# AN ABSTRACT OF THE THESIS OF

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Title: THE LENGTH OF RESIDENCE OF JUVENILE FALL CHINOOK SALMON IN SIXES RIVER, OREGON

Abstract approved:
J. D. Hall

This study was designed to provide life history information about juvenile fall chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in a small coastal river by 1) documenting the length of residence of the juveniles throughout the river, 2) exploring several factors possibly influencing their length of residence, and 3) assessing the relative importance of freshwater and estuarine rearing areas for producing returning spawners. The juveniles were followed from their emergence in the spawning streams to their entry into the ocean. Most information on the length of residence of the juveniles was obtained by seining and trapping at various times and locations in the river.

Spawning was distributed throughout the tributary streams, but most egg deposition occurred in Dry Creek. Most fish spawned from November to January. Fry emerged from the gravel from March to

May. Newly emerged fry moved downstream from the spawning areas in large numbers at night. Based on experimental studies of juvenile behavior, this movement apparently resulted from emergence at night and lack of visual orientation of the fry during darkness. Downstream movement was reduced during increased light levels (daylight or moonlight). This initial movement of fry is thought to assure rapid dispersal of juveniles throughout the river without extensive energy costs of dispersal by a social mechanism.

Many juveniles remained in fresh water until early summer. Most then entered the estuary, possibly because of the influence of high temperature in the main river. A small number of fish continued to reside in the cool spawning tributaries. Detailed studies in 1969 showed that juveniles began entering the estuary in spring, but large increases in the population did not occur until June. During the period of increasing abundance, many juveniles were also captured in the ocean surf. The population level in the estuary peaked at about 145,000 fish during July and August and then declined to a low level in autumn. The rate of growth of the juveniles was reduced for three months during the period of high population abundance. Population density is hypothesized as a major cause of the depressed rate of growth of the juveniles. After the population declined in late summer, growth of juveniles again improved. Following the autumn freshets, most fall chinook salmon remaining in the estuary and those in the cool spawning streams entered the ocean. A few fish from the tributary populations remained in fresh water through the winter and migrated to the ocean as yearlings the following spring.

Based on variation in the length of residence of the juveniles in fresh water and the estuary, five types of life histories were defined. Scale patterns from these types were distinguished and returning spawners from the 1965 brood sorted into the various types. The type-3 fish, those remaining in fresh water until early summer and then remaining for a period of improved growth in the estuary, represented about 90 percent of the returning spawners. Based on the return of these type-3 fish, freshwater and estuarine rearing were concluded to be about equally important to fall chinook salmon in Sixes River.

# The Length of Residence of Juvenile Fall Chinook Salmon in Sixes River, Oregon

by

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# THE LENGTH OF RESIDENCE OF JUVENILE FALL CHINOOK SALMON IN SIXES RIVER, OREGON

## INTRODUCTION

The fall chinook salmon, Oncorhynchus tshawytscha (Walbaum), is an important component of Oregon's commercial and sport fisheries. Significant contributions were recently made in understanding historical changes in the abundance of fall chinook salmon in the Columbia River and the fate of hatchery fish in the ocean (Van Hyning, 1968; Cleaver, 1969; Worlund, Wahle, and Zimmer, 1969). But despite general interest in maintaining or increasing the abundance of this fish, relatively little is known of its juvenile life history.

This study was designed to provide additional information about fall chinook salmon by 1) documenting the length of residence of juveniles in a small coastal river, 2) exploring several factors possibly influencing their length of residence, and 3) assessing the relative importance of freshwater and estuarine rearing areas of the river for producing returning spawners.

Chinook salmon are divided into several seasonal races, based on the time of freshwater entry of the adults on their spawning migration. Spring, summer, and fall races are present in the Columbia River (U. S. Army Corps of Engineers, 1969). In the Sacramento River a winter race is also present (Slater, 1963). In large rivers, adult chinook salmon can be found migrating during nearly every month of the year. In short coastal streams, such as the one in this study, only the fall race is present. Adults of this race enter fresh water from August to December and spawn from September to March, depending on the location of the stream (Mason, 1965).

Variability in the juvenile life history of chinook salmon appears to be common. The juvenile life histories of the two primary races, the spring and fall, are generally thought to be distinct. The various populations have been managed accordingly. Juvenile spring chinook salmon are expected to remain in fresh water for a year before migrating to the ocean during their second spring. Juvenile fall chinook salmon are expected to remain in fresh water for a short period of time, usually around three months after yolk absorption. The origin of these popular concepts seems to have been influenced by success or failure of hatchery operations (Wallis, 1968) and interpretation of adult scales (Rich, 1925).

Because of the advantage of increased growth in the ocean as opposed to fresh water, as early as 1900 there were recommendations to release hatchery fish as soon as possible (Rutter, 1903). The practice of planting recently hatched alevins was widespread, but as Rich (1920) points out, it may have led to low survival. Following that early practice, hatcheries held juveniles until the yolk was absorbed. Later data suggest further survival advantage in rearing hatchery fall chinook salmon to a large size (Cope and Slater, 1957; Junge and Phinney, 1963).

Reports of research on natural populations of chinook salmon are scarce. These studies faced two main difficulties that must be considered when attempting to decipher the history of our knowledge about the length of residence of the juveniles: 1) most studies were done on large rivers where sampling was difficult, and 2) more than one race was usually involved. Distinguishing among races was impossible because of the similar appearance of the juveniles.

Confusion occurs in the literature where interpretations of the life history of chinook salmon were made from adult scales without examining the length of residence of the juveniles. For example, analysis of adult scales from the Taku River suggested that the fish moved downstream as fry (Alaska Department of Fisheries, 1953), but Meehan and Siniff (1962) trapped the same population and found that most juveniles remained in fresh water for a year or longer. Mattson (1963) showed from adult scales that most spring chinook salmon in the Willamette River returned from juveniles residing a year in fresh water, but sampling showed that the majority of the juveniles went downstream as fry in the first spring (Mattson, 1962). Based on adult scale reading by Rich (1925), most juvenile fall chinook salmon in the Columbia River were thought to move quickly to the ocean. However, extensive freshwater residence of juveniles in tributaries of the lower Columbia River was later discovered (Reimers and Loeffel, 1967).

My research was primarily a field study where juveniles were traced from the time they emerged from the spawning gravel until they entered the ocean. The length of residence and downstream movement of the juveniles were associated with ecological data and examined in behavioral experiments. After exploratory work during the first few years, Sixes River was chosen as the primary stream for study because: 1) it had a relatively large natural population, 2) the river was small and accessible to study, and 3) considerable variation existed in the length of residence of the juveniles, with several rearing areas being utilized. Because the scope of this study involved work from the spawning areas to the estuary, all aspects could not be studied simultaneously. Various parts of the research were conducted from 1964 to 1970. Major emphasis in this thesis is placed on the later years of study, primarily 1969 and 1970, where more complete data are available for a particular brood.[1/] However, reference is made to work in earlier years where additional support of the central theme is required.

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[1/] Brood years are defined by the calendar year in which spawners begin depositing their eggs in the gravel. For example, fish in the 1968 brood were deposited as eggs into the gravel in autumn, 1968 and emerged from the gravel as fry in spring, 1969.

# DESCRIPTION OF THE STUDY AREA

Sixes River is located on the coast of Oregon 8 km north of Port Orford (Figure 1). Total drainage of the river is about 340 $km^2$. Flow in the river is influenced by rainfall; mean daily discharge varies from about 0.5 $m^3$/sec in summer to over 200 $m^3$/sec in winter (U. S. Geological Survey, 1968a).

Most of the tributaries have been logged, resulting in high turbidities in these streams and in the main river during freshets. Mean daily concentrations of suspended sediment in the lower main river in water-year 1968 were in excess of 100 mg/l on 37 days (U. S. Geological Survey, 1968b). The highest mean daily concentration of suspended sediment was 1,000 mg/l. In contrast to these high turbidities in the main river, Dry Creek and the South Fork remain relatively clear during high flows.

Dry Creek is probably the most important tributary for fall chinook salmon. During the summer the stream bed in the lower 3 km either contains a series of isolated pools or is dry. The surface water submerges and flows through the gravel bed. The remainder of the stream flows above the gravel surface.

Most of the tributaries, particularly Dry Creek, contain large quantities of good quality spawning gravel. This gravel consists of erosion-resistant sandstone, siltstone, and mudstone dating from the

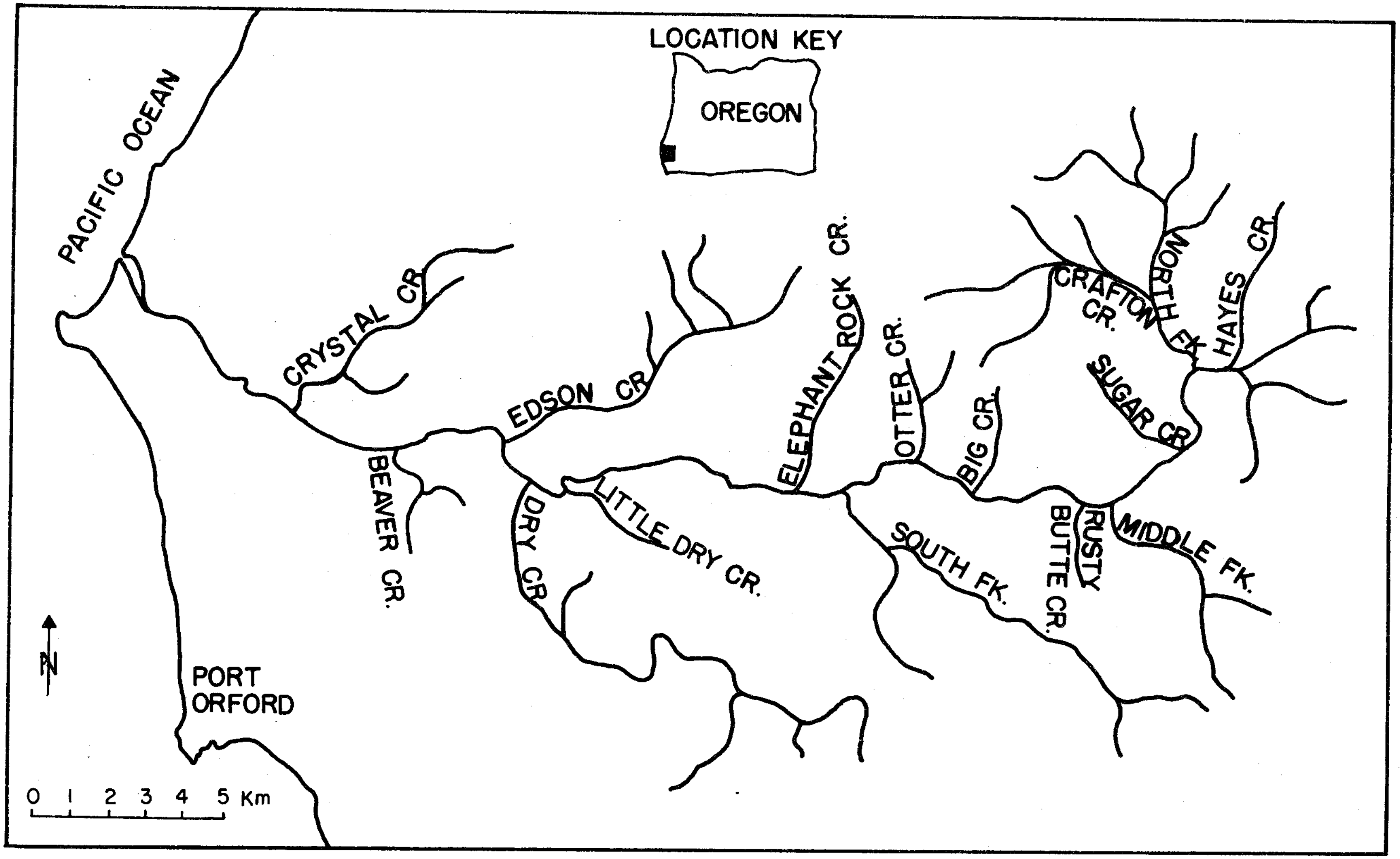

Figure 1. Location and drainage area of Sixes River.

Jurassic to the Cretaceous periods and volcanic igneous rock of various compositions from the Jurassic Period (Boggs, 1969). The main river differs from the tributaries by generally being of lower gradient and containing more deep pools. Riffles in the main river have a higher concentration of fine gravel and sand than those in the tributaries.

Most tributaries are cooler than the main river during the summer months (Figure 2). The wide, exposed main river probably receives more solar radiation than the narrow, shaded tributaries. During summer the main stem of Sixes River has considerable variation in maximum temperature along its course as measured on one of the warmest days (Figure 3). The lower part of the river is influenced by marine conditions of fog and strong northwest winds. However, inland about 10 km the climate is similar to that of interior valleys where high temperatures occur. The main river was warmest in the North Fork (31 km). From the North Fork to the South Fork, maximum temperatures ranged from 23 to 24 C. The South Fork had a major cooling influence on the maximum temperature in the main river, but that influence extended only a few kilometers downstream. Below 10 to 12 km prevailing winds and fog apparently prevented the stream from warming extensively.

The lower 4 km of the river form an intertidal or estuarine area. The river empties into the open ocean north of Cape Blanco

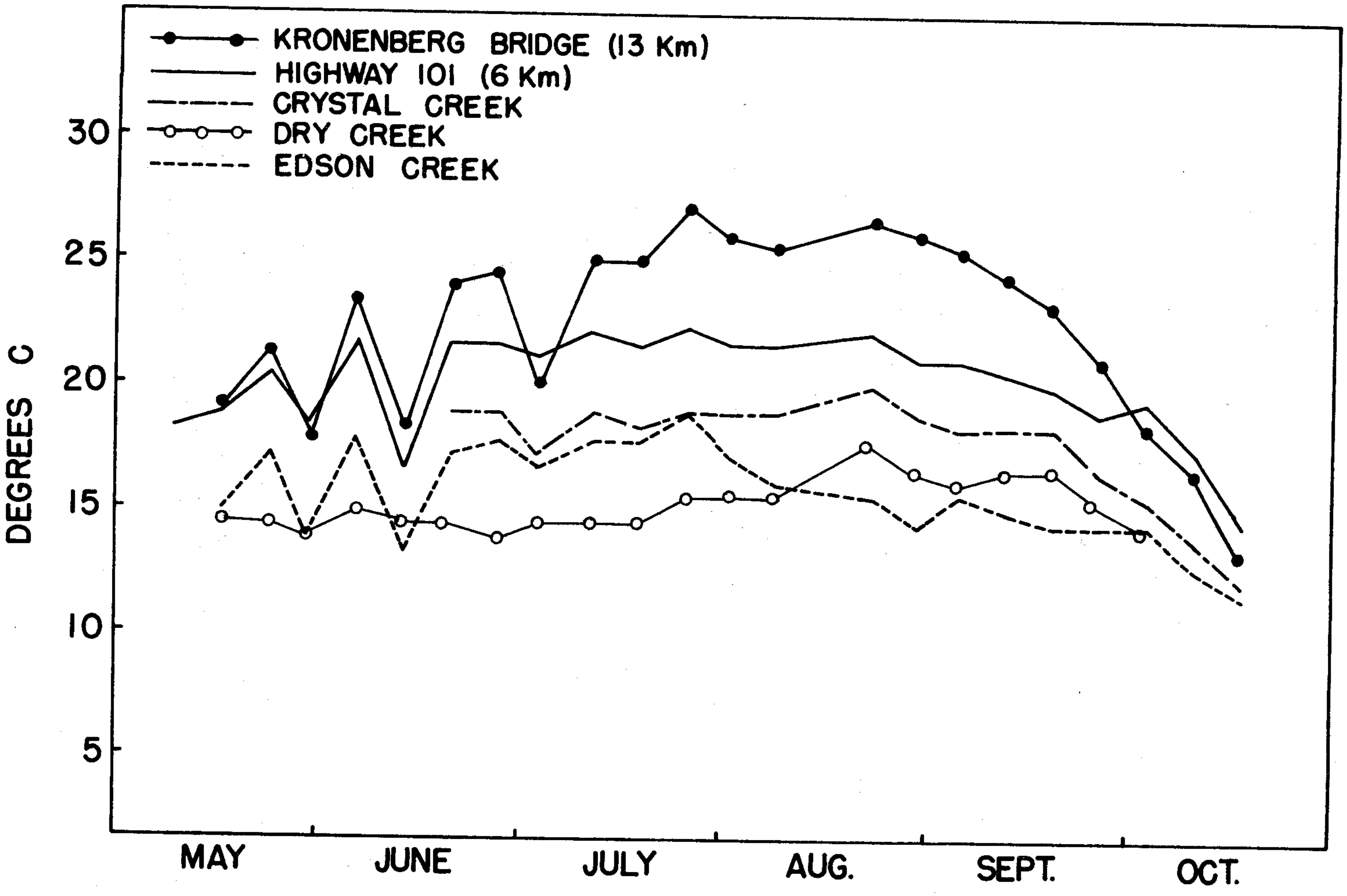

Figure 2. Comparison of maximum water temperatures recorded weekly in three tributaries and two locations in Sixes River, 1969.

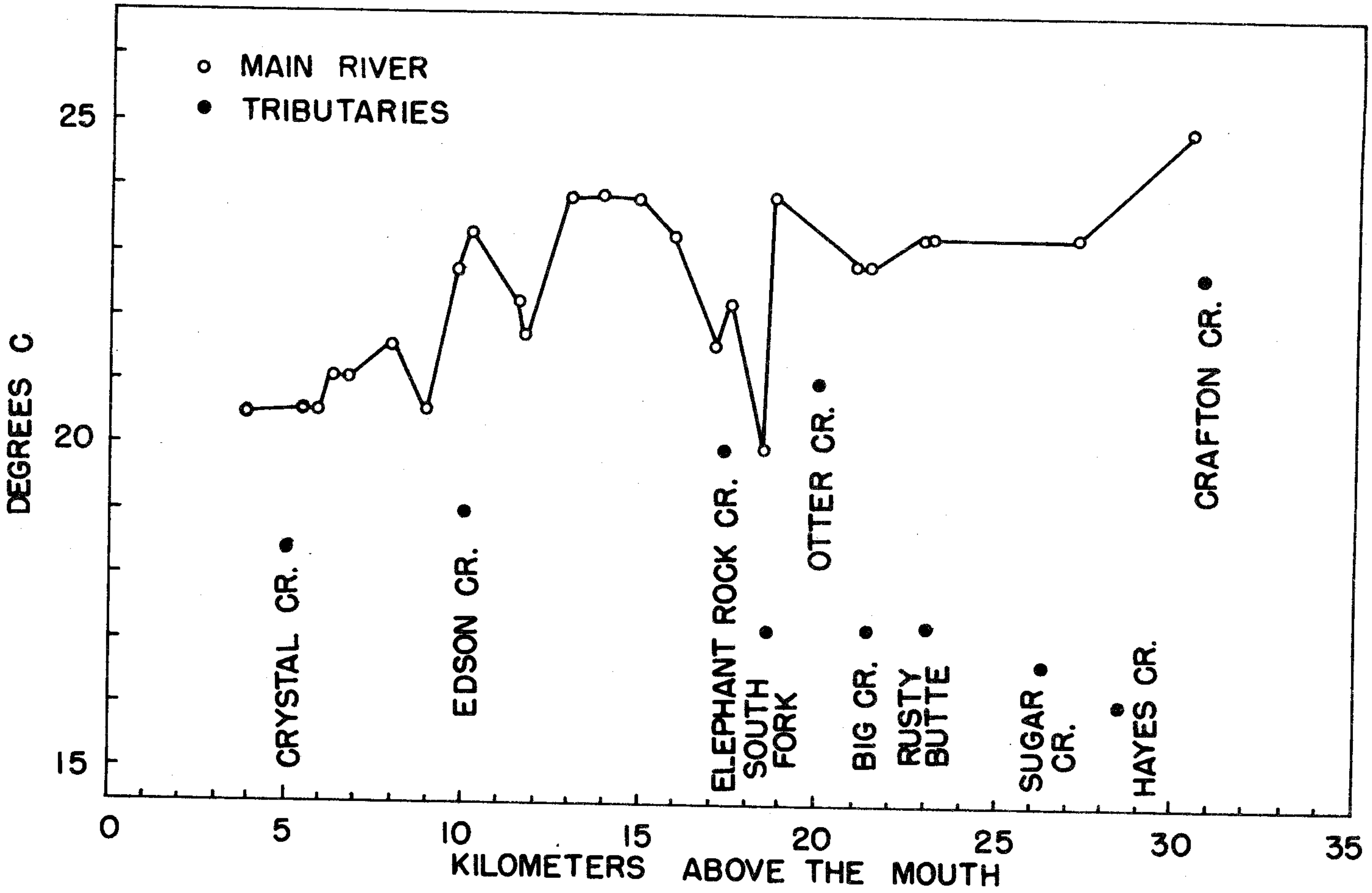

Figure 3. Profile of maximum temperatures along Sixes River and in tributaries on August 3, 1970 from 1642 to 1800 hours.

through a mouth restricted by low sand dunes. Most of the estuarine work in this study was confined to the lower kilometer, representing a unit somewhat distinct from the remainder of the estuary (Figure 4). Above the lower bay, the estuary is divided into deep pools separated by shallow riffles at low tide.

Prevailing northwest winds and longshore currents form a sill of sand at the mouth of the river in summer, creating a shallow embayment. Maximum depth is about 5 m at high tide. Tidal fluctuations are usually less than 1.5 m because of the sand sill and narrow mouth. As summer progresses and the sill develops at the mouth, the low tide level in the estuary gradually increases (Table 1). The shoreline is composed of relatively flat beaches of sand and gravel, so small increases in depth rapidly increase the size of the estuary. In some years short-term sand blocking irregularly occurs at the mouth, if the sill builds rapidly. The water level in the bay then rises from tidal invasion and river inflow. When the water level reaches the top of the sand bar, erosion rapidly opens a new channel and lowers the water level.

During high river discharge in winter, the intertidal area is fresh water and short. However, occasional low river discharge during winter allows temporary invasion of salt water along the bottom. In the spring, as river flows drop, estuarine conditions are reestablished.

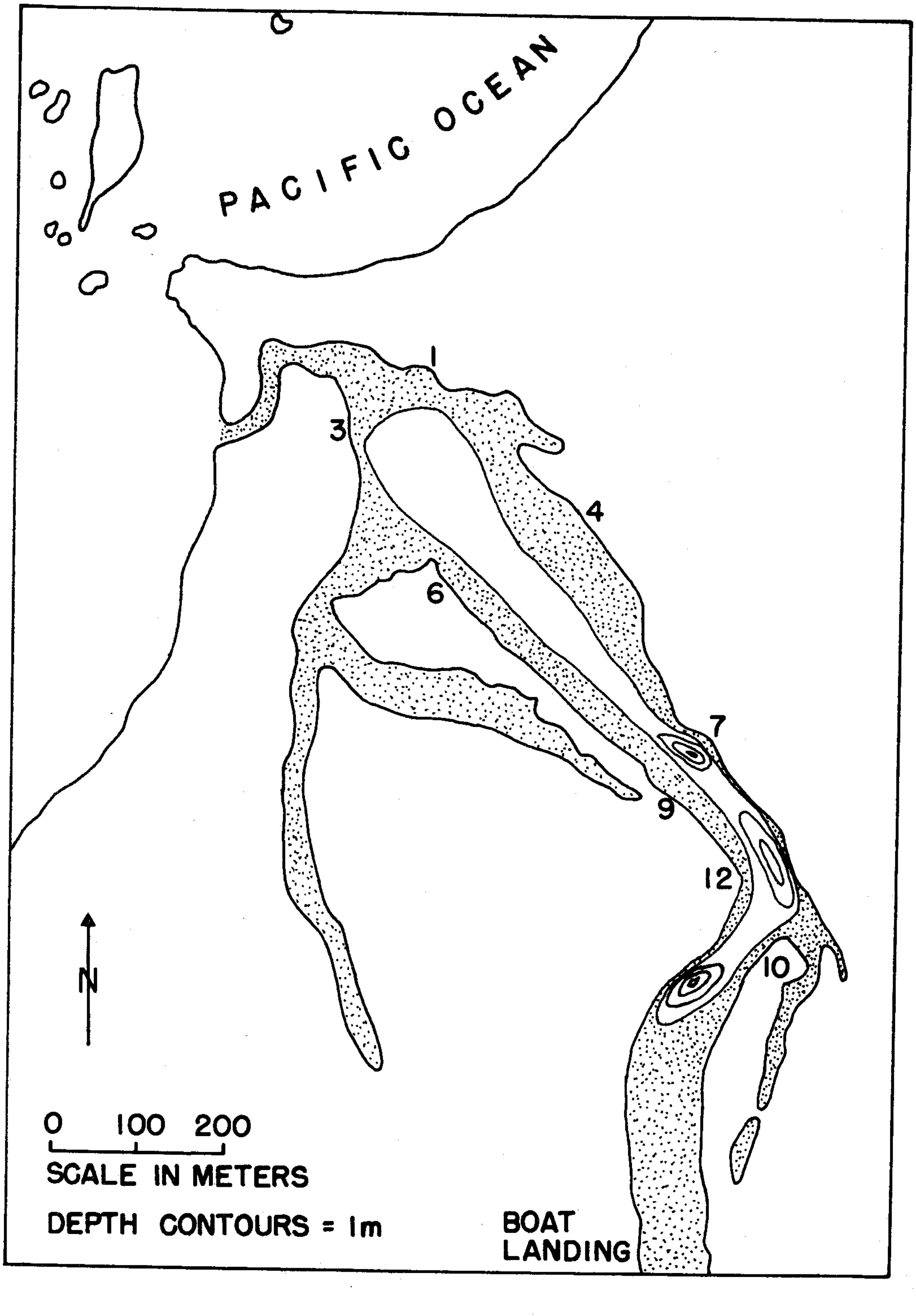

Figure 4. The lower part of Sixes River estuary at mean tide showing numbered sampling stations and depth contours (areas less than one meter deep are stippled).

Table 1. Low tide level of Sixes River estuary from spring to autumn, 1969.

| Date | | Water Level in Meters | Remarks |
|---|---|---|---|
| April | 7 | 0.10 | Staff reading just as tide started into the bay. Sill had just washed out. Lowest level observed.[a] |
| May | 14 | 0.55 | |
| June | 3 | 0.55 | |
| July | 25 | 0.60 | Water level recorder installed on this date and operated continuously thereafter. |
| August | 15 | 0.60 | |
| | 31 | 0.80 | |
| September | 15 | 0.75 | |
| | 31 | 0.90 | |
| October | 15 | 1.00 | |
| | 31 | 0.90 | |
| November | 15 | 0.20 | Freshets occurred from November 5 to November 9. Maximum height of the water during the period was 2.44 m. |

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[a] From March 10 to March 28, the river mouth moved far to the north and a sill rapidly formed during calm weather from March 26 to 28. A strong southerly wind on March 29 and 30 nearly closed the mouth. Water level began to back up to a height of at least 3.38 m and flooded the adjacent low land on April 5. A heavy rain produced more runoff on April 5, which put the water level over the sand sill at the mouth. In a few hours a new channel was cut straight out and the sand sill washed away. The new channel was cut deep as a result of the large volume of water flushing from the estuary.

The sill at the mouth creates a two-layered system in the estuary on ebb tide. Cold salt water is retained on the bottom, while warm fresh water moves downstream above the salt water and over the sill through the narrow channel into the ocean. The interface between these two layers at low tide is sharply defined with as much as 10 C difference in temperature and 25‰ difference in salinity. Water in each density layer apparently remains discrete despite strong northwest winds. On flood tide the mouth is innundated by cold, full-strength sea water, resulting in extensive vertical mixing at the mouth, movement of the water mass upstream, and presumably rejuvenation of nutrients in the estuary. Water flow is out of the bay about 75 percent of the time and into the bay about 25 percent of the time.

# METHODS

## Sampling of the Adult Population

Information on timing, distribution, and characteristics of spawning fish was obtained by examining live and dead fish on the spawning grounds. Attempts were made to sample spawning fish in proportion to their abundance, but frequency of sampling depended on stream conditions and the time required for each survey. During the last three years, all spawning areas were sampled every 7 to 10 days with counts kept of both live and dead fish. Total counts on a survey represented all live fish observed and those dead fish not previously counted. For each dead fish found on the spawning grounds, locality, date, length, and sex were recorded and a scale sample taken.

## Sampling of the Juvenile Population

A variety of gear was used to sample juveniles, but seines were the primary equipment. Operations extended from small tributaries downstream through the main river, estuary, and into the ocean surf.

### Freshwater Studies

In the spawning tributaries and the main river, seines of 4 or 9 m in length with stretched mesh size of 0.5 cm were used. Newly emerged fry were also captured with a "Y-frame" net with 0.5 cm mesh size.

Juveniles moving downstream were trapped at several sites as time permitted during the study. During the spring of 1970, a small downstream trap was operated in Edson Creek. This equipment consisted of a screen box with screen panels leading from each bank to the trap. The front part of the trap was built with a narrow "V" entrance so fish could enter but had difficulty finding their way out. This method provided good data for short periods during stable flows, but was unreliable for long-term trapping because of washouts during freshets.

A Craddock fyke trap was periodically operated in the lower river during spring and summer. Mesh size in the trap was 1.3 cm. In 1969 three fyke traps were set across the river. During high flows the trapping was incomplete, but at low flow the traps extended across the entire stream. This trapping indicated the timing of downstream migration and characteristics of migrating juveniles, but was inadequate to estimate the magnitude of downstream movement.

Captured juveniles were usually anaesthetized in MS 222 and measured in the field to the nearest 0.1 cm fork length. Samples of juveniles were preserved for scale analysis. Fish were fixed in a 7.6 percent solution of formaldehyde for 14 days, placed in water for 24 hours, and then stored in 36.5 percent isopropyl alcohol.

## Estuarine Studies

The primary sampling equipment used in the estuary was a 38-m bag seine with stretched mesh size of 2.0 cm in the wings and 1.3 cm in the bag. Standard sets were made from an outboard-powered boat 4.8 m long. During early spring of each year, the 9-m net was also used to sample the inshore estuarine population. Juveniles in the mouth of the river and in the ocean surf were caught with a 9-m net or 25-m beach seine. Occasionally an Oneida Lake trap net was set in the estuary.

Population estimates of juveniles in the lower estuary were made in 1969 by cold branding (Everest and Edmundson, 1967) and releasing fish captured over a two or three-day period and then resampling for the marked to unmarked ratio about five days later. Fish were marked at each station in proportion to the number seined. An attempt was made to mark 10 percent of the population, but the liquid nitrogen coolant was a limiting factor and was usually gone after three days.

Fish were marked at a central station under a shelter to reduce formation of ice on the brands caused by wind and moisture. All captured fish were hauled to the marking station and sorted into holding pens. Newly marked fish and recaptured marked fish were transported and released at their capture site. Random mixing was assumed, based on the distribution of recoveries of fish uniquely marked at individual stations in 1967 (Fish Commission of Oregon, 1968).

The recovery effort was completed in two days. On the first day, stations 1, 3, 4, and 6 were sampled (Figure 4). All fish were held until seining was completed at a station. The marked and unmarked fish were then sorted, measured, and released. The next station visited was "upstream" (against the tidal current from the last station) to prevent handled fish from drifting into the next sample. On the second day of the recovery, seining was done at stations 7, 9, 10, and 12 at the same tidal stage as the previous day. Fish were assumed to be in the same relative position on the two days.

Growth of juveniles in the estuary was monitored weekly. A sample of fish from various stations was measured to the nearest 0.1 cm fork length in MS 222. All branded fish that were recovered were measured to provide an independent check on the rate of growth of individuals in the population, eliminating the effect of recruitment from upstream. Samples of fish were preserved for scale analysis.

## Behavior Studies

The behavior of newly emerging fry and their subsequent fate in social populations were primarily investigated in small observation troughs simulating a stream environment. These observation troughs possessed simulated redds where eyed eggs could be planted to allow natural emergence of juveniles from the gravel. In addition, experiments were run in emergence boxes that consisted primarily of the simulated redd from the observation troughs. Description of the two systems has previously been presented (Reimers, 1970).

Some experiments were started by simply planting juveniles in the troughs. These fish were seined or trapped from a nearby natural rearing area or transplanted from another experimental system. In other experiments, natural emergence of juveniles from the gravel represented the beginning of an experiment.

## Scale Studies

Scales were removed from the second or third scale row above the lateral line in the area below the insertion of the dorsal fin. Scales from spawners were placed directly onto gummed tape in the field. Scales from juveniles were removed from preserved fish and placed on gummed tape. Usually three scales from spawners and three or more scales from juveniles were taken. Plastic impressions were made of these scales.

The scales were magnified (98X) with a Tri-simplex microprojector onto a table top. A mask was placed over the scale image and centered on the nucleus. The anterior-posterior line on the mask was oriented with the long axis of the scale. Counts and measurements of circuli were made along a line 20 degrees to the dorsal side of the anterior-posterior axis of the scale. The selected 20-degree lines on the scales of spawners and juveniles were felt to correspond closely.

The best scale was selected from each fish. Those that were obviously regenerated or those with irregularities along the 20-degree axis were not used. Regeneration of the first few circuli possibly not visible to the eye was checked by plotting the distribution of platelet distances. Platelet distance was defined as extending from the center of the nucleus to the outside edge of the first visible circulus. Scales with platelet distances larger than 8.2 mm were excluded (Figure 5).

A narrow strip of paper with a ruled line was placed directly over the 20-degree axis. The outside edge of the platelet and the outside edge of each succeeding circulus encountered along the line were marked. All circuli on the juvenile scales were marked, but a maximum of 50 were marked on the scales from spawners. Every fifth circulus was marked with a longer distinct line. Measurements of bands of five circuli were made to the nearest 0.1 mm with a vernier caliper. In addition, the point of separation between freshwater, estuarine, and oceanic growth on the scales of spawners was visually estimated and marked on the paper. Counts of circuli and measurements of scale diameter were made on these selected areas and were compared to similar data for juveniles of known life history.

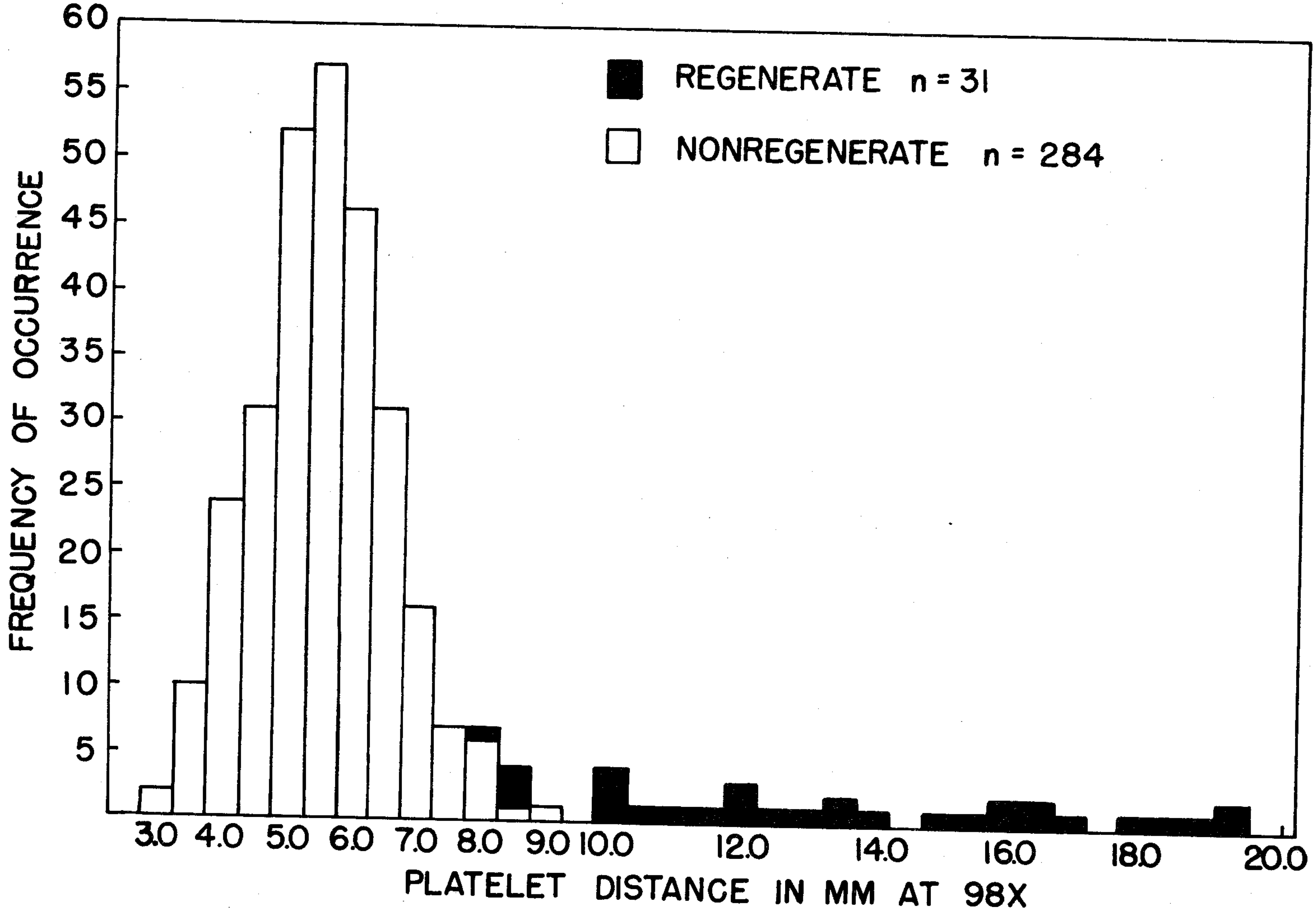


Figure 5. Distribution of platelet distances in a sample of scales from fall chinook salmon visually sorted into regenerate and non-regenerate.

# RESULTS

## Location and Time of Egg Deposition

Initially, information was gathered on spawning populations of fall chinook salmon in Sixes River to determine where and when eggs were deposited in the gravel. Spawning occurred primarily in Dry Creek, Edson Creek, Crystal Creek, and the upper main river (Figure 6). About 60 to 70 percent of the runs spawned in Dry Creek (Table 2).

Most spawning occurred from November to January, as indicated by counts in lower Dry Creek (Figure 7). Other streams showed a similar pattern. The earliest that any fish were observed on the spawning grounds in the seven years of the study was November 13. Fresh carcasses and an occasional live fish were observed as late as February 21. Data from the spawning populations showed that juveniles would emerge from the gravel throughout the river system and that emergence could be expected over a period of about 60 to 90 days.

## Timing of Emergence

The earliest that newly emerged juveniles were captured in the spawning streams was March 11 in Edson Creek. Five fish were

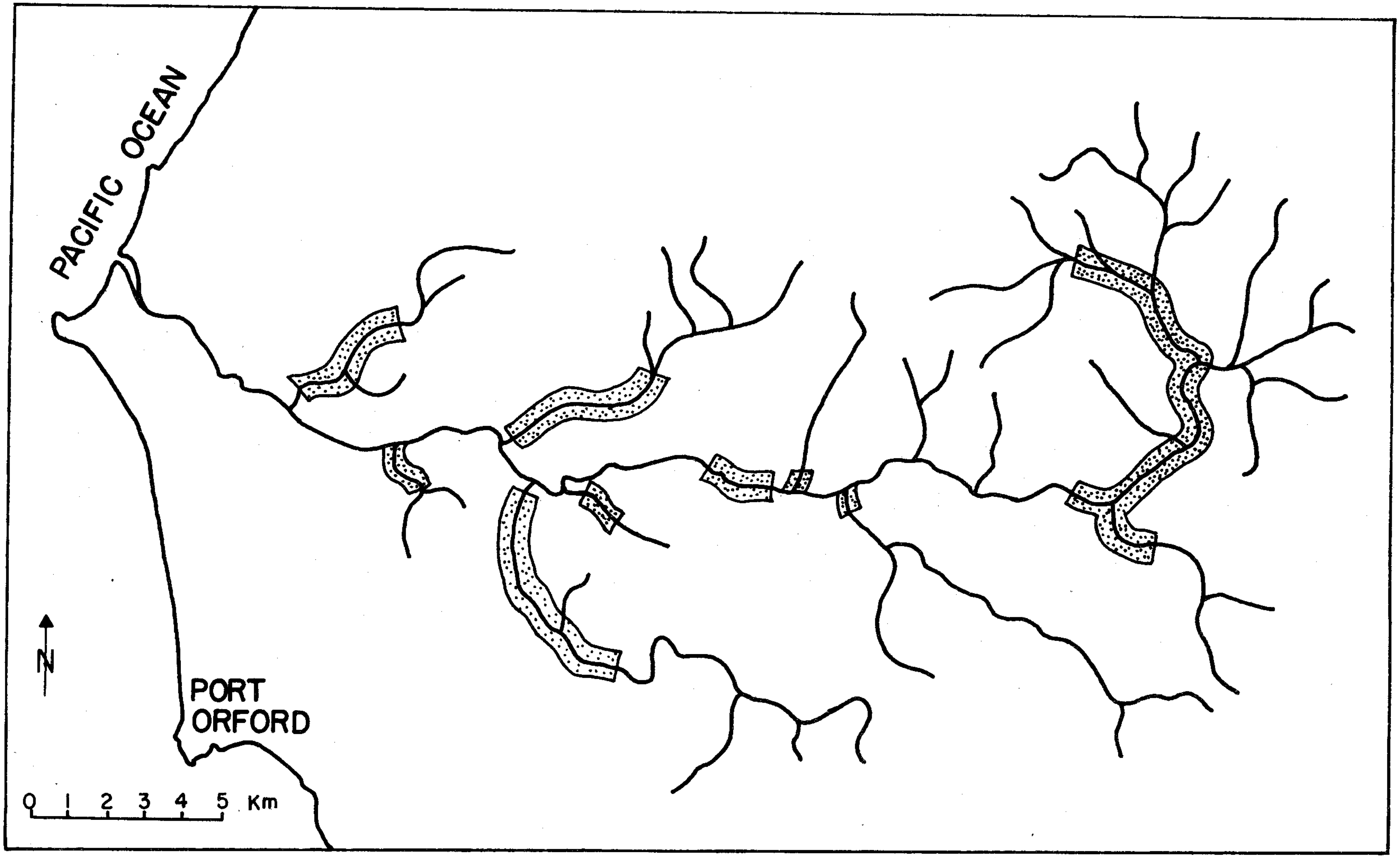


Figure 6. Distribution of the spawning population of fall chinook salmon in Sixes River, Oregon, 1964 to 1970.

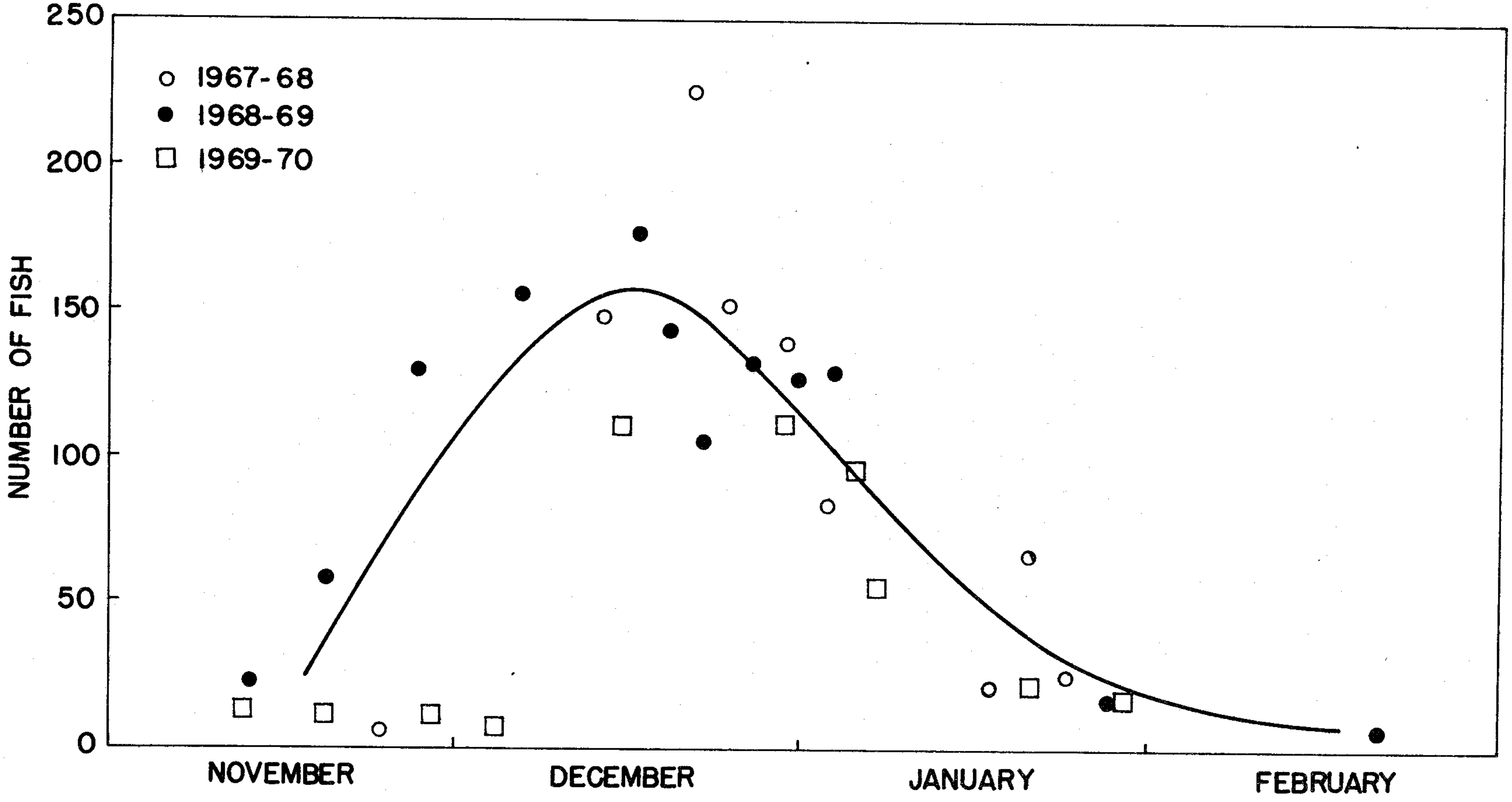


Figure 7. Total number of fall chinook salmon observed on each survey in lower Dry Creek, 1967-68 to 1969-70. Totals include live and dead fish, both adults and jacks (line fitted by inspection).

Table 2. Percentage of the observed chinook salmon population in Sixes River that spawned in Dry Creek.

| Year | Group | Sixes River | Dry Creek | |
|---|---|---|---|---|
| | | N | N | % |
| 1967-68 | Live adults | 1,158 | 835 | 72.1 |
| | Live jacks | 327 | 225 | 68.8 |
| | Dead adults | 363 | 255 | 70.2 |
| | Dead jacks | 54 | 36 | 66.7 |
| | Total | 1,902 | 1,351 | 71.0 |
| 1968-69 | Live adults | 1,597 | 1,152 | 72.1 |
| | Live jacks | 372 | 285 | 76.6 |
| | Dead adults | 514 | 371 | 72.2 |
| | Dead jacks | 21 | 15 | 71.4 |
| | Total | 2,504 | 1,823 | 72.8 |
| 1969-70 | Live adults | 832 | 529 | 63.5 |
| | Live jacks | 32 | 24 | 75.0 |
| | Dead adults | 399 | 223 | 55.9 |
| | Dead jacks | 8 | 3 | 37.5 |
| | Total | 1,271 | 779 | 61.3 |

caught in eight seine hauls with the 9-m net. By early April many newly emerged fish were found in Edson Creek and other parts of the river.

In 1970 the downstream trap was periodically operated in Edson Creek from March 27 to June 4. On the first night of trapping, 286 fry ranging in length from 3.9 to 4.3 cm were caught. Fish at this newly emerged size, some even with yolk remaining, were caught until the last trapping in June, suggesting that emergence was protracted (Figure 8). The trapping data were assumed to closely represent the pattern of emergence, because captured juveniles were small and often possessed yolk. Judged from the periodic trap catches through the spring, peak emergence in Edson Creek came from mid to late April (Figure 9). This was approximately 120 days after the time of peak spawning in that stream. The observations of newly emerged fry correspond with the protracted spawning.

The change in relative abundance of juveniles, based on seine catches in Edson Creek in 1970, agrees closely with the trapping data. There was an increase of juveniles in March, a peak during April and May, and a decline near the end of June (Figure 10). Many of these fish were also recently emerged fry.

## Downstream Migration and Behavior of Newly Emerged Fry

A large number of juveniles appeared to move downstream as recently emerged fry and most moved at night. The Edson Creek trap was checked at dawn and dusk on 15 days during 1970. Less than 5 percent of the fish moved during the hours of daylight and more than 95 percent of the fish moved during darkness (Table 3). Factors controlling this downstream movement were explored further in experimental work.

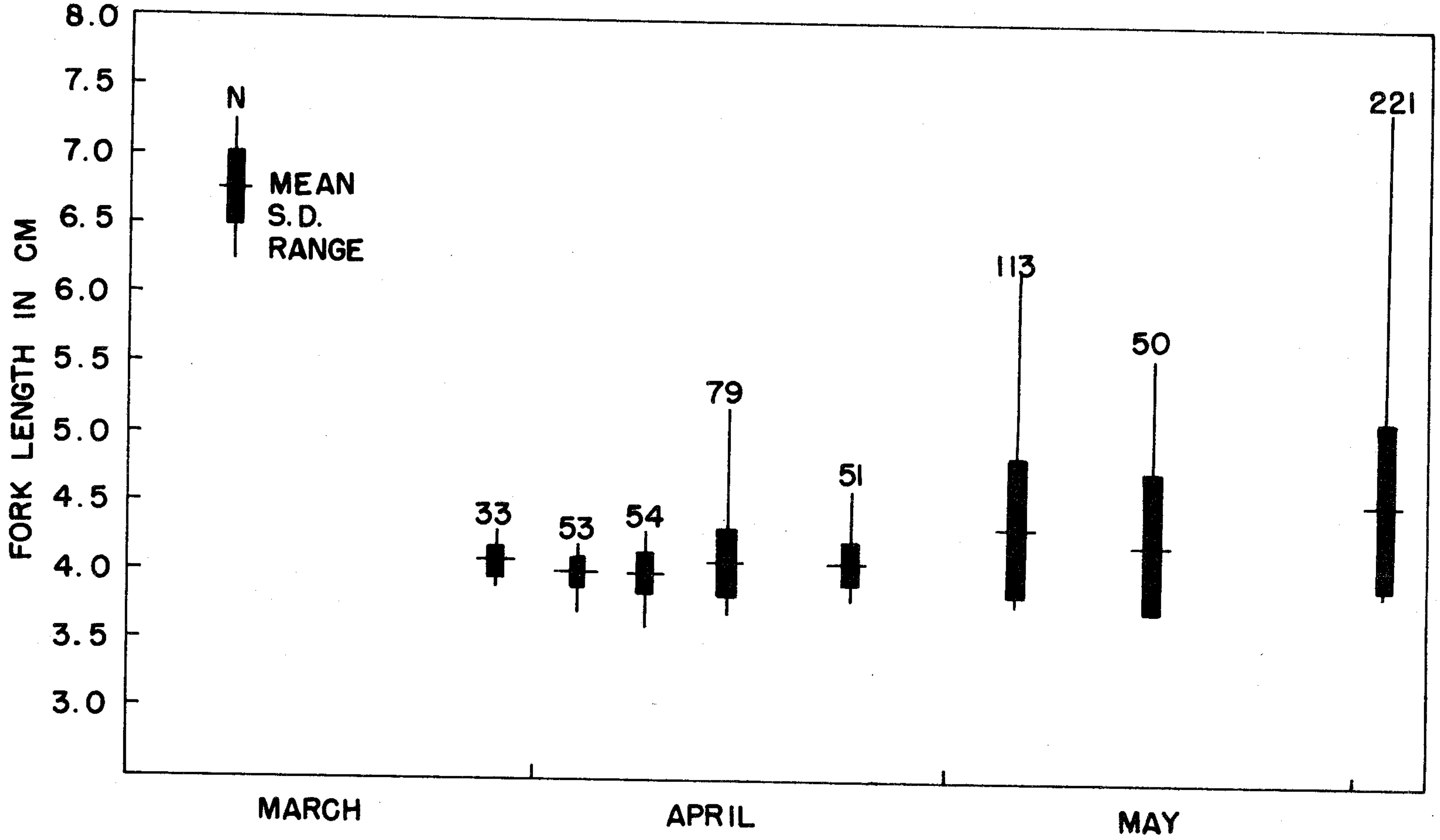


Figure 8. Length of juvenile fall chinook salmon moving downstream in Edson Creek, 1970.

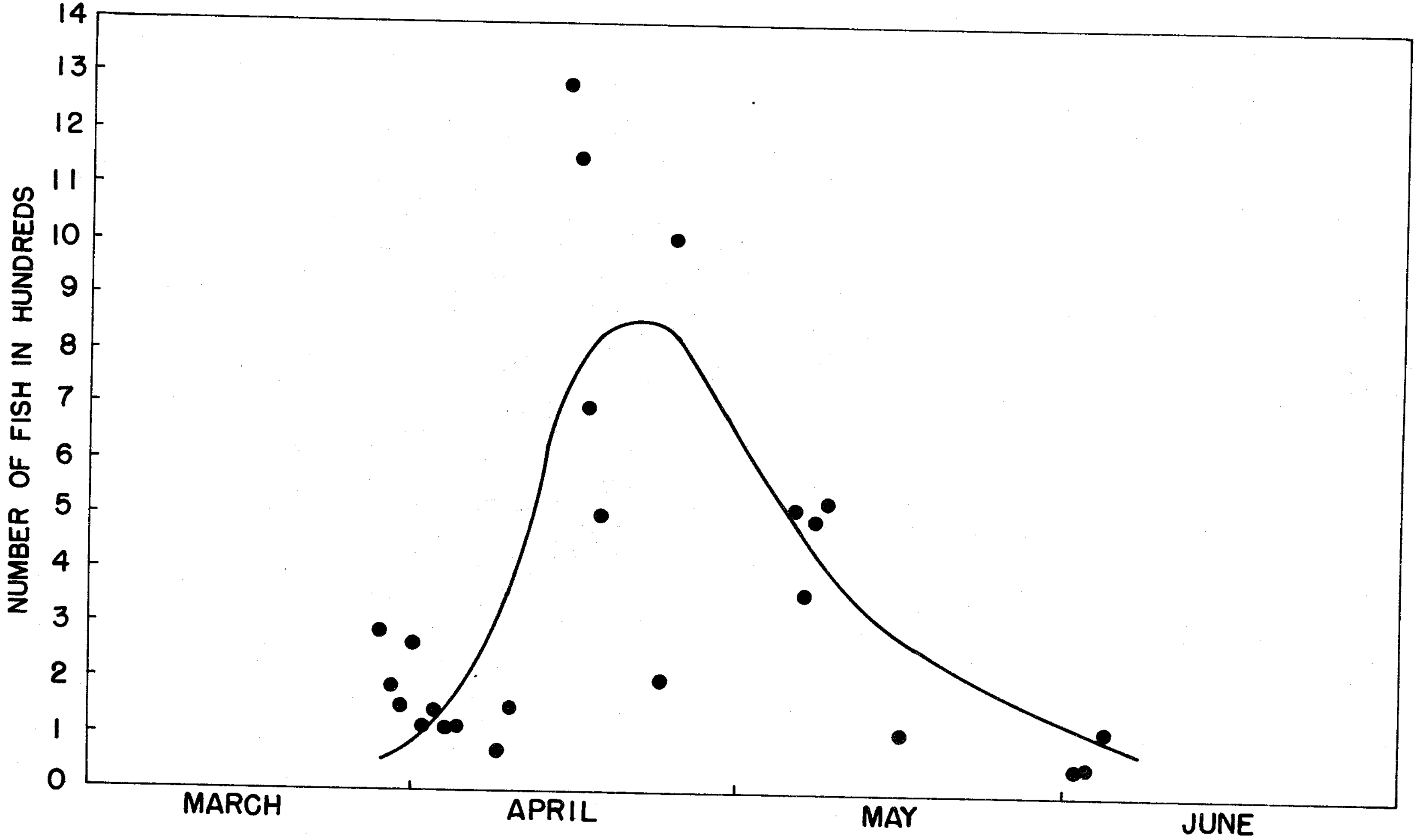


Figure 9. Catch per trap-night of juvenile fall chinook salmon moving downstream in Edson Creek, 1970 (line fitted by inspection).

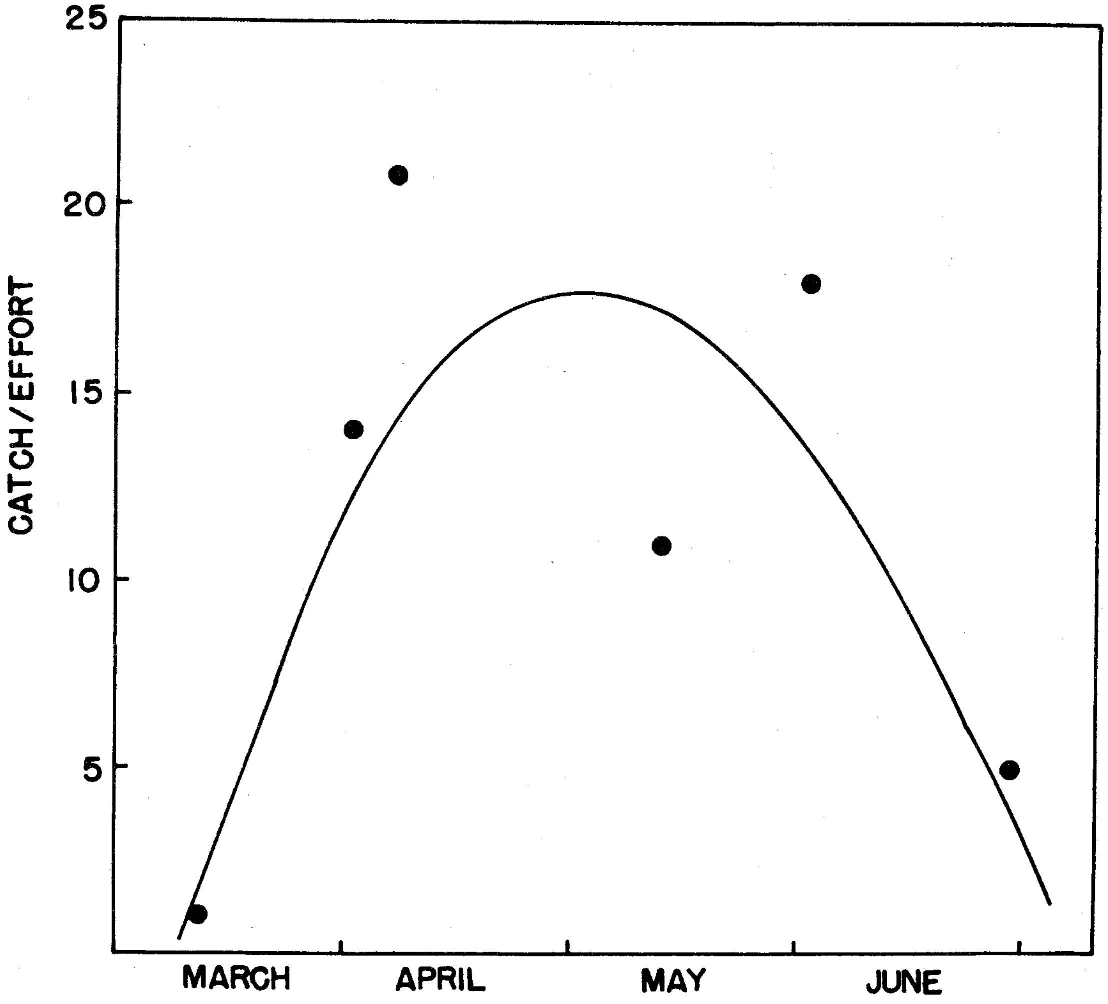


Figure 10. Catch per seine haul of juvenile fall chinook salmon with the 9-m net in Edson Creek, 1970 (line fitted by inspection).

Table 3. Temporal pattern of downstream migration of juvenile fall chinook salmon in Edson Creek, 1970.

| Date | | Day | | Night | | Total |
|---|---|---|---|---|---|---|
| | | N | % | N | % | N |
| March | 29 | 3 | 2.0 | 150 | 98.0 | 153 |
| | 30 | 1 | 0.4 | 264 | 99.6 | 265 |
| | 31 | 1 | 0.9 | 109 | 99.1 | 110 |
| April | 1 | 2 | 1.5 | 137 | 98.5 | 139 |
| | 2 | 1 | 0.9 | 109 | 99.1 | 110 |
| | 8 | 3 | 4.4 | 65 | 95.6 | 68 |
| | 9 | 4 | 2.7 | 146 | 97.3 | 150 |
| | 14 | 8 | 0.6 | 1,279 | 99.4 | 1,287 |
| | 15 | 21 | 1.8 | 1,131 | 98.2 | 1,152 |
| | 16 | 6 | 0.9 | 692 | 99.1 | 698 |
| | 23 | 3 | 1.5 | 200 | 98.5 | 203 |
| May | 5 | 5 | 1.0 | 510 | 99.0 | 515 |
| | 6 | 3 | 0.8 | 360 | 99.2 | 363 |
| | 7 | 5 | 1.0 | 494 | 99.0 | 499 |
| | 8 | 8 | 1.5 | 521 | 98.5 | 529 |
| Total | | 74 | 1.2 | 6,167 | 98.8 | 6,241 |

## Emergence Behavior

Several experiments were conducted to examine time of emergence of juveniles and to study changes in behavior of juveniles in the stream environment. The eggs from one female were taken from Edson Creek in autumn of 1969. They were fertilized with one male and held in a Heath incubator at the Elk River Salmon Hatchery. When the eggs reached the eyed stage, they were randomly divided into experimental lots.

In the first experiment, 600 eggs were planted into an emergence box. The emergence box was exposed to the normal light-dark cycle and temperatures followed the diel pattern (10-12 C). Records were kept of the diel pattern of emergence and the number of fish emerging daily in relation to their size.

Some fish began emerging from the gravel shortly after hatching (Figure 11). Others continued to emerge prior to total yolk absorption, but peak emergence did not occur until after the fry reached maximum weight. Beginning on March 15, 1970, when 7 percent of the fry had emerged from the gravel, the trap was checked at dawn and dusk for 14 consecutive days. About 20 percent of the juveniles emerged during the day and the rest at night (Table 4).

In a second experiment, two groups of advanced alevins were planted into separate emergence boxes. This experiment was

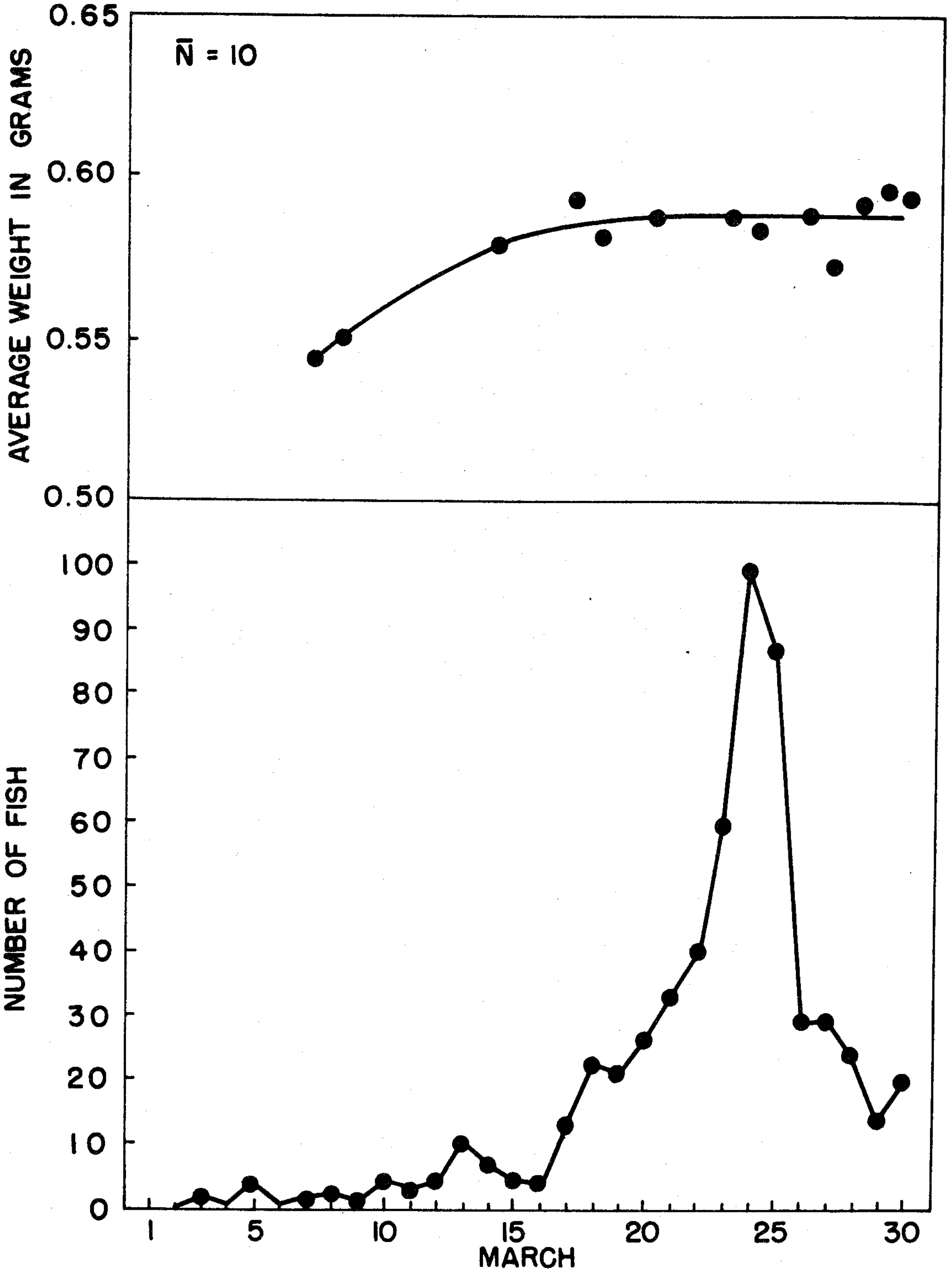


Figure 11. Temporal pattern of emergence and change in weight of newly emerged fall chinook salmon planted as eyed eggs in an emergence box, 1970.

Table 4. Diel pattern of emergence of juvenile fall chinook salmon planted as eyed eggs in an emergence box, 1970.

| Date | | Day | Night | Total |
|---|---|---|---|---|
| March | 15 | 1 | 3 | 4 |
| | 16 | 3 | 1 | 4 |
| | 17 | 5 | 8 | 13 |
| | 18 | 7 | 15 | 22 |
| | 19 | 4 | 17 | 21 |
| | 20 | 8 | 18 | 26 |
| | 21 | 8 | 25 | 33 |
| | 22 | 9 | 31 | 40 |
| | 23 | 9 | 52 | 61 |
| | 24 | 19 | 80 | 99 |
| | 25 | 7 | 80 | 87 |
| | 26 | 8 | 21 | 29 |
| | 27 | 8 | 21 | 29 |
| | 28 | 1 | 23 | 24 |
| Total | | 97 | 395 | 492 |
| Percent | | 19.7 | 80.3 | 100.0 |

identical in design to the first, except that one emergence box was completely covered with black polyethylene sheeting to maintain continual darkness. The other emergence box was exposed to the normal light-dark cycle. The experiment was checked on 12 days at dawn and dusk from April 11 to 23, 1970. In the control box about 9 percent or 30 fish emerged during the day and 91 percent or 317 fish emerged at night. In the experimental box about 59 percent or 214 fish emerged during the normal hours of daylight and 41 percent or 151 fish emerged during the normal period of darkness.

In this second experiment, checks of the trap catches were also made at the end of four major periods of the day: evening (dusk to midnight), night (midnight to dawn), morning (dawn to midday), and afternoon (midday to dusk). The control system was checked on seven days and the experimental system was checked on six days. In the control system a total of 300 fish emerged. The distribution of emergence showed that under the normal light-dark cycle, not only did more fish emerge during darkness, but most emerged in the evening period (Figure 12). In continual darkness, emergence of 299 fish was distributed throughout 24 hours but with a slightly higher peak in the afternoon (Figure 12). The null hypothesis of equal numbers emerging during the four periods was rejected ($\chi^2 = 18.6$; $P < .01$). Bams (1969) showed that fry increase their activity and move to the gravel surface during maximum temperatures in the afternoon. Under the normal light cycle, actual emergence of these fish from the gravel was inhibited until light levels decreased at dusk.

Based on stream and experimental observations, both

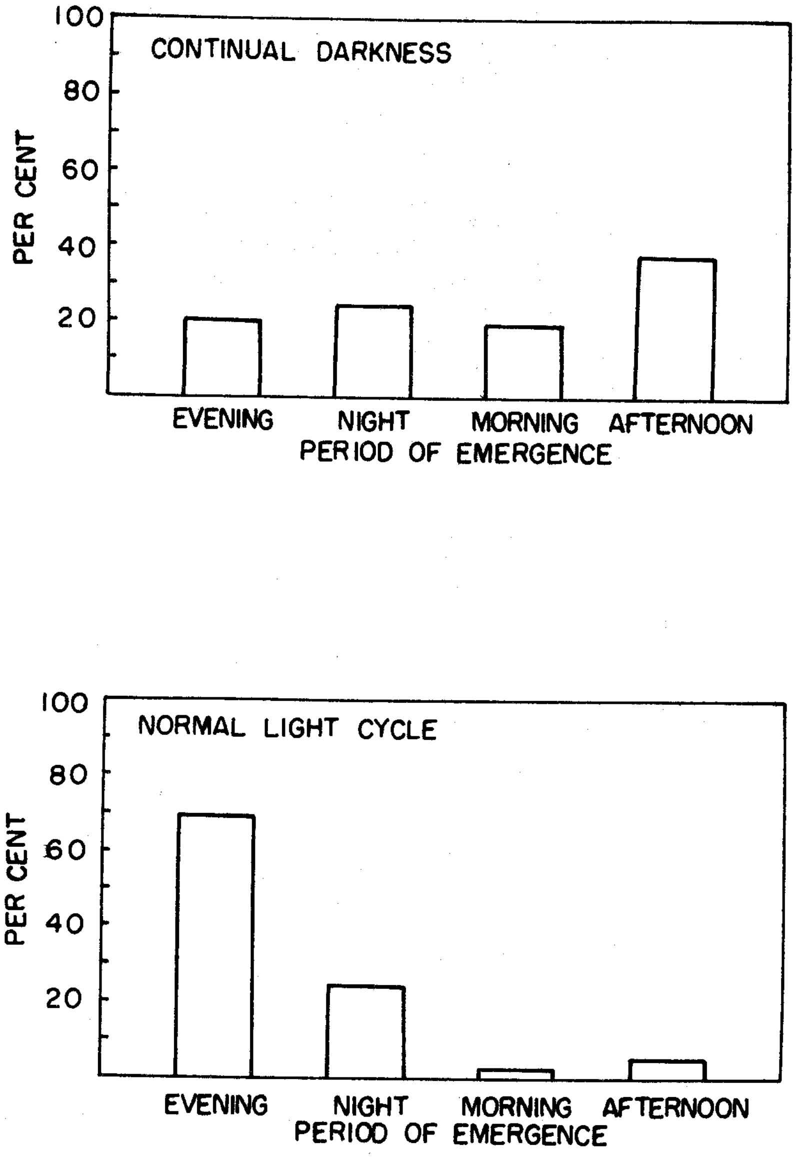


Figure 12. Diel pattern of emergence in four periods of the day for juvenile fall chinook salmon in emergence boxes exposed to the normal light cycle and continual darkness, 1970.

downstream migration and emergence from the gravel occur primarily during darkness. With the possibility that fry emergence and downstream movement could be closely related, and that fry moving downstream on any given night might also have emerged on that same night, additional observations were made.

In experiments in the observation troughs, the actual emergence of a few fry was observed during the day or at dusk. In most cases the fry made a rapid dart from the gravel and erratically swam downstream or into the upstream or side walls. Then the fish usually settled on the bottom for a few seconds to several minutes before swimming up in the water column. Filling of the swim bladder was usually attempted fairly soon but was not always successful on the first attempt. The fish generally swam in jerking movements with their tails lowered. Some fish swam to the surface and gulped air four or five times, while others gulped only once. Several fish were observed to calm down and remain stationary in the water column. One fish, identified by a unique parr mark pattern, was observed to remain at the same site where it emerged until the experiment was ended. Most fish immediately disappeared downstream and were lost among resident fish. Several fish were observed to immediately move out of the systems into the traps. These observations led to experiments examining the post-emergence development of juveniles resulting in their residence in stream populations.

## Development of Stream Residence

Three experiments were conducted from April 21 to 29, 1970 where small groups of fry that had emerged on a given night were placed in an observation trough to observe whether they tended to remain there or move downstream. Over the succeeding days any fish that moved downstream were placed back upstream on the next day. These experiments showed that very few fish remained in the troughs on the first day out of the gravel. Each day more fish tended to stay (Figure 13).

Whenever newly emerged fry were taken from the emergence box traps and placed in the observation troughs, they grouped near the bottom in a fright huddle. These newly emerged fry usually remained together during the first few days and were docile. There was a marked photo-negative response. In the presence of bright sunlight, the fry remained in the shadows of the pools or hid among the gravel. However, in the absence of bright sun, the entire group was usually stationed near the upper end of the riffle or moved together throughout the trough.

Usually by the third day, the fish tended to spread out, fed on drift, responded less to strong light, and showed some agonistic behavior. At emergence, most fall chinook salmon lacked color in their fins, but by the third or fourth day they started developing color

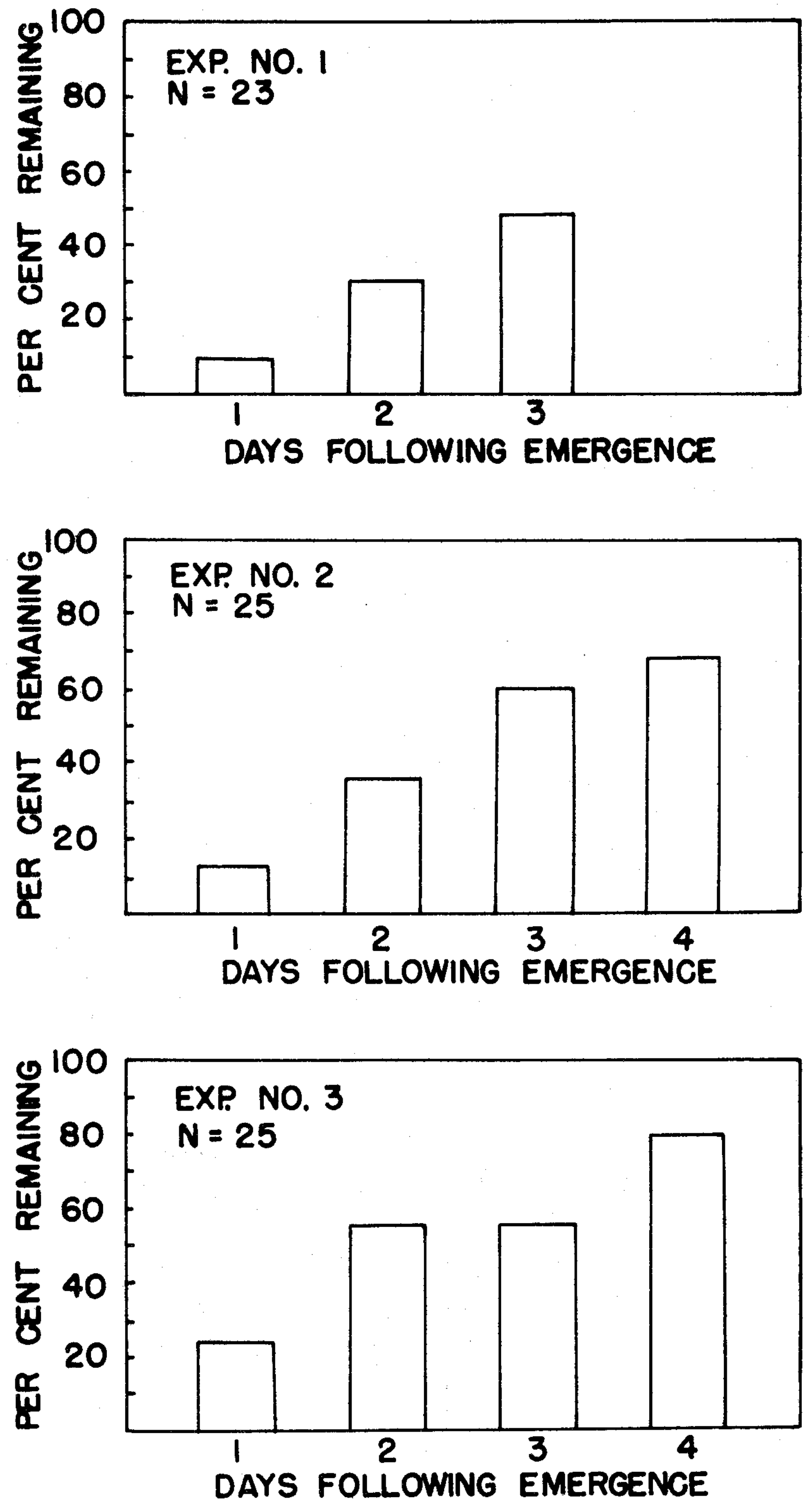


Figure 13. Number of newly emerged juvenile fall chinook salmon remaining in observation troughs with increasing daily age after emergence, 1970. See text for description of the experimental procedure.

patterns of stream fish (Stein and Reimers, 1970).

## Influence of Moonlight

Several observations suggested that moonlight had a depressing effect on the downstream migration of newly emerged fry during the night. This was discovered during experiments where newly emerged fry were planted in observation troughs at two times: 1) during daylight on the morning after emergence, and 2) during darkness at night shortly following their emergence. In most cases fish planted during the day stayed in the troughs until darkness, then moved downstream. Fish planted at night usually went downstream immediately. However, on one night during full moon, the entire lot of fish planted after dark remained in the trough. The next night one of the troughs was covered with black polyethylene sheeting and the other exposed to the normal night light. In the moonlight system, 38 remained in the trough and 2 went downstream, while in the darkened trough, 5 remained and 35 went downstream.

The trap in Edson Creek was checked at midnight on a few nights at different stages of the moon to substantiate the experimental findings (Figure 14). During those days prior to full moon, the moon was already in the sky when nightfall came. During these nights most fish moved after midnight, and presumably after the moon went down. During those days after full moon, the moon did not come up until later in the evening. During these nights most fish moved before midnight, and few after the moon was up. During the dark of the moon, fish were captured in the trap throughout the

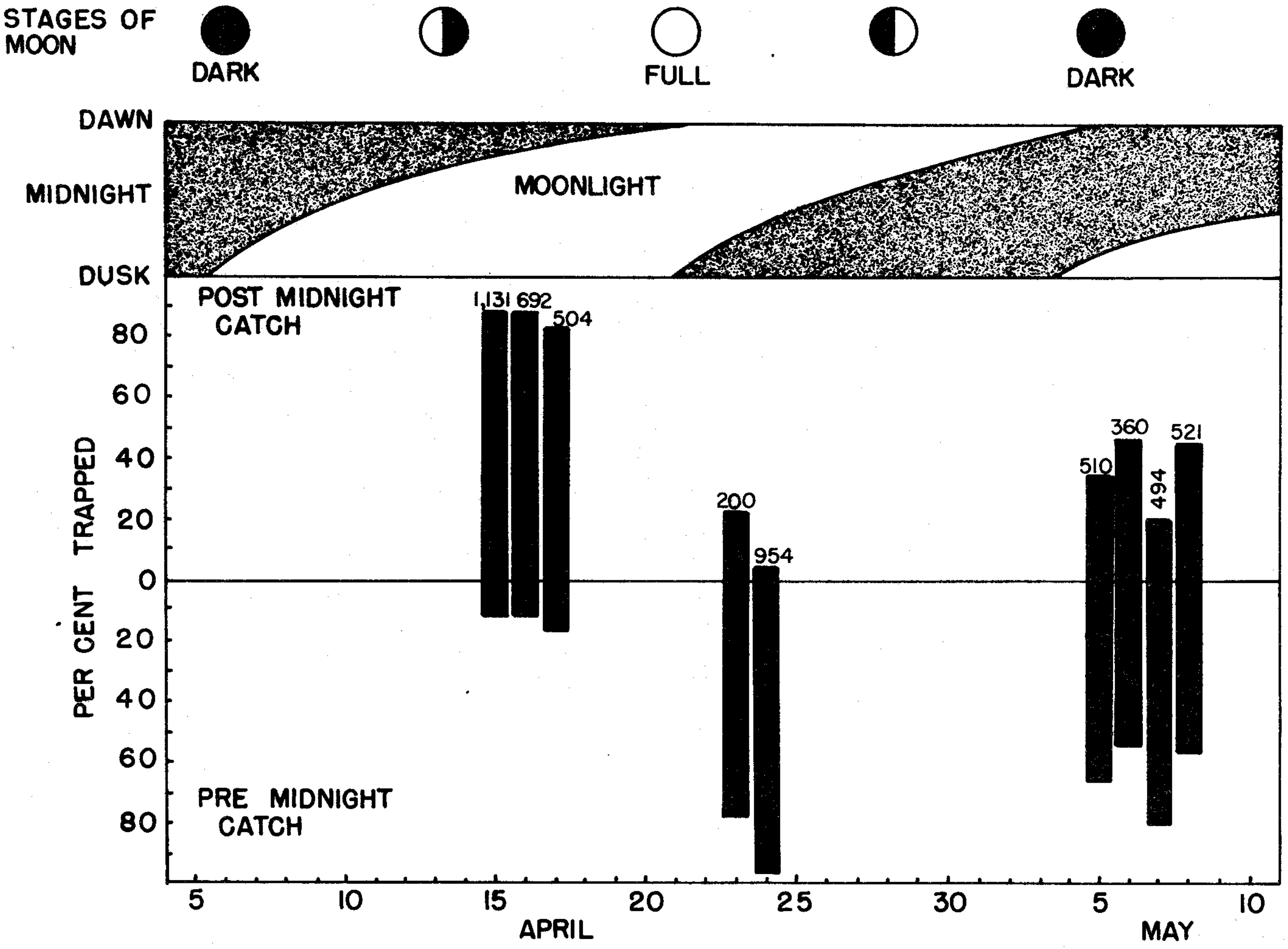


Figure 14. Period of downstream movement at night of newly emerged juvenile fall chinook salmon in Edson Creek compared to conditions of moonlight, 1970.

night. Variation in the distribution of catch may reflect differences in distance that newly emerged fish traveled downstream from emergence sites.

Based on the preceding analysis, I concluded that large numbers of juvenile fall chinook salmon in Sixes River left the spawning streams shortly after emergence and entered other areas in the river for rearing. A much smaller number of fish resided in the spawning streams.

## Long-Term Tributary Residence

Once residence in the tributaries was established, the fish developed patterns of agonistic social behavior (Reimers, 1968) and bright color patterns of stream fish (Stein and Reimers, 1970). Some fish remained and grew in the spawning streams through the summer and autumn. Unfortunately, no estimate of the number of fish residing in the tributaries is available, but the number was probably small considering the areas inhabited. Only an estimated 15 to 20 km of tributary streams were being used. Primary areas for this extended stream rearing were Edson, Dry, and Crystal creeks.

Most of these fish left the tributary streams during autumn. Some juveniles were fin marked or tagged with vinyl thread and pennant tags in Edson Creek during autumn, 1964. A total of 29 fish was marked in an upstream pool on September 16. Progressively fewer marked fish were recaptured each time the pool was seined (Table 5). These marked fish could not be identified downstream because the same mark had been used in other pools. From October 23 to November 4, a total of 107 fish was uniquely tagged along the stream. From October 27 to November 12, only 19 tagged fish were recovered, of which 9 had remained in the same pool. The remainder of the tagged fish that were recaptured were caught downstream from their tagging location. Seining in the creeks was difficult during the winter. Five juveniles were caught on January 17, 1965, but none could be caught on February 20, 1965.

Table 5. Number of marked juvenile fall chinook salmon recovered from one pool in Edson Creek at successive sampling, 1964.

| Date | Total Number Of Fish Caught | Number of Fish Marked | Number of Marked Fish Recovered | Percent Marked |
|---|---|---|---|---|
| September 16 | 29 | 29 | -- | -- |
| October 2 | 24 | -- | 20 | 83.0 |
| October 22 | 16 | -- | 12 | 75.0 |
| November 4 | 5 | -- | 2 | 40.0 |

## Residence in the Main River

In 1969, juveniles were followed from the spawning tributaries as they moved downstream through the main river and estuary and entered the ocean. Data on catch per seine haul for Dry Creek and Edson Creek were combined in 1969 and showed a pattern similar to that for Edson Creek in 1970 (Figure 15). The populations in the tributaries increased in April, peaked in May, and declined in June.

Peak abundance came about one month later in the main river than in the tributaries. At the time when peak numbers of fish were found in the tributaries, many fish were moving downstream into the main river. The population in the main river began increasing in May, reached a peak in June, and declined in July (Figure 15). A reduction in population by early to midsummer generally occurred during each year of this study. Relatively little information is available to explain this reduction, but high temperatures are thought to play an important role. In contrast to the cool tributaries where a small resident population remained, the main river became considerably warmer and possibly uninhabitable along much of its course (Figures 2 and 3).

The population of juveniles in the lower main river was larger in 1964 than in other years. These fish with extended residence grew well and reached an average size of about 9.0 cm. The summer of 1964 appeared cooler than other years, although direct data for comparison are not available.

In 1969 periodic trapping in the lower main river occurred from April 9 to August 13. Initial catches in April and May (Table 6)

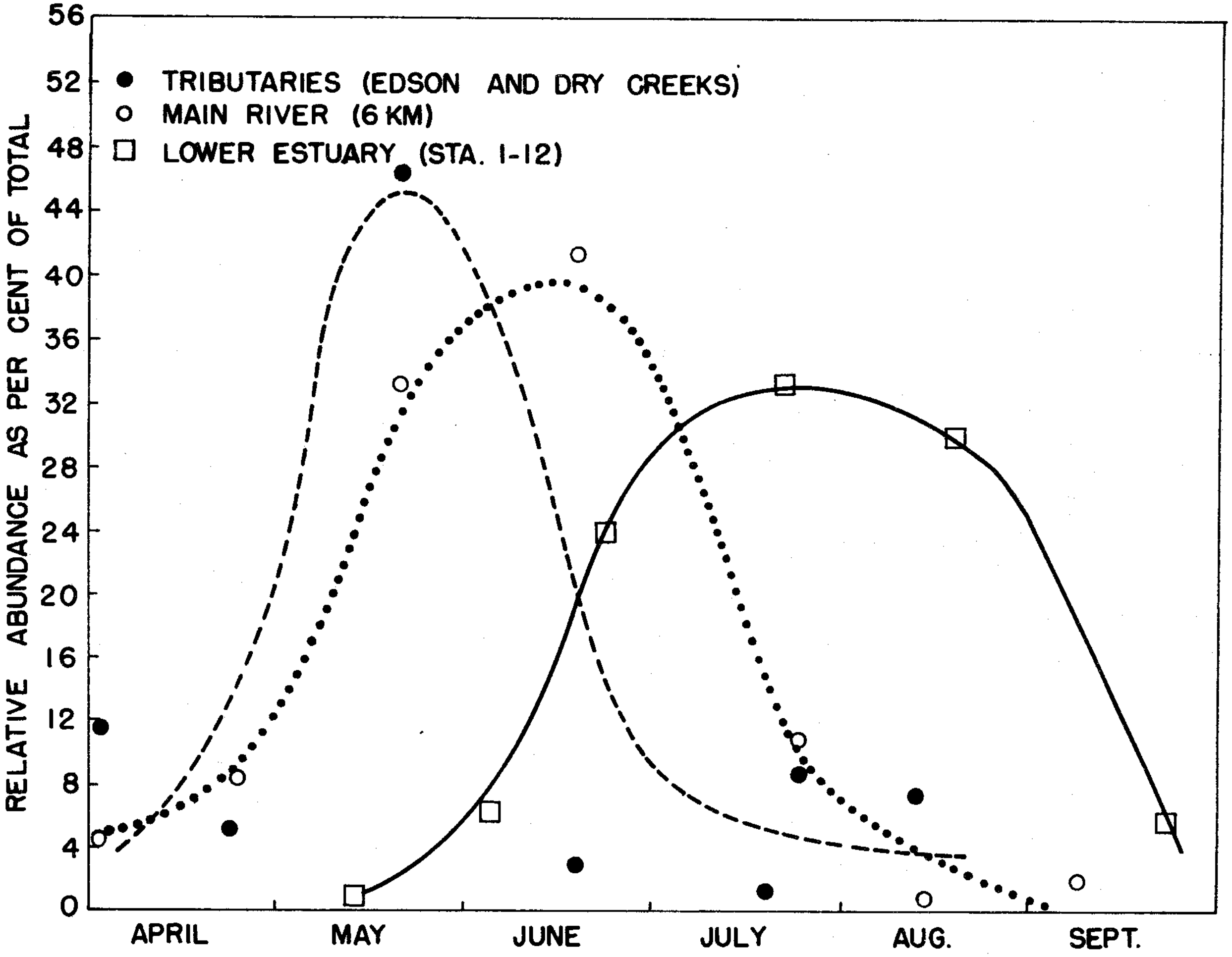


Figure 15. Estimated abundance of juvenile fall chinook salmon in tributaries (catch per seine haul), main river (catch per seine haul), and estuary (population estimates) of Sixes River, 1969.

indicated that some recently emerged fish moved into tidewater (Figure 16). The number of trapped fish reached a peak in late June and rapidly declined in July.

Table 6. Catch per trap-night of juvenile fall chinook salmon in lower Sixes River, 1969.

| Date | | Catch/Trap-night | Remarks |
|---|---|---|---|
| April | 9 | 65 | 1 trap operated near south shore |
| | 10 | 49 | 1 trap operated near south shore |
| | 24 | 91 | 3 traps, but incomplete trapping |
| | 29 | 13 | 1 trap operated near north shore |
| | 30 | 9 | 1 trap operated near north shore |
| May | 7 | 48 | 3 traps, but incomplete trapping |
| | 8 | 67 | 3 traps, but incomplete trapping |
| | 22 | 29 | 3 traps, but incomplete trapping |
| | 23 | 26 | 3 traps, but incomplete trapping |
| | 29 | 35 | 3 traps, but incomplete trapping |
| June | 11 | 252 | 3 traps extending across entire stream |
| | 12 | 183 | 3 traps extending across entire stream |
| | 18 | 110 | 3 traps extending across entire stream |
| | 19 | 276 | 3 traps extending across entire stream |
| | 20 | 321 | 3 traps extending across entire stream |
| | 26 | 414 | 3 traps extending across entire stream |
| | 27 | 616 | 3 traps extending across entire stream |
| July | 10 | 41 | 3 traps extending across entire stream |
| | 11 | 21 | 3 traps extending across entire stream |
| | 18 | 24 | 3 traps extending across entire stream |
| | 24 | 14 | 3 traps extending across entire stream |
| | 31 | 5 | 3 traps extending across entire stream |
| August | 13 | 2 | 3 traps extending across entire stream |

During their residence in the main river, the fish grew to an average size of 7.0 to 8.0 cm, based on the size of migrant and

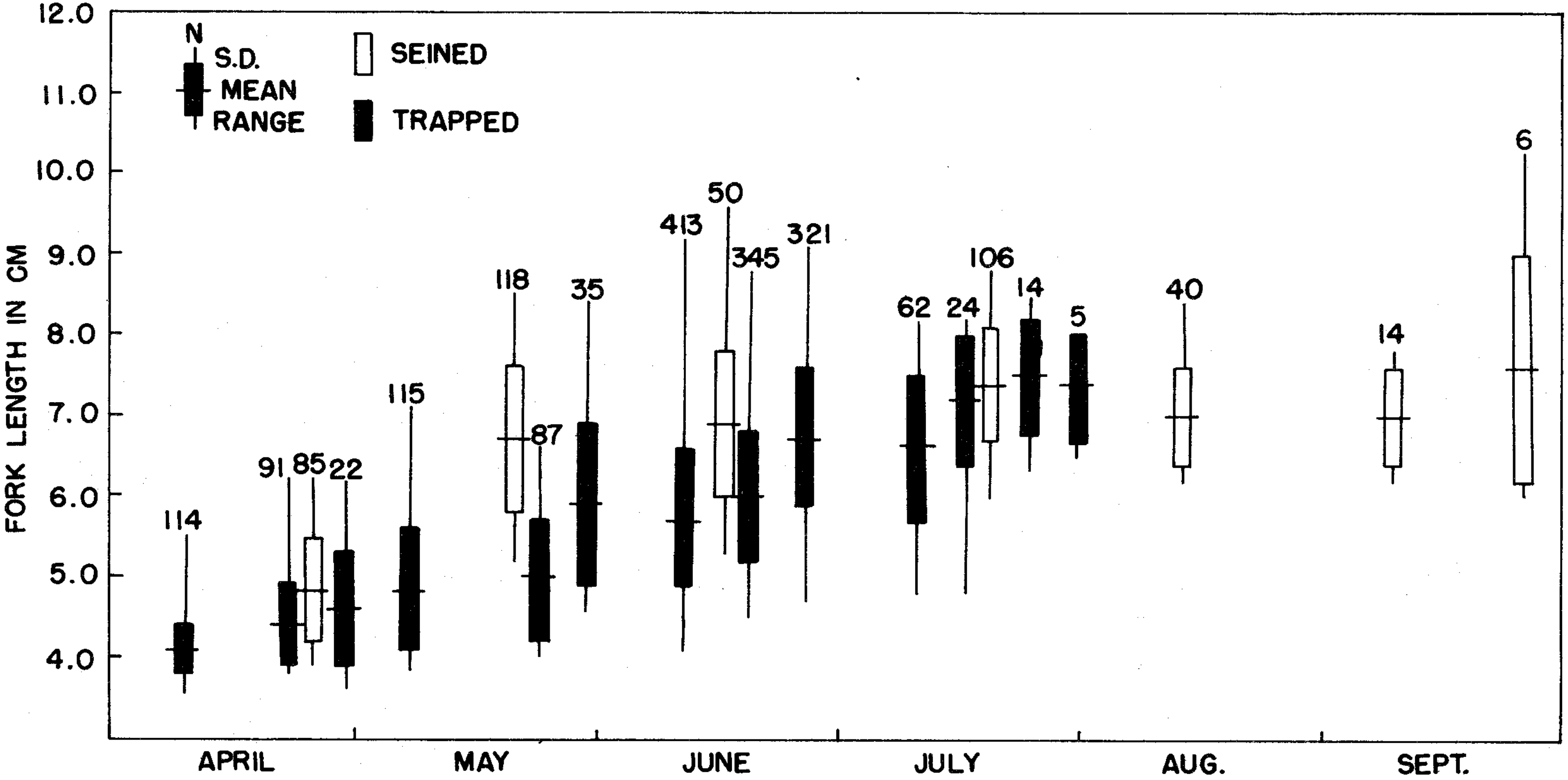


Figure 16. Length of juvenile fall chinook salmon captured in lower Sixes River, 1969. Fish caught with a seine were assumed to be resident. Trapped fish were captured moving downstream and were assumed to be migrants.

resident fish at the trapping location (Figure 16). Fish caught in the trap were assumed to be migrants, while fish caught with the seine were assumed to be residents. Migrants were slightly smaller than the residents. The number of juveniles residing in the main river before being recruited to the estuary was probably large, considering the large rearing pools in the main river and that juveniles were initially distributed along 30-35 km of river.

## Residence in the Estuary

After rearing for a time in the main river or tributaries, most juveniles from any brood moved downstream to the estuary (Figure 15). In 1969 the first juveniles entered the estuary in early spring, but there appeared to be few fish in the lower bay before mid-April. After the estuary flooded in late March and early April (Table 1), many juveniles were seined on April 7 and 14 at the Orchard Hole (near the head of tidewater), Boat Landing, and stations 10 and 6. Most fish appeared to be in shallow water near shore and were associated with logs and debris.

Relatively few fish were captured near the river mouth (stations 1 and 3) from March to May (Table 7). The first fish captured at stations 1 and 3 were three juveniles caught on April 21 and four juveniles caught on April 29. Juveniles had been captured at upper stations in the estuary about one month earlier. On May 13 and 14,

Table 7. Total number of juvenile fall chinook salmon seined from Sixes River estuary from March to May, 1969.

| Sampling Period | Number of Seine Hauls | Stations | |
|---|---|---|---|
| | | 1 and 3 | 4 to 12 |
| March | 22 | 0 | 13 |
| April | 38 | 7 | 357 |
| May | 86 | 28 | 596 |

the Oneida Lake trap net was fished at station 3. This trapping and seven seine hauls at stations 1 and 3 caught only 13 fish compared to 383 fish caught with 27 seine hauls at stations 4 to 12. Later in the summer the trap net caught from 200 to 1,000 fish per night at stations 1 and 3. Based on these observations, I concluded that few fish moved directly to the mouth of the river or into the ocean. By early June, juveniles were captured at all stations in the estuary and were also observed throughout the estuary and not just near the shore.

## Change in Abundance

The abundance of juveniles in the lower Sixes River estuary was estimated six times between May 12 and September 23, 1969 (Table 8). Although juveniles were present in the estuary during April and May, the population was small. However, by late May and early June, the population had greatly increased (Figure 17). A population of about 145,000 fish was reached in late July and early August. Subsequently,

Table 8. Population estimates of juvenile fall chinook salmon in lower Sixes River estuary, 1969.

| Marking Date | Recovery Date | Number Marked M | Number Sampled C | Number Recaptured R | Population Est.[a] N | Confidence Limits[b] 95% |
|---|---|---|---|---|---|---|
| May 12-14 | May 20-21 | 338 | 184 | 47 | 1,323 | $\overline{N}$ = 1,775<br>$\underline{N}$ = 987 |
| June 3-5 | June 9-10 | 1,780 | 1,934 | 124 | 27,800 | $\overline{N}$ = 32,920<br>$\underline{N}$ = 23,460 |
| June 23-25 | June 30-July 1 | 4,744 | 3,857 | 175 | 104,560 | $\overline{N}$ = 121,240<br>$\underline{N}$ = 90,180 |
| July 22-23 | July 28-29 | 5,412 | 3,183 | 119 | 144,760 | $\overline{N}$ = 173,200<br>$\underline{N}$ = 120,990 |
| August 18-19 | August 25-26 | 4,484 | 2,068 | 69 | 134,390 | $\overline{N}$ = 171,720<br>$\underline{N}$ = 106,590 |
| September 22-23 | September 29-30 | 2,520 | 1,643 | 172 | 24,070 | $\overline{N}$ = 27,820<br>$\underline{N}$ = 20,860 |

[a] Population estimates were calculated after Ricker (1958).

$$N = \frac{MC}{R}$$

[b] Confidence intervals (95%) were calculated using the various formulae of Chapman (1948).

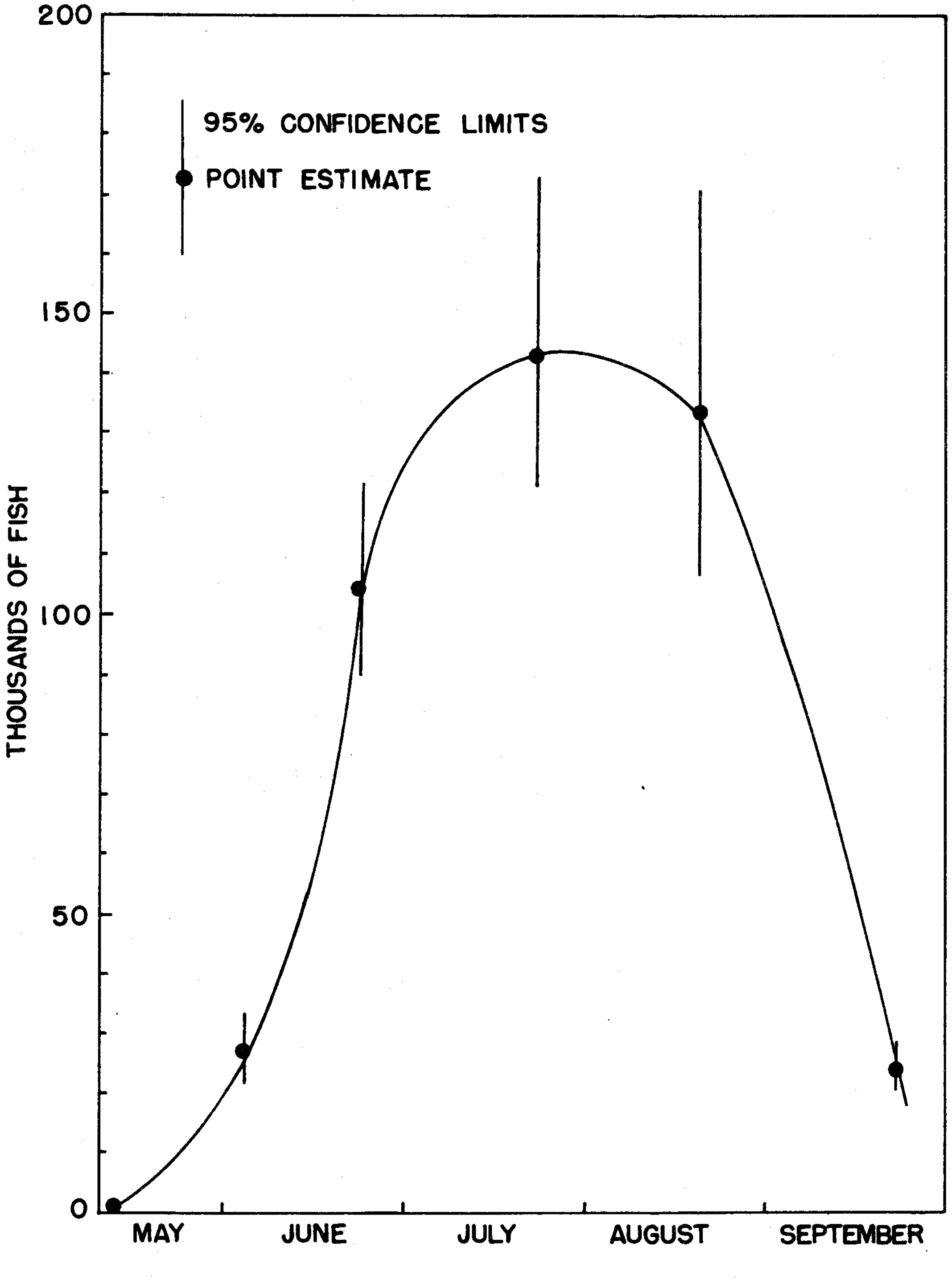


Figure 17. Estimated number of juvenile fall chinook salmon in lower Sixes River estuary, 1969.

the population declined to a low of about 25,000 fish in late September.

Many fish may have been moving to the ocean during the period of high population density in the estuary. In 1966 during June, as many as 300 juveniles per seine haul were captured in the outflow channel and ocean surf within 100 m to the north and south of Sixes River. However, later in summer only a few fish were captured in these localities. Juveniles captured in the ocean surf and outflow channel were the same size as the juveniles in the estuary (Fish Commission of Oregon, 1967).

Another measure of the change in population size in the estuary was data on catch per seine haul with the 38-m seine. Catch per seine haul of juveniles for the lower estuary during 1969 was variable but showed a pattern similar to the population estimates (Figure 18). Comparison of data on catch per seine haul for the upper and lower parts of the estuary suggests that peak abundance came about five to six weeks earlier at the head of tidewater than near the mouth.

There was a close relationship between catch per seine haul and the population estimates of juveniles in the lower bay (Figure 19). The first five population estimates and their corresponding catch per seine haul fell on a straight line. The last point deviated from the line. This probably resulted from variability in the catch per seine haul rather than an error in the population estimate. By autumn, these large, mobile juveniles tended to congregate near the mouth

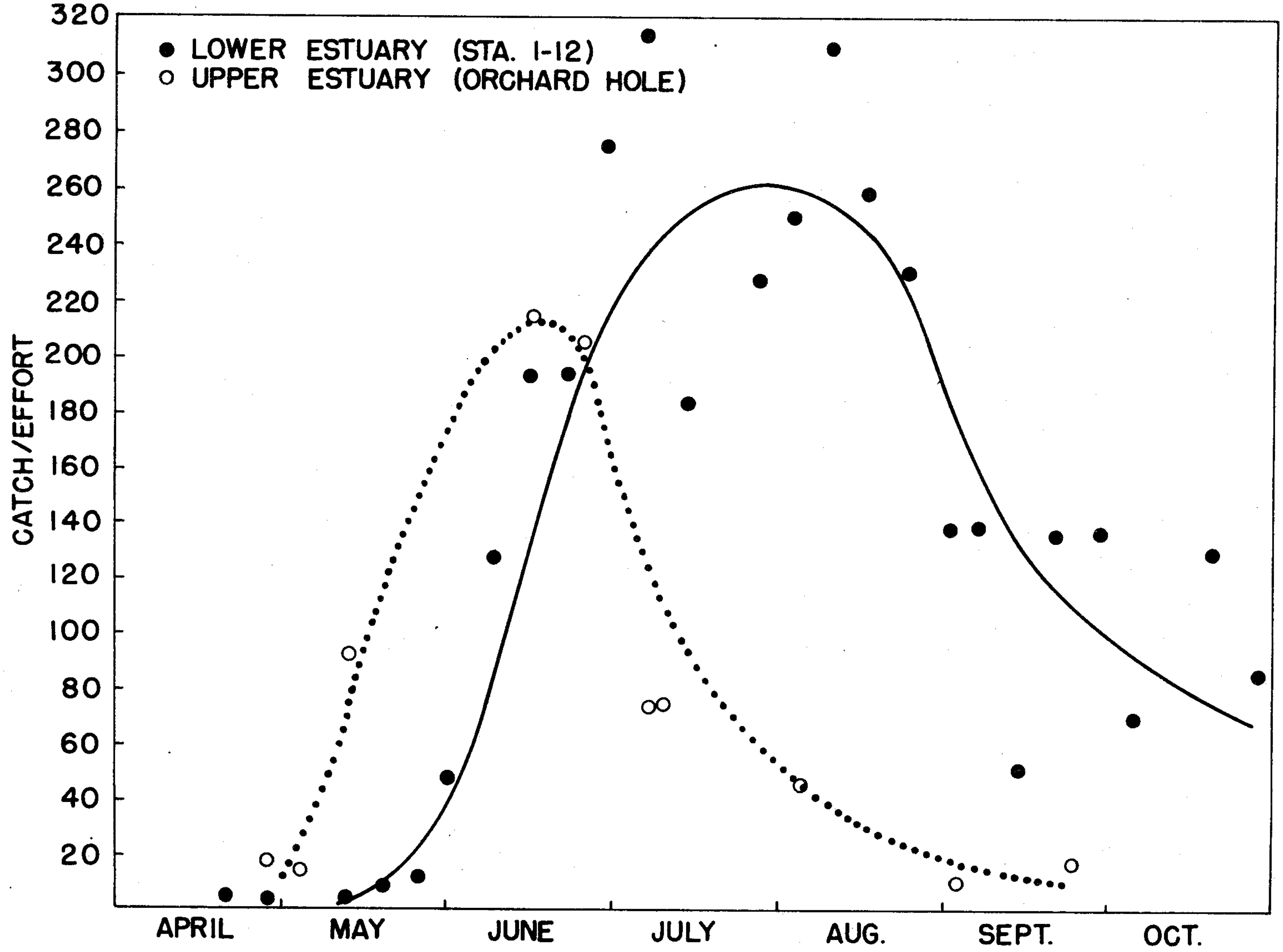


Figure 18. Catch per seine haul of juvenile fall chinook salmon collected with a 38-m beach seine in Sixes River estuary, 1969.

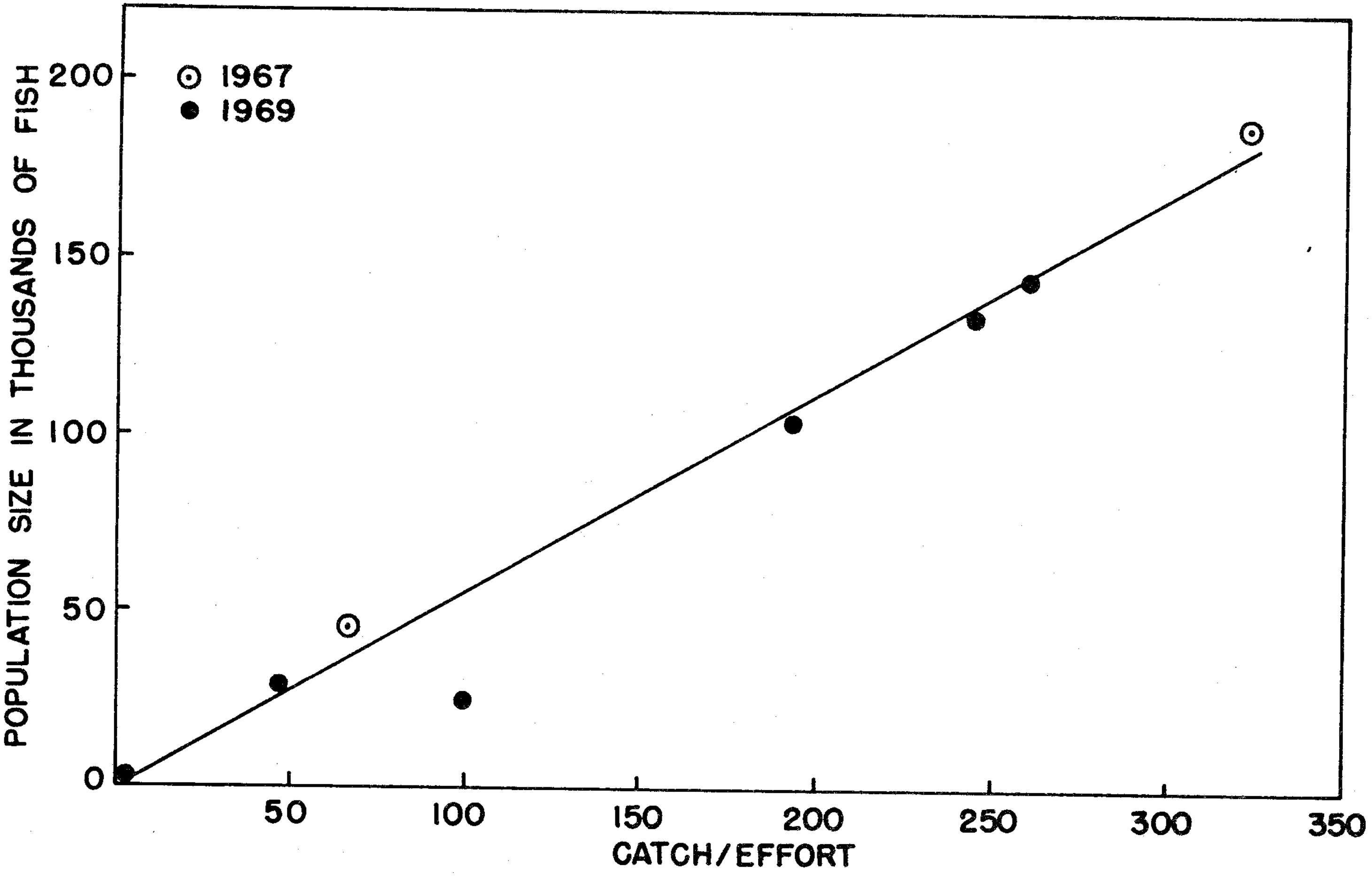


Figure 19. Relationship between average catch per seine haul with the 38-m seine and the estimated population of juvenile fall chinook salmon in lower Sixes River estuary, 1967 and 1969.

where they could be easily captured.

Two population estimates and their associated catch per seine haul obtained in Sixes River estuary during 1967 (Fish Commission of Oregon, 1968) were plotted in Figure 19. The data fit the line reasonably well, suggesting that in any year where data on catch per seine haul are available, population estimates may be obtained.

## Growth of Juveniles

In 1969, the length of 8,421 fish was measured in the lower estuary. The average weekly sample size was 290 fish. The first fish measured on March 18 were all recently emerged.

Initially, the few fish taken at stations 1 and 3 were larger than those taken at stations 4 to 12 (Table 9).

Table 9. Size of juvenile fall chinook salmon captured at stations 1and 3 compared to stations 4 to 12 in Sixes River estuary,1969.

| | Stations 1 and 3 | | | Stations 4 to 12 | | |
|---|---|---|---|---|---|---|
| Date | N | Mean Length (cm) | Range (cm) | N | Mean Length (cm) | Range (cm) |
| May 13-14 | 13 | 6.78 | 6.1-8.0 | 62 | 4.93 | 3.8-6.9 |
| May 20-21 | 15 | 6.20 | 4.7-7.2 | 118 | 6.67 | 4.1-9.3 |
| May 26 | 11 | 7.69 | 5.4-8.8 | 44 | 7.54 | 6.0-9.0 |

The average increase in length during April was small, although the increase of the upper range suggests that some growth was occurring (Figure 20). By late April and throughout May, the rate of growth in the lower estuary was rapid. Average fork length increased from 4.8 cm on April 29 to 7.9 cm on June 2. During June, July, and August, there was only a slight increase in the average length. From late August to mid-November, the average length increased from 8.5 to 12.5 cm.

Trapped fish entering the upper estuary were smaller than those residing in the lower estuary (Figures 16 and 20). The disparity was initially 0.2 cm in April and progressively increased to 2.0 cm in June.

During the period of reduced growth in the lower estuary, the upper range and entire distribution of size closely followed the pattern of the mean. As growth increased in late summer and autumn, the upper range increased at the same accelerated rate as the mean, and the entire size distribution shifted upward.

Growth of marked fish generally followed the same pattern as the unmarked fish but with slightly more variation. A direct comparison of the average size of the marked and unmarked fish suggests they grew at similar rates (Figure 21). The first group of marked fish grew rapidly from mid-May to early June, although not as fast as the unmarked fish. Marked fish in the second and third groups grew little from early June to mid-August. However, these marked

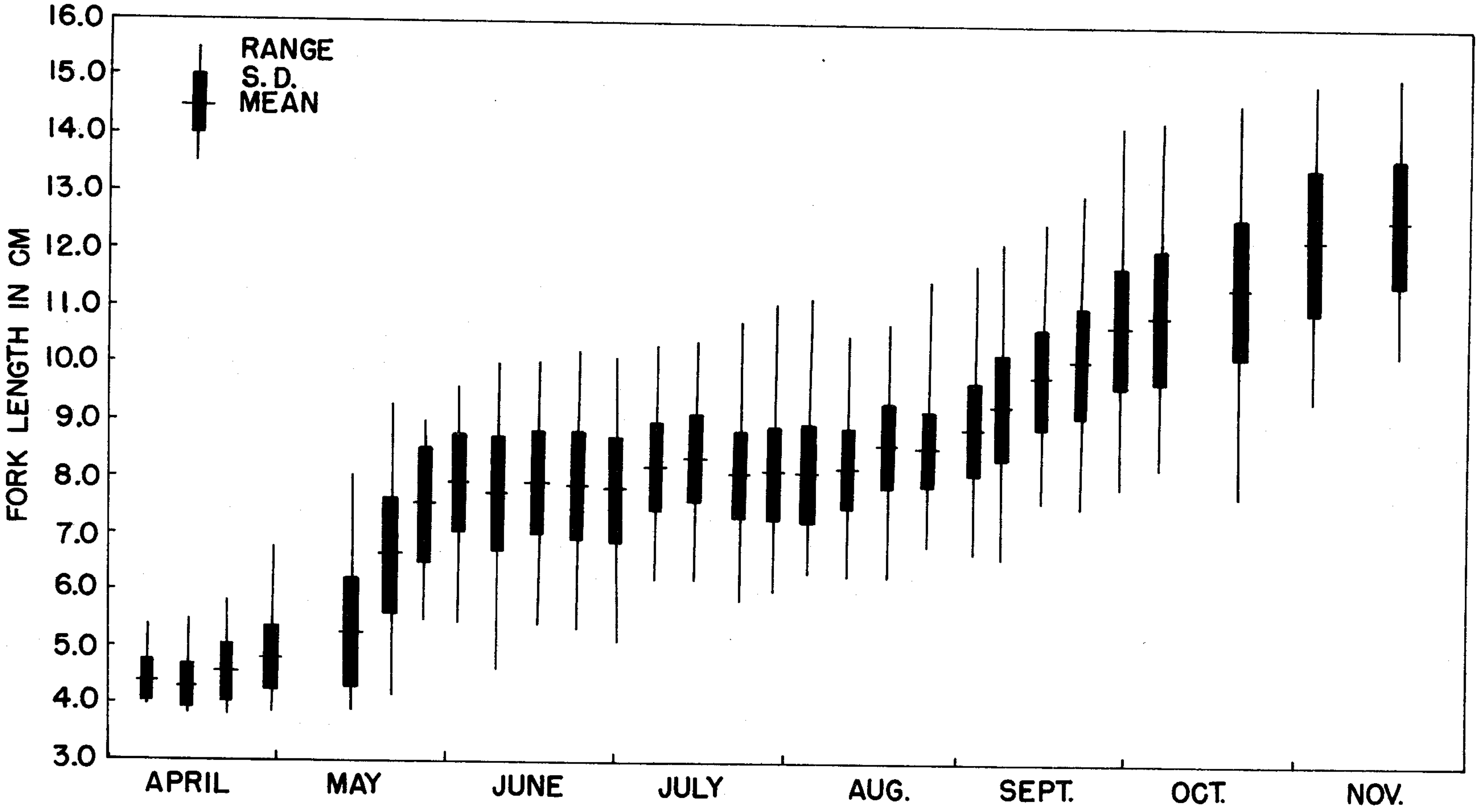


Figure 20. Length of juvenile fall chinook salmon seined in lower Sixes River estuary (stations 1-12), 1969. Sample size averaged 290 and ranged from 32 to 731.

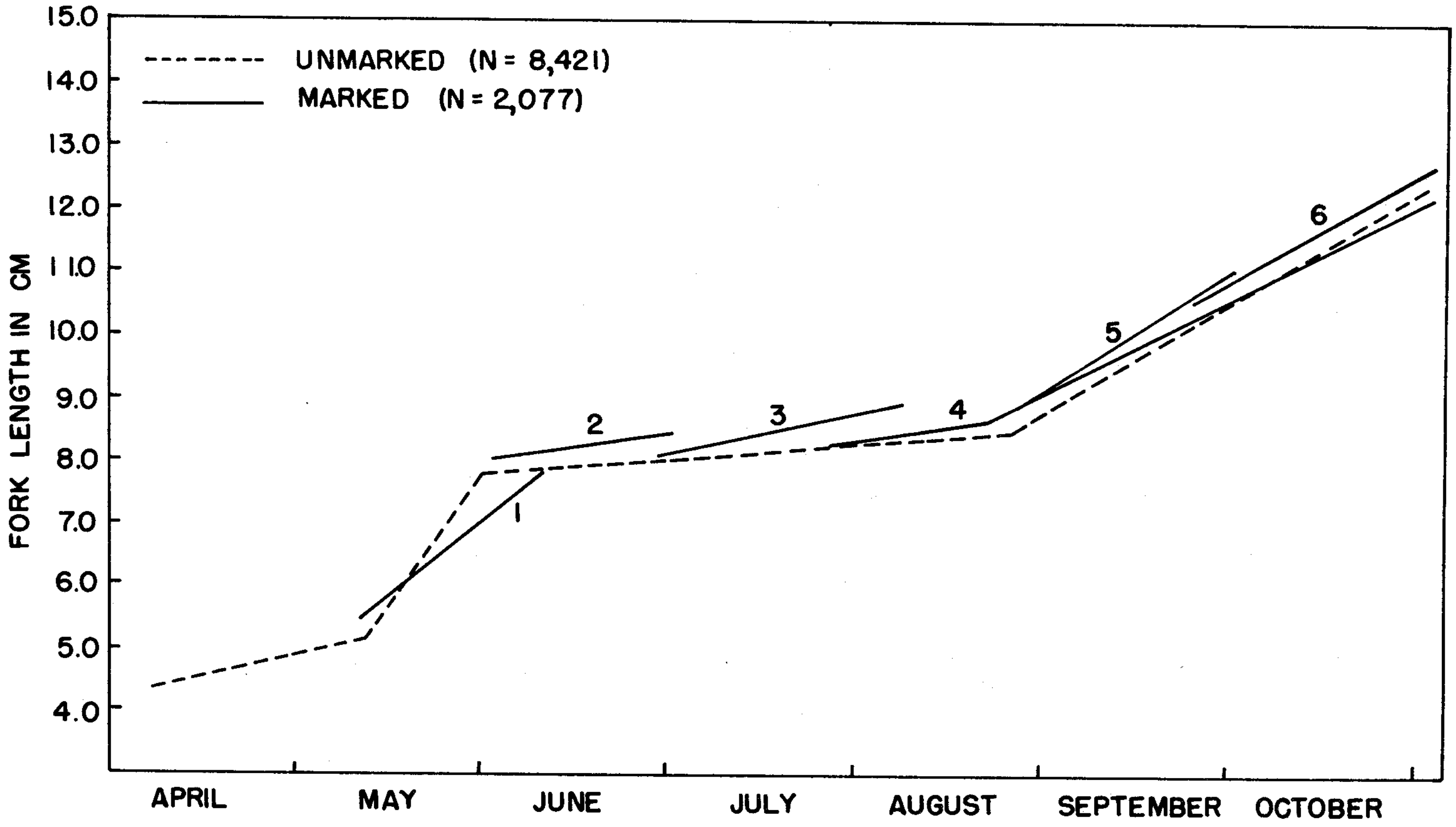


Figure 21. Average length of marked and unmarked juvenile fall chinook salmon seined in lower Sixes River estuary, 1969. Lines for each group were fitted by inspection through the average length of fish at each date.

groups did show signs of slightly improved growth after being at large about a month. Marked fish in the fourth group grew slowly from late July to the end of August. Then their growth showed the same increase as the unmarked fish. Through September and October their growth followed closely the accelerated rate of the unmarked fish. Marked fish in the fifth and sixth groups grew rapidly at the same rate as the unmarked fish.

### Terminal Population

By autumn relatively few fish remained in the estuary (Figure 17). These fish were large (Figure 20) and appeared to be in excellent condition. After the autumn rains, the estuary changed from a saline to a freshwater environment. At this time most of the fish apparently emigrated to the ocean.

## Yearling Migrants

During the winter and spring of each year, only a few yearlings have been collected in the main river and in the estuary. The total number captured in each year ranged from 1 to 63. No precise record of the number of seine hauls was kept, but the effort was extensive. The total number captured suggests that yearlings were scarce. These fish probably originated from the long-term residents in the spawning streams. In the winter of 1965, a few yearlings were found in Edson Creek. In several years, yearlings were also found just below Dry Creek in the main river. The size of yearlings seemed to be a continuation of growth of juveniles from the tributary streams (Figure 22), rather than of extended residents from the estuary. Yearlings reached a size in June similar to that of juveniles that were present in the estuary the preceding autumn just before migration to the ocean.

## Scale Studies

Now that a general picture of the length of residence of the juveniles has been developed, the need remains to determine the contribution of various juvenile life histories to returning spawners.

### Types of Life Histories

For purposes of discussion, five major types of life histories were arbitrarily defined from the study of juveniles (Table 10). Only sketchy information is available on the relative number of juveniles from any brood that resided in different areas of the river or migrated to the ocean at various times to be classified into one of the five types of life histories. Few fish were captured in the estuary in early spring and even fewer at the mouth of the river. Whether any of these juveniles entered the ocean to become type-1 fish is unknown, but the number was probably small. Most juveniles probably became

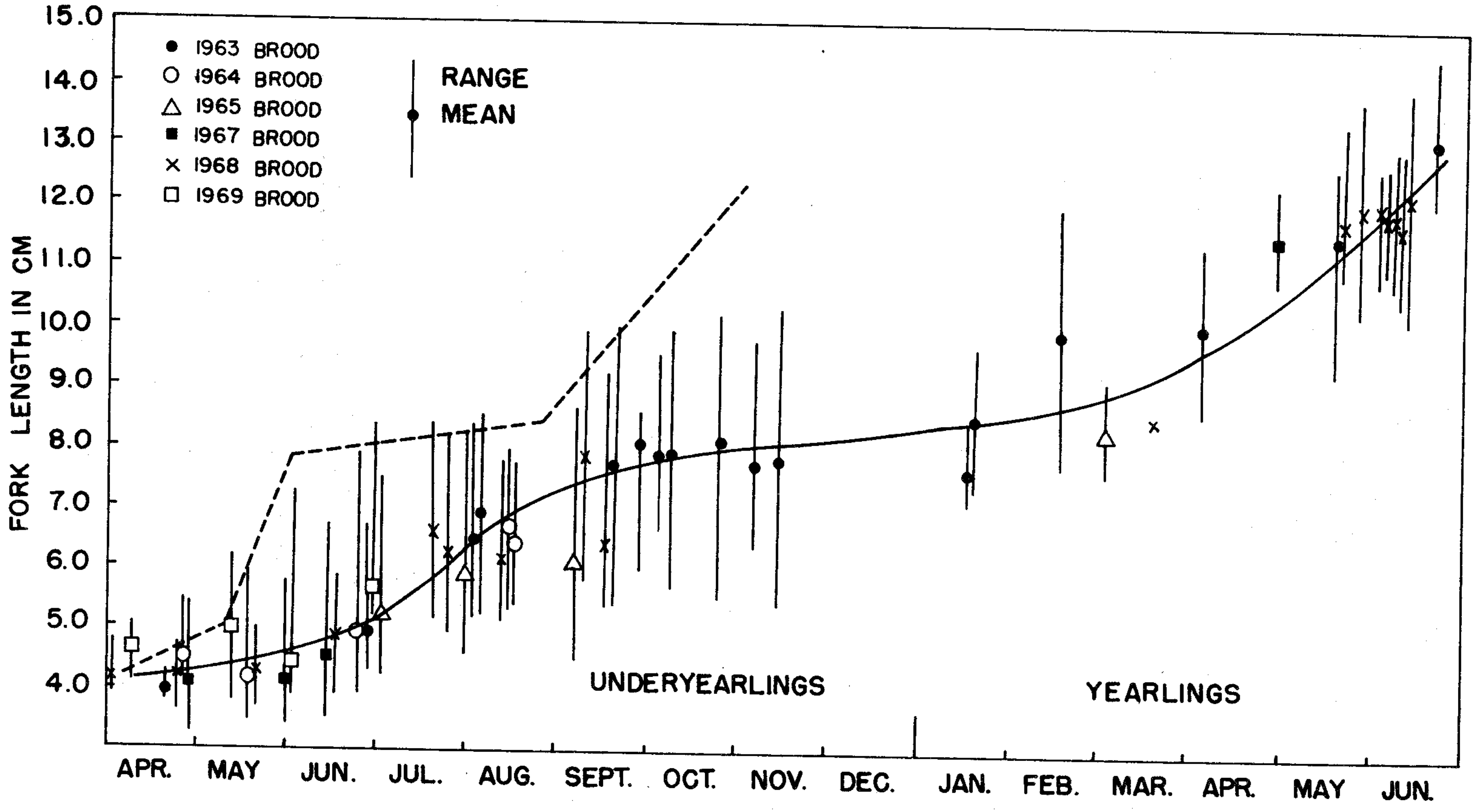


Figure 22. Length of juvenile fall chinook salmon seined as underyearlings in Edson Creek and as yearlings in Sixes River estuary from 1964 to 1970 (line fitted by inspection). Sample size averaged 45 and ranged from 1 to 338. The dotted line represents the change in average size of underyearlings in Sixes River estuary in 1969.

Table 10. Description of the major types of life histories of juvenile fall chinook salmon in Sixes River, Oregon.

| Type | Description |
|---|---|
| 1 | Emerge from the gravel, move directly downstream through the main river, estuary, and into the ocean within a few weeks. |
| 2 | Emerge from the gravel, move into the main river (or possibly stay in the tributaries) for rearing until early summer, then move into the estuary for a short period, and finally into the ocean prior to the period of improved growth in the estuary during late summer and autumn. |
| 3 | Emerge from the gravel, move into the main river (or possibly stay in the tributaries) for rearing until early summer, then move into the estuary for extended rearing, and finally enter the ocean after experiencing improved growth in the estuary during late summer and autumn. |
| 4 | Emerge from the gravel, stay in the tributary streams (or rarely in the main river) until the autumn rains, then move directly to the ocean. |
| 5 | Emerge from the gravel, stay in the tributary streams (or rarely in the main river) through the summer, autumn, and winter, and then enter the ocean during the following spring as yearlings. |

type-2 fish, based on the curve of population abundance derived for the estuary (Figure 17). During the time of large population abundance and reduced growth, many juveniles left the estuary and were captured in the ocean surf. Presumably, they were also present beyond the surf zone in the open ocean. Compared to the number of type-2 fish, fewer juveniles remained in the estuary until late summer and autumn to experience improved growth and be classified as type-3 fish. The differences between type-2 and type-3 fish were less distinct than among the other types. But the classification is preserved because the period of reduced growth in the estuary was long enough that many fish probably would have entered the ocean without forming typical estuarine circuli on their scales. After growth of juveniles in the estuary improved, fish continued to enter the ocean. These juveniles were classified as type-3 fish, since they probably would have possessed typical estuarine circuli on their scales. The number of fish remaining in the tributaries until autumn to become type-4 juveniles was probably intermediate between the number of type 3 and the combined total of types 1 and 5. Yearling fish were captured in each spring, but the number of these type-5 fish was always small. The suggested relative order of decreasing abundance for the different types of life histories is 2, 3, 4, 5, and 1.

## Scale Characteristics of Life History Types

An attempt was made to differentiate scale patterns of fish from the various types of life histories by comparing scales of juveniles and spawners. Fundamental to the scale analysis was the ability to distinguish among circuli formed in fresh water, estuary, and ocean. Differences in conditions for growth of fish in these three environments were assumed to be reflected on their scales. Slow growth was expected to be represented by narrow circuli spacing and rapid growth by wide circuli spacing. Therefore, estuarine circuli should have been intermediate in spacing between those formed in fresh water and the ocean.

Most of the scale analysis was conducted for 1965-brood fish, since that was the only brood for which complete returns of spawners were available. Since most of the data on length of residence and growth presented in this thesis are for the 1968 brood, differences between the years need to be resolved. Differences in the length of residence and growth of juveniles in fresh water among all the years studied appeared to be minimal, except for extended residence and larger size of juveniles in 1964. Length of residence in the estuary was similar among all the years studied, although variability in population abundance probably occurred. Possibly as a result of different population levels, there appeared to be considerable differences in growth of juveniles in the estuary among the years. Differences in growth were small between 1966 and 1969 and probably do not preclude a direct comparison between the scale patterns of 1965-brood fish and our detailed knowledge of growth and length of residence of 1968-brood juveniles. A period of reduced growth was also observed in 1966 (Fish Commission of Oregon, 1970). In 1966 and 1969 the size of juveniles during the period of reduced growth was almost identical (8.0 to 8.5 cm). In 1969 the period of reduced growth lasted about three months, but during 1966 it lasted only about two months. The length of this period appeared to dictate the final size of the juveniles in autumn, as the rates of growth in the two years were similar once growth improved. In 1966 they reached a length of about 12.5 cm near the middle of October, while in 1969 they were about 1 cm shorter.

Juveniles from the 1965 brood were collected for scale analysis at the following times and areas in Sixes River: 1) trapped moving downstream in the lower river from May 20 to June 13, 2) seined in the estuary from May 26 to June 26 (these fish were assumed to be recently recruited to the estuary, since the population was rapidly increasing), 3) seined from tributaries on September 6, 4) seined from the estuary on October 6, and 5) seined as yearlings during May and June (because of a lack of yearlings from the 1965 brood, fish from the 1967 brood were used). Available samples from each area were stratified by date and size of fish.

Comparative plots were made of average circuli spacing for a series of scales to examine differences among freshwater, estuarine, and oceanic circuli (Figure 23). In part one of the figure are the measurements for juveniles collected at four key locations and times. All of these measurements of average circuli spacing were small and known to have been produced in fresh water.

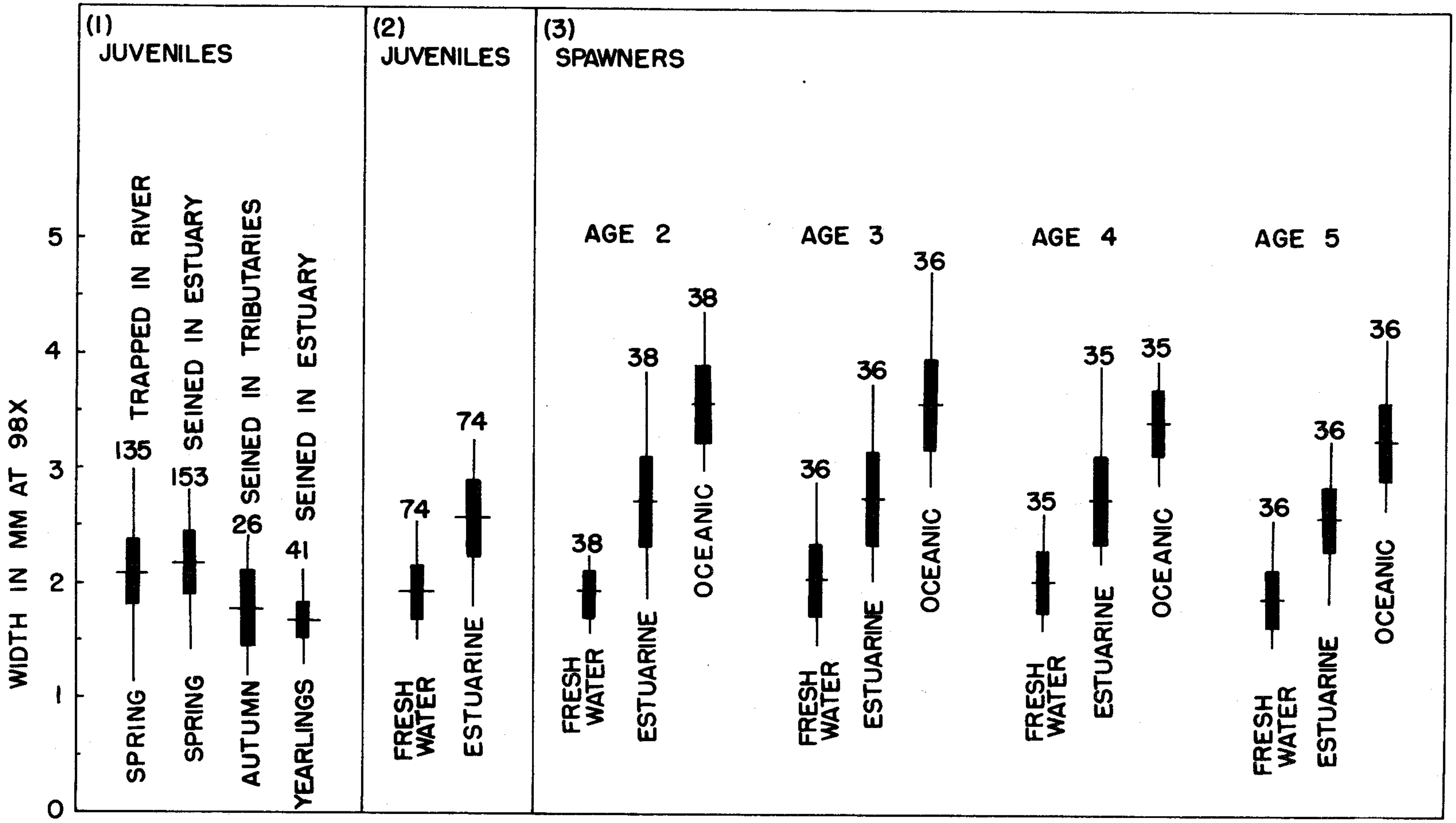


Figure 23. Comparison of average circuli spacing on scales of juvenile and spawning fall chinook salmon in Sixes River. 1. Freshwater circuli on scales of juveniles collected from four known areas and times. 2. Circuli visually separated into freshwater and estuarine zones on scales of juveniles collected from the estuary in autumn. 3. Circuli visually separated into freshwater, estuarine, and oceanic zones in the first 50 circuli of scales of spawners.

In part two of Figure 23 are scales from juveniles seined in the estuary in autumn. These fish possessed circuli that appeared to be of two distinct spacings. The boundary between these zones of circuli was abrupt. Because these fish were captured in the estuary in autumn, their background could have involved varying amounts of both freshwater and estuarine growth. The two major zones on the scales were arbitrarily called freshwater and estuarine when plotted. The zone classified as freshwater had measurements of average circuli spacing that were midway among measurements on the four groups of juveniles known to be from fresh water. The other zone had measurements of average circuli spacing that were larger and therefore must have been formed in the estuary.

These scales from juveniles captured in the estuary in autumn had an additional feature that needs description. If growth of juveniles in the estuary was reduced for a period during summer, some reflection of this should be present on their scales. Close examination of the scales revealed that about 70 percent possessed circuli near the outside edge of the area previously defined as "freshwater" that were either 1) thinner and with narrower spacing than those observed nearer the nucleus, or 2) interrupted or broken and appeared to cross other circuli. The number of these circuli of reduced estuarine growth ranged from 2 to 7 with a mode at 4. Further discussion of circuli classified as freshwater should be understood to also include circuli formed during the period of reduced growth.

In part three of Figure 23 are scales from four age groups of spawners collected throughout Sixes River. The first 50 circuli on these fish appeared to be of three distinct spacings. The boundaries between adjacent zones of circuli were abrupt. Because these fish could possess circuli formed in fresh water, estuary, and ocean, these zones were initially classified in this manner and plotted. Measurements of average circuli spacing for those circuli classified as freshwater match well with measurements of freshwater circuli in parts one and two of Figure 23. Also, measurements of average circuli spacing of the zone classified as estuarine on the spawning fish match well with the measurements obtained for estuarine circuli in part two of Figure 23. The measurements of the third zone on the scales were considerably wider than those classified as freshwater and estuarine and therefore, were probably formed in the ocean. Based on this examination, I concluded that circuli on returning spawners could be divided into those formed in the three major environments by using average circuli spacing and that these zones were distinct.

Separation of adults into the various types of life histories was based on recognizing freshwater, estuarine, and oceanic circuli on the scales and subjective determination of 1) the relative number of circuli formed in each area, and 2) the position of the first oceanic annulus.

The primary difficulty in this system was the recognition of the first oceanic annulus. For fish that enter the ocean in autumn, general conditions for growth are improved over those in fresh water or the estuary but apparently are not those of prime oceanic growth that might be experienced during the spring and summer. An annulus did not always show strong development but could usually be recognized by the rapid change to wider circuli spacing of prime spring growth that followed. Annuli formed in later years tended to be more obvious.

Criteria for recognizing the various types of life histories on spawners were developed (Figure 24). Although no examples of type-1 fish were found, they should show few, if any, freshwater circuli followed by wide circuli formed in the ocean. Type-2 fish show considerable freshwater circuli and then an abrupt change to wide circuli of the ocean. The first annulus is located far from the nucleus because of the extended good growth that these fish experienced in the ocean. Type-3 fish show considerable freshwater circuli followed by a band of intermediate estuarine circuli, before changing to oceanic circuli. The first oceanic annulus is near the estuarine circuli because these fish entered the ocean in autumn, leaving little time for oceanic growth before winter. Type-4 fish show an oceanic pattern similar to the type-3 fish but lack any estuarine

Figure 24. Scale characteristics of fall chinook salmon classified into various types of life histories.

A. Juvenile of type 3 captured in the estuary in autumn showing the outside edge of freshwater circuli (F) and the outside edge of estuarine circuli (E).

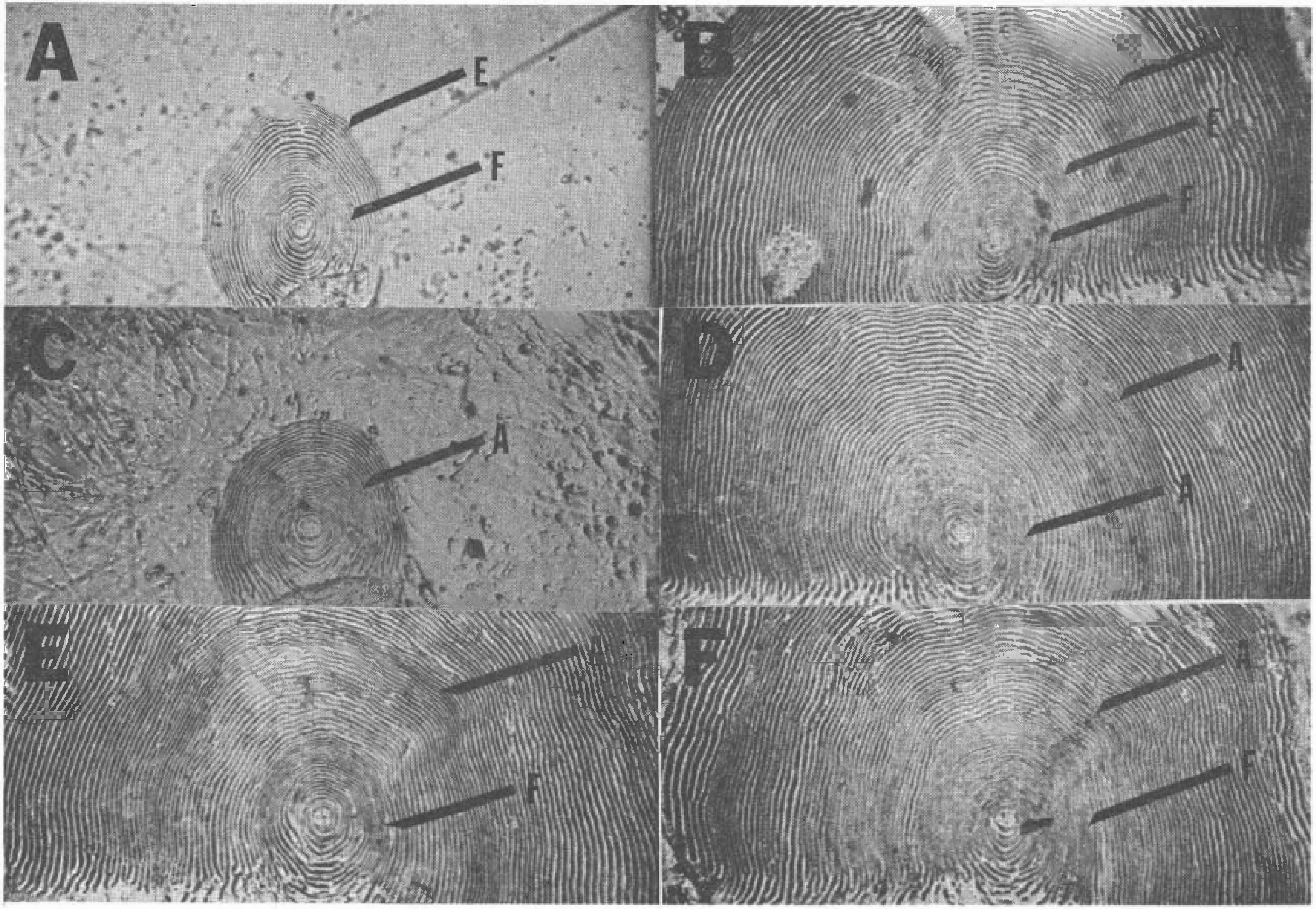
B. Spawner of type 3 showing the edge of freshwater circuli (F), the edge of estuarine circuli (E), and the first annulus (A) in the ocean.

C. Juvenile of type 5 captured in the estuary in spring showing the location of the annulus (A). The improved spring growth that follows was not observed on all scales.

D. Spawner of type 5 showing the location of the annulus (A) at the end of freshwater growth and the first annulus (A) in the ocean.

E. Spawner of type 2 showing the edge of freshwater circuli (F) and the first annulus (A) in the ocean. Note the similarity between the freshwater zones on this spawner and the type-3 juvenile.

F. Spawner of type 4 showing the edge of freshwater circuli (F) and the first annulus (A) in the ocean. Note the greater number of freshwater circuli than on the type-2 spawner.


A
E
F
B
A
E
F
C
A
D
A
A
E
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F

growth. They are distinguished from type-2 fish by differences in the relative amount of freshwater and oceanic growth and the average circuli spacing in the freshwater zone. Type-5 fish show many freshwater circuli followed by many oceanic circuli of prime growth. The first oceanic annulus is located farther from the nucleus on these scales than on types 2, 3, and 4.

Counts of freshwater circuli on the various juveniles support criteria for separation of the various types of life histories (Figure 25). The number of freshwater circuli on yearlings averaged about 32 and ranged from 23 to 38. They possessed many more freshwater circuli than any other group. Juveniles in the estuary in autumn had freshwater circuli ranging from 12 to 19 and averaging about 15. These circuli included those formed in the estuary during the period of reduced growth. This probably accounts for the additional four circuli on the average on these scales than on juveniles trapped entering the estuary or seined in the estuary in spring.

The number of freshwater circuli on scales of juveniles from the tributaries was smaller than the number of freshwater circuli on juveniles in the estuary in autumn. Since the juveniles in the tributaries were sampled early in autumn, they probably added more circuli and became similar to type-3 fish or may even have had numbers of circuli that approached those of yearlings, depending on how late they remained.

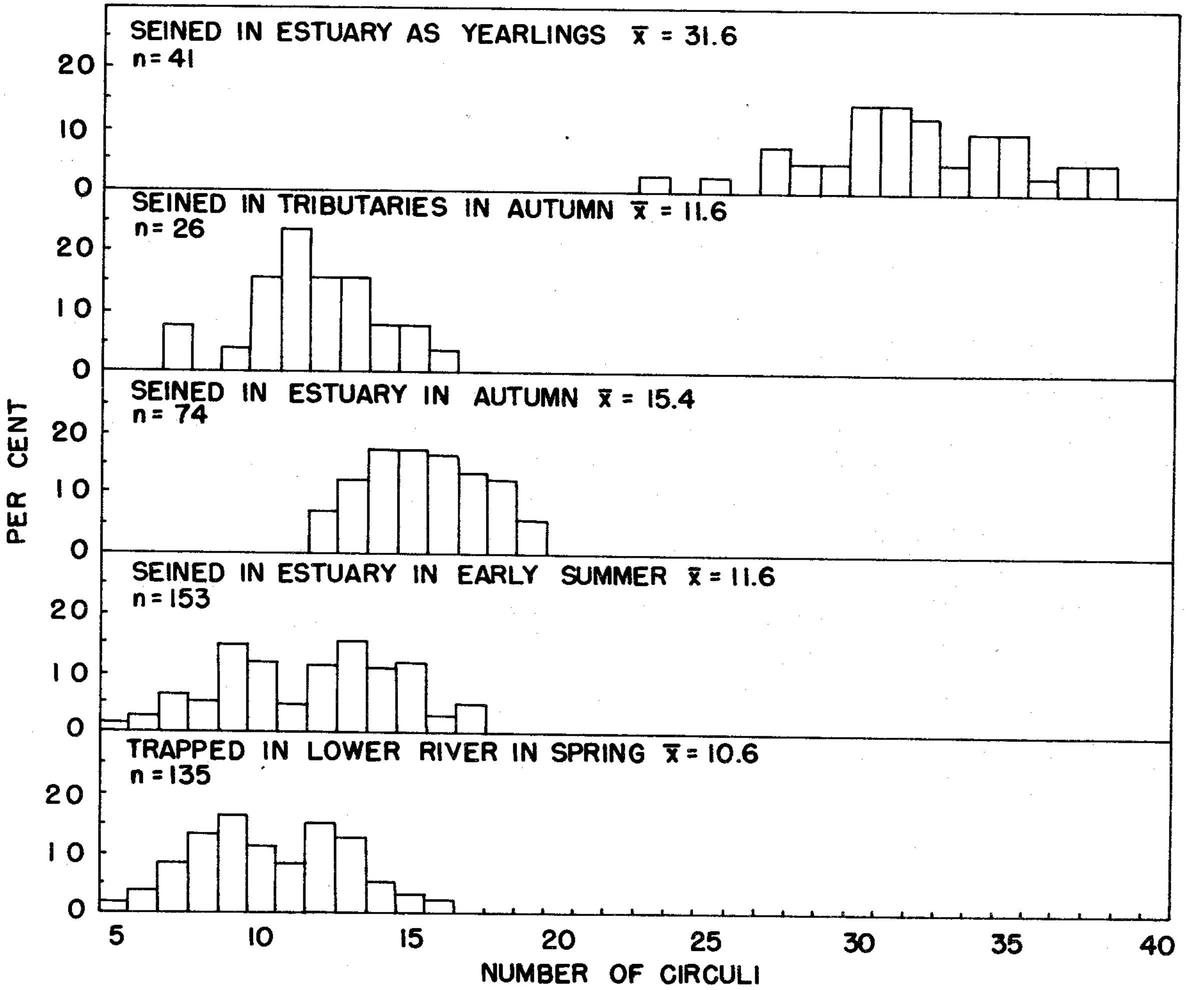

Figure 25. Number of circuli classified as freshwater on scales of juvenile fall chinook salmon collected at various locations and times, 1965 brood (yearlings were from the 1967 brood).

## Life History of Successful Spawners

A sample of 160 spawning fish originating from the 1965 brood was selected by stratifying by age and sampling date. As an initial approach to determining where the successful spawners reared in their first year of life, counts and measurements were made of the first 50 circuli on these fish (Figure 26).

The width of the scale image (98X) for the first five circuli averaged 10.6 mm, probably reflecting conditions of good growth in spring shortly after emergence from the gravel. The average width of the second and third bands of circuli was reduced to 9.9 and 9.5 mm. These measurements probably represented typical freshwater growth. The fourth band of circuli showed a rapid increase in width to 12.5 mm while the fifth and sixth bands leveled off at 14.0 mm. These bands probably represented improved growth in the estuary. The seventh band showed an additional increase in width to 17.2 mm. This wide spacing was generally maintained from the eighth to tenth groups, suggesting growth in the ocean.

The general pattern of measurements of the scales of spawners was similar to the defined life history of type-3 fish. Measurements of successive bands of five circuli were made on scales from 1965-brood juveniles captured in autumn in the estuary. The pattern of widths of successive bands of the juveniles was similar to

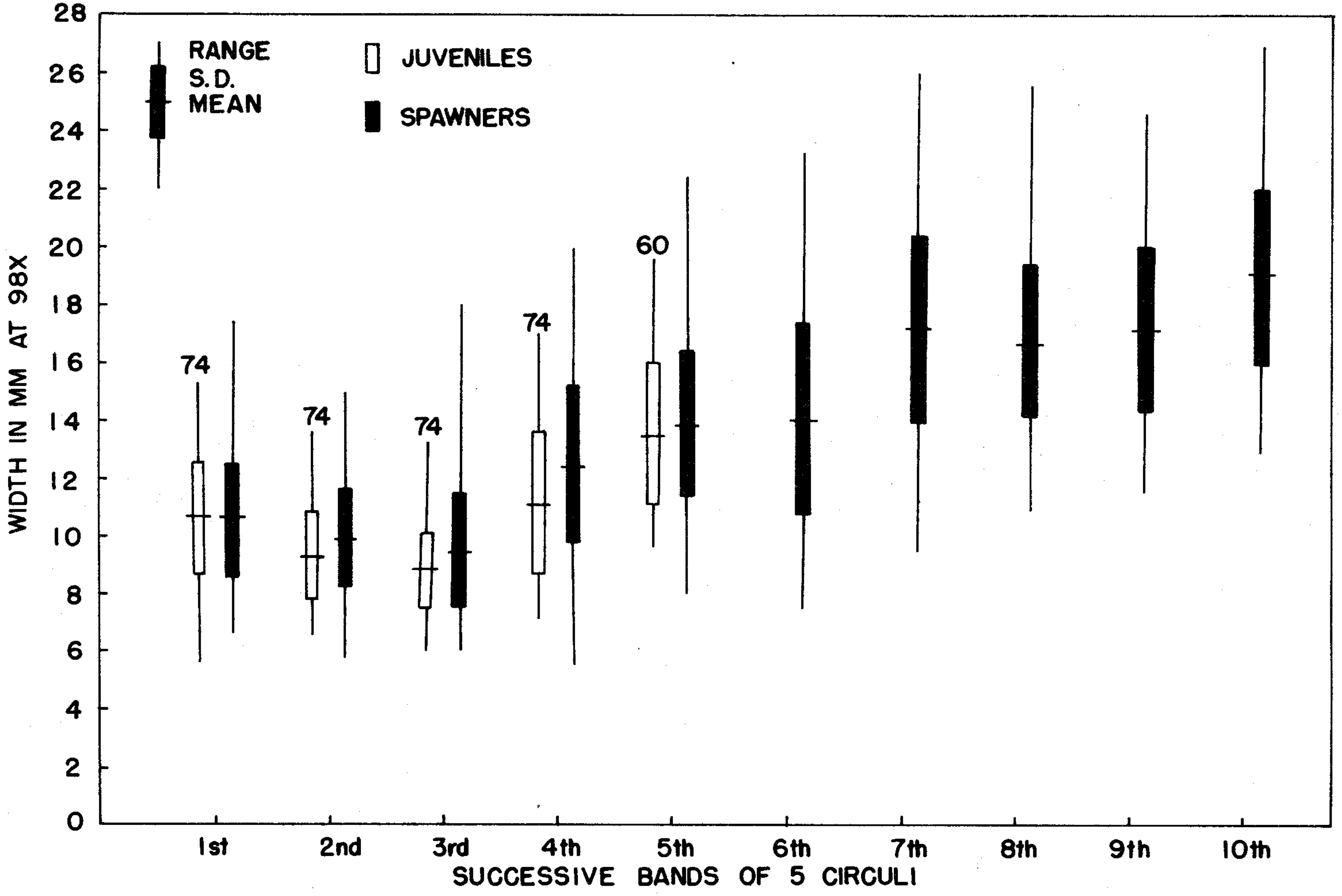

Figure 26. Width of bands of five circuli on scales of fall chinook salmon collected from 74 juveniles in the estuary in autumn and 160 spawners collected throughout Sixes River, 1965 brood.

measurements on the same areas of the adult scales, although in each band, the measurements from juveniles were slightly smaller (Figure 26). There was an increase in width in the fourth through sixth bands, reflecting growth in the estuary.

The scales of the spawners from the 1965 brood were then subjectively sorted into the five types of life histories with criteria previously established. The type-3 group was the most abundant (Table 11).

Table 11. Relative abundance of different types of life histories among spawning fall chinook salmon in Sixes River, based on the scale characteristics of the 1965 brood.

| Type of Life History | Age at Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | | 3 | | 4 | | 5 | |
| | N | % | N | % | N | % | N | % |
| 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 2 | 1 | 2.5 | 1 | 2.5 | 1 | 2.5 | 1 | 2.5 |
| 3 | 38 | 95.0 | 36 | 90.0 | 35 | 87.5 | 36 | 90.0 |
| 4 | 0 | 0.0 | 3 | 7.5 | 0 | 0.0 | 3 | 7.5 |
| 5 | 1 | 2.5 | 0 | 0.0 | 4 | 10.0 | 0 | 0.0 |
| Total | 40 | 100.0 | 40 | 100.0 | 40 | 100.0 | 40 | 100.0 |

The distribution of the various types of life histories with the age groups combined was: Type 1 - 0.0%, Type 2 - 2.5%, Type 3 - 90.6%, Type 4 - 3.8%, and Type 5 - 3.1%. There did not appear to to be any effect of juvenile life history on the age at return of spawners. The distribution of life history types was about equal among all the ages of spawners.

The distributions of freshwater and estuarine circuli on the type-3 spawners were compared to the distributions of freshwater and estuarine circuli on juveniles caught in Sixes River estuary in autumn (Figures 27 and 28). The distributions match sufficiently well to argue that these spawners and juveniles were from the same population.

The scales of type-4 and type-5 spawners did not match well with those of juveniles caught in the estuary in autumn. These spawners had numbers of freshwater circuli that ranged from 23 to 37 and averaged 28, in addition to lacking circuli that were recognizable as estuarine. The type-2 spawners also lacked recognizable estuarine circuli and had numbers of freshwater circuli that ranged from 18 to 20 and averaged 19. Since these type-2 spawners were probably larger than average, based on their numbers of circuli (Figure 27), they may have survived better after entering the ocean in summer than the majority of potential type-2 fish captured in the surf.

All age groups of spawners with the type-3 life history included a few fish with more freshwater circuli than were found on the juveniles. This suggests that largest juveniles have highest survival. A similar possibility exists for the number of estuarine circuli. The

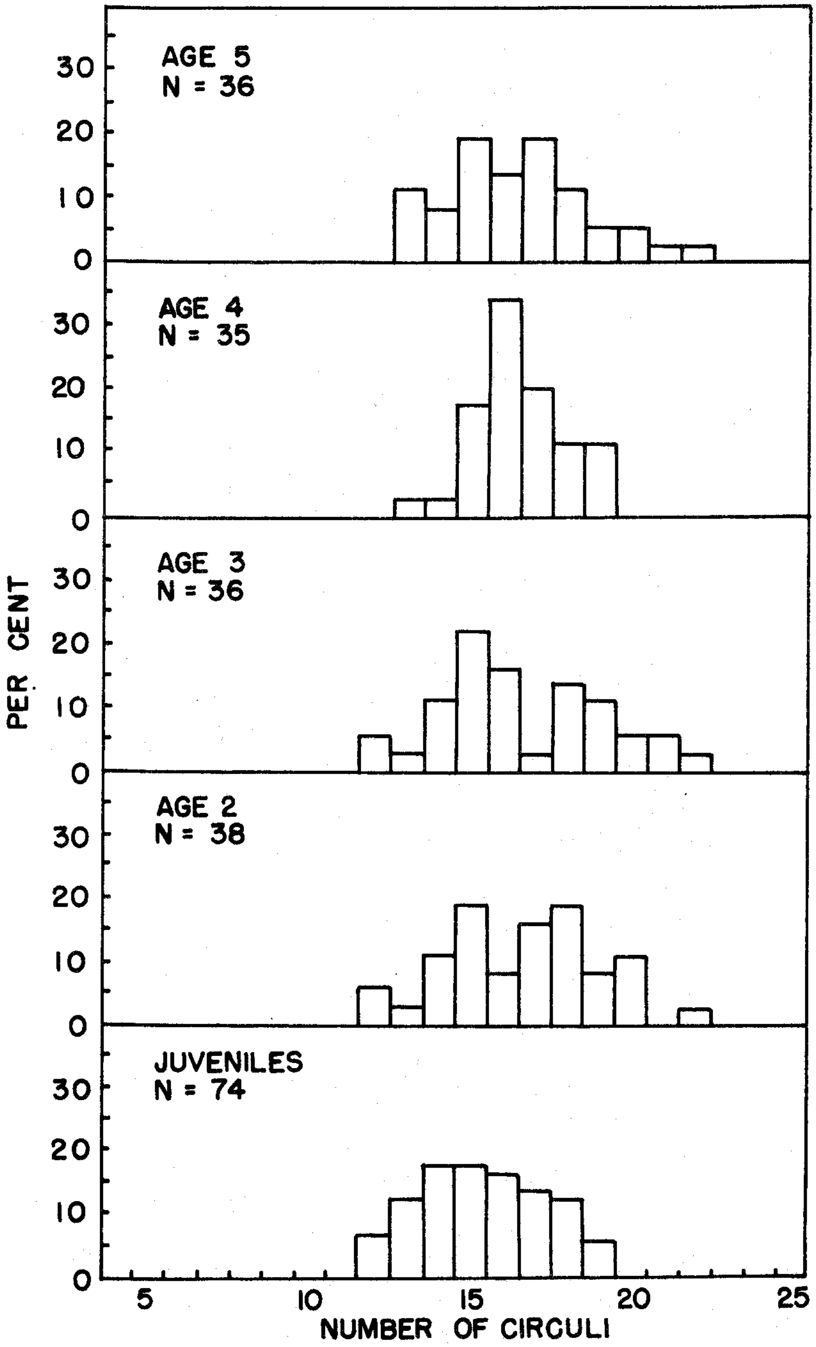

Figure 27. Number of circuli classified as freshwater on 1965-brood juvenile fall chinook salmon captured in Sixes River estuary in autumn of 1966 and on returning spawners with the type-3 life history.

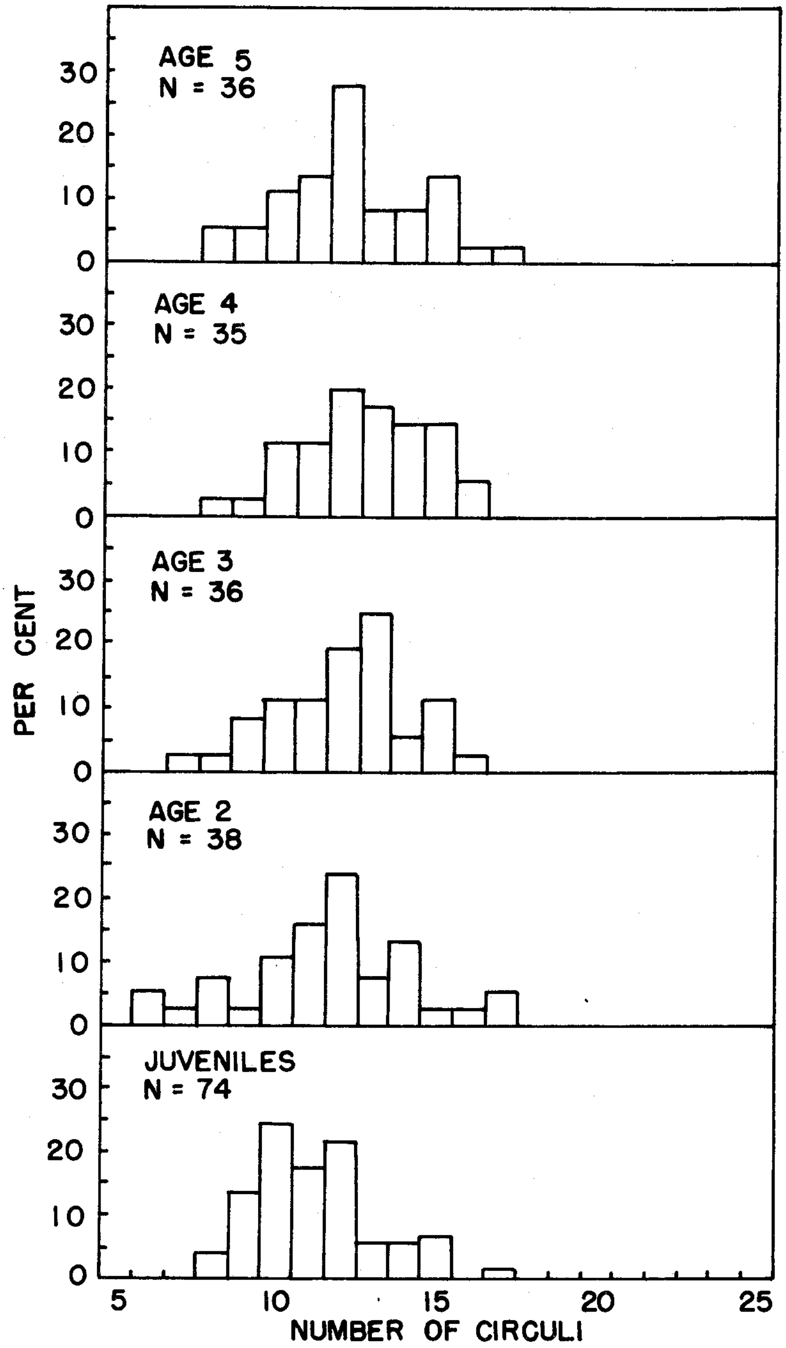

Figure 28. Number of circuli classified as estuarine on 1965-brood juvenile fall chinook salmon captured in Sixes River estuary in autumn of 1966 and on returning spawners with the type-3 life history.

mean number of about 16 freshwater circuli on returning spawners indicates that they were about 9.0 cm long at the beginning of the improved growth in the estuary (Figure 29). The mean number of estuarine circuli on the spawners suggests that an additional 4.0 cm of length was added in the estuary (Figure 30), making the average final size about 13.0 cm. This corresponds well with the average size of juveniles in the estuary in autumn (Figure 20).

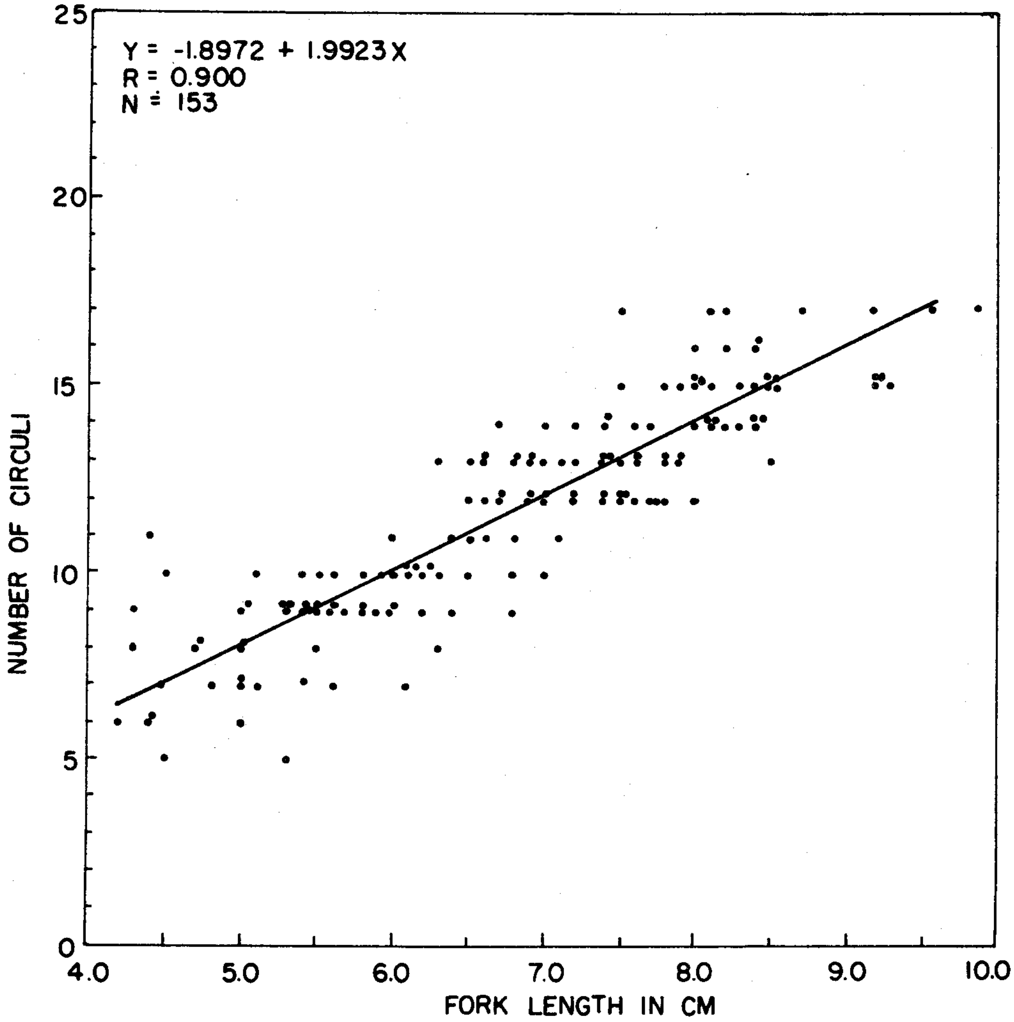

Figure 29. Relationship between number of circuli classified as freshwater and fork length of juvenile fall chinook salmon recently recruited to Sixes River estuary in spring, 1966.

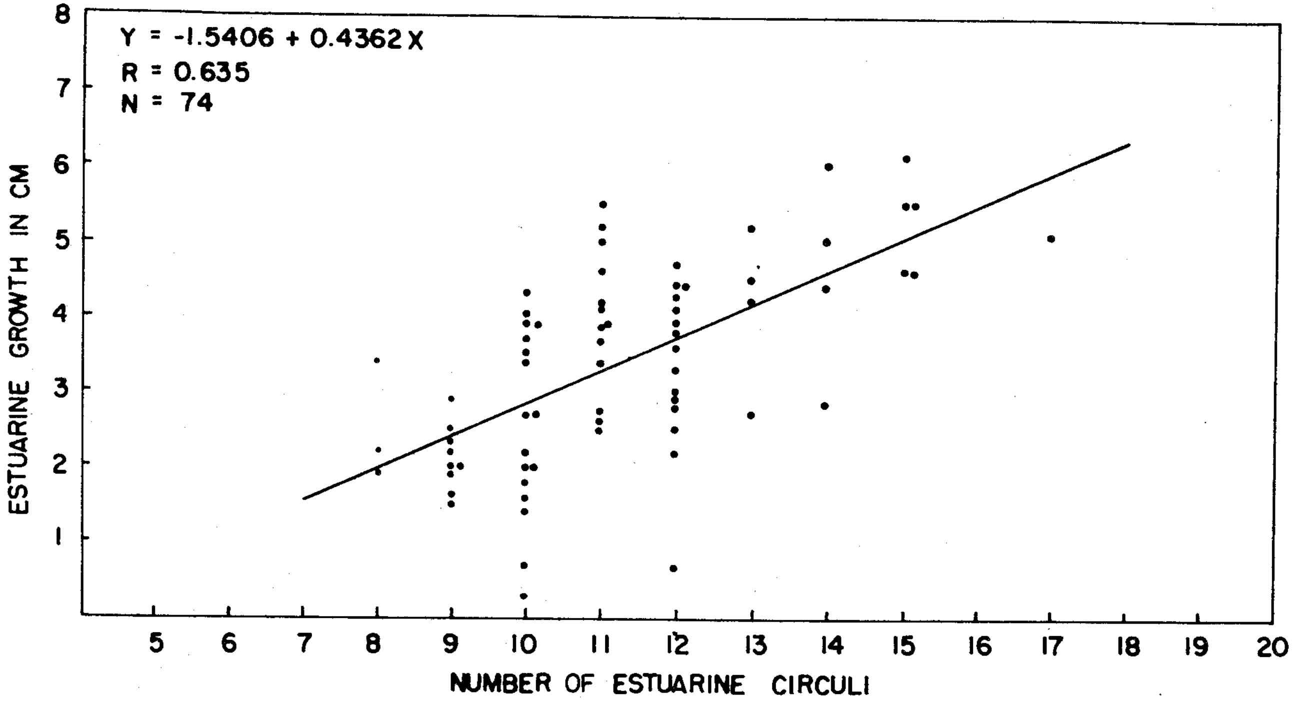

Figure 30. Relationship between estuarine growth in length and number of circuli classified as estuarine for juvenile fall chinook salmon captured in Sixes River estuary in autumn, 1966. The estimate of estuarine growth in length was the difference between the final measured size of the fish when captured and the predicted size at the beginning of the period of improved estuarine growth, based on the number of freshwater circuli (Figure 28).

# DISCUSSION

## Initial Downstream Dispersal of Fry

Most of the successful fall chinook salmon returning to Sixes River spent about three months of their juvenile life in fresh water. There is an advantage to freshwater residents when they fully utilize the available rearing area (Chapman, 1966). Spawning fish set the stage for this utilization by depositing their eggs in widely separated areas over a protracted period. The population also has evolved a mechanism that allows for rapid downstream dispersal of juveniles as they emerge from the gravel. The mechanism serves to reduce predation and minimize the energy expenditure necessary for adjusting population abundance in relation to food and space. This dispersal involves lack of visual orientation of the fry, resulting in their drifting downstream during the night of emergence. Fry probably drift with the currents during darkness until they reach quiet water or until light levels (moonlight or daylight) again allow visual orientation. Additional downstream movement of newly emerged fry may continue for several days until they develop the behavior of resident fish.

Downstream migration of newly emerged chinook salmon has been documented elsewhere (Chambers, 1965; Thomas, Banks, and Greenland, 1969; Lister and Genoe, 1970; Miller, 1970). Lister and Genoe (1970) found few fry residing in the Big Qualicum River during early spring, although large numbers had already moved downstream. They suggest the following sequence of behavior after emergence: initial hiding (possibly in the gravel), association with bank cover, appearance along open shorelines, and finally, movement into higher velocity locations along the stream margins or farther offshore. These observations agree with my studies in the experimental troughs and with my general observations in Sixes River.

Thomas, Banks, and Greenland (1969) demonstrated a marked reduction in swimming ability of alevins near the time of yolk absorption. This result is important to my conclusions about downstream migration, as this reduction in swimming ability may be a key factor facilitating immediate dispersal of fry after their emergence at night. The combination of reduced swimming ability and the behavior of newly emerged fry appear to be adaptive in stream living.

Miller (1970) argues that downstream migration results largely from poor swimming ability in cold temperatures. This factor was undoubtedly an important cause of fish leaving his experimental systems, but it may not have been the primary reason for downstream migration of newly emerged fry in the Lemhi River. Although Miller used fry that had been captured in the downstream trap in the river, his definition of a fry was a fish less than 5.0 cm in length. Because of a lack of fish at times, he also accumulated fry for a few days before running experiments and acclimated them for 24 hours in his systems. Many of these fish could no longer be considered newly emerged fry and were probably past the initial period of downstream migration.

Miller (1970) found that density was important in the number of fry remaining or leaving his experimental systems, but he suggested that social behavior did not play a role because movement occurred primarily at night. I suggest that high density may only be coincidental with downstream migration of newly emerged fry, and is probably not a primary causal factor. Considering that most emergence and downstream movement probably occur on the same night, there would be little opportunity for interaction among fry. However, on subsequent days as fry develop into resident fish and during the remainder of their residence in fresh water, social behavior appears important in governing their distribution. With the protracted emergence period, fry emerging late must face fish already occupying territories. Interaction occurs and is effective at dislodging smaller, less developed fish (Reimers, 1968). Contrary to Miller's conclusion about the relationship between nocturnal movement and social behavior, nocturnal movement does play a role in the displacement of socially inferior fish. I have observed subordinate fish that were nipped or threatened all day but did not move downstream until dusk.

Without the mechanism for rapid dispersal of fry that I have suggested, many more juveniles would be present at emergence sites than are currently observed. They would be vulnerable to extensive avian and piscine predation. Surviving fry would be extremely crowded and would face a shortage of food. For juveniles to emerge and remain in these high densities in the spawning streams and later to disperse primarily by means of social interaction would appear to be inefficient. In one experiment, Carline (1968) showed that socially dominant coho salmon, O. kisutch (Walbaum), expended more energy for activity than subordinates. They also obtained more food because of their social position and grew better than subordinates. Without a mechanism for rapid dispersal, densities of fry at emergence sites would be far greater than those tested by Carline. Energy costs in achieving dispersal would probably be proportional to the number of social interactions. Food rewards to fish attempting to become social dominants under this suggested intense competition might not offset the energy cost in acquiring limited food. Because of the potential energy cost and probable high rate of predation, rapid initial dispersal that does not involve social behavior would seem to have survival value to fry.

Miller (1970) considered spring chinook salmon fry moving downstream in the Lemhi River a loss to total production. Apparently the areas downstream were not suitable for rearing. In Sixes River I conclude that downstream movement of fall chinook salmon has survival value, since fish rearing in the main river and estuary grew better than those in the tributaries and were abundant as returning spawners.

## Influence of Temperature on Residence in the Main River

There was little evidence for the idea that temperature is an important factor influencing the length of residence of juveniles in the main river. However, I suggest that if cooler conditions prevailed, more fish would rear longer in the main river and reach a larger size than they presently do. Avoidance of high temperatures by salmonids or increased production associated with increased flow and reduced temperature have been documented.(Gibson, 1966; Havey and Davis, 1970). Even though maximum temperatures in Sixes River were not always above the lethal level for fall chinook salmon, growth efficiency has been shown to decline for other salmonids at temperatures considerably below the lethal level (Brett, Shelbourn, and Shoop, 1969). Before Sixes River was logged, timber extended to the mouth of the river, as evidenced by the presence of stumps. The earlier extensive cover in the watershed probably maintained cool temperatures in summer, as well as stability of flow during winter.

I suggest that the amount of freshwater rearing area used by juvenile fall chinook salmon in Sixes River was once substantially larger, and the total yield of effective migrants higher than today. However, the estuary was probably little affected by watershed alterations and may not have reared any more fish in past years than it does now. With greater rearing area in the main river, the number of autumn and yearling migrants was probably much larger. The cool conditions during 1964 yielded more autumn and yearling migrants than any other year of the study. Other years yielded few fish in these groups, owing to the small number of fish remaining in fresh water. During 1964, when a fair population remained in lower Sixes River, the resident fish were larger than in 1969, suggesting that summer residence would not necessarily be terminated at a particular size. A closer examination of annual variation in residence in relation to temperature would be valuable.

With more freshwater rearing area available, the run of fall chinook salmon in Sixes River was probably once larger than today. At the present time the total run averages about 2,500 fish (McGie, 1970). Unfortunately, there is little evidence to indicate the size of runs in earlier years. Records of commercial gillnet and seine catches in Sixes River were found for 1927 but were possibly incomplete. These poundage data suggest a landing of about 2,000 fish. Escapement may have been much higher than the catch, since local residents say that prior to extensive logging, spawning adults were numerous throughout the river and not just in the tributaries.

Another possible factor reducing the number of spawners is the extensive ocean troll fishery.

## Population Density Versus Growth of Juveniles in the Estuary

Most of the successful fall chinook salmon returning to Sixes River spent about three months in the estuary after they left fresh water. The number of juveniles in the lower estuary in 1969 began to increase during late May and then rapidly increased in June. When the population reached 20,000 fish in early June, the rate of growth of juveniles decreased. The population peaked in late July and early August and then subsided. The rate of growth of juveniles increased when the population fell to about 100,000 fish at the end of August.

I hypothesize that high population density was a major cause of the depressed rate of growth of juveniles during midsummer. There was essentially no growth for three months. If the relationship between biomass of juveniles and availability of their food was the major factor resulting in depressed growth of fish, growth of the fish should have begun at the same population size at which it stopped. That growth started at a population size or biomass five times higher than when it stopped appears to disprove the primary hypothesis. However, I further hypothesize that the capacity of the estuary to rear fall chinook salmon increased during the summer.

An increase in the rearing capacity of the estuary was probably indirectly produced by greater utilization of the estuary by the juveniles with time. Prior to the large increase in population in June, most juveniles were confined to the shoreline and were nearly absent at the lower stations. When the number of fish peaked in July, juveniles were living at all stations and were distributed throughout the estuary, even in deep water.

The reason that juveniles did not initially use the entire estuary is unknown, but is suspected to be behavioral rather than physiological. The early behavior of these fish appears to involve hiding and agonistic behavior and requires orientation with the bottom in shallow water. Areas around stumps or logs often had pools at low tide that contained isolated groups of small fish that presumably were temporarily trapped. They had opportunities to leave at high tide but did not. As density and the size of the fish increased, the individuals apparently changed to a pelagic, aggregative mode of life. A similar change in distribution with size was observed for pink salmon, _O. gorbuscha_ (Walbaum),in Fitz Hugh Sound, British Columbia (LeBrasseur and Parker, 1964).

Adaptation of fish to salt water was probably not limiting the distribution of juveniles in the estuary. Since the estuary was primarily a two-layered system, juveniles could have easily moved into the pelagic zone and remained in fresh water. Wagner, Conte, and Fessler (1969) showed in laboratory studies that juvenile fall chinook salmon would have little difficulty adapting to higher salinities at small sizes where they have opportunities for acclimation such as in a tidal estuary.

In addition to greater utilization of the estuary by juveniles with time, there is indirect evidence that the nutritional level and food production of the estuary increased during the summer. Shallow areas of the estuary were heavily colonized by *Corophium spinicorne* Stimpson, a tube-dwelling amphipod important in the diet of the juvenile salmon. As a result of the sill building at the mouth, the shallow area of the estuary rapidly increased over the flat shoreline. This enlarged the habitat for *Corophium* colonization and presumably provided more food for the juveniles.

The sill probably had an even greater effect than increasing the wetted productive area of the estuary. Although there was no direct measure of nutrient level, the sill may have created an effective nutrient trap in a manner similar to that reported for fjords with a shallow outer sill (Ketchum, 1967). At high tide, nutrient-rich water of high density enters the estuary over the sill, mixes at the mouth with estuarine water, and the entire water mass moves upstream. During ebb tide the sill acts to hold the dense sea water in the estuary, thereby trapping the nutrients, while the fresh water moves downstream in a shallow surface layer.

Strong northwest winds during the summer produce extensive upwelling of this nutrient-rich water along the southern coast of Oregon (Pattullo and Denner, 1965). This was particularly noticeable along the beach at the mouth of Sixes River where periodic "red tide" blooms were common. This "red tide" water was carried into the estuary at high tide.

Production of algae in the estuary was high, based on visual observations of the development of *Enteromorpha* and *Spongiomorpha*. As these and other primary producers died, sedimentation of detritus occurred. Organic detritus and debris also entered from the ocean. Sedimentation of fine sand and organic material continued throughout the summer. Organic detritus and associated microorganisms form the primary source of food for *Corophium* (Green, 1968). *Corophium* apparently also has specific requirements for substrate material to build its tubes (Green, 1968). *Corophium* in Sixes River estuary appeared to utilize a combination of sand and finer material for tube construction, so that sedimentation probably enhanced production. The rate of sedimentation was apparently high enough that *Corophium* was able to obtain material from the water column to build tubes on vertical filaments of algae.

Another possible explanation for the reduced growth in midsummer was suspected, since juveniles entering the estuary were considerably smaller than those already present at the lower stations. The outcome would have been that mean size would demonstrate only an "apparent" reduced rate of growth. This seems unlikely since marked fish, exempted from recruitment, grew at the same rate as fish in the unmarked population. However, a close examination is needed of the fate of juveniles entering the upper estuary from the main river to resolve the size disparity. Catch per seine haul of juveniles suggested a definite delay in their movement from the upper to the lower estuary. Numbers in the upper estuary peaked five to six weeks before those in the lower estuary. When newly recruited fish reached the upper estuary, their growth must have improved, and presumably this time lag allowed them to increase in size. Fish seined near the head of tidewater tended to be closer to the size of fish captured in the lower estuary than to downstream migrants trapped just above tidewater.

The reduced growth of juvenile fall chinook salmon in Sixes River estuary apparently was a real phenomenon, but could have been produced by factors other than changes in abundance of juveniles. Three possibilities include: 1) physiological changes associated with smolting, 2) changes in abundance or availability of food organisms, or 3) changes in competition from other species of fish. Before further judgements about potential physiological problems can be made, additional studies are needed. We particularly need a close examination of the smolting process in these fish and studies of salt-water adaptation under conditions that simulate regular changes in water velocity and temperature, such as those experienced at the mouth of the river. Abrupt changes in abundance of primary food organisms seem unlikely without obvious changes in some environmental parameters such as salinity or temperature, but should be examined in the future. Competition for the food resource with other fishes probably did occur, but its importance is unknown. Abundant species like the surf smelt, Hypomesus pretiosus (Girard), and shiner perch, Cymatogaster aggregata Gibbons, appeared to be about equally numerous throughout the summer.

## Importance of Freshwater and Estuarine Rearing

Based on the analysis of scales, fish with the type-3 life history were the most abundant group of returning spawners. These fish remained in fresh water for about three months and then entered the estuary for an additional three months of residence. Because these fish spent part of their juvenile life in each area, freshwater and estuarine rearing were judged to be about equally important to their success. Chinook salmon in the Columbia and Klamath rivers were also found to spend a significant portion of their juvenile life in the estuary after leaving fresh water.(Rich, 1920; Snyder, 1931).

With our knowledge of the importance of both the freshwater and estuarine rearing areas, the question has been raised whether the abundance of fall chinook salmon in Sixes River can be enhanced. If environmental conditions in this river control the number of long-term freshwater residents, then any efforts to reduce temperature or increase flow would probably favor a larger resident population. Despite the small number of juveniles remaining for an extended period in the main river or tributaries to become type-4 and type-5 fish, they may have a high rate of survival. Certainly in the future, Sixes River should be managed to improve summer conditions for rearing of these two types by allowing vegetation to develop along the streams and by leaving buffer strips in future logging operations.

A hatchery operation simulating the life history of type-4 or type-5 fish, but growing them to a larger size than naturally occurs, would probably also help to increase the run. Such a rearing program would provide for minimal interaction between hatchery and wild fish and would substantially increase the abundance of effective migrants to the ocean in autumn or as yearlings.

Enhancing the run of fall chinook salmon by manipulations of the juvenile population in the estuary may be difficult but deserves further investigation. Of particular concern is the fate of juveniles that remain in the estuary for only a short time. Adults with the type-2 life history were scarce in relation to the many juveniles that potentially fell into this group. Evidence presented here suggests that Sixes River estuary is not an unlimited environment, and that production of fall chinook salmon may be restricted by limitations of food and space. If a large share of the individuals contributing to fisheries in the ocean, or surviving to return to spawn, are obligated to spend an extended portion of their life short of the ocean, developing a program for hatchery releases of juveniles into the estuary in early summer would not be beneficial. Increasing the density of juvenile salmon in the estuary may be detrimental to growth and survival of both hatchery and wild fish. Also, if size of juveniles limits survival of fall chinook salmon in the ocean, planting hatchery fish at the same size as wild juveniles may produce extended residence in the estuary and the resulting problems associated with high density. However, if hatchery juveniles planted in the estuary in early summer were much larger than wild fish, they might acclimate quickly and enter the ocean. This would minimize competition with wild fish and possibly allow high survival of hatchery fish.

Another manipulation with the wild population in the estuary seems possible, since food appears to be a limiting factor for growth of juveniles during peak population abundance. Artificial feeding to maintain or improve growth of juveniles might increase the rearing capacity of the estuary and the rate of survival of those fish emigrating to the ocean during early summer.

Further research is needed to measure the importance of the estuary as a staging area for wild fall chinook salmon before ocean entry. We particularly need to measure rearing capacity of the estuary in terms of survival to maturity of these fish. Because of our ability to measure population statistics of the spawners returning to the river and to measure growth and abundance of the juveniles in the estuary, Sixes River appears to be ideal for continued research on the population dynamics of fall chinook salmon.

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