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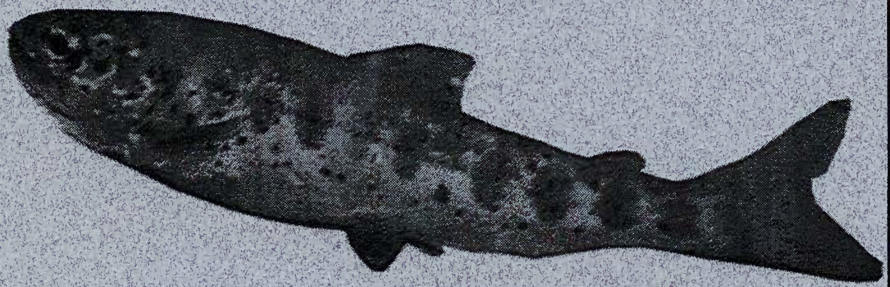
Juvenile Fish Passage Through Culverts in Alaska: A Field Study



by

Douglas L. Kane
Charles E. Behlke
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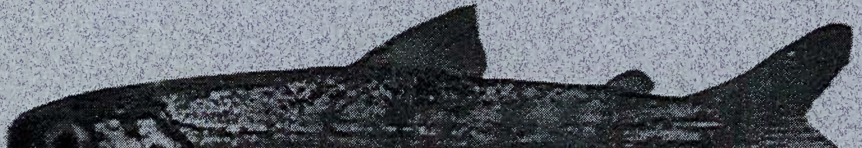
June 2000



FINAL REPORT

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Juvenile Fish Passage Through Culverts in Alaska:

A Field Study

a final report by

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Robert E. Gieck[1], and Robert F. McLean[2]

A report on research sponsored by the
Alaska Department of Transportation and Public Facilites

Report Number INE/WERC 00.05

July 2000

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the accuracty of the data presented herein. This research has been funded by the Alaska Department of Transportation and Public Facilities (AKDOT&PF). The contents of the report do not necessarily reflect the views of policies of AKDOT&PF or any local sponsor. This work does not constitute a standard, specification, or regulation.

ABSTRACT

In the past, culvert design where fish passage was considered generally has been based on the weakest-swimming adult fish in a river system. It has also been recognized for some time that juvenile fish are very active throughout the year, moving upstream and downstream in response to a number of environmental factors. In Alaska, many natal and nonnatal streams in southcentral and southeastern Alaska support both Chinook (*Oncorhynchus tschawytscha* (Walbaum)) and Coho (*Oncorhynchus kisutch* (Walbaum)) for one to three years, respectively, before they emigrate to sea. Are we restricting desirable habitat for these juvenile salmonids with hydraulic structures such as culverts? Unfortunately we have little information on either the behavior of juveniles in the vicinity of hydraulic structures or their swimming abilities. The objective of this study was to examine the behavior of juveniles when attempting to ascend a culvert. It was hypothesized that vertical obstacles or high velocity of opposing flow may prevent juvenile fish from moving upstream. It was also hypothesized that they would determine and take the path of least resistance to optimize their chances of successfully ascending a culvert.

Four culverts were selected for intensive study regarding juvenile fish passage: Beaver and Soldotna Creeks on Kenai Peninsula and No-name and Pass Creek Tributary on Prince of Wales Island. It was postulated that fish are motivated to move upstream to obtain food if they can establish its presence. We used salmon eggs as an attractive food source both to initially capture the juveniles and then to motivate them to ascend the culvert for possible recapture. Juvenile fish were captured in a baited minnow trap and stained with a dye. They were released downstream of the culvert while the food source was placed upstream in a minnow trap. We supplemented our visual observations with underwater video cameras. We made numerous hydrologic and

hydraulic measurements at each site. Although we attempted to select culverts that would prove to be quite challenging to juvenile fish passage, in three of the culverts selected, juvenile fish, of the full range of fork length initially captured, succeeded in ascending through the culvert. For the fourth culvert, some larger juvenile fish succeeded in ascending the culvert, but not the smaller of each fish type. It was clearly established that juvenile fish were motivated to move upstream to obtain food.

In the Beaver Creek culvert, fish used the large corrugations to their advantage when ascending the culverts. The Pass Creek Tributary culvert had corrugations too small for fish to utilize. No-name Creek appeared to present no problems for juvenile fish for the water levels at the time of the visit as they swam along the bottom on the centerline of the culvert. In general, observations of fish attempting to move upstream through the culvert revealed that they swam very close to the culvert wall, and in the case of high velocities (Beaver Creek and Pass Creek Tributary) they swam near the surface along the sidewall where velocities are reduced. It is obvious that the juvenile fish are attempting to minimize power output and energy expenditure by taking the path of least resistance.

Although not quantitatively proven, it appears that as long as fish make some headway in their upstream movement they are content. The rationale for this conclusion is that fish do not know what they may encounter upstream, so they attempt to conserve as much power and energy as possible while still moving forward. They generally do so by seeking out the lowest velocities in the cross-section. In areas of steep velocity gradients along the wall (where the areal extent of low velocities is limited), it is clear in our videotapes that fish have problems maintaining their position and preferred orientation. It is apparent from our observations that because of their small size, juvenile fish are hindered by turbulence and that this area needs more study.

ACKNOWLEDGEMENT

The authors would like to acknowledge the technical support and funding provided through the Alaska Department of Transportation and Public Facilities Highway Research Program, and the Federal Highway Administration. The authors appreciate the review comments of Mark Miles, AKDOT&PF Juneau. Special thanks are due to George S. Muller and Elizabeth K. Lilly, of the University of Alaska Fairbanks Water and Environmental Research Center, for their help in gathering data for this project.

JUVENILE FISH PASSAGE THROUGH CULVERTS IN A LASKA: A FIELD STUDY

INTRODUCTION

Concern that culverts at roadway crossings may hinder the upstream migration of juvenile fish, in this case juvenile salmon, was the impetus for this field study. The main objective of this study was to observe the behavior of juvenile salmon, in the vicinity of selected culverts, when enticed to move upstream to an artificial food source. If the opportunity presented itself, we would try to quantify energy and power expenditures by juvenile salmon attempting to ascend a culvert. For numerous reasons, we were unable to monitor individual fish for more than a few seconds or over short distances.

Both juvenile Chinook (*Oncorhynchus tschawytscha* (Walbaum)) and Coho (*Oncorhynchus kisutch* (Walbaum)) are known to spend from one to three years, respectively, in freshwater drainage networks before migrating out to sea. Basically, we were interested in studying the behavior and swimming ability of juvenile fish that may be motivated to move upstream through a culvert to reach suitable habitat and sources of food. Several scenarios exist that may result in a juvenile fish attempting to ascend a culvert. If a spawning area is located below a culvert impassible to juvenile fish, substantial habitat upstream may become unavailable. Low water flows, of seasonal or shorter duration, may drive juvenile fish downstream below a culvert. Later, these same fish may migrate upstream when flow conditions are more suitable. It appears that juvenile fish can remain upstream of a culvert during high flows, although those attempting to move upstream through a culvert will be delayed. There have been very few studies of the swimming capabilities or behavior of juvenile salmonids attempting to ascend culverts under any conditions. A critical question to address in this situation: is there a motivational factor that will impel these fish to go from one point to another with near-maximum power and energy expenditures?

OBJECTIVES

The main mission of this study was to document the behavior and swimming performance of juvenile Coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon at actual field installations of culverts. Culverts that were perceived as posing passage problems for the upstream migration of these juvenile fish were selected. The chosen culverts either required the juvenile fish to swim against high velocities or potentially jump over a vertical barrier such as a baffle. Numerous hypothesis were to be tested:

1. The swimming and leaping capability of juvenile fish is such that high velocities and/or vertical barriers may prevent their migration upstream past a culvert.
2. Motivation is an important factor in whether fish migrate upstream. For adult fish, reproduction is a strong motivating stimulus in the upstream migration. In this study, it was felt that a food source would be the most important motivational factor to entice juvenile fish to move upstream; in our case, upstream through a culvert.
3. Juvenile fish would take the path of least resistance when ascending a culvert, and this pathway would be near the wetted perimeter of the culvert. If steep velocity gradients exist close to the wall, the fish may move out away from the wall, where the velocity gradient is less normal to fish movement, although the velocities may be higher.
4. Although the corrugations on the culvert wall will produce turbulence, juvenile fish will utilize these corrugations to their advantage when migrating upstream.

It was assumed that these fish naturally move around in the drainage system of a watershed in response to environmental factors such as water temperature, discharge, availability of food, growth, habitat, etc. Other assumptions included:

1. The larger the fish the better the swimming capability, while fish of the same size have comparable abilities,
2. Variously sized juvenile fish of different species may have different preferred habitats,
3. Dyeing or staining of fish would have minimal impact on them during our study,
4. Both resident and anadromous juvenile fish that move downstream in response to some environmental change (such as low or high flow) may want to later move back upstream when conditions are more favorable,
5. If we recaptured upstream of the culvert the smallest fish released downstream of the culvert after dyeing, it was assumed that all fish could ascend the culvert for the prevailing conditions, and
6. It is not critical that juvenile fish be capable of immediately ascending a culvert; passage at lower flows within a few days is acceptable.

PROCEDURE

Two criteria dominated the selection of culverts for this study;

1. The culvert must have some challenging hydraulic characteristics that might prevent the upstream passage of juvenile fish through the culvert, and
2. There had to be sufficient number of juvenile fish present in the stream system impacted by the culvert.

We had decided to concentrate our effort on the Kenai Peninsula and Southeastern Alaska (Prince of Wales Island). Input from Alaska Department of Fish and Game personnel was utilized for finding suitable streams that had a sufficient number of juvenile Coho. After visiting these streams, we then selected culverts based on the hydraulics that existed at the culvert. We sought culverts where high velocities were uniformly distributed throughout the entire length of the culvert (fish would have to overcome uniform resistance when moving upstream). We were also looking for culverts where juvenile fish might be required to leap over a barrier for successful passage. Numerous culverts were visited before a decision was made on what culverts to study. Following is the step-by-step procedure used at each selected culvert site:

1. Our goal was to capture 200 to 300 juvenile fish at each site. We utilized Gee minnow traps with a 1 in (about 25 mm) opening at each end and ¼ in (about 6 mm) galvanized steel wire mesh. Upon arriving at a site we placed four to six baited minnow traps in the stream. The traps were baited with salmon eggs that had been disinfected with 1:100 Betadyne solution for a minimum of 10 minutes. Minnow traps were set both upstream and downstream (except in Beaver Creek, where all fish were captured downstream), wherever suitable pools could be found. Traps were checked frequently, every 20 to 60 minutes. Traps were only deployed while we were at the site. It was our experience that if we left the traps in the streams longer than 30 minutes, we seldom caught any of the small young-of-the-year fish (40 to 70 mm); they either escaped from the trap or possibly some may have been eaten by larger fish.

2. While waiting on the traps, we set-up our fish-staining equipment and installed a staff gage in the stream. We used neutral red and Bismark brown dyes at concentrations of 1:64,000 or less. We prepared about three gallons of dye solution by putting the dye in a coffee strainer and running stream water through it. The strainer prevented large clumps from forming in the make-up water for the fish. To avoid unnecessary stress on the fish, the solution was continually aerated with an aquarium-type aerator that was run off a 12-volt battery with an inverter. Contrary to our expectations, laboratory measurements showed that the oxygen saturation level over a range of temperatures was raised over 1 mg/l in the solutions of Bismark brown we used (Figure 1). Therefore the dye did not add any stress to the fish by reducing oxygen saturation levels. We also began using only Bismark brown the second year, because of a paper by Ward and Verhoeven (1963) which reported that the neutral red dye was fatal to juvenile salmon (although we never observed any fatalities from this dye). Either dye proved suitable for staining the fish (for at least 4 to 5 days) from an identification viewpoint.

3. When we had captured some fish, we measured fork length and total length. We also measured the depth and weight of some fish. To obtain lengths and weights, fish were generally placed in a zip-lock bag with a little water. We then placed them in the dye solution. The pail with the dyed water was kept in a cool place (generally in the stream) to maintain an acceptable water temperature for the fish.

4. The measurement of appropriate dimensions (diameter, width, height, and length of the culvert, and slope of water surface and culvert invert) of the culvert were obtained when we had spare time that was not occupied with capturing, measuring, dyeing, and recapturing fish. We also made discharge measurements, stage observations, and velocity profiles along the centerline, and, in some cases, for the entire cross-section of the culvert.

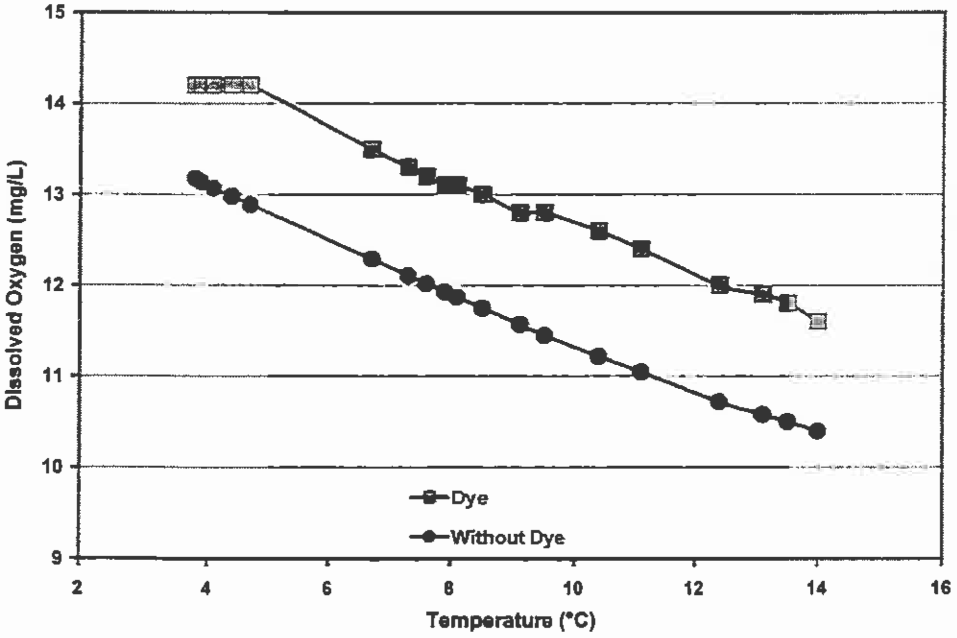


Figure 1. Oxygen saturation levels for a range of temperatures for water with and without dye.

5. We had two underwater video cameras (one black and white and one color) that we occasionally installed in the culvert at positions that we felt would yield potentially interesting information on juvenile fish behavior.

6. When the fish had been immersed in the dye solution for at least 40 minutes, they were released downstream of the culvert. At this time, traps were baited and placed upstream of the culvert to recapture dyed fish. Traps were no longer placed downstream in the vicinity of the dyed fish that were released. A comparison of a stained and unstained juvenile Coho is shown in Figure 2.

7. Upstream traps were checked at intervals of 30 to 60 minutes for dyed fish. If we still needed additional fish for dyeing, we usually used the un-dyed fish caught in the upstream traps (except Beaver Creek). All dyed fish caught upstream were measured and released again downstream of the culvert.

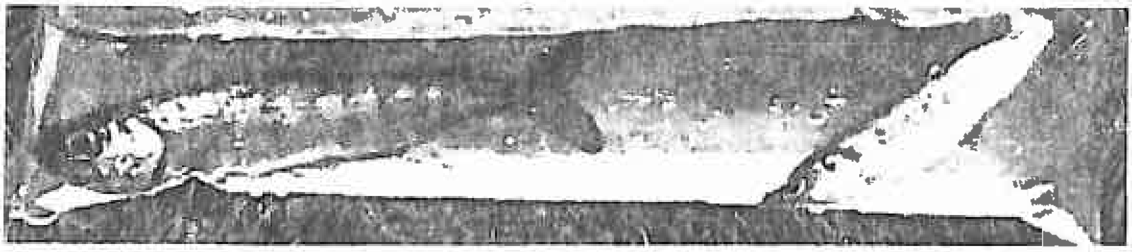


Figure 2. Comparison of two Coho, one stained (left) and one unstained (right).

8. At the Southeastern Alaska sites, we had difficulty in capturing large numbers of juvenile Coho. In these two cases we utilized all fish captured. Other species included cutthroat trout (*Salmo clarki*) and Dolly Varden (*Salvelinus malma*). On the Kenai Peninsula, we captured some Dolly Varden in addition to the Chinook and Coho. We did not attempt to maximize our recapture of dyed fish. Instead, we were satisfied when the full size range of fish that were stained and released were recaptured upstream within a two to three day period after release. This basically meant that when young-of-the-year successfully ascended a culvert, we would discontinue our recovery operation.

9. We made numerous visual observations of juvenile fish within the culvert. As these fish are generally in the 40 to 100 mm range, they can be difficult to see under less than optimum lighting conditions. Both No-name Creek (POW Island) and Soldotna Creek (Kenai Peninsula) had very poor lighting within the culverts; the first because of overstory vegetation; the second, because of its extreme length.

STUDY SITES

Selection

Four study sites were selected for detailed observations: Beaver and Soldotna Creeks, on the Kenai Peninsula and No-name Creek and Pass Creek Tributary, on Prince of Wales (POW) Island in Southeastern Alaska. Numerous other culverts were examined that were deemed acceptable because of potential hydraulic obstacles to juvenile fish passage; however, in most cases we did not find sufficient numbers of juvenile fish to work at these sites.

Beaver Creek

We selected Beaver Creek because of the high velocities that existed at all stages in the upstream inlet. The high velocities were due to a steep slope at the inlet end of the culvert, which approached 10 % in the first 10 feet (3.05 m); this produced supercritical flow (Froude number of 1.3) with a small hydraulic jump between 14 and 20 feet (4.3 to 6.1 m) into the culvert, depending upon flow conditions. Unfortunately, velocities in this culvert were not uniform and the only potential barrier to juvenile fish passage was the upstream end of the culvert.

Beaver Creek drains into the lower Kenai River on the western part of the Kenai Peninsula (Figure 3). The entire Beaver Creek watershed drains 51.4 mi^2 (133 km^2). The basin is dominated by wetlands with a few lakes. The culvert is located on the Kenai Spur Road. It is an elliptically shaped culvert 10 ft (3.0 m) high by 9 ft (2.7 m) wide, 116 ft (35.4 m) long. The corrugations in the culvert are 2 in (5.1 cm) deep and 6 in (15.2 cm) long. The water surface slopes upstream and downstream of the culvert and those within the culvert and the culvert invert are shown in Table 1. An old beaver dam is located just upstream of the culvert. A large scour pool is located at the outlet of the culvert. Downstream of the pool the Froude number for the flow is about 0.2, while upstream of the culvert it is less than this.

No-name Creek

No-name Creek was selected because it has fairly uniform velocities through the culvert with higher velocities associated with higher stages. Unfortunately, during most of our visit to this site, the stage was quite low. At the end of our visit, heavy rain produced high flow, but the flow was then too high for us to work in the culvert.

No-name Creek is located on Prince of Wales Island (Figure 4) in southeastern Alaska. This stream drains into the upper end of Klawock Lake at milepost 17 on the Klawock-Hollis Road. No-name Creek is a glaciated drainage with a relatively flat valley floor surrounded by steep valley walls. There is a network of beaver dams upstream of the culvert that provides rearing habitat for juvenile fish. In general, the channel is made up of pool and riffle flow, and occasionally a large, fallen tree across the stream. This arched culvert is 84 ft (25.6 m) long, 8.5 ft (2.6 m) high, and 15.5 ft (4.7 m) wide, with 2 in (5.1 cm) by 6 in (15.2 cm) corrugations. Slopes associated with the culvert are given in Table 1. The upper reaches of this watershed have been logged.

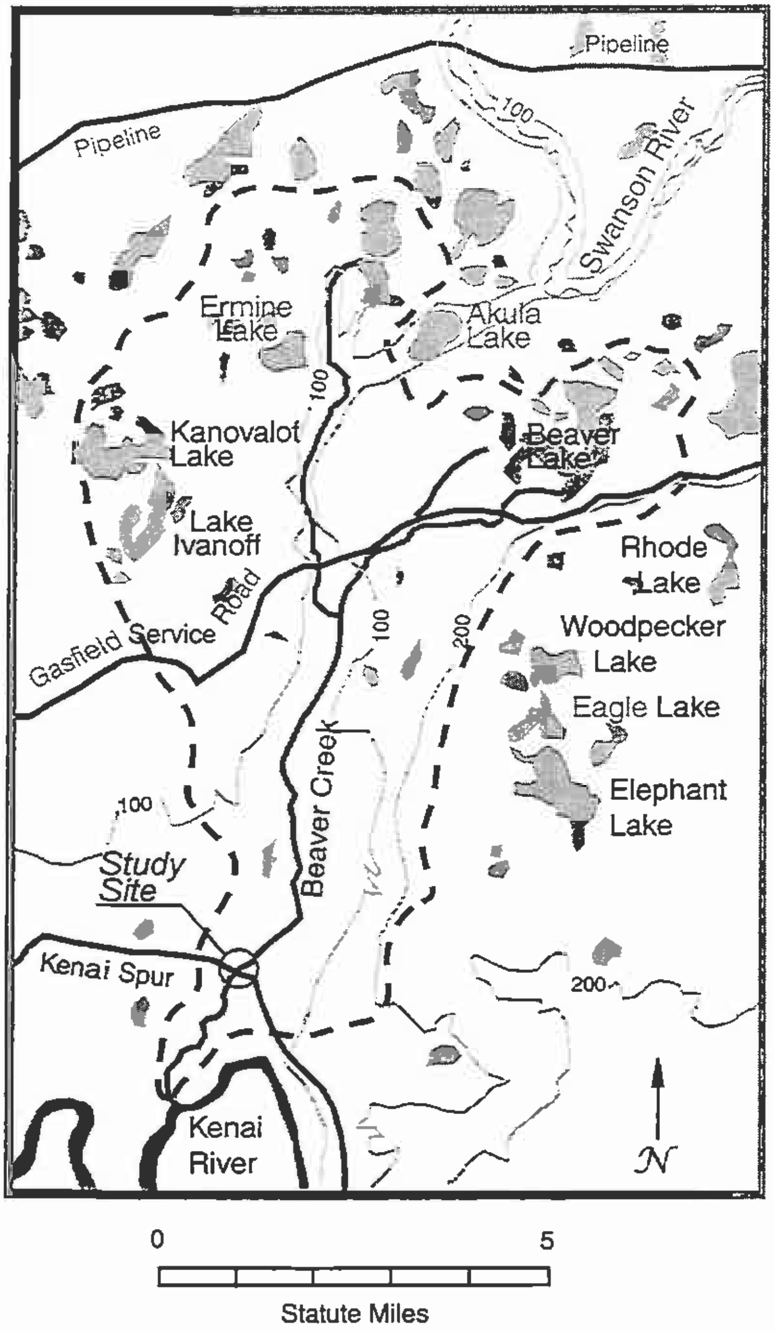


Figure 3. Watershed map of Beaver Creek on Kenai Peninsula, showing culvert studied on Kenai Spur Road.

Table 1. Hydraulic characteristics of four streams and culverts studied.

Stream Name	Culvert Length	Culvert Width	Culvert Height	Culvert Shape	Corrugation Dimensions
Beaver Creek	116'	9'	10'	Elliptical	6" wide 2 " deep
Soldotna Creek	298'	14' 6"	10'	Arched-Baffled	6" wide 2 " deep
No Name Creek	84'	15' 6"	8' 6"	Arched	6" wide 2 " deep
Pass Creek	53' 3"	8' 10"	8' 10"	Circular	3" wide 1 " deep

Stream Name	Upstream Slope	Downstream Slope	Culvert Water Surface Slope	Culvert Invert Slope
Beaver Creek	0.0072	0.0036	0.01	0.013
Soldotna Creek	0.0020	0.013	0.018	0.014
No Name Creek	0.014	0.0029	0.0069	0.0034
Pass Creek	0.041	0.038	0.019	0.015

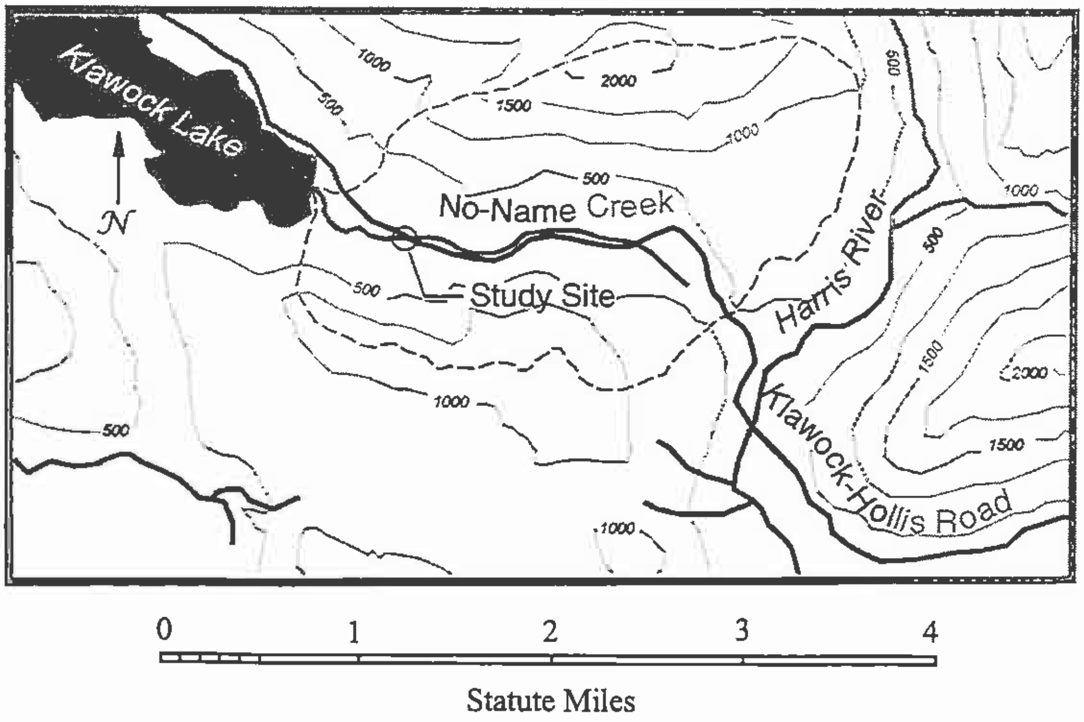


Figure 4. Watershed map of No-Name Creek on Prince of Wales Island, showing culvert studied on Klawock-Hollis Road.

Soldotna Creek

The Soldotna Creek culvert was selected because of its length and the presence of 13 baffles. The water surface drops around 6.8 feet (2.1 m) from the upstream water surface to the downstream water surface through the 298 foot (90.8 m) long culvert. The average water surface drop at each baffle is 0.5 ft. (.15 m), but individual drops (water surface above to water surface below) ranged from 0.25 to 1.00 ft (0.08 to 0.30 m). We anticipated that juvenile fish would need to leap over the baffles to ascend the culvert.

Soldotna Creek, like Beaver Creek, is also a tributary of the Kenai River (Figure 5). It drains a 25 mi^2 (64.8 km^2) area of upland kettle lakes and marshy valley lowlands. The culvert site is on the Sterling Highway just east of Soldotna. This arched-baffled culvert is 10 ft (3.0 m) high and 14.5 ft (4.4 m) wide with 2 in (5.1 cm) by 6 in (15.2 cm) corrugations. Slopes of the water surfaces and culvert invert are given in Table 1.

Pass Creek Tributary

We selected Pass Creek Tributary due to its relatively uniform slope and overall high velocities throughout the culvert. The corrugations were smaller than those of the other three culverts. Also, this culvert was located on a logging road, and its length was only 53.25 ft (16.2 m), plus a 2.5 ft long corrugated lip on the bottom of the culvert outlet. Pass Creek Tributary is a sub-watershed of Pass Creek that drains into Dog Salmon Creek on Prince of Wales Island (Figure 6). The drainage area for Pass Creek is 5.3 mi^2 (13.7 km^2); Pass Creek Tributary above the culvert at milepost 14.4 on Polk Inlet Road drains about one-third of the watershed area. This culvert is an 8.83 ft (2.7 m) diameter circular culvert (Table 1). The corrugation size on this culvert is one-half the size of the other three culverts, 1 in (2.5 cm) by 3 in (7.6 cm). The stream channel had pool and riffle flow with fallen trees occasionally crossing the stream. The stream channel (both up- and downstream) adjacent to this culvert had the highest slopes of those streams reported in this report. The watershed is composed of a narrow valley with steep side slopes.

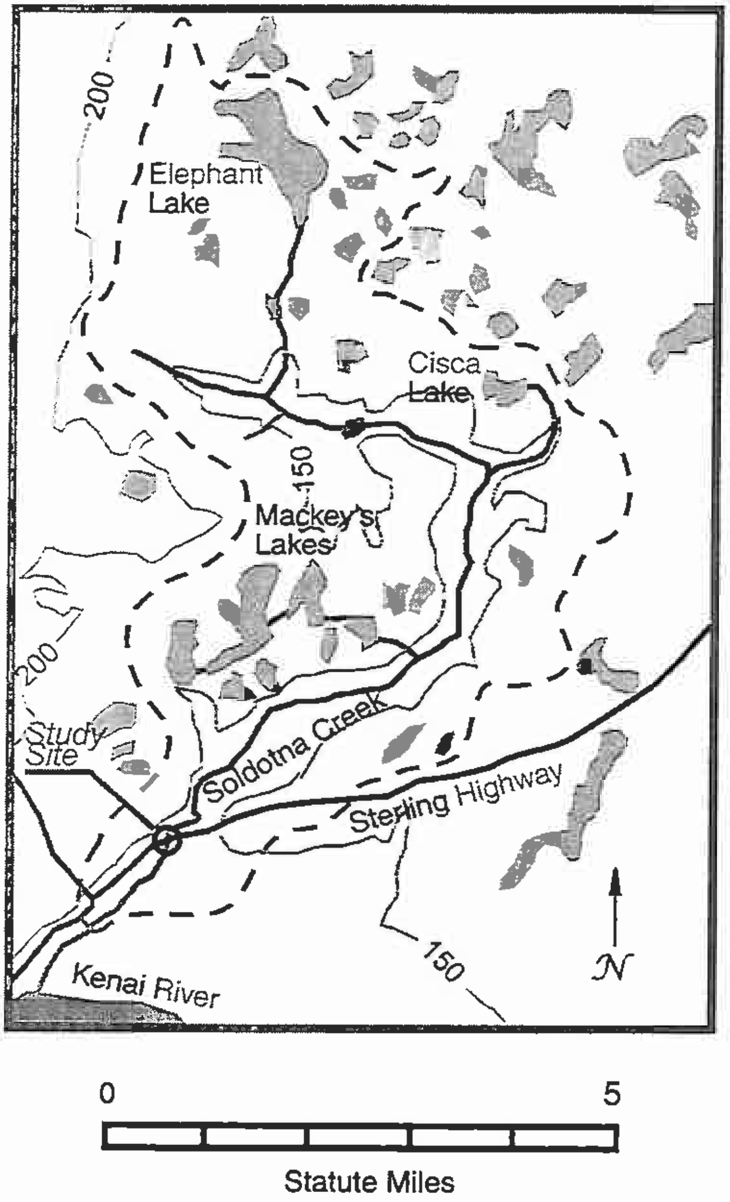


Figure 5. Watershed map of Soldotna Creek on Kenai Peninsula showing culvert studied on Sterling Highway.

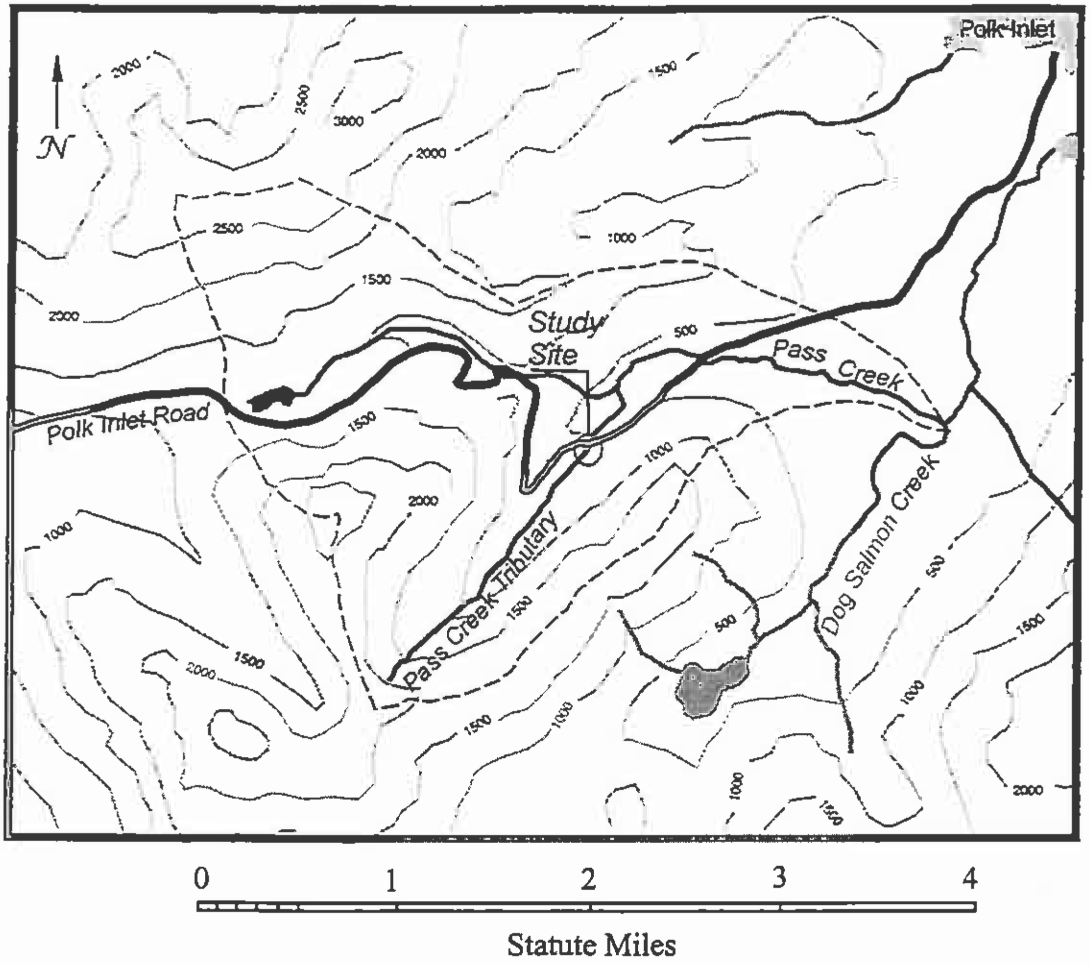


Figure 6. Watershed map of Pass Creek on Prince of Wales Island showing culvert site on Pass Creek Tributary at mile 14.4 Polk Inlet Road.

PAST STUDIES

Fish Behavior

Considerable effort has been expended over the past few years in developing an understanding of the motivational factors that influence fish movement and documenting fish movement. Obviously, for adult salmon, spawning is the major motivational element in the upstream migration just prior to their demise. When juvenile salmon appear on the scene, maximizing energy intake and minimizing energy expenditure are critical to the rapid growth of these fish (Fausch, 1984; Hughes, 1992). Many environmental factors are important in maximizing the difference between energy input and output. It is also obvious from the literature that such wide ranges of environmental conditions exist in watersheds containing juvenile salmon that results are often not transferable from one drainage to the next. Several examples of such contrasting results are:

i) Maximum fish movement can occur at various times of the year in different systems;

ii) In some cases juvenile salmon movement is upstream, in others downstream and in most cases both upstream and down with some that apparently move very little;

iii) Fry disperse after leaving the redd, in some cases they move to nonnatal streams and in others they remain in the natal stream;

iv) Overwintering juvenile fish sometimes move downstream and sometimes upstream to what they consider to be suitable habitat;

v) And fish may either move downstream or upstream during low flows depending upon where there is suitable habitat. It is not clear what happens at high flows, mainly because it is difficult to work at these conditions.

Juvenile Movement

There are numerous studies that document the movement of juvenile salmonids. Scrivener et al. (1994) reported that juvenile Chinook moved from the Upper Fraser River into nonnatal streams; they concluded that this movement was in response to the heavy sediment loads of the Upper Fraser River in spring and summer. For the Lower Fraser River, Murray and Rosenau (1989) found that juvenile Chinook also utilized nonnatal streams for rearing. Juveniles had migrated as far as 4 miles (6.5 km) up these streams. For Beaver and Soldotna Creeks that are included in this study, Bendock (1989) found that juvenile Chinook moved 35 miles (56 km) upstream over a period of 10 to 14 weeks. Peterson (1982) documented juvenile coho traveling upstream as much as 20.2 mi (32.6 km) to reach overwintering ponds in western Washington. Juvenile coho were found to travel up to 19.8 mi (32 km) downstream to reach four small tributaries of the Clearwater River in Washington State (Cederholm and Scarlett, 1981). There are numerous other papers that summarize fish movement (Godin, 1982; Kahler and Quinn, 1998); these demonstrate that juvenile fish are moving about the drainage systems in response to certain environmental factors. It should be expected that these juvenile fish would utilize as much of the drainage system as they can reach and some of these areas may be a substantial distance from spawning areas.

RESULTS

Beaver Creek

The culvert at Beaver Creek is 116 ft (35.4 m) long with a maximum width of 9 ft (2.7 m) and a maximum height of 10 ft (3.0 m, Table 1). The culvert is placed at a transition in the slope of the water surface and streambed from a relatively flat slope draining an upstream bog to a steeper slope where the stream drops down to the Kenai River (Figure 7). Although the average slope of the water surface is 1 % through the culvert, the maximum slope at the inlet end of the culvert is near 10 % for a short distance. This steep slope results in the acceleration of the water approaching the culvert and for some distance into the culvert. The flow accelerates from an approach velocity of approximately 1 fps (0.3 m/s) to a velocity of 8 fps (2.4 m/s) at about 10 to 12 feet into the culvert. Stream discharge remained near 13.4 CFS (0.38 cms) during our visit. Elliot and Nelson (1985) concluded that this culvert was a barrier to juvenile fish passage. Their conclusion was based on the fact that they found the mean fork length of marked juvenile fish to be greater upstream than downstream. They also concluded that the culvert was a complete barrier to juvenile Coho smaller than 60 mm fork length. Our first impression was that small fish would indeed encounter problems when trying to pass upstream through the culvert; particularly when they reached the high velocities just below the culvert inlet.

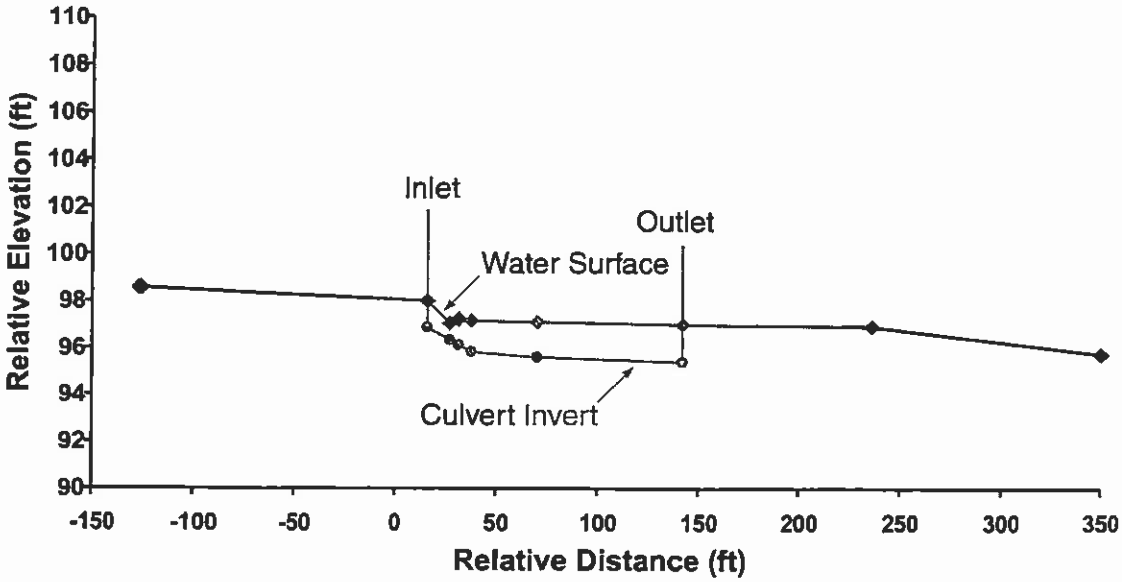


Figure 7. Water surface and culvert invert profiles for Beaver Creek August 1, 1997.

During the period of July 31 to August 4, 1997 observations were made at Beaver Creek. First, we captured and dyed about 500 juvenile fish; most of the fish were juvenile Coho, easily caught in the pool immediately downstream of the culvert. The fish were stained and released downstream of the culvert in the large pool. Baited fish traps were placed upstream to entice the fish through the culvert for possible recapture.

While making various hydrologic and hydraulic measurements within the culvert, large numbers of fish were observed in the culvert barrel when the baited traps were in place upstream. It was found that the flow in the culvert was subcritical (Froude number of 0.8) initially at the culvert inlet, but then the flow reached supercritical conditions (Froude number of 1.3) at the base of the steep sloping section approximately 12 ft (3.7 m) into the culvert. In fact, just below this point there was a small hydraulic jump where the depth of the water increased approximately 0.5 ft (0.15 m). Below this point the flow was again subcritical (Froude number = 0.2) and continued to be subcritical through the remainder of the culvert. Just below and along the walls of the culvert at the hydraulic jump, we observed small schools of juvenile fish milling around.

For a subset of the stained fish caught upstream, measurements of fork length, total length and depth were made (Table 2). Fork lengths ranged from 41 to 123 mm for juvenile Coho. Figures 8 and 9 show the relationship between fork length and total length and fork length and depth respectively for Coho, Chinook, Dolly Varden and rainbow trout. Whether the fork length or total length are measured is not important, as it is simple to go back and forth from one to the other. The relationships between fork length and depth or fork length and weight are much more variable. The data in these figures and tables (including some upcoming ones) does give an indication of the variability of the fish encountered at the various sites. Elliott and Finn (1984) carried out an extensive study of species composition and distribution during the summers of 1982 and 1983 for lower Kenai River tributaries, including Beaver and Soldotna Creeks (Table 3).

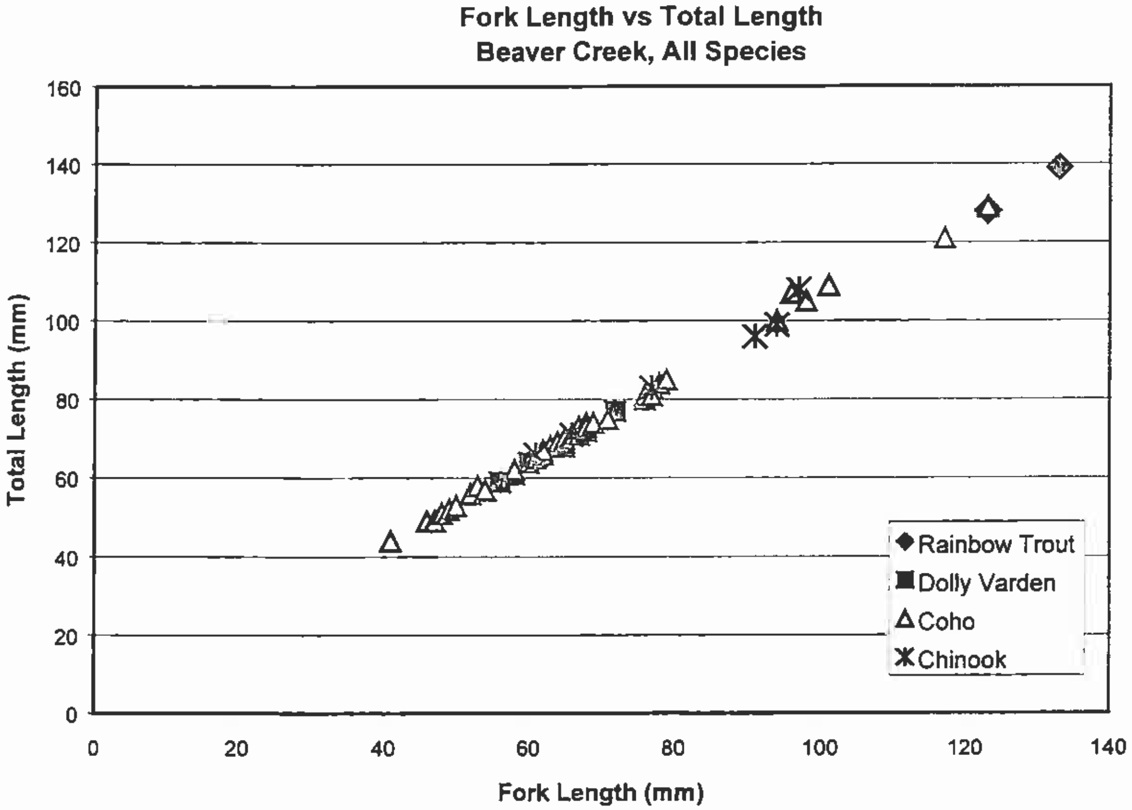


Figure 8. Beaver Creek (July 31 – August 1, 1997) – fork length versus total length for stained and recaptured fish.

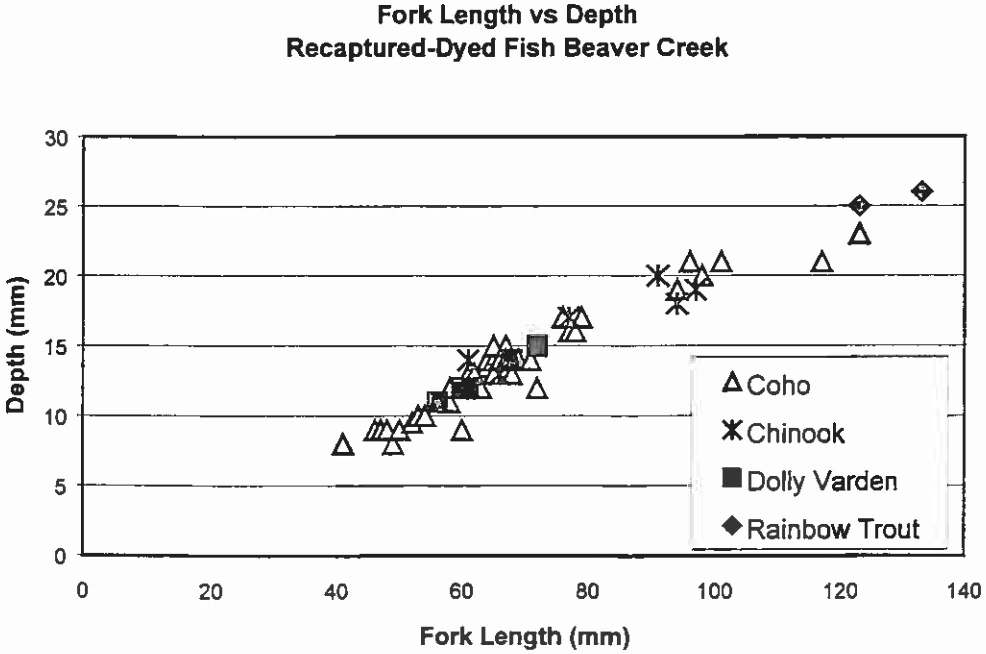


Figure 9. Beaver Creek (July 31 – August 1, 1997) – fork length versus depth for stained and recaptured juvenile fish.

Table 2. Fork and total length, weight, and depth of all juvenile fish that had been both recaptured upstream and originally stained, Beaver Creek (July 31 -- August 1, 1997).

Species	Fork Length (mm)	Total Length (mm)	Ratio FL/TL	Depth (mm)	Ratio Depth/TL
Coho	41	44	0.93	8	0.18
Coho	44				
Coho	46			9	
Coho	46	49	0.94	9	0.18
Coho	47	49	0.96	9	0.18
Coho	47	49	0.96	9	0.18
Coho	48	51	0.94	9	0.18
Coho	49	52	0.94	8	0.15
Coho	50	53	0.94	9	0.17
Coho	52	56	0.93	9.5	0.17
Coho	53	58	0.91	10	0.17
Coho	54	57	0.95	10	0.18
Coho	58	61	0.95	11	0.18
Coho	58	61	0.95	11	0.18
Coho	58	62	0.94	12	0.19
Coho	60	64	0.94	12	0.19
Coho	60	64	0.94	9	0.14
Coho	61	65	0.94	13	0.20
Coho	62	66	0.94	12	0.18
Coho	62	67	0.93	13	0.19
Coho	63	68	0.93	12	0.18
Coho	64	69	0.93	13.5	0.20
Coho	64	68	0.94	14	0.21
Coho	64	69	0.93	14	0.20
Coho	65	68	0.96	13	0.19
Coho	65	69	0.94	13	0.19
Coho	65	70	0.93	14	0.20
Coho	65	70	0.93	15	0.21
Coho	66	71	0.93	14	0.20
Coho	66	71	0.93	14	0.20
Coho	67	71	0.94	15	0.21
Coho	67	73	0.92	14	0.19
Coho	68	74	0.92	14	0.19
Coho	68	72	0.94	13	0.18
Coho	68	73	0.93	14	0.19
Coho	69	74	0.93	14	0.19
Coho	71	75	0.95	14	0.19
Coho	72			12	
Coho	76	80	0.95	17	0.21
Coho	76	81	0.94	17	0.21
Coho	77	81	0.95	16	0.20
Coho	78	84	0.93	16	0.19
Coho	79	85	0.93	17	0.20
Coho	94	100	0.94	19	0.19
Coho	96	107	0.90	21	0.20
Coho	98	105	0.93	20	0.19
Coho	101	109	0.93	21	0.19
Coho	117	121	0.97	21	0.17
Coho	123	129	0.95	23	0.18
Average	67	72	0.94	13	0.19
	n=49	n=46	n=46	n=48	n=46

Table 2 (cont.)

Species	Fork Length (mm)	Total Length (mm)	Ratio FL/TL	Depth (mm)	Ratio Depth/TL
Chinook	61	66	0.92	14	0.21
Chinook	66	71	0.93	13	0.18
Chinook	77	83	0.93	17	0.20
Chinook	91	96	0.95	20	0.21
Chinook	94	99	0.95	18	0.18
Chinook	97	108	0.90	19	0.18
average	81	87	0.93	17	0.19
	n=6	n=6	n=6	n=6	n=6
Dolly Varden	56	59	0.95	11	0.19
Dolly Varden	60	64	0.94	12	0.19
Dolly Varden	61			12	
Dolly Varden	63				
Dolly Varden	68	72	0.94	14	0.19
Dolly Varden	72	77	0.94	15	0.19
average	63	68	0.94	13	0.19
	n=6	n=4	n=4	n=5	n=4
Rainbow Trout	123	128	0.96	25	0.20
Rainbow Trout	133	139	0.96	26	0.19
average	128	134	0.96	26	0.19
	n=2	n=2	n=2	n=2	n=2

Table 3: Distribution of juvenile Coho by total length (mm) in Beaver Creek from Elliot and Finn, 1984.

Month	Age Class in Years			
	0 age	1 age	2 age	3 age
July	*	55-110	80-130	142
Aug	30-80	65-127	132-158	**
Oct	60-95	80-147	103-151	**

* Young-of-the-year not present or too small to be trapped.

** Smolts have left drainage by end of June.

In July, they found no young-of-the-year in their traps. We found that if the traps were checked frequently (< 30 minutes), we did find young-of-the-year. The longer we waited to check the traps, the larger the fish in the trap. We observed young-of-the-year enter traps only a minute or two after putting them in the stream, while traps left more than 30 minutes seldom had any young-of-the-year fish. In comparison with their survey, it would appear that most of the fish that we caught and studied were young-of-the-year and age 1+. Elliot and Finn (1983) reported that smolts out-migrate from April to June, so when we did this study all smolts should have vacated the drainage.

At the upstream inlet, at a point in the culvert near what appeared to be maximum velocities, we took numerous measurements of the velocities (Figure 10). This cross-section shows the high velocity gradients that exist near the boundaries. The highest water velocity gradients along the boundary are near the centerline at the bottom of the culvert; the lowest velocity gradients are near the water surface on each side. It is interesting to note that when we observed juvenile fish moving upstream in this section of culvert, they were near the water surface on either side of the culvert. Velocity profiles along the centerline of the culvert and near the edge of the culvert are shown in Figure 11 for the cross-section of Figure 10. Attempts to measure the velocity along the culvert wall at various points showed considerable variability depending upon the cross-section. At the shallowest depth and highest average velocity, the point velocities near the wall (as close as we could measure, approximately 0.15 feet (4.5 cm)) were around 3 fps (0.9 m/s).

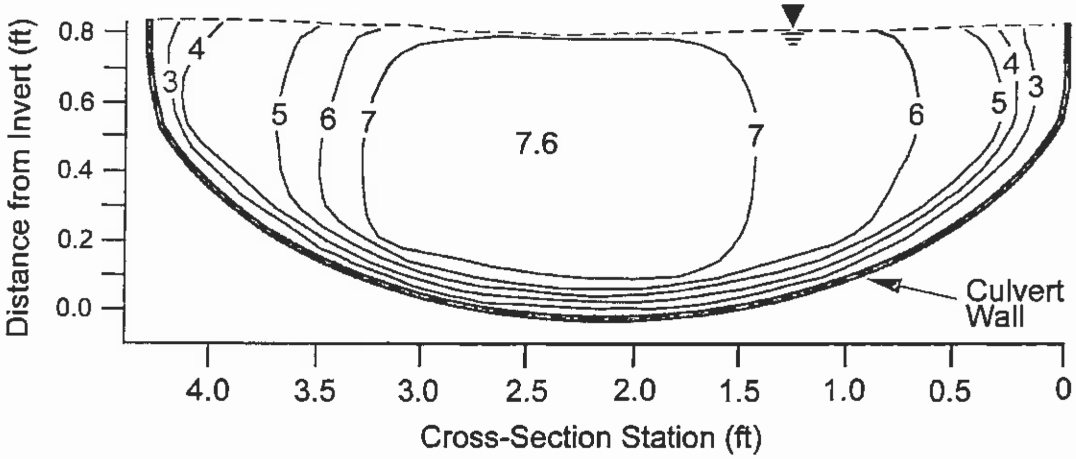


Figure 10. Cross-section of the velocity at 10 ft. (3 m) into Beaver Creek culvert from the upstream outlet (looking downstream).

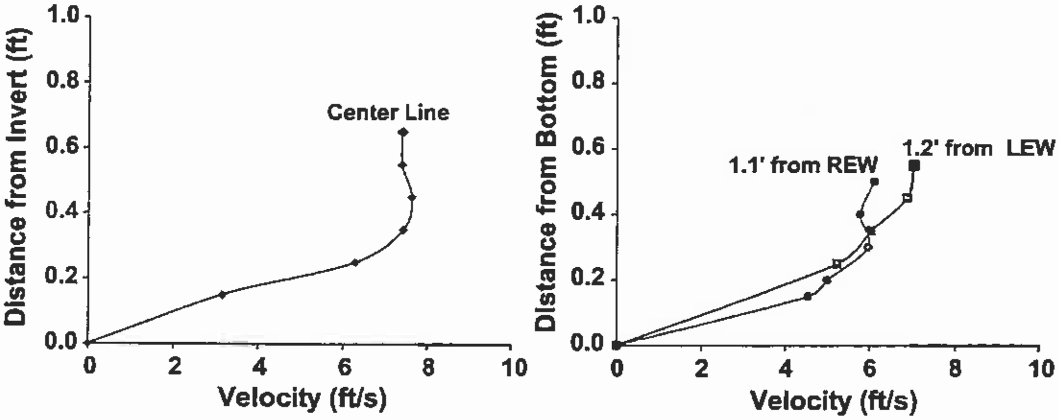


Figure 11. Velocity profiles along centerline of culvert and also near edges of cross-section shown in Figure 10 above (REW – right edge of water, LEW – left edge of water).

Of the approximately 500 dyed juvenile fish released downstream at Beaver Creek, 115 were recaptured upstream (Figure 12). It is not likely that we were successful in capturing all of the fish that successfully traveled upstream through the culvert, so all plots of the number of fish dyed-recaptured are conservative on the low side (or more fish succeeded than we indicate in graphs). Generally larger fish passed through the culvert first (true for all sites). We maintained our traps upstream for several days to allow young-of-the-year fish an opportunity to pass through the culvert. Late in the morning of July 31, we released our first dyed fish in Beaver Creek. On July 31 and August 1, we recaptured 63 dyed juvenile fish upstream (Table 2). The fork length of the juvenile Coho ranged from 44 to 123 mm. We continued to trap stained fish upstream for two more days with 52 additional stained fish recaptured. We were satisfied that young-of-the-year Coho could ascend through this culvert. Statistically, we could not show that there was a size difference between the dyed fish released downstream and the dyed fish caught upstream. Much of our remaining time was dedicated to observations, both visually by observers and with video cameras.

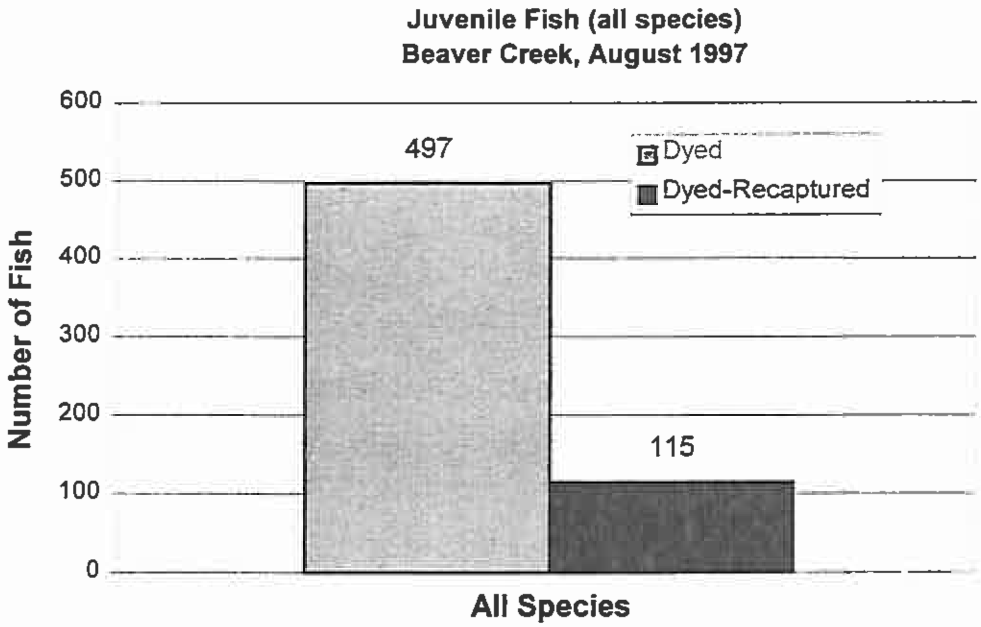


Figure 12. Plot of total number of juvenile fish stained and total number of fish recaptured at Beaver Creek (July 31 – August 4, 1997).

Lighting conditions were very good at the culvert inlet, particularly in late morning and afternoon. When we first arrived at the site the water was slightly turbid, however the turbidity continually decreased during our study. Although we thought it would be next to impossible to visually observe these small juvenile fish moving through the culvert, we were surprised when we saw a few juvenile Coho resting in the corrugations. They were positioned headfirst into the 2 in (51 mm) deep by 6 in (152 mm) corrugations with their bodies normal to the flow through the culvert. These fish were also located at the water surface. At times there were more on one side of the culvert than the other, but this situation could change for no obvious reason. By standing in the center of the culvert or outside the inlet relatively motionless, we were able to observe the juvenile fish moving up the culvert along the wall. These fish would swim along the culvert wall, but after passing two or three corrugations, they would rest in the corrugations. After a minute or two, they would move along upstream. The last four or five corrugations on the upstream end of the culvert appeared to be unattainable by the juvenile fish. We observed that a few juvenile fish reached these upper corrugations, but in all cases they were washed downstream out of the corrugations. We observed the fish congregating in either the fifth or sixth corrugation downstream of the inlet. At times we observed so many juvenile fish in the corrugations that we could only give a rough guess of between 15 and 25 juvenile fish. It was impossible to observe individual fish, but the fact that there were more fish in this corrugation than any downstream corrugation indicates that the fish were resting longer here than in the corrugations downstream. After several minutes, a fish would dart out into the flow in the center of the culvert and attempt to exit upstream. If they succeeded, they would dive either to the bottom or to the side of the stream. They would travel a distance of 4 or 5 ft (1.2 or 1.5 m) in little more than 1 second. Some of these fish were observed to fail, but from what we could see, many more succeeded than failed.

We observed, on numerous occasions, that juvenile fish were being washed back downstream when it appeared that they were resting in the corrugations. This seemed to be more frequent as the number of fish in a corrugation increased. The water levels were sloshing up and down and it looked as though some fish inadvertently got bumped out. We also have video documentation of this process. Numerous juvenile fish were observed entering the culvert from upstream. At this time, we attributed this behavior to the natural activity of these fish.

To test our hypothesis that juvenile fish would be motivated to move upstream to obtain food, we returned to this site in July 1998. On the first three days that we visited this site (with no planted food source), we observed no juvenile fish in the culvert. On two days following the three previous days, after checking inside the culvert and finding no juvenile fish, we put baited traps upstream of the culvert and waited from 30 to 60 minutes to check the culvert (It should be noted that adult fish do not spawn in the immediate reach above the culvert). On both days, we observed numerous juvenile fish resting in the corrugations during their attempt to ascend the culvert. With just a small aquarium fish net, we captured 10 of these juvenile Coho with a measured fork length that ranged from 56 to 80 mm (2.2 to 3.1 in). We concluded that the existence of the fish eggs in the trap upstream accounted for the fish observed in the culvert and the salmon eggs provided sufficient incentive for the upstream juvenile fish activity.

No-name Creek

Measurements were carried out at No-name Creek on Prince of Wales Island on September 13-17, 1997. This stream was selected because of the relatively uniform velocities through the culvert. The magnitude of the velocity in this culvert is a function of the water stage. Unfortunately, at the time of our visit the stage was quite low and water velocities were low. Stream discharge was approximately 10 CFS (0.28 cms). Water surface and culvert invert elevation profiles are shown in Figure 13. Measured velocity profiles at 6 ft (2m) into the culvert are shown in Figure 14. Station 5.5 is near the centerline of the culvert, while the other stations are on the same cross-section, but off to the side. The maximum velocities shown in Figure 14 are 3.0 fps (0.9 m/s) on the centerline near the surface. Velocities along the boundary are closer to 1 fps (0.3 m/s).

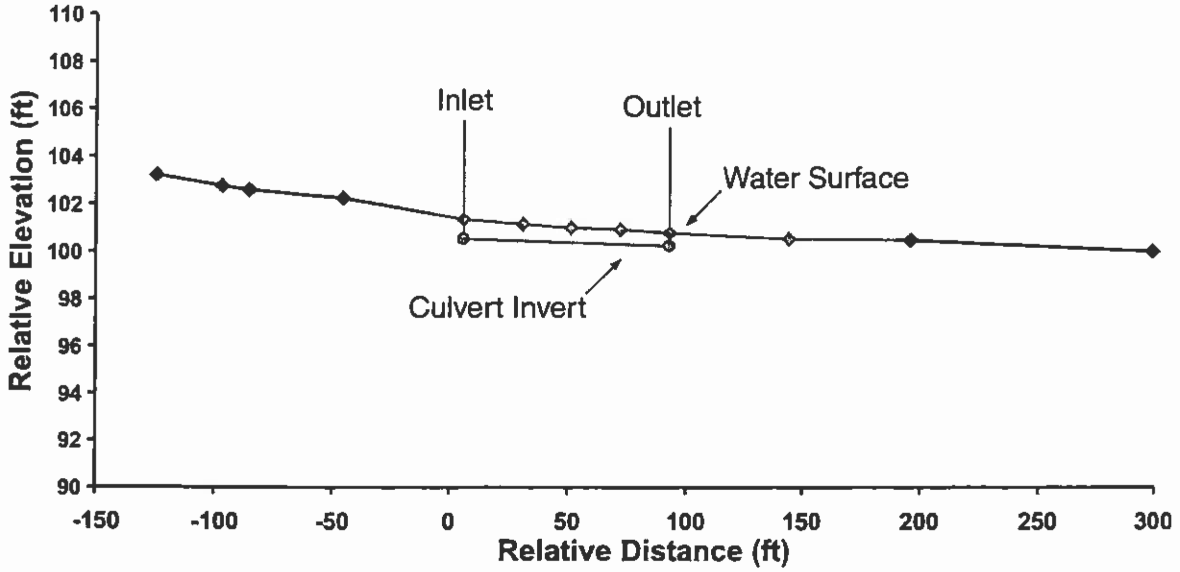


Figure 13. Water surface and culvert invert profiles for No-Name Creek September 13, 1997.

Lighting for visual observations in this culvert was poor due to the overstory vegetation. We utilized the video cameras extensively at this site. Juvenile fish had a different strategy for ascending through this culvert than the one at Beaver Creek. Essentially all of the fish observed with the video camera swam at the bottom of the culvert along the centerline. This can be contrasted with Beaver Creek, where they swam near the surface along the walls. Although it appeared, for the culvert at No-name Creek, that it would be easier to swim at the surface near the wall, we observed no fish attempting to take this pathway.

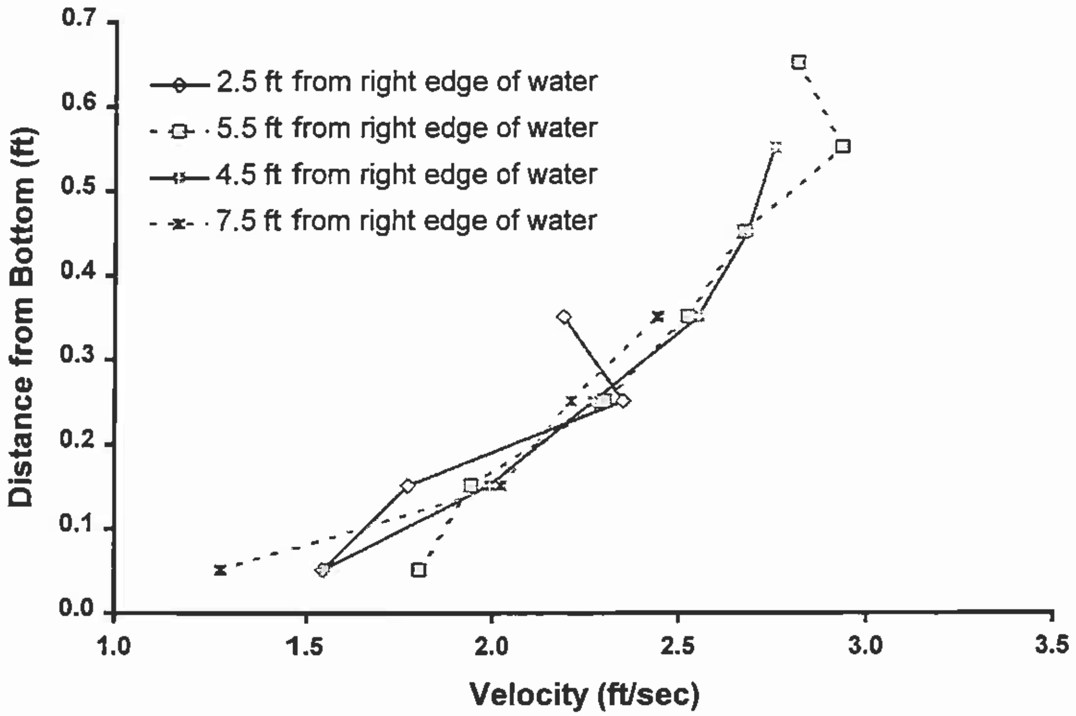


Figure 14. Velocity profiles of a cross-section located 6 feet upstream from culvert outlet on No-Name Creek.

Over 270 juvenile fish (Coho and Dolly Varden) were dyed and released below the culvert. Most of these fish were collected from beaver ponds upstream. Although there were several nice pools downstream, we failed to trap very many juvenile fish there. We recaptured 47 of the stained fish upstream (Figure 15). Many of these fish were recaptured shortly (within two hours) after their release. Most of the fish were recaptured just upstream of the culvert. However, we did recapture some stained fish in the beaver ponds farther upstream. To reach these ponds, fish needed to pass a large log lying across the stream. To leap over the log, the fish would be required to leap at least 18 in (0.46 m) into the air. It did not appear that there were any openings beneath the log.

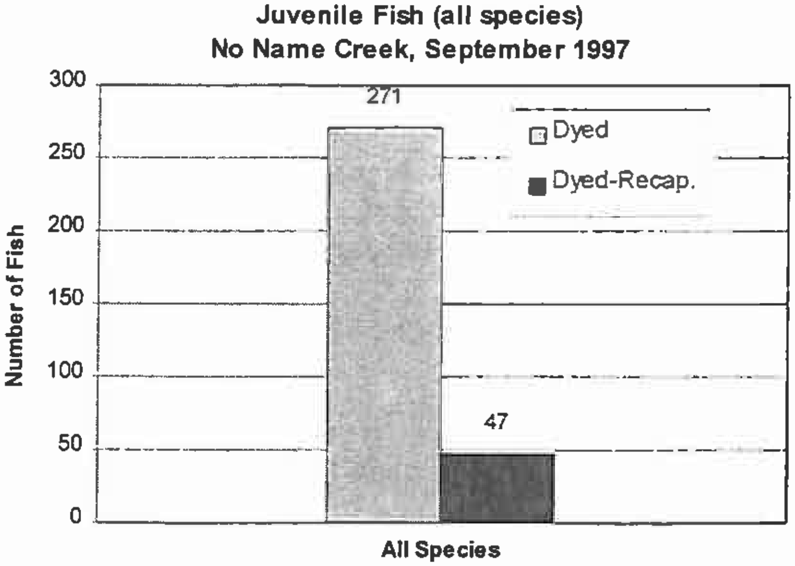


Figure 15. Plot of the total number of juvenile fish dyed against the total number of dyed fish recaptured for No-Name Creek (September 13-17, 1997).

It quickly became obvious at this site that under the existing hydraulic conditions the juvenile fish had no problems ascending the culvert. First, stained fish were quickly recaptured upstream. Second, fish observed on the video monitor were quickly ascending the culvert with little apparent difficulty. We did not observe any juvenile fish in a holding or resting position within the culvert. The Froude number was about 0.6 just upstream of the culvert and slightly less within the culvert. The size and range of juvenile Coho stained at No-name Creek was similar to those of Beaver Creek, except that we captured none smaller than 50 mm (young-of-the-year were two to three months older than juvenile fish studied at Beaver Creek). The full size-range of juvenile Coho stained at this site succeeded in ascending the culvert.

Soldotna Creek

Two visits were made in 1998 to Soldotna Creek on the Kenai Peninsula: July 8-10 and August 12-13. During the first visit, 379 fish (299 Coho, 59 Dolly Varden and 21 Chinook) were dyed. Most of these fish were trapped upstream of the culvert. Initially, we placed a trap in the middle of the culvert to verify that juvenile fish were present in the cells between the baffles. Stained fish were released just downstream of the culvert. The second visit in August was for the purpose of video taping juvenile fish ascending the culvert. Elliott and Nelson (1985) reported that this stream crossing was a barrier to fish passage; it should be noted that since the time of their visit, that culvert has been replaced with the present culvert containing 13 baffles. During our July visit, the discharge was quite low at 7.1 CFS (0.2 cms), and during August it was 22.7 CFS (0.64 cms).

The 92 juvenile Coho sampled at this stream (of 299 dyed) ranged in fork length from 44 to 101 mm (Table 4). Juvenile Chinook sampled (10 out of 21 dyed) ranged from 60 to 104 mm fork length. Fifty-nine Dolly Varden were also dyed. Figures 16 and 17 show the relationship between fork length and total length and fork length and weight for the juvenile Cohos and Kings combined respectively. We did not attempt to recapture fish on July 8, 1998 as the fish were not released until 1:30 pm AST. At 10:00 am AST the next day, while trapping more fish upstream to stain, we recaptured two dyed Dolly Varden (≅ 100 mm fork length). On the afternoon of July 9, we captured 5 juvenile Coho with fork lengths ranging from 70 to 79 mm (Table 5). On the morning of July 10 we recaptured several Coho in the 70 to 80 mm fork length range. Around noon of the same day, we recaptured several young-of-the-year Coho; some were as small as 44 mm fork length. Many more stained juvenile Coho of all sizes were captured during the afternoon of July 10. These results demonstrated that juvenile Coho of any size could get through this 298 ft long culvert with 13 baffles.

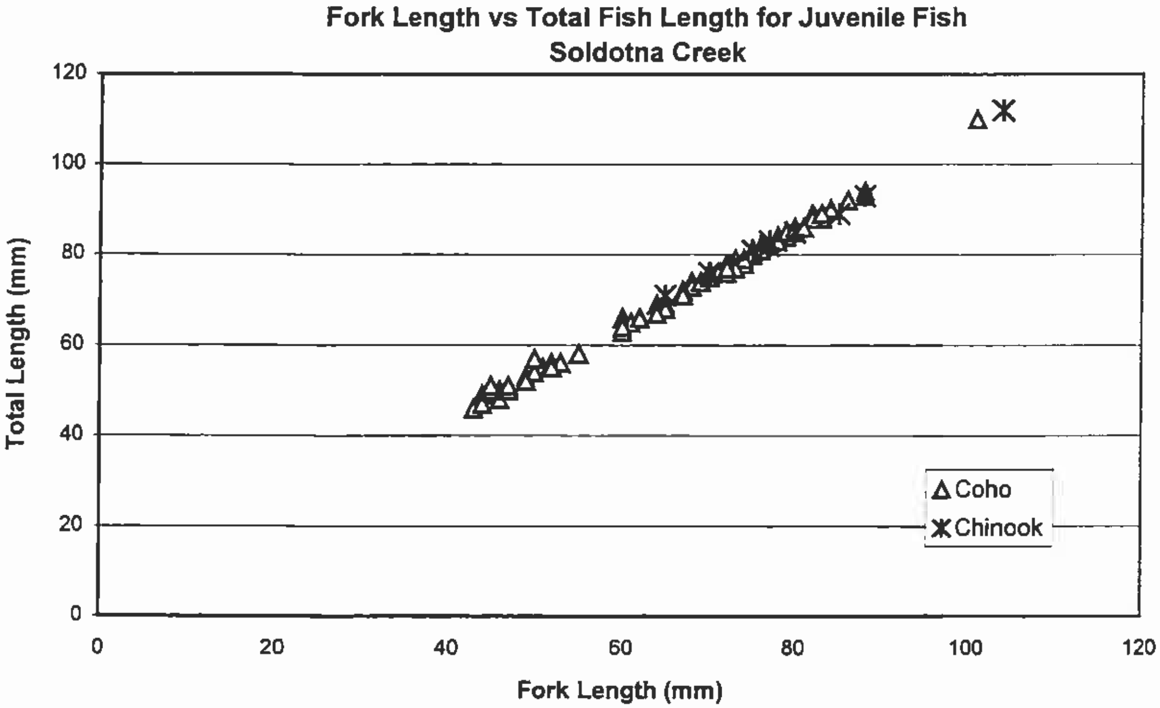


Figure 16. Relationship between total length and fork length for juvenile fish sampled on Soldotna Creek (July 8-9, 1998).

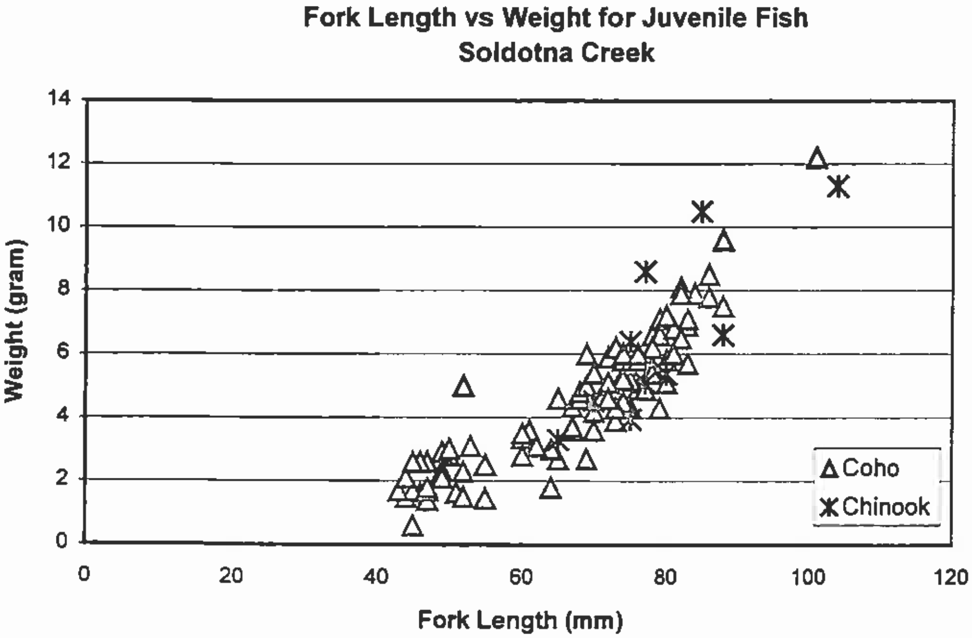


Figure 17. Relationship between fork length and weight for juvenile fish sampled in Soldotna Creek (July 8-9, 1998).

Table 4. Fork and total length, weight, and some depths for a sample of juvenile fish captured for staining, Soldotna Creek (July 8 and 9, 1998).

Date	Time (ast)	Species	Fork Length (mm)	Total Length (mm)	Weight (grams)	Ratio FL/TL	Depth (mm)	Ratio Depth/TL
8-Jul-98	1:30 PM	Coho	67	72	4.34	0.93		
8-Jul-98	1:30 PM	Coho	51	55	1.64	0.93		
8-Jul-98	1:30 PM	Coho	55	58	1.45	0.95		
8-Jul-98	1:30 PM	Coho	76	81	4.9	0.94		
8-Jul-98	1:30 PM	Coho	46	50	1.57	0.92		
8-Jul-98	1:30 PM	Coho	70	75	4.19	0.93		
8-Jul-98	1:30 PM	Coho	60	66	3.35	0.91		
8-Jul-98	1:30 PM	Coho	75	81	5.18	0.93		
8-Jul-98	1:30 PM	Coho	80	85	5.1	0.94		
8-Jul-98	1:30 PM	Coho	73	79	3.9	0.92		
8-Jul-98	1:30 PM	Coho	65	69	2.7	0.94		
8-Jul-98	1:30 PM	Coho	101	110	12.2	0.92		
8-Jul-98	1:30 PM	Coho	69	74	2.7	0.93		
8-Jul-98	1:30 PM	Coho	44	49	1.5	0.90		
8-Jul-98	1:30 PM	Coho	68	74	4.6	0.92		
8-Jul-98	1:30 PM	Coho	45	49	0.6	0.92		
8-Jul-98	1:30 PM	Coho	72	77		0.94		
8-Jul-98	1:30 PM	Coho	44	49	1.9	0.90		
8-Jul-98	1:30 PM	Coho	45	50	1.7	0.90		
8-Jul-98	1:30 PM	Coho	64	69	3	0.93		
8-Jul-98	1:30 PM	Coho	84	90	7.9	0.93		
8-Jul-98	1:30 PM	Coho	68	73	4.8	0.93		
8-Jul-98	1:30 PM	Coho	78	83	6.6	0.94		
8-Jul-98	1:30 PM	Coho	61	65	3.6	0.94		
8-Jul-98	1:30 PM	Coho	83	89	5.7	0.93		
8-Jul-98	1:30 PM	Coho	69	74	5	0.93		
8-Jul-98	1:30 PM	Coho	83	89	7.1	0.93		
8-Jul-98	1:30 PM	Coho	72	78	5.9	0.92		
8-Jul-98	1:30 PM	Coho	60	63	2.8	0.95		
8-Jul-98	1:30 PM	Coho	49	53	2.3	0.92		
8-Jul-98	1:30 PM	Coho	76	82	6	0.93		
8-Jul-98	1:30 PM	Coho	69	74	6	0.93		
8-Jul-98	1:30 PM	Coho	65	68	4.6	0.96		
8-Jul-98	1:30 PM	Coho	74	78	5.3	0.95		
8-Jul-98	1:30 PM	Coho	74	79	5.8	0.94		
8-Jul-98	1:30 PM	Coho	79	85	6.6	0.93		
8-Jul-98	1:30 PM	Coho	81	86	6.8	0.94		
8-Jul-98	1:30 PM	Coho	78	84	5.6	0.93		
8-Jul-98	1:30 PM	Coho	82	89	8.1	0.92		
8-Jul-98	1:30 PM	Coho	67	72	3.6	0.93		
8-Jul-98	1:30 PM	Coho	74	79	5.3	0.94		
8-Jul-98	1:30 PM	Coho	73	77	6.2	0.95		
8-Jul-98	1:30 PM	Coho	74	79	5.2	0.94		
8-Jul-98	1:30 PM	Coho	49	53	2.1	0.92		
8-Jul-98	1:30 PM	Coho	43	46	1.7	0.93		
8-Jul-98	1:30 PM	Coho	70	75	5.4	0.93		
8-Jul-98	1:30 PM	Coho	74	79	6	0.94		
8-Jul-98	1:30 PM	Coho	71	76	4.6	0.93		
8-Jul-98	1:30 PM	Coho	60	64	3.5	0.94		
8-Jul-98	1:30 PM	Coho	62	66	3.1	0.94		
8-Jul-98	1:30 PM	Coho	47	50	1.4	0.94		
8-Jul-98	1:30 PM	Coho	47	51	2.6	0.92		

8-Jul-98	1:30 PM	Coho	64	67	1.8	0.96		
9-Jul-98	10:50 AM	Coho	50	54	2.8	0.93		
9-Jul-98	10:50 AM	Coho	52	56	2.3	0.93		
9-Jul-98	10:50 AM	Coho	75	80	4.3	0.94		
9-Jul-98	10:50 AM	Coho	52	56	5	0.93		
9-Jul-98	10:50 AM	Coho	49	52	2.9	0.94		
9-Jul-98	10:50 AM	Coho	78	84	6.2	0.93		
9-Jul-98	10:50 AM	Coho	88	94	7.5	0.94		
9-Jul-98	10:50 AM	Coho	53	56	3.1	0.95		
9-Jul-98	10:50 AM	Coho	83	88	6.9	0.94		
9-Jul-98	10:50 AM	Coho	46	48	2.6	0.96		
9-Jul-98	10:50 AM	Coho	50	57	3	0.88		
9-Jul-98	10:50 AM	Coho	70	76	3.6	0.92		
9-Jul-98	10:50 AM	Coho	72	77	5.1	0.94		
9-Jul-98	10:50 AM	Coho	76	82	5.8	0.93		
9-Jul-98	10:50 AM	Coho	45	51	2.6	0.88		
9-Jul-98	10:50 AM	Coho	74	79	4.5	0.94		
9-Jul-98	10:50 AM	Coho	72	76	4.6	0.95		
9-Jul-98	10:50 AM	Coho	79	84	4.3	0.94		
9-Jul-98	10:50 AM	Coho	86	92	7.8	0.93		
9-Jul-98	10:50 AM	Coho	86	92	8.5	0.93		
9-Jul-98	10:50 AM	Coho	52	55	1.5	0.95	10	0.18
9-Jul-98	10:50 AM	Coho	77	82	4.9	0.94	18	0.22
9-Jul-98	10:50 AM	Coho	82	88	7.9	0.93	18	0.20
9-Jul-98	10:50 AM	Coho	78	83	5.4	0.94	16	0.19
9-Jul-98	10:50 AM	Coho	82	88	6.5	0.93	17	0.19
9-Jul-98	10:50 AM	Coho	47	50	1.7	0.94	10	0.20
9-Jul-98	10:50 AM	Coho	80	86	5.8	0.93	17	0.20
9-Jul-98	10:50 AM	Coho	79	85	7.1	0.93	18	0.21
9-Jul-98	10:50 AM	Coho	80	86	7.2	0.93	21	0.24
9-Jul-98	10:50 AM	Coho	76	81	6	0.94	16	0.20
9-Jul-98	10:50 AM	Coho	83	89	7.1	0.93	18	0.20
9-Jul-98	10:50 AM	Coho	73	77	4.3	0.95		
9-Jul-98	10:50 AM	Coho	67	71	3.7	0.94	15	0.21
9-Jul-98	10:50 AM	Coho	88	93	9.6	0.95	19	0.20
9-Jul-98	10:50 AM	Coho	81	86	6	0.94	16	0.19
9-Jul-98	10:50 AM	Coho	47	51	1.8	0.92	10	0.20
9-Jul-98	10:50 AM	Coho	44	47	2.1	0.94	9	0.19
9-Jul-98	10:50 AM	Coho	55	58	2.5	0.95	11	0.19
9-Jul-98	10:50 AM	Coho	72	77	4.6	0.94	14	0.18
		average	67	72	4.6	0.93	15	0.20
			n=92	n=92	n=91	n=92	n=18	n=18

8-Jul-98	1:30 PM	Chinook	75	81	3.95	0.93
8-Jul-98	1:30 PM	Chinook	65	71	3.3	0.92
8-Jul-98	1:30 PM	Chinook	70	76	4.53	0.92
8-Jul-98	1:30 PM	Chinook	80	85	5.38	0.94
8-Jul-98	1:30 PM	Chinook	77	82	8.6	0.94
8-Jul-98	1:30 PM	Chinook	77	83	5.1	0.93
8-Jul-98	1:30 PM	Chinook	85	89	10.5	0.96
8-Jul-98	1:30 PM	Chinook	104	112	11.3	0.93
8-Jul-98	1:30 PM	Chinook	75	81	6.4	0.93
8-Jul-98	1:30 PM	Chinook	88	93	6.6	0.95
		average	80	85	6.6	0.93
			n=10	n=10	n=10	n=10

Table 5. Fork and total length and depths for a sample of juvenile fish dyed and recaptured, Soldotna Creek (July 9 and 10, 1998).

Date	Time (ast)	Species	Fork Length (mm)	Total Length (mm)	Ratio FL/TL	Depth (mm)	Ratio Depth/TL
9-Jul-98	4:00 PM	Coho	79	86	0.92	17	0.20
9-Jul-98	5:15 PM	Coho	75	81	0.93	16	0.20
9-Jul-98	6:10 PM	Coho	77	82	0.94	15	0.18
9-Jul-98	6:10 PM	Coho	70	75	0.93	14	0.19
9-Jul-98	6:10 PM	Coho	75	79	0.95	15	0.19
10-Jul-98	11:30 AM	Coho	86	94	0.91	22	0.23
10-Jul-98	11:30 AM	Coho	74	79	0.94	15	0.19
10-Jul-98	11:30 AM	Coho	70	74	0.95	14	0.19
10-Jul-98	12:50 AM	Coho	44	47	0.94	8	0.17
10-Jul-98	12:50 AM	Coho	47	50	0.94	10	0.20
10-Jul-98	12:50 AM	Coho	45	48	0.94	9	0.19
10-Jul-98	12:50 AM	Coho	44	47	0.94	8	0.17
10-Jul-98	12:50 AM	Coho	55	59	0.93	10	0.17
10-Jul-98	12:50 AM	Coho	52	55	0.95	10	0.18
10-Jul-98	12:50 AM	Coho	44	47	0.94	9	0.19
10-Jul-98	4:00 PM	Coho	79	85	0.93	15	0.18
10-Jul-98	4:00 PM	Coho	96	102	0.94	21	0.21
10-Jul-98	4:00 PM	Coho	68	73	0.93	12	0.16
10-Jul-98	4:00 PM	Coho	70	74	0.95	11	0.15
10-Jul-98	4:00 PM	Coho	81	87	0.93	17	0.20
10-Jul-98	4:00 PM	Coho	81	88	0.92	17	0.19
10-Jul-98	4:00 PM	Coho	44	47	0.94	8	0.17
		average	66	71	0.94	13	0.19
			n=22	n=22	n=22	n=22	n=22
10-Jul-98	11:30 AM	Chinook	94	100	0.94	15	0.15
9-Jul-98	5:15 PM	Dolly Varden	n/a				
9-Jul-98	6:10 PM	Dolly Varden	n/a				
9-Jul-98	10:50 AM	Dolly Varden	n/a				
9-Jul-98	10:50 AM	Dolly Varden	n/a				
10-Jul-98	11:30 AM	Dolly Varden	104	110	0.95	19	0.17
10-Jul-98	4:00 PM	Dolly Varden	98	103	0.95	17	0.17
10-Jul-98	4:00 PM	Dolly Varden	116	123	0.94	21	0.17

A schematic of the culvert, along with the pattern of flow through the culvert for the observed stage at the time of the visit, is shown in Figure 18. When the baffles were installed in the culvert, the crown of the baffle was not horizontal. Instead they sloped downward from one side to the other, and the slope direction alternated between adjacent baffles. Consequently, the flow through the culvert wandered from side to side for the flow conditions during our visit. There was generally no flow over the baffle along the wall at the high side of a baffle. The drop in the water surface at each baffle (Figure 19) ranged from 0.25 (7 cm) to 1.0 ft (30 cm). Since we used just one dye, we could not separate recaptured fish according to the date dyed.

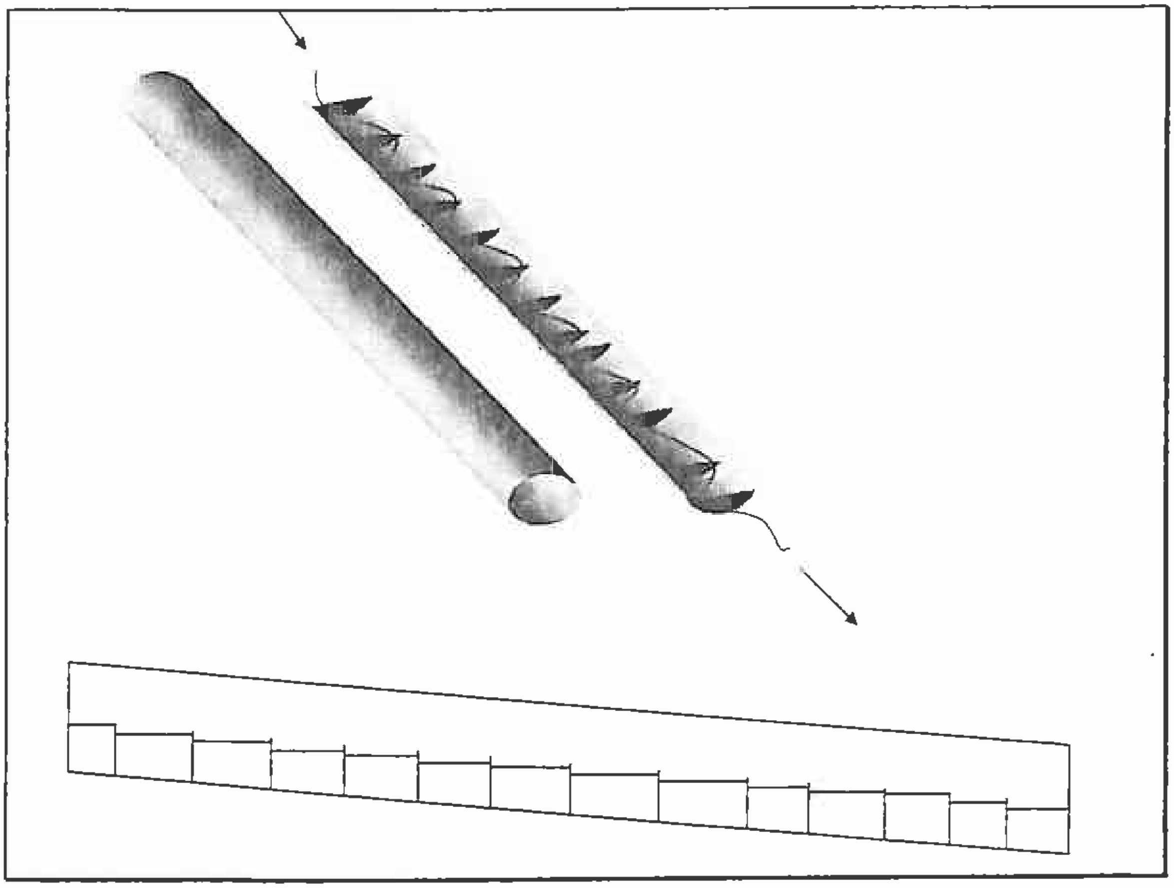


Figure 18. Schematic of Soldotna Creek culvert showing the pattern of flow through culvert and the placement of 13 baffles.

It appears that no young-of-the-year fish made it through the culvert on the day they were released; dyed fish were released on July 8 and 9 and young-of-the-year were first recaptured on July 10. A summary of the dyed fish that successfully passed the culvert and were recaptured is shown in Figure 20.

Upon reviewing our results collectively, we realized that we had not seen a single fish leap over a baffle during our July, 1998 visit to Soldotna Creek. When we surveyed the culvert and baffles, it was noted that in some cases the baffles did not appear to fit tightly against the culvert wall. Further investigation revealed that none of the baffles fit snugly against the sidewalls, as shown in Figure 21. We decided that we should determine if the juvenile fish were passing upstream through openings between the culvert wall and the baffles.

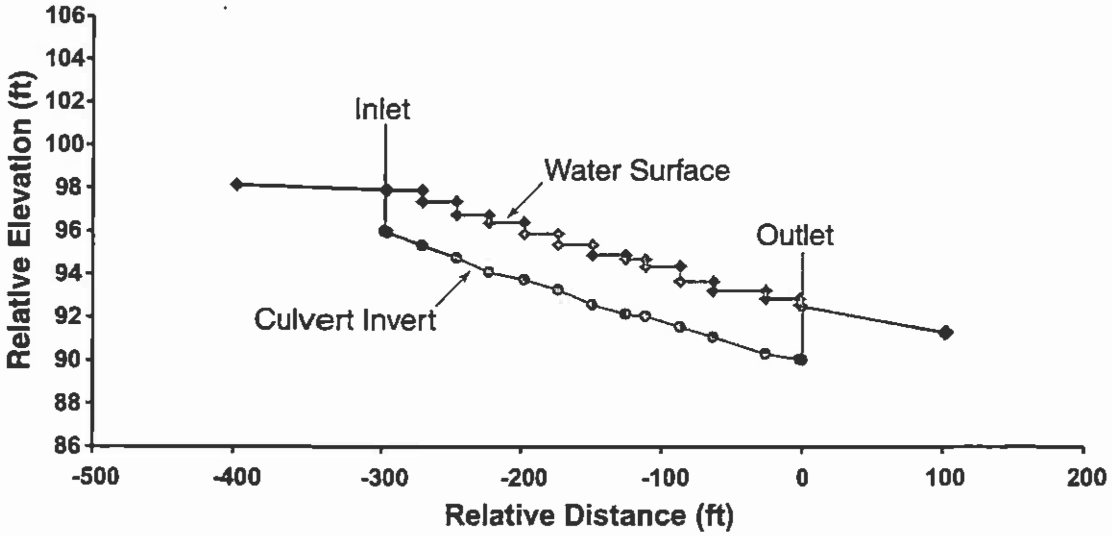


Figure 19. Water surface and culvert invert profiles for Soldotna Creek on August 2, 1997.

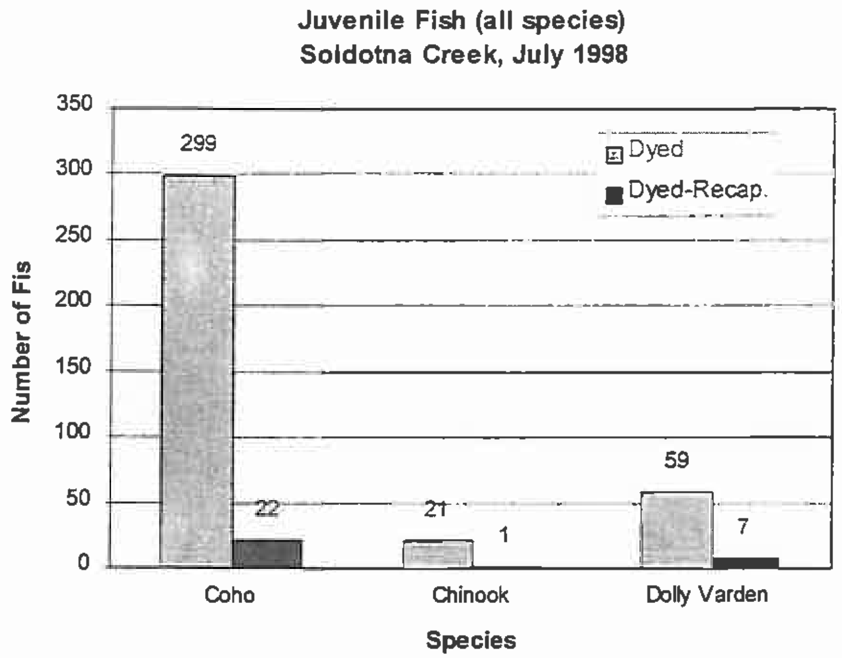


Figure 20. Comparison of the number of juvenile fish dyed against the total number of dyed fish recaptured upstream for Soldotna Creek (July 8-10, 1998).

The fabricated baffles generally made contact with the culvert invert along the bottom. It appears for ease of installation that the baffles were deliberately made smaller than the culvert opening. Near the top of the baffle the opening was approximately 1½ in (3.8 mm), and this tapered down to zero near the bottom of the baffle. Underwater video cameras were placed both upstream and downstream of the baffles on the bottom of the culvert near the sidewall, with the lens facing up at the water surface. Numerous fish were observed attempting and in many occasions successfully passing through the openings. Velocities measured at the openings were near 5 fps (1.5 m/s) in the vicinity of the successful fish passes (Figure 21).

The video cameras were placed on both sides of the culvert. Since the baffles are sloped transversely, for the flows at the time of this visit, one side of the culvert had water spilling over

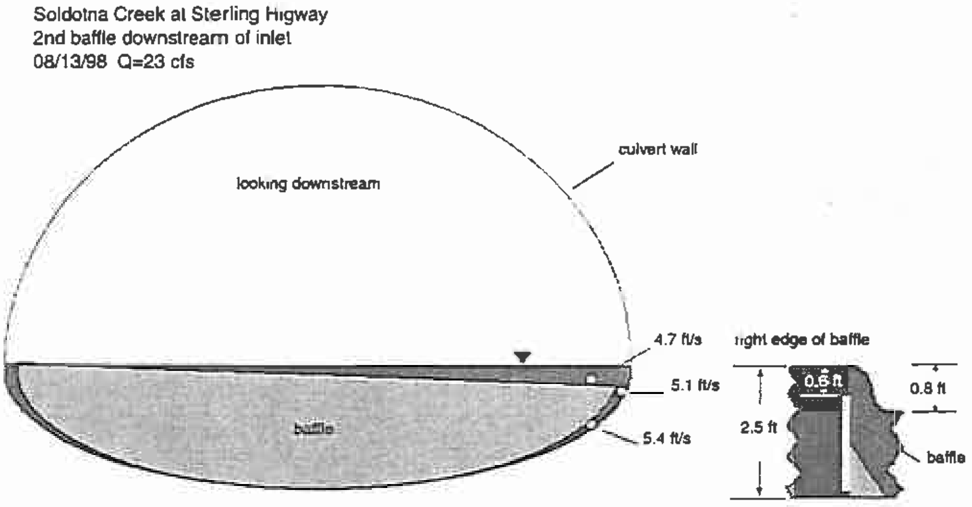


Figure 21. Typical cross-section of baffle showing the upstream water surface, the opening between baffle and culvert wall, and magnitude of water velocities where fish were observed attempting to swim upstream past baffle.

the top of the baffle while the other side did not (Figure 21). It appeared that the juvenile fish preferred to go beneath the left side of the baffle (shown in Figure 21), where there was no water spilling over the top of the baffle. With no water spilling over the top, the fish did not have to contend with vertical velocities of plunging flow. This observation is based on the frequency of attempts and the success rate for a given time period of the videotape.

In summary, all age classes of juvenile Coho were successful in passing upstream through this very long culvert that included 13 baffles. There was no evidence that the fish leaped over the baffles; instead, they swam through a slot between the culvert wall and the end of the baffle where the water velocities varied somewhat around 5 fps (1.5 m/s). These results indicate that slots may be an acceptable technique for improving juvenile fish passage in culverts with baffles.

Pass Creek Tributary

After our experience at the other three sites, we decided that a culvert with high velocities uniformly distributed throughout the full culvert length would be worthwhile to study. We expended considerable time on Prince of Wales (POW) Island trying to locate a culvert satisfying such criteria. Many culverts on POW Island are interesting from a hydraulic viewpoint; unfortunately we could not verify that sufficient fish were present for our study. We finally selected a culvert at mile 14.4, Polk Inlet Road. The culvert was only 53.25 ft (16.2 m) long, but depth of flow was fairly uniform throughout its length. The water surface and culvert invert elevation profiles appear in Figure 22 (Numerical values for slope shown in Table 1).

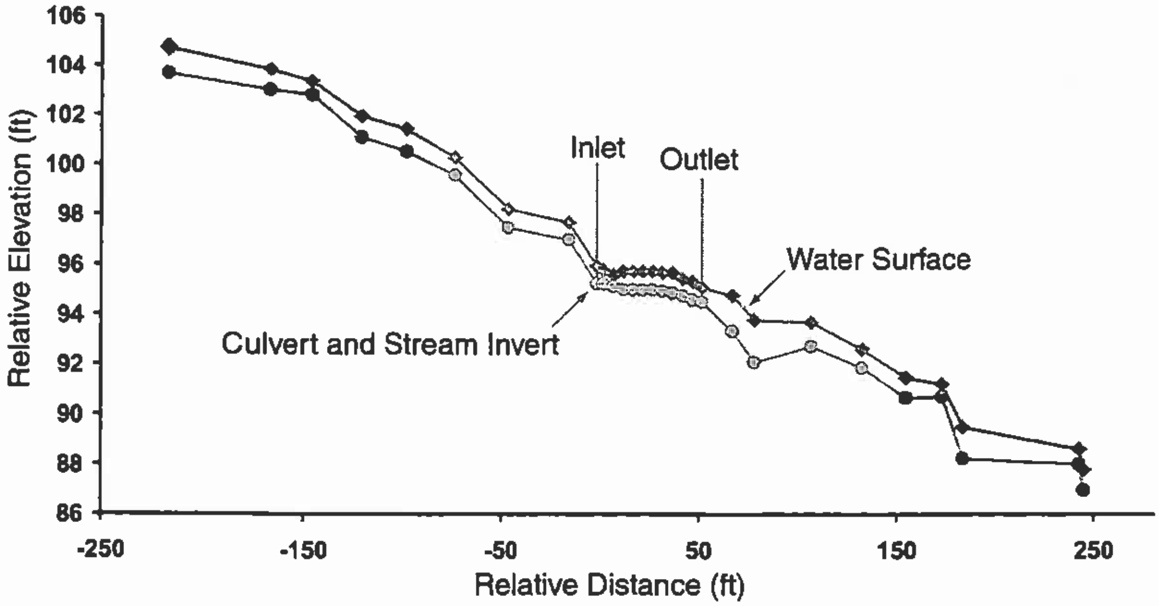
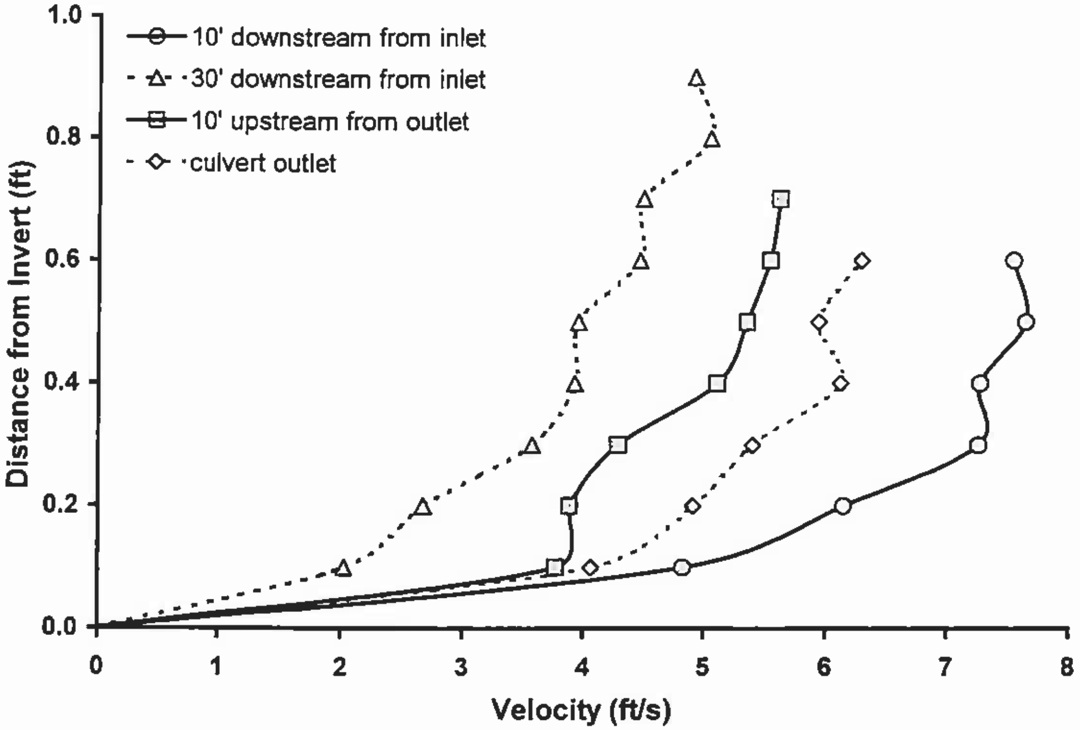


Figure 22. Water surface, stream and culvert invert profiles for Pass Creek Tributary on 14.4 mile Polk Inlet Road, Prince of Wales Island.

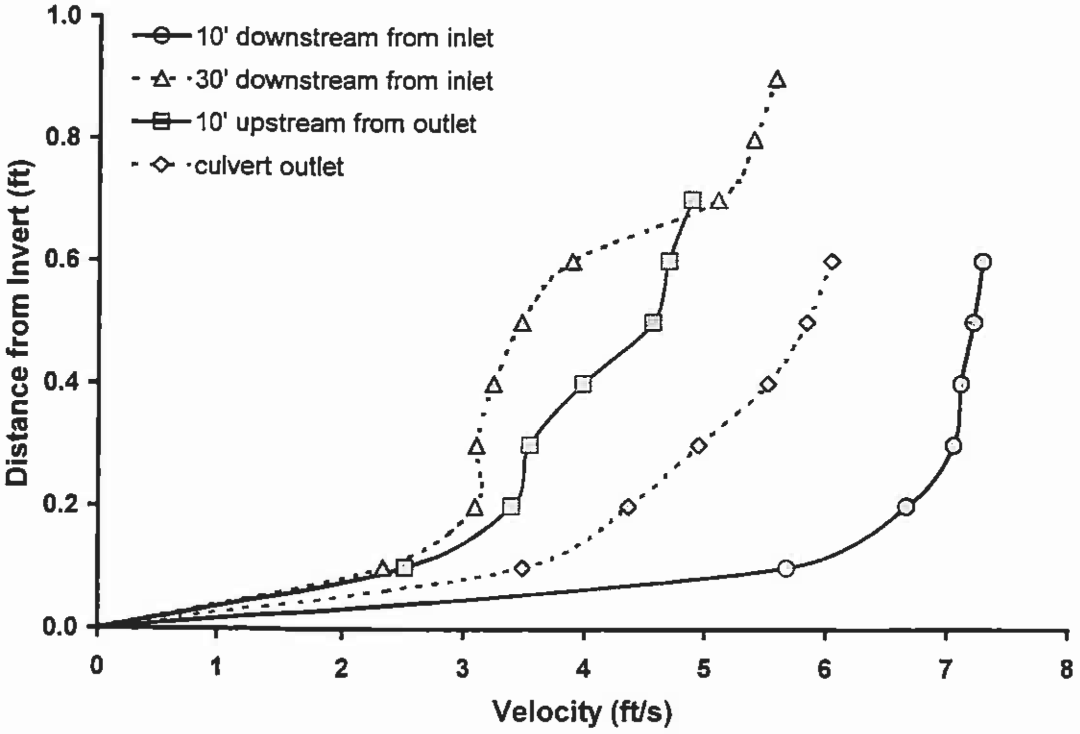
A staff gage was placed in an upstream pool. During most of the visit, the discharge was approximately 10 CFS (0.3 m^3/s). Maximum culvert velocities (Figures 23 a and b) along the centerline ranged from 5 to >7 fps (1.5 to >2.1 m/s) on October 5, 6 and 8, 1998. The Froude number for this culvert ranges around 1, in the deepest sections of the culvert the flow was subcritical and in the shallower sections the flow was supercritical.

This culvert differs from the other 3 culverts in that the corrugations are only 1 in (3 cm) deep and 3 in (8 cm) long (versus 2 in (5 cm) deep and 6 in (15 cm) long). On October 7, the discharge increased to 33.6 CFS (0.95 m^3/s). At this discharge, the combination of depth and velocity made it impossible to take velocity measurements in the culvert. One measurement at 0.1 ft (3 cm) from the culvert invert on the centerline was between 2 and 3 fps (0.6 to 0.9 m/s) greater than the same measurement on October 5 and 8 (Figure 24).

Fish were not numerous at this site. We were successful in capturing juvenile Coho, Dolly Varden and cut-throat trout. We had to travel some distance upstream and downstream to capture the 84 fish dyed on this stream (Table 6). When we trapped fish in the minnow traps on this stream, it was very common to catch just one species at a time. Fourteen of the fish used for staining were captured upstream, the remainder downstream. The distribution of fork length versus both total length and the weight are shown in Figures 25 and 26 for all fish that were captured and stained.



a. October 5, 1998.



b. October 8, 1998.

Figure 23a and b. Velocity profiles along centerline of culvert on Pass Creek Tributary on October 5 and 8, 1998.

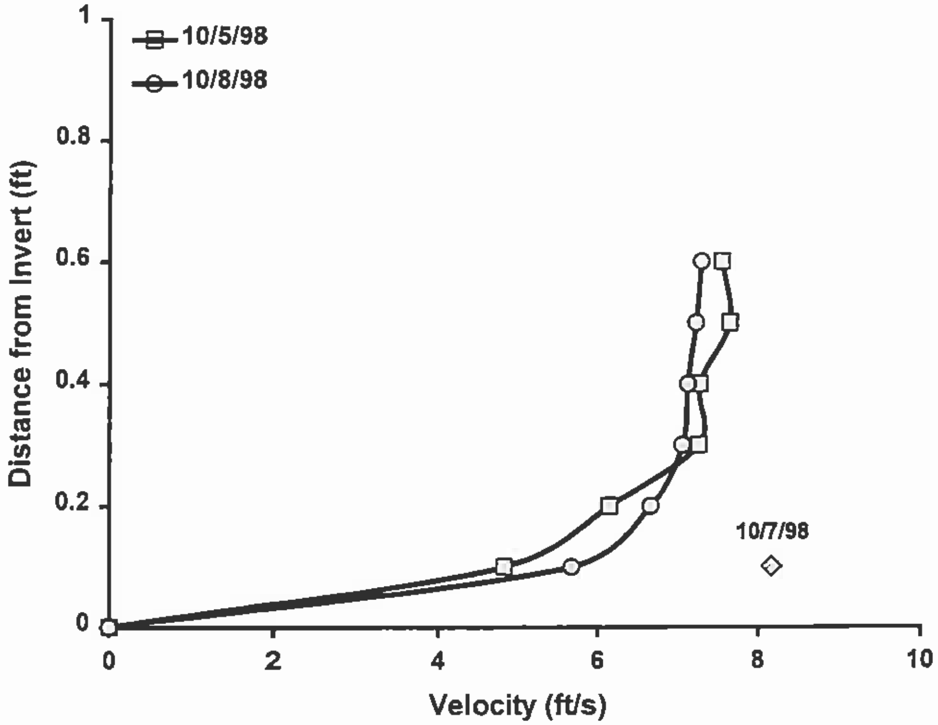


Figure 24. Velocity profiles 10 ft. (3 m) downstream from culvert inlet on Pass Creek Tributary.
Note, these profiles can be compared with the solitary velocity measurement at 0.1 ft (0.03 m) from the culvert invert that was made on October 7, 1998.

Fish that successfully ascended the culvert did it before and after October 7: our capturing effort indicated that no fish swam through at the higher stage on this date. Although some fish successfully ascended this culvert (Table 7), those that succeeded were generally the larger fork lengths of each type (Coho, 88 mm; Dolly Varden, 94, 123 and 124 mm; cut-throat trout, 124 mm). Also, they only accomplished this feat at the lower stages. The number of resting areas in this culvert was minimal. We observed several juvenile fish in the culvert; all were near the water surface along the sidewalls. The total number of dyed and dyed-recaptured fish is shown in Figure 27. We never saw or videotaped them in the corrugations. It was suspected that these corrugations were too small to serve as rest areas for fish.

It was conjectured that, since the water temperature (43 °F, 6 °C) was dropping, the fish may have been moving downstream. At the very end of the study, one baited trap was placed in the stream just below the culvert outlet. In one hour, a total of nine stained fish were re-captured (along with 16 unstained fish): one Coho, six Dolly Varden and two cutthroat trout. A total of 25 fish was far more than we ever captured in a single trap before the stained fish were released downstream of the culvert. This demonstrated that many fish were still present downstream of the culvert. We concluded that this culvert was close to the limit of passage by the smaller juvenile fish.

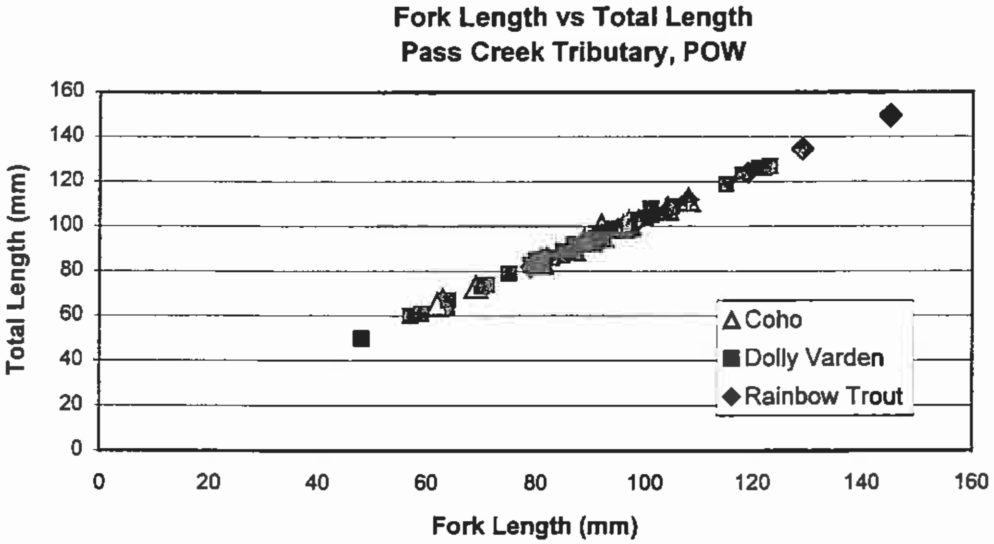


Figure 25. Pass Creek Tributary, Prince of Wales Island (October 4-6, 1998) – fork length versus total length for stained fish.

Table 6. Fork and total length and weight for juvenile fish dyed. Pass Creek Tributary, Prince of Wales Island (October 4-6, 1998).

Date	Time (AST)	Species	Fork Length (mm)	Total Length (mm)	Weight (grams)	Ratio FL/TL
4-Oct-98	2:05 PM	Coho	92	100	9.5	0.92
4-Oct-98	2:05 PM	Coho	69	73	6.1	0.95
4-Oct-98	2:05 PM	Coho	89	94	9.4	0.95
4-Oct-98	2:05 PM	Coho	92	96	7.9	0.96
4-Oct-98	2:05 PM	Coho	90	94	10.4	0.96
4-Oct-98	2:05 PM	Coho	96	100	9.4	0.96
4-Oct-98	2:05 PM	Coho	81	85	8.0	0.95
5-Oct-98	1:30 PM	Coho	97	102	5.9	0.95
5-Oct-98	1:30 PM	Coho	87	90	5.6	0.97
6-Oct-98	1:00 PM	Coho	63	66	3.2	0.95
6-Oct-98	1:00 PM	Coho	104	108	7.6	0.96
6-Oct-98	1:00 PM	Coho	108	112	10.5	0.96
6-Oct-98	1:00 PM	Coho	97	101	9.6	0.96
6-Oct-98	1:00 PM	Coho	63	67	3.0	0.94
6-Oct-98	1:00 PM	Coho	90	94	6.3	0.96
6-Oct-98	1:00 PM	Coho	97	102	8.9	0.95
6-Oct-98	1:00 PM	Coho	81	84	5.9	0.96
6-Oct-98	1:00 PM	Coho	62	65	3.5	0.95
		average	87	91	7.3	0.95
			n=18	n=18	n=18	n=18
4-Oct-98	2:05 PM	Dolly Varden	80	85	8.1	0.94
4-Oct-98	2:05 PM	Dolly Varden	91	97	8.8	0.94
4-Oct-98	2:05 PM	Dolly Varden	88	92	8.0	0.96
4-Oct-98	2:05 PM	Dolly Varden	115	119	11.1	0.97
4-Oct-98	2:05 PM	Dolly Varden	121	126	18.7	0.96
4-Oct-98	2:05 PM	Dolly Varden	79	83	7.6	0.95
4-Oct-98	2:05 PM	Dolly Varden	98	103	10.4	0.95
4-Oct-98	2:05 PM	Dolly Varden	92	96	7.4	0.96
4-Oct-98	2:05 PM	Dolly Varden	121	126	24	0.96
4-Oct-98	2:05 PM	Dolly Varden	87	92	10.4	0.95
4-Oct-98	2:05 PM	Dolly Varden	75	79	5.8	0.95
4-Oct-98	2:05 PM	Dolly Varden	101	108	13.0	0.94
4-Oct-98	2:05 PM	Dolly Varden	85	89	6.6	0.96
4-Oct-98	2:05 PM	Dolly Varden	122	126	16.1	0.97
4-Oct-98	2:05 PM	Dolly Varden	81	84	6.5	0.96
4-Oct-98	2:05 PM	Dolly Varden	92	96	10.2	0.96
4-Oct-98	2:05 PM	Dolly Varden	86	89	7.7	0.97
4-Oct-98	2:05 PM	Dolly Varden	105	109	11.5	0.96
4-Oct-98	2:05 PM	Dolly Varden	96	99	6.0	0.97
4-Oct-98	2:05 PM	Dolly Varden	57	60	2.5	0.95
4-Oct-98	2:05 PM	Dolly Varden	48	50	3.2	0.96
5-Oct-98	1:30 PM	Dolly Varden	70	73	3.8	0.96
5-Oct-98	1:30 PM	Dolly Varden	80	83	4.6	0.96
5-Oct-98	1:30 PM	Dolly Varden	118	123	16.8	0.96
5-Oct-98	1:30 PM	Dolly Varden	80	83	4.6	0.96
5-Oct-98	1:30 PM	Dolly Varden	64	67	3.6	0.96
5-Oct-98	1:30 PM	Dolly Varden	96	99	7.5	0.97
5-Oct-98	1:30 PM	Dolly Varden	100	104	9.1	0.96
6-Oct-98	1:00 PM	Dolly Varden	95	99	9.6	0.96
6-Oct-98	1:00 PM	Dolly Varden	94	99	6.6	0.95

Date	Time (AST)	Species	Fork Length (mm)	Total Length (mm)	Weight (grams)	Ratio FL/TL
6-Oct-98	1:00 PM	Dolly Varden	101	105	9.6	0.96
6-Oct-98	1:00 PM	Dolly Varden	123	127	16.5	0.97
6-Oct-98	1:00 PM	Dolly Varden	90	93	7.2	0.97
6-Oct-98	1:00 PM	Dolly Varden	95	98	8.7	0.97
6-Oct-98	1:00 PM	Dolly Varden	59	61	2.2	0.97
6-Oct-98	1:00 PM	Dolly Varden	91	94	7.9	0.97
6-Oct-98	1:00 PM	Dolly Varden	87	90	6.2	0.97
6-Oct-98	1:30 PM	Dolly Varden	90	94	9.3	0.96
6-Oct-98	1:30 PM	Dolly Varden	85	87	4.8	0.98
6-Oct-98	1:30 PM	Dolly Varden	83	86	8.1	0.97
6-Oct-98	1:30 PM	Dolly Varden	71	74	3.9	0.96
		average	90	94	8.6	0.96
			n=41	n=41	n=41	n=41
5-Oct-98	1:30 PM	Rainbow Trout	101	105	8.6	0.96
5-Oct-98	1:30 PM	Rainbow Trout	98	101	4.9	0.97
5-Oct-98	1:30 PM	Rainbow Trout	108	112	11.5	0.96
5-Oct-98	1:30 PM	Rainbow Trout	97	101	9.5	0.96
5-Oct-98	1:30 PM	Rainbow Trout	81	84	6.5	0.96
5-Oct-98	1:30 PM	Rainbow Trout	80	84	5.8	0.95
5-Oct-98	1:30 PM	Rainbow Trout	145	150	27.1	0.97
5-Oct-98	1:30 PM	Rainbow Trout	90	93	6.6	0.97
5-Oct-98	1:30 PM	Rainbow Trout	145	149	29.6	0.97
5-Oct-98	1:30 PM	Rainbow Trout	82	86	5.2	0.95
5-Oct-98	1:30 PM	Rainbow Trout	96	100	8.9	0.96
5-Oct-98	1:30 PM	Rainbow Trout	79	82	5.8	0.96
5-Oct-98	1:30 PM	Rainbow Trout	92	95	10.5	0.97
5-Oct-98	1:30 PM	Rainbow Trout	119	124	18.3	0.96
5-Oct-98	1:30 PM	Rainbow Trout	129	135	22.9	0.96
5-Oct-98	1:30 PM	Rainbow Trout	89	93	5.5	0.96
5-Oct-98	1:30 PM	Rainbow Trout	91	94	6.5	0.97
5-Oct-98	1:30 PM	Rainbow Trout	87	90	8.0	0.97
5-Oct-98	1:30 PM	Rainbow Trout	95	99	9.3	0.96
5-Oct-98	1:30 PM	Rainbow Trout	96	100	9.2	0.96
5-Oct-98	1:30 PM	Rainbow Trout	91	94	6	0.97
5-Oct-98	1:30 PM	Rainbow Trout	129	134	19.4	0.96
5-Oct-98	1:30 PM	Rainbow Trout	90	93	7.3	0.97
5-Oct-98	1:30 PM	Rainbow Trout	104	107	8.1	0.97
5-Oct-98	1:30 PM	Rainbow Trout	97	101	7.2	0.96
		average	100	104	10.7	0.96
			n=25	n=25	n=25	n=25

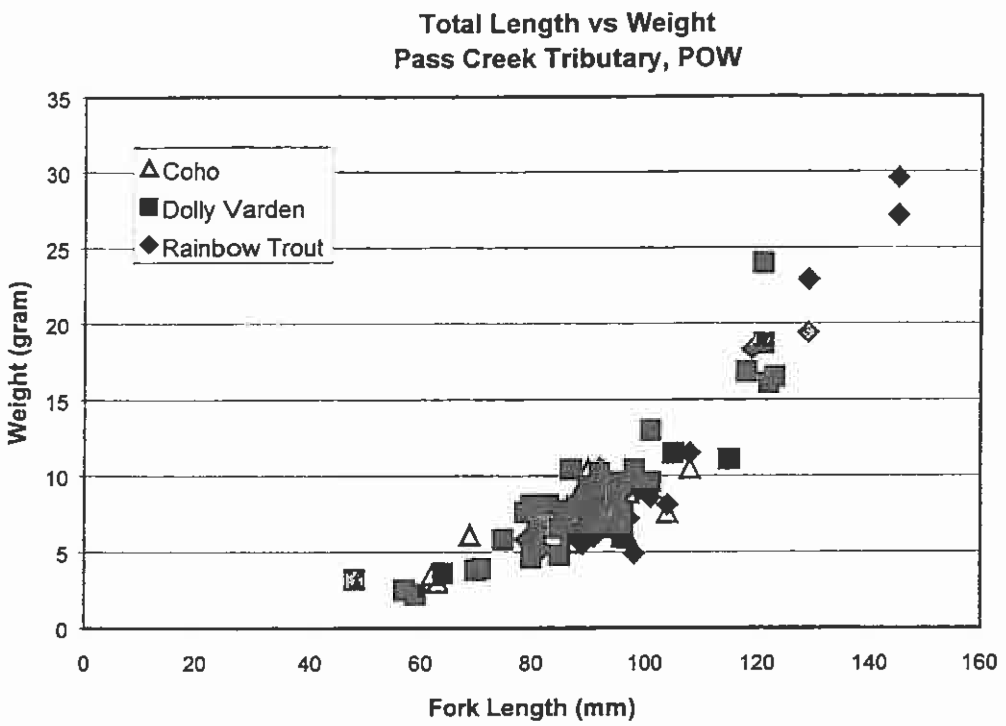


Figure 26. Pass Creek Tribuatry, Prince of Wales Island (October 4-6, 1998) - weight versus fork length for stained fish.

Table 7. Fork and total length for juvenile fish dyed and recaptured upstream of the culvert, Pass Creek Tributary, POW Island (Oct. 4-8, 1998).

Date	Time (AST)	Species	Fork Length (mm)	Total Length (mm)	Ratio FL/TL
8-Oct-98	14:25 PM	Coho	88	92	0.96
7-Oct-98	8:30 AM	Dolly Varden	118	123	0.96
8-Oct-98	14:25 PM	Dolly Varden	94	97	0.97
8-Oct-98	14:25 PM	Dolly Varden	123	127	0.97
8-Oct-98	12:45 PM	Trout	124	129	0.98

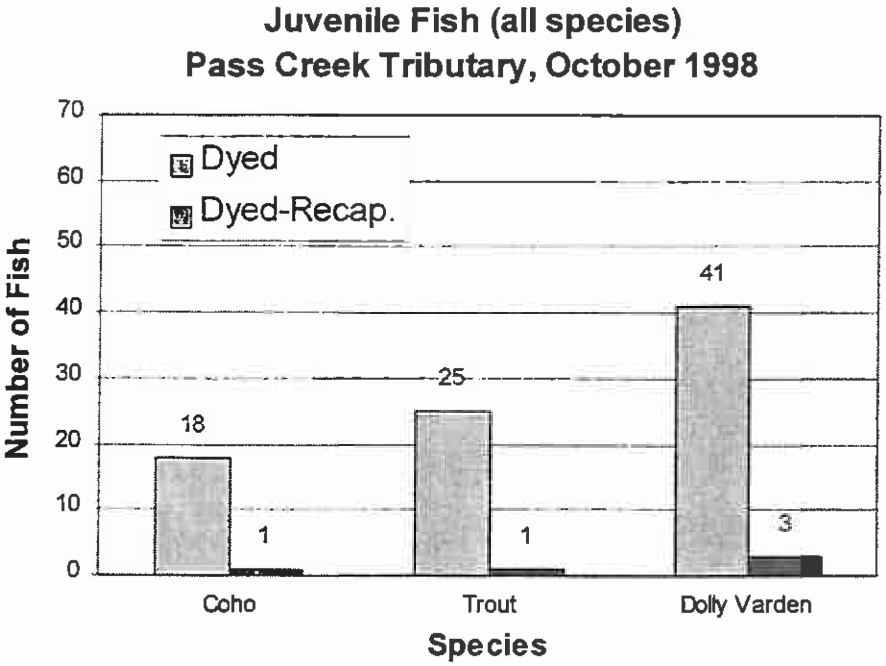


Figure 27. Pass Creek Tributary, Prince of Wales Island – the number of dyed and recaptured fish.

SUMMARY

It is important, when studying the physical performance capability of fish, that some motivational factor exists that will entice the fish to perform near their maximum capability. In this study, we first assumed that juvenile fish would be motivated to move upstream in response to a food source. For Beaver Creek, this proved to be an effective method during the first summer. During the second summer we demonstrated that, in fact, this was true when we observed no juvenile fish in the culvert during several visits until we placed baited traps upstream; afterwards the response was very rapid.

We also found that if the corrugations of a culvert are sufficiently large, the juvenile fish utilize them for resting. We observed this extensively through individual observation and on videotapes for Beaver Creek. In this case, the fish pushed their heads into the corrugations, a position in which their bodies are normal to the flow passing through the culvert. Our videos show several juvenile Coho holding their position in the bottom of a culvert (just below the hydraulic jump) with their bodies positioned horizontally just above the corrugations. When the fish had moved upstream of the hydraulic jump, they moved to the surface near the sidewalls.

For both Beaver Creek and Pass Creek Tributary, juvenile fish that ascended the fast water sections of the culvert did so near the top of the water column on either edge of the culvert. This section of the culvert has the lowest water velocity gradient in the culvert cross-section, combined with relatively low absolute velocities along the wall. On No-name Creek, where the maximum velocities were a relatively low 3.0 fps (0.9 m/s), we observed juvenile fish swimming near the bottom of the water column on the centerline. If high velocities and vertical velocity gradients exist along the centerline, fish migrate out to the edge of the culvert. In higher velocities, they also migrate up toward the water surface at the sides of the culvert. In each case, they look for a pathway that minimizes their power and energy expenditure.

The combination of fish selecting an upstream route through less challenging hydraulic conditions and the fact that they seek out the corrugations for resting demonstrates that fish seek the path of least resistance when moving upstream. Juvenile fish would not have succeeded in ascending Beaver Creek culvert without resting in the corrugations. For Pass Creek Tributary, the smaller juvenile fish apparently could not successfully ascend the culvert because of the lack of resting areas.

RESEARCH NEEDS

Several behavioral traits of juvenile fish attempting to ascend a culvert were observed in this study. First, juvenile salmonids utilized resting areas in the corrugations, where they were large enough, to enhance the probability that they would succeed in their upstream passage. From hydraulic measurements, it was also obvious that these fish successfully determined those areas in the culvert where the flow conditions improved their chances of success. Finally, it was clear that the juvenile fish preferred to pass through a high velocity slot between the baffle and culvert wall than to attempt passing a baffle by jumping.

Previously with adult Arctic grayling (*Thymallus Arcticus)*, we determined the energy and power requirements of these fish to ascend various culverts through field observations. In many cases we were able to track individual fish as they entered and exited culverts and thus determine the time required for passage (Behlke et al., 1988; Kane et al., 1989). With that data we were able to develop a model of fish passage through culverts for Arctic grayling (Behlke et al., 1991). In this study, we did not have the capability of monitoring rates of advancement up the culvert because we could not track and determine the travel time of individual fish. In some cases we were able to follow these juvenile fish for a few seconds when they were moving fast and a few feet when moving slow. However, we did observe them in many cases, both visually and with the video camera, utilizing the larger corrugations for resting and milling around in eddies (below baffles on Soldotna Creek and below the hydraulic jump in Beaver Creek). Whereas it would have been nice to get some measure of the energy and power required for juvenile salmon to ascend the four culverts studied, that was not the main objective of the study.

There are many areas of research related to juvenile fish passage in culverts that would prove fruitful.

1. It would be beneficial to ascertain the upper energy and power swimming capabilities of juvenile fish. From the literature, it is obvious that juvenile fish disperse in all directions in a drainage network, even into non-natal streams. This requires that all culverts be designed with juvenile fish passage in mind. Young-of-the-year juveniles should be the design fish; the question is at what size do they start to move considerable distances? To determine the swimming abilities of juvenile fish, it is important that the test be carried out properly. First, continuous observations of individual fish are a necessity. This can be accomplished by running the experiments in a controlled environment where natural flow can be routed through the experimental culvert. Various pipe diameters, corrugation sizes and types, slopes, flow rates and lengths could be used. The top of the culvert would be removed to aid observations. It is important that there be a motivational factor to ensure that fish attempt to ascend the culvert. As seen in this study, a food source would suffice for these juvenile fish.

2. The ability of juvenile fish to jump over a barrier, such as a baffle in a culvert, needs to be studied. We thought by studying the Soldotna Creek baffled culvert that we would get some relevant data on this aspect, but it became obvious that they preferred to pass through the slot at the end of the baffle and the culvert wall instead. Again, young-of-the-year fish would be the design fish.

3. Further study of the ability of juvenile fish to pass upstream through slots is needed. This may prove to be the best way to guarantee that juvenile fish can pass upstream past baffles. There are probably certain designs that are better than others, partially depending on the type of baffle. The location of the slot should also be studied, along with the width and depth.

4. In item 1 above, the cross-sectional shape (circular, elliptical, etc.) of the culvert is probably not critical. However, the size and configuration (regular versus spiral) of the corrugations is. From our field observations of fish movement in natural stream channels, it would appear that if the bed conditions in bottomless arch or depressed culverts are similar to the stream, juvenile fish should have no problems. These designs offer many potential resting places for fish to seek shelter.

5. One of the weaknesses of field studies is that you cannot control the flow. Therefore we were unable in most cases to look at the impact of various flows. In two cases (No-name Creek at end of study and Pass Creek Tributary on one day) we had increases in flow, but the flow conditions made it impossible to work in the culverts. The question is, are high flow conditions detrimental to the upstream movement of juvenile fish through hydraulic structures? During high flows, do they move upstream in natural channels? Is a delay during high flows detrimental to the juvenile fish or just an inconvenience?

6. Some attention should be directed at studying the hydraulic conditions at the upstream entrance and downstream exit of culverts. Conditions at either end of the culvert may

preclude the successful passage of juvenile fish that can effectively ascend the culvert barrel. This was demonstrated at the upstream end of Beaver Creek, where the fish had to switch from one technique (swimming along the wall and resting in corrugations) to another technique (swimming out into the center of the culvert) to successfully exit the culvert.

7. It was apparent from the video tapes that turbulence along a culvert wall (bottom and sides) impacts juvenile fish. Because of their negligible mass and small size, they are apt to be tossed around. At some point, their ability to swim is compromised and they are washed downstream into an area where they can recover. The boundary is responsible for reducing the wall velocity to a level that is advantageous to the fish, but this same boundary also produces turbulence that may be detrimental to juvenile fish. On Prince of Wales Island, we observed salmon at a natural waterfall where an Alaska steep-pass fish ladder had been installed on Dog Salmon Creek. Adult salmon were successfully ascending the fish ladder and we observed no adults jumping at the falls. We did observe numerous juvenile fish jumping at the falls, however we could not see any juvenile fish in the channel leading from the top of the fish ladder, and turbulence (with entrained air) prevented us from observing fish in ladder. In this fish ladder, was the scale of turbulence such that the much larger adults could handle it while the juveniles could not and therefore they were ineffectively jumping at the waterfall? Are fish ladders of any type useful for juvenile fish passage?

8. Eventually, we would construct models that would allow engineers to design culverts and other hydraulic structures for juvenile fish passage. Unlike the larger adult fish, juvenile fish can take advantage of corrugations for resting and do not have to swim non-stop through the culvert. Studies with culverts under controlled conditions (item 1 above) should shed some light on this topic.

There is no doubt that we know little about the swimming capabilities of juvenile salmon (or any juvenile fish). We have listed eight research areas above that would all expand our present understanding of juvenile fish. They are roughly ranked in order of priority (1 being the highest). Many of these recommendations are based on the behavior observed in this study of four culverts in Alaska. Finally, like most studies, based on our observations we would change our field data collection procedure if we were to do the study over. We learned considerably more from the video tapes than we anticipated, although it is difficult to quantify these observations.

REFERENCES

Behlke, C.E., D.L Kane, R.F. McLean, J.B. Reynolds and M.D. Travis. 1988. Spawning Migration of Arctic Grayling through Poplar Grove Creek Culvert, Glennallen, Alaska, 1986. State of Alaska, Dept. of Transportation and Public Facilities, Report No. FHWA-AK-RD-88-09, 103 pp.

Behlke, C.E., D.L Kane, R.F. McLean and M.D. Travis. 1991. Fundamentals of Culvert Design for Passage of Weak Swimming Fish. State of Alaska, Dept. of Transportation and Public Facilities, Report No. FHWA-AK-RD-90-10, 159 pp.

Bendock, T. 1989. Lakeward Movements of Juvenile Chinook Salmon and Recommendations for Habitat management in the Kenai River, Alaska, 1986-1988. AK Dept. of Fish and Game, Fisheries manuscript Series No. 7, 40 pp.

Cederholm, C.J. and W.J. Scarlett. 1982. Seasonal Immigrations of Juvenile Salmonids into Four Small Tributaries of the Clearwater River, Washington, 1977-1981. Salmon and Trout Migratory Behavior Symposium, June 1981, Seattle, WA, pp. 98-110.

Delaney, K., K. Hepler and K. Roth. 1981. Deshka River Chinook and Coho Salmon Study. Alaska Dept. of Fish and Game, Sport Fish Division, Annual Report, Project AFS-49-1&2, 39 pp.

Elliott, G.W. and J.E. Finn. 1983. Fish Utilization of Several Kenai River Tributaries. 1982 Field Report. U.S. Fish and Wildlife Service, Anchorage, AK, Special Studies, 70 pp.

Elliott, G.V. and J.E. Finn. 1984. Fish Use of Several Tributaries of the Kenai River, Alaska. U.S. Fish and Wildlife Service, Anchorage, AK, Final Report, 225 pp.

Elliott, G.V. and J.W. Nelson. 1985. Highway Culvert Barriers to Fish Passage in Two Tributaries to the Kenai River, Alaska. U.S. Fish and Wildlife Service, Special Studies, Anchorage, AK, 20 pp.

Fausch, K.D. 1984. Profitable Stream Position for Salmonids: Relating Specific Growth Rate to Net Energy Gain, *Canadian Journal of Zoology*, 62:441-451.

Godin, J.J. 1982. Migration of Salmonid Fishes during Early Life History Phase: Daily and Annual Timing. Salmon and Trout Migratory Behavior Symposium, June 1981, Seattle, WA, pp. 22-50.

Hillman, T.W. and J.S. Griffith. 1987. Summer and Winter Habitat Selection by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream. *Transactions of the American Fisheries Society*, 119:185-195.

Hughes, N.F. 1992. Selection of Positions by Drift-Feeding Salmonids in Dominance Hierarchies: Model and Test for Arctic Grayling *(Thymallus arcticus)* in Subarctic Mountain Streams, Interior Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, 49:1999-2008.

Kahler, T.H. and T.P. Quinn. 1998. Juvenile and Resident Salmonid Movement and Passage Through Culverts. Washington State Department of Transportation, Final Report WA-RD 457.1, 38 pp.

Kane, D.L., C.E. Behlke, D.L. Basketfield, R.E. Gieck, R.F. McLean and M.D. Travis. 1989. Hydrology, Hydraulics and Fish Passage Performance of Arctic Grayling *(Thymallus Arcticus)* at Fish Creek, Denali Highway near Cantwell Alaska. State of Alaska, Dept. of Transportation and Public Facilities, Report No. FHWA-AK-89-03, 180 pp.

Lister, D.B. and H.S. Genoe. 1970. Stream Habitat Utilization of Cohabitating Underyearlings of Chinook (*Oncorhynchus tshawytscha*) and Coho *(O. kisutch)* Salmon in the Big Qualicum River, British Columbia. *J. Fish Res. Bd. Canada, 27:1215-1224.*

Murray, C.B. and M.L. Rosenau. 1989. Rearing of Juvenile Chinook Salmon in Nonnatal Tributaries of the Lower Fraser River, British Columbia. *Transactions of the American Fisheries Society*, 118:284-289.

Peterson, N.P. 1982. Immigration of Juvenile Coho Salmon (*Oncorhynchus kisutch*) into Riverine Ponds. *Canadian Journal of Fisheries and Aquatic Sciences*, 39:1308-1310.

Scrivener, J.C., T.G. Brown and B.C. Andersen. 1994. Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) Utilization of Hawks Creek, A Small and Nonatal Tributary of the Upper Fraser River. *Canadian Journal of Fisheries and Aquatic Sciences*, 51:1139-1146.

Skeesick, D.G. 1970. The Fall Migration of Juvenile Coho Salmon into a Small Tributary. Fish Commission of Oregon, Research Report, Research Division, pp. 90-94.

Ward, F.J. and L.A.Verhoeven. 1963. Two Biological Stains as Markers for Sockeye Salmon Fry. *Trans. Am. Fish. Soc.*, 92:379-383.