techniques developed for channels or open water basins and mineral soils. It is not easy, for example, to measure diffuse surface flow through vegetation, or to measure groundwater flow. Hydrologic budgets, which are necessary for predicting the effects of hydrologic manipulation (e.g., upstream channelization) and understanding other functional values of wetlands (particularly water quality maintenance values), exist for only a few wetlands. It appears, however, that most wetlands are areas of high water consumption. Evapotranspiration is probably greater, and soils are often less permeable, than in upland areas, so that wetlands contribute less to groundwater and base flows than many undeveloped upland areas.

Wetlands associated with streams store and slow flood waters, reducing flood peaks and increasing the duration of flow. The flood-control effectiveness of any wetland depends on its size, hydrologic character, and location in the drainage basin, as well as the size, hydrologic character, flooding characteristics, and distribution of streams or rivers in the basin. Effectiveness is generally greatest during high-intensity, short-duration storm events, which generate the largest floods, and less for smaller floods resulting from longer-duration rainfall or snowmelt. It is possible for an isolated individual wetland to be singularly effective in flood control, but more often flood control is the result of the interrelated functioning of a series of wetlands and water bodies in the river basin. The amount of watershed area covered by wetlands is important: statistical studies indicate that in certain situations if a watershed has 15 percent of its area in wetlands or lakes, flood peaks will be 60 to 65 percent lower than they would be in the absence of the wetland/lake area; if wetlands or lakes occupy 30 percent of the watershed, there will be a further reduction in flood peaks up to about 75 or 80 percent. The relative effectiveness of different types of wetlands in controlling floods is not yet well known. In particular, the differences between depression and slope wetlands, and between peatlands and non-peatlands, have not been sufficiently studied. The impact of wetlands adjacent to estuaries or tidal rivers on floods may be either minimized or maximized by the tidal stage during which flooding occurs.

Most information on the value of wetlands in shoreline erosion control comes from studies on individual plant species rather than on plant communities. Thus there is not much information on the relative values of various wetland types, but there is substantial information on the species that may be planted to protect banks under various hydrological and hydraulic conditions. Along streams and lakes, reed canary grass (Phalaris arundinacea), common reed (Phragmites australis), and low-growing willows are especially effective in controlling bank erosion. In Chesapeake Bay, Spartina alterniflora has been successful in the intertidal zone, and S. patens, S. cynosuroides, Distichlis spicata, and Ammophila breviligulata in the supratidal zones. Under any given set of hydrological and hydraulic conditions, the effectiveness of shoreline vegetation in controlling erosion depends not only on the particular plant species (their flood tolerance and resistance to undermining) but on the width of the vegetated shoreline band, its efficiency in trapping sediment (based on growth form and density), the soil composition of the bank, the height and slope of the bank, and the elevation of the toe of the bank with respect to mean storm high water.

Wetland size and location within a drainage basin affect sediment trapping, erosion control, and flood control values, but wetland geometry and configuration are also important factors. For sediment trapping, and erosion control, the length of wetland edge across which water flows is probably more important than total wetland area. The length of the wetland edge may also be important to ground-water recharge.

Wetland soil type may affect hydrologic functions--chiefly floodwater storage and ground-water recharge--by influencing infiltration and water retention in the wetland. Recharge is greatest through coarse sands or gravels and successively lower in shallow fibric peats, silts, clays, and deep sapric peats. Soil type is also extremely important to wetland biological functions, since it affects the level of the water table, the size of the capillary fringe, and the availability of soil moisture and nutrients to plants. Plants in turn affect wetland soil composition by influencing surface water flow, filtering sediment and detritus out of flowing water, and producing litter. The development of an organic soil is a primary factor determining the hydrologic functions of peatlands.

Hydrologic and biologic functions of wetlands are strongly interrelated. For example, water circulation patterns are largely controlled by vegetation in non-peat wetlands and by the development of organic soil in peatlands. These patterns in turn affect the accumulation of sediment or organic soil and the distribution of seeds and vegetatively active plant parts. Wetland plant communities also vary according to the timing and duration of flooding, with duration being most important during the growing season. Flood tolerances of wetland plants are well documented (though their sensitivity to decreases in duration and frequency of flooding deserve additional research). There is insufficient information on water use by different plant species and how water use rates affect water flow patterns, recharge/discharge relationships, and surface water (e.g., flood) storage. Research on roughness coefficients of wetland vegetation is also badly needed. Information on relationships between animal communities and hydrologic variables, such as the duration of surface flooding, is scattered throughout the literature.

Wetland flora and fauna are well adapted to natural cycles of salinity, wetness and dryness, erosion and accretion--the "periodic pulsing" that occurs daily, seasonally, or annually. Extreme or persistent changes, such as earthquakes or impoundment, may, of course, change hydrologic conditions, and, consequently, the wetland plant community. A large body of literature documents the response of wetland vegetation to artificial increases in frequency and duration of flooding at man-made impoundments. However, long-term studies are needed to improve management techniques for maintaining the integrity and diversity of wetlands downstream from impoundments. Long-term studies are also necessary in a variety of wetland ecosystems to determine the extremes of natural variation and the effects of natural catastrophic events (hurricanes, hundred-year floods) on biological and hydrologic values.

General Hydrologic Functions of Wetlands

Question: What is known concerning the impacts of wetlands on the hydrologic cycle in terms of consumptive use of water, evaporation and transpiration, seepage, return flows (base flow?), etc.?

One of the basic concepts in hydrology is that water continually circulates from the atmosphere to the land and oceans and back to the atmosphere (65,66, many other texts on hydrology). Wetlands are landscape units where the consumptive use of water is generally very great. Most wetlands are collection points for surface water (precipitation, overland flow, channeled surface flow) and discharge points for ground water. Under certain conditions, water from some wetlands, especially depression wetlands with no surface outlets, may recharge to ground water (67,68,66). However, groundwater recharge from wetland areas will typically be less than recharge from other vegetated areas. Transpiration of wetland plants (except where water is present only for short periods) usually exceeds that of upland (62,66). Many wetland soils are typically less permeable than the sandy soils in recharge areas, so infiltration is inhibited in these wetland areas. Wetlands contribute little or nothing to base flow because of these high evapotranspiration (ET) rates, low infiltration rates and high water retention characteristics; wetlands even reduce groundwater recharge, and consequently base flows, in some parts of the U.S. (66,67,68).

Question: How do wetlands relate to the hydrology of river floodplains?

Wetlands occur on river floodplains because of the hydrologic conditions of the site. The floodplain of a river is a functional product of the stream system. The floodplain serves as an area of temporary storage of flood flows; energy is dissipated and the velocity of flood water slowed by floodplain vegetation. For these reasons, floodplain wetlands receive sediment and nutrients during periods of overbank flow, and decomposition products and detritus are washed into the river channels and moved downstream. (For details, see 69,66,70,67,68).

There appears to be little or no information regarding functional differences between different wetland types located on floodplains.

For example, roughness characteristics of floodplain vegetation are generally not well documented in the literature although they are calculated and used by hydrologists and engineers.

Questions: How dependent on groundwater flooding are wetlands in floodplains?

Groundwater may be the major factor maintaining some floodplain wetlands, but have no effect on higher-terrace wetlands that exist by virtue of surface flooding. The role of groundwater in influencing floodplain vegetation is poorly understood. This is an area where research is needed in order to predict effects of water management practices.

Flood Flows

Questions: How do wetlands affect flood flows? How can this effect be measured? How do wetland characteristics (vegetative cover, proportion of watershed, nature of substrate) affect flood flows?

This subject was addressed in the Symposium papers by Novitzki (68), Verry and Boelter (67), Doyle (70), Carter et al (66), and Dworsky (71). Floodplain wetlands serve as temporary storage areas for overbank flows. The temporary storage of surface water, combined with the retardation of floodwater velocities by floodplain vegetation, serves to reduce flood peaks and increase duration of flow.
Other processes taking place in wetlands during flooding include infiltration of water into the soil, recharge to ground water in some wetlands and increased opportunity for evaporation and

transpiration. These processes tend to attenuate the flood wave, but are generally minor relative to surface storage.

Factors such as wetland size, percentage of wetland area within a drainage basin, and position and distribution of wetlands within a basin influence the flow distribution and the time/flow response. Tributary wetlands tend to desynchronize mainstream flooding. Wetlands with restricted outlets, as well as natural river constrictions and lakes, hold back flood waters and reduce downstream flood peaks.

Standard surface-water techniques are used to analyze flow velocity, peak heights, peak discharge, and flood routing (70). Linear regressions relating basin characteristics to flood flows are useful in illustrating gross effects of wetlands on flood flows (68,67,66).

The effect of depression wetlands (no surface outlet) on flood flows has not been studied in detail (68), but it is obvious that depressions hold water that would otherwise contribute to immediate surface flow. The differences in flood flow modification between depression and slope wetlands (68) or between peatlands and non-peatlands (65) have not been sufficiently studied. Research is also needed on the effects of antecedent moisture conditions in the watershed.

Flooding in tidal rivers and estuaries is complicated by the action of wind and tide combined with stormflows generated higher in the basin. Again, temporary storage of flood water is a primary function of wetlands adjacent to estuaries and tidal rivers, but their effect may be either minimized or maximized by the tidal stage during which flooding occurs.

Base Flow and Groundwater Recharge

Question: What is the contribution of wetlands to stream low flow or base flow?

Base flow is the flow in a channel which is sustained by groundwater discharge. In several areas of the country, wetlands decrease base flow (66). This has been substantiated in New Jersey (72,73), Massachusetts (74), Wisconsin (68), and Minnesota (67). Streams on the margins of groundwater slope wetlands may have sustained base flows, but this is due to groundwater discharge from the local aquifer, not derived from the wetland.

Questions: Do wetlands function as areas of recharge? What is the overall role of wetlands in recharge of ground water? How do plant cover, wetland size and soil type affect recharge?

Recharge is movement of water into an aquifer. Recharge may occur by infiltration from the ground surface through the unsaturated soil zone to the water table; by seepage from a stream or lake; or by seepage across a confining bed into an aquifer. Most recharge takes place on drier upland sites, but some recharge may also take place in wetlands (see 66,68). Not all wetlands are recharge areas.

Maximum infiltration (recharge) from precipitation or surface flooding will occur where soils are most permeable and the water table is low. Because most wetland soils are typically less permeable than the sandy soils of major recharge areas, and wetland water tables are often high, recharge is generally less from wetland areas than from other areas. The size of a depression may affect the amount of water collected and thus available for recharge; however, larger basins may contain more silt and clay and be more impervious to infiltration (see questions on soils for more detail). Plant cover in wetlands competes with recharge for water during the growing season.

Where wetlands occur over groundwater recharge zones, they may reduce recharge somewhat, but they may also prevent the area from being developed for another use (e.g., parking lot, airport) which would effect an even larger reduction in recharge.

Question: Where in coastal areas do salt- and freshwater wetlands contribute significantly to groundwater recharge?

Most intertidal wetlands are discharge rather than recharge areas. As the tides rise, water is temporarily stored in the upper zones of marsh soils; as the tides fall, the upper layers of soil are aerated, and water moves back into the tidal river or estuary. Non-tidal freshwater wetlands on barrier islands may recharge the shallow freshwater lens overlying the deeper salt water, although part of the precipitation input is lost to ET.

Shoreline Stabilization

Questions: What shoreline characteristics are the most effective in shoreline protection, e.g., slope, area, grass height, wave steepness, etc.? What types of indigenous and/or exotic vegetation are most effective in controlling bank erosion? How might wetland fringes be constructed or shaped along reservoir shorelines to afford biological benefits and serve in lieu of "hard" shore protection?

Where plant cover exists along shorelines, the principal factors determining the degree of shoreline protection are the ability of the plants to survive prolonged flooding and their resistance to undermining. As a prerequisite to erosion control by plants, however, stable shoreline conditions must exist for a long enough period of time to ensure plant establishment. Plant establishment is influenced by slope, substrate type, wave action, length of substrate emergence, climatic and other factors. Regarding slope, most investigators of streambank erosion agree that if the river or stream has vertical banks that have been eroded and undercut, it will be necessary to grade that bank to an acceptable angle of repose before planting attempts are made. Gray (75) identifies the critical angle of repose for the establishment of vegetation on most slopes as 35 degrees, but this varies with soil type. If banks are being undercut, stone riprap will be needed at the toe of the slope in addition to vegetation (76).

According to Garbisch (77), provided that (1) a band of shore 10 feet wide or more is of suitable elevation and exposure to support marsh plants, and (2) the toe of the bank receives direct sunlight for at least four hours each day during the growing season, marsh development throughout this shore area will reduce the erosion rate. Garbisch (77) also discusses and gives a mathematical relationship for determining the distance of bank erosion that will occur before the erosion is controlled. He relates this distance to the width of the established marsh, its efficiency in trapping sand, the fraction of sand in the eroding bank, the vertical distance between the toe of the bank and the elevation of the mean storm high water, and the height of the bank. In addition, Garbisch provides guidelines for establishment of marsh plants in estuarine sites, giving consideration to tidal effects, limiting factors, site preparation, seeding, transplanting, maintenance and management.

As stated above, species most effective in controlling erosion are those that tolerate flooding and resist undermining. Plants that are resilient under pressure of encroaching water and ice are best at resisting undermining. The U.S. Soil Conservation Service (78) considers reed canary grass (*Phalaris arundinacea*) to be the outstanding grass for streambank control in frequently flooded areas. Common reed (*Phragmites australis*) provides good protection in areas below the average water level for several reasons. It is a very robust plant whose culms lignify in the autumn, so that protection is continued in the winter. Its roots and rhizomes are deep and strong and bind the soil firmly.

Purple-osier willow, white willow, and other low-growing willows are well adapted for bank erosion control because of their low growth form, branching morphology, and resiliency. Because of their many branches, these shrub-like willows can reduce the speed of currents and thereby the erosive force of the water. The springy resistance of the branches, which divide the water and slow it down by friction and by producing eddies, prevents the current from attacking the bank with its full force (79).

Spartina alterniflora has been successfully planted in the intertidal zone and *S. patens*, *S. cynosuroides*, *Distichlis spicata* and *Ammophila breviligulata* in the supratidal zones in Chesapeake Bay. Marsh establishment for erosion control has also been successful in New Jersey (77,80).

Allen (76) discusses a method of constructing shoreline wetlands using a combination of plants and an artificial revetment. The resulting composite revetment has the advantage of preventing undercutting without sacrificing vegetative cover for wildlife and fish. Garbisch (77) described a method of modifying a foreshore area by filling to suitable elevations for upland and marsh habitat development. He used a stone breakwater at the foot of the marsh development area to assist the vegetation in achieving long-term stabilization of the fill materials. He has also described shaping the foreshore area by grading the adjacent bank; here, as above, a stone breakwater is used at the foot of the development area. Sand fences could possibly be used in lieu of the stone breakwater in certain areas, depending upon the wave energies. These have been used by the Waterways Experiment Station at a marsh development project on the Columbia River (76).

Effect of Wetland Size and Location on Hydrologic Function

Questions: What is the hydrologic value of high-elevation wetlands relative to other wetlands? What are the relative values of high-elevation wetlands with various degrees of drainage, i.e., a high-elevation wetland with surface drainage compared to one without drainage?

This question is difficult to address because the use of the word *elevation* is unclear. Location of a wetland within a drainage basin is important because wetlands at higher elevations (further up tributaries away from the main stem) receive the runoff from only a small part of the basin, whereas those along the main river channel at lower elevations receive runoff from most of the basin.

High-altitude wetlands, e.g., alpine lakes and meadows, are often the source of downstream water and a collection point for snowmelt or precipitation. Establishing a relative value for high-elevation wetlands would require a site-by-site evaluation relative to whatever wetland function is being considered. Regarding flood storage, wetlands with surface drainage desynchronize flood peaks, reducing flood flows; depression wetlands hold water that would otherwise contribute to storm flows.

Question: How do variations in wetland size influence various functions and values?

The following generalizations can be made:

(1) Sediment trapping and erosion control: it is probable that the amount of wetland edge, rather than size, is most important. Silberhorn et al. (80) state that any marsh two feet or more in average width has significant value as an erosion deterrent and is capable of filtering sediment. Garbisch (77), on the other hand, specifies 10 feet as a minimum width for marsh development in order to reduce erosion. Gucinski (81) states that because of their geologic and hydrologic settings, small marshes at the headwaters of many small creeks usually trap more sediments and nutrients than a single large marsh in a lowland which probably has a lower runoff volume.

(2) Flood storage: the larger the wetland, the more area is provided for flood storage and velocity reduction.

(3) Groundwater recharge: ephemeral or temporary wetlands are probably the most effective wetlands in terms of recharge. Recharge often takes place along the wetland margin and therefore the length of edge may be important.

(4) Water supply indicators: a big wetland may indicate more groundwater discharge at that point, although any discharge is offset somewhat by increased consumptive use by plants in a larger wetland.

(5) Water quality: retention time is probably longer in large wetlands, increasing the opportunity for water quality changes to occur.

Size, geometry and configuration of wetlands are all important factors. A minimum size or "critical mass" of wetland is necessary for certain biological functions to become established. Hydraulically, wetland size is a function of the flow system operation. In turn, the wetland, as a part of the flow system, affects the magnitude of various flow components, i.e., flood flows, groundwater discharge, evapotranspiration. The hydrology of larger wetlands is more complex than that of smaller wetlands, and the hydrology of larger wetlands may vary more regionally. The larger the wetland, the less sensitive it should be to stress.

Perhaps the most valuable hydrologic function of wetlands is floodwater storage or the ability to reduce flood peaks by large amounts. Generally if a watershed has 15 percent of its area in wetlands and/or lakes, its flood peaks will be 60 to 65 percent lower than they would be in the absence of the wetland/lake area; and if wetlands or lakes occupy 30 percent of a watershed, there will be a further reduction in flood peaks up to about 75 or 80 percent (67,68,66).

The flood-control effectiveness of any wetland depends on its size, hydrologic character, and location in the drainage basin, as well as the hydrologic character, size, flooding characteristics, and distribution of streams or rivers in the basin. The flood-control effectiveness of wetlands is generally greatest during high-intensity, short-duration storm events, which generate the largest floods, and is less for smaller floods resulting from longer-duration rainfall and/or snowmelt.

It is possible for an isolated individual wetland to be a singularly effective flood control area, but more often an individual wetland is only one of an integrated series of wetlands and water bodies whose overall inter-related functioning determines the total hydrologic character of a river basin. Most wetland areas have some degree of flood-modifying effect in river basin systems and seldom does one wetland, due to its particular functioning within a system, have an adverse magnifying effect.

Effect of Soils on Hydrologic Function

Question: What is the importance of soil type, composition and permeability to wetland function and maintenance?

Wetland soils are either mineral or organic, and range from permeable to impermeable. The chief hydrologic functions affected by wetland soils are floodwater storage, infiltration (recharge), and change in water quality. Flood storage is chiefly above-surface, and storage in the soil is a small fraction of total flood storage, so differences among soil types are minor. Infiltration and storage in the soil will be greatest if the soil is dry immediately before flooding, with maximum infiltration occurring in dry, permeable soils. Water-quality changes should be greater where soils have large ion-exchange capacity (organic) or great surface area and slow water movement. "Wetland maintenance" presumably means maintenance of wet conditions, or retention of water, which would best be served by relatively impermeable soils that are rarely or never dry.

Water infiltrates (recharges) soils of different composition in direct proportion to their permeability. Water rapidly infiltrates coarse sands or gravels that have high permeabilities. Shallow fibric peats, silts, clays and deeper sapric peats follow in decreasing order, by infiltration rate.

Soil composition, soil type and soil permeability are only three of the factors that determine the existence and hydrologic function of wetlands, but they are exceedingly important as they affect the movement of groundwater, the level of the water table, the size of the capillary fringe and the availability of soil moisture and nutrients to plants. Much has been written about both peatland and non-peatland soils (see 66,67,82,83,84,85,86,87,88,89,90 and 91).

Questions: Comparatively, what effect does water transport through saturated and unsaturated soil have on flow capacity, time, etc.? How does this relate to water quality?

The velocity at which water moves through the soil depends upon the hydraulic gradient, the porosity, the hydraulic conductivity, and the moisture content of the soil (saturated or unsaturated). Comparatively speaking, water moves rapidly through stratified deposits of sand and gravel and through the active horizon of organic soils. It moves less rapidly through silts and clays and through the well-decomposed horizons of organic soils (66,67). The longer water remains in contact with soils of different types the more it will change because of solution, ion exchange, etc.

In northern peatlands, horizontal flow is rapid through the upper 30 cm of soil in a saturated layer, and slower through the deeper layers. The flow of water through this active horizon is primarily a function of the slope of the peatland and the hydraulic conductivity of the peat in this horizon. When peatlands are drained, direct delivery of rain to channels is very rapid, and storm peaks are higher than they would be with no drainage. (See 82,83,87, 88,67 and 92.)

When runoff rates (and water tables) are low, water movement is slow and all constituents are typically more concentrated. At average and high runoff rates or water table elevations, water movement is rapid, and water quality changes occurring within the wetland are less pronounced. When wetlands are drained and cleared of vegetation, the breakdown of organic soil can lead to increases in concentrations of iron, manganese, magnesium, potassium, and total phosphorus in water associated with the wetland according to unpublished data reported by E. S. Verry.

Relationship Between Hydrology and Wetland Plants and Animals

Questions: In what ways do various wetland plants affect patterns of water circulation in wetlands, and vice versa? What is the appropriate analysis of roughness coefficients to be used in hydraulic and hydrologic analyses of coastal wetlands?

In non-peatlands, water circulation patterns are influenced by the vegetation itself--its density, distribution and location relative to open water or shoreline. Vegetation retards the flow of water by friction (68,66,76) and absorbs wave and current energy. Roots and stems trap detritus and sediment, causing eddying and localized diversion of water flow. This is also true of estuarine wetlands which may or may not contain peat. In turn, currents and waves sort and redistribute sediments, seeds and vegetatively active plant parts and determine where plants can or will become established (76).

In peatlands, both northern and southern, the primary effect of plants on water circulation is manifested in the development of an organic soil. In the North, many peats have fibric horizons near the surface. Most water movement in these peats is horizontal through this active horizon, generally within the upper 30 cm. The development of sphagnum domes in large northern peatlands creates a precipitation-derived water table with flow lines radiating from a central ridge. Sphagnum domes can divert groundwater flows around them.

Water tracks in large peatlands in the North and South indicate broad concave drainage ways that carry water from relatively high areas to lower areas. The greater depth of water in these drainage ways usually excludes tree growth. Plants that do better in higher pH conditions and in waters with a high calcium content grow where groundwater enters a peatland and begins to flow horizontally through the peat. Northern white cedar is usually indicative of this condition in Minnesota and Wisconsin. As groundwater continues to flow through a peatland, it loses some of its nutrients because of large and constantly renewing cation exchange sites on the peat, and thus the vigor of the groundwater-loving plants may diminish as the "potency" of the groundwater diminishes.

In northern peatlands, tree growth is generally best where slopes are greater than 8 feet/mile and poorer where slopes are less than 8 feet/mile. The differences in slope provide for slight changes in root aeration conditions and a greater flux of water-borne nutrients. Thus plants and water circulation interact strongly in northern peatlands.

For additional information on northern peatlands see Verry and Boelter (67), Boelter and Verry (82), and Heinselman (59,60). For additional information on water flow and vegetation relationships in southern peatlands see Spackman et al. (93).

More research is needed on the measurement and hydraulics of sheet flow and its effect upon the development of peatlands and the distribution of peatland vegetation, especially in the southern

United States. In addition, research is badly needed on roughness coefficients of wetland vegetation as related to species, stand density and morphology. Manning's N (the roughness coefficient) should be determined for different vegetation types. Some coefficients and references are listed in Carter et al. (66). Water use by plants affects water flow patterns, and there is insufficient knowledge on the rate of water uses by different species, the effect of ET on recharge and discharge relationships, and the effect of different plants upon the water table and vice versa. Both naturally occurring species and those planted by man need to be studied.

Question: How does water flow rate through a wetland affect the pattern of colonization and the long-term conditions and species composition of benthic fauna?

Water flow rate affects accumulation of organic soils or sediment, which determines substrate type. Substrate type affects the vegetative community. All of these affect benthic fauna. In lakes, rivers and estuaries, waves and currents sort the marginal sediments on the basis of particle size and energy regime. Benthic species composition along these shorelines is a function of the substrate type, wave energy, water temperature, water level fluctuation, oxygen and nutrient availability (see 40). In vegetated wetlands, the distribution of benthic fauna is dependent also upon the species composition of the vegetation.

Question: What is the relationship between the duration of surface water, and soil, plant, and animal communities in the wetland environment?

In general, permanently flooded areas or regularly inundated tidal areas have the potential for accumulation of organic soils; little accumulates in wetlands where water is absent part of the year. The oxygen content of flooded soils is generally very low and anaerobic decomposition dominates while soils are flooded, unless the water turbulence or oxygen content of the surface water is extremely high.

Plant communities vary according to the timing and duration of flooding, with duration being the most critical during the growing season. Inter-specific tolerances to (and dependencies upon) frequency and duration of flooding largely control the stratificiation of species on the river floodplain, the lake margin, and indeed, in almost all palustrine, lacustrine, riverine and estuarine wetlands (40). Plant communities also vary according to the soil type (organic or mineral), which is influenced by the duration of flooding as discussed above.

Periods of draw-down or surface drying are essential to the germination of most species and the survival of many seedlings (69,76). There are numerous references in the literature on the effects of duration of surface water on plant communities of both tidal and non-tidal wetlands. For lists of references see Bedinger (69), Carter et al. (66), and Allen (76).

References to the relationship between the distribution of animal communities and duration of surface flooding are scattered throughout the literature. (For a partial summary of references see references 40 and 44). In general, nutrient and oxygen availability and substrate play a crucial role in determination of animal community composition (see response to preceding question). In lakes, water level fluctuation and spring flooding influence the initiation and success of fish spawning (71).

Effects of Natural and Artificial Changes in Wetland Hydrology

Questions: What changes in wetland values are effected (caused) by natural events such as extremes in dry or wet years, catastrophic floods, etc.? What is known concerning the storage and yield requirements to protect wetlands from prolonged drought periods? How do seasonal flooding and 100-year floods of record benefit an estuary?

Wetland flora and fauna appear well adapted to the natural cycles of wetness and dryness, erosion and accretion, and salinity--the so-called "periodic pulsing" that occurs annually, semi-annually, or on a less frequent basis.

Although wetland plant and animal communities are characterized by resilience and wide tolerance to desiccation, flooding, oxygen deficiency, salinity, etc., the pattern and composition of these communities may be shaped by the extreme events--hurricances, catastrophic floods, extreme droughts. Where more than one species can tolerate existing conditions, it may be the extreme event that allows one to become established and dominate the other. Extreme hydrologic events may cause changes in stream, lake, estuary or barrier island morphology. Changes in current and wave patterns, flow and transport characteristics, and water level are not unusual. These changes may indeed shift values--for example, destruction of vegetation may lessen erosion control; destruction of sensitive organisms by increased water levels or saltwater intrusion may alter habitat, decrease or increase harvests, or alter landscape aesthetics.

During dry periods, wetland soils, especially organic soils, retain large amounts of soil moisture that does not drain to gravity but is still available to plants. Severe droughts do, however, result in wetland change through invasion of less water-tolerant species, germination of seeds and survival of seedlings, decomposition and settling of organic soils, fires, and opportunistic farming. Research has only shown that wetlands in their natural unditched state are less vulnerable to drought (66,67).

Seasonal flooding is a normal estuarine phenomenon. High river flows dilute salinities in the upper estuary and bring in nutrients and sediments. The nutrient inflow may be timed at the beginning of the growing season. The 100-year flood causes increased dilution and may destroy sensitive organisms (e.g., oysters) but the estuary recovers relatively rapidly. Long-term studies are needed to determine the natural response of estuaries to changes in yearly river flows.

Question: How sensitive are white cedar and hardwood swamps to long-term increases in water levels due to artificial impoundment of water?

Northern white cedar, black spruce, or tamarack will slowly die over one growing season if water levels are maintained 6 to 10 inches higher than normal. Needles may persist with a drab color over winter and fall off the next spring. It takes two summers of continuous flooding to kill brush species in northern peatlands. There are many references in the literature to the flood tolerances of tree species (66,69,76). A large body of literature documents the response of wetland vegetation to artificial increases in frequency and duration of flooding at man-made impoundments (see papers by Carter, et al (66), Novitzki (68), Verry and Boelter (67), Bedinger (69), and Allen (76)). Wetland vegetation is likewise sensitive to decreases in duration and frequency of flooding, an aspect that deserves additional research.

Question: What information is available on the manipulation of lakes and downstream water releases to maintain the integrity and high species diversity of downstream wetlands?

This question poses two problems: (1) the hydraulics of flows, and (2) the effect of frequency and duration of flooding on wetland vegetation. The hydraulic problems of predicting downstream gage height and flood wave velocity are amenable to solution by standard procedures. The change in species composition of the wetland with a change in frequency and duration of flooding is less well-known. Generally, any change in flooding characteristics can be expected to produce a change in species composition.

The rate of change is not known, but the trend of the change or the ultimate change may be estimated if there is a background of observations on the species and the hydrologic environments involved. Predictions of the change may be done on a conceptual basis or with the utilization of stochastic or deterministic models.

Manipulation of lakes and downstream water releases should be designed to simulate the natural conditions as closely as possible. If an attempt is made to simulate and maintain natural conditions (timing, duration, and magnitude of flooding and flood flows), downstream impact should be minimized and species adjustment will be gradual. Long-term studies are needed to improve management techniques.

Question: What is the effect of water fluctuation on developing wetlands on the perimeter of impoundments, and do fluctuations retard or enhance the ecological succession in these shoreline wetlands?

Natural systems are subject to cyclical or non-periodic fluctuations in water level, developing wetland plant communities adjusted to this dynamic situation. Perennial plants such as cattail and willow tend to have a relatively wide tolerance to desiccation and flooding and are relatively permanent members of the wetland plant community; the annual plant composition generally varies from year-to-year depending upon flood stage during the growing season and seed availability and germination. Ecological succession in natural wetlands is not unidirectional, but is cyclical in response to water level periodicity.

In lakes having fluctuating water levels (i.e., hydroelectric and water-supply reservoirs), materials eroded by waves cannot accumulate and form a wave-breaking terrace (as happens in a natural lake) and in consequence, a large vertical range of the lake margin is intermittently eroded (76). Hence shorelines of impoundments with fluctuating water levels are extremely unstable in terms of natural plant communities.

Hoffman (94), speaking of shoreline communities on lakes Oahe and Sakakawea, contends that the possibilities are remote for shore vegetation to remain indefinitely in a given area. However, he goes on to say that even if shore vegetation is not permanent, its development can be enhanced, and the mosaic of shore communities that shift and change in composition in relation to factors of the environment can itself be considered a permanent part of the shore environment. Shorelines subject to severe fluctuations in water level may have vegetation communities which never succeed beyond the disclimax stage.

The random aspect of impoundment fluctuations makes it difficult to find adaptable plants for artificial planting. We are slowly developing some expertise in this area (76).

4. WATER QUALITY MAINTENANCE VALUES

Panel Convenor: Dr. Robert H. Kadlec

Water passing through a wetland undergoes changes in quality. Surface flow is slowed, allowing sedimentation and adsorption of some materials to sediments. Larger particles suspended in the water are filtered out by aquatic vegetation. Some dissolved materials are precipitated when inflowing water comes in contact with water of a different quality--for example, when fresh water meets salt water in an estuarine wetland, or when surface runoff meets iron-rich groundwater seeping into a freshwater wetland. In addition, many water quality changes occur as a result of biological activities in the wetland: oxygen is added to the water as a recult of photosynthesis; nutrients, metals, hydrocarbon pollutants, and other chemicals are taken up by plants during the growing season; some of these are later released through plant decay; organic materials are decomposed by microbiota on and in wetland sediments.

The water quality changes that occur naturally in various unstressed wetlands, the extent to which wetlands can be relied upon to clean up waters polluted by non-point sources, the extent to which wetlands can be used to treat waste, and the sensitivity of wetland-dependent animals and plants to a whole range of water quality conditions are all relevant to the values of wetlands in maintaining water quality.

Summary

The ability of wetlands to trap water-borne sediments and remove nutrients from secondary wastewater has been demonstrated many times. It has been done in many wetland types, and has been evaluated economically. The large body of scientific information on water quality maintenance by wetlands is quantitative, but largely site-specific. Research on wetland hydrologic budgets, mass balance and compartmental studies on the movement of materials in wetlands, and the efficiency of different wetlands in assimilating water-borne materials are all badly needed.

There is still very little information on nutrient budgets of wetlands under either natural or stressed conditions. Neither is there good information on the consequences of stress to wetland fauna. Secondary sewage effluent may contain toxic substances, but the effects of introducing them into wetlands and the potential for transferring these substances through the food web or concentrating them in sensitive species are not well studied.

The capacity of a wetland to assimilate water-borne materials is determined mainly by hydrologic and sediment parameters. However, there is no standardized method of ascertaining when the assimilation capacity of a wetland is about to be reached.

There is a clear need for:

(a) information on the long-term effects of waste loading on wetlands;

(b) information on the effects of contaminants on a variety of wildlife and on the potential for transferring contaminants through both detrital and direct consumption food webs;

(c) information spanning a variety of wetland systems.

Plant uptake of heavy metals, chlorinated hydrocarbons, and other toxic chemicals occurs primarily via wetland sediments and water, although chlorinated hydrocarbons may also be taken up following volatilization. The extent of uptake depends on the particular substance, the plant species, and the substrate characteristics that determine the availability of the substance to the plant. Certain compounds, such as mercury or arsenic, are solubilized under reduced conditions or can be made available to plants through methylation. Other compounds, such as cadmium, are solubilized under acidic, oxidized conditions, that are characteristic of other wetland environments.

Transfer of such compounds through the food chain depends on the extent to which the particular chemical is translocated to plant parts that are either consumed directly by herbivores or broken down and consumed as detritus. There is evidence that heavy metal concentrations increase from living plant tissue to dead tissue to detrital material, and also that aboveground parts of emergent wetland plants generally contribute more detritus than belowground parts. Translocation varies with the particular chemical and plant species. Thus food chain transfer is known to occur with mercury but may not occur with lead, since it is not usually taken up into the aerial parts of plants.

In general, studies of plant uptake of heavy metals and other chemicals have ignored the food chain ramifications of uptake. Research is needed on the ultimate fate of toxic materials both in artificial wetlands and in natural wetlands.

Water Quality Values of Different Wetland Types

Questions: What are the major water purification functions of the various types of wetlands? At what rates do these purification processes occur, and what are the threshold levels of organic and inorganic nutrient loadings for each wetland type?

The list of major purification functions of any given wetland is very long (filtration, sedimentation, anaerobic decomposition, biological assimilation, etc.), even for a small number of water quality parameters, such as nitrogen, phosphorus, and sulfur. How such functions change wiTh wetland type is simply a matter of different weights of different processes in different wetland sites. The function of nitrogen removal might be one example. In some tidal wetlands, nitrate is assimilated during the summer growing season; in some other wetlands (specifically, central Florida wetlands dominated by herbaceous plants), nitrogen is assimilated during the entire year. For a good discussion of the purification functions of freshwater wetlands, see Good et al. (95); for information on saltwater wetlands, see Valiela et al. (96).

Very few data exist on the rates at which any processes occur in wetlands. Threshold levels of nutrient loading have almost never been measured. An exception is the work by Stewart and Ornes (97).

Question: What are the relative water quality values of the various types of freshwater wetlands?

Filtration, sedimentation, and pollutant assimilation values of perched, open, freshwater wetlands appear to be high over short-term periods (98), but there are serious questions about the long-term picture. Annual nutrient removal efficiencies of palustrine wetlands depend on the dominant plant species. All such wetlands trap sediments, but they may or may not trap nitrogen and phosphorus (on an annual basis). Some wetlands associated with lakes may be nutrient sources (99); other lakeshore wetlands are nutrient and sediment traps. Riverine wetlands are known to alter the quality of water flowing through them, but there are no data on their annual nutrient budgets. Freshwater tidal wetlands are rapid flow-through systems but seem to retain nitrogen and phosphorus during the growing season. When treated with sewage effluent, they seem to be capable of holding some additional nitrogen, but not additional phosphorus.

Wetlands can play an important role in reducing the impact of non-point sources of pollution. The value of wetlands in any specific situation will depend on the characteristics of the local landscape, i.e., drainage patterns, and the type and size of wetlands in the landscape. The best sources of information and ideas are Drew (100) and van der Valk et al. (101).

Question: How sensitive are bog areas to changes in pH and increased nutrient levels?

Bog areas in Michigan appear to be able to absorb increased nutrient inputs and to alter the pH of incoming waters, so that pH 10 waters entering a bog will have background pH levels, well below 7, within a few hours. In many peat-based systems, e.g., peat meadows in Florida, the situation is similar.

Question: What interactive relationships occur between bottomland hardwoods and water quality?

There are almost no data to answer this question. Papers by

Kitchens et al. (102) indicate that bottomland hardwoods may be capable of processing nutrients. Similar evidence comes from Brinson (103) and recent papers by Rykiel (104) and Schlesinger (105).

Questions: To what extent can the creation of wetlands along streams improve the overall water quality of the stream? To what degree do shoreline wetlands that develop around reservoirs affect the water quality of the lake? Do wetlands at the upstream ends of small flood control reservoirs act as sediment and/or nutrient traps, and thus reduce the trophic levels of the reservoirs, which in turn increases the useful life of the reservoirs and makes them more attractive and healthful for recreation?

Natural marshes along the margins of streams and lakes can be effective in trapping nutrients in water passing into the water body from upland areas (106,107). In a study in Hungary, a reed swamp bordering Lake Balaton was shown to be very effective in assimilating nutrients in wastewater applied at the upland edge of the swamp (108); similar results have been reported from Poland (109). The Dutch are presently creating wetlands around the Ysselmeer, in an attempt to improve the lake's water quality. Other European work, however, indicates that shoreline emergents can pump nutrients into adjacent lake waters (99).

In many cases, the role of shoreline wetlands in maintaining water quality is not apparent until the wetlands are destroyed. In Florida, for example, water quality generally declines when fringing mangrove swamps are replaced by bulkheads. The importance of fringing wetlands in maintaining water quality is likely to increase as pollution from point sources is eliminated and pollution from non-point sources is recognized as a major problem. The effectiveness of riverine marshes in controlling non-point-source pollution is presently being studied in Georgia and New Jersey, but data are not yet available.

Although more work needs to be done, there is some evidence that, with proper design of fringing wetland vegetation, stormwater retention basins created to mitigate flood peaks in urban areas could improve water quality significantly, through nutrient removal and sediment trapping.

Regarding the sedimentation question, as Patrick (110) points out, it is possible for dams to upset the balance of sediment accretion, compaction, and decomposition in delta wetlands such that wetlands are lost downstream of the dam and created in the reservoir behind the dam. There are no published studies of this shifting of wetlands.

Nutrient and Waste Assimilation Capacity

Question: Wetlands have been known for their uptake of nutrients from storm flows during the growing season, yet during the non-growing season the decay of aquatic vegetation releases nutrients. What is the annual nutrient budget for water flowing through wetlands?

Although plant decay does release nutrients during the non-growing season (111), the fate of those nutrients depends on what happens in the wetland sediments. Nutrients released into the wetland during the non-growing season may not leave the ecosystem, although such loss of nutrients is known to occur in some cases.

The amount and timing of water flow through the wetland have a critical influence on the annual nutrient budget. A tremendous amount of nitrogen and phosphorus in fresh litter is leached out within 24 or 48 hours (111). If there is significant water outflow during this period, then these nutrients will be lost from the wetland, but if the water in which they are dissolved can be retained within the wetland long enough for them to be assimilated, there will be no net loss from the wetland (112). In tropical areas with wet and dry seasons, decomposition occurs primarily during the dry season when the water is drawn down. When the wetland is flooded again, large amounts of released nutrients may be lost from the system. Losses during the wet season can be great enough that, on an annual basis, the wetland functions as a nutrient source.

For information on nutrient budgets of freshwater wetlands, see van der Valk, et al. (101) and Whigham and Bayley (113); for salt marshes see Valiela et al. (114) and Valiela and Teal (115).

Questions: Under what conditions can wetlands be used to treat waste effluent, and for how long and at what carrying capacity? What is the capacity for "open wetlands" to treat organic waste effluents? What is the capacity of "closed wetlands"? Compared to non-perched wetlands, how significantly do perched wetlands affect water quality?

There have been no studies comparing the assimilation capacities of different kinds of wetlands. Individual studies have been site-specific. One difficulty in making any comparison between wetlands is that the assimilation capacity of a given wetland is not constant, but changes as the wetland vegetation and other physical features of the wetland change over time.

Measurements of groundwater flow and quality are extremely difficult to make, and consequently most wetland water quality studies have been done on perched, open wetlands (rather than on non-perched, closed wetlands, which are connected to groundwater), where the water inputs and outputs are easier to get at (but see Odum and Ewel (116,117)). For information on an open wetland in Michigan, see Kadlec and Tilton (118); for general information on the use of freshwater wetlands for sewage effluent treatment, see Tilton et al. (119) and Tourbier and Pierson (120).

One East Coast salt marsh treated with fertilizer containing sewage sludge retained a high proportion of the input of nutrients and many metals during an eight-year treatment period (121,122,123,124,125). Invertebrates and plants were more productive, and few deleterious effects on salt marsh biota were evident (126,127,128,129,130). The sediments of this salt marsh were 40 percent carbon and very anaerobic. In marshes with less carbon or more aerobic conditions, assimilation would probably be proportionately less effective. However, we simply do not have normalized data allowing comparison of the different wetland systems that have been studied. Research is ongoing, but it will be a few years before we can give engineering recommendations for the use of marshes in treating sewage effluent.

Questions: Can wetlands be managed to maximize organic waste reduction from introduced effluent? What ecosystem parameters are important in determining the capacity of wetlands for waste treatment? How critical are flushing rates and tidal flows to the capacity of a wetland to remove heavy metals, pollutants, sediments, etc., from water?

Organic waste reduction by wetlands appears to be manageable through hydrologic control, and not through many other mechanisms. Waste reduction is effected by sedimentation and microbial processes, and these are controlled by residence time and sedimentation rates. There is evidence from Dutch work on artificial marshes treated with primary sewage effluent (131), and from work on natural marshes in the United States (132), that with increased retention time there are dramatic increases in BOD and COD removal.

The main factors determining the capacity of a wetland for waste treatment are hydrologic (the water regime) and sediment characteristics --e.g., whether the sediment is clay or sand, and how much organic matter is present. The presence of organic matter is particularly important to the build-up of microbial populations, which are responsible for most of the chemical transformations involved in waste assimilation by wetlands. Flushing rate (turnover time, residence time--whatever you want to call it) is a very important parameter to consider in evaluating the ability of a wetland to remove any pollutant from the water. Vegetation is also important, not only for its direct role in waste assimilation, but for its role in maintaining appropriate sediment conditions. For further information on the factors controlling waste assimilation in tidal wetlands, see Correll et al. (133) and Whigham and Simpson (134).

<u>Questions</u>: <u>How is the pollution absorption capacity of a wetland system evaluated? How can we recognize when this capacity is reached or is about to be exceeded?</u>

There is no standardized methodology for evaluating the pollution absorption capacity of a wetland. Procedures (and conclusions) depend on what aspect of that capacity you are interested in. For example, if you look only at the quality of wetland outflow and compare it with standards for trout streams, you may come to very different conclusions than if you looked at mass balance for the wetland.

As far as recognizing when a particular wetland's pollution absorption capacity is reached or is about to be reached, we do not yet have enough long-term comparative studies of wetlands to know which variables are critical indicators for each type of wetland (135). Death of wetland plants is too crude an indicator to be useful. To recognize when a wetland's capacity is about to be reached, it is necessary to have mass balance data obtained over a long period of time on that wetland. For this reason, long-term mass balance studies of pilot projects are recommended before wetlands are used for waste treatment.

Uptake of Heavy Metals, Hydrocarbons, and Other Pollutants

Question: To what extent do salt and freshwater marshes uptake heavy metals and other pollutants?

There is no question that marsh plants--both freshwater and saltwater--can take up metals and other compounds, such as chlorinated hydrocarbons, from the marsh substrate or from the water flowing into the marsh. The extent to which this occurs is complicated by variables related to the species of plant, the quality of the substrate, and the particular chemical--metal, chlorinated hydrocarbon, or other compound. For most compounds, what needs to be understood is the relationship between the sediment characteristics affecting the solubility and availability of the chemical, and the transport of the chemical into a plant tissue. Uptake of both heavy metals and chlorinated hydrocarbon compounds is enhanced by solubilizing conditions and decreased by conditions that associate the compounds with particulate phases. Hence certain compounds, such as mercury or arsenic, which are solubilized under reduced conditions or which can be methylated, may be of more concern in wetland environments than other compounds, such as cadmium, which are solubilized under acidic, oxidized conditions that are not characteristic of wetland substrates. For chlorinated hydrocarbons, it should be noted that there are two known mechanisms of uptake--(1) direct absorption and translocation, and (2) volatilization and sorption--and that the latter mechanism may have a very important effect on the concentrations of chlorinated hydrocarbons in plant tissues. See Khalid et al. (136) for a comparative review of factors influencing the uptake of metals by marsh vegetation.

Although some data exist on pollutant uptake by natural marshes treated with sewage (see, for example, 122,123,124) or by artificial marshes created on dredge spoil (see 137), the extent of uptake has not been quantified in many natural systems. Lunz (137) reviews what is known concerning uptake of metals and chlorinated hydrocarbons.

Questions: Is there any selectivity of uptake of heavy metals by particular wetland plant species? What is the distribution of heavy metals within the wetland vegetation? Where are heavy metals concentrated within particular wetland plants (e.g., Spartina alterniflora)? Are the heavy metals in plant tissues available and utilized by food chains, or are they irreversibly bound and eliminated from the food chain?

There probably is some selectivity of uptake of heavy metals by particular wetland plant species, but the available data are insufficient to indicate any trends.

The distribution of a metal within a plant depends on characteristics of the metal, the plant, and the uptake pathway (138). Heavy metals may enter wetland plants from the soil, the water, or the air. Lead, for example, may be an airborne contaminant deposited on aerial plant tissues, or it may enter the plant from the soil, in which case it tends to be localized in underground tissues. Translocation of other heavy metals from roots to aerial parts of plants has been demonstrated in salt marshes, but the distributional patterns of different compounds within plants vary so widely that no generalizations can be made. In some salt marsh plants, heavy metal concentrations apparently increase going from live tissue to dead tissue to detrital material. It has been suggested that the increase may simply be due to higher ash weight concentration as the plant dries. The mechanism for detrital concentration is not known.

Food chain transfer of metals associated with plant tissues will depend on the metal, its form, and its location in the plant (138,139). Preliminary considerations for evaluating plant tissue concentration data include the importance of the plant tissue as a food item for fish or wildlife, the turnover rate of the standing crop, the detrital production potential of the plant, and the refractory nature (resistance to decomposition) of the plant tissue. One study of pollutant uptake by an artificial freshwater marsh created on dredge spoil (140) selected the plant tissues to be examined on the basis of their value as wildlife food. Metals were detected in these tissues, though at lower concentrations than those generally observed in dose-response studies of upland crop plants. The study was carried no further. Other studies have demonstrated food chain accumulation of mercury and cadmium; at least one study (141) has shown that food chain accumulation of lead does not occur.

Question: Are synthetic materials--PCB's, DDE, toxaphene, etc.--taken up by wetlands and removed from the food chain?

Synthetic materials, including chlorinated hydrocarbon compounds, are taken up by wetlands. Plant retention of such materials probably occurs by surface tissue contamination as well as by internal uptake and translocation. Food chain effects are not known.

Question: To what extent does the uptake of heavy metals or other pollutants by marsh plants interfere with, or have chronic effects on, wetland plants and their consumers?

Toxicological studies to determine the effect of metals and other pollutants on wetland plants and their consumers have not been conducted. Concentrations of chemicals observed in wetland plants are generally lower than those observed in upland crop plants during dose-response studies, but the relative tolerances of wetland versus upland plants and fauna to chemicals taken up by plants are not known. Estuarine organisms do have some mechanisms for coping with high concentrations of metals and other compounds. Oysters can produce vacuoles of crystalline metal salts and thus isolate such compounds from their metabolic system. Other animals, such as crustaceans, can transfer environmental pollutants or metabolic by-products into their exoskeleton, which is shed periodically. There is some question whether the pollutants in the chitinous exoskeleton can be transferred to higher consumers, e.g., fish, since chitin is not a digestible material.

Question: If the quality of the water inundating a particular wetland community is improved, will the heavy metals or other pollutants previously taken up be released back into the improved aquatic system?

Some pollutants probably will be released. Heavy metals are associated with sediments and soils of wetland (and upland and aquatic environments) in various forms. Some are in solution within the water that fills the spaces between soil particles; some are weakly attached to particle surfaces or present on particle surfaces with precipitates of other chemicals which can be dissolved to release these metals when environmental conditions change; some are trapped in mineral crystals; and some exist in other forms. Metals associated with these different phases vary in the ease with which they can be released and made available for biological uptake. According to Jenne and Luoma (139) "the biological importance of trace elements may be principally due to their regulation of equilibrium solute concentrations in the associated waters via sorption-desorption and dissolution-precipitation reactions." This suggests that improving the quality of the water inundating a wetland can release those forms or phases of metals in wetland soils which are dissolved or can be dissolved under the range of environmental conditions found there. In most instances the metals that might be released include some whose concentrations have increased due to pollution from industrial, domestic, and urban waste discharges. Under "pristine" to moderately contaminated conditions, the "potentially soluble" metals might account for about 10-30 percent of the total sediment metal levels. Under highly contaminated sediment conditions, the percentage may be greater. However, it is not appropriate to consider any percentage of the total mass of metals in a sediment reservoir as definitely available or releasable when water quality improvements are effected. The percentage actually released will depend not only on the percentage in "potentially soluble" form but on conditions that influence the movement of solute through the soil medium and other site-specific soil characteristics.

Pollutants other than metals may behave differently; less is known about them. Chemicals such as chlorinated hydrocarbons are unnatural and not fixed or trapped in mineral crystals like metals. These compouNds are typically characterized by low water solubility and association with solid phases, but are bioaccumulative to a great extent. As indicated by Lunz (140), very little is known about the behavior of these chemicals in wetland environments.

<u>Question</u>: <u>Can wetland/estuary sediments be used as indicators of pollution level fluctuations and water quality over short- or long-term periods?</u>

In wetlands or aquatic systems receiving urban, industrial, or agricultural runoff, sediments usually do reflect runoff water quality. For example, a wetland system in northern Michigan which has been receiving wastewater for 20 years has, instead of the normal peat substrate, a black, jello-like bottom--a dramatic indicator of water pollution. Hundreds of publications refer to sediment contamination by metals from plating or shipbuilding activities, kraft mill effluent, or organic loading from sewage effluent.

Various predictable and unpredictable conditions determine the spatial relationships between sources of pollution (either point or non-point) and the sedimentary response. Of special importance are hydrologic conditions, which control sediment entrainment, transport, and deposition; watershed geology, which affects soil composition, conductivity, pH, alkalinity, etc.; and the aquatic ion pool available for adsorption/desorption, flocculation/precipitation, and buffering reactions. To a lesser extent, drainage from adjacent natural systems (especially wetlands) containing organic materials (such as fulvic acids) capable of chelation/complex formation influences chemical exchange between the water and the wetland sediments.

Pollutant concentrations in the sediments are usually so much greater than those in the overlying waters that short-term changes in water quality do not cause detectable movement of materials between sediments and water. Thus short-term fluctuations in water quality cannot be measured by observing sediment quality. Longer-term fluctuations can be reflected in sediment quality, as evidenced by lake restoration studies, but the sediment response may also be site-specific. Hence, in Lake Washington, phosphorus levels in the sediments have declined since the period of waste loading, whereas in Shagawah Lake the sediments have not responded to water quality improvement, apparently because the aquatic macrophytes are not pumping the phosphorus out of the sediments and back into deeper water.

Effects of Water Quality on Wetland Plants and Animals

Questions: What are the maximum, minimum, and preferred salinity ranges tolerated by wetland plants? What effect does salinity have on competition and dominance among various species of plants?

These questions are well answered by Reimold and Queen (142) and the series of papers by Irwin Ungar (e.g., 143, 144).

Questions: What effect do varying degrees of turbidity have on BOD, COD, photosynthesis, temperature, pH, salinity, and concentrations of toxic compounds in wetlands? In what ways does turbidity affect quality of wetland habitat for species at high trophic levels?

To imply cause and effect between turbidity and most of the parameters listed is incorrect. However, turbidity is an important water quality characteristic of wetland systems. In Florida coastal wetlands, for example, a certain amount of turbidity is necessary to maintain the wetland biota, in the sense that turbidity is the result of suspended zooplankton and detritus, which are important food sources for species such as oysters. Dams which cut off the flow of sediment and detritus into an estuary can be very deleterious to estuarine wetland populations.

High turbidity in inland wetlands kills aquatic plants and invertebrates, upon which waterfowl and also fish depend, and so has disastrous effects on these higher-food-chain organisms. The literature discussing turbidity effects on fish and invertebrates is extensive.

Questions: Are chemical or biological pollutants concentrated or stratified at the fresh/salt water interface in the estuary? Can this effectively repel or pose a barrier to fish movement?

Most wetlands, because they are relatively shallow and have high vertical shear, are vertically unstratified. In vertically stratified estuaries, it is not likely that chemical or biological pollutants would be concentrated at an interface (an interface would in fact be difficult to define), but it is possible for the water quality of upper and lower layers to differ. The lower layer could, for example, be more anaerobic than the upper layer. Vertical differences in the concentration of many materials are a function of the seepage rate from the sediment versus the effects of transport.

Questions: What degree of treatment of sewage effluent is required to make it suitable for use in maintenance of wetlands, and can marshes and associated wild communities tolerate secondarily treated sewage effluent? What is the relationship between release of sewage effluents into wetlands and the quality of waterbird habitat? How does the water quality affect the biota before, during, and after the vegetation absorbs the nutrients from the water?

Although there is some evidence that wetlands can accommodate primary sewage effluents at least over a short time period (145), the data base is too narrow to support a recommendation that wetlands be maintained by, or used to treat, primary effluent. Depending on its source, such effluent may contain unacceptable levels of toxic substances, particularly chlorinated hydrocarbons, to which wetland fauna in general and arthropods in particular (insects, crayfish, crabs) are extremely sensitive. Levels of chlorinated hydrocarbons in municipal waste have declined in recent years, but levels in industrial effluent may still be high, and industrial waste may also contain many other toxic substances (for example, heavy metals).

Spartina-dominated salt marshes seem to be able to handle secondarily treated effluent (96). Application of sludge to coastal marshes is not recommended. In freshwater marshes, there is good evidence that emergent plants can tolerate secondary effluent (145, 146,147), but there are no data on long-term effects or on the effects on organisms higher up on the food chain.

5. USE VALUES: HARVEST AND HERITAGE

Panel Convenors: Drs. William A. Niering and A. William Palmisano

Harvest and heritage values differ from habitat, water quality maintenance, and other functional values of wetlands in that they concern direct human use or benefit from wetland resources. The harvest value of a wetland depends on the contribution of the wetland to the production of something harvested or harvestable by people--e.g., food or fuels. Heritage value depends on the meanings people have attached to the wetland through personal or cultural interaction with it. The whole array of "intangible" wetland values--historical, anthropological, educational, recreational, aesthetic, symbolic--is included under heritage value. In addition, some wetland resources or functions which are valued primarily on ethical or aesthetic grounds are considered here even though they have other values; examples are wetland-dependent endangered species and climate modification or amelioration by wetlands.

Many of the issues surrounding wetland harvest and heritage values are related to defining value or finding means to assess it. Harvest value is not particularly easy to determine because of the open nature of wetland systems: the flows of energy and materials between any given wetland and other systems make it difficult to specify which harvestable resources in the complex of systems may be attributed to the wetland rather than to some other system. With respect to heritage value, the difficulty is not the nature of wetlands but our inexperience in assessing the human perceptions that define heritage value. Other issues relevant to the definition and assessment of wetland use values are: the factors limiting standing crop, yield, or other aspects of harvest values; the importance of endangered species; and the relationship of negatively viewed properties of wetlands to heritage values.

Summary

Use values of wetlands are more difficult to define than functional values because of the special importance of human interaction with the wetland as a factor determining value. The concept of harvest value is fairly straightforward but is not easily applied to open systems such as wetlands. Wetland boundaries are not respected by either harvestable resources (such as fish) or the materials and energy on which they depend. Thus in the case of fish, wetlands are often the source of harvestable populations but not the site of the harvest, whereas in the case of timber, harvest occurs in the wetland but may controlled by conditions upstream or in other ecosystems connected to the wetland. Standing crop data are inadequate measures of the importance of wetlands to harvestable populations of mobile or migratory animals.

The overall harvest value of a wetland can be approached by estimating potential optimum yield, i.e., composite yield for all harvestable resources if present in optimum proportions. Animal catch figures are usually lower than potential yield and should not be used to represent harvest value.

Other issues related to wetland harvest values include the costs and environmental consequences of harvesting wetland resources, and the role these factors play in determining harvest value.

No existing study documents the value of a wetland to the harvest of all wetland-dependent resources. In fact, most studies focus on only one resource, e.g., waterfowl, or oysters. Good data on wetland standing crops exist only for timber, agricultural crops, and certain shellfish, and the data for timber and agricultural crops cannot be related to wetland type. Research is needed to determine how much harvestable material various wetlands produce, what factors limit production, and what the economics of harvest are. Site-specific information is available for oysters, some estuarine-dependent fish (East and Gulf coasts), some wetland-dependent fish (Great Lakes region), waterfowl (prairie potholes), and muskrats and some other fur-bearing mammals.

Harvests of wild rice, cranberries, salt marsh hay, and other wetland resources are part of our cultural heritage but, like our other interactions with wetlands, have not been part of the dominant popular heritage of America. Though not praised in popular literature or art, wetlands are an important part of our consciousness. They have been symbols of adversity, but also of wildness and serenity. The few studies on human preferences for various landscapes indicate the high aesthetic and experiential values Americans now place on wetlands; these values normally go unmeasured and unadvertised.

Educational, recreational, aesthetic, and other heritage values of wetlands are intertwined, since human experience of wetlands is multidimensional and holistic. For example, the value of a wetland to a canoeing naturalist is not only recreational but aesthetic, educational, perhaps even mythical.

Human perceptions (or socio-cultural functions, or heritage values) of wetlands have not been quantified but are probably quantifiable. One way to develop methods of assessing these perceptions would be to turn to professionals in psychology, history, aesthetics, recreation, anthropology, theology, and so forth for information about the basic principles of these disciplines that would enable one to understand the experience of a person using a wetland. Professionals should then meet to integrate their findings, and methods for assessing human experience should be developed. Agency personnel who would be involved in assessment of heritage values should receive training in the sensitive use of such methods.

Endangered species are an important part of the heritage value of wetlands, being identifiable, concrete reminders of the importance of ecological diversity and temporal change. Many people initially find it easier to identify with endangered species than with wetlands, so that endangered species may play a role in stimulating interest in, and understanding of, the environment, including wetlands. The concept of endangered landscapes--rare and disappearing wetland systems--may have similar value.

The size of a wetland does not of itself determine its heritage value. As far as aesthetic, recreational, educational, and other cultural values are concerned, location and accessibility are often more important than size; hence small wetlands easily accessible to urban populations have high cultural value.

The negative values associated with wetlands due to their role in producing biting insects are disproportionate to the actual health hazard or nuisance caused by wetlands. In fact, human activities (e.g., isolated ditching, spoil disposal, digging and siltation) have often been responsible for increasing mosquito habitat in wetlands. There are mosquito control techniques that simultaneously reduce mosquito populations and maintain or improve wildlife habitat.

Assessment of Harvest Value

Question: How can the harvest value of a wetland be assessed?

Harvested resources include the broad categories of food, fiber, fuels, and water, or more specifically, fish and shellfish production, waterfowl production, crops, timber, fur-bearing animals, and peat or above-ground biomass that can be harvested to produce energy.

The harvest value of a wetland is difficult to define because wetlands are not closed systems. Arbitrary wetland boundaries set for regulatory or management purposes, such as the offshore boundary at a depth of 2 meters, are not respected by either harvestable resources (e.g., fish) or the materials and energy on which they depend. Thus in the case of fish, wetlands are often the source of harvestable populations but not the site of harvest, whereas in the case of timber, harvest occurs in the wetland but may be controlled by conditions upstream or in other ecosystems connected to the wetland.

The harvest value of a particular wetland necessarily depends on how many, and which, resources are considered desirable to harvest. If only one or two products are desirable, then wetlands managed to produce those resources will be rated more highly than natural wetlands; if a diversity of harvestable products is desired, then natural wetlands will be rated more highly than managed systems.

The value of a wetland to the harvest of a single resource (e.g., oysters) is often estimated by the predicted maximum sustained yield of that resource. In natural wetlands, however, there are many potentially harvestable resources, and it is better to define the overall harvest value of a wetland by defining the optimum yield of all the harvestable resources, or all the resources that are desirable to harvest.

Standing crop is another measure used in determining harvest value. Good standing crop data presently exist only for timber, certain crops, and shellfish. Like maximum sustained yield, standing crop is difficult to define for migratory organisms which use wetlands during only a part of their life cycle. A distinction should be made between standing crop and spawning crop, and the importance of wetlands to each. As indicated above, wetlands are parts of larger systems and cannot be evaluated in isolation.

Question: What methods can be used to determine sustained yield in a wetland (e.g., logging swamps, cutting salt marsh hay, etc.) without significantly altering their natural functional values?

Such methods have not been developed. It should be emphasized, however, that in most situations, given the unique characteristics of wetland productivity, composite yield is more important (though more difficult to evaluate) than sustained yield of one or two harvestable products.

Factors Limiting Harvest Value

Questions: Does the ratio of open water to marsh in bay systems affect the potential fisheries harvest? At what point, if any, would the creation of additional marsh at the expense of open water cease to result in a larger fisheries harvest?

No resolution of these questions has been reached, partly because so many variables other than the ratio of marsh to open water are at work. For some species in some bay systems, marsh area may limit production, but in other cases creating additional marsh area would have no effect on fish production. For example, menhaden populations on the East Coast are limited by the degree to which larvae are successful in entering estuarine channels, which is controlled by wind direction and water movement. Estuarine wetlands play no role unless the menhaden larvae succeed in entering the estuary. In many cases it is simply not known whether the system is at capacity for fish production or whether there is some limiting factor (which may be marsh area or any of a host of other variables such as salinity, water temperature, or turbidity) that can be adjusted to increase production.

Question: What factor or factors are considered to limit the standing crop of harvestable organisms in estuaries of the northwestern Gulf of Mexico?

There are few organisms for which standing crop, limiting factors, and their interrelationships have been determined. Factors limiting the standing crop of oysters along the Gulf Coast include salinity (5-15 ppp TDS is the optimum range), predators (e.g., oyster drills), bottom type, current patterns, siltation, and pollution problems in limited areas. Since so much oyster production occurs under managed conditions, the degree of management and factors such as the number of harvesters and the price of oysters also affect standing crops. Catastrophic limiting factors include storms and anaerobic conditions, which affect populations of other estuarine organisms as well as oysters.

For shrimp, the size of the standing crop is not known, so it is not possible to state quantitatively how estuarine wetlands influence standing crop. It is clear, however, that shallow bays and both salt and brackish marshes are critical nursery habitats for brown and white shrimp. The salinity requirements of shrimp are similar to those of oysters. Shrimp harvest is determined partly by shrimp prices, which are higher for larger shrimp, and shrimp size is controlled partly by temperature, so temperature is another factor limiting standing crop.

Assessment of Heritage Values

Question: How can values of the "intangible" elements of a wetland be determined (environmental, aesthetic, and cultural values)?

Socio-cultural values, or functions, of wetlands are human perceptions of the forms, processes, and productions of wetlands over time. These functions are multi-dimensional, the most significant of these dimensions being the spatial, temporal, psychological, and socio-economic components of human experience of wetlands. Socio-cultural functions of wetlands have played a vital role in the evolution of human relations to the environment; our understanding of such wetland functions nevertheless is poor, and sophisticated instruments for assessing these functions are sorely needed.

Fortunately, there is nothing inherent in our experiences of wetlands (aesthetic, recreational, educational, etc.) to prohibit them from being quantified in a way at least as sophisticated, complex, and accurate as the ways we quantify energy flow or productivity. The distinction we commonly draw between the quantitative and the qualitative is to a degree a convenient and arbitrary way of saying that while we understand some things quite well, we understand other things poorly and are unwilling to invest time and money in developing reliable and valid means not only to understand but to appraise them. Although heritage values, or socio-cultural functions, are sometimes considered intangible or accessory values by the uninitiated, they appear readily measurable to people trained in the social sciences and even in the humanities and the arts.

The best way to develop methods for assessing recreational, aesthetic, scientific, educational, anthropological, theological, mythical, or other socio-cultural functions of wetlands is to turn to professionals in each of these fields for information about the basic principles of psychology, aesthetics, history, anthropology, etc., that would enable us to understand and appraise these dimensions of human experience of wetlands. Once such information has been gathered, professionals in these disciplines must meet to integrate and correlate their findings. Only after such deliberations can methodologies and instruments for assessing, rating, or scaling the socio-cultural functions of wetlands be formulated. It probably is not possible to develop adequate means of determining "intangible" values of wetlands in a short period of time. If a team of professionals (say 8 or 10 of them) could work uninterruptedly over a period of two years, however, they could prepare adequate means of assessing such values. After initial testing of the instruments developed, all agency personnal who will be involved in the assessment of socio-cultural functions of wetlands must be intensively trained both in the fundamentals of the discipline involved and in the sensitive use of such instruments.

Factors Determining Heritage Values

Question: In areas where a long history of positive social attitudes toward wetlands have developed, what have been the essential perceptions and how have they been formed?

There is no readily available account of the "essential perceptions" that have formed in such areas as Cedar Bog, Ohio, or Horicon Marsh, Wisconsin, where there is a history of positive social attitudes toward wetlands. It appears, however, that in almost all cases where such attitudes have developed, wetlands have been crucial to some important dimension of the life of the people of the area: for example, as a source of water, a source of protein or recreative experience (because of the presence of fish and waterfowl), a home of a mythological figure or deity (good or evil), a site of memorable historic or mythological experiences, a place of worship or annual celebration, or a combination of such things. Where a wetland has such practical centrality, the shared experience has almost always been encoded and communicated. That is to say, the people have written, painted, and carved their understanding of the place in several media, and they have reproduced and distributed their expressions, perpetuating the communal understanding. The communication has seldom been planned or engineered: it has grown (or worked) in a fashion almost organic, from within the community, rather than by being imposed from without.

A successful campaign for preserving a wetland is another matter, depending not only on the existence of positive attitudes toward the wetland but on the play of politics and publicity.

Question: How critical is wetland size in terms of providing significant heritage functions?

There is no minimum size for heritage value. There are threshold sizes for the existence of certain biologial functions, e.g., nesting by territorial wetland birds, but these thresholds are affected by the location and type of wetland. For example, an isolated 7-acre prairie pothole located outside a flyway might be used by only a few waterfowl, whereas a 7-acre restored marsh in Madison, Wisconsin, produces 7-10 waterfowl broods (mallard, wood duck, teal, grebe, coot, and gallinule) per year. The Madison marsh is in a major flyway and adjacent to several lakes in which waterfowl habitat has been much diminished in recent years.

Regarding educational value, access is as important as the quality or size of the wetland; a schoolyard pond, even if too small for birds, can have high value.

Wetland size is one variable affecting the value of the wetland in climate amelioration, but even relatively small (1 km. wide), highly stressed wetlands in urban areas can moderate temperature extremes (148).

Endangered Species

Question: From an ecosystem viewpoint, are endangered species worth maintaining?

There are many kinds of endangered species. Among those with geographically restricted distributions, some are the result of relatively recent mutations and are pre-adapted to conditions that may exist in the future; others are evolutionary relics; both types provide clues to the nature or history of evolutionary change.

Among those endangered species which are widely distributed, but in low numbers, some are located at the top of wetland food chains or play other important roles in the ecosystem. Because of their sensitivity to environmental change, endangered species can often be used as indicators of the health of wetland systems. All endangered species have value as gene banks for future evolutionary change or possible human use.

From the point of view of wetland heritage and protection, endangered species have special value in stimulating interest in the environment and history. Many people initially find it easier to relate to an endangered species than to an ecosystem. Endangered species may thus serve as a tool for bringing wetland values to public attention.

Question: Which endangered species depend specifically upon wetlands for habitat for part or all of their life cycle?

A complete list has not been compiled. For examples, see Williams and Dodd (149).

Negative Heritage Values

Questions: What natural characteristics of wetlands affect man adversely in ways that motivate action for control, such as breeding grounds for mosquitoes and biting flies, and how are their values affected thereby? Within regard to insect pests, how do the positive values of wetlands relate to the health hazards potential? What roles do wetlands play as habitat for vectors of human disease and sickness?

Several natural characteristics of wetlands are negatively valued. The presence of water and unconsolidated sediments, the nature of the vegetation, and the populations of nuisance insects all limit the ease of human access, mobility, and habitation, and have consequently motivated people to modify wetland environments.

The problems of nuisance insects and the potential health hazards posed by wetlands should be put in proper perspective. First, wetlands may not have a larger share of disease vectors than do forests and grasslands; a comparison is needed. Second, human modification of wetlands has often increased the habitat available for mosquitoes and other nuisance insects by interfering with water flow. For example, ditches or ponds have been dug too shallow for fish that prey on nuisance insects; partial drainage or filling has produced stagnant, isolated pools and allowed invasion by forest species whose shade lowers photosynthesis by aquatic plants and thus excludes predatory fish and invertebrates that depend on photosynthetic oxygenation of the water. Upland development has caused siltation in wetlands, isolating small pools, and has accelerated and accentuated runoff peaks, leading to exaggerated water level fluctuations in wetlands. As a result, flooding is too temporary for most predatory fish and invertebrates but ideal for the hatching of mosquito eggs. It appears possible to control undesirable insects without sacrificing habitat values for wildlife. In Massachusetts salt marshes, ponds used by waterbirds and fish have been left undrained and insects have been controlled through the installation of biting fly traps or partial ditching of the ponds.

The myth that wetlands are dangerous, unhealthy, or simply bad places has put the "insect problem" of wetlands out of proportion. Wetland insects are defintely a nuisance, but the hazard they pose to human health is not so great as popularly imagined. As a challenge to the negative wetland myth, it would be worthwhile to ask: What roles do wetlands play as habitat for vectors of human health?

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THE NEED FOR A NATIONAL WETLANDS RESEARCH ASSESSMENT

Federal agencies often have trouble finding facts to support their wetlands regulatory decisions, particularly for fresh water wetlands. Problems arise over which wetlands to preserve intact, what uses to permit, what impacts will arise, what performance standards to demand, and what type of mitigation to require.

When wetland facts are unavailable to agencies it is because (1) the data from completed research has not been consolidated, interpreted, and made available for transfer, or (2) the research has not been done.

The National Wetlands Technical Council (NWTC) believes that the situation could be much improved by a Federally supported volunteer effort by the Nation's wetlands scientists. The NWTC therefore proposes the National Wetlands Research Assessment, an intensive review of the Nation's stock of scientific knowledge and research needs on wetlands to be conducted over a three year period. Its major purpose is to consolidate, evaluate and interpret all available scientific information on wetlands for transfer to regulators and to provide continuing scientific guidance on wetlands management for Federal agencies over the period of the assessment. This would involve hundreds of the Nation's wetland scientists organized by the National Wetlands Technical Council.

A national assessment of sorts has been underway for more than a year in a series of ad hoc assessments culminating in the NWTC managed National Symposium on Wetlands at Lake Buena Vista, Florida, in November 1978. The undertaking proposed here would build on this beginning, formalizing and organizing the process. The success of the 1978 series demonstrates that the National Wetlands Research Assessment would be a good investment.

An ongoing National Wetlands Reseach Assessment would identify the major issue areas where scientific information transfer and guidance would be useful, investigate those areas, and provide appropriate reports and consultations to the agencies. It would concentrate particularly on articulating clearly the differences between regional wetland types. The Assessment would enable the Council and cooperating scientists to do the following:

- o Establish regional and national scientific task forces to deal with major scientific needs of Federal wetland management programs, to consolidate, evaluate, and interpret existing data, and to report the findings to the agencies. Reporting would be accomplished through a series of focused task force reports released at regular intervals during the three-year period. Examples are: the evaluation and rating of wetlands according to their natural values, the assessment and evaluation of the need for and application of various types of mitigation, the delineation of regulatory boundaries of transitional wetland types.

- Establish regional and national task forces to review the state of knowledge and to identify research priorities and prepare recommendations for the agencies.

- Establish regional task forces to provide continual updating of the state of knowledge of regional types of wetlands, to identify priority short term research tasks, and report regularly to the agencies.

- Establish categorical task forces to conduct intensive reviews of particular subjects such as wetland rating or wetland mitigation methodology.

- Prepare guidebooks on simplified field methods for wetland field evaluations by agency personnel.

- Maintain a central coordinating center in Washington, D.C., to facilitate interaction with agencies and with scientists.

- Maintain a continuously updated directory of scientists with particular types of expertise available to agencies in various regions of the country.