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CONTENTS

NITROGEN GAS BUBBLE DISEASE RELATED TO A HATCHERY WATER SUPPLY FROM THE FOREBAY OF A HIGH-HEAD RE-REGULATING DAM

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Abstract

Studies of the water supply system at the Fish Commission of Oregon's South Santiam River Hatchery were made following the loss of nearly a half million salmonid fishes due to gas embolism. Hatchery water from the forebay of adjacent Foster Dam had become supersaturated with dissolved nitrogen as the result of air entering the supply system. Experiments revealed that fish were exposed to concentrations in excess of 150% of saturation and rapidly died from the effects of gas bubble disease. Biological assay data regarding supersaturation rates, exposure times, death rates, and gross pathology are reported.

Introduction

During the night of September 5, 1969, nearly a half million salmonid fingerlings were lost at the Fish Commission of Oregon's South Santiam Hatchery as a result of nitrogen (N_2) gas embolism. The loss comprised approximately 75% of the station's spring chinook (*Oncorhynchus tshawytscha* Walbaum), fingerlings and 99% of the summer steelhead (*Salmo gairdneri* Richardson).

The hatchery water supply is delivered by gravity flow via two pipelines which originate in the forebay of adjacent Foster Dam (Figure 1). At the time of the loss, water from the upper intake (at the 17-18°C epilimnion) and lower intake (at the 10-11°C hypolimnion) was being mixed to provide a mean water temperature of 13.5°C. The grate guarding the upper intake aperture became partially plugged with submerged debris and, as the forebay water level was lowered, the blockage increased when surface debris also lodged against the grating. Apparently water no longer flowed smoothly into the upper pipeline but entered around the periphery of the grating at a reduced rate of flow and became highly aerated as it tumbled into the throat of the pipe. It was suspected that entrained air was forced into solution at an accelerated rate as the mixture flowed to a lower elevation under increased pressure. During the morning of September 5, the reduced flow of epilimnion water caused the headbox water temperature to drop from 13.5 to 10.5°C. The following morning hatchery personnel observed dead and dying fish in all rearing ponds. Nearly all the fish examined showed subcutaneous air bubbles symptomatic of nitrogen gas bubble disease.

Previous investigators have reported on N_2 gas supersaturation in hatchery ponds (Rucker and Hodgeboom, 1953; Harvey and Smith, 1961) and natural environments (Harvey and Cooper, 1962; Ebel, 1969). This paper reports on experiments at the South Santiam Hatchery in late September and early October 1969 where the conditions of September 5 were simulated in order to develop criteria for safe operation of the water supply system. Water chemistry and bioassay results regarding supersaturation rates, exposure times, death rates, and gross pathology are given.

Materials and Methods

Experiments were conducted from September 29 to October 2 at various resor-

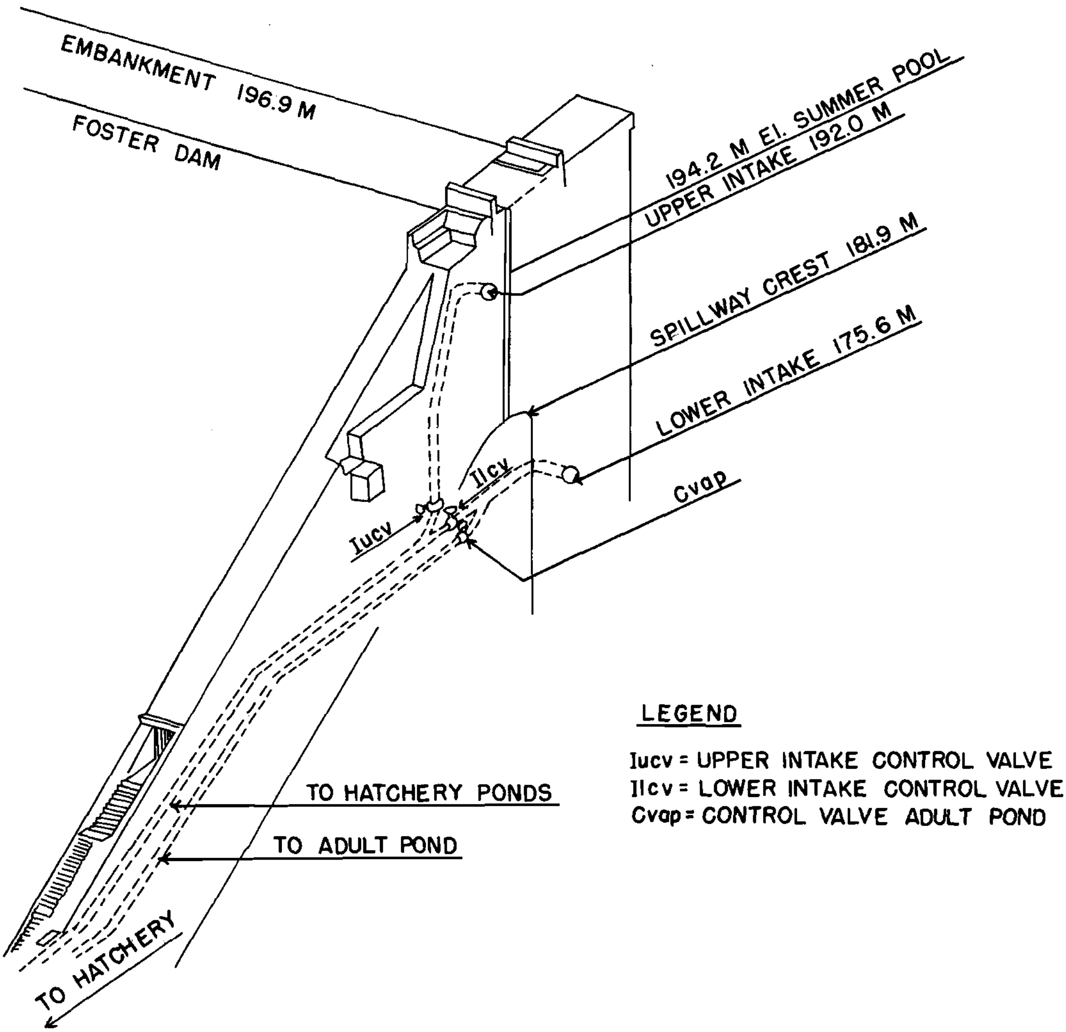

Figure 1. Simplified drawing of water intake system at Foster Dam.

voir elevations, flow rates, and under different combinations of intake valve settings. From the morning of October 2 to the morning of October 3, the reservoir was at 192.3 m elevation which equaled the situation existing on September 5. A 1 m by 1 m piece of plywood was placed over the grating to simulate submergent debris, and manipulation of mixing-valve settings and flow rates established parameters within which supersaturated water conditions were achieved.

The upper pipeline, the center of which is 192.0 m above mean sea level, is 0.8 m in diameter with a 1 m bell flange at its opening into the reservoir. Water from the upper and lower pipelines merge at 175.7 m elevation, and flow 259 m via a single 50.8 cm diameter pipe to a screening box at the hatchery (Figure 2). A control valve regulates the rate of flow from the screening box to the hatchery building and 10 rearing ponds. Water temperature is controlled by manipulation of butterfly valves to regulate flow rates of the upper and lower intake pipelines.

Water samples were taken in the forebay of Foster Dam near the upper intake orifice, in the screening box, and in the rearing ponds. Other samples were taken in the forebay at the surface and near the bottom at 175.7 m elevation (near the lower intake orifice). Samples were collected with a Van Dorn water sampler. Temperature of each water sample was recorded to the nearest 0.1 °C. The samples were stored in standard 300 ml glass-stoppered bottles and immediately placed on ice. Analyses were performed as soon as possible to minimize the effect of changes in water quality. Dissolved N_2 concentrations were measured with a Van

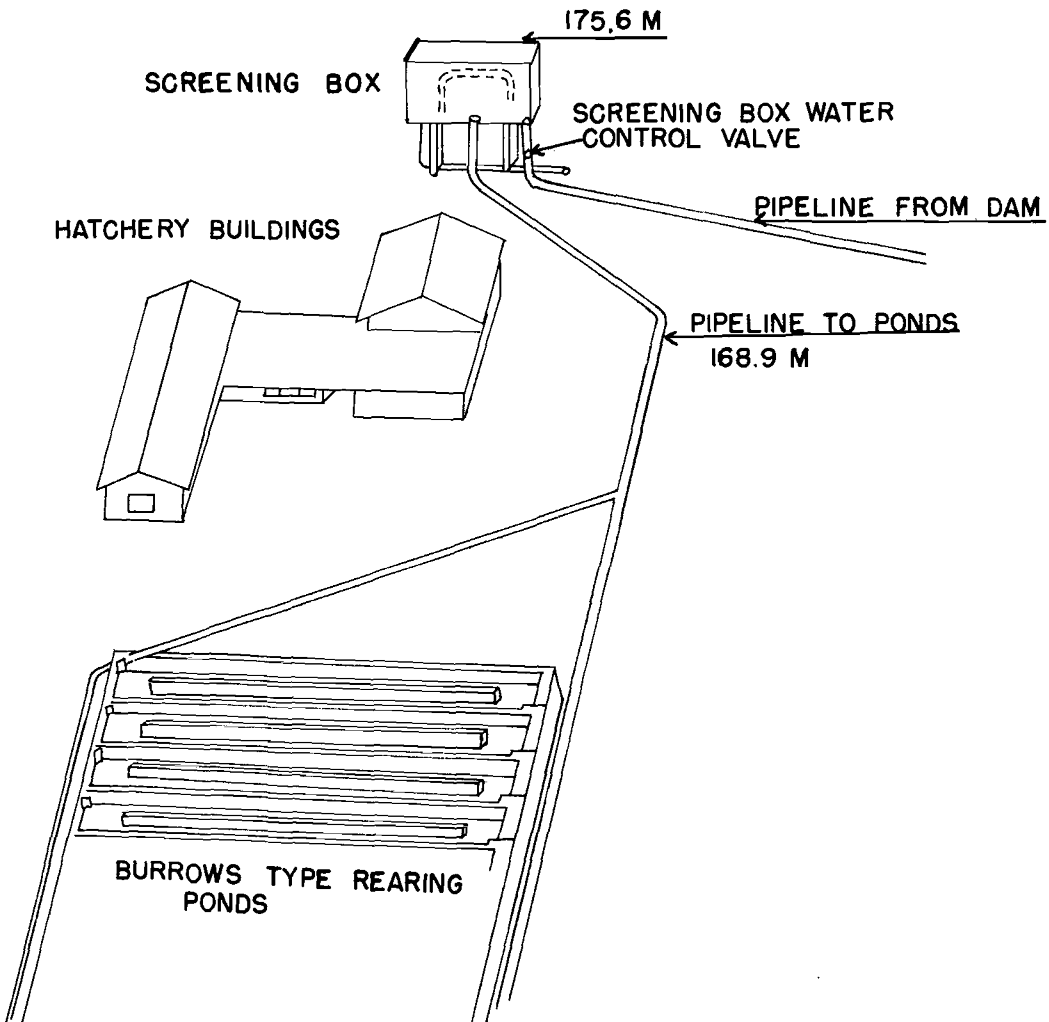

Figure 2. Water supply system on hatchery grounds.

Slyke-Neill manometric blood gas analyzer modified for water determinations. Saturations are believed to be correct to within ±2% of their true value. Dissolved oxygen (O_2) values were obtained by the modified Winkler technique.

Biological assays were conducted with 1968-brood Willamette River spring chinook fingerlings, averaging 44 fish per kilogram, from the Marion Forks Hatchery. Prior to testing, control and test fish were maintained in live boxes in the adult holding pond which is supplied with water via a separate line from the lower intake and therefore was not affected by events on September 5 or tests performed in this study. Bioassay fish were held in 175 x 84 cm wire-mesh cages, suspended in 61 cm of water in four different rearing ponds. On September 30 and October 1, 185 fish each were placed in test cages in Ponds 7 and 6, for 30 and 54 hours before being subjected to 134 and 152% concentration of N_2. A third group, placed in Pond 9 ($N=106$), was immediately subjected to a 134% concentration, followed by an increase to 152% The fourth group, tested in Pond 8 ($N=476$), was exposed immediately to a 152% concentration. The levels used in the tests were determined by the physical structure of the water supply system when the conditions which caused mortality were simulated. Prior to the tests the different holding periods were used to investigate the influence of handling stress on the fish. Dead fish were removed at 30-minute intervals until the tests were completed, and pathological examinations were promptly conducted.

Results

Hydraulic Observations and Supersaturation Rates

Results of nitrogen concentrations found in water samples during experiments are presented in Table 1. With reservoir elevations of 192.8 m or greater, the upper intake orifice remained submerged and excessive supersaturation of the water supply did not occur at any combination of valve settings and flow rates. When the forebay was drawn down to 192.3 m elevation, the top 20 cm of the upper intake orifice became exposed. A plywood board placed over the lower portion of the grating to simulate submerged debris resulted in an inadequate water flow to keep the upper intake line full. Within 10 minutes dissolved N_2 concentrations rose from 103 to 153% of saturation in the screening box and to 124% in the rearing ponds (Sample No. 3 on October 2). The plywood barrier was then removed for an extended period, the flow of water entering the screening box was doubled to 0.85 m^3/sec., the lower intake valve was closed, and only water from the upper intake was permitted to enter the system. A volume of water less than 0.85 m^3/sec. flowed through the system, resulting in a frothy air-water mixture that surged into the screening box. Sample 4, taken when the pond water temperature rose to the same level as the forebay water temperature, contained 134% dissolved N_2. The plywood board was then replaced and all other conditions were set as described for Sample No. 3 for the remainder of the test.

By October 3, dissolved N_2 concentrations in the screening box had increased from 103 to 175% of saturation. The colder water temperature of this sample indicated that most of the water in the system came from the hypolimnion.

Behavior

All groups of fish were under close observation when the first mortalities occurred. There was no indication that the fish were aware of the potentially lethal nature of the environment. The following sequence describes a typical behavior pattern during the first 60 seconds of abnor-

Table 1. Nitrogen and Oxygen Concentrations Under Various Experimental Conditions

Date	Approx. Pool Elev. (m)	Sample No.	Flow Rate at Screening Box Valve m^3/sec.	Butterfly Valve Setting (% Open) Upper Intake	Lower Intake	Sample Stations①	Temp. (C)	O_2 (ppm)	O_2 %	N_2 (ppm)	N_2 %
9/26	194.2	1	—	—	—	Forebay 0 m	15.7	9.8	98.7	16.8	100
9/29	194.2	1	0.43	40	100	Forebay 2.1 m②	16.7	9.8	100.8	16.8	102
9/29	194.2	1	0.43	40	100	Screening box	13.5	9.4	90.6	18.0	103
9/29	194.2	1	0.43	40	100	Pond #6	13.6	9.5	91.7	18.3	105
9/29	194.2	2	0.43	100	0	Forebay 2.1 m②	16.5	9.9	101.4	16.9	102
9/29	194.2	2	0.43	100	0	Screening box	15.9	10.0	101.5	17.1	103
9/29	194.2	2	0.43	100	0	Pond # 6	15.8	9.9	99.8	17.2	103
9/30	193.6	1	0.43	40	100	Forebay 1.5 m②	16.0	9.7	98.8	16.9	101
9/30	193.6	1	0.43	40	100	Screening box	13.6	9.5	91.6	18.0	103
9/30	193.6	1	0.43	40	100	Pond #6	13.4	9.7	92.8	18.1	103
9/30	193.6	2	0.43	100	0	Forebay 1.5 m②	16.1	9.7	98.6	16.9	102
9/30	193.6	2	0.43	100	0	Screening Box	16.1	9.6	97.5	16.9	102
9/30	193.6	2	0.43	100	0	Pond #6	16.0	9.5	96.7	16.9	101
10/1	193.0	1	0.43	44	100	Forebay 0.9m②	15.8	9.6	97.4	16.7	100
10/1	193.0	1	0.43	44	100	Screening box	13.4	9.4	90.3	18.1	103
10/1	193.0	1	0.43	44	100	Pond #6	13.2	9.5	90.8	18.2	104
10/1	193.0	2	0.43	100	0	Forebay 0.9 m②	15.7	9.7	97.7	16.9	101
10/1	193.0	2	0.43	100	0	Screening box	15.7	9.8	99.2	16.8	101
10/1	193.0	2	0.43	100	0	Pond #6	15.7	9.8	98.6	17.0	101
10/1	192.8	3	0.85	100	0	Pond #6	14.9	9.8	96.9	17.4	103
10/2	192.3	1	0.43	44	100	Forebay 0.3 m②	15.1	9.7	96.9	17.0	100
10/2	192.3	1	0.43	44	100	Screening box	13.2	9.5	90.4	18.1	103
10/2	192.3	1	0.43	44	100	Pond #6	13.2	9.4	90.0	18.1	103
10/2	192.3	2	0.43	100	0	Screening box	15.4	10.0	100.5	17.0	101
10/2	192.3	2	0.43	100	0	Pond #6	15.2	10.0	100.1	17.5	104
10/2	192.3	3③	0.85④	44	100	Screening box	11.5	12.1	110.9	27.7	153
10/2	192.3	3③	0.85④	44	100	Pond #6	13.5	10.7	103.1	21.6	124
10/2	192.3	4	0.85	100	0	Pond #6	15.2	12.7	127.1	22.6	134
10/3	192.3	1③	0.43	44	100	Forebay 16.8 m⑤	10.2	9.4	83.7	20.0	108
10/3	192.3	1③	0.43	44	100	Screening box	11.5	13.8	127.0	31.8	175
10/3	192.3	1③	0.43	44	100	Pond #6	11.8	12.3	113.9	27.4	152
10/3	192.3	1③	0.43	44	100	Pond #1	11.7	12.2	112.3	26.9	149

① Figures denote depths at which water sample was taken.
② Forebay sample taken in front of upper intake orifice.
③ Upper intake orifice partially blocked.
④ Valve opened to supply this amount but plywood and trash impeded flow so that less water was delivered.
⑤ Forebay sample taken in front of lower intake orifice.

mal reaction: (1) sudden loss of ability to swim into the current, (2) loss of ability to avoid other fish, cage sides, or a flashlight beam, (3) loss of equilibrium and vertical station in the water, and (4) lateral movement near the surface without a sense of direction. During the next 60 seconds fish exhibited violent writhing movements, interspersed with moments of inactivity as they lay at various depths with ventral surfaces upward. After 3 minutes fish became moribund and showed little or no reaction to handling. Nearly all fish died within 4 minutes after the onset of abnormal swimming behavior. In a few instances, the fish exhibited leaping and writhing movements in an attempt to clear the water surface. None attempted to seek a greater depth before or during this activity.

Some salmon and steelhead that survived the catastrophe of September 5 remained in Ponds 8 and 9 during the test. They averaged about the same size as the test fish and died at the same rate. There were no survivors in these ponds after the tests were completed.

Mortality Rates

Cumulative percentage mortality is plotted against time for the four test groups in Figure 3. These data show that after 5 hours exposure, mortality was much greater in Ponds 6 and 7 at 152 than at 134%, and that prior exposure to water with a N_2 content of 134% accelerated the death rate when the fish were subjected to 152% levels. Group 8 exposed directly to 152% N_2 died rapidly but, as was expected, required a longer period before the first deaths than those previously placed in 134% water.

In testing for the effect of handling stress and subsequent susceptibility of fish to high levels of nitrogen gas, it was found that fish tested immediately after handling did not show a significant difference in death rate when compared to those held in cages for 30 and 54 hours.

Pathology

Gas emboli in the vascular elements of the fins (most frequently the caudal) were the most prominent external symptoms. In some fish, emboli were seen only in the dorsal lobe of the caudal fin; in others only the lower lobe was affected, and in a few cases emboli could not be found in any fins. Observations on September 5 showed emboli to be most numerous in the dorsal fin, followed by lesser amounts in the caudal, anal, and paired fins. In addition, some fish contained prominent gas bubbles in the intercostal vascular elements behind the peritoneum along the lateral body wall.

External gill damage was noted in all fish checked. The central vascular element of gill filaments contained numerous tiny, bead-like vesicles and the lamellae fed by these vascular elements were ruptured and minutely hemorraged. Several filaments in a series damaged in this manner were followed by a group of intact filaments. Severity of the damage varied. One fish died showing gill damage but none of the other symptoms. In another, an embolus was seen underneath the epithelium in the anterior part of the roof of the mouth. Emboli were present in the dorsal aorta of most fish examined; however, search under magnification, but without dissection, for emboli in and around the eyes proved negative.

Discussion

Hydraulic Observations and Supersaturation Rates

Supersaturation of the hatchery water supply system occurred only when the upper intake line was not full of water. Data from Samples 1 and 2, on October 2, showed no increase in saturation levels even though the upper intake grating was partially exposed for several hours. With the plywood barrier in place, just prior to taking Sample 3 on October 2, the water level was 4 or 5 inches higher outside the upper intake grating than inside, forcing an agitated air-water mixture into the throat of the intake. This highly aerated water obviously came under considerable pressure as it fell 17.4 m and joined the higher-velocity flow from the lower intake. The screening box valve restriction further increased back pressure on the system, which probably accelerated the

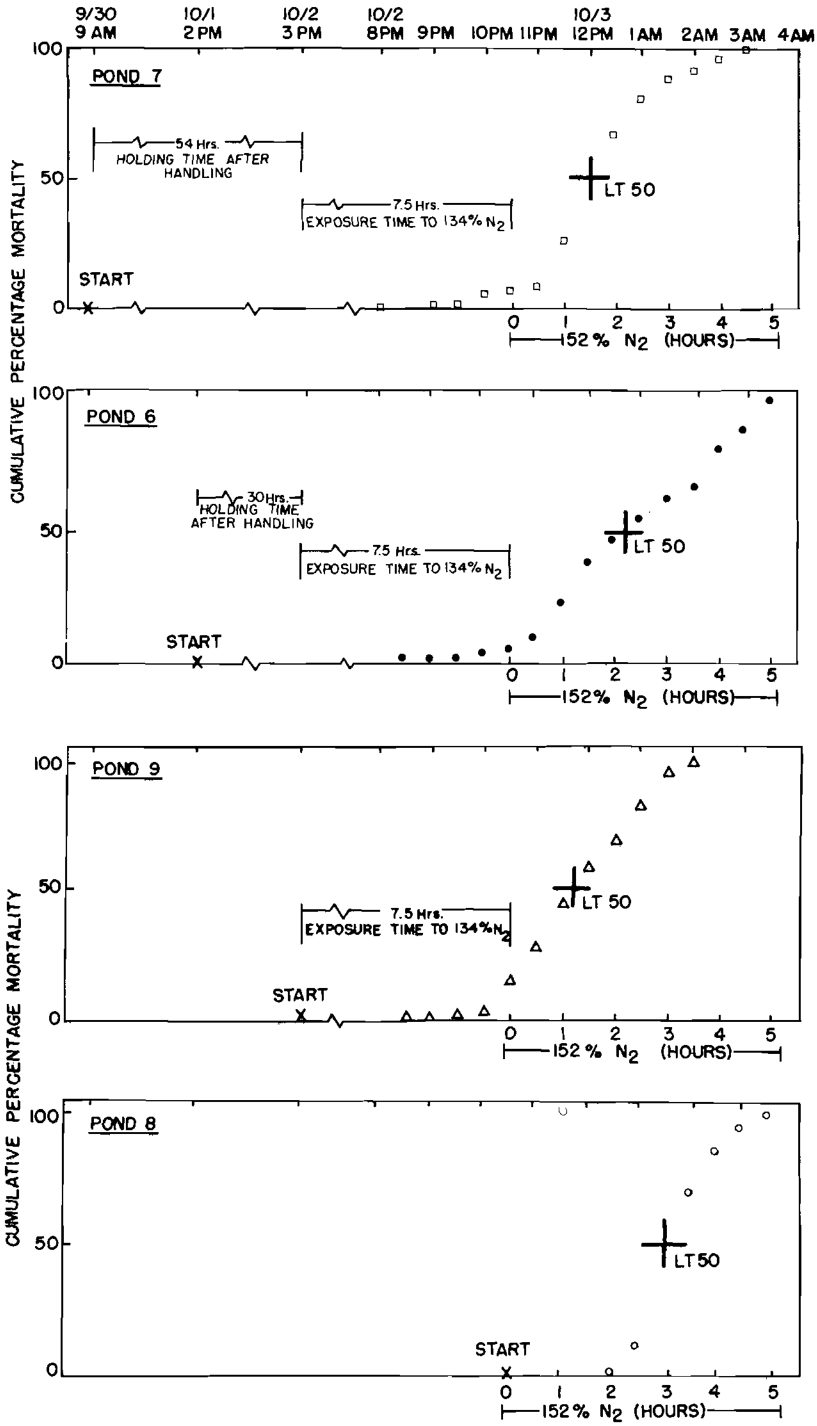

Figure 3. Cumulative percentage mortality of chinook salmon fingerlings under different test conditions.

solubility of water-borne bubbles.

Partial occlusion of the upper intake grating was not the only means of supersaturating the water supply. However, it was the only way under normal operating procedures (flow rates and valve settings) that superaturation could be induced. The exception was achieved while experimenting with valve combinations with the upper intake partially exposed. It was found that we could produce dissolved nitrogen concentrations of 134% without having to impede the flow of water through the grating. It was apparent that with a delivery rate which does not satisfy the capacity of the system, due to valves being 100% open at the hatchery and with little or no back pressure on the line, there was ample opportunity for a water-gas mixture to occur because the pipe was not full.

The epilimnion of Foster Dam forebay was warmer in early September than in early October, requiring less surface water to achieve a pond temperature of 13.5°C. Sample 1, on October 3, was taken after hydraulic conditions existing on September 5 were simulated (except as noted above) and the system had operated at stability for several hours. The resulting nitrogen concentration of 175% in the screening box was the highest measured in over 4 years of research on nitrogen supersaturation in the Columbia River and its tributaries① We believe that supersaturated water, by passing through a closed pipeline for an extended period, combined with a 21.3 m head pressure at the discharge end, created this unusually high concentration.

There was considerable reduction in concentrations of dissolved gases in pond water compared to water in the screening box. This agrees with the findings of Marsh and Gorham (1904) who demonstrated that exposure of supersaturated water to the open atmosphere removed excess gasses at a rate dependent on the degree of exposure. After water upwells into the screening box enclosure, it passes over and through a perforated plate before entering a pipeline for distribution to the hatchery ponds. Exposure of the water mass to the atmosphere at this point permitted rapid dissipation of some of the dissolved gases — from 175 to 152% (Table 1). The subsurface position of entrance nozzles in the Burrows-type rearing ponds does not produce any significant aeration.

① Kirk T. Beiningen and Wesley J. Ebel. 1970. Supersaturation of dissolved nitrogen in the Columbia and Snake rivers. Data Report, 1965-69. U.S. Fish and Wildlife Service, National Marine Fisheries Service, Biological Laboratory, Seattle, Washington. Manuscript submitted for publication.

Behavior

The behavior of fish affected by highly supersaturated water at South Santiam Hatchery appears to be characteristic. Rukavina and Varenika (1956) reported a reaction sequence among trout (*Salmo* sp.) dying from gas bubble disease in the River Boxna, Yugoslavia, similar to that observed during our tests.

Our observations also indicated these fish were unaware of the lethal effects of a nitrogen-supersaturated environment. In another experiment Ebel① reported dead and distressed fish with gas bubble disease symptoms in water supersatured to 135% with dissolved N_2. These fish, held in a vertical cage, were permitted to seek any depth between the surface and 4.6 m. Within 7 days 26% died and half the survivors exibited gas bubble disease symptoms. Even with the opportunity to avoid stress, nearly two-thirds failed to do so.

Mortality Rates

Recent findings by Ebel (personal com-

① Wesley J. Ebel, National Marine Fisheries Service, Biological Laboratory, Seattle, Washington, personal communication.

munication) in laboratory experiments indicate that prior exposure to supersaturation merely shortens the time when the test group will die in a higher concentration. These data are similar to ours.

On September 5, records at the screening box showed a decrease in water temperature 6.75 hours before the fish loss was discovered. Our experiments indicated that it takes about 3 hours for equalization of screening box and pond temperatures. It thus appears that the LT 100 (lethal time for 100% mortality) on September 5 was about 3.75 hours. This implies that nitrogen supersaturation was 152% or higher, based on the LT 100 of Group 8 after only 5 hours during these tests.

The few survivors of the September 5 loss provided an unexpected control. These fish showed that confinement to a live box did not alter death rates. They also provided evidence that survivors of exposure to highly supersaturated water apparently do not have in inherent physiological tolerance to high concentrations of N_2.

Pathology

Gas emboli with associated hemorrhages in the gill tissues were the most important cause of death. Marsh and Gorham (1904) first described gas emboli in the gills of marine fishes exposed to supersaturated sea water, and their observations have since been confirmed by other investigators. Woodbury (1942) reported severe gill damage due to gas emboli which he thought was caused by oxygen supersaturation from an algae bloom in a fresh-water lake. Pauley and Nakatani (1967) were the first to report on the histopathology of gills and other tissues of fish affected by gas bubble disease. The specimens used for their study showed a light but detectable stage of the disease. Gill filaments were swollen and edematous, and contained hemolyzed red blood cells. Fibrous scar tissue had replaced a portion of the gill filament in one case and a hydropic degeneration of the squamous epithelium had occurred. It is believed that the more severe damage observed in our tests was related to a very high concentration of dissolved nitrogen. We found a gill fungus in all broods of fish reared at the South Santiam Hatchery. It is known that 1969-brood fry were exposed to 115% levels of saturation during the fry rearing period (Beiningen and Wyatt, 1970.) Harvey and Cooper (1962) suggest that injuries might appear when alevins exposed to supersaturated water reach the fry stage. Whether this could produce damage sufficient to allow the invasion of *Saprolegnia* sp. on the gills is not known. Westgard (1964) reported damage to the eyes of adult chinook salmon due to supersaturated water. Examination of survivors 18 days after the loss on September 5, showed that some had exopthalmia. Their eyes were hemorrhaged, as reported in adults by Westgard. There were also survivors with fungus on the caudal fin, gills, snout, and opercula. Marsh and Gorham (1904) were also the first to report emboli in the dorsal aorta and heart. The dorsal aorta in the fish we examined was found heavily occluded with emboli. This was considered to be the second major cause of death.

Summary

Severe losses of juvenile salmon and steelhead at the South Santiam Hatchery due to gas bubble disease prompted studies of its water supply system. Hatchery water is obtained from the epilimnion and hypolimnion of the forebay behind high-head Foster Dam. It was determined that when the reservoir level was at the middle of the upper supply line, restriction of water flow by trash caused a frothy air-water mixture at the entrance to the pipe, leading to high N_2 supersaturation (152%) in hatchery ponds. Fish placed

in this water began to die within 2 hours and all were dead in 5 hours. The fish did not appear to be aware of the lethal environment until minutes before they died. Typical pathology of gas bubble disease was found in the affected fish.

Acknowledgments

Grateful appreciation is extended to members of several agencies who provided valuable assistance in this study. Hydraulic observations were made by Emery Wagner, Paul Ingram, and William Pilkington, Fish Commission of Oregon. The hatchery manager, Ted Williams, and his crew were helpful throughout the study. Members of the Army Corps of Engineers including Donald Westrick, Project Engineer, H. P. Toovoren, Hydraulic Engineer, and Phli Moon, Chief, Fish Planning Section, provided their expertise; J. C. Archibald made the drawings from which Figures 1 and 3 were adapted. Wesley Ebel, National Marine Fisheries Services, assisted in solving technical problems as they arose and reviewed the manuscript. John Conrad and Kenneth Johnson of the Fish Commission of Oregon also critically reviewed the manuscript.

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ESTIMATES OF MATURATION AND OCEAN MORTALITY FOR COLUMBIA RIVER HATCHERY FALL CHINOOK SALMON AND THE EFFECT OF NO OCEAN FISHING ON YIELD

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Abstract

Nearly 31 million fall chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), were marked and released in 1962-65 from 12 Columbia River hatcheries. All the major fisheries that caught these fish were systematically sampled in 1964-69.

The estimated fishing intensities and maturity schedules for the 1962-brood releases were calculated and wherever possible comparisons made with the 1961 brood data. A general model that was developed for the 1961 brood data, and which equates ocean catch and river entry with recruitment, mortality, and maturation rates, was utilized in this work. The calculated 6-month fishing intensity rates were higher for 1962 than 1961 brood for both general marks and Kalama Hatchery marks. Since it was not possible to make estimates for the 1962 brood Spring Creek fish, no direct comparisons for the two broods from this hatchery were attempted. Estimates of fishing mortality and proportions maturing changed relatively little when large changes in natural mortality were used. Apparently only about 0.3% of all marked fish released were alive at the beginning of their third year, when most of them became available to the fisheries.

Mortality rates for marked Kalama fish were used for unmarked Kalama Hatchery fish, but maturation rates were adjusted for possible delayed maturity of marked fish. The total catch of 1962-brood chinook from the Kalama Hatchery was estimated to be 134,409 kg, compared to 203,331 kg for the 1961 brood. Elimination of the estimated loss due to marking would have raised the 1962 catch to 153,045 kg. Ocean fishing apparently reduced the number of Kalama fish that returned to the Columbia River by about 70% and the weight yield of hatchery fish by 25%. This compares with a reduction of about one-half in number and 19% in weight for 1961-brood Kalama Hatchery fish.

Introduction

A cooperative marking experiment was undertaken, beginning in 1962, by various federal and state fisheries agencies along the Pacific Coast to estimate the contribution of hatchery-reared fall chinook salmon (*Oncorhynchus tshawytscha* Walbaum) to the various fisheries. Hatcheries included in the study are shown in Figure 1. Marking continued over 4 years (1962-65) and included the 1961-64 broods. Data collection was completed at the end of 1969. Worlund *et al.* (1969) published preliminary estimates of the contribution to the fisheries by the 1961 brood of hatchery fall chinook salmon; Rose and Arp (1970) did the same for the 1962 brood. Cleaver (1969) made additional analysis of the 1961 brood, including estimates of ocean mortality, maturity schedules based on mark recoveries, and ocean catch of Spring Creek and Kalama Hatchery fish that would have returned to the Columbia River in the absence of ocean fishing. Using Cleaver's equations, similar estimates (except for effects of ocean fishing on Spring Creek fish) are made in this report for the 1962 brood and compared with results for the 1961 brood. Effects of ocean fishing on 1962 brood Spring Creek fish could not be evaluated because there were no river recoveries of 5-year-olds. The numbers marked from each hatchery for the 1962 brood are listed in Table 1.

Estimates of Ocean Mortality Rates and Maturity Schedules for Marked Fish

Estimated Capture of Marked Fish

Table 2 summarizes the capture of marked fish from the 1962-brood fall chinook as calculated by participants in the hatchery evaluation program. The totals represent the complete recoveries of marks during the years 1964-67 with the exception of tributary streams in 1967 which were not examined for marked fish.

[1] National Marine Fisheries Service Biological Laboratory, Seattle, Washington.

Table 1. Estimated numbers of fall chinook salmon released from study hatcheries for the 1962-brood year

Mark	Hatchery Source	Marked and Released (No.)	Ratio of Marked to Unmarked	Marked and Unmarked Released (No.)
Ad-LM	10 hatcheries ①	3,949,299	0.1137	39,462,410
Ad-LM	Spring Creek	868,574	0.1302	8,408,267
Ad-LM	Kalama	431,206	0.1156	4,599,326
Ad-LV-LM	Spring Creek	866,892	0.1129	8,408,267
Ad-RV-LM	Kalama	437,669	0.1173	4,599,326
RV-LM	Cascade	541,158	0.1667	4,217,910
LV-LM	Grays River	241,494	0.2437	1,359,761
	Total Marked	7,336,292		

① Includes all study hatcheries except Spring Creek and Kalama.

However, this is believed to have involved few, if any, marked 1962 brood fish. Ocean and river catch includes sport and commercial fisheries, and river total includes catch and number of spawning fish. Although Cleaver used only fish on which the complete mark was readily recognizable, I have included partial marks (Ad, Ad-LV, and Ad-RV) which appear to have been due to regeneration of maxillary bone. Furthermore, there were considerably fewer mark recoveries from the 1962 brood than from previous brood, so these additional recoveries are desirable. For the three marks that indicate maxillary regeneration, estimated regeneration is slightly over 18% and is remarkably consistent: Ad-LM, 18.1%, Ad-LV-LM, 18.6%, and Ad-RV-LM, 18.6%. This compares with 17% calculated by Cleaver for the 1961 brood.

Proportions of Fish Maturing

Using Cleaver's equation (12), and assuming F and M constant,

$$P_4 = \frac{C_5}{C_4} \cdot \frac{E_4}{E_5} \quad \text{where}$$

F_n = instantaneous ocean fishing mortality rate in nth year

M_n = instantaneous ocean natural mortality rate in nth year

P_n = proportion of survivors maturing in nth year ($P_5 = 1$)

C_n = ocean catch in nth year

E_n = number entering the river in nth year

The following estimates of P_4 were derived for the general (Ad-LM) and Kalama River (Ad-RV-LM) marks. Because $E_5 = O$ for the other three hatchery marks, equation (12) could not be used for them.

General mark $P_4 = 1.849$

Kalama River mark $P_4 = 0.913$

The first value of P_4 is too large. The proportion maturing in the 4th year cannot exceed 1.0 since no fish would remain at sea into the 5th year. The P_4 value for Kalama River fish also appears to be high, particularly in comparison with estimates calculated later in this paper. This follows the general pattern for the 1961 brood which led Cleaver (1969) to state, "The best explanation seems to be that all marks were not equally available for capture, and that no single mark was subjected to a constant fishing rate during the last 3 years of life."

Since the assumption of F and M constant did not produce meaningful results for the 1962 brood, other possible as-

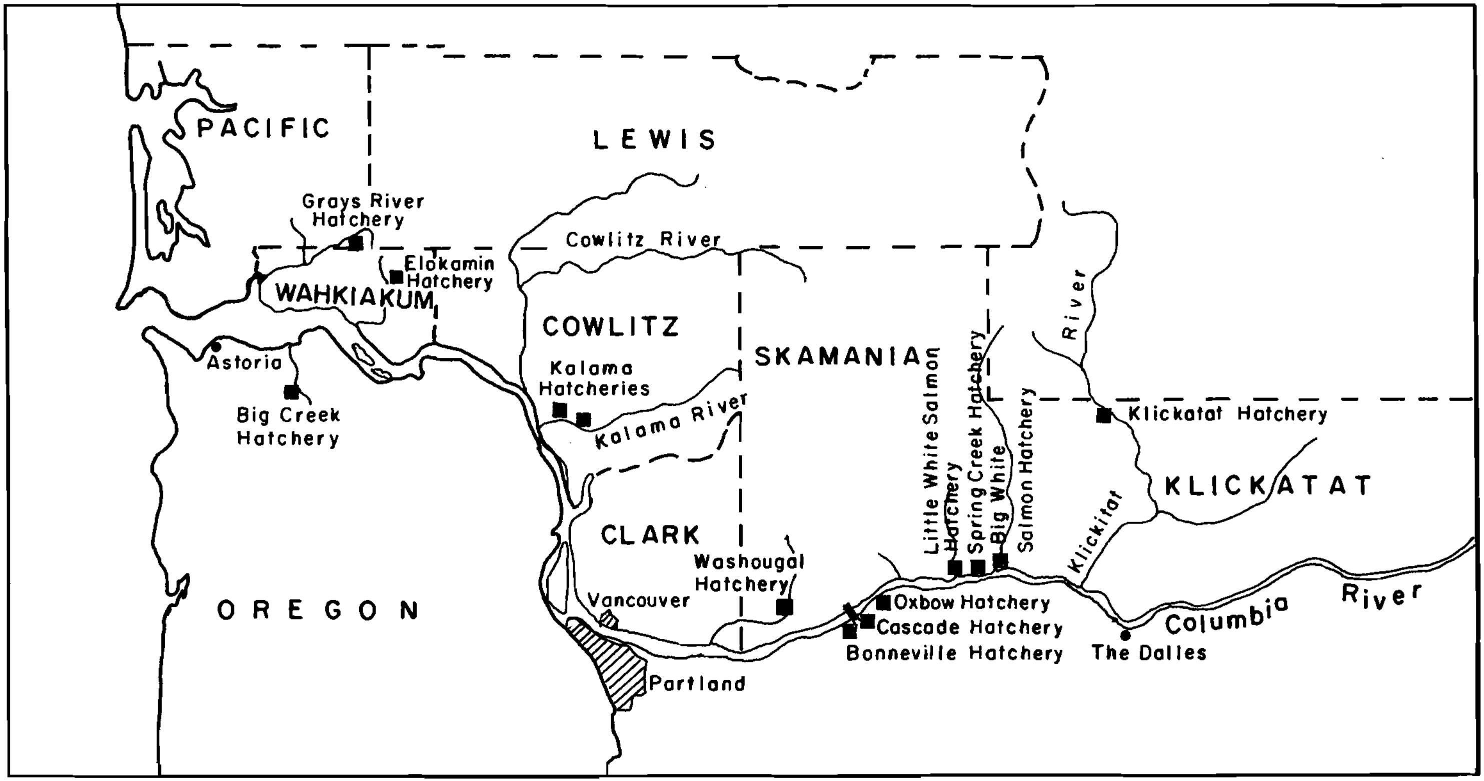

Figure 1. Location of Lower Columbia River hatcheries involved in marking studies (adapted from Cleaver, 1969).

Table 2. Number of Columbia River fall chinook salmon of the 1962 brood, by age and mark①, captured by all sources in years 1964-67

Age at Capture	Ocean catch (C)	River catch	Number spawning	River total (E)	Grand total
	General mark (AD-LM)②; 5,249,079 fish released, 0.15% recovered				
2	270	54	40	94	364
3	3,565	1,234	363	1,597	5,162
4	1,416	685	251	936	2,352
5	126	24	21	45	171
Total	5,377	1,997	675	2,672	8,049
	Spring Creek Hatchery mark (AD-LV-LM)②; 866,892 fish released, 0.12% recovered				
2	34	10	8	18	52
3	376	272	49	321	697
4	150	85	35	120	270
5	14	0	0	0	14
Total	574	367	92	459	1,033
	Kalama Hatchery mark (AD-RV-LM)②; 437,669 fish released, 0.15% recovered				
2	0	6	1	7	7
3	293	21	8	29	322
4	190	60	24	84	274
5	31	10	5	15	46
Total	514	97	38	135	649
	Grays River Hatchery mark (LV-LM); 241,494 fish released, 0.07% recovered				
2	0	0	0	0	0
3	106	0	2	2	108
4	64	4	1	5	69
5	3	0	0	0	3
Total	173	4	3	7	180
	Cascade Hatchery mark (RV-LM); 541,158 fish released, 0.03% recovered				
2	0	0	0	0	0
3	66	5	0	5	71
4	43	24	6	30	73
5	2	0	0	0	2
Total	111	29	6	35	146

① AD = Adipose fin, LV = left ventral fin, RV = right ventral fin, and LM = left maxillary bone.
② Includes partial marks Ad-LV(RV).

sumptions need to be examined. If it is assumed that $M = O$ and $P = 1$, the highest values of e^{-Z_n} (where Z_n = total instantaneous mortality rate, and e^{-Z_n} = survival rate), P_n and F_n, and lowest values of Z_n can be calculated using Cleaver's equations (1969, p. 53).① For example,

$$e^{-Z_5} = \frac{E_5}{C_5 + E_3} = \frac{45}{171} = 0.263$$

for general marks. The results, using data from Table 2 for the general and Kalama

Table 3. Maximal values of e^{-Z} and P, and minimal values of Z from 1962 brood data, assuming $M = O$①

Data	General mark (AD-LM)	Kalama mark (AD-RV-LM)
e^{-Z_5}	.263	.326
e^{-Z_4}	.439	.406
e^{-Z_3}	.536	.544
e^{-Z_2}	.966	1.000
Z_5	1.335	1.121
Z_4	.823	.901
Z_3	.624	.609
Z_2	.035	.000
P_4	.846	.646
P_3	.388	.083
P_2	.012	.011

① Z_n values are also the highest possible values of F_n.

marks, are listed in Table 3. These survival rates suggest that loss from mortality is at least 67-74% in the 5th year, 56-59% in the 4th and 46% in the 3rd year. These mortality levels are generally higher than estimates calculated by Cleaver for the 1961 brood (38-61% in the 5th year, 27-45% in the 4th, and 30-53% in the 3rd year.) Furthermore, there is no indication that the loss may have been lower in the 4th year, as occurred for the 1961 brood.

The highest values of P_4 shown in Table 3 are much larger than for P_3 (0.646 to 0.846 compared with 0.083 to 0.388). The proportion of fish that mature in their 2nd year is relatively unimportant. The P_4 values could be either an overestimate or underestimate, depending on whether the C_4 fish would have matured mainly as 4- or 5-year-olds. Furthermore, as pointed out by Charles O. Junge of the Fish Commission of Oregon (personal communicaton), the proportion maturing (P_n) calculated by this method is really that which matures at the end of the fishing season and not necessarily the same as that at the beginning of the fishing year. If ocean fishing mortalities were the same for both mature and immature fish, then P_n would not be changed by fishing. However, it is intriguing that in spite of a considerable difference in estimated ocean fishing intensities, the P_n's are quite similar for the two brood years of Kalama fish.

Effect of Arbitrary Values of M on F and P

Assuming that $M_3 = M_4 = M_5$ and $P_5 = 1$, arbitrary values of M_c (mortality constant) were next used to investigate relationships between P_n, F_n, and M_c and to see how great the effect of error in M_c upon estimated values of F_n and P_n. To be comparable with the analysis for the previous brood year, instantaneous yearly values of M_c were taken as 0.24, 0.45, 0.48, 0.60, 0.72, and 0.96. For values of M_c, F_n, and P_n, and also for R_n (recruits to the nth year of life), each year of life was considered to begin on October 1. From October to March 31, only natural mortality was assumed to be effective. During the entire fishing season (April 1 to September 30), both natural and fishing mortality were assumed to affect fish at sea. Mortality rates were held constant throughout the periods in which they were acting.

The 1962-brood data in Table 2 were again used with equations (20) to (25) from Cleaver (1969, P. 55).① The results are given in Table 4 and Figures 2 and 3. Similar data have been recalculated for the 1961 brood, using partial marks and more complete recovery data (Table 5). This inclusion generally caused an increase in the calculated fishing intensities except for the F_5 value for Spring Creek fish which is noticeably reduced. As with the 1961 brood, the changes in F_n and P_n are nearly linear with the change in M for the range of values used. Also, in no case

① It should be noted that in Cleaver's paper this equation is printed with C_6 in the denominator; it should be C_5 as shown here.

Table 4. F, P, and R values for marked[1] fall chinook salmon of the 1962 brood; M is summed for 12 months and F for 6 months

Natural mortality M	Fishing intensity F_5	F_4	F_3	Proportion maturing P_4	P_3	P_2	Recruitment R_5	R_4	R_3
				General mark (AD-LM)					
.24	1.346	.781	.535	.810	.332	.009	220	3,216	10,441
.45	1.304	.733	.460	.783	.290	.007	260	3,912	13,681
.48	1.298	.727	.449	.779	.284	.007	266	4,028	14,238
.60	1.275	.698	.410	.761	.262	.006	293	4,516	16,736
.72	1.251	.671	.372	.743	.240	.005	323	5,076	19,831
.96	1.206	.616	.301	.705	.199	.003	393	6,438	28,320
				Kalama mark (AD-RV-LM)					
.24	1.115	.830	.485	.591	.065	.008	58	416	921
.45	1.078	.758	.400	.549	.054	.006	69	514	1,256
.48	1.073	.748	.385	.542	.052	.005	71	531	1,325
.60	1.052	.707	.338	.518	.046	.004	78	602	1,611
.72	1.031	.667	.298	.493	.041	.004	86	685	1,958
.96	0.991	.587	.221	.443	.031	.002	106	895	3,047

[1] Includes partial marks.

does the change in F_n or P_n equal the changes in M_c.

Because of the relatively small change in F_n and P_n with changes in M_c, estimates in Table 4 for values between $M_c = 0.24$ and 0.72 have a relatively narrow range. Consequently, a modest error in estimating M_c will have little effect on the other estimates.

Table 4 shows that even if M were constant for the 3-year period, F is not constant from age to age nor hatchery to hatchery for the 1962 brood. It is unfortunate that no analysis could be made for Spring Creek marks of the 1962 brood. However, a number of interesting comparisons can be made between recoveries of general and Kalama marks of the 1961 and 1962 broods, as shown in Tables 4 and 5. The F_5 values were much greater for the 1962 brood recoveries for both groups. In fact, all F values were higher for this brood. On the other hand, the P

[1] Equation (21) in Cleaver's paper should have P_4 in the denominator as was subsequently noted in an errata sheet.

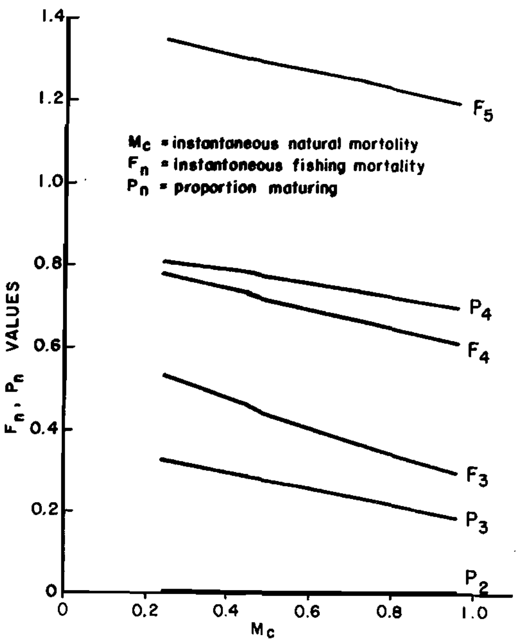

Figure 2. Change in F_n and P_n with arbitrary values of M_c, general mark (AD-LM and AD), 1962 brood.

Table 5. F, P, and R values for marked[1] fall chinook salmon of the 1961 brood; M is summed for 12 months and F for 6 months

Natural mortality M	Fishing intensity F_5	F_4	F_3	Proportion maturing P_4	P_3	P_2	Recruitment R_5	R_4	R_3
				General mark (AD-RM)					
.24	.933	.443	.499	.843	.281	.008	905	11,415	33,166
.45	.900	.413	.421	.818	.240	.006	1,080	14,085	44,312
.48	.895	.409	.411	.814	.235	.006	1,107	14,527	46,169
.60	.877	.392	.370	.798	.213	.005	1,226	16,427	55,124
.72	.859	.376	.331	.781	.193	.004	1,358	18,625	65,970
.96	.823	.343	.261	.744	.156	.003	1,665	24,051	96,740
				Spring Creek mark (AD-LV-RM)					
.24	.151	.334	.667	.951	.375	.011	43	1,558	6,231
.45	.144	.316	.589	.941	.329	.008	53	1,908	8,024
.48	.143	.314	.576	.939	.322	.008	54	1,967	8,339
.60	.139	.304	.528	.932	.297	.007	61	2,212	9,716
.72	.135	.293	.482	.924	.273	.006	68	2,488	11,382
.96	.128	.274	.396	.906	.228	.004	86	3,165	15,897
				Kalama mark (AD-RV-RM)					
.24	.522	.583	.270	.626	.024	—	343	2,095	3,539
.45	.500	.528	.209	.582	.019	—	414	2,636	5,188
.48	.497	.520	.197	.575	.018	—	425	2,728	5,576
.60	.485	.488	.173	.548	.016	—	474	3,126	6,905
.72	.474	.458	.148	.521	.014	—	528	3,598	8,678
.96	.452	.398	.112	.467	.011	—	657	4,808	13,544

[1] Includes partial marks.

values were fairly comparable for the two broods. The 1962 brood Kalama data indicated a very small percentage maturing before age 4, as was the case with the 1961 brood. The ranges of Kalama P_4 values for the two broods were very similar (0.443-0.591 for 1962; 0.467-0.626 for 1961). For the general mark (Ad-LM, Ad-RM), the P_2 values were fairly comparable for the two broods. The phenomenon of F_4 being greater than F_2 for the Kalama marks of the 1961 brood at M values of less than about 0.6, did not occur with the 1962-brood recoveries. Finally, from the number of marked fish released (Table 1) and the estimated number recruited to the 3rd year of life, it appears that survival was 0.003 or less (at $M = 0.45$) for the 1962 brood in the first 18 months after liberation. This compares with 0.011 for the 1961 brood.

Survival of Marked Spring Creek and Kalama Fish

The 1961 and 1962 broods are compared in Table 6. As mentioned previously, it was not possible to make a similar computation for the 1962 brood Spring Creek fish. It is apparent from these data that a much smaller proportion (R_3/N) of the marked 1962 brood fish survived the first 18 months following release. Futhermore, a greater percentage of those that survived and entered the ocean fishery was caught. Although a comparison between the two brood years for Spring Creek fish is not possible, certain speculations may be made. In most instances,

Table 6. Estimated number of recruits (R_3) to the ocean fishery, ocean catch (C), and other data for marked Columbia River fall chinook salmon of the 1961 and 1962 brood, M=0.45; based on recovery of Kalama, Spring Creek, and general marks

Data	General mark		Spring Creek mark	Kalama mark	
	1961 brood	1962 brood	1961 brood	1961 brood	1962 brood
No. marked released (N)	5,446,439	5,249,079	1,133,019	475,964	437,669
R_3	44,312	13,681	8,024	5,188	1,256
R_3/N	.008	.003	.007	.011	.003
F_3	.421	.460	.589	.209	.400
F_4	.413	.733	.316	.528	.758
F_5	.900	1.304	.144	.500	1.078
P_2	.006	.007	.008	—	.006
P_3	.240	.290	.329	.019	.054
P_4	.818	.783	.941	.582	.549
Calculated ocean catch in the 3rd, 4th, and 5th year (C)	14,975	5,107	2,974	1,617	514
C/R_3	.338	.373	.371	.312	.409

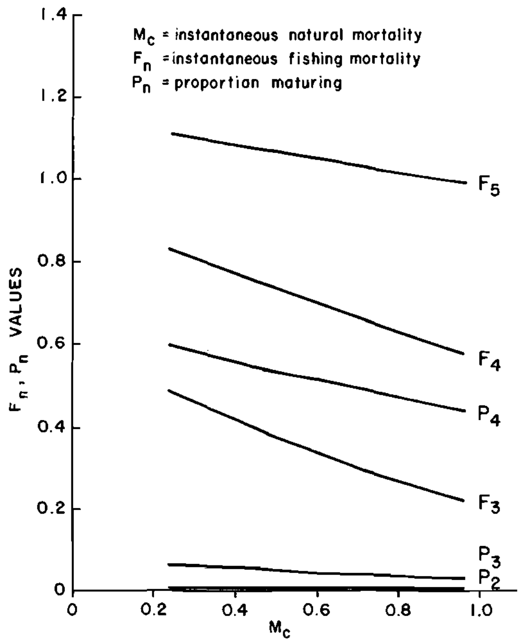

Figure 3. Change in F_n and P_n with arbitrary values of M_c, Kalama mark (AD-RV-LM and AD-RV), 1962 brood.

data for the general mark for 1961 returns were intermediate between those for Kalama and Spring Creek (i.e., R_3/N: Kalama 0.011, General 0.008, Spring Creek 0.007). On this basis, the data suggest that 1962 Spring Creek fish survived and entered the ocean fishery in about the same proportions as Kalama fish (Kalama 0.003, General 0.003), but in much smaller proportions than the 1961 Kalama brood (Kalama 0.011, Spring Creek 0.007). Likewise, it appears that the ocean fishery caught a smaller percentage (C/R_3) of the 1962 Spring Creek recruits than Kalama recruits (Kalama 0.409, General 0,373), whereas among the 1961 brood, a greater percentage of the Spring Creek recruits had been taken by the ocean fishery (Kalama 0.312, Spring Creek 0.371). This conclusion—that the ocean fishery was less intense on the 1962 brood Spring Creek fish—is also indicated (Table 2) by the ratio of ocean catch to river escapement (574/459 = 1.25 for Spring Creek and 514/135 = 3.81 for Kalama). On the other hand, the percentage of the river escapement caught by the river fishery was roughly similar for the

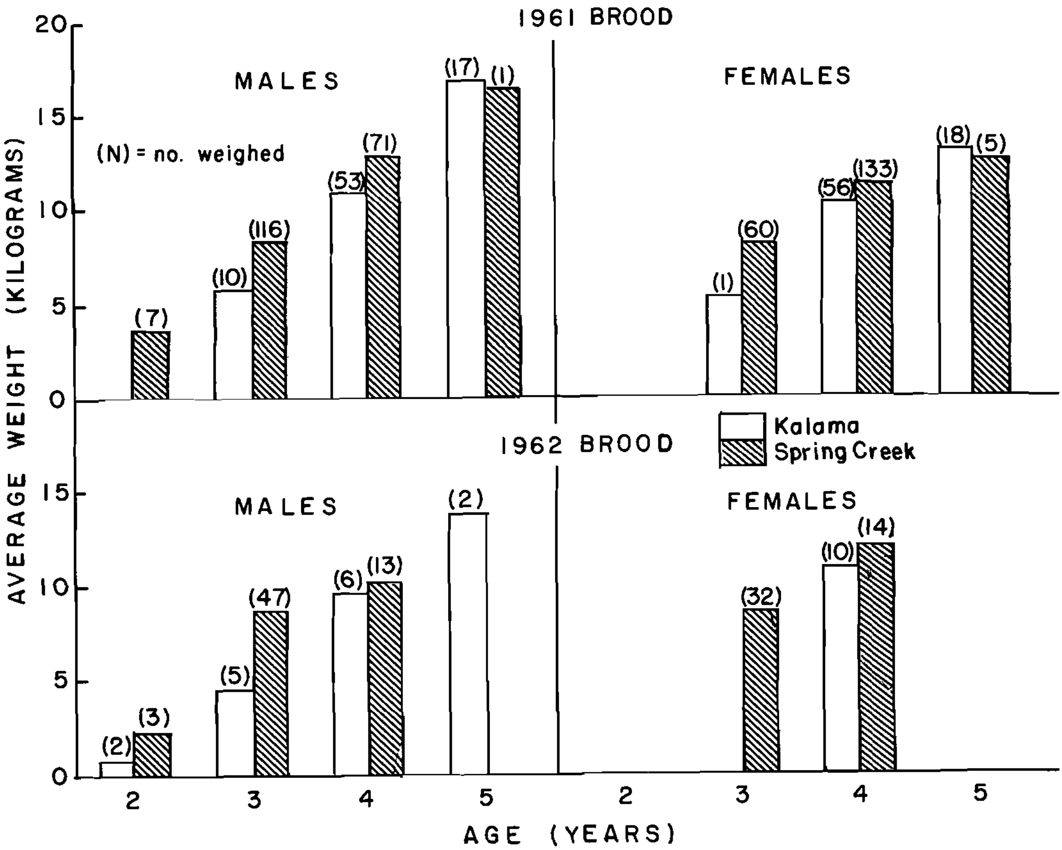

Figure 4. Average weights by age and sex of 1961- and 1962-brood Kalama and Spring Creek hatchery marked chinook salmon caught in the Columbia River gill-net fishery.

two hatcheries: 80% for Spring Creek and 72% for Kalama.

As might be expected, there is a close relationship between the size of returning fish and proportion of each age group maturing. Not only did a consistently lower proportion of Kalama fish mature at the younger ages, compared with Spring Creek, but Kalama fish that returned to the Columbia River each year also weighed less. This is apparent from Figure 4 where average weights are depicted by age and sex for marked fish from these two hatcheries caught in the Columbia River gill-net fishery. For both brood years and both sexes, the 2, 3, and 4-year-old Kalama chinook salmon caught in the river were consistently smaller than Spring Creek fish. These differences probably reflect different growth patterns for the two stocks. These data also indicate that after the faster growing, earlier maturing Spring Creek fish are eliminated, the residual, slower growing 5-year-old Spring Creek chinook salmon are slightly smaller than the Kalama stocks which are fished less intensively at the younger ages.

Delayed Maturity

Cleaver (1969, Figure 5) reported a difference in delay of return to the hatcheries for the Kalama and Spring Creek

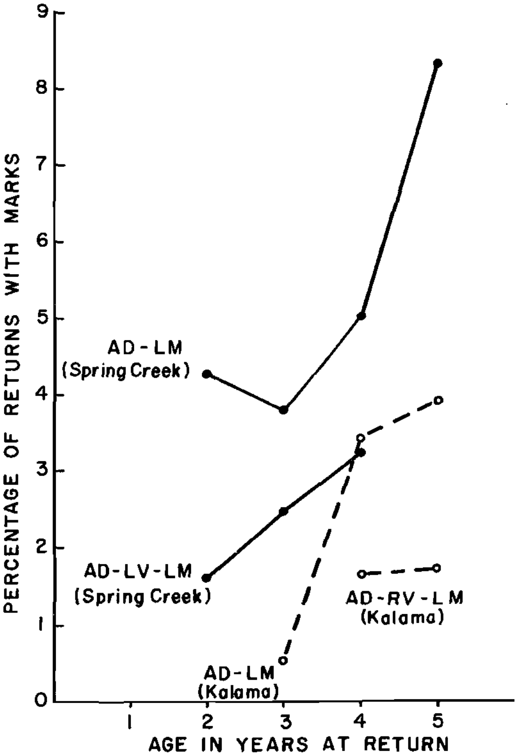

Figure 5. Percentage of 1962-brood marked fall chinook salmon, by age and mark, in returns to Kalama and Spring Creek hatcheries.

1961 brood fish. Similar data (Figure 5) indicate that the relationship is quite different for the 1962 brood. In fact, the Spring Creek marked fish (Ad-LM) of the 1962 brood exhibit an almost identical curve with the one shown for 1961-brood Kalama fish (AD-RM).

For the 1961-brood recoveries, Cleaver (1969, Table 31) used maturity schedules (P_n) for unmarked fish to estimate returns of marked fish and, when compared with observed values, concluded that the additional time at sea, due to delayed maturity, caused a reduction of 16% or less in fish returning to the river. Similar calculations for the 1962 brood (Table 7) did not indicate any major overall loss from this factor. However, the differences between the two estimates of E_n are so variable and inconsistant for individual age groups that conclusions based on the combined data may be questionable.

In discussing the change in maturity schedule, Cleaver (1969, Table 34) shows the average age composition of returns for marked Spring Creek fish from the Columbia River gill-net fishery for a number of selected years. The age composition of the 1939, 1942, and 1943 brood from Spring Creek was very close to that of the 1922 brood, but from the 1961 brood there were relatively fewer 4th and 5th year fish. Cleaver made his analysis before all the sampling data were available. Although his conclusions are not materially altered, there is a significant change in the percentage age composition for the 1961 brood when the complete data are included. The corrected figures for Spring Creek for the 1961 and 1962 broods are listed in Table 8. The increased proportion of younger fish is evident for the 1961 and 1962 broods. These differences perhaps reflect gear changes and fishing selectivity over the years. The more intense ocean fishery in recent years would tend to reduce the numbers of older fish returning to the river. Also, the comment by Jensen (1971) in his study of brook trout populations might apply to chinook salmon: "The brook trout populations even matured at an earlied age under heavy exploitation."

Effect of Ocean Fishing on Unmarked Kalama Hatchery Fish

Assuming common distribution patterns and mortality rates, it is possible to estimate how many fish were caught at sea from hatchery stocks and what the return to the river would have been in the absence of an ocean fishery. Sufficient data are available for only the Kalama stock. The P_n values from Table 7 for un-

Table 7. Estimates of proportion maturing (P_n) for unmarked fall chinook salmon of the 1962 brood and reduction in numbers entering the Columbia River due to delayed maturity

Hatchery group and age	Number of unmarked hatchery returns	Survival in river fishery	Estimated number entering river	P (unmarked)	Adjusted E_n (marked)	Estimated actual E_n (marked)
General Hatchery						
2	253	.44	575	.003	39	94
3	3,760	.24	15,667	.200	1,101	1,597
4	4,242	.27	15,711	.820	1,107	936
5	280	.47	596	—	42	45
Total	8,535		32,549		2,289	2,672
Precentage of marked fish due to delayed maturity...........0.0						
Kalama Hatchery						
2	2	.14	14	.0003	0	7
3	371	.28	1,325	.067	36	29
4	953	.29	3,286	.592	89	84
5	162	.33	491	—	13	15
Total	1,488		5,116		138	135
Percentage loss of marked fish due to delayed maturity..........2.2%						

marked fish were used.

Estimated Number in the Ocean Catch

Estimated ocean catches for unmarked chinook of the 1962 Kalama brood are given in Table 9. Details of the calculations are given by Cleaver (1969, p. 64).

The estimated catch of 1962 brood unmarked Kalama Hatchery fish at sea (19,375) were considerably greater than the number estimated to have entered the Columbia River as maturing fish (5,116). If none had been caught in the ocean, the number returning would have still been less than the sum of river entry and ocean

Table 8. Age composition of marked Spring Creek hatchery fall chinook salmon caught in the Columbia River fishery from selected brood years ①

Brood year	Mark	Year of return: 2	3	4	5	6	Number of fish
		Percent					
1939	AN-RV and AN-LV	.00	.33	.42	.24	0	33
1942	AD-RV and AD-LV	.00	.12	.70	.17	0	673
1943	AD-LP and AD-RP		.15	.68	.17	0	471
Average 1939-43		.00	.14	.68	.17	0	1,177
1922	AD-LV	.01	.15	.66	.18	0	349
1961	AD-LV-RM	.02	.42	.56	.01	0	1,090
1962	AD-LV-LM	.02	.75	.23	.00	0	302

① All data except for 1961 and 1962 broods from Cleaver (1969, Table 34).

Table 9. Estimated ocean catch in numbers and weight of unmarked Kalama Hatchery fall chinook salmon①, 1962 brood

Age	Estimated ocean catch			
	Number of fish weighed	Average weight (kg)	Number of fish caught	Weight of catch (kg)
2	0	0	0	0
3	32	2.89	11,052	31,984
4	33	6.69	7,213	48,259
5	5	10.66	1,110	11,837
Total	—	—	19,375	92,080

① Seasonal average weight of marked AD-RV-LM troll caught hatchery fish landed at Vancouver, Canada, used for ages 3, 4 and 5. Weight of troll caught fish adjusted by 100/85 to compensate for loss in dressing.

catch due to deaths at sea (Table 10).

A greater proportion of the number of unmarked 1962 Kalama fish caught came from the ocean fisheries than was the case with the 1961 brood. For example, the calculated ocean catch from the 1961 brood was about 70% of those caught, whereas the ocean catch from the 1962 brood was about 84%.

Estimated Returns with No Ocean Fisheries

Table 10 gives the estimates of numbers and weight of unmarked 1962 Kalama fish that would have returned to the Columbia River had there been no ocean fishing. Numbers entering the river were calculated from $E_n = \frac{R_n e^{-Z_n}}{P_n}$, starting with $n = 3$. Then,

Table 10. Estimated number and weight of unmarked Kalama Hatchery fall chinook salmon, 1962 brood, that would have entered the Columbia River, using different values of M and assuming $F = O$ for ocean fisheries

Values of F and M	Age 2	3	4	5	Total
		Number			
Actual	14	1,325	3,286	491	5,116
$F = 0$, $M = .24$	12	2,152	13,955	7,566	23,685
$F = 0$, $M = .45$	14	1,977	10,389	4,565	16,945
$F = 0$, $M = .48$	14	1,947	9,934	4,236	16,131
$F = 0$, $M = .60$	15	1,858	8,405	3,179	13,457
$F = 0$, $M = .72$	16	1,785	7,164	2,403	11,368
$F = 0$, $M = .96$	19	1,653	5,217	1,377	8,266
		Weight in Kilograms			
Actual	10	4,604	33,894	6,949	45,457
$F = 0$, $M = .24$	9	7,477	143,942	107,075	258,503
$F = 0$, $M = .45$	10	6,869	107,159	64,604	178,642
$F = 0$, $M = .48$	10	6,765	102,466	59,948	169,189
$F = 0$, $M = .60$	11	6,456	86,695	44,990	138,151
$F = 0$, $M = .72$	12	6,202	73,894	34,008	114,116
$F = 0$, $M = .96$	14	5,743	53,812	19,487	79,056

Table 11. Comparison of estimated Columbia River catch of unmarked 1962-brood Kalama Hatchery fall chinook with the potential catch, assuming no ocean fishery

Age	Number spawning	Average weight (kg)	Number x weight (kg)	Estimated 1962 run to river (kg)	Catch in river (kg)	Estimated kg values with $F = 0$, $M = .45$: Return to river	Estimated kg values with $F = 0$, $M = .45$: Potential catch in river (Col. 7 — Col. 4)
2	2	0.73	1	10	9	10	9
3	371	3.47	1,289	4,604	3,315	6,869	5,580
4	953	10.31	9,830	33,894	24,064	107,159	97,329
5	162	14.15	2,293	6,949	4,656	64,604	62,311
Total	1,488		13,413	45,457	32,044	178,642	165,229

Apparent reduction in yield due to ocean fishing (165,229 — 32,044 — 92,080)/165,229 = .249

$R_4 = R_3 e^{-Z_3} (1 - P_3)$;

R_3 was obtained in a similar manner.

The estimated returns at $M_c = .45$, $F = 0$ were then used to calculate differences in yield due to ocean fishing (Table 11). The number spawning and rate of fishing on each age group were taken from Table 7. The estimated catch if there had been no ocean fisheries was obtained by assuming that the number escaping to spawn would remain constant. Yield is the estimated weight of the potential return to the river with no ocean fisheries less the weight of the 1962 brood spawners.

The data in Table 10 show that, with $M = .45$ and no ocean fishing, more than three times (3.31) as many unmarked maturing Kalama fish would have returned to the Columbia River as actually entered. Using river survival rates from Table 7, the returns to the Kalama Hatchery would have increased 3.41 times. The calculated potential increase in weight of fish returning to the river under the assumption of no ocean fisheries is 3.93 times greater than the increase in numbers. Assuming $M = .45$ and no ocean fishery, the calculated potential return of 1962 unmarked Kalama fish would have been 178,642 kg (Table 11). Allowing for the same magnitude of spawning escapement as actually occurred (13,413 kg), there would have been a potential river harvest of 165,229 kg. Since the combined ocean and river fisheries actually caught only 124,124 kg (river, 32,044 kg and ocean, 92,080 kg), there was an apparent reduction in potential yield in the river of about 25% due to ocean fishing.

Estimated catches are considered to be too low because weights of marked fish were used. Weights for unmarked fish were not available. Furthermore, only losses due to capture were considered. No adjustment was made for other losses such as hooking mortality which tend to increase the apparent M.

Total Yield of Marked and Unmarked Fish

The foregoing data can be used to estimate hatchery yields, which are the sum of river and ocean catches of marked and unmarked fish. The catch of marked Spring Creek and Kalama fish is calculated in Table 12. Numbers of fish were taken from Table 2 and average weight from Table 11. Because origins of fish in the catch with the general Ad-LM and regenerated marks were not indentifiable but should be considered as a valid component of hatchery yield, the following relationship was used to estimate the weight contribution of non-assignable

Table 12. Number and weight (kilograms) of marked Spring Creek and Kalama Hatchery fall chinook salmon, 1962 brood, taken by all fisheries

Age	Ocean catch (number)	Average weight (kg)	Ocean catch (kg)	River catch number	Average weight (kg)	River catch (kg)
			Spring Creek			
2	34	1.86	63	10	2.52	25
3	376	5.56	2,124	272	8.88	2,415
4	150	8.21	1,232	85	10.78	916
5	14	10.66①	149	—	—	—
Total	574		3,568	367		3,356
Non-assignable marks = 1.635 x assignable marks = 1.635 x (3,568 + 3,356) = 11,321 kg.						
Total yield to the fisheries = 3,568 + 3,356 + 11,321 = 18,245 kg.						
			Kalama			
2	0	—	—	6	.73	4
3	293	2.39	847	21	3.47	73
4	190	6.69	1,271	60	10.31	619
5	31	10.66	330	10	14.15	142
	514		2,448	97		838
Non-assignable marks = 2.130 x assignable marks = 2.1130 x (2,448 + 838) = 6,999 kg.						
Total yield to the fisheries = 2,448 + 838 + 6,999 = 10,285 kg.						

① From Kalama data.

marks originating from a specific hatchery:

$$\frac{\text{Wt. of non-assignable marks in catch}}{\text{Wt. of assignable marks in catch}} = \frac{\text{No. of non-assignable marks at hatchery}}{\text{No. of assignable marks at hatchery}}$$

It is estimated that the fisheries caught a total of 18,245 kg of marked Spring Creek fish and 10,285 kg of marked Kalama fish. It was impossible to estimate the catch of unmarked Spring Creek fish. However, the river catch of unmarked Kalama fish was estimated at 32,044 kg and the ocean catch at 92,080 kg. Thus, the total estimated yield to the fisheries from the 1962 brood fingerlings released at the Kalama Hatchery was 134,409 kg. This compares with 203,321 kg for the 1961 brood.

It is possible to compute the potential yield from the Kalama Hatchery if no fish had been marked and no marking mortality occurred. If the catch of unmarked Kalama fish is adjusted upward in the same proportion as the number unmarked is increased to account for the total number released, the catch of unmarked fish would be multiplied by 1.233 and the potential yield becomes 153,045 kg. On this basis, the cost of the marking program includes a loss of 18,636 kg of Kalama fish from the 1962 brood. It was not possible to compute a comparable figure for Spring Creek fish.

Cleaver also computed the likelihood of survival to the spawning stage for fish maturing at 3, 4, and 5 years of age, mainly to show the difference between Spring Creek and Kalama fish. In Table 13, similar information is listed for the 1962 brood Kalama fish. It was assumed that mortality rates were the same for mature and immature members of the same age group, and also for marked fish. Survival to the hatchery was considerably lower for the 1962 than 1961 brood, as would be expected in view of the higher

Table 13. Expected survival to the hatchery for Kalama fall chinook salmon, 1962 brood, alive at the beginning of their third year①

Age	Survival in river fishery	Third year survival at sea	Fourth year survival at sea	Fifth year survival at sea	Survival to hatchery	
					1962 brood	1961 brood②
3	.28	$e^{-.85}$	—	—	.120	.151
4	.29	$e^{-.85}$	$e^{-1.21}$	—	.037	.064
5	.33	$e^{-.85}$	$e^{-1.21}$	$e^{-1.53}$	.009	.025

① River survival from Table 6; ocean survival with $M = .45$ from Table 3.
② From Cleaver (1969, Table 40).

fishing mortality.

Summary

The ocean fishery had a significant effect upon the yield of 1962-brood hatchery fall chinook in the Columbia River. Calculated fishing intensity rates for both general and Kalama Hatchery marks for the 1962 brood were higher than for the 1961 brood. Only about 0.3% of all marked fish were estimated to be alive at the beginning of their third year. Under the assumptions stated, the effect of the ocean fishery was to reduce the number of Kalama Hatchery fish returning to the Columbia River by about 70% and the total yield in weight by at least 25%. The yield to all fisheries from the Kalama Hatchery for 1962-brood fall chinook was estimated to have been 134,409 kg; without marking loss, it would have been 153,045 kg. Similar losses probably occurred for the Spring Creek fish, but could not be calculated.

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INVESTIGATION OF SCALE PATTERNS AS A MEANS OF IDENTIFYING RACES OF SPRING CHINOOK SALMON IN THE COLUMBIA RIVER

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Abstract

An attempt was made to identify races of spring chinook, *Oncorhynchus tshawytscha* (Walbaum), from scale samples collected from adult fish in major tributaries of the Columbia River system during 1966. The following characteristics were compared: (1) number of circuli to the first annulus, (2) number of circuli to the end of fresh-water growth, and (3) mean distances between circuli. Tributary streams were grouped into four geographic areas: (1) lower Columbia River, (2) middle Columbia River, (3) upper Columbia River, and (4) Snake River. It was concluded that races could not be separated by the methods used. Although counts differed somewhat, the distinction between groups was insufficient for practical separation.

Counts to the first annulus did provide a means of identifying wild and hatchery fish in the Willamette River. Examination of scales from known wild and hatchery fish indicated that an error of about 20% would result when 16 or less circuli were used to identify wild fish and 17 or more to identify hatchery stocks.

Introduction

Knowledge of the racial composition of a salmon run is important in regulating the harvest to insure adequate escapement of racial components. Some races in the Columbia River have been identified as to time of migration. Studies using tagged fish show that upriver races of spring chinook are intermingled in their migration through the lower Columbia (Galbreath, 1966). This mixing of races in an area where a commercial and sport harvest takes place indicates a need for discovering a characteristic peculiar to each racial group to serve as a means of identification. In this study the use of scale patterns was investigated for identifying races of spring chinook in the Columbia. The International Pacific Salmon Fisheries Commission has successfully used scales to identify and manage races of sockeye salmon (*O. nerka*) in the Fraser River (Henry, 1961).

The use of scales in identifying races is based on the assumption that numbers of circuli and spacing between circuli are functions of the environment. Good growth conditions (i.e., adequate food supply, optimum temperatures, etc.) result in circuli being more numerous and more widely separated; and the opposite is true with poor growing conditions. Therefore, we hypothesized that if environmental differences exist between major tributaries, they might be detected in the fresh-water area of the scales. We also assumed that differences in growth of hatchery and wild fish exist and would likewise be indicated in the scale patterns.

Methods

Collecting Scale Samples

Scales were collected in 1966 from adult spring chinook in major tributaries of the Columbia River system (Figure 1). The data were grouped into four geographic areas: (1) the lower Columbia tributaries from the mouth upstream to Wind River; (2) middle Columbia tributaries from above Wind River to the Snake River; (3) upper Columbia River tributaries; and (4) Snake River tributaries. We felt the environmental conditions were similar among tributaries in these areas, thus providing a logical grouping for analysis. Samples were obtained from both wild and hatchery fish.

Scales were taken from the area immediately above the lateral line and slightly posterior to the origin of the dorsal fin. Koo (1955) indicated scales first start to grow in this area and afford the most complete record of growth. We took two or more scales from each fish but often discarded all scales collected because of regenerated nuclear areas. We used 1,787 scales from 3,432 fish sampled (Table 1). Scales were placed on gummed tapes and pressed into plastic with a scale press. These impressions were projected at 100X magnification.

Counting and Measuring Circuli

The following characteristics were compared for all scale samples: (1) number of circuli from the focus to the first annulus; (2) number of circuli from the focus to the end of fresh-water growth; (3) mean distance between circuli to the first annulus; and (4) mean distance between circuli to the end of fresh-water growth.

A clear plastic overlay with the 20° dorso-radial line marked off in 2-millimeter intervals was placed over the projected scale image. Circulus counts and measurements were made from the focus to the first annulus and from the focus to the end of fresh-water growth along the 20° dorso-radial line of the scale (Figure 2). Clutter and Whitesel (1956) found that on sockeye scales circuli in this area were more complete and more widely spaced. This also appeared to be true of spring chinook scales.

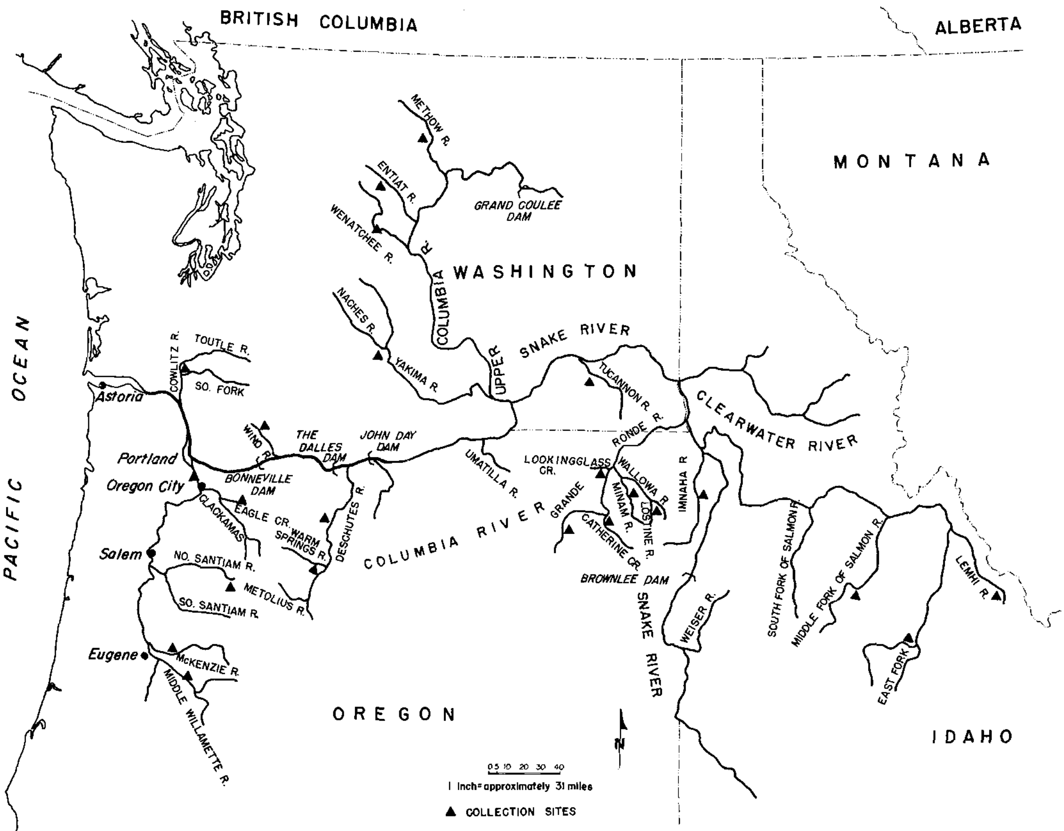

Figure 1. Map of the Columbia River system.

Table 1. Number of scale samples collected and usable scales, by geographic area and tributary

Area and tributary	Number of scales: Collected	Usable
LOWER COLUMBIA RIVER		
Cowlitz River	14	13
Willamette River		
Willamette sport catch	637	185
Clackamas River (Eagle Cr. Hatchery)	205	106
North Santiam River (Minto Pond)	381	262
McKenzie River		
Below Leaburg Dam	106	80
Above Leaburg Dam	126	99
Middle Fork (Dexter Pond)	231	160
Wind River (Carson Hatchery)	238	59
Area Total	1,938	964
MIDDLE COLUMBIA RIVER		
Deschutes River (*Warm Springs River and Shearar's Falls*)	116	79
Area Total	116	79
SNAKE RIVER		
Tucanon River	7	3
Grand Ronde River		
Minam River	11	7
Lostine River	126	76
Lookingglass Creek	337	133
Catherine Creek	4	3
Upper Grande Ronde River	43	25
Imnaha River	131	73
Salmon River		
Upper Salmon River	133	64
Middle Fork Salmon River	162	93
Lemhi River	120	67
Area Total	1,074	544
UPPER COLUMBIA RIVER		
Yakima River	31	19
Wenatchee River	130	80
Entiat River	48	36
Methow River	95	65
Area Total	304	200
GRAND TOTAL	3,432	1,787

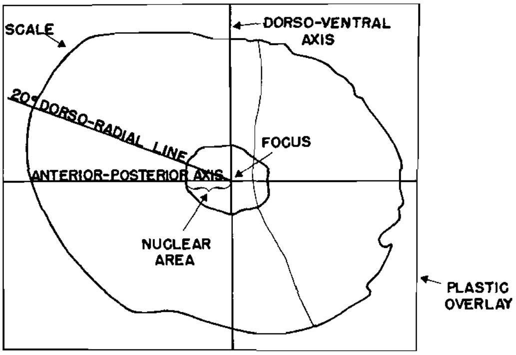

Figure 2. Position of plastic overlay and 20° dorso-radial line on outline of magnified scale image.

The procedure used in counting and measuring circuli follows:

(1) Orient the plastic overlay with the focus and vertical and horizontal axes of the scale (Figure 2).

(2) Locate the intersection of the annulus and 20° dorso-radial line.

(3) Determine the last complete circulus before the annulus.

(4) Measure the distance in millimeters from the focus to the midpoint of the last circulus preceding the annulus.

(5) Count the circuli from the focus to and including the last circulus preceding the annulus.

(6) Measure the distance in millimeters from the focus to the midpoint of the last fresh-water circulus.

(7) Count the circuli from the focus to and including the last fresh-water. circulus.

We defined the annulus as the area of incomplete, closely spaced circuli followed by complete, widely spaced circuli. Since counts of these incomplete circuli varied, even on scales of the same fish, we decided to count through the last complete circulus before the annulus. Despite our attemps to standardize this technique, certain decisions such as the location of the annulus and end of fresh-water growth were sometimes rather subjective. Some scales also had unusual shapes and placement of the plastic overlay was arbitrary.

Results and Discussion

One assumption of our study is that circulus counts for spring chinook from a given tributary show similar patterns annually. This assumption was partially tested for the 1961-62 brood years in most of the streams sampled by comparing fish maturing as 4 and 5 year olds in 1966. The comparisons showed close agreement. The test was extended to the 1960 brood year at Lookingglass Creek, tributary to the Grande Ronde River, by examining scales from adults returning to this stream as 4-year-old fish in 1964-66. The mean number of circuli to the first annulus for 1964, 1965, and 1966 was 12.5, 12.9, and 12.7, respectively, and the frequency distributions of counts were almost identical (Figure 3). We found no evidence to justify splitting the samples by brood year or age at maturity, and consequently all age groups were combined for analysis. Scale samples from males and females also showed similar patterns and were combined.

Since the hatchery environment can differ substantially from that in natural streams, only wild stocks were compared among geographic areas. Results of these comparisons are presented in the order in which we believe the measurements would prove most useful for racial identification: circulus counts to the first annulus are considered first; circulus counts to the end of fresh-water growth second; and mean distances between circuli third.

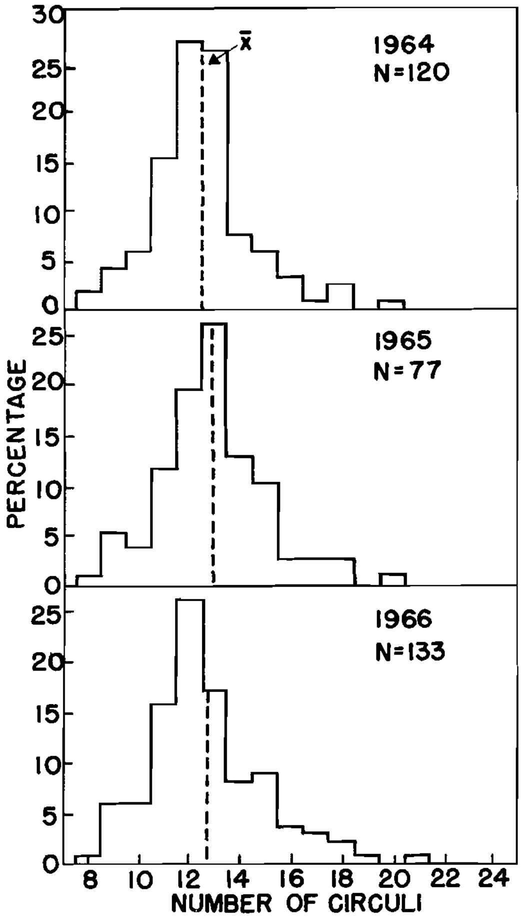

Figure 3. Percentage distribution and means (x) of circulus counts to the first annulus for scale samples from Lookingglass Creek, 1964-66.

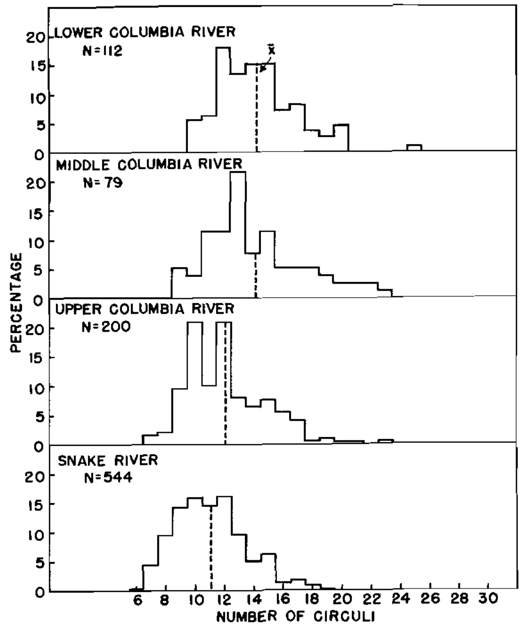

Figure 4. Percentage distribution and means (x) of circulus counts to the first annulus by geographic areas.

Circulus Counts to the First Annulus

Table 2 shows the frequency distribution and means of circulus counts to the first annulus for wild fish in tributaries within the four geographic areas. Generally, scale samples from the lower and middle Columbia River tributaries had the highest circulus counts to the first annulus, and the upper Columbia and Snake river tributaries had lower counts. There are some variations between means for tributaries within these areas which may indicate that significant environmental effects occur over smaller areas than those we chose. In some cases small samples may not be representative of an individual tributary such as the Cowlitz or Yakima.

The percentage distribution and means of circulus counts to the first annulus for the four geographic areas are presented in Figure 4. The mean counts for the lower Columbia, middle Columbia, upper Columbia, and Snake river areas were 14.3, 14.2, 12.1, and 11.1, respectively. These means were tested, each against the others, using a ranking test. At the 5% significance level, the lower and middle Columbia areas did not differ statistically. All the other comparisons were found to be significantly different by the test. Although statistical differences exist between mean counts, separation of a mixed population of races from each area by circulus counts to the first annulus

Table 2. Frequency distribution and means of circulus counts to the first annulus for scale samples of spring chinook from wild stocks in tributaries of four areas in the Columbia River system

	Lower Columbia			Middle Columbia	Upper Columbia					Snake River			
No. of circuli	Cowlitz River	Willamette River	Total	Deschutes River	Yakima River	Wenatchee River	Entiat River	Methow River	Total	Grande Ronde River	Imnaha River	Salmon River	Total
6												1	1
7						3			3	2	5	16	24
8						4			4	4	5	43	52
9				4		15	1	3	19	18	17	42	77
10	1	5	6	3	1	22	6	13	42	29	11	46	86
1	—	7	7	9	—	9	4	7	20	40	16	22	79
2	3	17	20	9	—	15	8	20	43	58	8	21	88
3	3	12	15	17	2	4	6	4	16	34	4	15	53
4	1	16	17	6	4	4	2	3	13	18	4	6	28
15	3	14	17	9	3	2	5	5	15	23	2	9	34
6	1	7	8	4	2	1	2	6	11	6	—	1	7
7	1	8	9	4	4	—	1	3	8	6	1	2	9
8		4	4	4	1	—	—	—	1	4			4
9		3	3	3	1	—	—	1	2	1			1
20		5	5	2	1	—	—		1	—			—
1		—	—	2		—	1		—	1			1
2		—	—	2		—			—				
3		—	—	1		1			1				
4		—											
25		1	1										
Total Scales	13	99	112	79	19	80	36	65	200	244	73	224	544
Mean Count	13.6	14.4	14.3	14.2	15.5	10.8	12.8	12.4	12.1	12.2	10.5	10.1	11.1

does not appear to be feasible because of the extensive overlap in the distributions.

Lower Columbia River. Scales were collected from the Cowlitz and Willamette rivers, the major spring chinook producing tributaries of the lower Columbia. The overall mean for wild fish of the lower Columbia area was 14.3 circuli to the first annulus. Since only 13 usable scales were obtained from the Cowlitz, the mean number of circuli to the first annulus (13.6) may not be representative. As of 1966, the run in the Cowlitz was composed entirely of wild stocks, but in future years stocks from a recently completed hatchery will contribute to the run.

In the Willamette drainage, scales were collected from both hatchery and wild stocks. The only sample from known wild fish was 99 scales from the McKenzie River above Leaburg Dam. The wild fish averaged only 14.4 circuli to the first annulus, similar to wild fish from the Cowlitz. Samples were not obtained from other known wild populations in the Willamette drainage.

Middle Columbia River. In this section of the Columbia, the three most important spring chinook tributaries are the Deschutes, Klickitat, and John Day rivers. We sampled Deschutes River fish only. Samples were collected from the Indian dip-net fishery at Shearar's Falls about 71 km upstream from the mouth, and from the Warm Springs River 135 km above the mouth. The mean number of circuli to the first annulus was 14.2, similar to wild fish from the lower Columbia. This is intermediate between the high mean for hatchery fish in the lower river and the low means for wild fish from the upper Columbia and Snake rivers.

Snake River. Scales were examined from the Grande Ronde, Imnaha, and Salmon rivers and their tributaries. These streams produce most of the spring chinook in the Snake River drainage. The overall mean for the Snake was 11.1 circuli to the first annulus.

In the Grande Ronde system, samples were obtained from the Lostine, Minam, and Upper Grande Ronde rivers, Catherine Creek, and Lookingglass Creek. Fish in the drainage exibited an overall mean of 12.2 circuli to the first annulus, with fish from all tributaries showing the same basic pattern except for the upper Grande Ronde where they had a mean of 10.3 circuli from a small sample of 25 scales.

Samples from the Imnaha and Salmon rivers had mean circulus counts of 10.5 and 10.1. Subsamples from the upper Salmon, Middle Fork of the Salmon, and Lemhi rivers had mean circulus counts of 9.8, 8.9, and 12.0, respectively. The upper and Middle Fork of the Salmon had fewer circuli to the first annulus than any tributaries in the Columbia River system.

Upper Columbia River. The mean count of circuli to the first annulus for spring chinook from the upper Columbia tributaries combined was 12.1, similar to the mean for the Grande Ronde drainage. The Yakima, Wenatchee, Entiat, and Methow rivers had mean counts of 15.5, 10.8, 12.8, and 12.4, respectively. The mean count for fish from the Yakima River was the highest of any tributary but this may have been due to the small number of scales collected.

Circulus Counts to the End of Fresh-Water Growth

Total counts of fresh-water circuli were made for all major tributaries. The means and frequency distributions were compared by the same method as the circulus counts to the first annulus.

We had difficulty locating the last fresh-water circulus. This problem of indistinct termination of fresh-water growth and beginning of ocean circuli occurred to some degree in all samples collected. Also, counting circuli through the annulus area introduced inconsistencies in repeated readings and between readers.

The relationship shown by circulus counts to the end of fresh-water growth was similar to that of counts to the first annulus. However, differences were less pronounced. Mean total circulus counts for fish from the lower Columbia, middle Columbia, upper Columbia, and Snake River were 18.6, 20.4, 17.2, and 17.6, respectively (Figure 5). We believe that counts to the end of fresh-water growth would not provide a practical method of racial separation of Columbia River spring chinook.

Mean Distances Between Circuli

Mean distances between circuli were computed in millimeters for counts to the first annulus and to the end of fresh-water growth. The overall mean distances between circuli for each of the geographic areas, beginning with the lowermost, were 2.3 mm, 2.1 mm, 2.5 mm, and 2.4 mm to the first annulus and 2.2 mm, 2.1 mm, 2.3 mm, and 2.3 mm to the end of fresh water. All four areas also showed nearly the same frequency distributions. Because of this similarity, mean distances would not be usable as the criterion for separatng races.

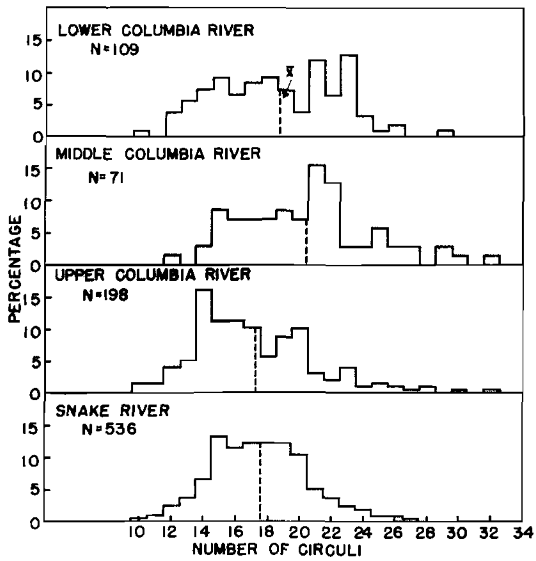

Figure 5. Percentage distribution and means ($\bar{x}$) of circulus counts to the end of fresh-water growth by geographic areas.

Separation of Hatchery and Wild Fish

Our data showed that extreme environmental differences are required to create indentifiable scale patterns in wild fish. Such differences can occur between the wild environment and modern hatcheries where larger juveniles are produced.

In the Willamette River system we sampled three of five spring chinook hatcheries and assumed these scale samples to be representative of hatchery fish in the system. We also assumed the McKenzie River sample from above Leaburg Dam is representative of the wild population in the system. Distributions of the circulus counts to the first annulus presented in Figure 6 show the relative differences between wild and hatchery fish. Examination of the distributions indicates that the selection of 16 circuli or less to identify wild fish and 17 or over to identify hatchery fish will minimize improper classification. In this case 21% of the wild and 17% of the hatchery samples would be improperly classified.

We feel that this level of error would

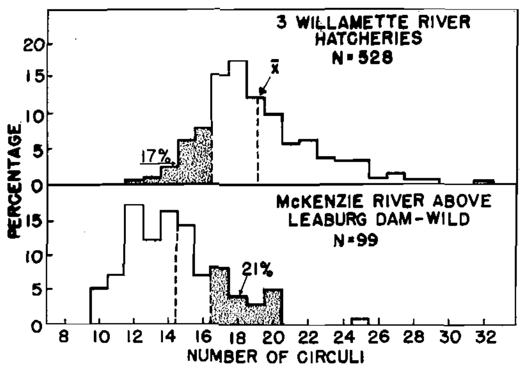

Figure 6. Comparison of percentage distribution of circulus counts to the first annulus for hatchery and wild fish in the Willamette River system, 1966.

not prevent this criterion from serving as a practical method for determining proportions of hatchery and wild fish in populations not heavily weighted toward one group, either wild or hatchery. If the population is heavily weighted toward one group, the error in classification of the larger group exaggerates the size of the smaller group.

When this classification by circulus counts was applied to a sample of 185 scales from the 1966 lower Willamette River sport fishery, 31% of the fish were assigned to hatchery origin and 69% to wild origin. This might be slightly biased in favor of hatchery fish (smaller group). Taking this into consideration, the results compare favorably with the Willamette Falls count and hatchery returns in 1966 when 28,200 were counted at the falls and about 6,200, or 22%, were subsequently handled at upstream hatcheries. This is a minimum percentage because not all hatchery fish in the run were actually received into the hatchery collecting systems.

This circulus counting technique was applied to fish which were juveniles in the early 1960's, and since that time, hatchery rearing programs have been pointed toward raising larger fish which emphasizes the difference between wild and hatchery stocks. In addition, selected reservoirs in the Willamette system have recently been utilized to rear spring chinook. Indications are that these reservoir fish will have circulus counts intermediate between stream-reared wild fish and hatchery stocks. We believe that using new reference values for hatchery and reservoir scale patterns would provide criteria for identifying hatchery, reservoir, and wild stocks.

Conclusions

An attempt was made to separate tributary races of spring chinook in the Columbia River by analyzing scale patterns as follows: (1) circulus counts to the first annulus, (2) circulus counts to the end of fresh-water growth, and (3) mean distances between circuli. The same methods were used to separate hatchery and wild fish in the lower Columbia River.

It was concluded that wild stocks could not be separated by these methods. Although differences among races were indicated the overlap was too great for practical separation when all four groups were intermingled. However, counts to the first annulus did provide a means of separating wild and hatchery fish in the Willamette River system.

Acknowledgments

The authors appreciate the help of individuals from the Fish Commission of Oregon, Oregon Game Commission, Washington Department of Fisheries, and the Idaho Department of Fish and Game in collecting the scale samples analyzed in this paper. Without their cooperation this study would not have been possible.

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GROWTH OF JUVENILE SPRING CHINOOK SALMON IN LOOKINGGLASS CREEK

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Abstract

I studied growth of juvenile spring chinook salmon (*Oncorhynchus tshawytscha* Walbaum) in Lookingglass Creek during 1964-68. Mean lengths of fish sampled increased from about 35 mm in March to over 80 mm in October. Growth was rapid and relatively uniform from April to September and averaged between 7.2 and 9.6 mm per month. Condition factor was near 0.8 in April and ranged between 1.0 and 1.1 in most samples collected from June through November. Condition factor increased with fish length.

The length-weight regression equation calculated from the sample data is log $W = -5.44454 + 3.25386$ log L.

Fish reared in separate areas of the stream showed some differences in linear growth which may be a reflection of differences in water temperature in these areas.

Introduction

In 1964 the Fish Commission of Oregon began a study designed to investigate production, early life history, and ecology of juvenile spring chinook salmon (*Oncorhynchus tshawytscha* Walbaum). One objective was to measure growth of juvenile salmon to provide a basis for understanding its relationship to size at migration and numbers of adults which subsequently return to spawn. This report presents the results obtained from the growth studies. It describes growth as evidenced by length-frequency distributions, average lengths, and condition factors; presents a length-weight relationship; and compares growth of fish reared in separate areas of the stream.

Materials and Methods

Lookingglass Creek, a tributary of the Grande Ronde River in Union County, Oregon, was the study stream. It is approximately 27 km (16 miles) long and has one major tributary, Little Lookingglass Creek, which is about 16 km (10 miles) long and enters the main stream 6-1/2 km (4 miles) above the mouth (Figure 1).

I seined samples of juvenile chinook from 1964-68. Samples were obtained once each month as early as March and as late as November and generally consisted of the first 50 fish seined. "Standard samples" were obtained in main Lookingglass Creek between mileposts 4.50 and 4.75 (standard area). Additional samples were obtained during 1966-68 between mileposts 0.00 and 0.50 (lower sampling area, lower samples), during 1966 and 1967 between mileposts 10.00 and 10.25 (upper sampling area, upper samples), and during 1967 and 1968 near milepost 1.75 in Little Lookingglass Creek. Location of the four sampling areas is shown on Figure 1 and sampling activity is summarized in Table 1.

Fork length of each fish was measured to the nearest millimeter and weight to the nearest 0.1 gram. Excess water was shaken off before weight was measured Mean length of each sample was calculated from ungrouped data. However, I grouped the length data into 5-mm intervals to simplify graphic presentation of the length-frequency distributions.

Condition factor (K) was calculated for every fish in the samples according to the formula $(W)(10^5)/L^3$, where $W =$

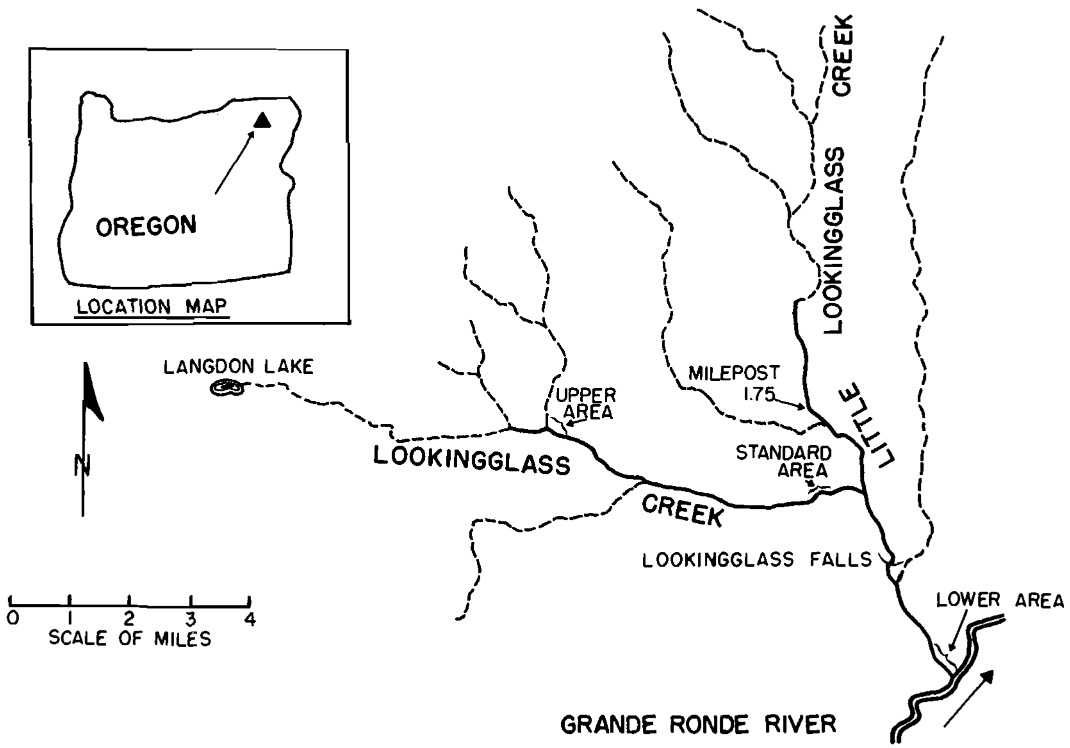

Figure 1. Lookingglass Creek system.

weight in grams and L = fork length in millimeters. Sample conditon factor is the arithmetic mean of the condition factors of all individuals in the sample.

I calculated the length-weight relationship according to the equation $\log W = \log a + b \log L$, where W = weight in grams and L = fork length in millimeters. Measurements were grouped into 5-mm class intervals. Logarithmic transformation was at the midpoint of each of the resulting 13 intervals, using the mean weight from the corresponding interval as the dependent variable. The constants a and b were determined by least squares.

Results

Linear Growth

Chinook fry emerged from the gravel of Lookingglass Creek as early as mid-January at a minimum length of 32 mm. Maximum length of downstream migrants seldom exceeded 110 mm.

Length range of fish in samples collected during March and April was narrow, and distributions were skewed right, reflecting recruitment of emerging fry. Length ranges in May remained narrow, but length distributions began losing skewness. After May, growth rates and length ranges increased and distributions approximated the normal curve (Figure 2).

Mean lengths ranged between 34.8 mm in March (1967) and 86.1 mm in October (1964) and September (1965) (Figure 3). Annual variation in mean lengths within the same calendar month

Table 1. Summary of length and length-weight samples of juvenile spring chinook salmon collected in Lookingglass Creek

Area and year / Month	Standard					Lower			Upper		Little Lookingglass	
	1964	1965	1966	1967	1968	1966	1967	1968	1966	1967	1967	1968
March				L			L					
April		LW	L	L	LW		L					
May		LW	LW	LW	LW		LW	L				LW
June		LW	LW	LW	LW	LW	LW	L	LW	L		LW
July		LW	LW	LW	LW	LW	LW	L	LW	LW		LW
August	LW	LW	LW	LW	LW	LW	LW	L	LW			LW
September	LW	LW	LW	LW	LW		LW				LW	LW
October	LW		LW	LW			LW				LW	
November	LW			LW			LW					

L = length only; *LW* = length and weight.

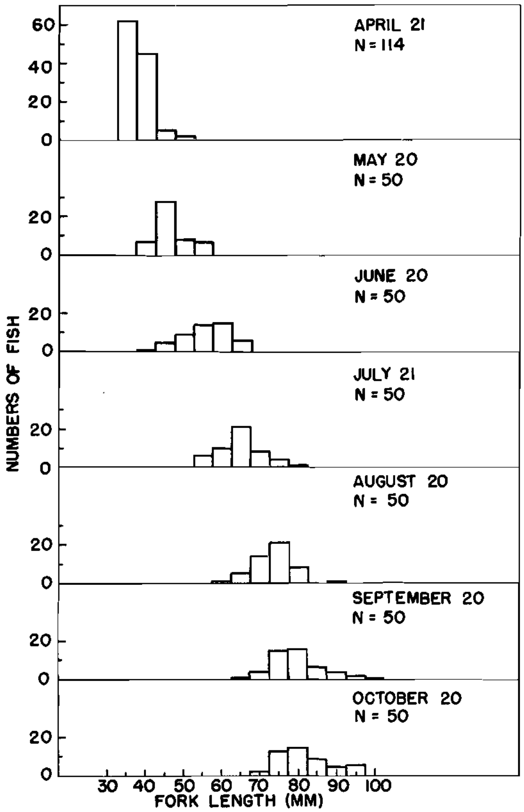

Figure 2. Seasonal growth pattern of juvenile spring chinook salmon in Lookingglass Creek based on standard samples, April-October 1966.

was small from April through August except for 1967. Mean length of the fish sampled in July 1967 was 8 mm less than in July of other years, and subsequent mean lengths during 1967 were correspondingly low (Figure 3). Mean length decreased from October to November.

Growth of juvenile spring chinook was rapid and relatively uniform from April through September when the average monthly growth increments ranged between 7.2 and 9.6 mm (Figure 4). Length increase during October averaged 4 mm, or about half the average from April through September. The sampling data show negative growth during November. This result will be considered in the Discussion section.

Condition

Mean condition factor of the juvenile chinook was lowest during April (approximately 0.8). Condition factor values increased sharply from April to June and gradually but steadily from June through September, and decreased after September (Figure 5). Mean condition factor ranged between 1.0 and 1.1 in most samples collected between June and November.

The data plotted in Figure 6 show that within each sample longer fish were rela-

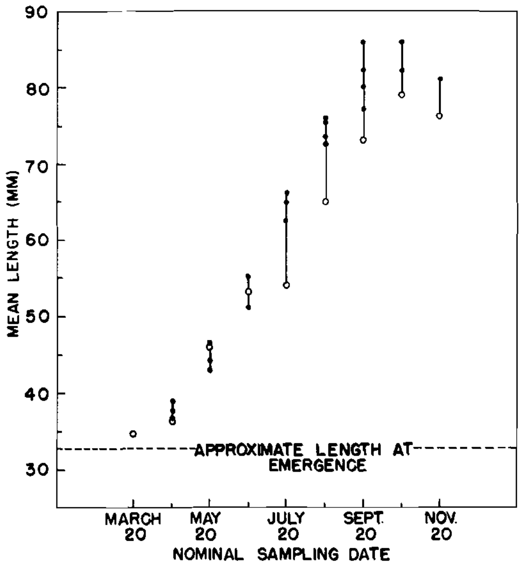

Figure 3. Mean length of juvenile spring chinook salmon in Lookingglass Creek based on standard samples, 1964-68 (dots represent undesignated years; circles represent 1967).

tively heavier than shorter ones, thus suggesting that condition is a function of length as well as time.

Length-weight Relationship

I calculated a length-weight relation-

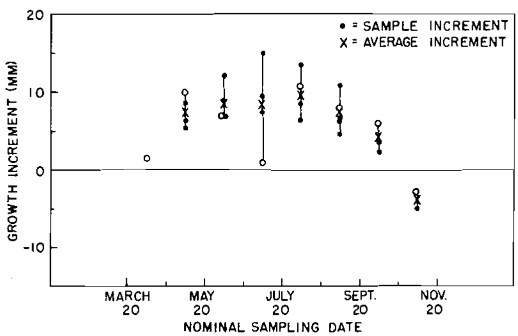

Figure 4. Growth of juvenile spring chinook salmon in Lookingglass Creek based on standard samples, 1964-68 (dots represent undesignated years; circles represent 1967).

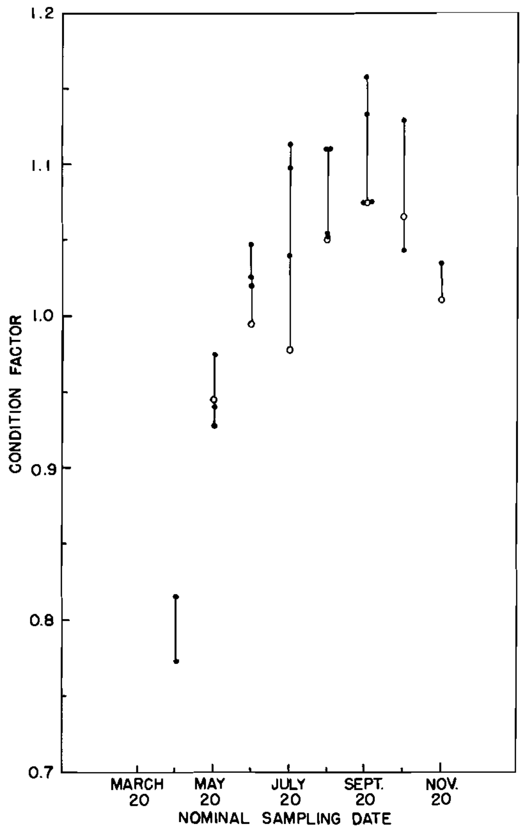

Figure 5. Mean condition factor of juvenile spring chinook salmon in Lookingglass Creek, 1964-68 (dots represent undesignated years; circles represent 1967).

ship based on all the data from standard samples grouped into thirteen 5 mm class intervals. A total of 1,420 measurements were involved and no class interval had fewer than 24 measurements. The resulting regression equation is $\log W = -5.44454 + 3.25386 \log L$. The fit obtained is excellent ($r^2 = 0.9993$), and empirical and calculated sample weights agree closely (Table 2). This equation is believed to be reliable for predicting weight, when length is known, of juvenile chinook in all areas of Lookingglass Creek.

The observed mean weights used in calculating the length-weight relationship are compared with predicted weights in

Table 3.

Differences in Growth Among Areas

I found that juvenile salmon reared in the standard sampling area were shorter than those in the lower area but longer than in the upper area (Figure 7). Length ranges were greater and distributions had less distinct modes in samples from the lower area. Juvenile chinook were not abundant in the upper area and samples were not obtained there after July 1967. Results of sampling in Little Lookingglass Creek during 1968 showed that juvenile chinook in this tributary were longer, on the average, than in the standard area.

Little variation was found in condition factors of fish in a given length interval regardless of where they were reared or when they reached the given length.

Discussion

The small mean length of the July 1967 standard sample, and the apparent small gain in growth between June and July 1967 samples (Figures 3 and 4) could

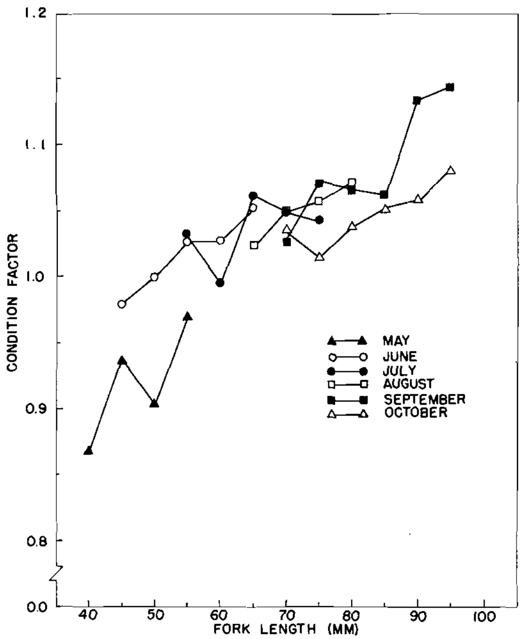

Figure 6. Relationship, within month, between length and condition of juvenile spring chinook salmon in Lookingglass Creek (from standard samples in 1966).

Table 2. Observed and calculated weight of samples of juvenile spring chinook salmon in Lookingglass Creek

Source of samples	Total Weight of Samples (g) Observed	Calculated①	Difference (%)
Standard area			
1964	1,129.9	1,119.8	−0.9
1965	864.9	840.9	−2.8
1966	1,074.8	1,096.3	+2.0
1967	1,080.5	1,105.4	+2.3
1968	766.5	760.2	−0.8
Lower area			
1966	555.6	558.1	+0.4
1967	1,242.6	1,317.2	+6.0
Upper area			
1966	308.0	309.1	+0.4
Little Lookingglass			
1967	469.2	503.1	+7.2
1968	850.0	852.3	+0.3

① $\log W = -5.44454 + 3.25386 \log L$.

Table 3. Observed and predicted mean weight of juvenile spring chinook salmon in Lookingglass Creek

Fork Length (mm)		Mean Weight (g)	
Interval	Midpoint	Observed	Predicted①
28- 32	30	—	0.23
33- 37	35	0.36	0.38
38- 42	40	0.57	0.59
43- 47	45	0.89	0.86
48- 52	50	1.24	1.21
53- 57	55	1.70	1.65
58- 62	60	2.25	2.19
63- 67	65	2.93	2.85
68- 72	70	3.71	3.62
73- 77	75	4.50	4.54
78- 82	80	5.54	5.60
83- 87	85	6.71	6.82
88- 92	90	8.16	8.21
93- 97	95	9.41	9.79
98-102	100	—	11.57

① $\text{Log } W = -5.44454 + 3.25386 \text{ Log } L.$

have been the result of sampling error. But if sampling error had been a factor in July, the August sample should have shown a large growth increment and an average length approximating other August samples. This did not happen. I believe population density was responsible for the small increase in growth measured in July 1967. An estimated 98,000 1966-brood chinook (sampled for growth during 1967) emigrated from Lookingglass Creek, and 45,000 of these left during July and August 1967. This compares with estimates of 49,000 emigrants for the entire 1965 brood (sampled for growth during 1966) and only 41,000 for the 1967 brood (sampled for growth during 1968) (unpublished data). I believe competition for space, food, or both probably retarded growth during June and July 1967. After many of these fish emigrated, growth of those remaining in the stream returned to "normal," but mean lengths continued to be low in comparison with other years.

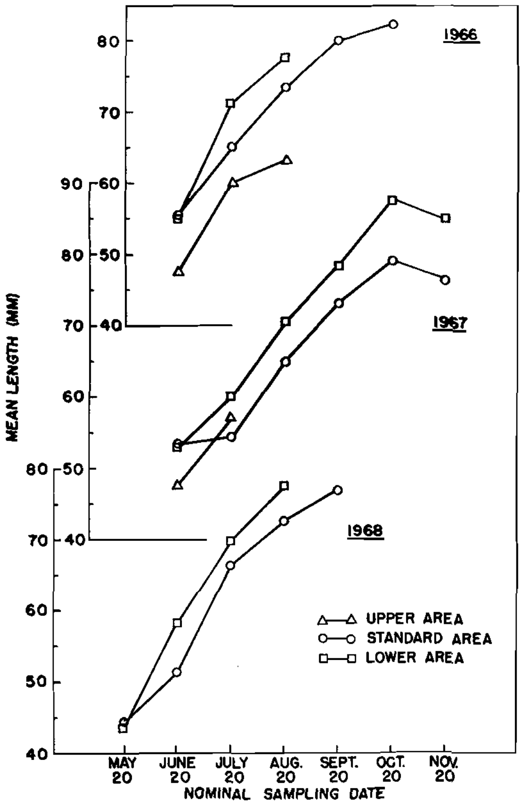

Figure 7. Seasonal variation in mean length of juvenile spring chinook salmon collected from three areas of Lookingglass Creek.

An apparent anomaly occurred when mean lengths of the November samples were less than mean lengths in October (Figure 3) and negative growth was indicated (Figure 4). I doubt that sampling error was a factor since this condition prevailed whenever and wherever November samples were obtained (Figure 7). However, November samples were collected from a single habitat type. Larger fish may undergo a change in habitat preference at this time of year and not be represented in the November samples I obtained. It is also possible that a selective emigration of larger, individuals takes place at this time of year. My observations of the timing of downstream migration show that a small "peak" of migratory activity occurs during October and November. A series of length samples indicates that mean length of migrating juveniles increased with time during this period (unpublished data).

Water temperature may be an important, although perhaps an indirect factor retarding growth in upper Lookingglass Creek. Comparative water temperature data are few, but those available suggest that water was colder in the upper and warmer in the lower area and in Little Lookingglass Creek than in the standard sampling area. Differences were as great as 5°C, but mostly ranged from 1.7° to 3.3°C (unpublished data).

DEPTH DISTRIBUTION OF SOME SMALL FLATFISHES OFF THE NORTHERN OREGON-SOUTHERN WASHINGTON COAST

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Abstract

The depth distribution of small flatfish of six species common to the Oregon and Washington coasts is shown. Depth distribution varies with season in that small fish of most species inhabit deeper water in winter than in spring or summer. There is little separation by depth of small fish from their larger kin.

Generally, small flatfish are constantly exposed to encounters with commercial trawl gear since about 95% of commercial trawl effort is expended on the continental shelf.

Introduction

A sustained groundfish fishery has operated off the northern Oregon-southern Washington coast since about 1942. Research effort was largely limited to market-size fish. Work on juveniles was lacking except for a study on juvenile English sole, *Parophrys vetulus*, in Yaquina Bay, Oregon (Westrhein, 1955). In the fall of 1956 and summer of 1957, an effort was made by Fish Commission personnel to collect juvenile Dover sole, *Microstomus pacificus*, but lack of suitable gear precluded the capture of smaller juveniles.

This report deals with depth distribution information on juvenile and adult flounders collected during a series of cruises from July 1966 to February 1968. My objectives in analyzing the catch data from these cruises were (1) to determine the extent of overlap between juvenile and adult stocks within the depth range of the present trawl fishery, and (2) to determine if nursery areas exist which could be closed to trawling.

Methods

I fished from a chartered commercial trawler using two nets, one of which was a Gulf of Mexico semi-balloon shrimp trawl, with 3.8 cm mesh (stretch measure) in the body. The cod end had 3.8 cm mesh with a 1.3 cm liner. Foot rope and head rope measured 15.8 m and 12.5 m, respectively. The other net was a small-fish trawl with 6.3 cm mesh in the body. The cod end had 3.8 cm mesh, with 2.86 cm mesh liner. The foot rope and head rope measured 18.9 m and 14.3 m, respectively.

Both nets had a 0.8 cm tickler chain attached to the end of each wing and rigged to fish approximately 0.5 m ahead of the foot rope. Gear type was constant within a cruise.

I used data from four groundfish cruises (July 1966, May and August 1967, and February 1968) and one shrimp cruise (November 1966). The general area of investigation extended from Willapa Bay, Washington to Cape Lookout, Oregon (Figure 1).

I collected depth distribution data on Dover sole, *Microstomus pacificus*, English sole, *Parophrys vetulus*, Rex sole, *Glyptocephalus zachirus*, Pacific sand dab, *Citharichthys sordidus*, slender sole, *Lyopsetta exilis*, and butter sole, *Isopsetta isolepsis*. Limited catches of some species on some cruises precluded analysis. No cruise provided sufficient information on small petrale sole, *Eopsetta jordani*, to permit analysis.

Tow duration ranged from 6 to 35 minutes, but was usually 15 minutes. Since a 15 minute tow usually covers a linear distance of six Loran micro-seconds, or one-half nautical mile. I adjusted catch

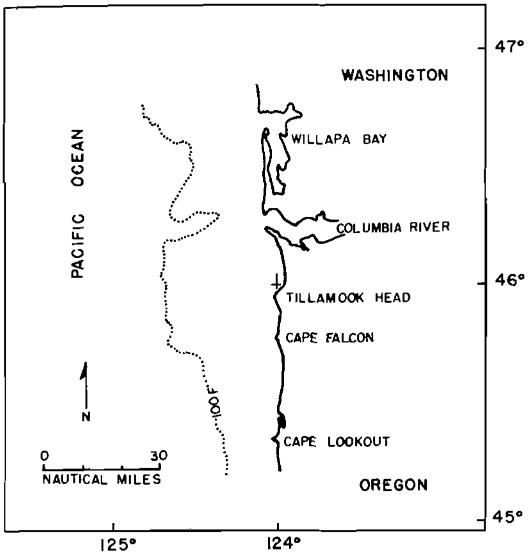

Figure 1. General area of study.

rates to conform to a 0.8 kilometer tow.

Depth of fishing ranged from 6 to 175 fathoms. I measured fish to the nearest lower mm and summarized lengths by 2 cm intervals. On the four groundfish cruises, I measured all Dover sole and usually measured the entire catch of other soles. If I had to subsample the catch of other soles, I expanded the subsample to the entire catch of the respective species. On the shrimp cruises only Dover sole were sampled. These were processed as time permitted, or preserved in a 10% formalin solution and processed later. I adjusted the numbers of fish making up the catch from each tow, to the numbers of fish which would have been caught in a 0.8 kilometer tow.

As used here, small fish implies juvenile, but rather than relate to sizes at maturity, "small fish" means fish equal to or less than 18 cm in length for Dover, English and Rex sole, and fish equal to or less than 14 cm in length for sand dabs, butter sole, and slender sole.

Data are arranged by season on the assumption of similar distribution patterns between years, even though 17 months elapsed between the first and last cruise.

Tows within a season were stratified by 10 fathom depth intervals. The percentage occurrence of fish by depth was calculated separately for each size group. Thus, for Dover sole in February, the summation of percentages in each depth interval for fish equal to or less than 18 cm equals 100% as it does for fish greater than 18 cm.

Results

Occurrence and relative abundance are shown in Figures 2 through 7, but I caution the reader to note sample sizes when reviewing these figures.

Dover Sole

Small Dover sole occurred on the continental shelf mostly between 30 and 80 fathoms, although they are found at least

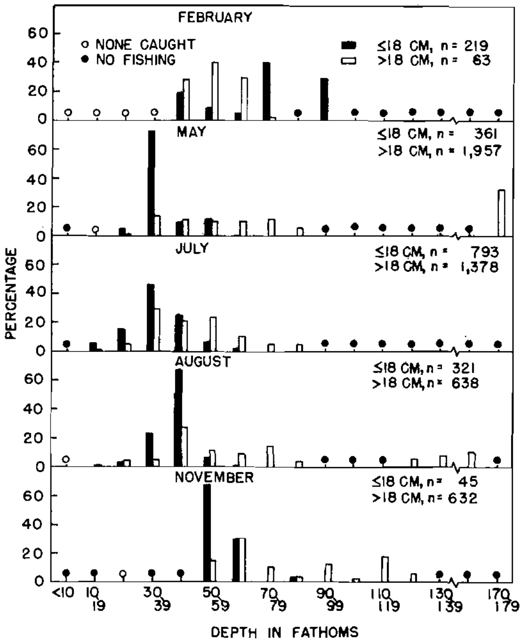

Figure 2. Depth distribution of two size groups of Dover sole by 10-fathom interval and season.

to the 100 fathom contour. There was a definite seasonal movement also. In February most small fish were at depths greater than 70 fathoms, but during May, July, and August the bulk of the small fish occurred between 30 and 49 fathoms. In November the depth of greatest abundance of small fish was in the 50-59 fathom stratum. Small fish were not caught in the 20-29 fathom stratum where they had occurred in May, July, and August.

In all sampling periods there was a noticeable overlap in the depth distribution of large and small fish. This was most pronounced in February and was only slightly less in July.

English Sole

Small English sole occurred only from the most inshore stratum to the 40-49 fathom range regardless of sampling period. There is some indication of movement from deeper water in winter to shallower water in summer. About 25% of the small fish caught in February were caught in the 40-49 fathom stratum, but none were caught in this depth in May or August. The bulk of the small fish caught within any sampling period occurred in the 20-29 fathom range.

There was some separation of small fish from larger fish, especially in May, but during February and August stocks are well blended.

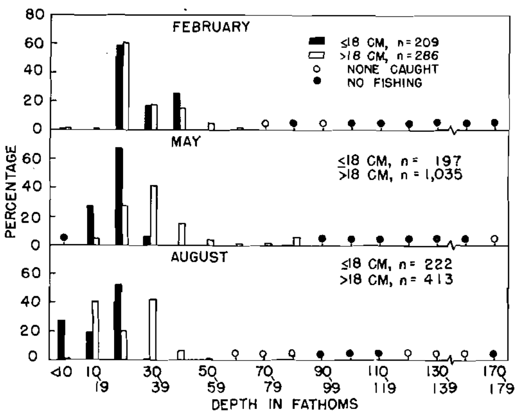

Figure 3. Depth distribution of two size groups of English sole by 10-fathom interval and season.

Rex Sole

Small Rex sole occurred from the 20-29 fathom interval to at least the 130-139 fathom range. An inshore movement is evident with Rex sole also. In February, small fish were not found inshore of 40 fathoms, but in May and August they occurred in the 20-29 fathom stratum. Larger fish showed a similar pattern of movement.

Overlap in depth distribution between small and large fish was present at almost all depths.

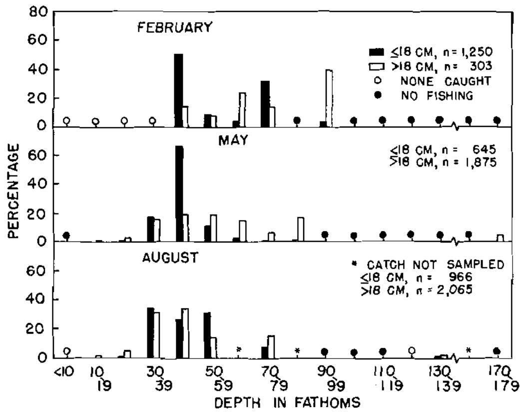

Figure 4. Depth distribution of two size groups of Rex sole by 10-fathom interval and season.

Sand Dabs

Sand dabs are unique among the species studied, in that during February, small fish were more widely distributed than in May or August. They were most abundant between 20 and 49 fathoms. There was no separation between small and large fish.

Slender Sole

Small slender sole were found from the 30-39 fathom stratum to the 90-99 fathom depth, but were most abundant between 50 and 100 fathoms. Even though sampling during the August period was

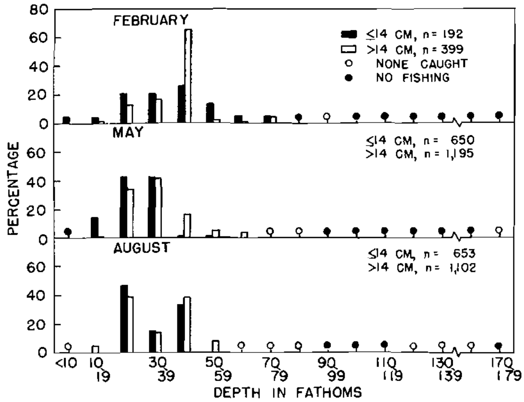

Figure 5. Depth distribution of two size groups of sand dab by 10-fathom interval and season.

sketchy, slender sole were caught closer inshore than during the other sampling periods. Both large and small fish were present in catches from almost all depths.

Butter Sole

Butter sole are unique in that both small and large fish occupy a narrow inshore depth range. They were not caught beyond the 40-49 fathom stratum. Small butter sole were found at this depth in February, but not deeper than the 20-29 fathom stratum in May. There was no separation of small and large fish.

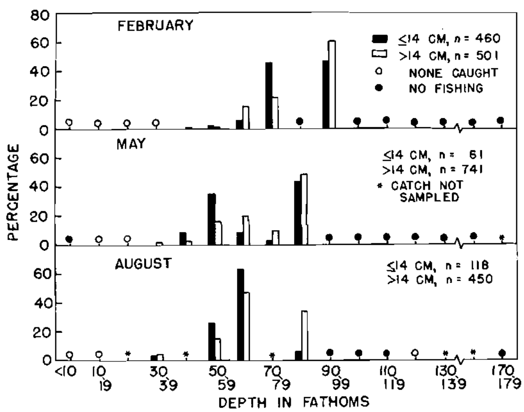

Figure 6. Depth distribution of two size groups of slender sole by 10-fathom interval and season.

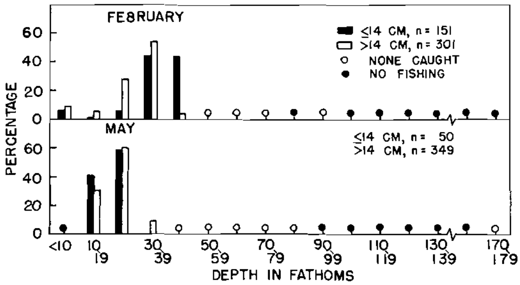

Figure 7. Depth distribution of two size groups of butter sole by 10-fathom interval and season.

Composite Distribution

Figure 8 shows a composite picture of depth distribution of the species studied and their relationship to commercial trawl effort. The depth distribution of small fish is by 30 fathom intervals and thereby conforms with the present method of compiling catch and effort statistics by depth. Major effort occurs between 30 and 59 fathoms, as do the bulk of the small fish. In fact, nearly 90% of the total trawl effort occurs at depths under 90 fathoms.

Discussion

Small flounder of the species studied generally occur over the entire continental shelf and nowhere does the small fish complex escape the influence of commercial trawl gear. Thus, the creation of exclusive nursery areas to protect small fish would result in a reduced adult harvest by the fishery since it appears that the majority of adult fish protected in nursery areas would remain there and not contribute to fisheries elsewhere.

For certain species, estuaries provide some protection from commercial trawling by acting as rearing areas for juveniles. English sole is a case in pont. Westrheim (1955) working in Yaquina Bay found large numbers of 0 age English sole, but relatively few age 1 juveniles. By contrast,

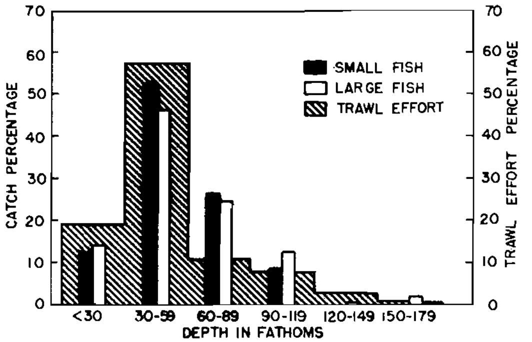

Figure 8. Composite of depth distritbution for all species caught during February, May, and August sampling periods superimposed on commercial trawl effort for years 1966-68.

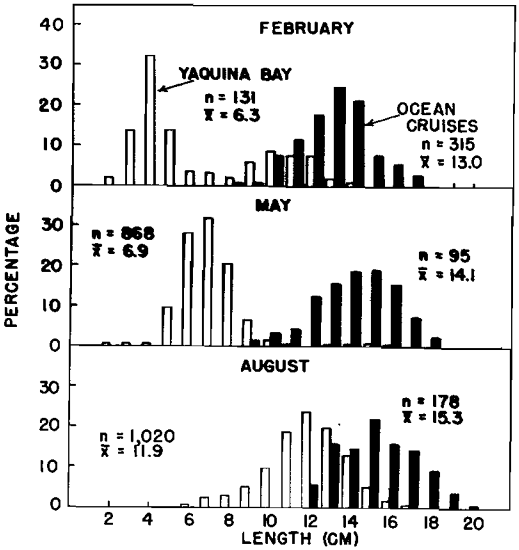

Figure 9. Length frequency distribution of juvenile English sole caught in Yaquina Bay (Westrheim, 1955) and in the ocean off the northern Oregon coast.

my ocean sampling (Figure 9) revealed no 0 age fish. This suggests that, at least during the initial phase of the rearing period, juvenile English sole are not available to trawling gear.

The absence of smaller English sole in ocean waters was apparently not a function of gear. During the course of my investigation, the smallest English sole caught was 8 cm and very rarely were individuals less than 10 cm taken; however, numerous other flounder measuring 6 cm in length were caught.

The impact of commercial trawling on the stocks of juvenile flatfish remains to be determined. The importance of estuaries as sanctuary areas will be directly related to the seriousness of this impact, and also to the degree of rearing which takes place in the estuarine environment. Recent observations have indicated that flounder other than English sole make use of estuaries, but the extent of use is unknown.

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NEARSHORE OCEAN CURRENTS OFF CLATSOP BEACH, OREGON, AND THEIR RELATION TO THE DISTRIBUTION OF RAZOR CLAM LARVAE

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Introduction

Clatsop Beach is the most productive area for Pacific razor clams (*Siliqua patula*) in Oregon. Both commercial and recreational fisheries have been active for many years, taking 1 to 2 million clams annually.

The 29 km (18 mile) beach extends from Tillamook Head (lat. 45°57'N, long. 123°57'W) to the south jetty of the Columbia River (lat. 46°12'N, long. 124°W) and is fully exposed to wind and wave action from the west. According to Bascom (1951), Clatsop Beach is characterized by flat slopes (1:70) of the beach face and small median diameter values of sand (0.2 mm). The beach undergoes an annual cycle as described by Shepard (1950) where high waves erode the sand from the beach in the fall and winter and small waves move the sand shoreward in the spring and summer.

The sporadic and sometimes isolated occurrence of razor clams on Clatsop Beach suggests that the nearshore ocean currents are an important factor in the distribution of the planktonic larvae. Weymouth, McMillian, and Holmes (1925) report that veliger larvae of razor clams are free swimming for about 8 weeks and drift with the ocean currents near the surface. A shoreward movement of these currents would tend to deposit the larvae in the beach area accessible to diggers. Conversely, a seaward set of the current would move the larvae away from the beach.

In 1963-64, a drift bottle study was conducted off Clatsop Beach to determine the pattern of nearshore currents and their effect on the distribution of razor clams. The study was done during May to September, the peak spawning and setting time.

A pilot study was first conducted in 1963 to determine which methods to use and how to apply them. Some supplemental work was done in 1965 to learn the effect of longshore drift on bottles once they landed on the beach.

Most studies in the vicinity of Clatsop Beach pertain to conditions several miles offshore. Burt and Wyatt (1964) investigated the Davidson current about 64 km (40 miles) offshore. Some of their drift bottles were recovered from Clatsop Beach. Morse, Gross, and Barnes (1967) studied the bottom currents near the mouth of the Columbia River by the use of sea-bed drifters. The results showed that bottom currents within 10 km from the mouth of the river and south of the jetty were southeasterly toward the shore. Measurements taken by the University of Washington Department of Oceanagraphy show a southerly current along the coast of Vancouver Island, Washington, and Oregon as reported by Barnes and Paquette (1954). A study by Ballard (1964) dealt with marine sediments from the Columbia River. Some of these sediments are deposited along Clatsop Beach, indicating that the currents near the river at times are southerly toward the beach.

Methods

Anchored styrofoam buoys marked the drop stations along the 5-fathom curve about 1.5 km (1 mile) offshore at approximately 1.5 km intervals between Tillamook Head and the south jetty of the Columbia River. Three additional stations were included later due west of station 16 off Seaside at 0.8 km (1/2 mile) intervals.

The drift bottles were 325 cc (11 ounce) beer bottles ballasted with sand so that about 2.5 cm (1 inch) of the neck was above water and then corked and sealed with roofing cement. A numbered identification card with instructions to the finder was enclosed in each. The finder was instructed to return the bottle to the Astoria Laboratory of the Fish Commission, or to the Seaside Aquarium. No reward was offered, but a letter of explanation was sent to each finder.

Five different releases, excluding the pilot study, were made between May 1963 and September 1964. Five bottles were released at each station, using a 10.7-m (35-foot) boat on the first four release dates, and a helicopter flying at an altitude of 30 m (100 feet) and a speed of 111 km per hour (60 knots) for the last release. The date, time, and number of bottles released at each station are given in Table 1.

I made most of the recoveries by driving the beach, but a few were found by beachcombers. About 75% of the bottles were retrieved the day of release.

Twelve sea-bed drifters were released June 26, 1964, at stations 4, 9, and 15. A sea-bed drifter resembles an open umbrella with a weight fastened to the stem which keeps it on or near the bottom. Its use in determining residual bottom currents has been described by Lee, Bumpus, and Lauzier (1965). None of these were recovered.

Supplemental work in 1965 consisted of throwing drift bottles into the surf by hand and noting the time and distance of drift in the longshore trough. Once on the beach, the path of movement was noted as succeeding waves washed the bottles up the beach.

Results and Discussion

Recovery data are shown in Table 1. A total of 570 bottles were released and 367 were recovered, a return of 64.4%. This contrasts with returns of 4.6% (Schwartzlose, 1963), 12.9%. (Burt and Wyatt, 1965), 3.2% (Tibby, 1939), and 3.3% (Dodimead and Hallister, 1958) for high seas studies, and 44% (Lauzier, 1964) and 41% (Waldichuk, 1958) for nearshore studies.

The returns are plotted in Figures 1-3 with the pilot study included for comparison. No attempt was made to infer the paths of returns so the velocities calculated are minimal.

In general, the surface currents within 1 mile of the beach are southerly and toward the beach during the spring and summer months. This pattern would be favorable to deposition of razor clam larvae in the area of beach accessible to diggers. However, there are some noteworthy exceptions to the general pattern.

Table 1. Number and percentage of drift bottles released and recovered

Release Date	Time Released	Number Released	Number Recovered	Percentage Recovered
3-7-63	0855-1013	140	59	42.1①
5-31-63	0609-0729	80	67	83.8
6-28-63	0746-0925	80	66	82.5
6-26-64	1005-1142	95	71	74.7
8-4-64	1006-1151	95	53	55.8
9-14-64②	1336-1351	80	51	63.8
Total		570	367	64.4

① Pilot study; 71% of floaters and 12% of sinkers recovered.

② Helicopter drop.

Returns from the pilot study (Figure 1) show a pronounced southerly drift with bottles concentrated at Seaside and some drifting south of Tillamook Head up to 220 km (137 miles) from point of release. A southwest current or upwelling near the beach north of station 6, with

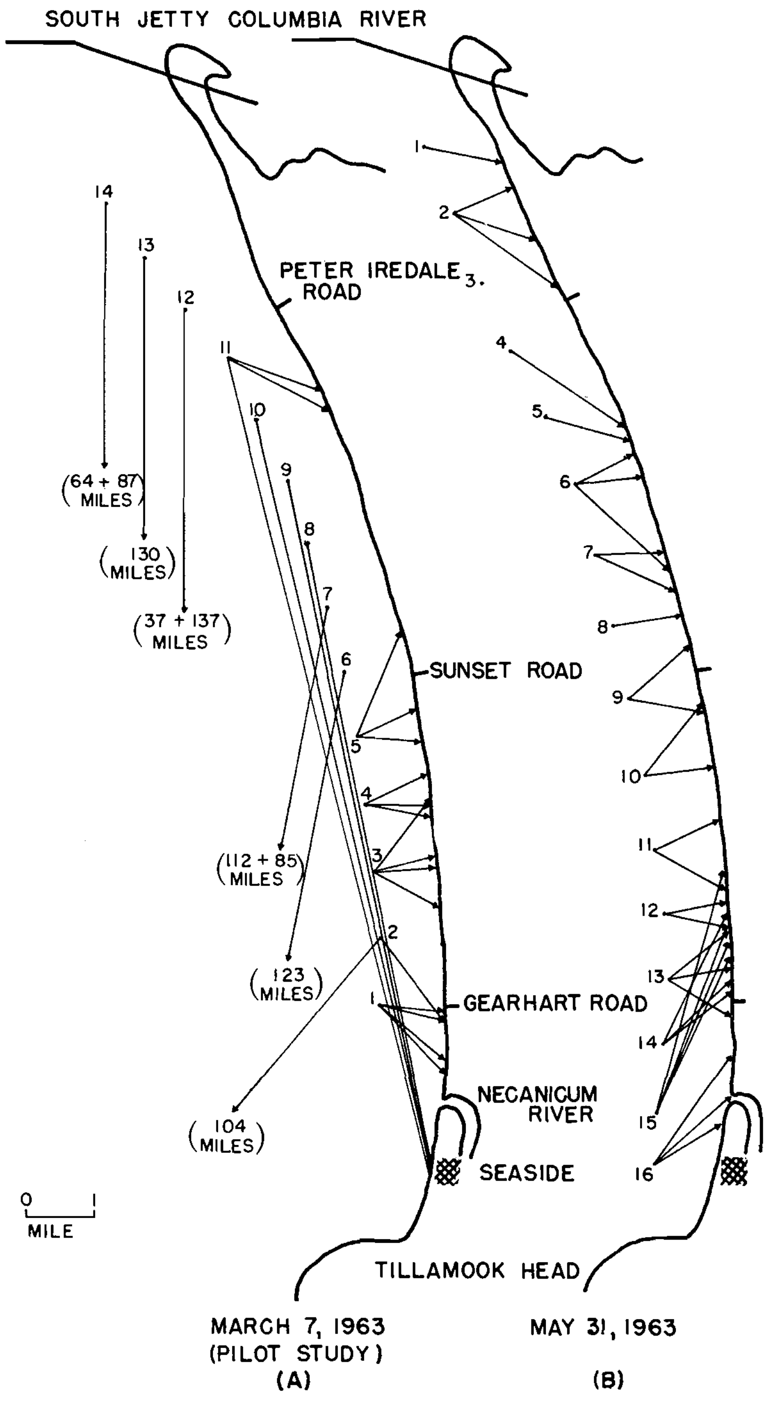

Figure 1. (A) Drift bottle returns from March 7, 1963 pilot study and (B) returns from May 31, 1963 release.

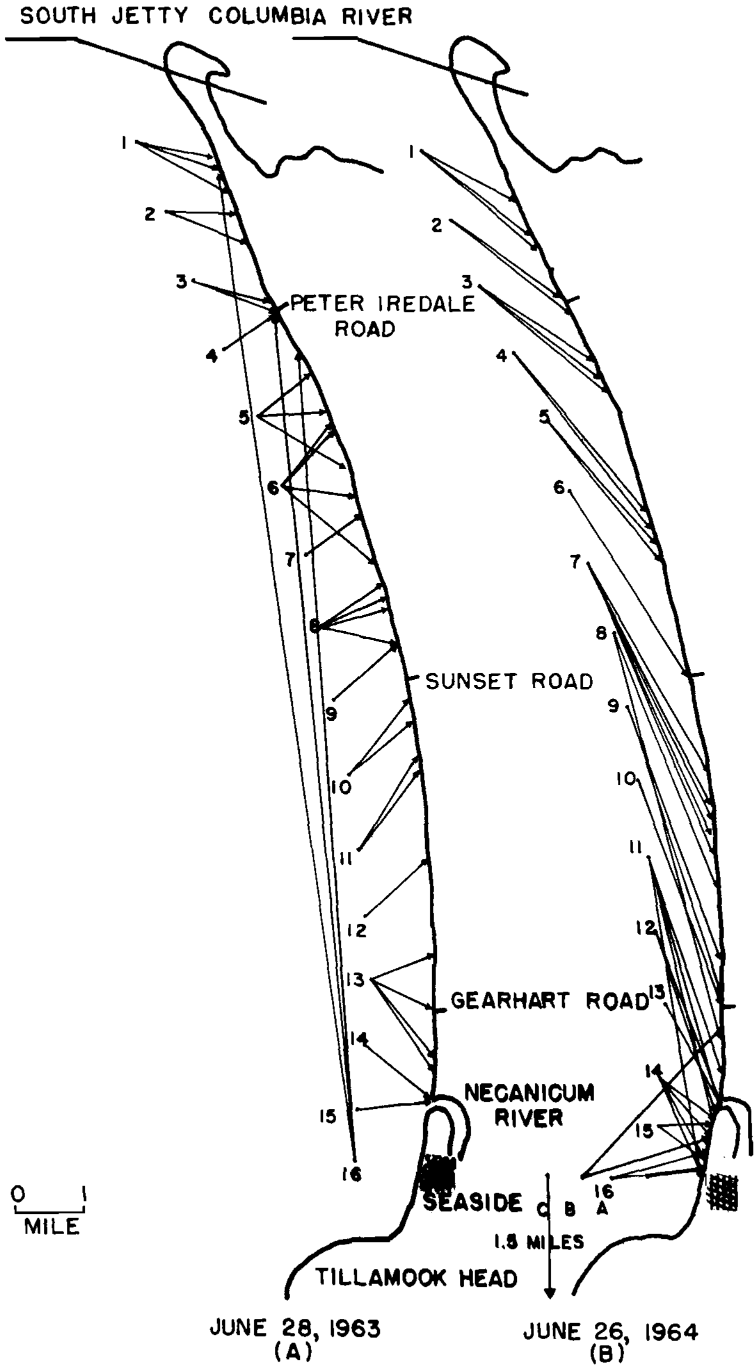

Figure 2. (A) Drift bottle returns from June 28, 1963 release and (B) Returns from June 26, 1963 release.

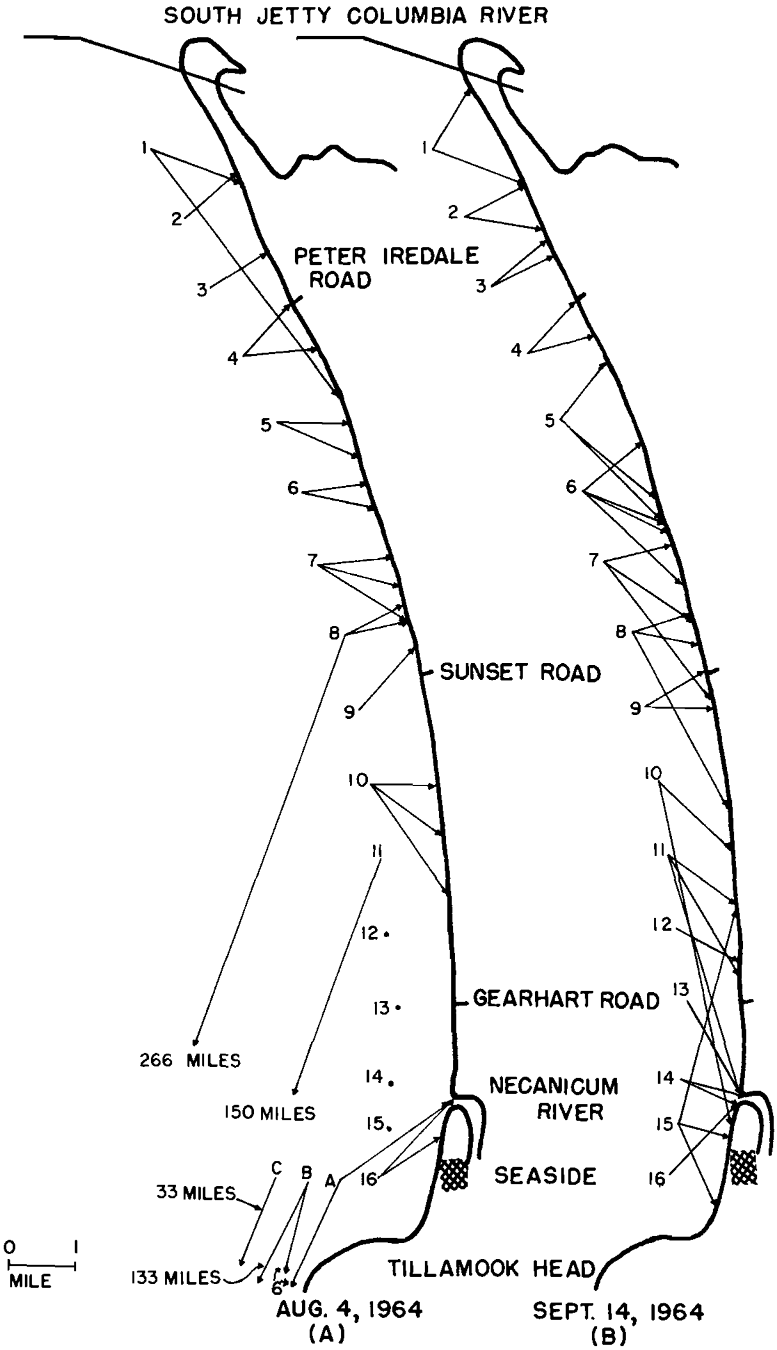

Figure 3. (A) Drift bottle returns from August 4, 1964 release and (B) Returns from September 14, 1964 release.

the possible aid of an east wind, moved the bottles seaward into the southerly offshore current.

The results generally show a slight southerly drift except for a marked northward movement off Seaside. According to Tibby (1939), this dispersal suggests an eddy. Minor dispersal from stations 5-9 (Figures 2A and 3B) might indicate eddies or rip currents. Bascom (1964) states that as waves recede from the beach the longshore trough is overfilled and excess water flows seaward over the lowest part of the longshore bar. A rip channel forms as this part of the bar is eroded, and strong rip currents flow through the channel and disperse seaward. Drift bottles caught in a rip current might be carried some distance seaward.

Both eddies and rip currents help explain the apparent crossing of lines of drift of the plotted returns. The hydrographic charts referred to by Tibby (1939) and Dodimead (1958) show that currents do not cross, but there may be exceptions near the beach under local conditions.

Most recoveries were made the day of release, but some were found 1 to 4 days later and were subject to nearshore wave action of both flood and ebb tides. On the ebb tide, the bottles are not cast up on the beach, but drift in the longshore trough until the tide begins to flood. Bottles thrown into the longshore trough by hand near low tide drifted up to 5 km (3 miles) from the release point before being cast on the beach, and others were not recovered. It was possible at times to visually follow those bottles which were only a few yards offshore.

Figure 2B illustrates a strong longshore current. Minimum velocities of 1.3 to 1.85 km per hour (0.7 to 1.0 knot) were recorded while 0.4 to 0.9 km per hour (0.2 to 0.5 knot) prevailed for all other releases.

A lack of drift bottle returns in August 1964 from stations 9-15 (Figure 3A) and a drop in water temperature of 50 C (Wyatt, Still, and Hoag, 1965) suggests upwelling. Two returns from the south coast, 241 and 428 km (150 and 266 miles) from stations 8 and 11, indicate that upwelling was significant and probably transported the bottles beyond the north counter current into the dominant south current offshore.

One drift bottle was reported from north of the Columbia River. On August 29, 1968, one was found on the west coast of Vancouver Island near Tofino. The bottle had been at liberty 134 days.

Wind effect on drift bottles is negligible according to Dodimead (1958), but Burt and Wyatt (1964) point out that local wind stress appears to be important. Wind roses constructed from U.S. Weather Bureau records at Clatsop airport for a 30-day period prior to release dates showed little correlation with recovery location.

Summary and Conclusions

Drift bottles released off Clatsop Beach indicate that the nearshore surface currents are southerly and toward the shore during the spawning and setting time of the razor clam. This pattern of drift is favorable to the deposition of larvae on the beach area accessible to clam diggers.

A prominent southerly longshore current and a large eddy at Seaside are evident. These two factors probably enhance the population of clams at Seaside by concentrating the larvae in the beach area. Razor clam production at Seaside has been stable in past years and accounted for 75% of the total Clatsop Beach harvest in 1965. Harvests from beaches north of Seaside fluctuate greatly.

Upwelling was indicated north of Gearhart in August 1964. This seaward set of surface currents would displace clam larvae away from the beach, depending upon the timing of upwelling and larvae setting. Digging was poor in this area in 1966.

Acknowledgments

Grateful acknowledgment is made to the Oregon State Police for use of their patrol boat; Andy Olsen, skipper of the *Lela-E* for use of his fishing boat; the staff of the Seaside Aquarium for acting as depository; the U.S. Coast Guard for use of a helicopter; and to those interested persons who found and reported drift bottles.

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ALGAE GROWTH AS A CAUSE OF TAG LOSS FROM JUVENILE FALL CHINOOK SALMON IN SIXES RIVER ESTUARY, OREGON

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During the summer of 1966, about 2,500 vinyl thread and pennant tags were applied to juvenile fall chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in Sixes River estuary to determine various population statistics. The tag was previously developed for work in fresh-water impoundments (Korn, et al., 1967) and consisted of a numbered pennant 4.7 mm long, 2.4 mm wide, and 0.4 mm thick. The pennant was attached under the insertion of the dorsal fin using vinyl thread either 0.41 or 0.48 mm in diameter. I later learned from Korn (personal communication) that his tags were attached under the origin of the dorsal fin with the trailing part of the tag riding on the fin. He also indicated that juvenile salmonids tagged in fresh water showed little tag loss and negligible effect by the tag. Some of his fish retained tags after migrating to sea and returning to the spawning grounds. However, Pyle (1965) observed that tagged brook trout, *Salvelinus fontinalis* (Mitchill), retained this tag poorly and the vinyl irritated the surrounding tissue.

The vinyl thread and pennant tag was of only limited value in Sixes River estuary because of growth of the algae, *Enteromorpha* sp., and several diatoms, *Schizonema* sp., *Melosira* sp., and *Fragilaria* sp. on the tag and thread. Most attachment occurred at the overhand knot in the thread. *Enteromorpha* sp. probably caused the greatest problem because filaments were up to 90 mm long (Figure 1). Maximum length of the diatom masses was about 15 mm.

This work was conducted in cooperation with the U.S. Department of Interior, Bureau of Commercial Fisheries under The Anadromons Fisheries Act (PL 89-304), Project 26-1, Contract Number 14-17-0007-897.

The effect of the additional weight and resistance of the algae was to gradually pull the tag out of the fish. Tagged fish in fresh water and those without algae in the estuary were not observed to be losing their tags. Many tags with algae were found only superficially attached by a layer of skin. Other fish were found just after the tag had pulled out leaving an open wound. As the tag pulled back and out, the path of migration left a characteristic "V" extending from the last point of attachment to the original thread hole on each side of the fish. As the wound healed the "V" remained as a black scar.

The rate of tag loss could not be measured because the rate of mortality on fish about to lose their tags was not known, and fish were thought to be continually emigrating to the ocean.

An increased proportion of recovered tags possessed algae at longer intervals after tagging (Figure 2). Most fish recaptured within 15 days had only small amounts of algae. The decreasing percentage of recoveries at longer intervals may have resulted from a combination of tag loss, mortality, and emigration.

A comparison of rate of growth was made for fish with and without algae on their tags and no difference was found.

Quite possibly tag loss would have been less had the thread been attached under the origin instead of the insertion of the dorsal fin. On adult salmon, placing Petersen disc tags under the origin of the dorsal fin provided greater tag retention (Thompson, et al., 1958.) Had the vinyl thread and pennant tag been attached un-

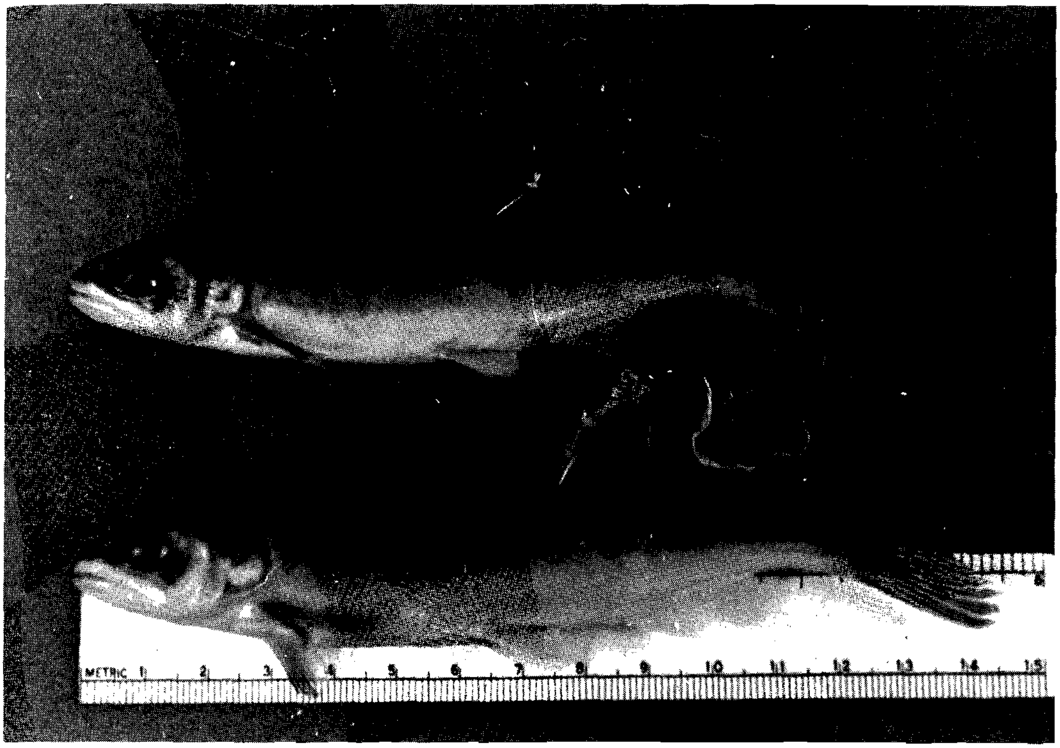

Figure 1. Comparison of a tag without algae at time of tagging and a tag with algae at time of recovery.

der the origin of the dorsal fin, action of the tag against the fin might have served to reduce the growth of algae.

Others have reported animal and plant growth on tags as possible cause of tag loss. Bonner (1965) reported growth of algae as a cause of loss of spaghetti tags from striped bass, *Roccus saxatilis* (Walbaum), in Chesapeake Bay. Lasater (1966) reported algae growth and high tag loss on yearling chinook salmon in Bowman's Bay, Washington, but did not necessarily link them. (Chadwick (1963) found barnacles, hydroids, and algae on tags being tested for striped bass. Allee (personal communication) tagged juvenile salmonids in Big Beef Creek, Washington, and noted accumulations of algae. He used a small plastic acetate tag attached under the insertion of the dorsal fin using nylon fishing line.

If the vinyl thread and pennant tag is

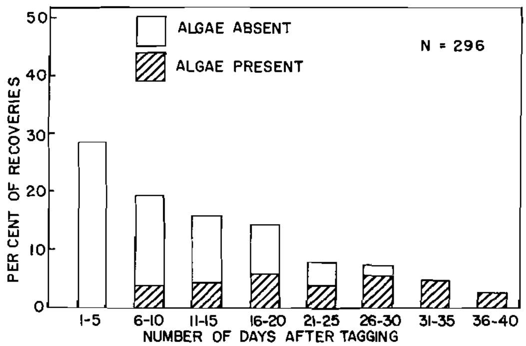

Figure 2. Change in number of tags recovered at 5-day intervals after tagging and increase in proportion of recovered tags possessing algae.

used in estuarine studies again, I suggest that tagging under the origin of the dorsal fin be tested before using the tag extensively.

Acknowledgments

I appreciate the help of Mr. K. Crenshaw in putting out the tags. Dr. A. Stein, Department of Botany, the University of British Columbia, identified the plant growth on the tag. Mr. Lawrence Korn supplied some of the tags and was very helpful. Mr. Alan McGie reviewed the manuscript.

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THE USE OF OXYTETRACYCLINE MARKS IN VERTEBRA OF ADULT SALMON TO DETERMINE SMOLT SIZE

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Observations made during examination of oxytetracycline (OTC) marks on vertebra from large numbers of adult salmon led to the belief that there is a relationship between the OTC mark size and the size of the fish when it was marked. The OTC mark in a fish vertebra corresponds to the size and shape of that bone at the time the mark was produced much the same as a growth ring in a tree indicates the dimension of the trunk at a particular age. Thus, if hatchery smolts are OTC marked immediately prior to release, the marked vertebra from resultant adults will provide information as to the size at release of those smolts that survived.

An experiment was carried out to determine if fish of similar size (fork length) acquire OTC marks of similar size in vertebra from the caudal peduncle and further to establish the relationship between OTC mark size and fork length. From the production stocks at two Willamette River hatcheries, 133 yearling spring chinook (*Oncorhynchus tshawytscha*, Walbaum) were selected at the conclusion of OTC marking treatments in March 1970. Fork lengths ranged from 10 to 24 cm giving 15 length groups (1 cm intervals). The minimum group size was 4 and the largest was 23. With a fin clip and freeze brand employed to identify length groups, the selected fish were reared an additional 10 weeks in a 6-foot circular tank. The additional growth was considered necessary to provide clear definition of the OTC mark in the vertebra.

A vertebra from the caudal peduncle of each fish was examined under ultraviolet illumination with a binocular microscope at 20X. The diameter of the OTC mark on the vertical axis of the vertebra was measured by use of an optic micrometer located in the eyepiece of the microscope. Little variation in OTC mark diameter was noted within a given length group. When OTC mark diameters were compared with fork length at time of marking, a straight line relationship was observed (Figure 1). The correlation was significant at the 1% level.

The 1967-brood spring chinook at the Fish Commission of Oregon's Trask River Hatchery received an OTC marking treatment just prior to release into that river in October 1968, and February 1969. In 1970, 37 male 3-year returnees bearing OTC marks were recovered at the hatchery. Comparing OTC mark diameters with adult fork length, a fair, though highly significant, correlation was found to exist.

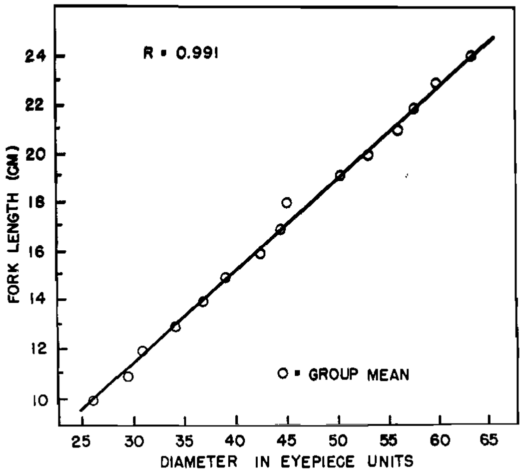

Figure 1. Relationship between OTC mark diameter and fish size at time of OTC treatment for spring chinook from Willamette River hatcheries.

(Figure 2). Small returnees tended to have smaller OTC mark diameters than larger returnees. Further investigation of this relationship will be made when 4- and 5-year fish return to the hatchery.

The observed relationship appears to provide a means throughout the life of the fish of accurately estimating fork length at the time of the OTC treatment. The Fish Commission will employ this method to determine the smolt size of those fish which are contributing most heavily to our adult returns.

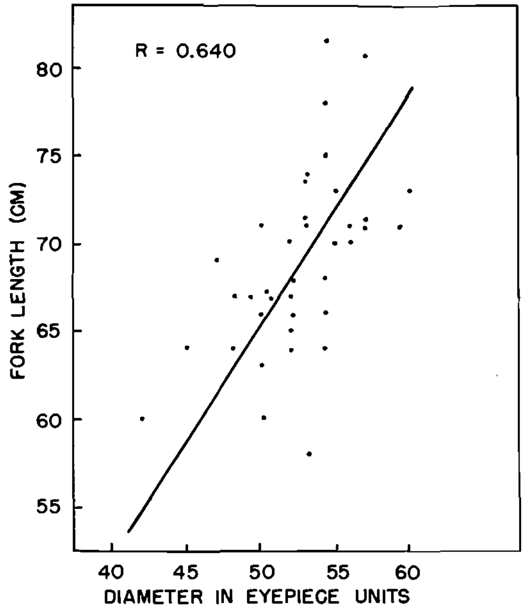

Figure 2. Relationship between OTC mark diameter and fork length of 3-year-old Trask River spring chinook.

A Note on Coastal Movement of Shad

There are from 400 to 500 thousand pounds of shad *Alosa sapidisima* harvested commercially from five streams along the central coast of Oregon each year. Our knowledge of the life history of these particular stocks is limited. However, we do know that shad on the east coast spend a major portion of their life in the ocean, and that shad have been taken incidentally in trawl nets fished for shrimp and bottomfish off Oregon.

Some insight into the coastal movement of shad comes from the recovery of a tagged shad in 70 fathoms of water off Willapa Bay, Washington, on September 9, 1969. The fish was captured in a shrimp trawl fished by the commercial boat *Owners Joy*. The fish had been tagged some 180 nautical miles to the south, on April 4, 1969, as part of a Fish Commission of Oregon project to estimate the numbers of shad available to commercial nets in the Umpqua River system.

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