THE EFFECTS OF HANDLING AND TRANSPORTATION ON COHO SALMON FRY INCUBATED IN HATCHBOXES

by

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Approved: Dr. Paul P. Rudy

The differential survival between transported and non-transported groups of Coho Salmon fry incubated in Salmon and Trout Enhancement Program hatchboxes were compared in three experiments. Groups of fry were released into a natural stream divided into two reaches of nearly equal pool area and recovered after 63, 60, and 49 days. Non-transported fry released into Lower Confusion Creek had the highest survivability in Experiment 1 and in Lower Confusion Creek in Experiment 3 when water flow rates were low. Transported fry showed higher survivability in Experiment 2 when water flow rates were higher and in Upper Confusion Creek in Experiment 3. Short term holding experiments of handled, handled and transported, and fin clipped fry resulted in very low mortality. The effects of

handling and transporting could not adequately explain the observed differences between groups of Coho salmon fry.

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________, 1987. Evaluation of hybrid bass in Tenmile Lakes. Ore. Dept. Fish Wildl., Annual Report.

________, 1986. Evaluation of hybrid bass in Tenmile Lakes. Ore. Dept. Fish Wildl., Unpublished Report.

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CHAPTER I

INTRODUCTION

The Salmon and Trout Enhancement Program (STEP) is a citizen volunteer program supervised by the Oregon Department of Fish and Wildlife. The two primary objectives of this program are: 1) to improve in-stream conditions of coastal waters utilized by salmon and steelhead for spawning and rearing; and 2) to produce more fish to occupy underseeded stream habitat.

One of the methods used to produce more fish is to place salmonid eggs ready to hatch in streamside incubators commonly referred to as hatchboxes. Fish produced in these hatchboxes are generally allowed to leave the hatchbox of their own volition and to reside in the adjacent stream. In some cases, fish incubated at one site are transported and released into a nearby stream. This latter procedure is usually used for streams that are too remote to properly maintain a hatchbox or where production from the hatchbox exceeds the habitat capacity below the incubation site.

Many studies have assessed the effects of handling and transportation of salmonids (Wedemeyer 1972; Mazeaud et al. 1977; Strange 1978; Redding & Schreck 1983; Woodward & Smith 1985; Barton et al.

1986). The general conclusion is that even minimal handling can evoke detrimental physiological responses in the fish. These responses can result in death of the fish if severe enough or of sufficient duration. These mortalities can occur shortly after the handling period or up to several days later (Strange et al. 1977; Barton & Peter 1982).

The purpose of this study was to assess the effects of handling and subsequent transportation on coho salmon (Onchorynchus kisutch) fry removed from hatchboxes. The fish were treated in a manner similar to that used by STEP volunteers. Three tests were conducted between groups of coho salmon which were allowed to leave the hatchboxes volitionally and those which were collected from the hatchbox and transported approximately one hour and released into the stream. The first comparison was between two groups of coho salmon fry handled in the same manner but one group was also transported. Each group was placed into one of two natural stream sections where they remained. In the second test one group was handled and transported while the other was volitionally released into the study stream section. The third test compared groups given the same treatment as the inital test but fry from both groups were differentially fin clipped and placed in both sections of the study stream.

CHAPTER II

MATERIALS AND METHODS

Stream Selection

Several streams in the Pony Creek drainage basin were surveyed as potential study streams. The criteria examined were length, gradient, pool area, and bottom morphology. Only one small tributary of Pony Creek (Confusion Creek) was found suitable for use (Figures 1, 2). Confusion Creek flows over bottom sediments composed primarily of sand and sandstone cobble. Shallow pools and short riffles alternate along the length of the creek. Small woody debris in the creek and undercut banks provide additional in-stream cover. Streamside vegetation includes various grasses, ferns (Cl. Filicinae), second growth Douglas Fir (*Psuedotsuga menziesii*), Western red cedar (*Thuja plicata*), and Hemlock (*Tsuga* sp.).

Confusion Creek was divided into two sections of approximately equal length. Pool area for each section was determined by using a field guide used by the Bureau of Land Management stream surveyors. Two small weirs were installed in one study section to increase its pool area and make the two sections nearly

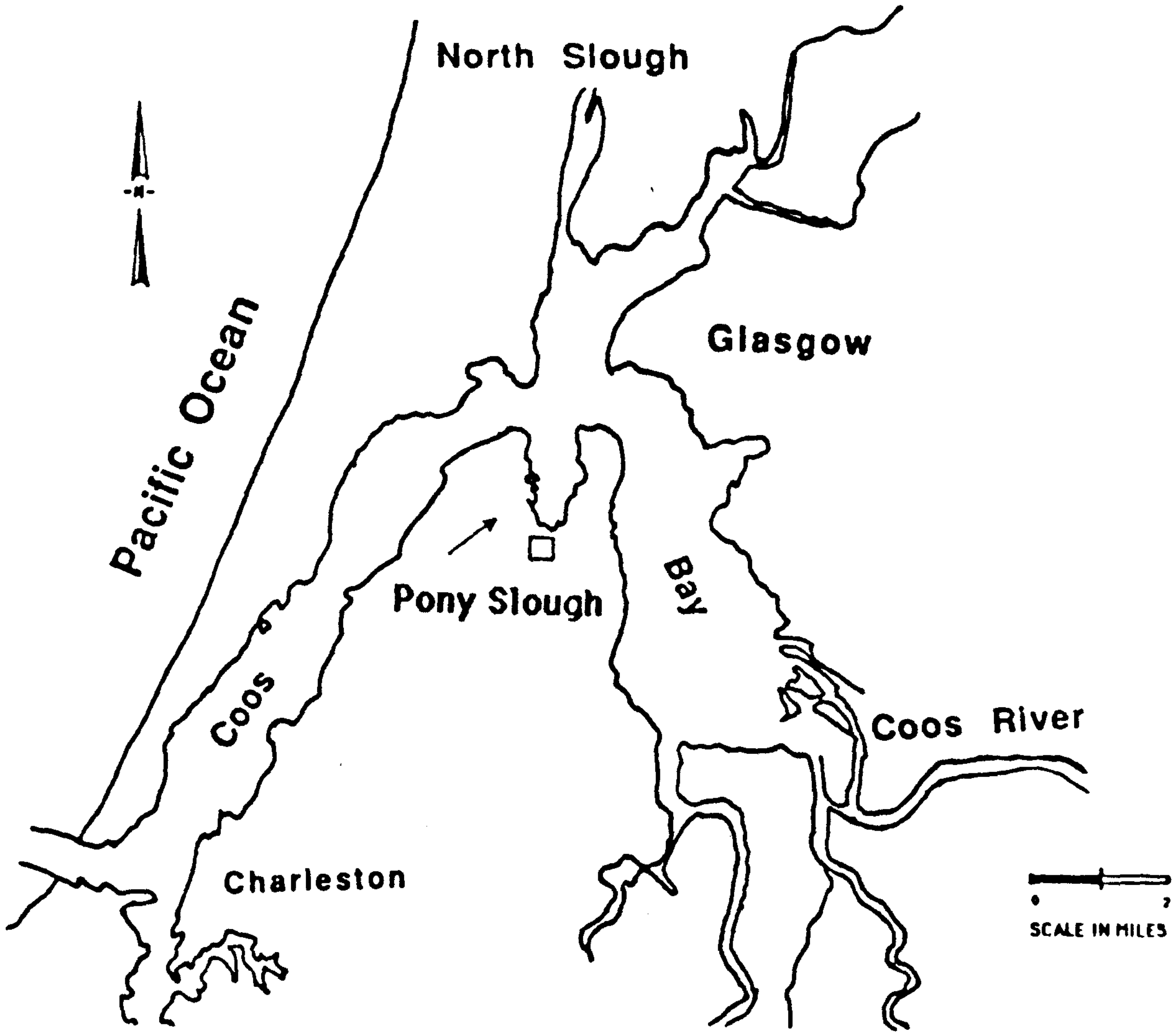


FIGURE 1. Map of Coos Bay, Oregon. Pony Creek drainage basin represented by the open box.

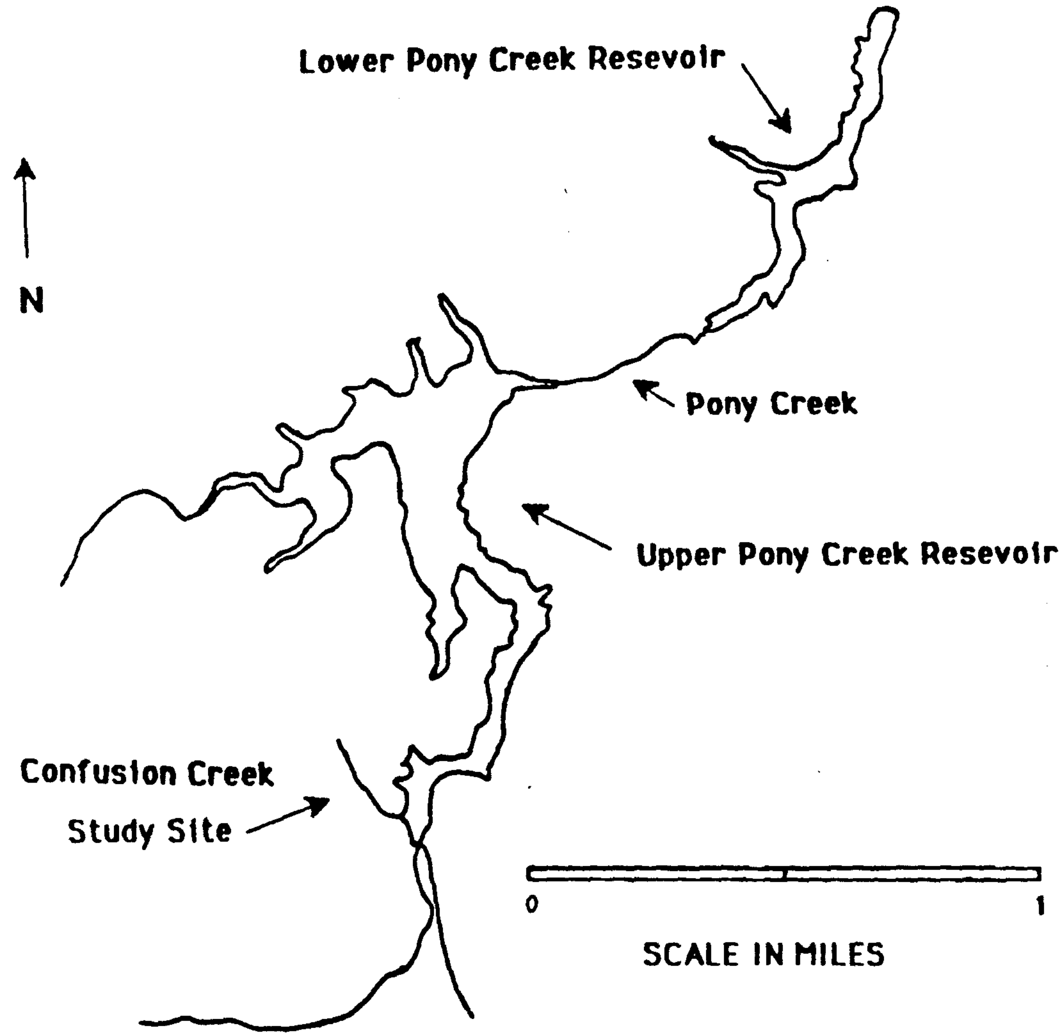


FIGURE 2. Pony Creek drainage basin showing the Confusion Creek study site

equal in this parameter.

Construction and Installation of Weirs

To determine the influence of stream flow on the displacement or downstream migration of Coho salmon fry, a weir was installed in each of the reaches studied. The lower weir was placed against the upstream face of a four foot diameter culvert which ran under the access road of the study area. Due to potentially heavy rainfall with resultant high runoff, the weir design had to accurately determine stream flows at all levels and have a wide enough weir crest to allow debris to pass through relatively unhindered.

The weirs were faced with 3 mil plastic with approximately two feet of plastic apron retained across the face of the weir which was buried in the stream bed to prevent water from seeping under the weir. The weirs were leveled and steel fence posts were driven immediately upstream of the weir which was placed against the culvert and behind the weir in Upper Confusion Creek for structural support. The bottom and ends of the weirs were buried with sand and mud and constantly monitored for leaks. The lower weir also had caulking forced between the downstream face of the weir and the culvert for further waterproofing.

A staff gauge delineated in hundredths of feet was mounted on a two by four stake. Two steel fence posts were driven into the streambed at least four feet upstream of the weir. This was the minimum distance required to obtain accurate stream level readings.

Hatchbox Design and Construction

Water for the hatchboxes was obtained from a small tributary stream of Confusion Creek. Water fell into a catch bucket, flowed through approximately 100 feet of 1.25 inch ABS pipe and into a 50 gallon filter barrel. The water passed through a baffle plate and exited through 1.0 inch ABS pipe at the top of the barrel. This supplied 7 gallons per minute (gpm) to the hatchbox used in experiment 1. Two hatchboxes were used in experiments 2 and 3 so an additional water source (supplying 3 gpm) was plumbed into the system and a flow of 5 gpm to each hatchbox was maintained during the incubation periods

The hatchboxes were fibreglas boxes 2 feet wide, 4 feet long and 2 feet deep. A three - foot length of perforated 1.5 inch PVC pipe plugged at one end ran along the bottom of the box and was covered with approximately 8 inches of washed river rock 2 inches in diameter or less. A wood divider 8 inches high, running the width of the hatchbox, separated the rock from the remaining portion of the box. A 1.50 inch PVC standpipe was centered in the ungraveled end of the box. Water depth in the hatchbox was maintained at about 20 inches. Trays constructed of 1 inch by 1 inch lumber and 0.25 inch square mesh Vexar rested on a small ledge built into the box and were held underwater by a small piece of wood attached to the side of the box. Water flowed through the perforated pipe running along the bottom of the hatchbox and up through the gravel. The box was filled to the height of the standpipe and the water flowed down a 1.0 inch ABS pipe into the creek.

Handling of Fish

The approximate number of eyed coho salmon eggs required to produce one smolt for every square meter of pool area was calculated using a chart developed by the Oregon Department of Fish and Wildlife. Eyed coho salmon eggs for each experiment were obtained from Coos River stock fish captured at the Morgan Creek STEP hatchery. The eggs were placed in wet burlap bags on a styrofoam tray and transported to the study site. The eggs were then individually counted and placed in the appropriate hatchbox.

The coho salmon eggs were placed in a single layer on the tray and a screen surrounded the standpipe to prevent fry from prematurely leaving the hatchbox. A wooden cover was then placed over the hatchbox. The box was checked approximately daily and all dead eggs were removed.

When all the fry had hatched and were in the gravel, the trays were removed. The screen around the standpipe was removed when the first of the fry had absorbed their yolk so that only 1 mm of yolk showed in the abdominal opening. At this developmental stage, coho salmon fry become photopositive. The cover of the hatchbox was pulled back from the area near the standpipe and the fry allowed to swim out of the hatchbox directly into the creek or into a live box.

The fry to be transported were dipnetted from the live box, tallied and placed in a 5 gallon bucket containing approximately 4 gallons of water. A lid was placed on the bucket and it was hand carried 450 feet to the pick-up. The fry were driven over a 22.4 mile loop and were carried for an additional 950 feet to the upstream end of the study section. The fry were then released. The entire trip required 60 to 70 minutes to complete.

Live Box

The live box was constructed by attaching 0.125 inch square mesh Vexar to a 2 inch by 2 inch lumber frame which was 16 inches square. The bottom of the live box was 0.75 inch plywood and the top was left open to receive the pipe. The function of the live box was to collect and hold coho salmon fry migrating out of the hatchbox until they could be tallied and released or transported and then released into the stream.

Downstream Migrant Traps

A downstream migrant trap was placed at the lower end of each of the two study reaches. Prior to installation, a shallow depression was excavated in the streambed. The base of the trap, with the entrance oriented upstream, was placed in the hole. The base of the trap was widened so that rocks and sand could be placed on the lip. This prevented the trap from being pushed downstream by high stream flows. Window screen material was attached to the sides of the trap on the upstream side. The screen was attached to the bank at approximately a 45-degree angle upstream using 13 mm rebar stakes. Support stakes were centered in the span between the trap and the bank. This screening was placed to prevent the escape of fry around the trap as well as to funnel migrants toward the entrance of the trap. An apron of window screening was attached to the base of the trap and covered with sand. This prevented water from undermining the base of the trap with the possible escapement of fry.

Coho salmon fry which were migrating downstream entered the trap and remained in a small holding area. These migrants were removed from the trap on a daily basis and taken to the laboratory where fork length was recorded in millimeters and weight determined in grams on a Mettler 1200 scale. The daily catch from each study reach was placed in sample bottles containing a 7.5% solution of formaldehyde.

Electroshocking

A Dirigo Electrofisher 600 backpack electroshocker was used to collect the resident coho salmon fingerlings from each study reach at the conclusion of each experiment. Electroshocking began at the downstream end of each study reach and proceeded upstream to the beginning of the reach. Each study reach was electroshocked four times after each experiment. When weather conditions allowed, both of the study reaches were electroshocked on the same day. The fish collected during electroshocking were taken to the laboratory where fork length and weight were recorded. In the third experiment, fin clips were also recorded.

Water Temperature and Flow Rates

Water temperatures were recorded daily using a Taylor maximum-minimum thermometer. Water flow rates in cubic feet per second (cfs) were determined using staff gauge readings and a Cipolletti weir table. Readings were taken at consistent times during each of the experiments.

Predators

In order to assess the levels and impacts of predation upon the coho salmon fry, all potential predators (primarily birds and fishes) were noted as being present and a subsample of predatory fishes were collected and dissected to determine the presence or absence of coho salmon fry in the diets of these fishes. No attempt was made to estimate consumption rates of coho salmon fry by these fishes or other predators.

Holding Experiments

Holding experiments were conducted to assess the short term delayed mortality losses of coho salmon fry which had been handled, transported, or fin clipped. Test groups of fry were held in a live box and monitored for up to 48 hours.

CHAPTER III

RESULTS

This study consists of three related experiments. In the first experiment conducted in 1985, both groups of fry were handled in the same manner by dipnetting the fry from a collection bucket. One group was additionally transported. The second experiment was a comparison between fry which were handled and transported to fry which were allowed to volitionally leave a hatchbox and enter the test stream section. The volitionally released group was used as the control for this study. The third experiment tested two groups of differentially fin clipped fry. One group was transported while the other group was released into the stream reaches. Approximately the same number of fry from each group were released into each of the stream reaches.

Experiment 1

From a total of 1,978 eyed coho salmon eggs placed in a hatchbox and incubated, 1,759 survived to the swim-up stage (Table 1). Of the 1759 swim-up fry, 873 fry were released into Lower Confusion Creek and

Table 1. Summary of hatchbox losses, migrant trap catches, and electroshocking recoveries for Upper (UCC) and Lower (LCC) Confusion Creek, Experiment 1 (3-25-85 to 5-27-85)

	Number	Percent of Total
Eggs placed in hatchbox	1,978	
Dead eggs	36	1.8
Dead fry in hatchbox	183	9.2
Initial hatchbox fry sample	30	1.5
Number of fry Released	1,729	87.4
Non-transported: LCC	873	44.1
Transported: UCC	856	43.2
Downstream Migrant Trap Catch		
Non-transported: LCC	133	15.2
Transported: UCC	111	12.9
Electroshocking Recoveries		
Non-transported: LCC	100	11.4
Transported: UCC	76	8.8

856 fry were transported and then released into Upper Confusion Creek. The remaining 30 fry were taken to the laboratory where initial weights and fork length (FL) were determined. The standard deviation values are given in parentheses following each mean. The hatchbox sample (n = 30) had a mean FL of 31.4 (3.19) mm and a mean wet weight of 0.3 (0.1) grams.

Over the duration of the experiment, 133 (15.2%) and 111 (12.9%) of the released fry were collected in the downstream migrant traps on Lower and Upper Confusion Creek respectively. When electroshocking was completed, 100 (11.4%) fry from the non-transported group were collected and 76 (8.8%) transported fry were collected from Upper Confusion Creek.

Weights and lengths of all the coho salmon fry collected in the downstream migrant traps were recorded as were those of the electroshocked coho salmon fry. The weights and lengths of the hatchbox sampled fry and the numbers, weights, and lengths of the electroshocked fry were used in data analysis and comparisons. The non-transported group (n = 100) had a mean fork length of 44.7 (6.4) mm and mean wet weight of 1.3 (0.6) grams. The transported group (n = 76) had a mean fork length of 46.7 (6.1) mm and a mean wet weight of 1.4 (0.6) grams. Chi-square analysis of the values obtained indicated no significant differences between the groups (Table 2).

A holding experiment was conducted to assess the short term delayed mortality losses incurred by coho salmon fry which had been handled and transported. The treatment group (n = 30) were randomly selected from a larger group of fry which had just been transported. The fry were held in a live cage similar to the one used to collect fry leaving the hatchbox. The fry were monitored for 48 hours. Only 1 mortality was observed.

Table 2. Mean fork length and mean wet weight of hatchbox sampled and electroshocked coho salmon fry from Upper (UCC) and Lower (LCC) Confusion Creek, Experiment 1, 1985

	N	FL (mm)	SD	Wet Wt. (g)	SD
Hatchbox sample	30	31.4	3.2	0.3	0.1
Transported (UCC)	76	46.7	6.1	1.4	0.6
Non-transported (LCC)	100	44.7	6.4	1.3	0.6

Experiment 2

For this experiment, 800 eyed Coho eggs were placed in each of two hatchboxes and allowed to incubate, hatch, and rear to the swim-up stage (Table 3). A total of 689 fry were transported and then released into Upper Confusion Creek. The volitionally released fry were allowed to swim directly from the hatchbox into Lower Confusion Creek. No mortalities were incurred during the handling and transporting phases of this experiment.

The assumption was made that the number of swim-up fry produced from both boxes was equivalent. There was no observable disparity of mortalities between the two boxes. 14 dead eggs were removed from each of the hatchboxes and water flow to the hatchboxes was nearly equal and remained constant throughout the incubation and rearing period.

Over the course of the experiment, 55 (5.7%) fry and 53 (6.6%) fry were collected in the downstream migrant traps from Upper and Lower Confusion Creek respectively. After electroshocking was completed, 160 (20.0%) fry were collected from Upper Confusion Creek and 83 (10.3%) were collected from Lower Confusion Creek (Table 3).

Table 3. Summary of hatchbox losses, migrant trap catches and electroshocking recoveries for Upper (UCC) and Lower (LCC) Confusion Creek, Experiment 2 (3-13-86 to 5-11-86)

	Upper Confusion		Lower Confusion	
	N	Percent of Total	N	Percent of Total
Eggs in hatchbox	800		800	
Dead eggs	14	1.7	14	1.7
Dead fry	58	7.2	57	7.1
Initial fry sample	30	3.7	0	0.0
Live cage mortalities	9	1.1	--	---

	N	Percent of Total
Volitionally released fry: LCC	729	91.1
Transported fry : UCC	689	86.1
Downstream Migrant Trap Catch		
Volitionally released: LCC	53	7.2
Transported: UCC	46	5.7
Electroshocking Recoveries		
Volitionally released: LCC	83	11.3
Transported: UCC	160	23.2

Table 4. Mean fork length and mean wet weight of hatchbox sampled and electro-shocked coho salmon fry from Upper (UCC) and Lower (LCC) Confusion Creek, Experiment 2, 1986

	N	FL (mm)	SD	Wet Wt. (g)	SD
Hatchbox sample	30	33.1	0.6	0.4	0.0
Transported (UCC)	160	44.0	3.4	1.1	0.3
Volitional (LCC)	83	44.2	3.6	1.1	0.3

Experiment 3

In this experiment, differentially fin clipped groups of coho fry, transported or non-transported, were released into Upper and Lower Confusion Creek. In Upper Confusion Creek a total of 396 transported fry and 455 non-transported fry were released. In Lower Confusion Creek, 394 transported fry and 458 non-transported fry were released. Comparisons could therefore be made between the two groups in each stream section as well as a comparison between the two stream sections to see if stream effects might be responsible for any differences observed in any of the three experiments.

Due to the diminutive size of the coho at the time of fin clipping, a small number of fry had both ventral fins clipped (n = 5). In addition, no fin clip could be discerned in a small number of fry (n = 9). Lengths and weights were recorded for these fish but were not included in the analysis.

The downstream migrant trap on Upper Confusion Creek collected 73 (18.4%) transported fry and 86 (18.9%) non-transported fry. On Lower Confusion Creek, 93 (23.6%) transport fry and 78 (17.0%) non-transported fry were collected in the migrant trap. The electroshocking results indicate that the transported group in Upper Confusion Creek was slightly more successful in survivability (n = 52), while the non-transported group was the most successful in Lower Confusion Creek (n = 103) (Table 5).

A holding experiment was conducted to determine if delayed mortality resulted from the stress incurred from the fin clipping procedure. Four groups of 10 fry were tested. Two groups were anesthetized and the left or right ventral fin was removed. The third group was only anesthetized. A fourth group served as the control. Two groups were placed in one of two live cages placed in the creek. The fry were held for 48 hours. There were no mortalities from the test groups or the control.

Table 5. Summary of hatchbox losses, migrant trap catches, and electroshocking recoveries for Upper and Lower Confusion Creek, Experiment 3 (5-19-86 to 7-6-86)

	Transport (RV)		Non-Transport (LV)	
	N	Percent of Total	N	Percent of Total
Eggs in hatchbox	1,091		1,091	
Dead eggs	41	3.7	39	3.5
Dead fry	215	19.7	94	8.6
Hatchbox fry sample	15	1.3	15	1.3
Number of fry released:	805	73.7	928	85.0
Downstream Migrant Trap Catch				
Lower Confusion Creek:	93	23.6	78	17.0
Upper Confusion Creek:	73	18.4	86	18.9
Electroshocking Recoveries				
Lower Confusion Creek:	60	15.2	103	22.8
Upper Confusion Creek:	52	13.1	44	9.6

Table 6. Mean fork length and mean wet weight of hatchbox sampled and electroshocked transported and non-transported coho salmon fry from Upper and Lower Confusion Creek, Experiment 3, 1986

	N	FL (mm)	SD	Wet Wt.	SD (g)
Upper Confusion Creek					
Hatchbox sample	30	34.8	1.4	0.2	0.0
Transported fry	52	38.6	3.3	0.7	0.2
Non-transported	44	39.6	3.5	0.7	0.1
Lower Confusion Creek					
Transported	60	41.2	3.2	0.8	0.2
Non-transported	103	42.8	4.2	0.9	0.3

Predation

Population Estimates

Confusion Creek contains a small population of resident coastal cutthroat trout (*Salmo clarki clarki*) and coastrange sculpin (*Cottus aleuticus*). Population estimates of these fish in Upper and Lower Confusion Creek were made by visual inspection, migrant trap tallies, and electroshocking recoveries.

In Experiment 1, a total of 15 adult cutthroat trout were observed in Upper and Lower Confusion Creek while 6 to 8 were actually observed spawning. These spawning fish remained in both stream sections for approximately two weeks before migrating downstream to Pony Creek reservoir.

The population estimate of resident cutthroat trout in Experiment 1 was made primarily by electroshocking recoveries. Visual monitoring was inaccurate due to areas of heavy stream cover and undercut banks. Migrant trap tallies were not used because all the cutthroat trout and sculpins collected, (except for those kept for stomach analysis), were released back into the study stream section. In Upper and Lower Confusion Creek, the number of resident Cutthroat trout was estimated to be 5 to 7 individuals in each stream section. This population estimate remained constant for each stream section for the duration of the study.

In Experiment 1, the population of sculpins in Upper and Lower Confusion Creek were estimated to be 5 to 7 and 50 to 60 (including the 28 collected for stomach analysis) respectively. The estimates for this experiment were made by electroshocking recoveries and visual sightings during electroshocking.

The electroshocking recoveries and visual sightings in Experiment 2 indicated that the population levels of adult and resident cutthroat trout were similar to those found in Experiment 1. Adult cutthroat trout were observed in both stream sections for about three weeks during the test before they migrated downstream to Pony Creek reservoir. The population of resident cutthroat trout increased slightly to 7 to 10 individuals in both stream sections. The population levels of sculpins were estimated to be 15 to 20 in Upper Confusion Creek and 40 to 45 in Lower Confusion Creek.

Unlike Experiments 1 and 2, during Experiment 3 no adult cutthroat trout were present in Confusion Creek due to their post-spawning migration to Pony Creek reservoir. The number of resident cutthroat trout were estimated at 7 to 10 individuals in each stream section. The population of sculpins in the study stream sections were estimated at 15 to 20 in Upper Confusion Creek and 40 to 45 in Lower Confusion Creek. These estimates were made by electroshocking recoveries at the conclusion of Experiment 3.

Predation Pressure

Small samples of cutthroat trout and sculpins were dissected to determine the presence or absence of coho salmon fry in their diet. No attempt was made to fully describe the diet of these fish. The primary purpose was of these gut analyses was to document whether or not these fish were consuming coho salmon fry.

A small sample (n = 2) of adult cutthroat trout were dissected during Experiment 1 to determine the presence or absence of coho salmon fry in their diet. No fry were found in either of the fish. A small sample of resident cutthroat trout(n = 4) were examined to see if coho salmon fry were present in their diet. A total of 7 coho salmon fry were found in this sample. The frequency of occurrence of coho salmon fry in the diet of resident cutthroat trout was 75.0% One cutthroat trout measuring 95 mm FL contained 4 fry.

During Experiment 2, no coho salmon fry were recovered from adult cutthroat trout (n = 3), or resident cutthroat trout (n = 4). None of the resident cutthroat trout were stomach sampled during Experiment 3. The small population size restricted the number which could be collected for analysis. It was also felt that by removing additional cutthroat trout, the differences in potential predation pressure of these fish between Experiments 2 and 3 might be significant.

The potential predation impact of the cottid, C. aleuticus, on coho salmon fry was also examined. In

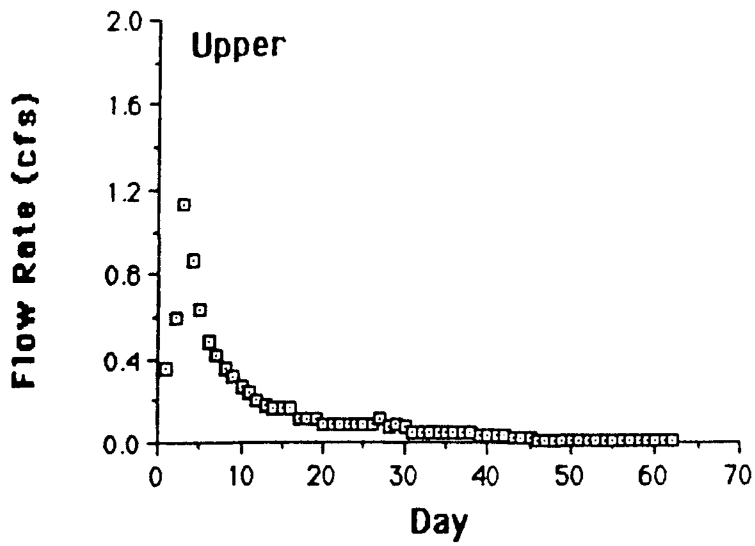
Experiment 1, a sample (n = 28) of C. aleuticus were collected from the downstream migrant trap on Lower Confusion Creek between 3-28-85 and 4-13-85. No sculpins were collected in the downstream migrant trap on Upper Confusion Creek during this same time period. The size of the sculpins sampled ranged in total length (TL) from 50 tO 73 mm with a mean length of 61 mm. All other sculpins captured in the downstream migrant trap were returned to the study stream section. The frequency of occurrence of coho salmon fry found in this sample was 25.0% From this sample, sculpins in Lower Confusion Creek consumed 0.3 coho salmon fry per sculpin. Fry were found only in the diet of sculpins larger than 60.0 mm TL. Only one sculpin measuring 73 mm TL contained more than 1 fry. The observed predation occurred between March 28, and April 4, 1985 when the number of coho salmon fry present in the creek were increasing from 4.3% to 73.8% of the total number of fry released into Lower Confusion Creek for this experiment.

In Experiment 2, a small sample of C. aleuticus (n = 10) were collected from the downstream migrant trap on Lower Confusion Creek and examined for the presence of coho salmon fry in their diet. No coho salmon fry were found.

During Experiment 3, a sample of C. aleuticus (n = 10) were collected for diet analysis. These fish ranged in length from 51-72mm TL. From this sample, one sculpin measuring 63 mm TL contained 1 LV-marked fry from the non-transported release group. This is equal to a frequency of occurrence of 10.0%. All other sculpins and cutthroat trout collected in the downstream migrant traps were returned to the study stream section.

Stream Flow

Stream flow rates were determined daily for each stream section (Figures 3, 4, 5) and coho salmon fry were removed daily from the downstream migrant traps (Table 7). The stream flow data for each experiment was log transformed for analysis. No statistical differences were observed between any of the experiments. For each of the three experiments a linear regression was conducted in order to determine if the number of coho salmon fry collected in the downstream migrant trap was dependent on stream flow (Figures 6, 7, 8). In each of the three experiments, the r values obtained indicates no significant relationship between these two factors.



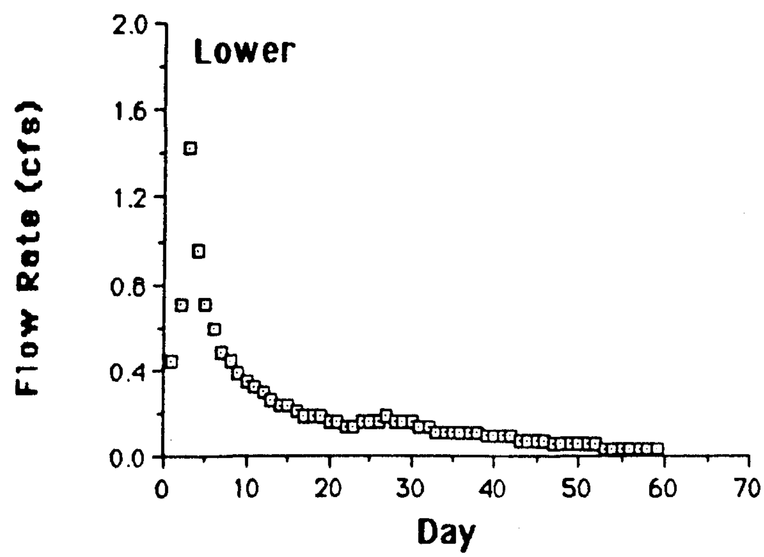


FIGURE 3. Observed daily flow rates of Upper and Lower Confusion Creek, Experiment 1, 3-25-85 to 5-26-85.

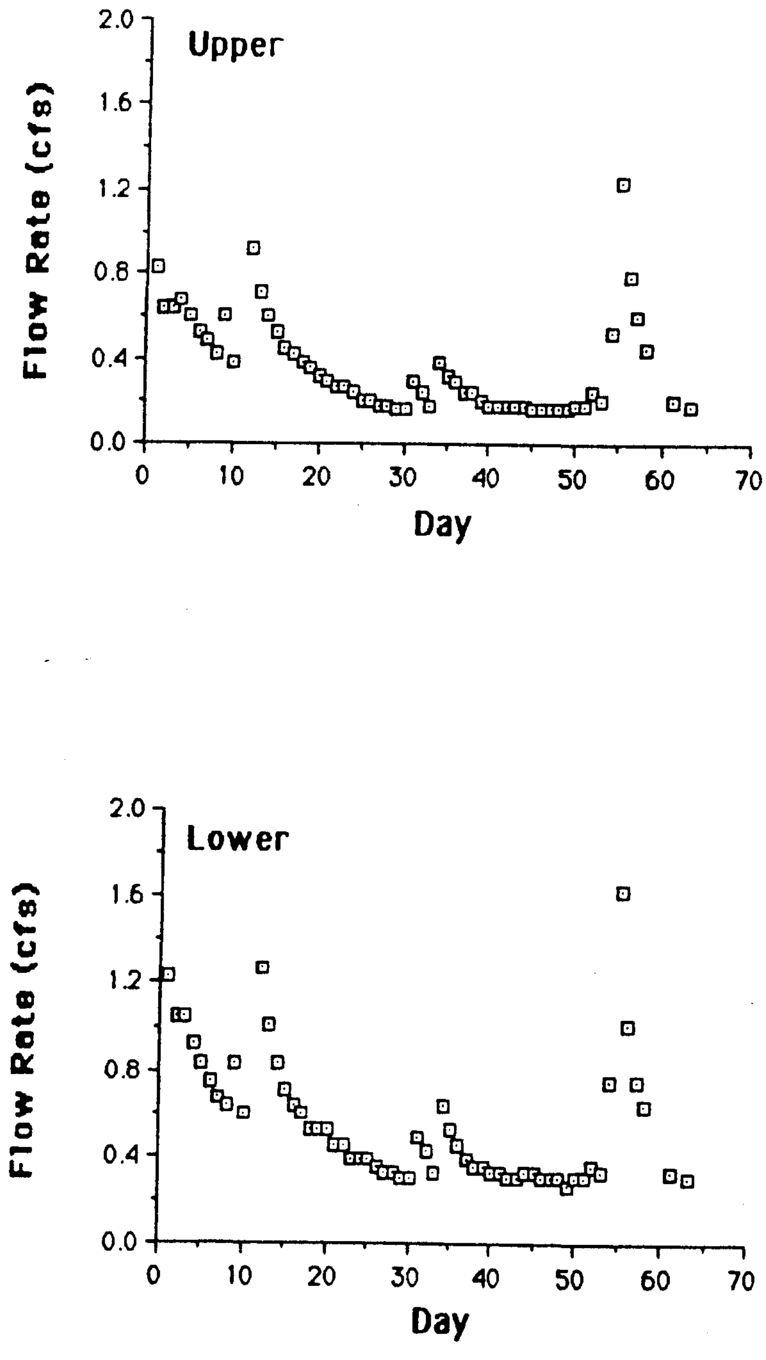


FIGURE 4. Observed daily flow rates of Upper and Lower Confusion Creek, Experiment 2, 3-13-86 to 5-11-86.

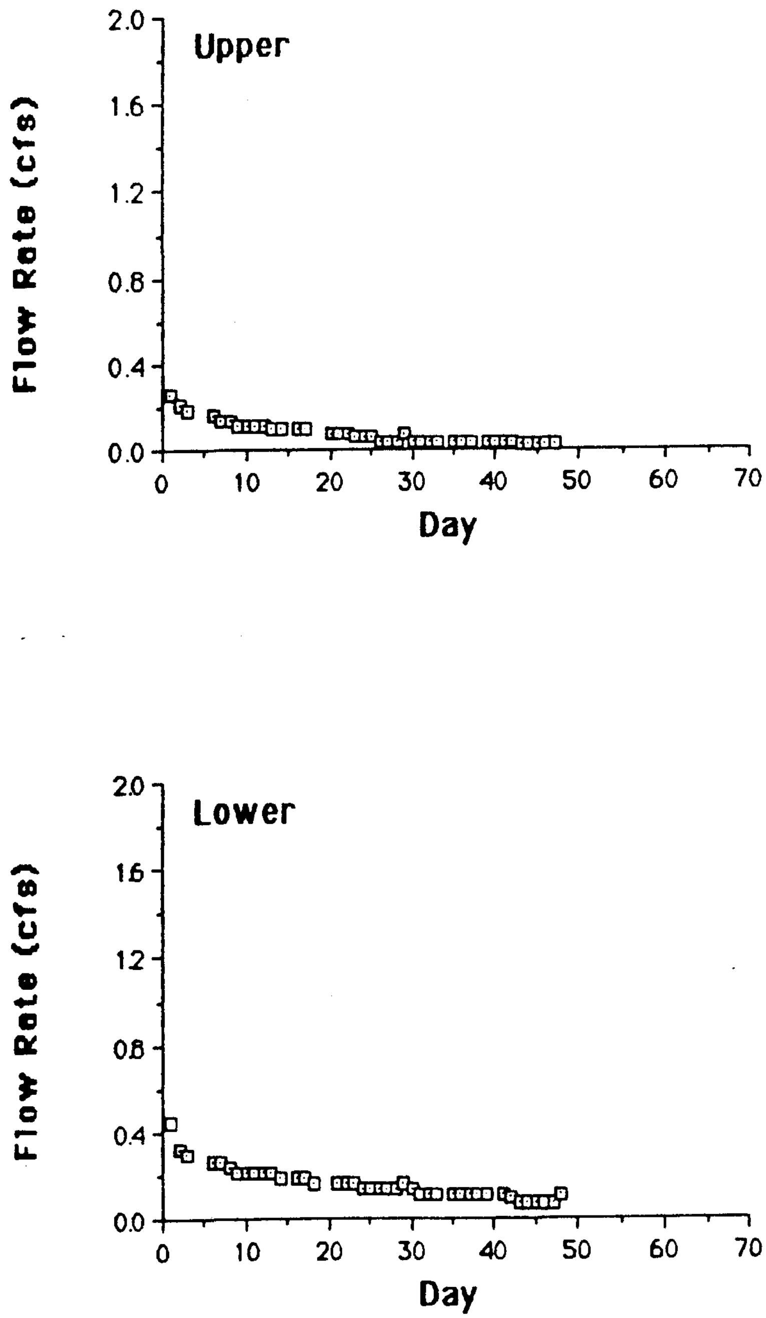


FIGURE 5. Observed daily flow rates of Upper and Lower Confusion Creek, Experiment 3, 5-19-86 to 7-6-86.

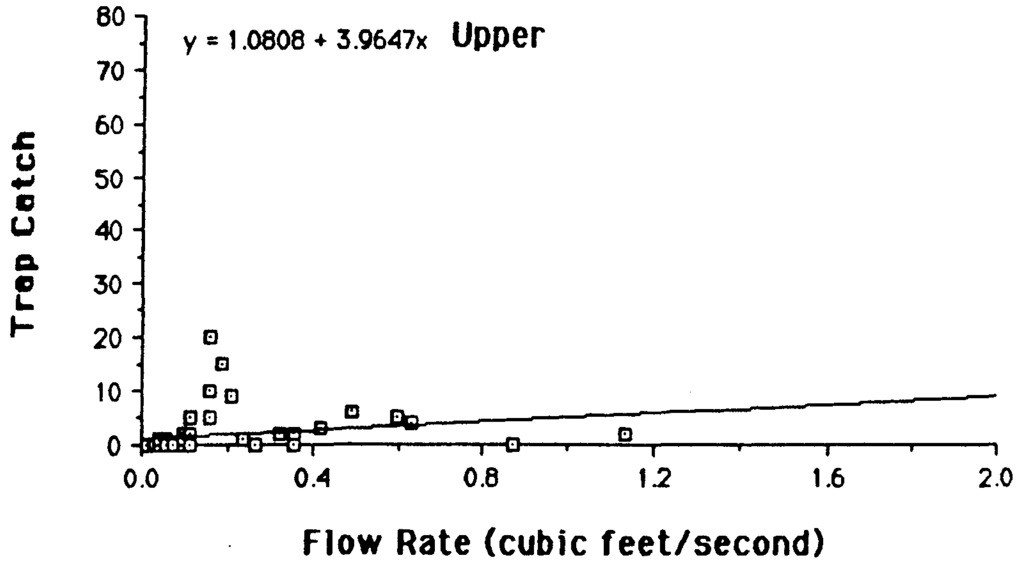
Table 7. Flow rates, downstream migrant trap catches and electroshocking recoveries from Upper (UCC) and Lower (LCC) Confusion Creek, Experiments 1, 2, and 3

		Exp. 1	Exp. 2	Exp. 3
Flow Rate (cfs)	UCC	0.14	0.36	0.07
	LCC	0.20	0.55	0.16
Migrant Trap Catches	UCC	111	46	159
	LCC	133	53	171
Electroshocking Recoveries	UCC	76	160	96
	LCC	100	83	163

Water Temperature

Water temperatures were recorded daily for each stream section (Figures 9, 10, 11). In the first experiment the mean water temperature of Upper Confusion Creek over the course of the study was 9.96 C and for Lower Confusion Creek 9.85 C. In the second experiment the mean temperature for Upper Confusion Creek was 9.83 C and for Lower Confusion Creek 10.14 C. In the third experiment the mean temperature of Upper Confusion was 11.74 C and 12.07 C in Lower Confusion Creek.

A T-test analysis of the mean water temperatures for Upper and Lower Confusion Creek between experiments indicated a significant difference



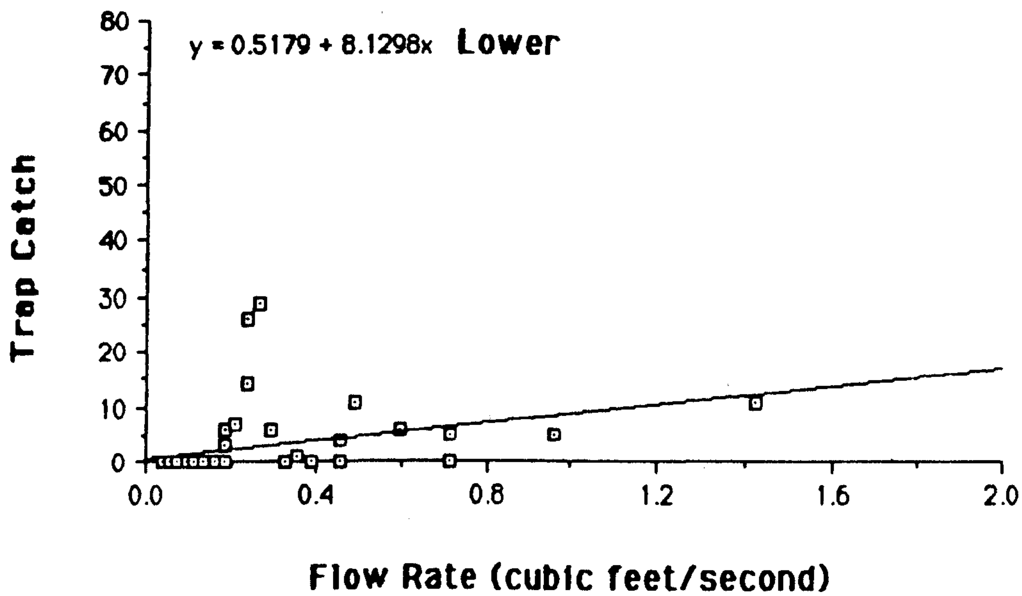


FIGURE 6. Linear regression of downstream migrant trap catch on flow rate for Upper and Lower Confusion Creek, Experiment 1, 3-25-85 to 5-26-85.

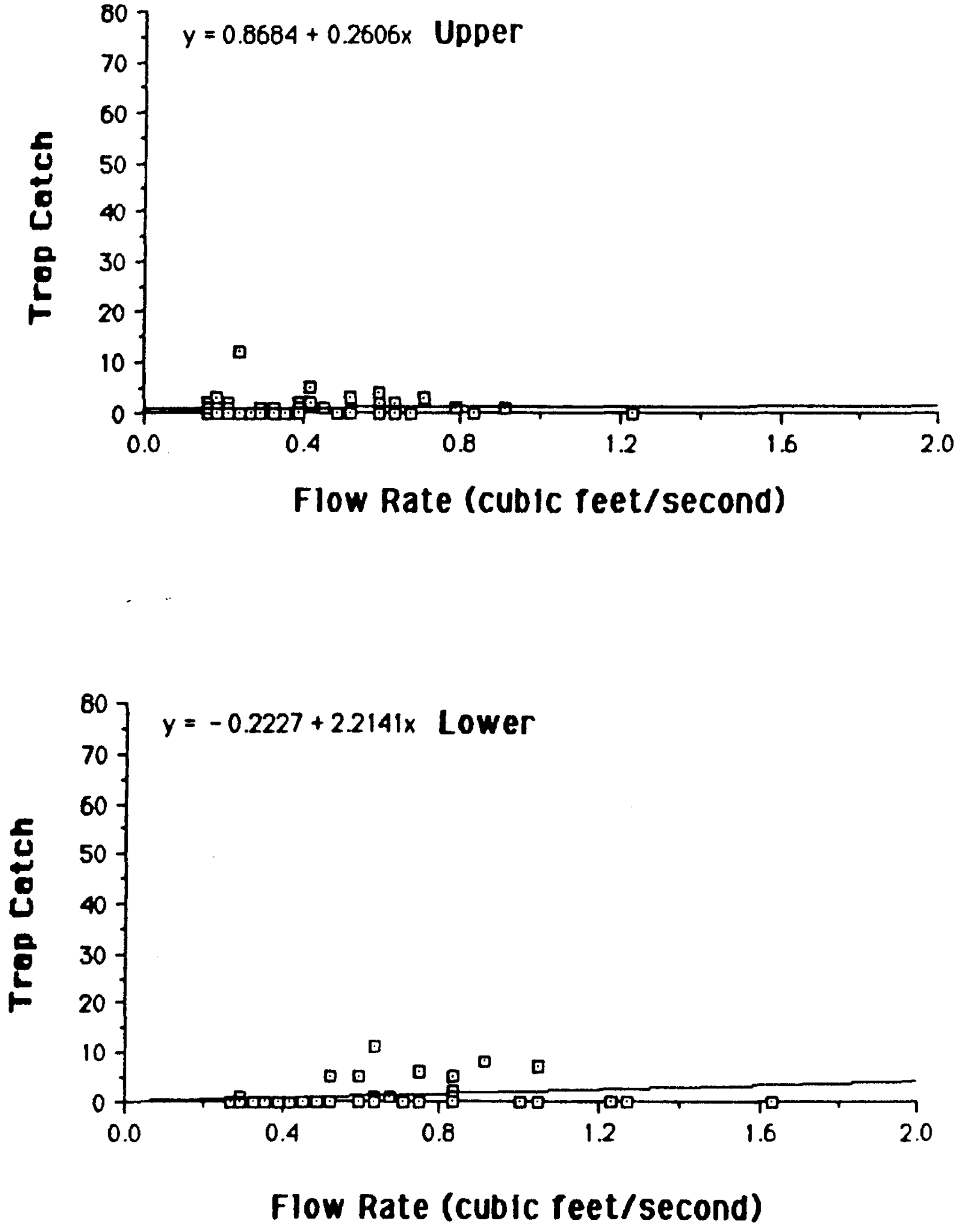
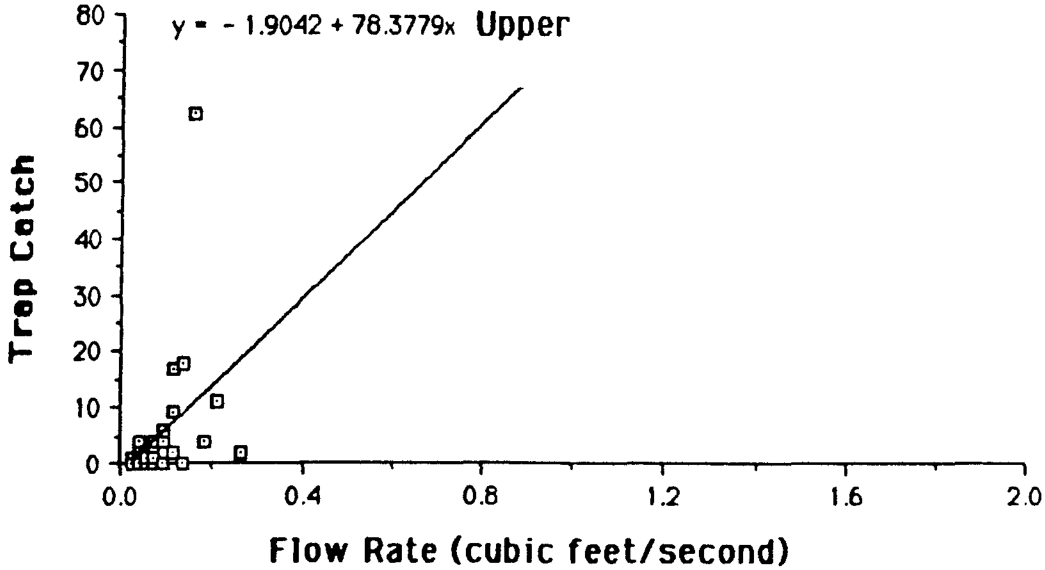


FIGURE 7. Linear regression of downstream migrant trap catch on flow rate for Upper and Lower Confusion Creek, Experiment 2, 3-13-86 to 5-11-86.



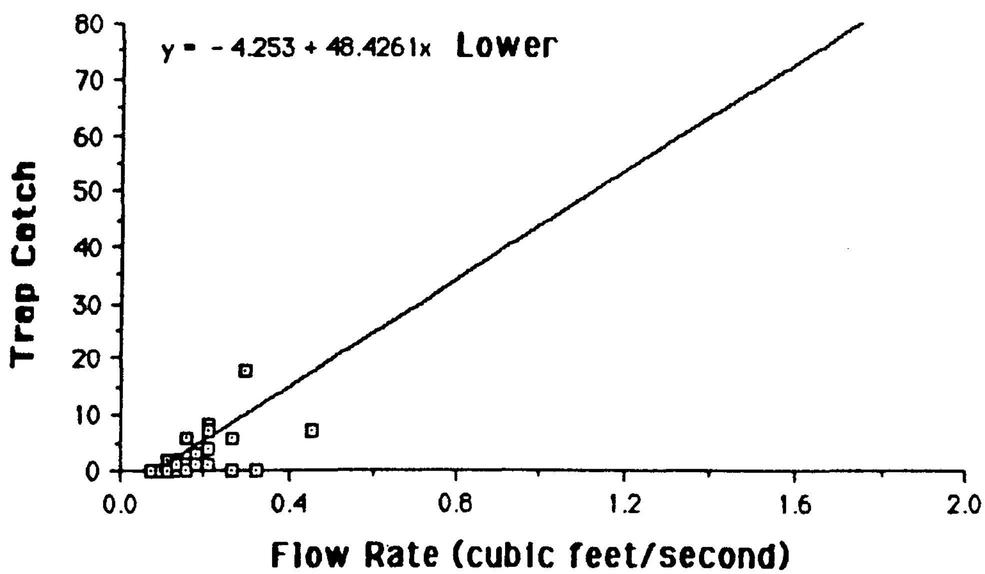


FIGURE 8. Linear regression of downstream migrant trap catch on flow rate for Upper and Lower Confusion Creek, Experiment 3, 5-19-86 to 7-6-86.

(0.05 > p > 0.01) between both experiments 1 and 3, and 2 and 3. No significant difference was observed between experiments 1 and 2.

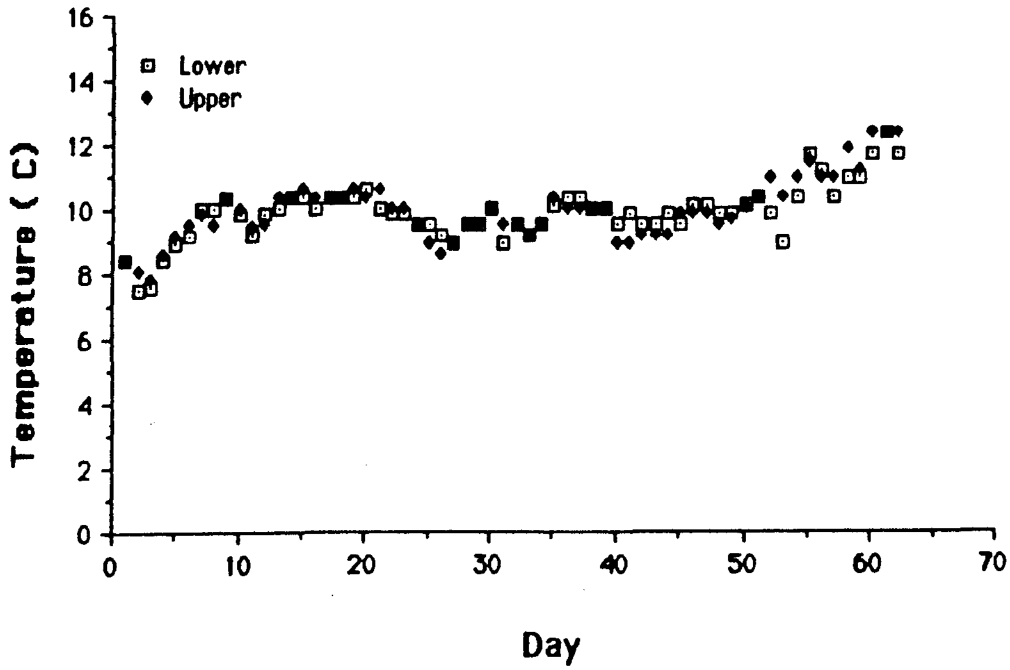


FIGURE 9. Mean daily water temperature of Upper and Lower Confusion Creek, Experiment 1, 3-25-85 to 5-26-85.

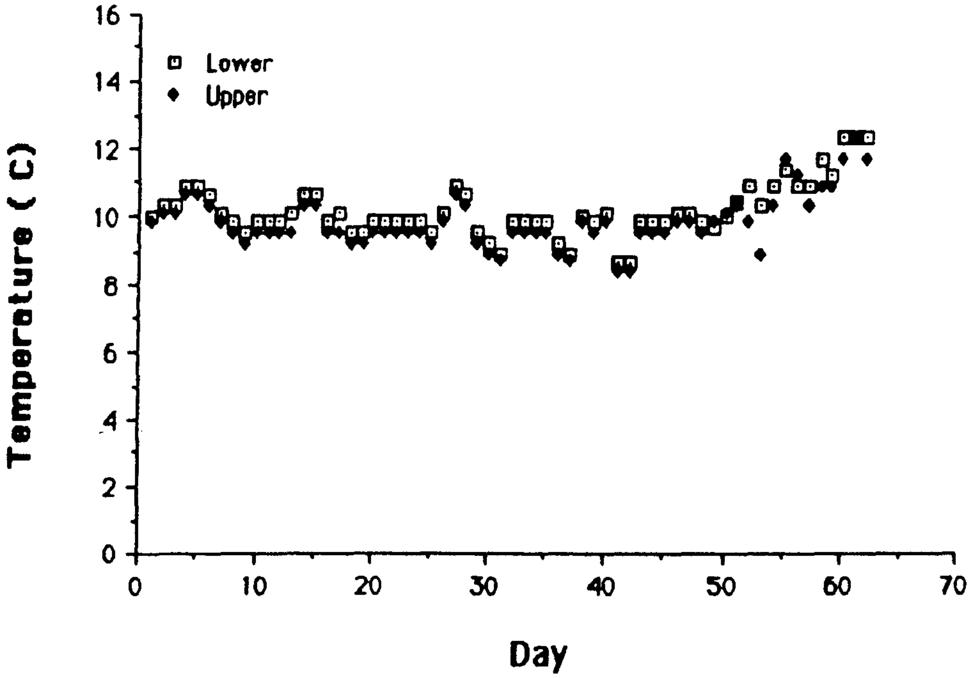


FIGURE 10. Mean daily water temperature of Upper and Lower Confusion Creek, Experiment 2, 3-13-86 to 5-11-86.

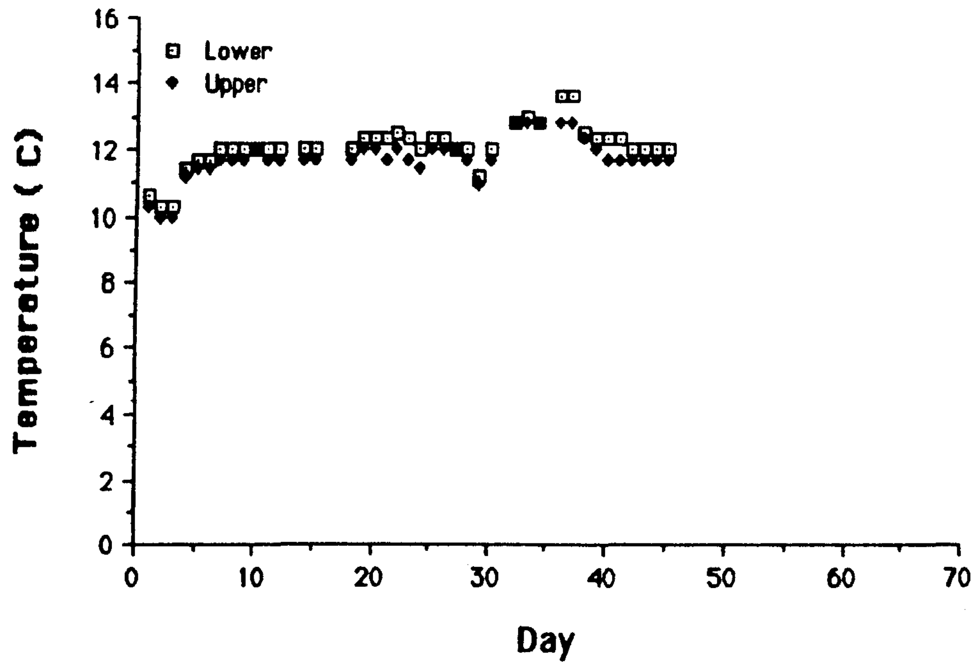


FIGURE 11. Mean daily water temperature of Upper and Lower Confusion Creek, Experiment 3, 5-19-86 to 7-6-86.

DISCUSSION

This study consisted of three related experiments, of which, one was conducted in 1985 and two were completed in 1986.In the first experiment, both groups were handled in the same manner with one group additonally being transported. The test groups were then placed in one of two study stream sections. The test period was 63 days after which both stream sections were electroshocked and the fry collected. The non-transported group had a higher relative survival than the transported group (Table 1). The transported fry were slightly longer and heavier than their non-transported counterparts (Table 2).

The second experiment compared fry which were handled and transported to fry which were allowed to volitionally leave the hatchbox and enter their respective study stream section. The stream sections were electroshocked after 60 days and the fry recovered. In this experiment, the number of transported fry recovered was nearly double the number of non-transported fry. The mean wet weight of the fry was the same for both groups. Fry from the transported group were slightly longer than the non-transported fry (Table 4).

For the third experiment, the non-transported and transported fry were given differential fin clips. Approximately equal numbers of fry from each group were placed in the two stream sections. The stream sections were electroshocked after 49 days and the fry collected. In Upper Confusion Creek,the number of transported fry recovered was slightly higher than the number of non-transported fry. The mean wet weights were equal between the two groups but the non-transported fry were slightly longer (Table 6). In Lower Confusion Creek, non-transported had the highest relative survival and were heavier and longer than the fry from the transported group.

A more accurate determination of handling and stress induced differences between groups would result from the count of returning adults. Unfortunately, this was beyond the scope of this study. Short term experiments with fry would were hoped to indicate if handling and transport induced stress resulted in lower survival.

The primary goal of this study was to assess what effects handling and transportation had on the terminal population size of coho salmon fry released into a natural stream. Handling has been documented to evoke stress responses in salmonids as indicated by elevated plasma cortisol concentrations (Wedemeyer 1972; Strange et al. 1977, 1978; Mazeaud et al. 1977;

Barton and Peter 1982; Fagerlund and Donaldson 1970; Hane et al. 1966; Barton et al. 1986). The effects of stress on juvenile salmonids appears to be dependent on the severity and duration of the stressor(s). Severe stress can result in nearly immediate death even if the stress period is short (Strange et al. 1978). Short-term handling elevates corticoid concentrations but fish mortality is minimal (Strange et al. 1977). Transporting, a common STEP procedure, is stressful to fishes (Barton and Peter 1982; Johnson and Metcalf 1982) but is virtually unavoidable in most hatchery operations.

Most of the fry used in this study were netted from a live box and transported in a 5 gallon bucket for 60 to 70 minutes prior to release. Live box mortalities were very minimal and no mortalities occured during transport. A holding experiment using transported fry (n = 30) resulted in only 1 mortality in 48 hours. The anesthetic, tricaine methanesulfonate (MS 222), used in this study to facilitate finclipping, has been demonstrated to cause chemical stress in salmonids (Houston et al. 1971; Wedemeyer 1970; Strange and Schreck 1978; Hattingh and Burger 1979; Barton and Peter 1982). No mortalities were observed after 48 hours in test groups of fry which had been anesthetized or anesthetized and finclipped.

The most striking finding of this study was the high variability and low predictability of the results. Stress itself could not adequately explain the differences because in Experiment 2 and in Upper Confusion Creek in Experiment 3, the transported (stressed) fry had a higher relative survival than the non-stressed fry. This study was conducted in a natural stream and therefore was subject to physical perturbations and biological interactions which may be responsible for the variability both within and between experiments. Some of the most likely factors which could have influenced the outcome of this study will be discussed.

Small streams provide a diversity of habitat types important in the early life history of many stream dwelling salmonids (Moore and Gregory 1988). The margins, backwaters, and side channels of streams are commonly utilized by the fry of coho salmon, chinook salmon (*O. tshawytscha*) (Lister and Genoe 1970; Everest and Chapman 1972; Hartman and Brown 1987), and cutthroat trout (*Salmo clarki*) (Bustard and Narver 1975). These lateral habitats support high densities of aquatic invertebrates and provide structural protection from high stream discharge. Cover associated with these lateral habitats include logs, upturned roots, debris accumulations and undercut banks. In cases where these habitats contain water only during winter and contained the appropriate cover, coho salmon juveniles utilized these areas in the winter (Bustard and Narver 1985; Hartman and Brown 1985). It is apparent that the volume of water present in a stream or river is a very important factor in determining the areal extent and quality of habitat available to salmonid fry.

Erman and Leidy (1975) demonstrated that during a low flow year, steelhead trout fry (Salmo gardneri), posessed a behavioral mechanism which allowed them to escape the tributary before it dried up. Restated, this suggests that as the water flow decreased, the amount of suitable fry habitat also decreased, which triggered a behavioral response in the fry to migrate downstream or risk being trapped in whatever pools remained. Conversely, Erman and Leidy (1975) also demonstrated that in wet years, many of the fry remained in the tributary with fewer fry migrating downstream. Appropriate habitat was available to the remaining fry.

Many stimuli may contribute to the downstream movement of salmonids. Advanced yolk sac absorption results in reduced swimming performance and subsequent downstream movement in chinook salmon (Thomas 1969).

Rising stream flows can cause downstream movement by reducing the numbers and area of low velocity.

High numbers of chinook salmon fry in observation troughs may result in density dependent adjustments in population sizes based on available food and living space (Chapman 1962; Reimers 1968). A genetically induced mechanism for downstream movement if differential drift distance after emergence (or leaving the hatchbox). Chapman (1962) demonstrated that some fry migrate downstream despite the availability of suitable habitat along the margin of the stream. This dispersment may lessen competion for rearing habitat near the point of emergence and play an important role in seeding downstream habitat.

Intraspecific agnostic behavior appears to be an important factor in the dispersal and downstream movement of coho salmon fry (Chapman 1962; Mason and Chapman 1965). These studies demonstrated that coho salmon fry establish territories and form hierarchies based on size. The dominant fry, which are larger and more aggressive, actively harrass their smaller counterparts. These small fry are forced into occupying suboptimal living areas or are chased downstream.

In trying to assess the significance of downstream migrant trap catches, it must be pointed out that in Experiments 1 and 2, the fry were the progeny of two females. This introduces the possibility of genetically induced developmental or behavioral differences between groups of fry which could be manifested by disparate downstream migrant trap catches. However, the random selection and placement of eggs in the hatchboxes makes it unlikely that this situation could occur.

A comparison of the downstream migrant trap catches and flow rates between Experiments 1 and 2 and Experiments 2 and 3 suggests that intraspecific interactions and a deteriorating stream habitat could help explain the observed differences between experiments. The flow rates were low in Experiments 1 and 3 and downstream migrant trap catches were high. In Experiment 2, the flow rate was higher but migrant trap catches were much lower than in Experiments 1 and 3.

During years of low flow, first emerging coho salmon fry could achieve a selective advantage by occupying optimal stream positions along the margins of streams (Mason and Chapman 1965), which afford maximum energy gain (Faush 1983). Chapman (1962) demonstrated that coho salmon fry hierarchies were organized on the basis of size, with larger individuals occupying stream positions allowing for better growth opportunities. He also demonstrated that smaller fry, which could be later emerging fry, occupied areas of lower growth potential or were forced downstream. The fry collected in the downstream migrant traps during Experiment 2 could represent a surplus production under that specific flow regime. Here again, the available fry habitat may have been fully occupied forcing these fry to disperse downstream .

Under high flow conditions, Upper Confusion Creek may contain more fry habitat than Lower Confusion Creek as indicated by higher electroshocking recoveries from Upper Confusion Creek. However, under low flow conditions, Lower Confusion Creek may contain more fry habitat even though the pool area for both sections were nearly equal under low flow conditions.

Pool habitat has long been recognized for its importance in the ecology of stream dwelling salmonids, (Everest and Chapman 1972; Mundie 1974; Bustard and Narver 1975; Binns and Eiserman 1979). However, the various life stages of juvenile coho salmon require habitats specifically suited to the respective life stage. The abundance and quality of microhabitat available to a particular life stage of juvenile salmonid at fluctuating stream flows may determine the population size of juveniles within the particular stream system.

During the course of this study, the two resident fish species in Confusion Creek, coastrange sculpin and cutthroat trout, were both found to prey upon coho salmon fry. In Experiment 1, the frequency of occurrence of coho fry in the diet of sculpins was 25.0%. From this sample, sculpins in Lower Confusion Creek consumed 0.3 fry per sculpin. This data may not reflect a true measure of predation impact in that the stomachs examined were all from sculpins collected in the downstream migrant trap. Similarly, Clary (1972) demonstrated that slimy sculpin (C. cognatus) readily consumed brown trout (Salmo trutta) when placed in a small stream exclosure that contained the sculpins. Ricker (1941), demonstrated that in unnatural situations, cottids would gorge on salmon fry if the opportunity presented itself.

The effectiveness of cottid predation on salmonid fry is dependent on several factors including size of the salmonid fry, innate behavioral characteristics of the salmonid species (Patten 1975), and size of the sculpin (Clary 1972). In this study, smaller fry were more susceptible to predation than larger fry. Similar results were found by Bams (1967); Patten (1975); and Taylor and McPhail (1985). Patten (1975) suggested that the size of coho salmon fry captured by a cottid is limited to the size of fry the cottid can ambush, subdue, and swallow. Survival of coho salmon fry in the presence of cottids is attained by a well developed avoidance response. In this study, only cottids longer than 60 mm TL consumed coho salmon fry. Similarly, Hunter (1959) and Patten (1959, 1977) found very little predation on salmon fry by cottids smaller than 60 mm TL.

Cutthroat trout were also found to prey on coho salmon fry in this study. The population size of cutthroat trout large enough to prey on coho salmon fry was low, ranging from 5 to 10 individuals per stream section. However, in a small sample (n = 4) of cutthroat trout stomach sampled, 3 of the stomachs contained 7 coho salmon fry. The fry consumed by the cutthroat tended to be smaller suggesting that the size of fry influences its susceptibility to predation.

Cutthroat trout generally attack prey from close range, involving a short burst of swimming and if unsuccessful, a short pursuit (Bams 1967). Taylor and McPhail (1985) documented that larger coho salmon fry attained a higher burst swimming speed than smaller fry. This size mediated difference in burst speed increased the susceptibility of smaller fry to predation.

A variety of factors can influence the rate of predation by trout on salmon fry. Such factors include varying natural light intensities, stream flow rates, turbidity of the stream, and previous exposure to predators, (Ginetz and Larkin 1975). These factors are probably not mutually exclusive to trout but could easily apply to any other piscivores present in the streams.

Throughout the course of this study, the populations of sculpins and cutthroat trout of a size large enough to prey on coho salmon fry were consistently higher in Lower Confusion Creek. However, the number of downstream migrants collected and more importantly, the number of coho salmon fry electroshocked were both higher in Lower Confusion Creek in Experiments 1 and 3. Stream conditions during these experiments can be characterized by low flows and clear water; conditions which Ginetz and Larkin (1975) found increased predation on sockeye salmon fry by rainbow trout (Salmo gairdneri). In Experiment 2, stream flow rates were higher and the water more turbid due to several small freshets which Ginetz and Larkin (1975) found decreased fry mortality by predators.

The population of potential predators was higher in Lower Confusion Creek during this study but the electroshocking recoveries were almost half that of Upper Confusion Creek. This suggests that even though predation by coastrange sculpins and cutthroat trout did occur, their role in determining the population size of coho salmon fry at the termination of the three experiments appears to be relatively minor. Moyle (1977), in a literature review of sculpin-salmonid fry predation interactions concluded that in natural stream systems, sculpins appear to have little impact on salmonid populations and may even improve production in some cases.

No avian or mammalian predators were observed over the entire study but should not be discounted. The impact of other potential predators such as rough skinned newts (*Taricha granulosa*), Pacific giant salamander (*Dicamtodon ensatus*), and frogs (*Rana* spp.) is unknown.

Attempts to seed streams using hatchery produced fry have generally been unsuccessful. Some possible reasons for this are as follows. First, deliterious stress induced effects incurred during handling and transport. Second, the fry may not be genetically suited to the local conditions with resultant high mortality. Third, the fry may be at a developmental stage which physically limits their ability to hold favorable stream position, escape predators or find food.

Stream side incubators, hatchboxes, are being used to simulate natural spawning conditions without the associated in-gravel mortality of eggs and fry. The hatchboxes are generally used for streams with at best, a very low population of wild salmon. In most cases, the hatchbox fry are allowed to volitionally leave the hatchbox at a developmental stage which mirrors that of their wild counterparts when they emerge from the gravel. This should ensure the maximum potential for survival of the hatchbox fry.

In some cases, production from the hatchbox exceeds the rearing capacity of the stream and a portion of the fry are transported to another stream and released. This study indicates that under conditions similar to those used by STEP volunteers, coho salmon fry can be transported 60 to 70 minutes with little or no short-term mortality. The survival of the fry is dependent more on the physical and biological properties of the stream than the stress incurred during transport.

LITERATURE CITED

Bams, R. A. 1967. Differences in performance of naturally and artificially propagated sockeye salmon migrant fry, as measured with swimming and predation tests. J. Fish. Res. Board Can. 24: 1117-1153.

Barton, B. A. and R. E. Peter. 1982. Plasma cortisol stress response in fingerling rainbow trout, Salmo gairdneri Richardson, to various transport conditions, anaesthesia, and cold shock. Fish. Bio. 20: 39-51.

Barton, B. A., C. B. Schreck, and L. A. Sigismondi. 1986. Multiple acute disturbances evoke cumulative physiological stress responses in juvenile chinook salmon. Trans. Am. Fish. Soc. 115: 245-251.

Binns, N. A. and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108: 215-228.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Onchorhynchus kisutch) and steehead trout (Salmo gairdneri). J. Fish. Res. Board Can. 32: 667-680.

Chapman, D. W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. J. Fish. Res. Board Can. 19: 1047-1080.

1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Am. Fish. Soc. 94: 40-53.

1966. Food and space as regulators of salmonid populations in streams. Am. Nat. 100: 345-357.

Clary, J. R. 1972. Predation on the brown trout by the slimy sculpin. Prog. Fish Cult. 34: 91-95.

Erman, D. C. and G. R. Leidy. 1975. Downstream movement of rainbow trout fry in a tributary of Sagehen Creek, under permanent and intermittent flow. Trans. Am. Fish. Soc. 3: 467-473.

Everest, F. H. and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Board Can. 29: 91-100.

Fagerlund, U. H. M. and E. M. Donaldson. 1970. Dynamics of cortisone secretion in sockeye salmon (Onchorhynchus nerka) during sexual maturation and after gonadectomy. J. Fish. Res. Board Can. 27: 2323-2331.

Fausch, K. D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Can. J. Zool. 62: 441-450.

Ginetz, R. M. and P. A. Larkin. 1975. Factors affecting rainbow trout (Salmo gairdneri) predation on migrant fry of sockeye salmon (Onchorhynchus nerka). J. Fish. Res. Board Can. 33: 19-24.

Hane, M., O. H. Robertson, B. C. Bernard, and M. A. Krupp. 1965. Adrenocortical response to stress and ACTH in Pacific salmon (Onchorhynchus tshawytscha) and steelhead trout (Salmo gairdneri) at successive stages in the sexual cycle. Endocrinology 78: 791-800.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (Onchorhynchus kisutch) and steehead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22: 1035-1081.

Hartman, G. F. and T. G. Brown. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a West coast rain-forest drainage basin, Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 44: 262-270.

Houston, A. H., J. A. Madden, R. J. Woods, and H. M. Miles. 1971. Some physiological effects of handling and tricaine methanesulfonate anesthetization upon the brook trout, Salvelinus fontinalis. J. Fish. Res. Board Can. 28: 625-633.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board of Can. 16: 839-886.

Johnson, D. L. and M. T. Metcalf. 1982. Causes and controls of freshwater drum mortality during transportation. Trans. Am. Fish. Soc. 111: 58-62.

Mason, J. C. and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. J. Fish. Res. Board of Can. 22: 173-189.

Mazeaud, M. M., F. Mazeaud, and E. M. Donaldson. 1977. Primary and secondary effects of stress in fish: some new data with a general review. Trans. Amer. Fish. Soc. 106: 201-212.

Moore, K. M. S. and S. V. Gregory. 1988. Summer habitat utilization and ecology of cutthroat trout fry (Salmo clarki) in Cascade Mountain streams. Can. J. Fish. Aquat. Sci. 45: 1921-1930.

Moyle, P. B. 1977. In defense of sculpins. Fisheries 2: 20-23.

Mundie, J. H. 1974. Optimization of the salmonid nursery stream. J. Fish. Res. Board Can. 31: 1827-1837.

Patten, B. G. 1959. Cottid predation upon salmon fry in a Washington stream. Trans. Am. Fish. Soc. 91: 427-429.

1975. Comparitive vulnerability of fry of Pacific salmon and steelhead trout to predation by torrent sculpin in stream aquaria. U.S. Nat. Mar. Fish. Serv. Fish. Bull. 73: 931-934.

1977. Body size and learned avoidance as factors affecting predation on coho salmon, Onchorhynchus kisutch, fry by torrent sculpin, Cottus rhotheus. U.S. Nat. Mar. Fish. Serv. Fish. Bull. 75: 457-459.

Reimers, P. E. 1968. Social behavior among juvenile fall chinook salmon. J. Fish. Res. Board Can. 25: 2005-2008.

Ricker, W. E. 1941. The consumption of young sockeye salmon by predaceous fish. J. Fish. Res. Board Can. 5: 293-313.

Rosenau, M. L. and J. D. McPhail. 1987. Inherited differences in agnostic behavior between two populations of coho salmon. Trans. Am. Fish. Soc. 116: 646-654.

Smit, G. L., J. Hattingh, and A. P. Burger. 1979. Haematological assessment of the effects of the anesthetic MS 222 in natural and neutralized form in three freshwater fish species: interspecies differences. J. Fish Biol. 15: 633-643.

Strange, R. J. and C. B. Schreck. 1977. Anesthetic and handling stress on survival and cortisol concentration in yearling chinook salmon (Onchorhynchus tshawytscha). J. Fish. Res. Board Can. 35: 345-349.

Strange, R. J. and C. B. Schreck. 1978. Cortisol concentrations in confined juvenile chinook salmon (Onchorhynchus tshawytscha). Trans. Am. Fish. Soc. 107: 812-819.

Strange, R. J., C. B. Schreck, J. T. Golden. 1977. Corticoid stress responses to handling and temperature in salmonids. Trans. Am. Fish. Soc. 106: 213-217.

Taylor, E. B. and J. D. McPhail. 1985. Burst swimming and size-related predation of newly emerged coho salmon Onchorhynchus kisutch. Trans. Am. Fish. Soc. 114: 546-551.

Wedemeyer, G. 1970. Stress of anesthesia with M.S. 222 and benzocaine in rainbow trout (Salmo gairdneri). J. Fish. Res. Board Can. 27: 909-914.

Woodward, J. J. and L. S. Smith. 1985. Exercise training and the stress response in rainbow trout, Salmo gairdneri Richardson. J. Fish. Biol. 26: 435-447.