AN ABSTRACT OF THE THESIS OF

Jeffrey Dale Rodgers for the degree of Master of Science

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Title: THE WINTER DISTRIBUTION, MOVEMENT, AND SMOLT TRANSFORMATION OF JUVENILE COHO SALMON IN AN OREGON COASTAL STREAM

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Dr. James Hall

The abundance of the 1982 brood of juvenile coho salmon (Oncorhynchus kisutch) was determined in August 1983, and January and April 1984 at 20 study sites spread throughout Knowles Creek, an Oregon coastal watershed. The timing of emigration of juvenile coho from the watershed was monitored from October 1983 through June 1984. Condition factor, fork length, and gill (Na+K)-ATPase activity were measured in migrants, a captive group of Knowles Creek juvenile coho held in the laboratory, and nonmigrant fish periodically sampled from the stream. Skin guanine levels were also measured in migrant and nonmigrant groups.

Juvenile coho abundance in January was significantly correlated with abundance in August. Wood volume and amount of undercut streambank were the pair of physical variables that best explained variation in the number of fish per square meter or per cubic meter in January. Two debris torrent ponds in the middle

of the watershed contained large amounts of woody debris and were the most heavily used overwintering habitats for juvenile coho in the Knowles Creek. Few juvenile coho overwintered in the lower half of watershed, an area lacking woody debris.

Peaks in outmigration occurred in November and May. Approximately 24% of the total number of migrants emigrated in November. Fish that reared in two of three third-order areas in summer, together with fish from the lower (fifth-order) half of the mainstem, were the first to leave the watershed. While lack of winter habitat may have been the cause of migration from the lower mainstem, low summer streamflows may have caused early migration from the low order sites.

Gill (Na+K)-ATPase activity of migrants rose gradually from a low in January to a peak at the end of the study in June. Mean gill (Na+K)-ATPase activity of nonmigrants was only significantly lower than that of migrant fish during April. Gill (Na+K)-ATPase of captives was similar to that of nonmigrants until it peaked during the last two weeks in April, after which the activity fell below that of migrants or nonmigrants. Condition factor of nonmigrant fish was higher than either migrants or captives throughout the study. Migrant skin guanine levels rose sharply during the first two weeks in April and continued to rise until the end of the study in June.

Approximately 8,300 juvenile coho, 44% of the estimated number of juvenile coho present in Knowles Creek in August, migrated from the watershed by the following June. An estimated 9% of the August population migrated as smolts after April 1.

The Winter Distribution, Movement, and Smolt Transformation of Juvenile Coho Salmon in an Oregon Coastal Stream

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GENERAL INTRODUCTION

In recent years there has been increasing interest in enhancing and protecting the freshwater habitat of coho salmon (Oncorhynchus kisutch) and other anadromous salmonids in Oregon coastal streams. For these efforts to be successful, they must be directed toward those aspects of the habitat that are actually limiting production (Hall and Baker 1982). Although the habitat preference of coho changes with the seasons (Bustard and Narver 1975), most habitat enhancement efforts have been directed toward improving summer rearing habitat. These efforts may not benefit coho or other salmonids that overwinter in freshwater if the bottleneck limiting production occurs during the winter.

The lack of effort to enhance winter habitat is due largely to a lack of information on what makes good winter habitat. It was an awareness of the need for such information on coho salmon that led me to undertake the study described in Chapter I of this thesis. Specifically, a portion of this thesis describes research conducted on juvenile coho salmon overwintering in Knowles Creek, a fifth-order tributary of the Siuslaw River near Mapleton, Oregon.

Information on the winter habitat of juvenile coho is not, however, the only topic of this thesis. In the planning of this project, a recurring question was whether fish that migrated from Knowles Creek in the winter were leaving because of habitat limitations or because they were smolts on their way to the ocean. It was also clear that little information in general existed on the smolting process in naturally reared coho. As a result, I decided to also conduct a study on aspects of the smolting process in Knowles Creek coho. This study is described in Chapter II of this thesis.

Study Area Description

Knowles Creek is a fifth-order tributary of the Siuslaw River in Oregon's central Coast Range. The stream heads at an elevation of 950 m and drains a 58 km^2 area of highly erodable Tyee Sandstone formation before flowing into tidewater of the Siuslaw River near Mapleton, Oregon.

The climate of the area is Pacific maritime typified by cool moist winters and warm summers with intermittent rains. Annual precipitation may exceed 300 cm, with over 75 percent falling between October and March. Low summer streamflows at the mouth of Knowles Creek are less than 0.3 cubic meter per second (cms). Many of the riffles in the third-order and smaller stream channels are dry at these streamflows. Intense winter storms may yield 10 to 15 cm of precipitation in a 24 hour period. These storms result in peak streamflows that are 1,000 to 5,000 times larger than minimum summer streamflows (Harr 1976).

Douglas-fir with an understory of vine maple, salal, sword fern, and salmonberry typify the area's forest. Logging activities, dating as far back as the late 1800's, have removed most of the old growth timber from the riparian zone. Extensive splash damming during early logging operations scoured much of the stream channel down to bedrock. In addition, cleanup measures conducted after logging in the 1950's and 1960's removed much large woody debris from the stream (Jim Sedell, USFS, personal communication). As a result, except for an unlogged Douglas-fir dominated area in the upper watershed, red alder predominates in the streamside zone, and much of the stream channel is devoid of structure and habitat diversity.

The watershed topography is steep. This, combined with the area's high precipitation, highly erodable geology, and the effects of logging have led to a number of debris torrents within the watershed. Debris torrents that occurred in 1977, 1980, 1981, and 1982 resulted in stable debris dams that formed long, deep stillwater pools in the middle of the basin.

Coho salmon and freshwater sculpins (Cottus sp.) are the most common species of fish found in Knowles Creek, followed in approximate order of abundance by cutthroat trout (Salmo clarki), steelhead trout (S. gairdneri), redside shiner (Richardsonius balteatus), two species of lamprey (Lampetra tridentata and L. richardsoni), blackside dace (Rhinichthys osculus nubilis), fall chinook salmon (Oncorhynchus tschawytscha) and northern squawfish (Ptychocheilus oregonensis).

CHAPTER I. The Winter Distribution and Movement of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in an Oregon Coastal Watershed.

INTRODUCTION

Juvenile coho salmon (*Oncorhynchus kisutch*) native to Oregon's coastal streams typically spend one year in fresh water before migrating to the ocean as smolts. While much is known about juvenile coho in Oregon during their first spring and summer of life (e.g. Chapman 1962; Chapman 1965; Nickelson and Hafele 1978), relatively little is known about their winter and final spring in fresh water. Studies by Mason (1976) suggest that winter conditions significantly influence the smolt production of British Columbia streams. With a declining trend in the number of wild coho produced by Oregon coastal streams (McGie 1981) there is a need for more information on the ecology of juvenile coho in Oregon during the winter, especially if winter conditions limit smolt production.

This paper presents the results of research on juvenile coho wintering in the Knowles Creek watershed of west central Oregon. The specific objectives were to: 1) determine areas in the watershed used by overwintering juvenile coho; 2) monitor movement and outmigration of fish marked in different areas of the watershed; and 3) relate distribution and movement to abundance of coho the previous summer, fish size, pool size, and amount of woody debris and amount of undercut streambank in pools.

METHODS

The mainstem of Knowles Creek was divided into four distinct areas based on differences in stream order and amount of large woody debris in the stream channel (Table I.1). The three largest pools in each of these four mainstem areas, along with the three largest pools in two tributary streams (South Canyon Creek and Hood Creek), and the 1980 and 1982 debris torrent ponds were selected as study sites (Figure I.1).

Table I.1. Stream order, stream length, and amount of woody debris in mainstem areas and selected tributaries of the Knowles Creek watershed (woody debris data from Fred Everest, USFS, personal communication).

Area	Stream Order	Length (Km)	M^3wood/ Km	Wood Pieces/Km
South Canyon Cr.	3	1.61	453.7	45.0
Hood Cr.	3	0.81	530.9	161.8
Old Growth	3	1.61	214.2	36.2
Upper Mainstem	4	5.70	737.0	38.4
Middle Mainstem	5	4.33	238.6	26.2
Lower Mainstem	5	7.03	20.7	4.6

In late summer, measurements of width and depth (to nearest cm) were made at a number of equally spaced transects established at each study site. The number of transects and depth measurements at a particular site was based on a visual estimate of the number needed to accurately determine the average width and depth of the study site.

Estimates were made of the amount of woody debris present at each study site during low streamflow conditions in March. The length and diameter of all woody debris greater than 20 cm in diameter were measured. Total wood volume was estimated for

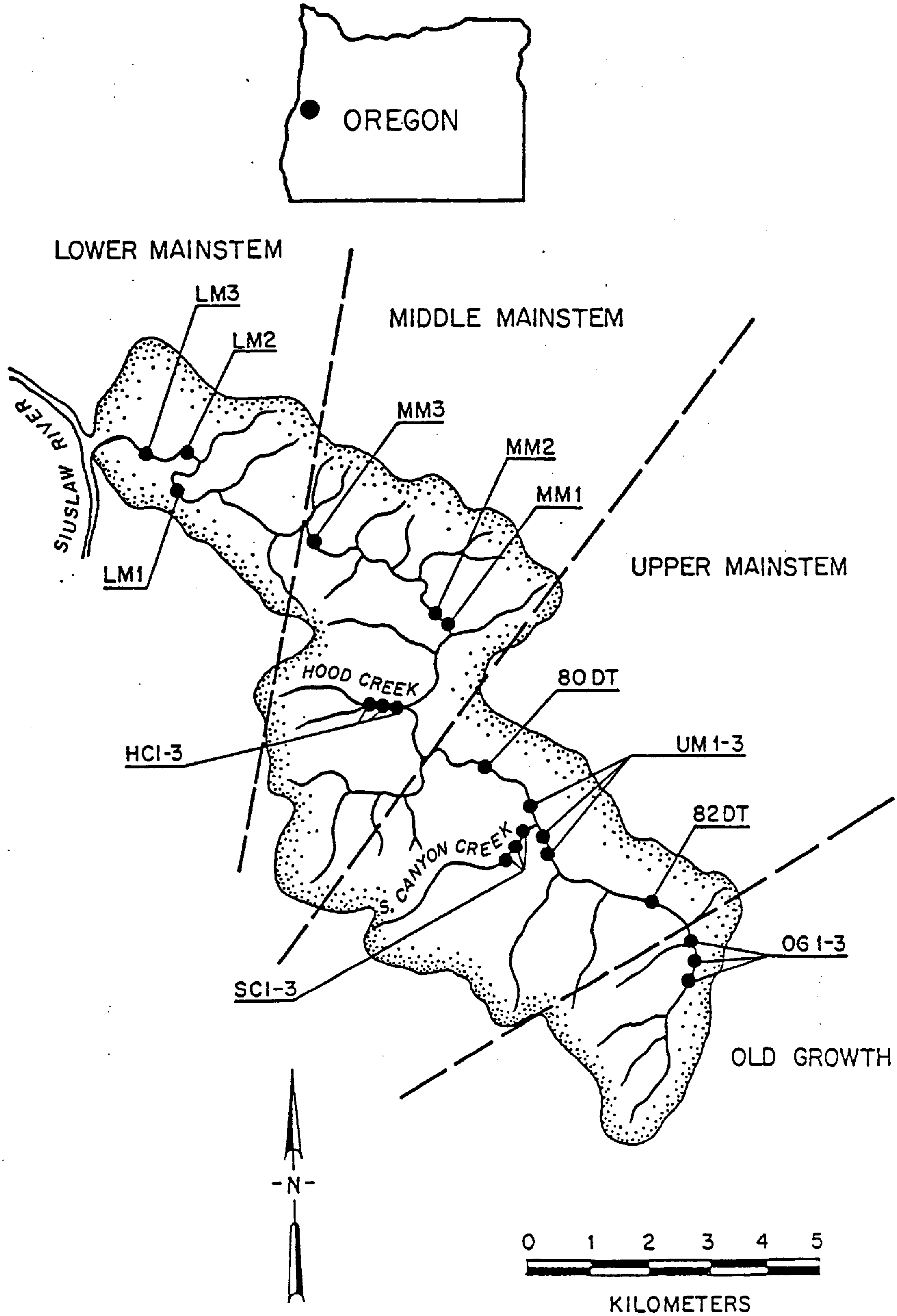

Figure I.1. Location of the four main study areas and 20 sample sites in the Knowles Creek watershed.

large accumulations of wood that could not be measured by individual piece. Estimates included only wood actually in contact with the water at the time of the survey. The proportion of streambank undercut more than 40 cm at each site was also measured during the wood surveys.

Population estimates were conducted at each study site in late August 1983, and in mid-January and early April 1984. Two methods were used for these estimates. Multiple pass-removal estimates were made at each site except the two debris torrent ponds in January and April. The upstream and downstream ends of the site were blocked with seines to prevent fish from escaping. At least two electrofishing and/or seining passes were made at each site, with additional passes made until there was a 50 percent or greater reduction in catch from one pass to the next. The pass-removal data were converted to population estimates by the methods of Armour et al. (1983). In January and April, immediately prior to the pass-removal sampling, a snorkle census was conducted at each site. Snorkle surveys were made by a diver slowly swimming upstream and counting the juvenile coho observed. An underwater flashlight was used to illuminate darkened areas such as rootwads and undercut banks. Although low summer streamflows made it possible to conduct pass-removal sampling at the two debris torrent ponds in August, higher streamflows made it impossible to conduct such sampling in January and April. As a result, snorkle censuses were the only form of population estimate conducted at these two ponds in those months.

During the late August population estimates, 1245 juvenile coho were differentially marked at the 20 sample sites in the watershed. Captured fish were anesthetized with MS-222 and marked with a brass brand chilled with liquid nitrogen and held for 3 secs in the middle of the body immediately below the lateral line. Branded fish were allowed to recover in a live box before being released back to the site from which they were collected. Care was taken to minimize handling stress during marking, and individuals that were visibly stressed were not released. A group of 20 marked juvenile coho were transported to a holding facility where they were reared for the duration of the study and periodically examined for mark retention. All captive fish retained their brands for the duration of the study.

A water level recorder and Partlow thermograph situated approximately 300 m from the mouth of Knowles Creek were used to monitor streamflow and water temperature continuously during the study.

From October through June, the migration of juvenile coho from the watershed was monitored with one of two types of downstream migrant traps operated continuously at the site of the water level recorder. An inclined plane trap with 6-mm wire mesh wings was used to capture all outmigrating fish at streamflows less than or equal to 2.7 cms. At greater streamflows, a floating scoop trap with a moving screen (Raymond and Collins 1975) was used to capture a proportion of the outmigrants. Except during periods of little or no fish movement, the downstream migrant traps were checked in the morning and at dusk. All captured juvenile coho were measured and examined for brands.

The inclined plane trap captured all outmigrant juvenile coho, while the scoop trap captured only a sample of outmigrants that varied with streamflow. To estimate the total number of emigrants from scoop trap catches, trapping efficiency was estimated by releasing known numbers of fin clipped emigrant juvenile coho at eight different levels of streamflow. All coho used in efficiency tests had been previously captured in the migrant traps. Releases were made at dusk 50 m upstream from the scoop trap. The number of fish recaptured the next morning was divided by the number released to provide an estimate of trap efficiency at that streamflow. Because downstream migration occurred primarily at night, streamflow was defined as the average between highest and lowest nightly flows. Dividing scoop trap catches by the estimated trap efficiency for a given streamflow (Figure I.2) produced an estimate of the total number of migrating juvenile coho. Analysis of variance showed no significant monthly differences in streamflow for days that the scoop trap was operated ($F_{7,126}$=1.48). This suggests that scoop trap efficiency was not biased for a particular time period.

Timing of the outmigration of juvenile coho branded at different study sites was compared by dividing the number of outmigrants captured with a particular brand by the trap efficiency for the night they were captured. The estimated number of branded emigrants was divided by the total number of fish given that particular mark to correct for differences in the number of fish marked at a particular site.

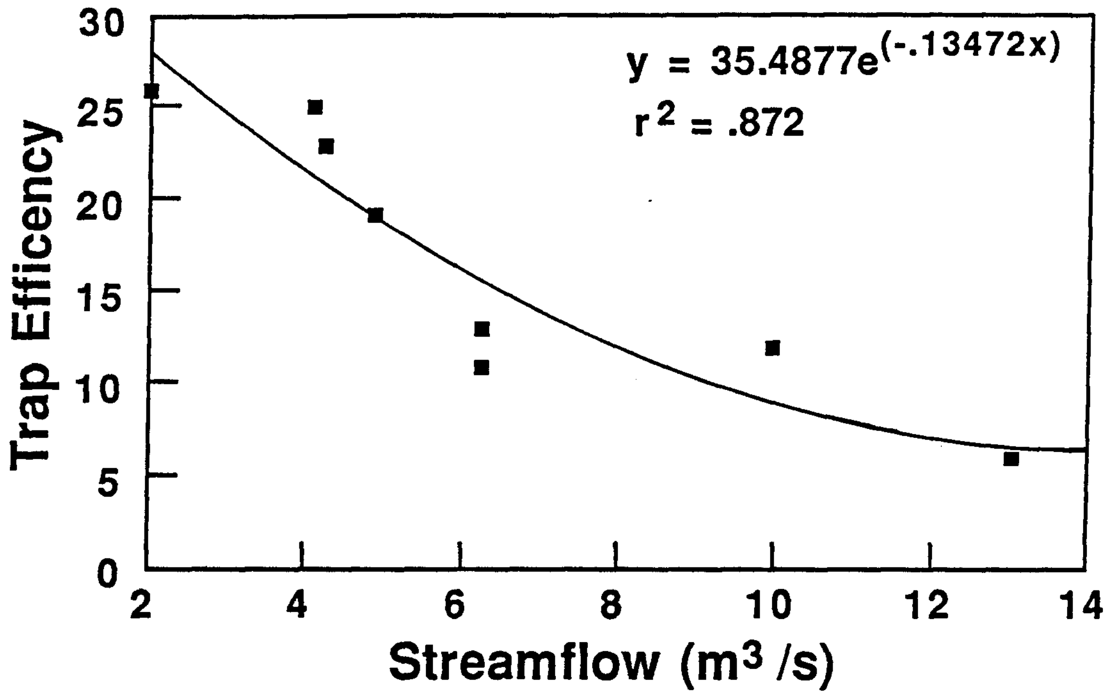

Figure I.2. Scoop trap efficiency versus average nightly streamflow. Trap efficiency is the proportion of finclipped juvenile coho released at dusk that were recaptured by the next morning.

RESULTS

Comparison of population estimates obtained from snorkle surveys and pass-removal sampling (Table I.2) suggests that snorkle surveys in winter and spring tended to underestimate the number of fish present at a site. As a result, all analyses were based on pass-removal population estimates, except for the two debris torrent ponds sampled in January and April. Because snorkle counts were the only population estimates available for the two debris torrent ponds, they had to be used in analyses of juvenile coho abundance at these two sites in January and April, even though the actual number of fish present was probably higher than indicated by the snorkle counts.

In late summer, juvenile coho tended to be most abundant in pools of third-order stream channels and least abundant in pools of the fifth-order lower mainstem (Figure I.3). Late summer numbers of juvenile coho per lineal meter of stream sampled in the debris torrent ponds were similar to those of neighboring fourth-order sites and intermediate to those of third- and fifth-order sites. In January, the two debris torrent ponds had the highest abundance of juvenile coho. By April, juvenile coho were over four times more abundant at the two debris torrent ponds than at any other site sampled.

With the exception of the two debris torrent ponds, which had substantial increases, there was a reduction in the number of juvenile coho present at each site in January compared to the number present in late summer. This reduction was generally greatest for the fifth-order stream sites, with four of the six

Table I.2. Comparison of snorkle counts and pass removal population estimates of juvenile coho salmon in the Knowles Creek watershed to the number of juveniles actually caught by electrofishing. Percent is either snorkle count or pass-removal estimate divided by the number of juvenile coho actually caught.

Site	Date	Number caught	Snorkle Count	Snorkle Percent	Pass-removal Estimate	Pass-removal Percent
OG1	1/18	25	10	40	28	112
OG2	1/18	13	0	0	13	100
OG3	1/18	28	1	4	28	100
SC1	1/16	18	15	83	19	106
SC3	1/18	22	27	122	26	118
HC1	1/21	4	0	0	5	125
HC2	1/18	6	0	0	6	100
HC3	1/17	9	0	0	10	111
UM1	1/17	59	1	2	63	107
UM2	1/16	62	0	0	62	100
UM3	1/18	21	18	86	24	114
MM1	1/19	4	0	0	4	100
LM2	4/04	8	0	0	9	112
OG1	4/04	2	1	50	2	100
OG2	4/04	7	0	0	7	100
OG3	4/03	4	0	0	4	100
SC1	4/03	3	0	0	3	100
SC3	4/05	11	13	118	15	136
HC1	4/05	2	2	100	2	100
HC2	4/05	4	3	75	5	125
HC3	4/03	6	3	50	6	100
UM1	4/03	6	0	0	6	100
UM2	4/03	8	0	0	9	112
UM3	4/03	6	0	0	8	133
MM2	4/04	1	0	0	1	100

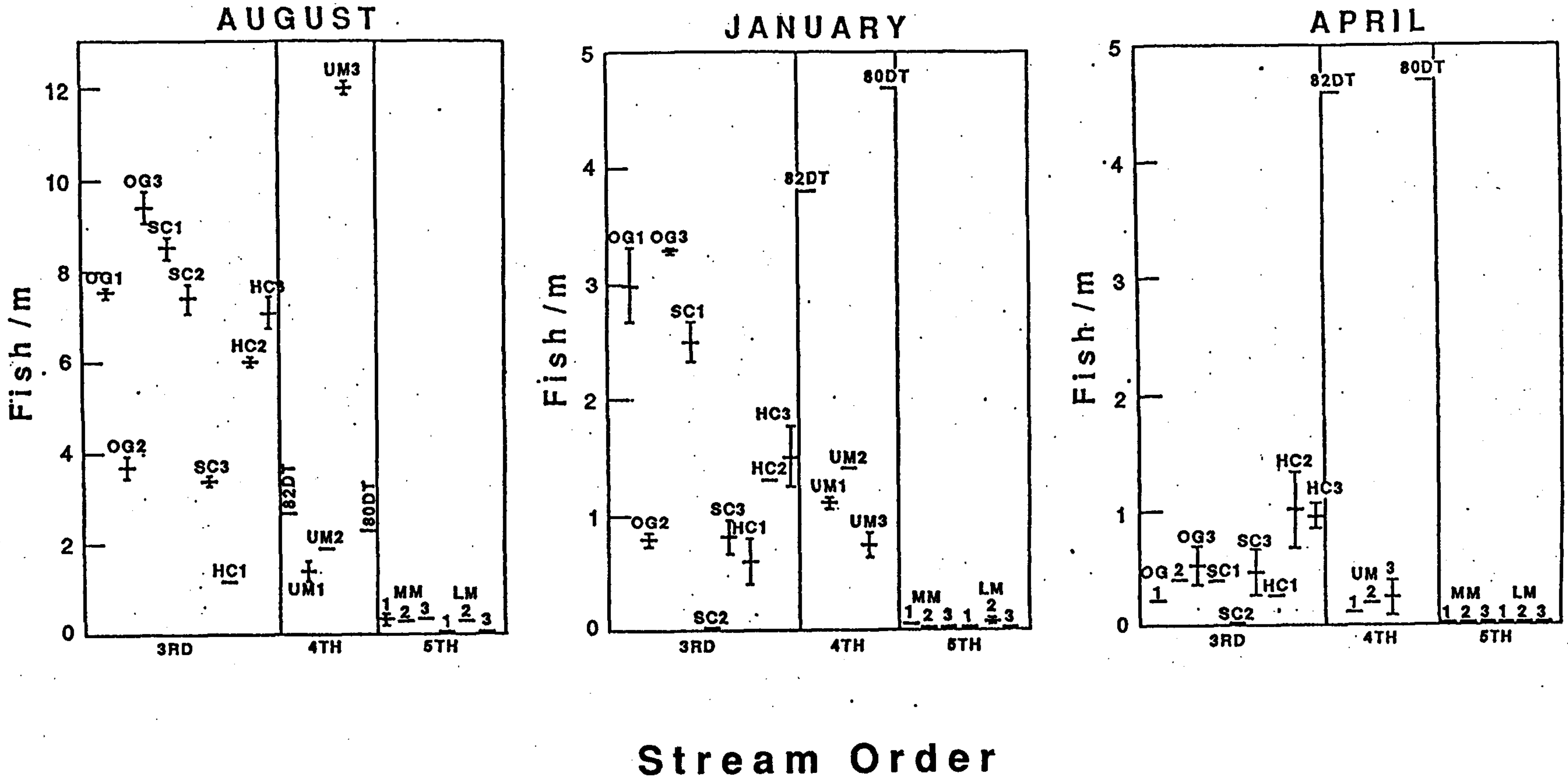

Figure I.3. The number (+ standard error) of juvenile coho per m of stream estimated at each of the 20 sample sites in the Knowles Creek watershed in August, January, and April.

sites having no juvenile coho present in January.

In late summer, fish in downstream areas were larger than those in the headwaters (Figure I.4). By January, with the exception of the few fish found at a lower mainstem site, the largest fish were at the two debris torrent ponds. By April, juvenile coho were similarly sized at all sites except for the significantly smaller fish in the Old Growth area. Mean fork length was positively correlated with pool volume in January, but not in August or April (Figure I.5).

The variables most highly correlated with the abundance of juvenile coho in January depended on which index of fish abundance was used (Table I.3). The total number of fish and the number of fish per m of stream were most highly correlated to total wood volume. The number of fish per m^2 or m^3 of stream was most highly correlated to the respective measure of summer fish abundance, with wood volume per m^3 of stream being the next most highly correlated variable.

Forward stepwise regression (Neter and Wasserman 1974) showed that total wood volume and stream surface area were the two variables that best explained variation in the total number of juvenile coho present at a site in January (Table I.4). Variation in the number of fish per m of stream was best explained by variation in total wood volume and summer number of juvenile coho per m^3 of stream. Variation in the number of fish per m^2 or m^3 in January was best explained by the respective measure of juvenile coho abundance in the summer and wood volume per m of stream.

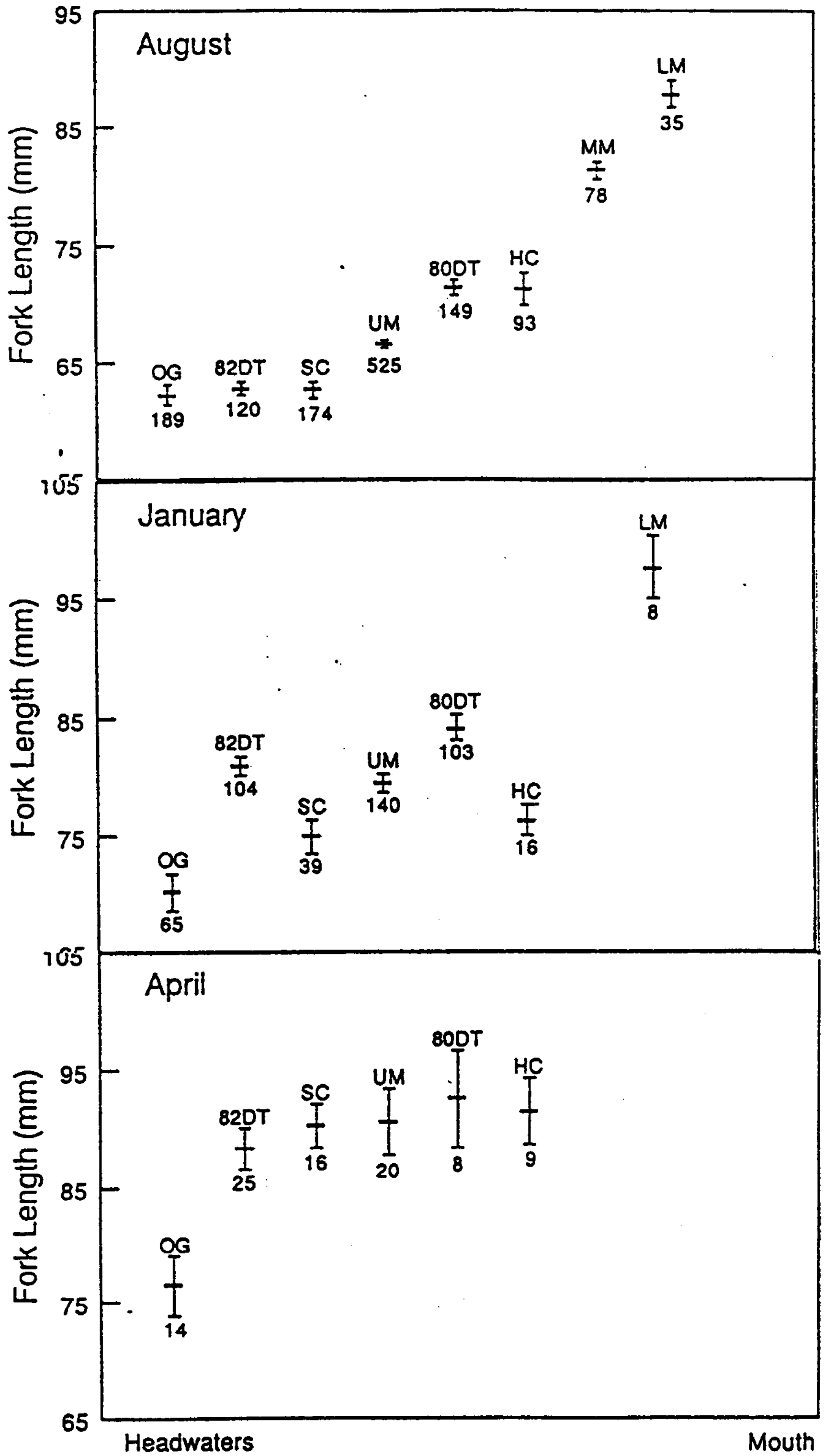

Figure I.4 Mean fork lengths (± standard error) and numbers of juvenile coho measured in different areas of the Knowles Creek watershed in August, January, and April. Areas are arranged from left to right by decreasing distance from the mouth of Knowles Creek. Length data are given only for areas at which more than five fish were captured.

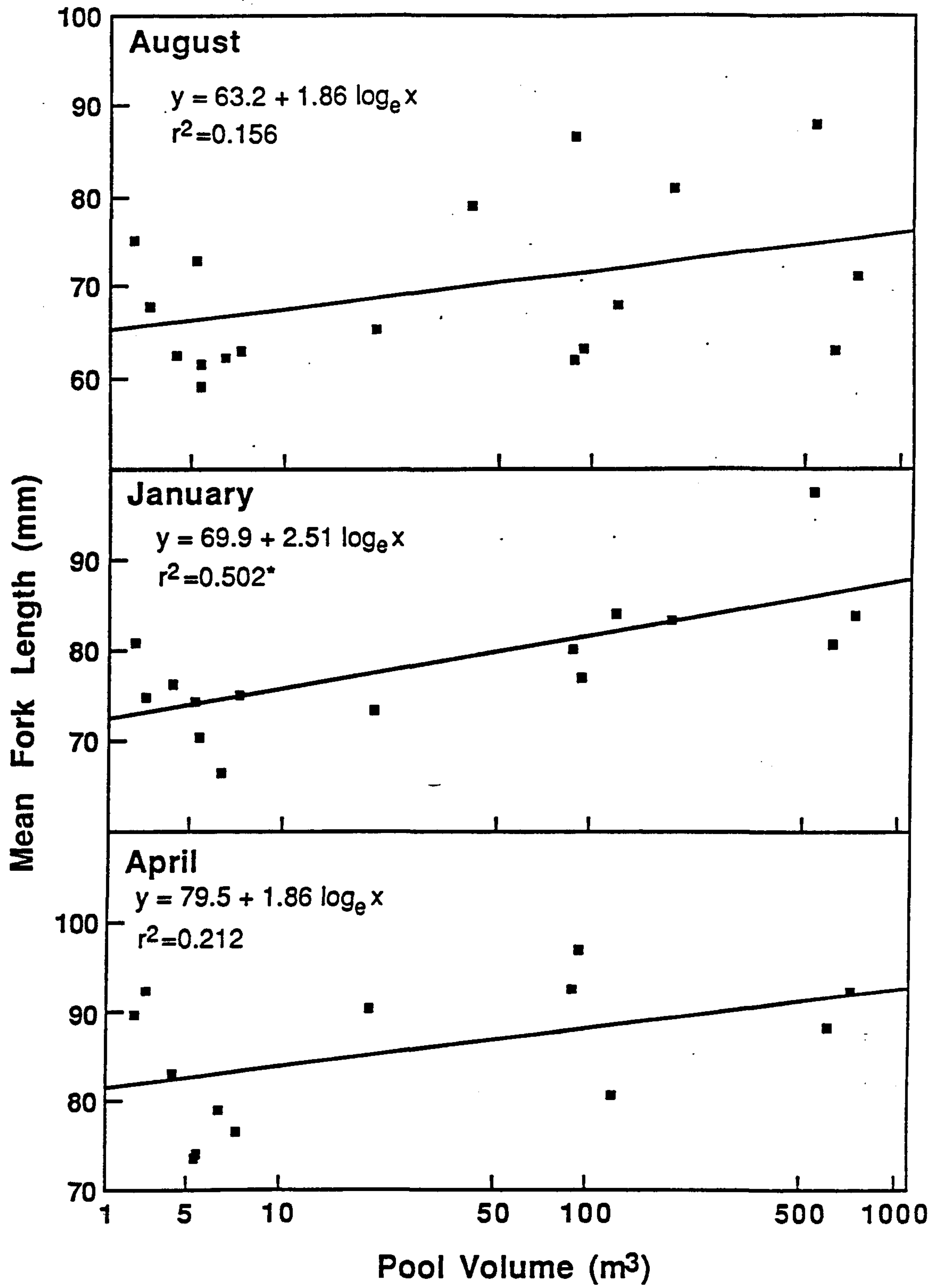

Figure I.5. Correlation of mean fish fork length and the $\log_e$ of pool volume in August, January, and April (* significant at P=0.05).

Table I.3. Linear correlation between different measures of juvenile coho abundance at the 20 Knowles Creek sample sites in January and various physical variables or measures of summer fish abundance. Only significant correlations are shown (** significant at $P \leq 0.01$; * significant at $P \leq 0.05$).

January measure of fish abundance	Correlated variable	Correlation Coeff. (r)
	Total wood volume	0.805 **
	Site volume	0.781 **
Fish/site	Site area	0.660 **
	Mean site depth	0.630 **
	Mean site width	0.517 *
	Total wood volume	0.741 **
Fish/m	Wood vol/stream m	0.648 **
	Mean site depth	0.452 *
	Summer fish/m^2	0.728 **
	Wood vol/site volume	0.664 **
Fish/m^2	Wood vol/site area	0.606 **
	Wood vol/stream m	0.557 *
	Mean site width	-0.500 *
	Summer fish/m^3	0.843 **
Fish/m^3	Wood vol/site volume	0.599 **
	Mean site width	-0.555 *
	Wood vol/site area	0.516 *

Table I.4. The results of forward stepwise regression analysis to obtain the pair of variables that best explained variation in different measures of the January abundance of juvenile coho at the 20 sample sites in Knowles Creek. All regressions are significant at $P \leq 0.01$.

January measure of fish abundance	Variable	R^2
Fish/site	Total wood volume (X1)	0.647
	Site surface area (X2)	0.739
Fish/m	Total wood volume (X1)	0.548
	Summer fish/m^3 (X2)	0.760
Fish/m^2	Summer fish/m^2 (X1)	0.531
	Wood vol/m (X2)	0.632
Fish/m^3	Summer fish/m^3 (X1)	0.711
	Wood vol/m (X2)	0.728

Table I.5. The results of forward stepwise regression analysis to obtain the pair of physical variables that best explained variation in different measures of the January abundance of juvenile coho at the 20 sample sites in Knowles Creek. All regressions are significant at $P \leq 0.01$.

January measure of fish abundance	Physical variable	R^2
Fish/site	Total wood volume (X1)	0.647
	Site surface area (X2)	0.739
Fish/m	Total wood volume (X1)	0.548
	Site width (X2)	0.760
Fish/m^2	Wood vol/m^3 (X1)	0.441
	% undercut streambank (X2)	0.542
Fish/m^3	Wood vol/m^3 (X1)	0.359
	% undercut streambank (X2)	0.473

When summer abundance was not considered and forward stepwise regression was used to determine which pair of physical variables best explained variation in the January abundance of juvenile coho, wood volume was always the most important independent variable (Table I.5). There was, however, a difference in the second most important physical variable depending again on what index of abundance was used.

The movement of juvenile coho within Knowles Creek varied with the area in which they were marked. More juvenile coho marked at the Old Growth and South Canyon Creek areas were recaptured at other sites than fish marked in any other area of the watershed (Table I.6). A higher percentage of marked fish remained in the debris torrent ponds than in other areas, while no marked fish were recaptured in the two lower mainstem areas. The debris torrent ponds also held the highest number of juvenile coho marked at other areas in the watershed.

Approximately 8,300 yearling juvenile coho left the Knowles Creek watershed during the study. A peak in outmigration occurred in November in conjunction with the first fall freshets (Figure I.6). Almost 24% of the total number of fish that left Knowles Creek migrated during November. Few fish left the system during conditions of low streamflow and cold water in January. Another peak in outmigration occurred during the first two weeks in May. The outmigration of yearling juvenile coho from Knowles Creek had ceased by the last two weeks in June.

Over 70% of the total number of juvenile coho marked at the Old Growth, South Canyon, and Middle Mainstem sample sites were

Table I.6. The estimated percentage or number of juvenile coho marked at study sites in August that were present at those sites in January.

	OG	SC	82DT	UM	80DT	MM	HC	LM
% Marked at Site in Aug. Present at Site in Jan.	8.5	6.3	21.6	2.0	22.6	0.0	5.0	0.0
% Marked at Site in Aug. Present at Other Sites in January	6.8	5.8	0.0	3.0	0.0	0.0	0.0	0.0
# Marked at Other Sites in August Present at Site in Jan.	0	3	4	2	34	0	0	0

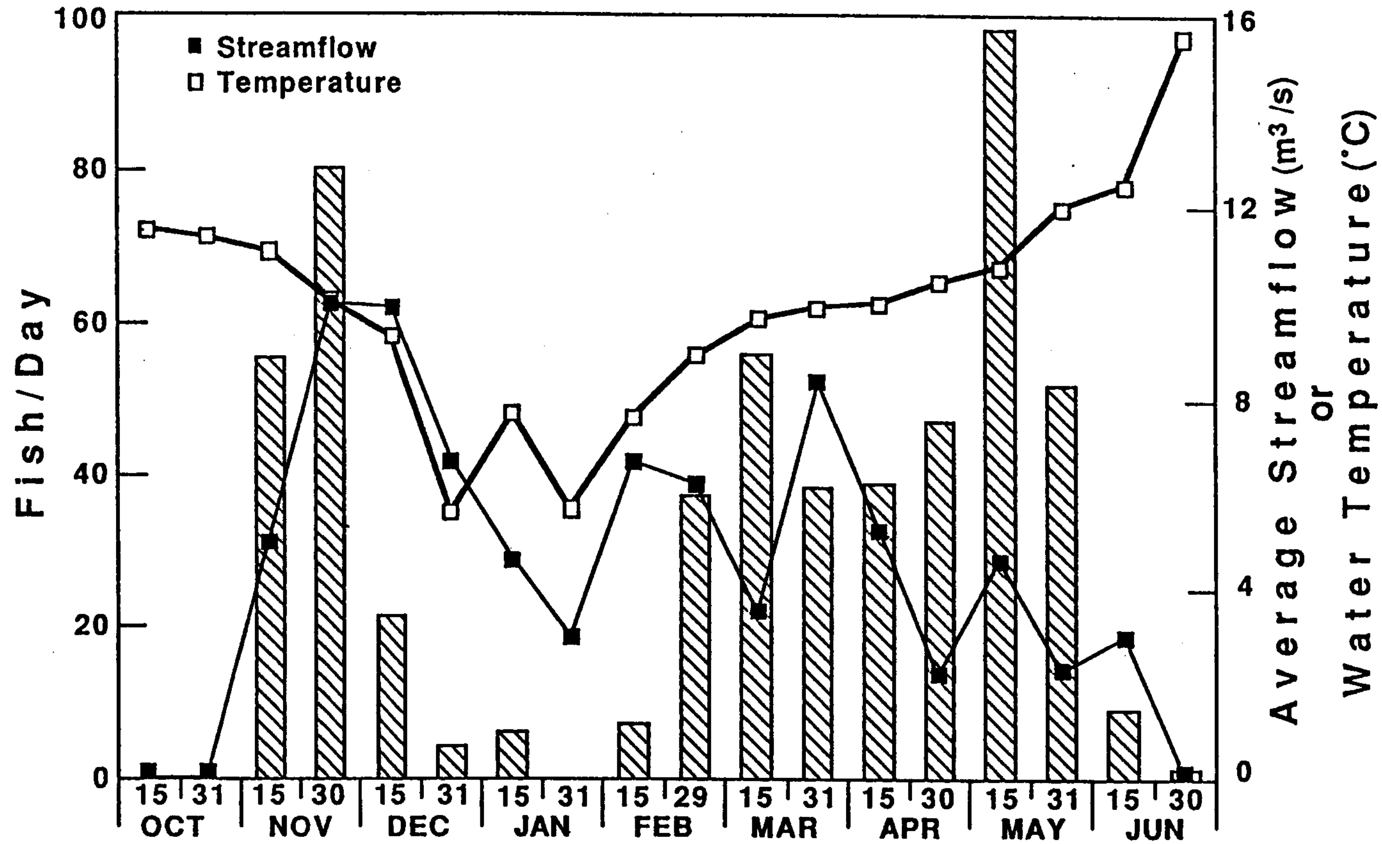

Figure I.6. Average semi-monthly water temperature, streamflow, and juvenile coho outmigration (vertical bars) from the Knowles Creek watershed.

Table I.7. The percentage of the total number of juvenile coho salmon marked in different areas of the watershed estimated to have outmigrated during each month (C% is the cumulative percentage). Percentages estimated from 63 marked fish caught in migrant traps (Appendix 3).

	Area Where Marked[a]													
	OG		SC		HC		82DT		UM		80DT		MM	
Month	%	C%	%	C%	%	C%	%	C%	%	C%	%	C%	%	C%
November	0	0	38	38	0	0	0	0	0	0	0	0	59	59
December	0	0	0	38	0	0	0	0	0	0	0	0	0	59
January	0	0	0	38	0	0	0	0	0	0	0	0	0	59
February	54	54	19	57	0	0	0	0	10	10	0	0	0	59
March	2	56	15	72	0	0	0	0	0	10	5	5	32	91
April	14	70	16	89	0	0	36	36	51	61	43	48	9	100
May	30	100	11	100	95	95	64	100	39	100	43	91	-	-
June	-	-	-	-	5	100	-	-	-	-	9	100	-	-

[a]No fish were present at the lower mainstem sites from November through June.

estimated to have migrated from the Knowles Creek before the end of March (Table I.7). Conversely, almost 100% of the total number of fish marked at the two debris torrent ponds migrated after the end of March. No fish marked in the lower mainstem were recaptured, probably reflecting the low number originally marked at these sites.

DISCUSSION

Prior to the first fall rains juvenile coho occupy a wide variety of habitats, but prefer the heads of pools fed by riffles and runs (Hartman 1965; Mason 1966; Chapman and Bjornn 1969; Allee 1974). A social dominance hierarchy associated with intraspecific competition for food and space regulates coho density in pools in the summer (Chapman 1966). Pool volume in small streams has been identified as the most important physical variable determining the summer carrying capacity of juvenile coho in fully seeded streams (Nickelson et al. 1979).

With the onset of winter, the habitat preferences and behavior of juvenile coho change. As water temperature drops below $8^{\circ}C$, juvenile coho become less active, and seek deeper, slower moving areas with rootwads, logjams, or other stable woody debris (Bustard and Narver 1975; Tschaplinski and Hartman 1983). Reduced activity levels of juvenile coho during winter may be a physiological response to low water temperature. Because low water temperature reduces swimming ability (Glova and McInerny 1977), hiding behavior may be an adaptation that prevents displacement or injury during high winter streamflows (Hartman 1965; Bustard and Narver 1975) or reduces predation during the winter (Hartman 1965).

Wood volume was the physical variable most highly correlated with the winter abundance of juvenile coho in the Knowles Creek watershed. The two debris torrent ponds contained large amounts of wood debris and were the most heavily used overwintering habitats for juvenile coho in Knowles Creek. Lack of wood at the middle and lower mainstem sites apparently precluded their use as overwintering areas, despite the fact that they were some of the largest pools in the watershed.

While this study suggests that woody debris is important in determining the winter abundance of juvenile coho, other physical characteristics of a site, such as pool type, may also be important. Using the habitat classification scheme devised by Bisson et al. (1982), the Oregon Department of Fish and Wildlife has collected data suggesting that dammed pools have significantly more juvenile coho in the winter than lateral scour or other types of pools (Tom Nickelson, ODFW, personal communication). Five of the 20 sites sampled in Knowles Creek were dammed pools (OG1, OG3, 82DT, 80DT, and HC3). Except for HC3, these pools had the highest number of fish per m in January of any of the 20 sites in the watershed (Figure I.3). Because wood was associated with each of the five dammed pools, and in fact was responsible for damming all but the two debris torrent ponds, it is difficult to tell if the cover provided by wood or its pool forming properties resulted in high correlations between juvenile coho abundance and amount of wood debris in this study. It is probable, however, that a pool formed by a log dam will provide better winter habitat for juvenile coho than a scoured pool with no wood.

Previous studies have documented large fall migrations of juvenile coho from mainstem summer rearing areas into tributary streams (Skeesick 1970; Cederholm and Scarlett 1981). However, juvenile coho in Knowles Creek emigrated from low order stream sites into the mainstem debris torrent ponds. Fish that reared in two of the three third-order stream areas in the summer (Old Growth and South Canyon Creek) together with fish from the fifth-order (Middle Mainstem) area were also the earliest fish to migrate out of Knowles Creek.

While lack of adequate winter habitat may have been responsible for the early outmigration of fish from the fifth-order sites, it may not have been the only factor responsible for early migration of fish from the third-order sites. Many of the riffles in the low order tributaries of Knowles Creek are dry during low summer streamflows. With no avenue for escape, overcrowding may result as juveniles grow in the tributary pools. A comparison of the August number of fish per m^2 at the 20 study sites in Knowles Creek, and to the density of juvenile coho reported for other Siuslaw River tributaries, shows relatively high densities at the third-order sites (Table I.8). The lack of correlation between fish length and pool size in August (Figure I.5) may be the result of this summer entrapment of fish. With the first fall freshets, juveniles may have migrated to escape overcrowded summer rearing conditions, even though adequate winter habitat may have been present at those sites.

Comprehensive sampling conducted by the U.S. Forest Service in late August yielded a population estimate of approximately 19,000 juvenile coho (Fred Everest, USFS, personal communication). Based on the results of migrant trapping, approximately 8,300, or 44% of the juveniles present in late summer, left the Knowles Creek watershed during this study. Not all of these

Table I.8. Comparison by stream order of the August number of juvenile coho per m^2 at the 20 study sites in Knowles Creek and of the density of juvenile coho reported for other Siuslaw River tributaries (Data on juvenile coho densities from Siuslaw River tributaries from Solazzi et al. 1983).

Knowles Creek					
Third-order		Fourth-order		Fifth-order	
OG1	2.57	UM1	0.26	MM1	0.04
OG2	1.29	UM2	0.37	MM2	0.06
OG3	3.19	UM3	1.31	MM3	0.03
SC1	2.97	82DT	0.22	LM1	<0.01
SC2	3.01	80DT	0.15	LM2	0.02
SC3	0.85		----	LM3	<0.01
HC1	0.58	Mean	0.46		----
HC2	2.21			Mean	0.02
HC3	3.56				

Mean	2.25				

Siuslaw River tributaries			
Panther Creek	0.46	Doe Creek	0.14
Rogers Creek	0.23	Dogwood Creek	0.19
Misery Creek	0.30	Billie Creek	0.22

outmigrants, however, left the stream as smolts. Studies on the smolt physiology of Knowles Creek coho (Chapter II) suggest that the smolt migration may have begun about April 1. Using this starting date, approximately 1,660, or 9% of the August population, migrated as smolts from Knowles Creek. The fate of the presmolt emigrants from Knowles Creek is unknown. The Siuslaw River below Knowles Creek lacks woody debris or dammed pools. If the habitat needs of juvenile coho do not change once they enter the Siuslaw River, is unlikely that juvenile coho from Knowles Creek found adequate winter refuge after emigrating unless they moved into other tributaries of the Siuslaw. Although juvenile coho the size of the early outmigrants from Knowles Creek can osmoregulate (Conte et al. 1966), the low survival of early released hatchery reared fish (Washington Department of Fisheries 1977) suggests that it is unlikely that substantial numbers of early outmigrants would survive to adults.

When compared to the emigration of juvenile coho from three streams in the Alsea Watershed Study, the timing of outmigration from Knowles Creek is most similar to that of Needle Branch (Figure I.7). A November peak in migration did not occur in the other two Alsea watershed streams. In 1966, the Needle Branch watershed was completely clearcut. No buffer strips were left and logs were yarded through the stream channel (Knight 1980). The Deer Creek watershed was only partially cut and the Flynn Creek watershed was not logged at all. The similarity in migration timing between Knowles Creek and Needle Branch may mean that the winter habitat quality of Knowles Creek is poor. Preferred winter habitat is scarce in the system because of splash damming and debris removal associated with nearly 100 years of logging in the basin. The debris torrent ponds currently provide the best winter habitat in the system. Less degraded streams may have a greater abundance of the type of winter habitat provided by the debris torrent ponds in Knowles Creek. Ponds created by debris torrents are beneficial to coho production in the middle basin of Knowles Creek in summer (Everest and Meehan 1981) and winter, but more information is needed on the effects of torrents in the lower reaches of the stream

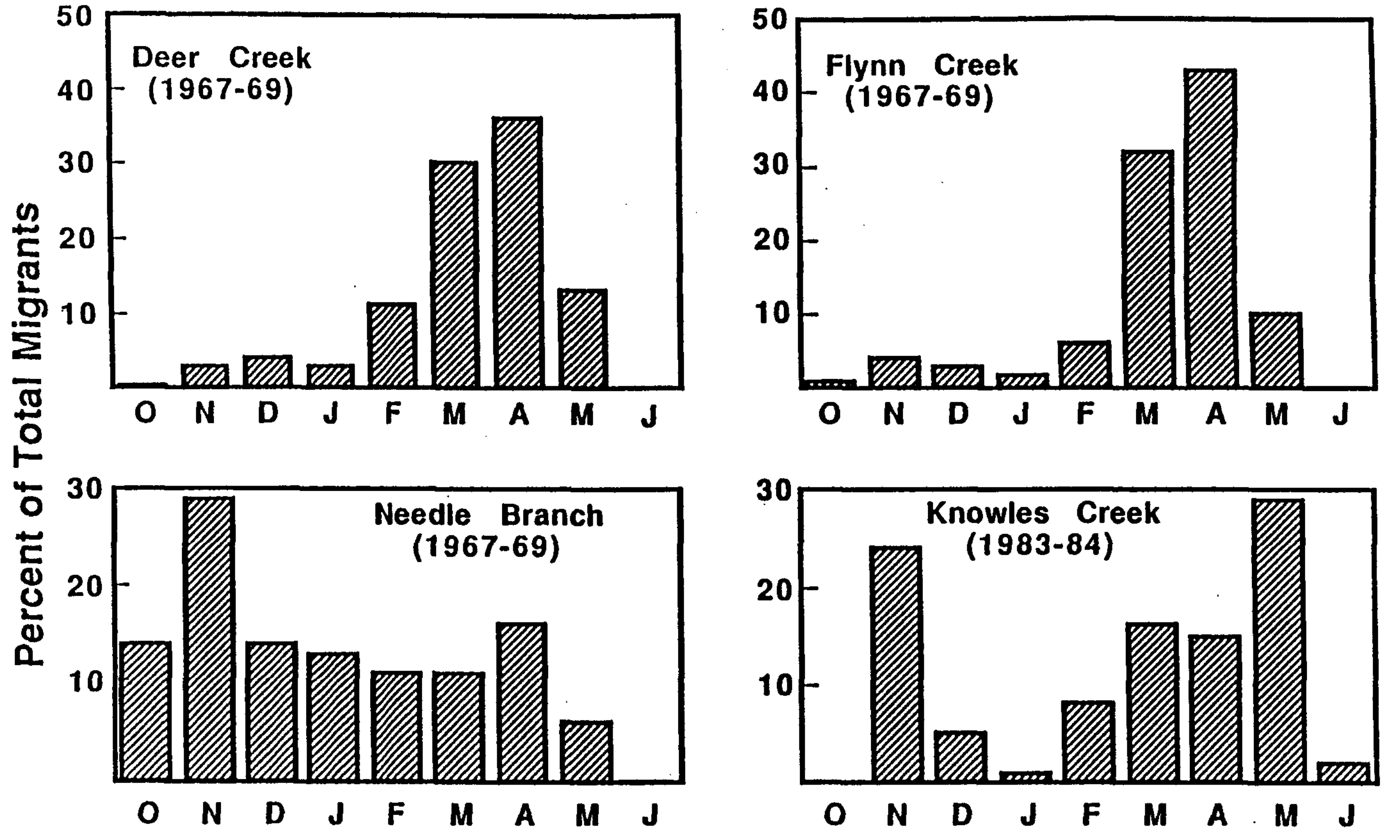

Figure I.7. Comparison of the timing of outmigration of juvenile coho from three streams in the Alsea watershed study and Knowles Creek. Years shown for Alsea watershed streams are immediately after the Needle Branch watershed was clearcut [data from Knight (1980) and unpublished].

and in other streams.

While this study provides information on the winter habitat requirements of juvenile coho in Oregon's coastal streams, more research is needed, especially on the relative importance that winter conditions have on smolt production. While most efforts to enhance stream habitat for coho in Oregon are directed toward improving aspects of summer rearing habitat, these efforts may be futile if winter conditions are the major factor limiting smolt production. The correlation between abundance of juvenile coho in summer and their abundance in winter suggests that there may be similarities between good summer and good winter habitat. By identifying the habitat characteristics that are similar, it may be possible to enhance both summer and winter habitat using the same techniques, thereby maximizing benefit from enhancement efforts.

Chapter II. Physiological changes during the outmigration of wild juvenile coho salmon (Oncorhynchus kisutch) from an Oregon coastal stream.

INTRODUCTION

Anadromous salmonids begin juvenile life in rivers and streams, then develop a migratory urge that propels them to the sea where they complete their growth and development. Prior to and during development of the migratory urge and seaward migration, the juveniles undergo a myriad of behavioral, morphological, and physiological changes so that the transition from fresh to saltwater is made quickly and efficiently.

The estimated ocean survival of naturally reared smolts is thought to be higher than those artificially propagated (Wedemeyer et al. 1980). Hatchery conditions may impair the smolting process of hatchery reared fish (Schreck et al. 1985). Most studies of smolting, however, have examined hatchery reared salmonids; little is known about the smoltification process in wild salmonids. By increasing our knowledge of the physiological and behavioral changes that take place in wild salmonids, we may be able to increase the efficiency of hatchery production.

This paper presents the results of research conducted on the smolting of wild juvenile coho salmon (Oncorhynchus kisutch) in Knowles Creek, a tributary of the Siuslaw River, Oregon. Specifically, the objectives of this study were to: 1) determine the timing and magnitude of migration of juvenile coho out of the watershed; 2) examine changes in condition factor, skin guanine levels and gill (Na+K)-ATPase activity between migrating, nonmigrating, and captive groups of Knowles Creek juvenile coho; 3) examine the relationship between skin guanine levels, gill (Na+K)-ATPase activity and fish fork length; and 4) relate these changes in smolt indices to those reported for hatchery reared fish and to the timing of seaward migration.

METHODS

In mid-October 1983, 100 juvenile coho were collected from Knowles Creek and transported to laboratory facilities in Corvallis. This captive group of fish was held in a circular tank 0.91 m in diameter and 0.78 m deep supplied with 13° C well water. Captive fish were fed Oregon Moist Pellet _ad libitum_ daily. Once in January, February, March and June, and bi-weekly in April and May, 20 randomly sampled fish were anesthetized with MS222, weighed to the nearest 0.1 gram, and measured to the nearest millimeter fork length. Condition factor for each sampled fish was determined with the formula: $KFL=(\text{weight} \times \text{length}^{-3}) \times 10^5$.

Gill filaments were clipped from each of the 20 fish, homogenized, and analyzed for (Na+K)-ATPase activity by the method of Johnson et al. (1977). All sampled fish were returned alive to the holding tank and were eligible for future sampling. A maximum of four samples were taken per fish. Previous experiments had determined that the excision of four gill tissue samples from an individual fish did not affect subsequent gill (Na+K)-ATPase specific activity.

Once in November and February, and twice in March, April, and May, a random sample of 20 juvenile coho was electrofished from upper Knowles Creek. These juveniles were presumed to be nonmigrating fish. Fork lengths and weights were recorded, and gill samples were taken for analysis of (Na+K)-ATPase activities from all captured fish. The skins from a random sample of 15 fish from each sample date were analyzed for guanine levels by the method of Staley (1984).

From October through June, the migration of juvenile coho from the watershed was monitored by one of two types of downstream migrant trap operated continuously near the mouth of Knowles Creek. The methods used to estimate the total number of outmigrating fish from the floating scoop trap catches are described in Chapter I of this thesis.

Except during periods of little or no fish movement, the downstream migrant traps were checked twice daily, once in the morning and again at dusk. All captured juvenile coho were enumerated, anesthetized, weighed, and measured. Once in November, December, January, and February and bi-weekly thereafter, gill samples for (Na+K)-ATPase activity were collected from the first 20 migrants captured in each of four size groups: 1) $<$ 80mm; 2) 80 to 90 mm; 3) 91 to 100 mm; and 4) $>$ 100mm. Similarly, skin samples for skin guanine levels were taken from the first 15 migrants captured in each of the four size groups.

The fork lengths, condition factors, and (Na+K)-ATPase activities of the first 20 migrant coho captured during each sample interval were used for comparison with those of nonmigrants and the captive population. The guanine levels of the first 15 migrant coho captured were used for comparison with those of nonmigrants. Groups were determined to be significantly different from each other if analysis of variance or "t"-tests (Snedecor and Cochran 1980) showed p values ≤ 0.05. The relationships between skin guanine levels or gill (Na+K)-ATPase activities and migrant fish fork lengths during any given sample interval were examined using a linear regression model.

RESULTS

Approximately 8,300 juvenile coho migrated from the Knowles Creek watershed during the course of the study. An early peak in outmigration occurred during November in conjunction with the first major freshet (Figure I.6). Few fish migrated during the conditions of low streamflow and cold water in late December and January. The largest peak in outmigration occurred during the first two weeks in May, followed by a gradual decline to near zero during the last two weeks in June. By this time few yearling juveniles remained in the river system.

Migrant fish were usually larger and their lengths increased more rapidly than those of nonmigrants (Figure II.1). Fish in the captive group of Knowles Creek coho were consistently larger than either migrant or nonmigrant fish, most likely reflecting the effects of warmer rearing water and abundant food.

The condition factor of migrant fish reached a maximum in February and then decreased in March (Figure II.2). Nonmigrant condition factor peaked during the first two weeks of February and the last two weeks of April, and was significantly higher than either migrants or the captive population of juvenile coho throughout the study. Condition factor of the captive population of juveniles was highest in January, then decreased through the remainder of the study.

Statistically significant negative correlations existed between the skin guanine levels of migrant fish and their fork lengths in December and February (Table II.1). A significant positive correlation in this relationship occurred during the

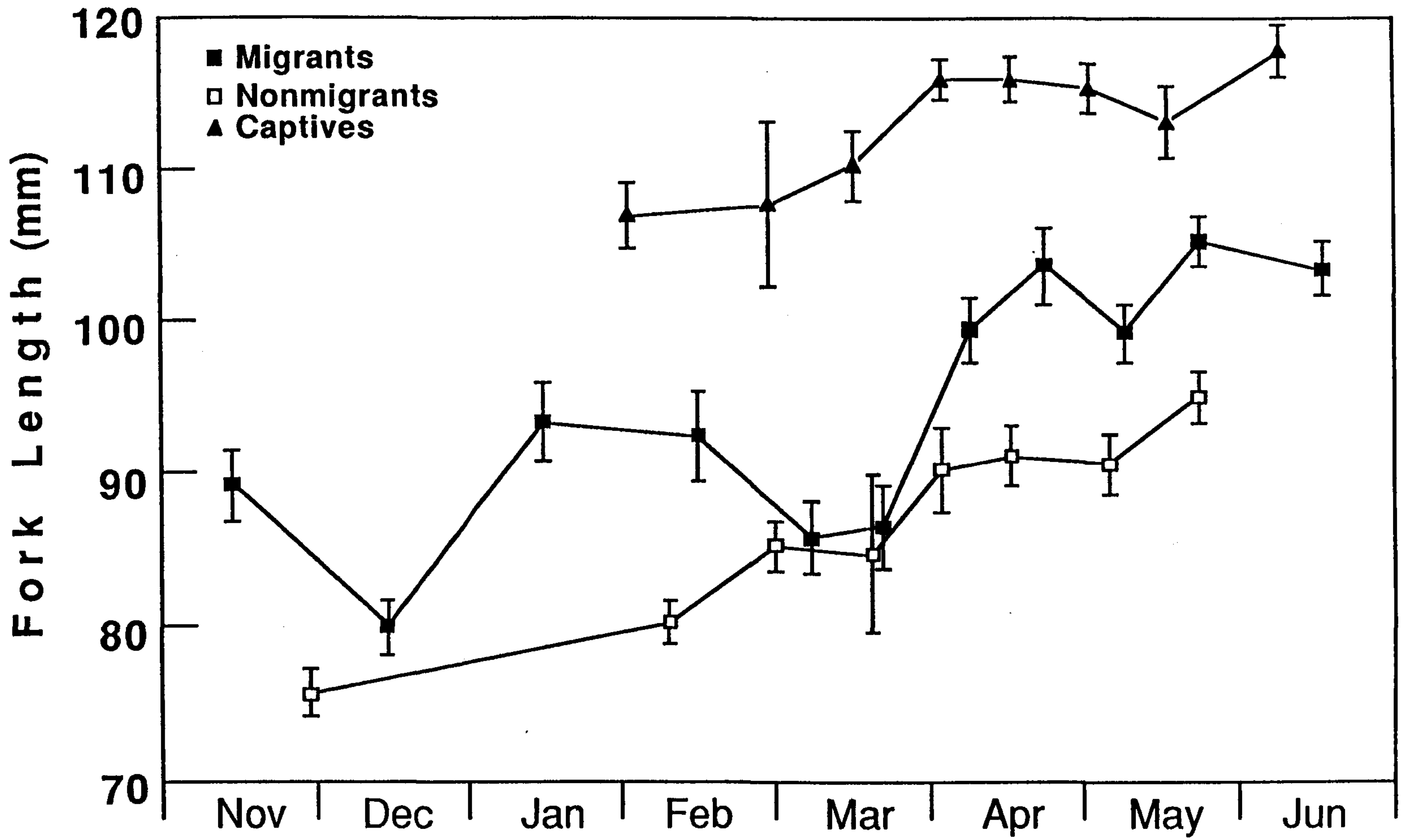

Figure II.1. Fork lengths (means and standard errors) of migrants, nonmigrants, and a captive group of Knowles Creek juvenile coho sampled for gill (Na+K)-ATpase, November 1983 through June 1984.

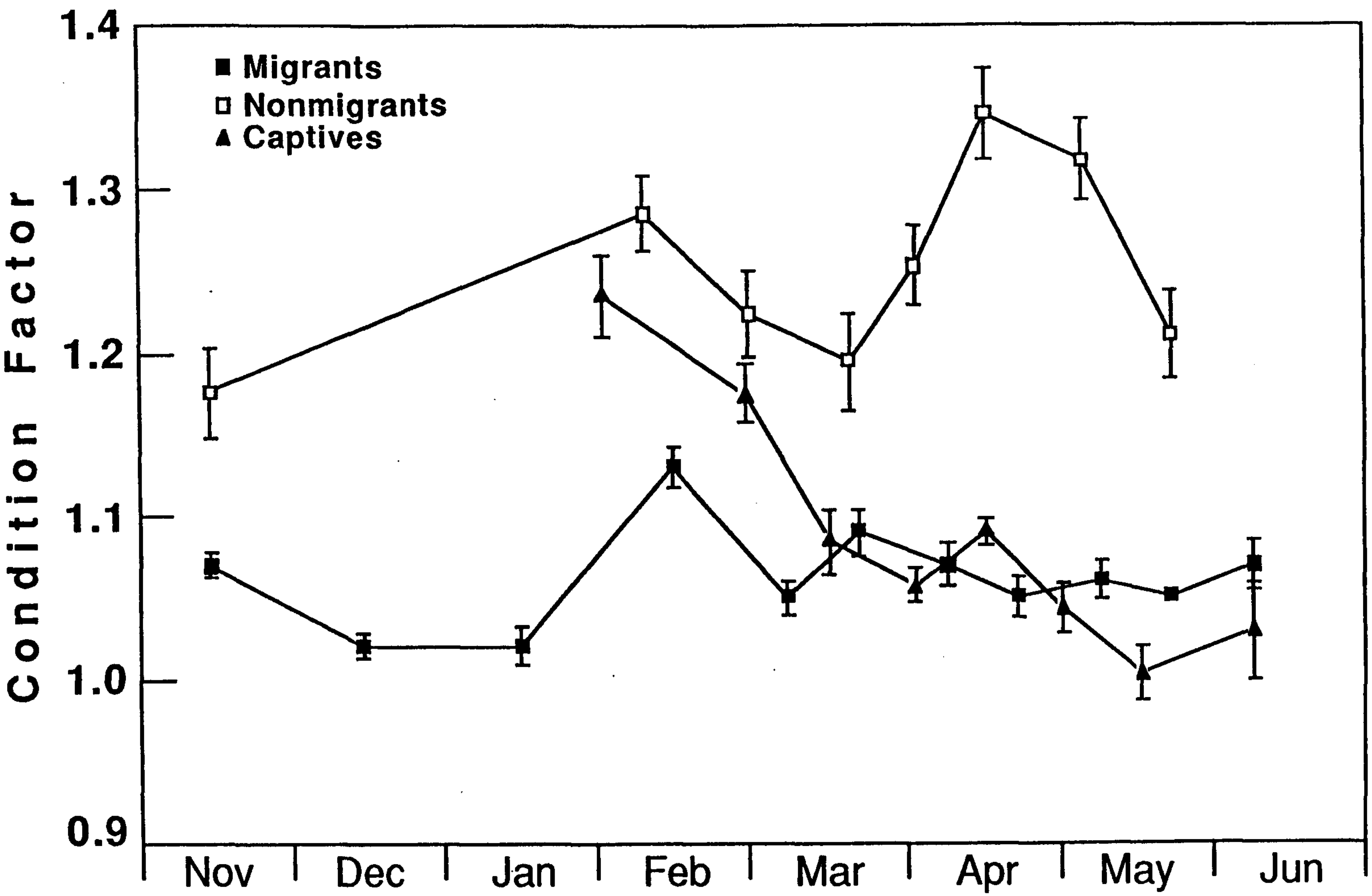

Figure II.2. Condition factor (means and standard errors) of migrants, non-migrants, and a captive group of Knowles Creek juvenile coho sampled for gill (Na+K)-ATpase, November 1983 through June 1984.

Table II.1. Linear correlation between skin guanine level and fork length or gill (Na+K)-ATPase activity and fork length of juvenile coho captured in migrant trap at various time periods in Knowles Creek (** signficant at $P \leq 0.01$; * significant at $P \leq 0.05$).

	Skin Guanine		Gill (Na+K)-ATPase	
Sample Interval	Sample size	Correlation coefficient (r)	Sample size	Correlation coefficient (r)
November	36	-0.334	57	-0.175
December	36	-0.573 **	33	-0.303
January	13	-0.350	13	0.346
February	50	-0.320 *	68	-0.154
March 1-15	60	0.004	77	-0.068
March 16-31	55	-0.005	56	0.306 *
April 1-15	40	0.385 *	58	0.229
April 16-30	44	0.017	63	-0.082
May 1-15	34	-0.091	42	0.313 *
May 16-31	26	0.107	35	0.232
June	12	0.299	19	0.332

first two weeks in April. No significant relationship was found between skin guanine levels of migrant fish and fork lengths measured during any of the other sample intervals. Skin guanine levels of migrant fish reached minimum levels during March, rose sharply during the first two weeks in April, and reached a maximum in June (Figure II.3). Skin guanine levels of nonmigrant fish rose significantly from March to April, but then decreased. Samples from nonmigrant fish in May and June were not significantly different from those at the first of April. From the last of April until the end of May, guanine levels of nonmigrant fish were significantly less than those of migrant fish.

Statistically significant positive correlations existed between migrant fish gill (Na+K)-ATPase activities and fork lengths during the last two weeks in March and the first two weeks in May (Table II.1). No significant relationship was found between migrant fish gill (Na+K)-ATPase and fork lengths measured during any of the other sample intervals. Average gill (Na+K)-ATPase activity of migrant fish reached a minimum in January, then rose gradually throughout the remainder of the study (Figure II.4). Mean gill (Na+K)-ATPase activity of nonmigrants was consistently below that of migrants until the peak of outmigration during the first two weeks in May, when it rose to equal that of migrants. Gill (Na+K)-ATPase activity of captive fish was similar to that of nonmigrants until the end of April. It reached a maximum during the last 2 weeks of April, then fell significantly below that of either migrants or nonmigrants.

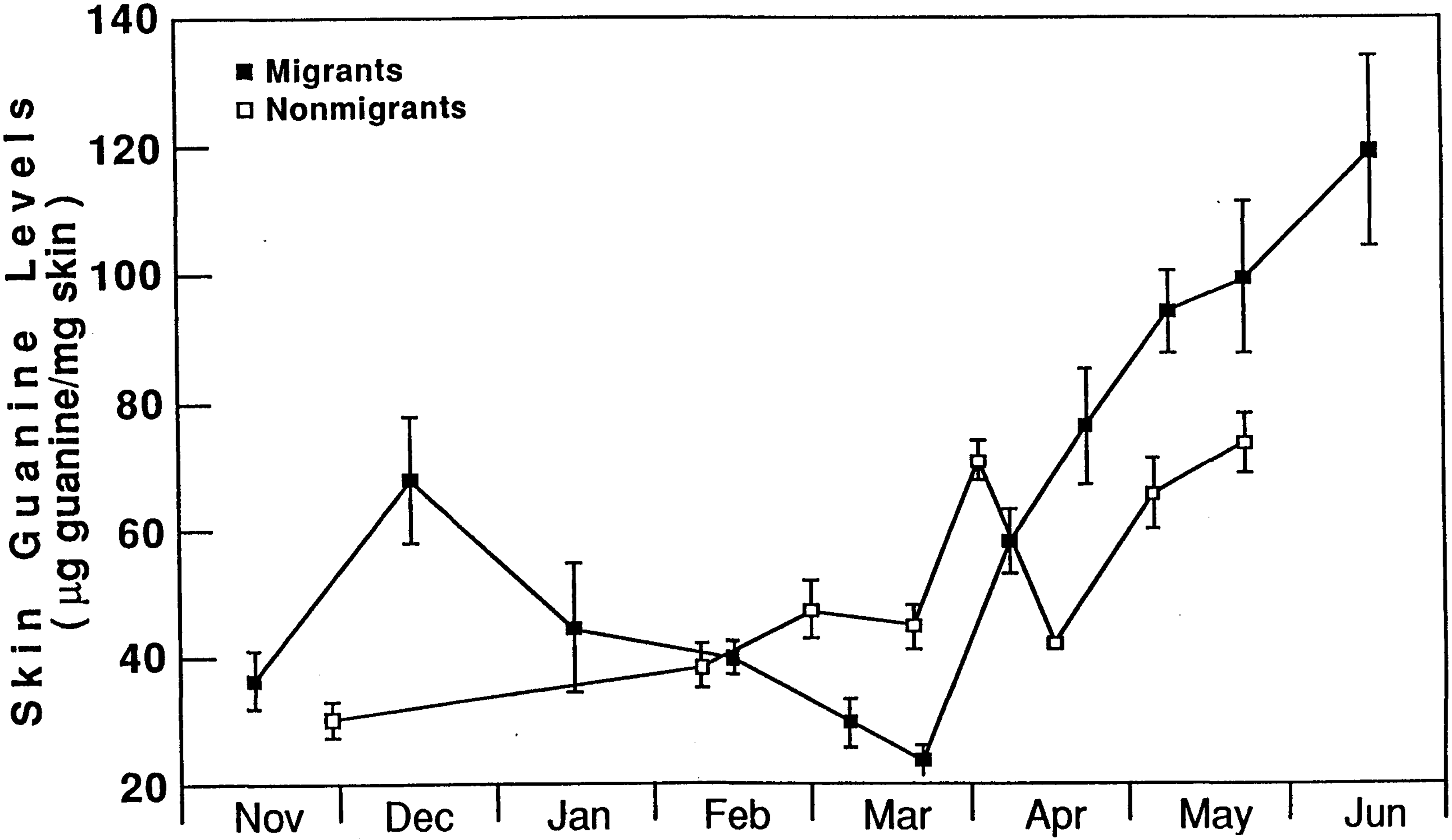

Figure II.3. Skin guanine levels (means and standard errors) of migrant and nonmigrant juvenile coho in Knowles Creek, November 1983 through June 1984.

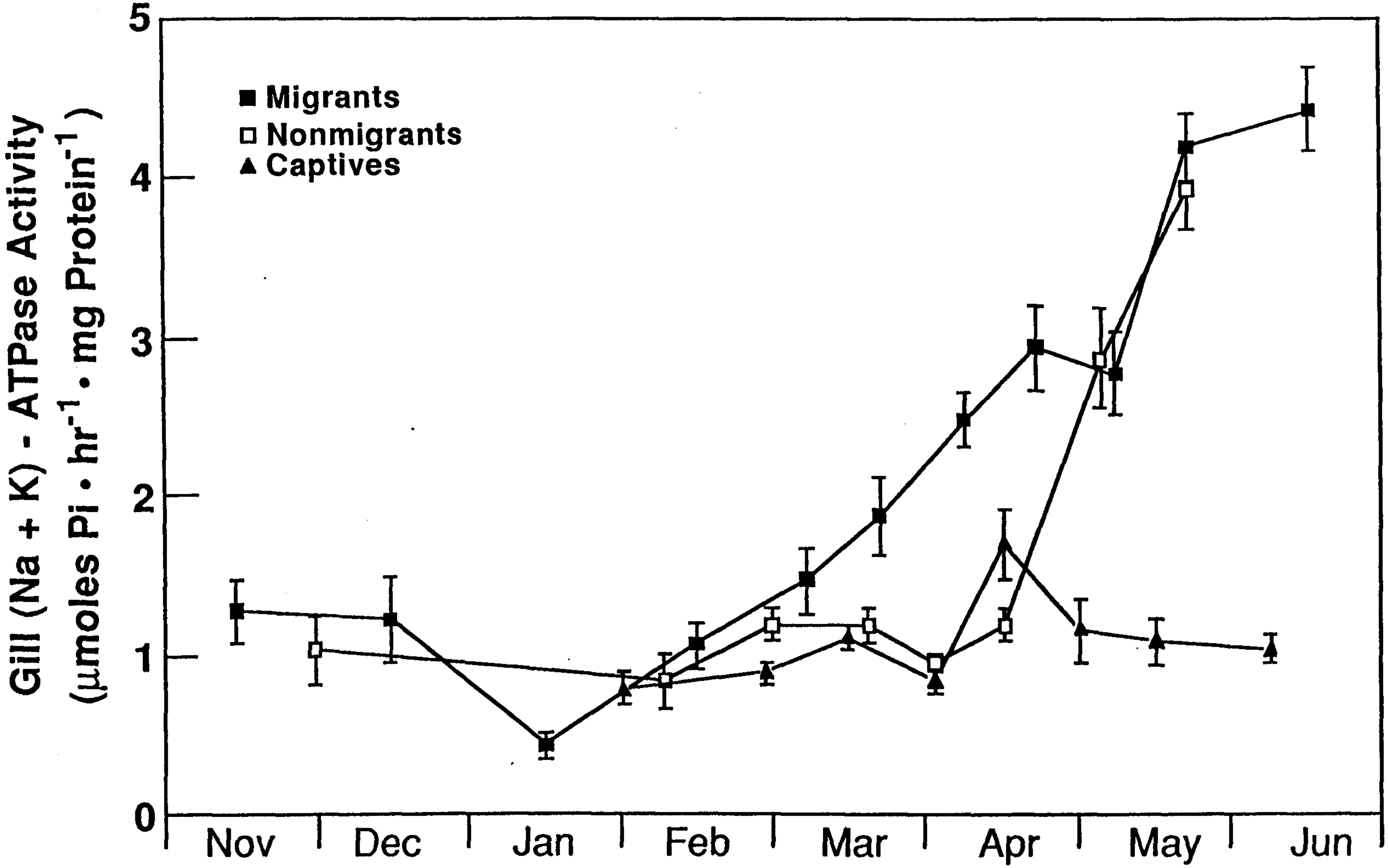

Figure II.4. Gill (Na+K)-ATPase activity (means and standard errors) of migrants, nonmigrants, and a captive group of Knowles Creek juvenile coho, November 1983 through June 1984.

DISCUSSION

Migration of juvenile coho from Knowles Creek, as measured by capture in downstream migrant traps, reached two maxima, one in November and one in May. Whether both are smolt migrations is a matter of concern to management agencies. The seaward migration of coho smolts is generally thought to occur in the spring (Scott and Crossman 1973; Lorz and McPherson 1977). During the first two weeks in April, migrant fish showed simultaneous increases in gill (Na+K)-ATPase activity, skin guanine, and fork length, and the first significant elevation of gill (Na+K)-ATPase activity above that of nonmigrants. These results suggest that the outmigration of juveniles from April onward was the result of a smolt migration from Knowles Creek. The November peak in outmigration was probably the result of juveniles either being displaced by strong stream currents or actively searching for better overwintering habitat.

Condition factor was always significantly lower for juvenile coho caught in the migrant traps than for fish electroshocked in the upper watershed. A lowering of condition factor thus appears to be a prerequisite for outmigration. The decline in condition factor of the captive group from February through March suggests that these fish may have migrated if given the opportunity.

The increases in skin guanine levels observed in the spring in juvenile coho from Knowles Creek were similar to those observed for juvenile Atlantic salmon (Johnston and Eales 1967) and for coho salmon held in captivity (Staley 1984). Increased amounts of guanine and other purines in the skin may be an adaptation that increases the survival of smolts at ocean entry. In the underwater illumination that occurs in the ocean, skin silvering may help conceal the pelagic juveniles from predators (Denton and Nichol 1965).

Gill (Na+K)-ATPase activity of migrant juveniles during April was significantly higher than that of nonmigrant fish (Figure II.4). During the first two weeks of May the gill (Na+K)-ATPase activity of nonmigrant fish rose to levels similar to migrant fish. These fish were assumed to be nonmigrants because their condition factor was significantly higher than that of fish captured in the traps. If this assumption is correct, the results suggests that smolt migration may be preceded by an increase in gill (Na+K)-ATPase.

Ewing et al. (1979) found a strong positive correlation between the size of migrant juvenile spring chinook salmon captured in the Rogue River, and their gill (Na+K)-ATPase activity. Although there were a few times during this study that statistically significant relationships existed between the size of migrant juvenile coho captured in Knowles Creek and either their gill (Na+K)-ATPase activity or skin guanine levels, the low values obtained for correlation coefficients (Table II.1) suggest that the smolting process is not as directly related to fish size in coho as it is in chinook.

Zaugg (1982) has shown that gill (Na+K)-ATPase activity of hatchery reared coho peaks and then declines in late April or early May in a pattern similar to that observed for the captive group of juvenile coho in this study. However, neither migrant or nonmigrant juvenile coho showed any tendency for cyclic changes in gill (Na+K)-ATPase activity. This suggests that cyclic changes in gill (Na+K)-ATPase activity observed in hatchery fish may not occur in the wild and may result from confinement. In support of this hypothesis, Bjornn et al. (1978), Hart et al. (1981), and Zaugg (1982) have shown that salmonids released from hatcheries have increased gill (Na+K)-ATPase activity when recaptured downstream. The high densities at which fish are reared in a hatchery may cause suppression of the normal expression of gill (Na+K)-ATPase activity (Schreck et al. 1985).

The captive population of coho from Knowles Creek slowly adapted to life in the circular tank, and fed well by the time the experiment was initiated. Although captive fish were larger than migrants or nonmigrants (Figure II.1), their average growth rate from January through June was very low, about half that of nonmigrant fish. Gill (Na+K)-ATPase activity of captive fish reached a maximum in April (Figure II.4) but the activity was much lower than that of fish captured in the stream.

The present study points out the utility of combining field sampling with biochemical analyses to gain a better understanding of the migration phenomenon in salmonids. To my knowledge this is the only study that has measured skin guanine levels and gill (Na+K)-ATPase activities in wild coho. From my results, I can hypothesize that the early migrations were not true smolt migrations and probably do not result in a behavior directed toward entry into the sea. Further studies on the eventual destination of each group of migrant fish and the timing of their entry into the sea are required to resolve this question. The results presented here also suggest that at least some of the physiological changes measured in captive fish, either in laboratories or hatcheries, may result from the captivity itself rather than the natural cycles of the salmonids. Whether these alterations in physiological changes are responsible for the lesser survival of hatchery fish is a matter for future research.

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APPENDICES

Appendix 1. Physical characteristics and population estimates for the 20 sample sites in the Knowles Creek watershed.

Site	Length (m)	Mean width (m)	Mean depth (m)	Area (m^2)	Volume (m^3)	Wood volume (m^3)	% cut-bank	Population estimate: August Est.	August SE	January Est.	January SE	April Est.	April SE
OG1	9.2	2.900	0.235	27	6.3	18.1	5.4	69	1.0	28	2.9	2	0.0
OG2	17.2	2.800	0.195	48.8	9.80	23.1	43.6	63	4.3	13	1.0	7	0.4
OG3	8.6	2.951	0.209	25	5.3	.22.8	0.0	81	3.2	28	0.2	4	1.5
SC1	7.5	2.863	0.204	21	4.4	0.0	6.7	64	1.9	19	1.3	3	0.0
SC2	8.5	2.467	0.254	21	5.3	0.0	0.0	63	2.9	0	0.0	0	0.0
SC3	31.8	3.983	0.153	127	19.4	1.0	31.4	108	3.5	26	4.5	15	6.3
HC1	7.5	2.119	0.330	16	5.2	17.0	50.0	9	0.5	4	1.5	2	0.0
HC2	4.5	2.730	0.269	12	3.3	12.0	56.7	27	0.5	6	0.0	4	1.5
HC3	6.5	2.000	0.276	13	3.6	26.3	52.3	46	2.4	10	1.7	6	0.8
UM1	32.5	9.060	0.401	294	117	2.6	15.4	80	12.9	63	3.5	6	0.8
UM2	46.0	5.000	0.379	230	87.3	1.9	44.6	85	2.2	62	0.6	9	2.1
UM3	59.0	5.057	0.308	298	92.0	9.0	33.9	390	4.8	24	3.6	8	4.9
82DT	118.4	12.500	0.410	1480	606.8	133.1	3.0	322	*	450	*	550	*
80DT	63.7	15.657	0.716	997	714	300.0	3.9	149	*	300	*	300	*
MM1	63.7	9.038	0.327	576	188	0.0	15.7	24	9.0	4	0.0	0	0.0
MM2	40.8	4.867	0.203	199	40.3	0.0	0.0	13	1.1	0	0.0	1	0.0
MM3	26.7	11.880	0.273	317	86.5	0.0	3.7	9	0.0	0	0.0	0	0.0
LM1	55.8	9.157	0.224	511	115	0.0	2.7	1	0.0	0	0.0	0	0.0
LM2	118.4	12.627	0.352	1494	525.7	0.6	26.3	36	0.2	9	2.1	0	0.0
LM3	28.8	11.640	0.371	335	124	0.0	8.7	1	0.0	0	0.0	0	0.0

* Standard error estimates were not made for debris torrent pond population estimates.

Appendix 2. The mark-recapture data for juvenile coho marked in 8 study areas in August and recaptured in January. Mark area is the area where fish were marked in August. Number recaptured is a breakdown by area of the number of marked fish recaptured in January. For example, 17 of the 213 fish marked in the Old Growth area in August were recaptured at the Old Growth area in January, while two fish that were marked in the Old Growth area were recaptured at in South Canyon Creek. Percent checked is the percentage of the total population of juvenile coho estimated to be at the mark area in January that were examined for marks.

Mark area	Number Marked	Number recaptured								Percent checked
		OG	SCC	82DT	UM	80DT	MM	HC	LM	
OG	213	17	2	1	2	1	0	0	0	94
SCC	195	0	11	0	0	2	0	0	0	89
82DT	120	0	0	6	0	0	0	0	0	23
UM	415	0	1	0	8	2	0	0	0	95
80DT	100	0	0	0	0	4	0	0	0	18
MM	78	0	0	0	0	0	0	0	0	100
HC	89	0	0	0	0	0	0	4	0	90
LM	35	0	0	0	0	0	0	0	0	89

Appendix 3. Date of capture, area at which fish was marked in August, fork length, weight, and trap efficiency on date that freeze branded juvenile coho were captured in the migrant traps in Knowles Creek. Trap efficiency of 1.00 was for days when fish were captured in the inclined plane trap.

Date	Area	Length (mm)	Weight (g)	Trap Efficiency
11/14	SC	76	4.85	0.07
11/14	SC	75	4.24	0.07
11/15	MM	91	7.65	0.12
11/16	MM	86	6.23	0.15
11/22	MM	94	8.32	0.11
02/16	OG	99	10.44	0.13
02/22	OG	87	6.67	0.13
02/23	OG	106	11.60	0.15
02/24	SC	93	8.81	0.14
02/24	OG	80	5.59	0.14
02/26	SC	87	7.21	0.12
02/29	UM	87	7.05	0.24
03/08	80DT	77	5.21	1.00
03/15	MM	110	14.64	0.09
03/15	SC	78	4.86	0.09
03/28	OG	88	7.69	1.00
04/03	82DT	89	7.41	0.27
04/13	SC	89	7.10	0.11
04/20	MM	100	9.26	0.23
04/22	UM	117	16.19	0.25
04/23	UM	110	14.15	0.27
04/25	82DT	107	12.21	0.27
04/25	UM	97	9.22	0.27
04/26	80DT	117	17.04	0.27
04/26	OG	114	15.44	0.27
04/26	SC	97	10.34	0.27
04/26	OG	102	no data	0.27
04/26	80DT	110	14.38	0.27
04/27	UM	106	12.17	0.27
04/27	UM	106	12.03	0.27
04/29	80DT	103	13.47	1.00
05/01	SC	105	12.33	0.26
05/04	HC	104	12.01	0.11
05/06	SC	107	14.61	0.18
05/07	OG	128	19.99	0.22
05/07	82DT	97	10.00	0.22
05/09	OG	97	9.64	0.26
05/12	82DT	106	12.56	0.24
05/12	OG	107	12.62	0.24
05/12	OG	101	11.23	0.24
05/13	82DT	93	no data	0.26
05/16	80DT	112	14.61	0.27
05/17	UM	110	14.39	0.27
05/22	UM	94	9.4	1.00
05/22	82DT	109	13.8	1.00

Appendix 3. (continued)

Date	Area	Length (mm)	Weight (g)	Trap Efficiency
05/22	HC	108	13.77	1.00
05/24	UM	118	16.85	0.18
05/25	HC	94	9.97	0.25
05/26	UM	108	13.48	0.22
05/29	80DT	111	14.54	0.26
05/29	HC	107	13.53	0.26
06/01	80DT	113	15.69	1.00
06/03	HC	110	13.20	1.00
06/03	80DT	95	9.15	1.00

Appendix 4. Average nightly streamflow, trap efficiency, scoop trap catch, inclined plane trap catch, and total number of juvenile coho estimated to have migrated from Knowles Creek October 1, 1983 through June 30, 1984.

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
10/01	0.10	1.000	-	0	0
10/02	0.10	1.000	-	0	0
10/03	0.10	1.000	-	0	0
10/04	0.10	1.000	-	0	0
10/05	0.10	1.000	-	0	0
10/06	0.10	1.000	-	0	0
10/07	0.10	1.000	-	0	0
10/08	0.10	1.000	-	0	0
10/09	0.10	1.000	-	0	0
10/10	0.10	1.000	-	0	0
10/11	0.10	1.000	-	0	0
10/12	0.10	1.000	-	0	0
10/13	0.10	1.000	-	0	0
10/14	0.10	1.000	-	0	0
10/15	0.10	1.000	-	0	0
10/16	0.10	1.000	-	0	0
10/17	0.10	1.000	-	0	0
10/18	0.10	1.000	-	0	0
10/19	0.10	1.000	-	0	0
10/20	0.10	1.000	-	0	0
10/21	0.10	1.000	-	0	0
10/22	0.10	1.000	-	0	0
10/23	0.10	1.000	-	0	0
10/24	0.10	1.000	-	0	0
10/25	0.10	1.000	-	0	0
10/26	0.10	1.000	-	0	0
10/27	0.10	1.000	-	0	0
10/28	0.10	1.000	-	0	0
10/29	0.10	1.000	-	0	0
10/30	0.10	1.000	-	0	0
10/31	0.10	1.000	-	0	0
11/01	0.10	1.000	-	0	0
11/02	0.10	1.000	-	0	0
11/03	0.27	1.000	-	0	0
11/04	4.89	0.184	5	-	27
11/05	3.26	0.229	1	-	4
11/06	5.43	0.171	0	-	0
11/07	5.16	0.177	2	-	11
11/08	2.99	0.237	2	-	8
11/09	2.72	0.246	1	-	4
11/10	4.89	0.184	0	-	0
11/11	9.24	0.102	0	-	0
11/12	7.88	0.123	10	-	81

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
11/13	11.41	0.076	13	-	176
11/14	12.50	0.066	18	-	271
11/15	7.88	0.123	29	-	235
11/16	6.25	0.153	24	-	156
11/17	12.77	0.064	15	-	234
11/18	16.58	0.038	11	-	286
11/19	10.06	0.092	12	-	130
11/20	13.59	0.057	3	-	52
11/21	14.95	0.047	6	-	125
11/22	8.97	0.106	10	-	94
11/23	6.79	0.142	5	-	35
11/24	11.41	0.076	2	-	26
11/25	16.58	0.038	0	-	0
11/26	9.78	0.095	5	-	52
11/27	7.07	0.137	0	-	0
11/28	4.08	0.205	0	-	0
11/29	4.08	0.205	1	-	5
11/30	3.53	0.220	0	-	0
12/01	4.62	0.190	1	-	5
12/02	3.53	0.220	1	-	5
12/03	3.53	0.220	0	-	0
12/04	3.53	0.220	1	-	5
12/05	6.52	0.147	0	-	0
12/06	11.14	0.079	4	-	50
12/07	13.92	0.014	0	-	0
12/08	15.76	0.042	1	-	23
12/09	8.97	0.106	5	-	47
12/10	9.24	0.102	3	-	29
12/11	9.78	0.095	5	-	52
12/12	6.79	0.142	3	-	21
12/13	6.25	0.153	5	-	33
12/14	8.70	0.110	1	-	9
12/15	18.48	0.029	1	-	34
12/16	8.69	0.110	1	-	9
12/17	4.89	0.184	1	-	5
12/18	3.80	0.213	1	-	5
12/19	2.98	0.237	0	-	0
12/20	2.98	0.237	0	-	0
12/21	2.98	0.237	1	-	4
12/22	2.17	1.000	-	0	0
12/23	2.44	1.000	-	0	0
12/24	2.44	1.000	-	0	0
12/25	2.17	1.000	-	0	0
12/26	2.98	0.237	0	-	0
12/27	2.98	0.237	0	-	0

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
12/28	2.98	0.237	0	-	0
12/29	3.26	0.229	0	-	0
12/30	3.70	0.169	3	-	17
12/31	12.77	0.064	2	-	31
01/01	8.42	0.114	4	-	35
01/02	7.33	0.132	4	-	30
01/03	6.79	0.142	3	-	21
01/04	6.79	0.142	0	-	0
01/05	6.25	0.153	0	-	0
01/06	4.34	0.198	0	-	0
01/07	3.53	0.220	0	-	0
01/08	2.98	0.237	0	-	0
01/09	2.44	1.000	-	0	0
01/10	1.90	1.000	-	0	0
01/11	5.97	0.159	0	-	0
01/12	5.70	0.165	1	-	6
01/13	3.26	0.229	0	-	0
01/14	2.71	0.246	0	-	0
01/15	1.90	1.000	-	0	0
01/16	1.90	1.000	-	0	0
01/17	1.63	1.000	-	0	0
01/18	1.35	1.000	-	0	0
01/19	1.08	1.000	-	0	0
01/20	0.81	1.000	-	0	0
01/21	0.81	1.000	-	0	0
01/22	3.53	1.000	-	0	0
01/23	4.62	0.190	1	-	5
01/24	4.89	0.184	0	-	0
01/25	7.88	0.123	0	-	0
01/26	6.25	0.153	0	-	0
01/27	5.16	0.177	0	-	0
01/28	3.53	0.220	0	-	0
01/29	2.17	1.000	-	0	0
01/30	1.63	1.000	-	0	0
01/31	1.35	1.000	-	0	0
02/01	1.35	1.000	-	0	0
02/02	1.35	1.000	-	0	0
02/03	0.81	1.000	-	0	0
02/04	0.81	1.000	-	0	0
02/05	0.54	1.000	-	0	0
02/06	0.27	1.000	-	0	0
02/07	0.27	1.000	-	0	0
02/08	0.27	1.000	-	0	0
02/09	0.27	1.000	-	0	0
02/10	5.70	0.165	0	-	0

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
02/11	7.60	0.127	0	-	0
02/12	7.88	0.123	3	-	24
02/13	3.75	0.165	5	-	30
02/14	18.20	0.030	1	-	32
02/15	8.42	0.114	3	-	26
02/16	7.33	0.132	14	-	106
02/17	6.79	0.142	1	-	7
02/18	5.43	0.171	0	-	0
02/19	4.34	0.198	2	-	10
02/20	3.53	0.220	2	-	9
02/21	5.16	0.177	2	-	11
02/22	7.60	0.127	5	-	39
02/23	6.25	0.153	17	-	111
02/24	7.06	0.137	13	-	94
02/25	16.03	0.041	2	-	48
02/26	7.88	0.123	4	-	32
02/27	4.89	0.184	4	-	22
02/28	3.53	0.220	4	-	18
02/29	2.98	0.237	4	-	17
03/01	2.98	0.237	4	-	17
03/02	3.53	0.220	10	-	45
03/03	2.98	0.237	10	-	42
03/04	2.71	0.246	5	-	20
03/05	1.90	1.000	-	15	15
03/06	1.35	1.000	-	15	15
03/07	1.08	1.000	-	9	9
03/08	0.81	1.000	-	18	18
03/09	0.81	1.000	-	12	12
03/10	0.81	1.000	-	12	12
03/11	0.81	1.000	-	12	12
03/12	0.81	1.000	-	12	12
03/13	3.53	0.220	44	-	199
03/14	10.87	0.082	17	-	206
03/15	10.59	0.085	18	-	210
03/16	13.86	0.055	3	-	54
03/17	11.95	0.071	3	-	42
03/18	10.05	0.092	4	-	43
03/19	7.60	0.127	3	-	23
03/20	8.15	0.118	9	-	76
03/21	8.42	0.114	14	-	122
03/22	10.59	0.085	9	-	105
03/23	7.33	0.132	6	-	45
03/24	4.62	1.000	-	0	29
03/25	4.07	1.000	-	13	13
03/26	7.60	1.000	-	0	12

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
03/27	9.78	1.000	-	0	11
03/28	5.43	1.000	-	10	10
03/29	4.89	1.000	-	1	1
03/30	4.07	1.000	-	9	9
03/31	2.68	1.000	-	19	19
04/01	2.44	1.000	-	8	0
04/02	1.90	1.000	-	11	11
04/03	1.90	1.000	-	4	4
04/04	1.35	1.000	-	2	2
04/05	1.35	1.000	-	0	0
04/06	1.35	1.000	-	21	21
04/07	1.35	1.000	-	21	21
04/08	7.06	0.137	9	-	65
04/09	8.96	0.106	5	-	47
04/10	9.24	0.102	2	-	19
04/11	10.59	0.085	8	-	93
04/12	9.51	0.099	4	-	40
04/13	8.96	0.106	19	-	178
04/14	5.70	0.165	11	-	67
04/15	4.34	0.198	3	-	15
04/16	3.26	0.229	1	-	4
04/17	2.44	1.000	-	0	0
04/18	2.44	1.000	-	8	8
04/19	2.44	1.000	-	12	12
04/20	3.26	0.229	4	0	17
04/21	3.53	0.220	7	-	32
04/22	2.70	1.006	-	89	89
04/23	2.17	1.000	-	53	53
04/24	1.90	1.000	-	80	80
04/25	1.90	1.000	-	87	87
04/26	2.17	1.000	-	75	75
04/27	2.17	1.000	-	64	64
04/28	1.63	1.000	-	90	90
04/29	1.35	1.000	-	69	69
04/30	1.08	1.000	-	19	19
05/01	2.44	1.000	-	23	23
05/02	3.58	0.179	11	-	62
05/03	11.41	0.076	8	-	104
05/04	8.96	0.106	17	-	159
05/05	6.79	0.142	1	-	7
05/06	4.89	0.184	41	-	223
05/07	3.53	0.220	33	-	149
05/08	2.70	1.000	-	108	108
05/09	2.44	1.000	-	67	67
05/10	1.90	1.000	-	29	29

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
05/11	1.35	1.000	-	29	29
05/12	2.98	0.237	56	-	236
05/13	2.44	1.000	-	168	168
05/14	1.90	1.000	-	40	40
05/15	1.90	1.000	-	65	65
05/16	1.90	1.000	-	44	44
05/17	1.90	1.000	-	33	33
05/18	1.35	1.000	-	29	29
05/19	1.08	1.000	-	30	30
05/20	1.08	1.000	-	39	39
05/21	0.81	1.000	-	33	33
05/22	0.54	1.000	-	43	43
05/23	2.98	0.237	16	-	67
05/24	4.89	0.184	26	-	141
05/25	2.70	1.000	-	105	105
05/26	3.53	0.220	4	-	18
05/27	6.52	0.147	20	-	135
05/28	3.80	0.213	7	-	33
05/29	2.44	1.000	-	25	25
05/30	1.63	1.000	-	29	29
05/31	1.08	1.000	-	27	27
06/01	0.81	1.000	-	7	7
06/02	0.81	1.000	-	5	5
06/03	0.27	1.000	-	19	19
06/04	0.54	1.000	-	22	22
06/05	5.70	0.165	4	-	24
06/06	6.25	0.153	2	-	13
06/07	8.96	0.106	1	-	9
06/08	6.79	0.142	2	-	14
06/09	4.89	0.184	2	-	11
06/10	4.07	0.205	2	-	10
06/11	2.98	0.237	1	-	4
06/12	1.08	1.000	-	0	0
06/13	0.81	1.000	-	0	0
06/14	0.54	1.000	-	0	0
06/15	0.27	1.000	-	0	0
06/16	0.10	1.000	-	0	0
06/17	0.10	1.000	-	0	0
06/18	0.10	1.000	-	0	0
06/19	0.10	1.000	-	0	0
06/20	0.10	1.000	-	0	0
06/21	0.10	1.000	-	10	10
06/22	0.10	1.000	-	8	8
06/23	0.10	1.000	-	0	0
06/24	0.10	1.000	-	0	0

Appendix 4 (continued)

Date	Average nightly flow (m^3/s)	Trap Efficiency	Scoop trap catch	Inclined plane trap catch	Total migrants
06/25	0.10	1.000	-	0	0
06/26	0.10	1.000	-	0	0
06/27	0.10	1.000	-	0	0
06/28	0.10	1.000	-	0	0
06/29	0.10	1.000	-	0	0
06/30	0.10	1.000	-	0	0