# ECOLOGY AND PRODUCTION OF JUVENILE SPRING CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, IN A EUTROPHIC RESERVOIR[1,2]

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## ABSTRACT

Juvenile spring chinook salmon, *Oncorhynchus tshawytscha*, were reared in a central Oregon reservoir of 7.5 hectare. The reservoir is strongly eutrophic, as shown by its heavy sedimentation, summer stratification, and chemical qualities (total dissolved solids over 200 ppm, total phosphorus to 0.4 ppm, and summer pH between 9 and 10). Surface water temperatures ranged from 3° to 29°C. Salmon were apparently confined to the upper 3 m during the summer because of low dissolved oxygen below this depth. In 1961, epilimnion conditions of high pH, high temperatures, decreasing oxygen concentrations, and possibly algal toxins caused condition loss and deaths among salmon. Fry planted in 1961 (75,300) and in 1962 (150,000) suffered first-summer mortalities in excess of 80%, primarily due to predation by older salmon. Summer growth was rapid, but dependent on population densities. Coho salmon, *O. kisutch*, and chinook salmon remaining from a 1959 plant averaged 280 and 215 g after 30 mo. The 1961 year class averaged 62 g at 10 mo and 89 g at 22 mo. The 1962 year class averaged 22 g at 9 mo. Average condition factor values rose above 1.20 in the summer. Net production by the 1961 year class was 159 kg/hectare in 1961 and 35.5 kg/hectare in 1962. The 1962 year class produced 170 kg/hectare in 1962. Potential December yield of first-year salmon was 98 kg/hectare in 1961 and 73.5 kg/hectare in 1962. First-year salmon ate primarily Entomostraca and chaoborid larvae. Apparently competition from the 1962 year class caused the 1961 year class to feed more on littoral and terrestrial forms and to grow and produce less in their second year. Age class I and age class II salmon weighing from 25 to 189 g emigrated via spillway outflows. In 1963, migrations occurred only at temperatures above 10°C; this relationship was not observed in 1962. This reservoir, or others with similar limnological conditions, cannot be recommended as a rearing site for chinook salmon because of the severe summer conditions.


Reduction in natural rearing sites available to Pacific salmon, *Oncorhynchus* spp., has led to a search for ways of augmenting the smolt production of various stream systems in the Pacific Northwest. One possibility is to rear the young salmon in impoundments where they presumably would develop into naturally fed, vigorous smolts. The smolts could then be released into nearby streams suitable for downstream migration. Various pond, lake, and estuarial habitats have been utilized as rearing impoundments. This paper describes the results of the rearing of chinook salmon, *O. tshawytscha* (Walbaum), of the spring race in Happy Valley Reservoir, a eutrophic impoundment located on the Warm Springs Indian Reservation in central Oregon. The research correlated reservoir limnology with the growth, survival, food habits, and migratorial tendencies of salmon planted in the reservoir. The project period was February 1961 to June 1963.

The reservoir was the site of an earlier study on the survival and growth of 30,000 coho salmon, *O. kisutch* (Walbaum), and 23,000 spring chinook salmon, which were planted in January 1959. Shelton (pers. comm.) reported that growth was rapid in both species, coho salmon averaging 41 g and chinook salmon 32 g, after an 18-mo

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residence. In June 1960, the reservoir was treated with rotenone in an attempt to remove both salmon and resident rainbow trout, *Salmo gairdneri* Richardson. Survival of the salmon, to this time, was estimated to have been 90%.

In the present study, the reservoir received two plantings of spring chinook salmon fry: on 8 February 1961, 75,300 unfed fry at 3,300/kg from the Bureau of Sport Fisheries and Wildlife hatchery at Carson, Wash.; and on 22 March 1962, 150,000 advanced fry at 2,200/kg from the Bureau of Sport Fisheries and Wildlife Eagle Creek hatchery at Estacada, Oreg.

A fry planted in 1961 is called a 1961 year class fish; it is designated as 0-age from February 1961 to February 1962 and as age class I from February 1962 to February 1963, so that the Roman numeral corresponds to the number of winters spent in freshwater life (Koo, 1962).

## METHODS AND MATERIALS

A stadia survey and depth sounding provided data from which a hydrographic map was made. Area and volume were computed from this map. Temperature patterns of the upper strata of water were recorded with a maximum-minimum thermometer and constant-recording thermographs. A transistorized thermometer was used to take vertical temperature series. Light penetration was measured with a Secchi disc.

A Kemmerer water bottle was employed to take water samples in vertical series for pH and dissolved oxygen determinations. The Winkler method was used for oxygen determinations, and either a color-comparator or portable conductivity meter was used to measure pH.

Other determinations made were total dissolved solids, volatile dissolved solids, total phosphorus, and methyl orange alkalinity. The same water sample sufficed for the first two; after the suspended solids were removed by centrifugation, the sample was evaporated at 60°C and ashed at 600°C for these measurements. The phosphorus analyses were conducted by the analytical laboratory of the Department of Soils at Oregon State University. A 0.02 N sulfuric acid solution was used in the titration for methyl orange alkalinity.

From 14 to 59 chinook salmon were collected at approximately 1 mo intervals for food and growth studies. These collections, in addition to the more extensive ones for survival estimates, were made by means of gill nets and beach seines, and by angling. Each fish in a monthly sample was measured for fork length to the nearest millimeter and weighed on a double-pan balance to the nearest 0.1 g. Fish to be used in the food analyses were preserved in 10% Formalin[4] after their body cavities had been slit open. The exception to this procedure involved the recently planted fish, which were preserved in 70% ethyl alcohol or 5% Formalin prior to measurement.

The condition factor for each fish was computed from the following formula, as modified from Rounsefell and Everhart (1953):

$$K = 100W/L^3$$

where $K$ = a condition factor near unity
$W$ = weight in grams
$L$ = fork length in centimeters.

In preparation for stomach analyses, the preserved fish were transferred to 5% Formalin and eventually to 20% isopropyl alcohol. Ten fish from each sample were chosen for analysis. Only the contents of the anterior halves of the stomachs were removed in order to reduce error caused by partially digested foods. The stomach contents were pooled and thoroughly mixed, and a random subsample was extracted for dry-weight analysis.

Population estimates were determined through the mark-and-recapture method. Fish were captured with seines, anesthetized in a solution of quinaldine (8 to 12 ppm), marked with a fin-clip, and then distributed over the reservoir in accordance with the apparent distribution of the population. Fins clipped included both pelvics and anterior third of the anal fin on the 1961 year class, and adipose and posterior third of the anal on the 1962 year class.

Salmon which migrated from the reservoir via spillway outflows were captured in an

[4] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

inclined-plane trap. Screens on the spillway forced emigrating fish to enter the trap. After spill had ceased, additional outflows of 0.071 $m^3/s$ [2.5 cfs (cubic feet per second)] were produced by using a U-shaped iron tube as a siphon. The time or amount of outflow was otherwise uncontrolled.

Many of the measurements were taken in English units, and these occasionally are presented for clarity.

## DESCRIPTION OF RESERVOIR

Happy Valley Reservoir (Figure 1) lies behind an earth-filled dam constructed on Quartz Creek in the Warm Spring River watershed. The stream flowed at rates up to 1.13 $m^3/s$ (40 cfs) during the winters of the study. These inflows replaced water used for summer irrigation and produced spillway outflows of up to 0.56 $m^3/s$ (20 cfs). Summer inflows dropped to less than 0.028 $m^3/s$ (1 cfs).

At full pool, the reservoir covers 7.5 hectares and has a maximum depth of 12.8 m (42 feet). For most of the 1961 and 1962 summers these dimensions were reduced to 6.1 hectares and 10.7 m (35 feet) by irrigation drawdown. Minimal dimensions were 4.9 hectares and 9.1 m (30 feet), occurring from late summer to early winter.

The reservoir receives a heavy sediment load; Secchi disc visibility was 10 cm after a 1961 rainstorm and did not exceed 2.1 m during the study. The flat central plain region of the reservoir is a mixture of this sediment and organic deposits capable of releasing large gas bubbles.

Air temperatures of −34°C and ice cover to 18-cm thick occurred under winter conditions; summer temperatures exceeded 27°C at 0.8 m (Figure 2). Thermal stratification was evident from May to September. In July and August, when temperatures were high and stratification most severe, the upper 1.5 m was frequently 21° to 27°C, and only at depths of 2 m or more could temperatures below 20°C be found. Figure 3 illustrates the seasonal patterns in temperature profiles.

The concentration of dissolved oxygen was greatly affected by thermal stratification and by decomposition occurring in the organically rich bottom of the reservoir. During July and August, measurable amounts of dissolved oxy-

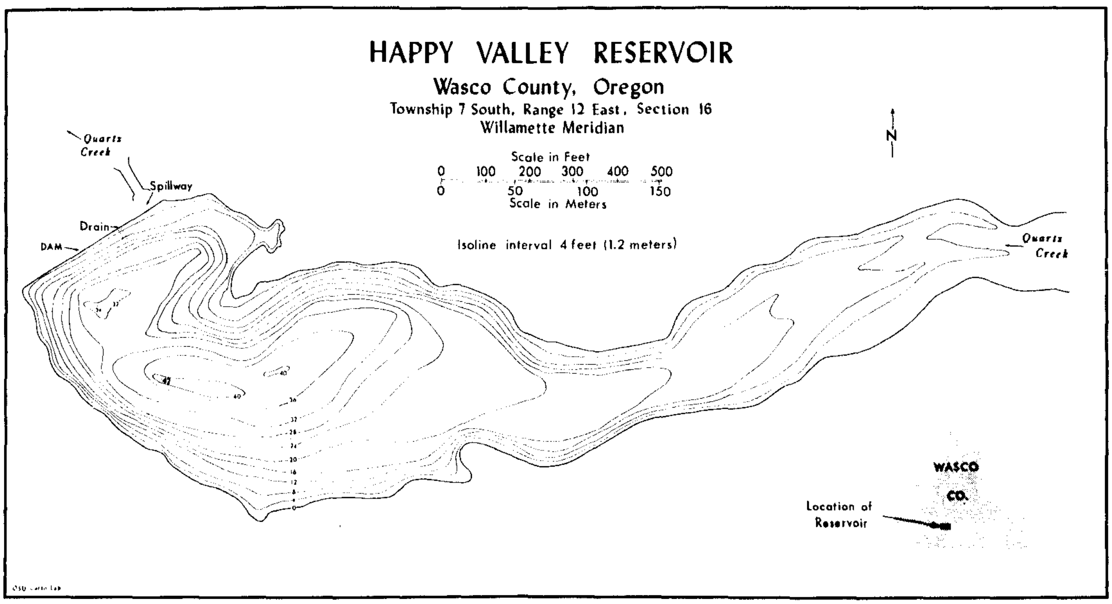


FIGURE 1.—Contour map of Happy Valley Reservoir. The 42-foot depth was sampling station 1, and 45 m directly off the spillway was sampling station 2.

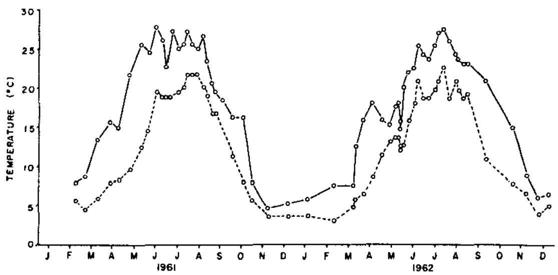


FIGURE 2.—Maximum-minimum temperatures at 0.8 m (2.5 feet) taken with reversing thermometer at station 2, 1961-62.

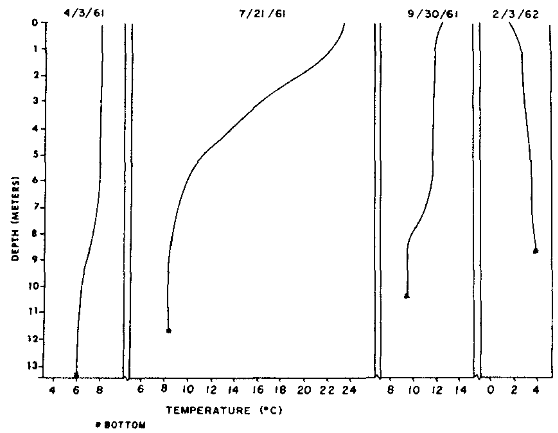


FIGURE 3.—Representative temperature profiles for station 1 on 3 April, 21 July, and 30 September 1961 and 3 February 1962. Changes in depth were caused by irrigation drawdown.

gen were usually absent in the nearly stable water mass below 4.3 m (e.g., the 8 August 1961 profile in Figure 4). Upward from this depth, concentrations increased to maxima of 6 to 13 mg/liter, depending upon algal activity. After fall turnover and the second irrigation drawdown (in late September), dissolved oxygen concentrations exceeded 6 mg/liter at all depths, even during periods of ice cover, until the following spring (Figure 4, profiles for 30 September and 9 December 1961).

Chemical analyses of water indicated a high basic fertility for the reservoir. Total dissolved solids generally exceeded 80 ppm and occasionally were as high as 220 ppm on the bottom; and early-to midsummer volatile dissolved solids mostly varied between 80 and 100 ppm (Figure 5). Total phosphorus concentrations exceeded

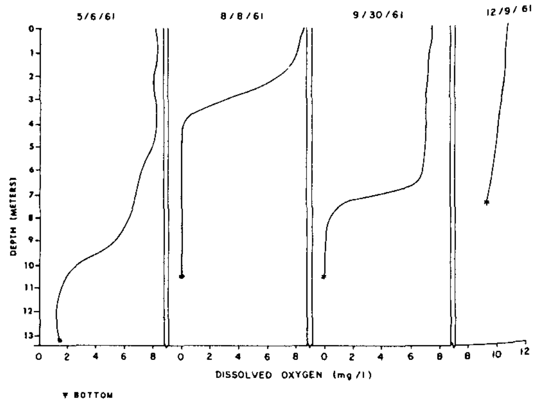


FIGURE 4.—Representative dissolved oxygen profiles for station 1 on 6 May, 8 August, 30 September, and 9 December 1961.

0.4 ppm at the bottom and 0.2 ppm at the surface (Figure 5). Surface pH (Figure 6) rose to 10.0 during algal blooms, although it generally varied between 7.0 and 8.5 for all depths. Methyl orange alkalinity usually exceeded 60 ppm and approached 130 ppm expressed as $CaCO_3$ (Figure 7).

The reservoir supported high summer densities of plant and animal life. Sago pond weed, *Potomogeton pectinatus* L., choked the inlet until water drawdown stranded the plants. Much less rooted aquatic vegetation grew outside the inlet area because of limited shallow water. Blue-green algae of the genera *Aphanizomenon* and *Microcystis* dominated the phytoplankton and gave a characteristic copper-blue stain to the shoreline. Cladocera and lesser numbers of other Entomostraca composed the bulk of the zooplankton and were noted to be abundant at various times of the year. Native rainbow trout were kept at low numbers by the chemical treatment (made several months before fry were introduced) and by subsequent gillnetting. The littoral zone was well populated with larvae of Ephemeroptera, Odonata (mostly Coenagrionidae), Trichoptera, and Diptera (Chironomidae). Amphipods (Gammaridae) were numerous, and some crayfish (*Pacifasticus*) and snails (*Physa*) were observed. The deeper benthic zones were inhabited primarily by oligochaetes and by *Chironomus* and *Chaoborus* larvae. At times during the summer, large

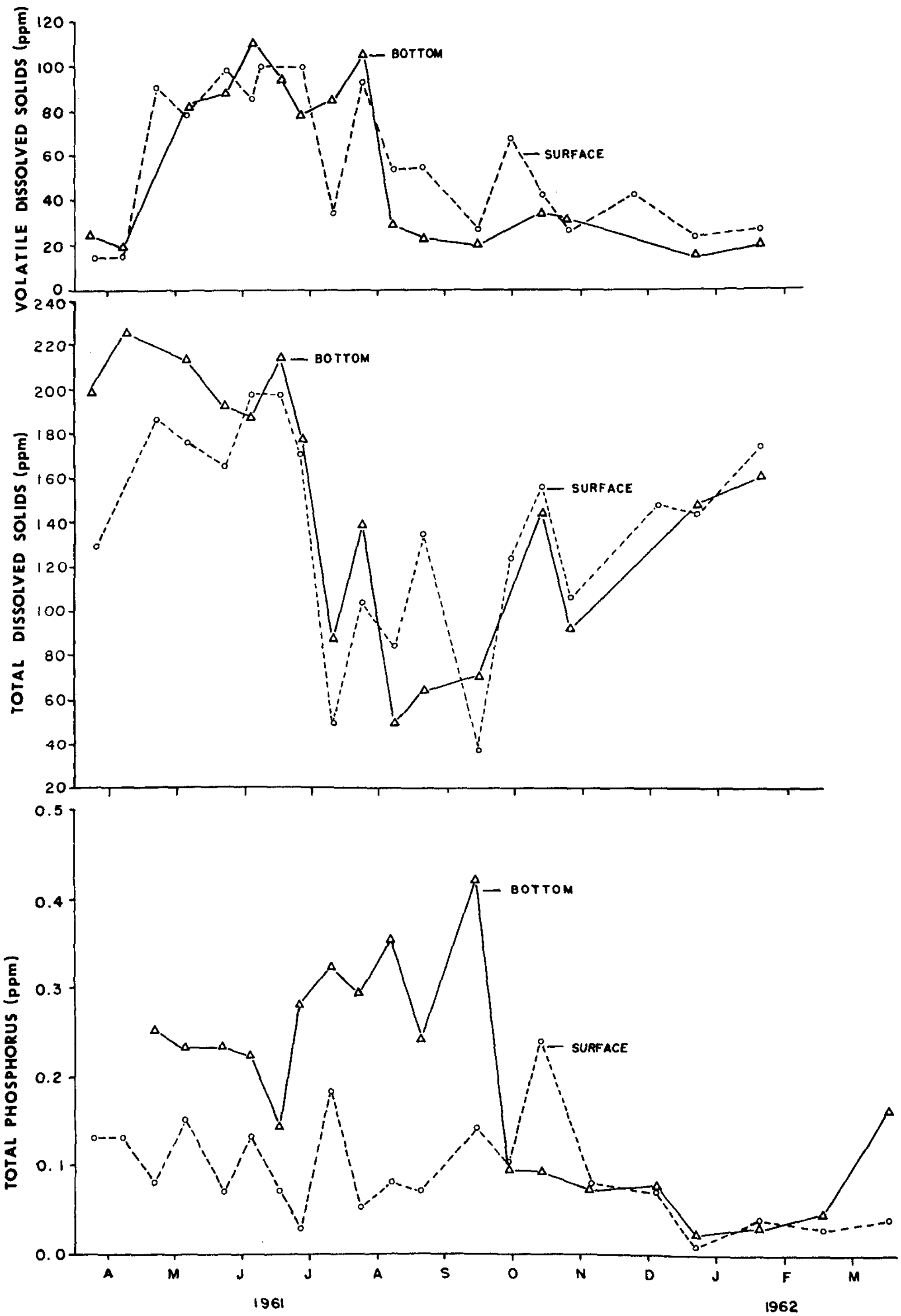


FIGURE 5.—Total phosphorus, total dissolved solids, and volatile dissolved solids at station 1, April 1961 to March 1962.

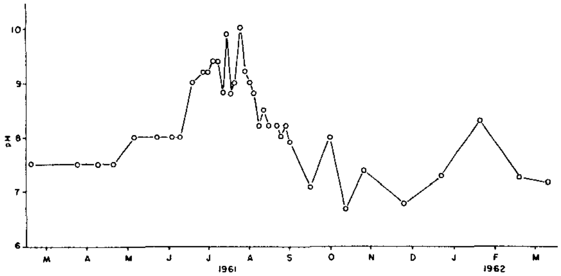


FIGURE 6.—Surface pH at station 1, March 1961 to March 1962. Summer increases reflect blooms of blue-green algae.

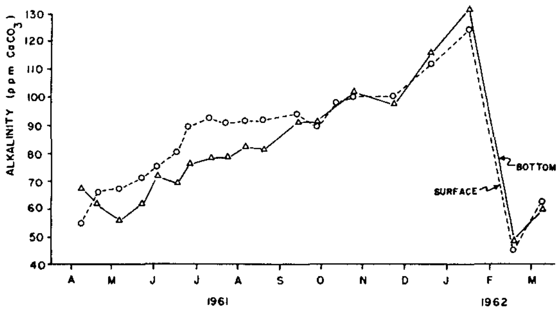


FIGURE 7.—Methyl orange alkalinity expressed as ppm $CaCO_3$ at station 1, April 1961 to March 1962.

swarms of adult Diptera hovered above the reservoir.

## EFFECTS OF RESERVOIR CONDITIONS ON SALMON

Happy Valley Reservoir, a eutrophic impoundment with warm summer conditions, is markedly different as a rearing site from the streams naturally inhabited by juvenile chinook salmon. Spring chinook salmon normally make the parr-to-smolt transformation during the spring after 1 yr of freshwater residence. Salmon reared 1 yr in the reservoir met severe midsummer conditions. They were driven upward by low oxygen concentrations and downward by high temperatures, high pH, and possibly by algal toxins released by decomposing blue-green algae. As an example of midsummer conditions, temperature and dissolved oxygen profiles are presented in Figure 8 for 1 August 1961. Under these conditions, which likely did not represent the extreme for that day, fish

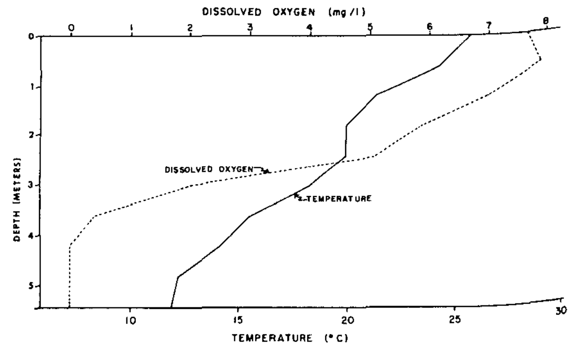


FIGURE 8.—Midday conditions of temperature and dissolved oxygen on 1 August 1961 at station 1. Fish die-off occurred on this date.

seeking temperatures below 20°C would have had to accept dissolved oxygen concentrations below 5 mg/liter. The preferred temperature is 12° to 13°C (Brett, 1952), at which depth oxygen levels would not have sustained life.

Scores of observations of fish "echoes" on the dial of a depth-sounder indicated that the fish sought the least extreme combination of these low oxygen and high temperature stresses and congregated near the 1.7-m (5- to 6-foot) depth. Similarly, gill nets set at various depths in August 1962 captured fish almost exclusively at depths of 1.8 m (6 feet) or less (Table 1). Water at 1.8 m usually held 5 mg/liter or more oxygen and was just above the zone of rapid oxygen decline (Figure 9). These observations are in accord with those by Whitmore, Warren, and

TABLE 1.—Frequency of capture by gill net at approximate depth of capture, 8 to 15 August 1962. Surface 0.6 m was not fished. Most sets were made in waters more than 4.6 m deep.

| Depth of capture (m) (feet) | Number of fish caught per hour | Number of hours fished at depth |
|---|---|---|
| 0.6 (2) | 0.25 | 22 |
| 0.9 (3) | 0.18 | 22 |
| 1.2 (4) | 0.96 | 22 |
| 1.5 (5) | 0.77 | 22 |
| 1.8 (6) | 0.27 | 22 |
| 2.1 (7) | 0.00 | 22 |
| 2.4 (8) | 0.10 | 95 |
| 2.7 (9) | 0.08 | 95 |
| 3.0 (10) | 0.01 | 95 |
| 3.4 (11) | 0.00 | 95 |
| 3.7-4.3 (12-14) | 0.00 | 74 |
| 4.6-5.2 (15-17) | 0.00 | 144 |
| 5.5-7.3 (18-24) | 0.00 | 71 |

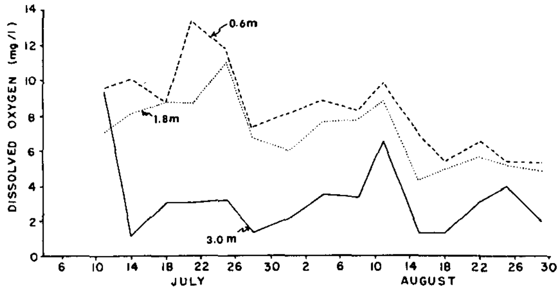


FIGURE 9.—Dissolved oxygen concentrations at 0.6, 1.8, and 3 m (2, 6, and 10 feet) during July and August 1961. Salmon typically inhabited water 1.2 to 1.8 m deep during this period. Samples taken midday at station 1.

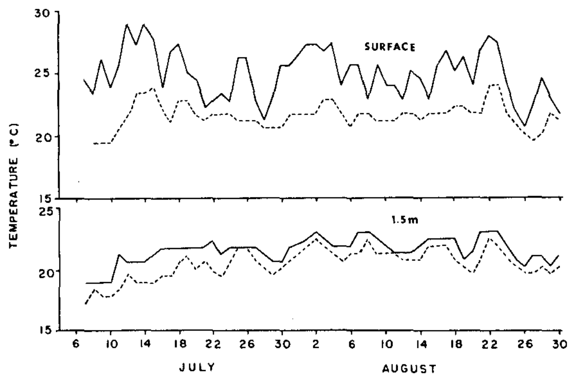


FIGURE 10.—Daily maximum-minimum temperatures at surface and at 1.5 m (5 feet) during July and August 1961. Maxima at the surface exceeded the lethal limit (25.1°C) for chinook salmon fry, and reached 23°C at 1.5 m. Data from thermograph records for station 2.

Doudoroff (1960), who state that at 16.5° to 25.5°C, under controlled conditions, juvenile chinook salmon directly avoided oxygen concentrations of 4.5 mg/liter and below.

Conditions in the upper 1.8 m of water were sometimes marginal for survival of the salmon because of 18° to 29°C temperatures (Figure 10), varying oxygen concentrations, and other stresses. Between 31 July and 3 August 1961, 65 dead salmon (50 of 1959 year class and 15 of 1961 year class) were collected at the water surface. Fish broke water in obvious distress at various hours of the day. At this time, a heavy bloom of *Aphanizomenon* was decomposing, accompanied by declines in surface pH (Figure 6) and oxygen concentrations (Figure 9). Oxygen concentrations remained at 5 to 8 mg/liter in the upper 1.5 m of water during a 24-h series taken 31 July-1 August. During the die-off, daily temperature maxima were reaching 23°C at 1.5 m (Figure 10). Brett (1956) estimated that 25.1°C is the upper lethal limit for chinook salmon acclimated to 20°C. The combination of low oxygen, high temperature, high pH, and possibly algal toxins apparently formed untenable conditions for some of the fish.

During the extreme conditions of midsummer 1961, the 0-age class salmon lost condition (see later section on Condition). Herrmann, Warren, and Doudoroff (1962) observed progressively lower food consumption and growth rates among juvenile coho salmon held at 20°C and exposed to decreasing oxygen concentrations. The most rapid decline in these rates occurred at concentrations decreasing below 4 mg/liter and weight losses occurred at 2 mg/liter. Salmon in Happy Valley Reservoir, on the whole, grew rapidly during the summer despite occasionally critical conditions. They surface-fed in the mornings and evenings in water as warm as 21° to 23.5°C. Brett (1952) also noted that his experimental salmon fry would move up through strong temperature gradients and into temperatures near their lethal level to feed at the surface.

During the summer, salmon generally congregated along the dam face and in the southwest corner. The reason for this is not known; oxygen concentrations and temperatures were similar to those in other areas of the reservoir. However, when a freshet brought a cooler (and probably more highly oxygenated) water mass into the inlet, the salmon quickly congregated there. On 14 August 1962, surface temperature was 24.5°C in the lower reservoir and 19°C in the inlet. The temperature difference soon disappeared, but the salmon remained abundant in the inlet until late September when fall turnover began.

The salmon were less frequently captured and were more uniformly distributed about the reservoir during the winter than in the summer. No vertical limitation was evident. Cold water caused no observed deaths, but apparently reduced the activity of the fish, and this reduced gill-net catches. The lower lethal temperature was estimated by Brett (1956) as 0.8°C for chinook salmon fry acclimated to 10°C. Cold tolerance, Brett indicated, is gained slowly by fish. Winter temperatures of 7°C and below were reached at Happy Valley only after about a 2-mo period of decreasing temperatures (Figure 2). This period seems sufficient for the salmon to have acclimated to cold.

## SURVIVAL

Mortality of 0-age salmon exceeded 80% for both the 1961 and 1962 year classes. This contrasted with the light losses among 1959 0-age salmon, which did not face predation by older salmon at planting.

Predation rate in 1962 was estimated in two ways. In the first method, stomach contents from 1961 year class salmon were studied. A total of 29 0-age salmon were found in the stomachs of 299 salmon collected between 26 May and 29 June 1962. There were about 10,000 of the 1961 year class present during this period (Figure 11). Assuming that the stomach contents represented daily consumption, the daily consumption rate was on the order of 1 prey per 10 predators, and mortality was about 1,000 fry per day. Predation rate by the 1961 year class was also estimated using growth and food habits data (see sections on Growth and Food Habits). Relative growth of the 1961 year class was 1.4 mg/g per day from 15 May to 15 June 1962. Experimental evidence, provided by Davis and Warren (1968) for chinook salmon fry held at 10°C, indicated that at 1.4 mg/g per day, food consumption was about 40 mg/g per day. The total 1961 year class biomass was about 700,000 g (10,000 fish times 70 g average weight). Thus, consumption was 28,000 g per day. According to food studies on the 1961 year class, 21% of this consumption, or 5,880 g per day, was fry. At 4 g per fry, 1,470 fry per day were consumed by the older salmon. A similar calculation for 18 June to 20 July gave a mortality rate estimate of 1,125 fry per day.

The two estimates agree on a predation rate sufficiently high to account for most of the losses in 1962 and, by inference, in 1961. The heaviest losses actually would have occurred when the fry were smallest and most abundant, i.e., close to planting time as shown by the survival curves in Figure 11. More specific information about the fates of the 1961 and 1962 year classes is given below.

The 75,300 fry planted on 8 February 1961 (1961 year class) met severe predation by 1959 year class salmon and rainbow trout surviving chemical treatment. Additional losses occurred when a flash flood on 11 February carried many of the fry over the spillway. A mark-and-recapture operation indicated population size was 28,600 fish (38% survival) on 22 March 1961 (Table 2). According to a second estimate, the population contained 6,800 fish (9% survival) in late August 1962. Continued losses were caused by predation, harmful summer water conditions, and a transplantation program which removed 2,500 salmon to Beaver Creek, a tributary of the Warm Springs River.

The second plant of chinook salmon (1962 year class) was made on 22 March 1962. Because predation was expected, a large, fine-mesh seine was used to impound and protect the fry in a cove of about 0.05 hectare, while gill nets were set to deter predator movement. These measures reduced predation at planting, but also produced a high fry density in the cove and this caused the fry to grow relatively slowly. Some fry escaped from the cove; these fish were substantially larger than fry still in the cove

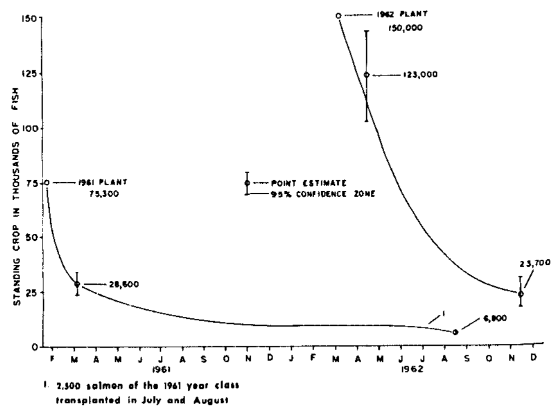


FIGURE 11.—Survival curves for 1961 and 1962 year class salmon. Curves were fit by eye according to population estimates and information on predation rates described in text.

TABLE 2.—Statistics used in estimating the standing crop in numbers of the 1961 and 1962 year classes.

| Date | Fins marked | Number marked | Marks recovered | Total catch | Estimate of population at marking time | 95% Confidence limits | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| 1961 year class | | | | | | | |
| 22 Mar. 1961 | Both pelvics | 984 | 133 | 3,871 | [1]28,640 | 23,760 | 33,520 |
| 30 Aug. 1962 | Anterior one-third of anal | 1,203 | 131 | 739 | [1] 6,786 | 5,710 | 7,862 |
| 1962 year class | | | | | | | |
| 1 May 1962 | Adipose | 5,080 | 143 | 3,461 | [1]122,950 | 102,810 | 143,090 |
| 30 Nov. 1962 | Posterior one-third of anal | 1,793 | 59 | 1,261 | [2]23,722 | [3]18,900 | 31,845 |

[1] Direct-proportion estimate.
[2] Schnabel estimate (Rounsefell and Everhart, 1953).
[3] Limits set with Poisson distribution (Rounsefell and Everhart, 1953).

(0.79 g vs. 0.48 g) on 28 April, when the seine was removed. The reduced growth evidently extended the period during which the fry were susceptible to predation, and losses were again high. Population size was estimated at 123,000 (82% survival) on 1 May and 23,700 (16% survival) in late November 1962.

## GROWTH

The salmon grew rapidly, especially under conditions of low population density. During their initial 18-mo residence (January 1959 to June 1960), the 48,000 members of the 1959 year class grew to average weights of 32 g (chinook salmon) and 41 g (coho salmon). Chemical treatment of the reservoir in June 1960 drastically reduced population size, and surviving salmon grew at very rapid rates. By August 1961, chinook salmon averaged 215 g and coho salmon 280 g. These salmon were captured less and less frequently during the 1961 summer, apparently because of deaths brought on by sexual maturation and water conditions. By fall 1961, the population was virtually extinct.

Growth by the 1961 and 1962 year class salmon also appeared density-regulated. About 30,000 of the 1961 year class escaped initial predation and other losses. By December 1961, population size was about 10,000 fish, which averaged 17 cm in fork length (Figure 12) and 62 g (Figure 13). In December 1962, 5,000 of these salmon remained. They then averaged 21 cm and 89 g, which represented relatively small 12-mo increases. Rapid second-year growth, such as occurred in the 1959 year class, appears to have been prevented by the introduction of the 1962 year class. Of the 150,000 fry planted in March 1962, about 23,000 remained in December 1962, when they averaged 13 cm and 22 g (Figures 12 and 13). Thus, slower growth occurred among first-year salmon in 1962 than in 1961 due to the higher density in 1962. Other influences may have been the later planting date in 1962 and the protective enclosure of the 1962 year class in a relatively small area for 5 wk.

Ricker and Foerster (1948) studied competition and population size in juvenile sockeye salmon, *O. nerka* (Walbaum), of Cultus Lake.

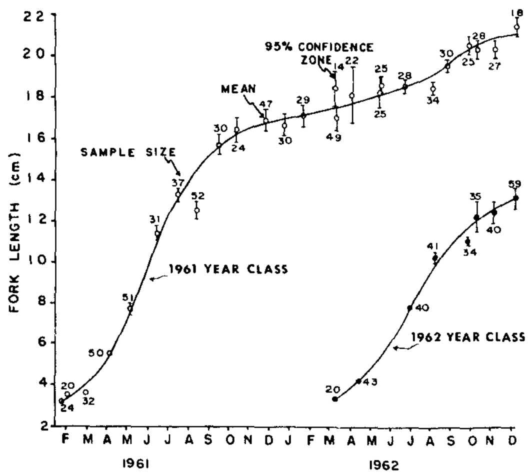


FIGURE 12.—Growth in length of 1961 and 1962 year class salmon. Some confidence zones were omitted because of their small size.

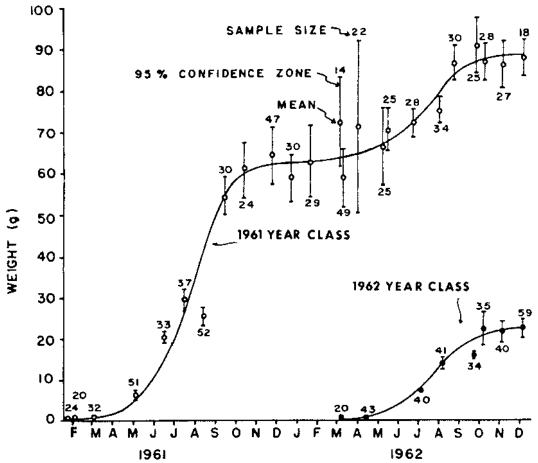


FIGURE 13.—Growth in weight of 1961 and 1962 year class salmon. Confidence zones for the first three samples of 1961 year class were too small to be shown. Those for the first three samples of 1962 year class were not calculated because the fish were weighed in groups.

They postulated, "a very nice regulatory mechanism: the more fry present, the less each eats, hence the slower it grows, and hence the longer it remains at a size especially vulnerable to predator attack." A similar mechanism probably produced the heavy losses and comparatively slow growth in the 1962 year class in Happy Valley Reservoir.

Hoover (1936) described the growth achieved by chinook salmon in New Hampshire Lakes. The fish generally matured at 4 yr, when they averaged about 2.3 kg. Where rainbow smelt, *Osmerus mordax*, were abundant, however, the salmon averaged 4.5 to 5.4 kg and one reached 7.3 kg. Hoover thus also implied a food regulation of growth, with these impounded salmon being capable of growth approaching that of sea-run fish when abundant foods were present. Similarly, Johnson and Hasler (1954) depicted food and the space over which it was concentrated as a primary factor limiting trout growth in the lakes they studied. At Happy Valley, under circumstances of low competition, growth by first-year and second-year chinook salmon was rapid; increased size as obtained in the New Hampshire lakes, however, would likely not have occurred in the absence of a forage fish or other large foods.

The average weight of 62 g attained by members of the 1961 year class at the end of their first summer represented a more rapid growth rate than usually found in stream-living chinook salmon juveniles. The 22 g average of the 1962 year class, however, is close to that estimated by Breuser (1961) for chinook salmon in the Willamette River of western Oregon, which grew from an average of 2.35 g in May to 20.17 g in November.

## CONDITION

The salmon gained condition during the spring, and lost condition during the midsummer when temperatures were highest (Figures 14 and 2). In 1961, condition increased again in the fall to the highest level measured (1.38). Neither age class gained condition in fall 1962, likely because of more slowly decreasing temperatures and the presence of a higher fish density. The 1962 year class lost condition during the 5-wk period after planting when they were concentrated behind the seine.

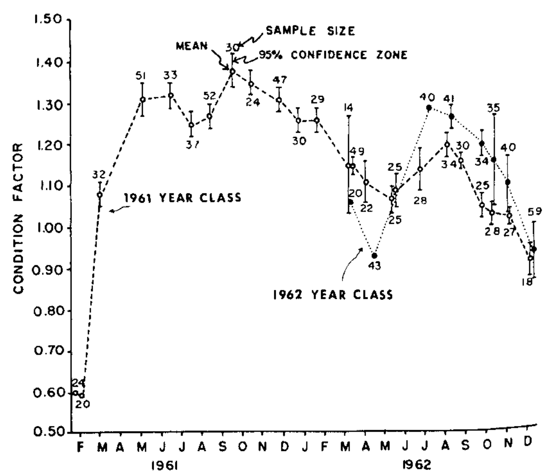


FIGURE 14.—Changes in condition factor of 1961 and 1962 year class salmon. Confidence zones of some samples were omitted for reasons stated for Figure 13.

During the winter, average weight increased little, and may have decreased (Figure 13). Average length slowly increased (Figure 14) resulting in decreasing condition factor values.

## NET PRODUCTION AND YIELD

The production of a given group of organisms was defined by Ivlev (1966) as the total elaboration of tissue by that group over a given time period, regardless of the fate of the tissue. Ricker and Foerster (1948) used this viewpoint with mathematical formulation to calculate the production of juvenile sockeye salmon in Cultus Lake. Allen (1951) described the graphical method of computation which was used here.

Allen's method uses survival and growth information in plotting estimated population size against average weight at successive intervals. The area under the curve between plottings (month intervals were used here) represents the net production for that period. Survival data are usually more difficult to obtain than growth data, and deficiencies may introduce considerable error into production estimates. For example, estimated annual production in Happy Valley by the 1962 year class would be increased by one-half if mortalities were assumed to have occurred later in the summer. Despite such limitations, production estimates are valuable measures for comparing the rearing capacities of various bodies of water (Ricker and Foerster, 1948).

Both net production and potential yield were computed for salmon impounded in Happy Valley during 1961 and 1962, and compared with values obtained for fish in other bodies of water. Extrapolation of survival and growth curves through December 1962 was required to make the 1962 computations. Annual production for first-year salmon was considered to be the tissue produced from planting until 31 December. Production by rainbow trout and 1959 year class salmon was not computed. Because production was concentrated in the summer, the average summer surface area of 6.1 hectares was used in comparisons with other bodies of water.

Total production by the 1961 year class in its first year was 972 kg (159 kg/hectare). A similar biomass—1,039 kg (170 kg/hectare)—was elaborated by the 1962 year class in its first year, with less individual growth being attained by larger numbers of fish. In 1962, production by yearling salmon was only 217 kg (35.5 kg/hectare), or 22% of their production in 1961. Reduced population size and slower growth created by competition from the 1962 year class apparently caused this low production. Much of the 217 kg elaborated depended on the consumption of foods different from those used by the younger salmon and on the consumption of the younger salmon themselves. Total production by both age classes in 1962 was 1,256 kg (206 kg/hectare). In both years, about 75% of the production occurred from June through September. Similarly, two-thirds to three-quarters of the sockeye salmon production in Cultus Lake occurred between 15 June and 15 September (Ricker and Foerster, 1948). Gerking (1962) stated that, "production is an event of the summer," for the bluegill, *Lepomis macrochirus* Rafinesque, of the Indiana lake he studied. These observations simply assert the importance of the limited growing season in temperate waters.

The potential yield of salmon tissue from Happy Valley is here defined as production surviving to the end of the year. This was calculated as the biomass introduced at planting subtracted from the standing crop present on 31 December. Standing crop was estimated by multiplying the number of surviving fish (Figure 11) times their average weight (Figure 13). Potential yield of first-year salmon on 31 December 1961 was 98 kg/hectare, and on 31 December 1962 was 73.5 kg/hectare. These yields amounted to 61% in 1961 and 43% in 1962 of the tissue produced. Coche (1967) estimated 59.4% was the yield of first-year steelhead trout, *S. gairdneri* from a western Oregon reservoir. Survival in Coche's experiment was 38.4% as compared with 13% and 15% for the two year classes in this study.

Coche (1967) has summarized net production values for a variety of streams and impoundments. Salmonids studied in oligotrophic lakes produced from 0.6 to 65 kg/hectare/yr, those in dystrophic lakes 19 to 84 kg/hectare/yr, and those in North American streams 41 to 198 kg/hectare/yr. Brown trout, *S. trutta* Linnaeus, in a New Zealand stream produced 275 to 837 kg/hectare/yr. Largemouth bass, *Micropterus salmoides* (Lacépède), in fertilized ponds of western Oregon produced up to 128 kg/hectare/yr. The maximum first-year production of 170 kg/hectare/yr and the total 1962 production of 206 kg/hectare/yr by salmon in Happy Valley rank this reservoir as high among impoundments studied and apparently comparable to some of the more productive streams studied.

The yield of juvenile salmonids from 10 impoundments has also been summarized by Coche (1967). The lowest value (2.3 kg/hectare/yr) was for sockeye salmon in a large oligotrophic lake in Canada. Most values ranged between 20 and 100 kg/hectare/yr; the highest was 143 kg/hectare/yr. Ellis, Pressey, and Smith (1958), citing Washington Department of Game figures, stated that Washington lakes yield 45 to 209 kg/hectare/yr (average 112) in rainbow trout. Although covering a wide range, these figures suggest that yields of 100 kg/hectare/yr may be expected of fertile impoundments. This was true for Happy Valley which, despite high mortality rates, yielded 98 and 73.5 kg/hectare/yr of first-year salmon in the 2-yr of this study. Both net production and yield estimates corroborate chemical evidence that the reservoir is highly fertile.

## FOOD HABITS

Studies such as those by Johnson and Hasler (1954) and Ricker and Foerster (1948) have shown Entomostraca to be the primary food type eaten by many lake-resident juvenile salmonids. The coho salmon of the small lake in Kamchatka Penninsula studied by Dvinin (1949), however, fed on insects (midges and mosquitoes), although older fish took some zooplankton. In food-habit studies of stream-inhabiting coho and chinook salmon juveniles, Brueser (1961) and Chapman et al. (1961) found mainly Diptera and Trichoptera larvae, Ephemeroptera nymphs, and terrestrial insects. Availability very likely played a major role in these differences of food habits; for example, planktonic forms in a stratified lake and "drift" organisms in a stream would be available forms, with salmonids capable of eating a variety of foods.

Food habits of the 1961 year class in Happy Valley Reservoir were determined by dry-weight analyses of stomach contents from 17 samples of fish taken between April 1961 and November 1962. The results (Table 3) indicated a heavy utilization of Entomostraca (mostly Cladocera) and chaoborid larvae in both summer and winter until the 1962 year class was released. These foods averaged 97% of the stomach contents for the samples taken before the 1962 salmon were released, and only about 6% of the sample contents taken thereafter. The planktonic Entomostraca and vertically migrating chaoborid larvae were apparently both abundant and available to the salmon, which probably fed in the upper 3 m of water during the summer. Competition from the 1962 year class, however, evidently forced a shift in food habits and led to the slow growth already mentioned. A variety of benthic forms (crayfish, snails, damsel fly naiads, and amphipods) as well as chironomid pupae, terrestrial insects, and members of the 1962 year class were then eaten.

Meanwhile, the 1962 year class was utilizing Entomostraca, as shown by field checks of stomach contents. In a 23-member sample of these fish taken on 21 August 1962, Entomostraca were found in all stomachs and made up roughly 80% of the total contents identified. In another sample of 10 fish taken on 2 September 1962, 9 stomachs contained Entomostraca, which formed 45% of the total contents. Most of the remaining food in both samples was chironomids.

Increased size does not seem to have been the direct cause of the change in food preference by the 1961 salmon because their size (Figures 12 and 13) did not appreciably increase from fall 1961 to spring 1962, when the apparent food shift occurred. That fish of their size are capable of feeding upon the Entomostraca was shown by an earlier analysis of the stomach contents from 25 salmon of the 1959 year class. These fish averaged 193 g when collected on 8 April 1961. Entomostraca were found in 13 of the stomachs and constituted 90% of the combined sample on a settle volume basis. The high production by first-year salmon in Happy Valley Reservoir apparently was supported chiefly by entomostracan foods.

TABLE 3.——Contents of stomachs taken from chinook salmon of the 1961 year class, April 1961 to November 1962. Contents were subjected to dry weight analysis; results are presented according to percentage contribution of each food type.

| | 1961 | | | | | | | 1962 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4-22 | 7-1 | 8-10 | 8-28 | 10-1 | 10-29 | 12-10 | 1-1 | 2-4 | 3-23 | 5-29 | 7-5 | 8-14 | 9-6 | 10-6 | 10-29 | 11-18 | Av. % |
| Aquatic organisms: | | | | | | | | | | | | | | | | | | |
| Entomostraca | 18.72 | 55.88 | 30.77 | 91.72 | 98.26 | 99.28 | 90.61 | 96.07 | 100.00 | 29.24 | | | | 39.04 | | | | 44.1 |
| Gastropoda | | | | | | | | | | | | | | | 100.00 | | 80.01 | 10.6 |
| Zygoptera | 0.52 | 0.73 | | 0.45 | 1.59 | 0.72 | | | | | | 3.15 | 68.97 | 60.96 | | | 8.11 | 8.5 |
| Chaoboridae | | | | | | | | | | | | | | | | | | |
| Larvae | 74.91 | 24.18 | 69.23 | 7.83 | | | 9.39 | 3.93 | | 70.76 | | | | | | | | 15.3 |
| Pupae | | | | | | | | | | | | 6.49 | 6.92 | | | | | 0.8 |
| Chironomidae | | | | | | | | | | | | | | | | | | |
| Larvae | 5.33 | 3.07 | | | | | | | | | | | | | | | | 0.5 |
| Pupae | | 1.22 | | | | | | | | | 79.02 | 6.98 | 24.11 | | | | | 6.6 |
| Crayfish | | | | | | | | | | | | 52.59 | | | | | | 3.1 |
| Hemiptera | | 14.92 | | | | | | | | | | | | | | | | 0.9 |
| Annelida | | | | | | | | | | | | | | | | | 3.50 | 0.2 |
| Juvenile salmon (1962 year class) | | | | | | | | | | | 20.98 | 30.35 | | | | | | 3.0 |
| Amphipoda | 0.52 | | | | | | | | | | | 0.44 | | | | 31.31 | 8.38 | |
| Terrestrial organisms: | | | | | | | | | | | | | | | | | | 2.4 |
| Hymenoptera | | | | | | | | | | | | | | | | 64.54 | | 3.8 |
| Coleoptera | | | | | | | | | | | | | | | | 4.15 | | 0.2 |
| Lepidoptera | | | | | 0.15 | | | | | | | | | | | | | 0.0 |

## MIGRATION OF SALMON FROM RESERVOIR

Intrinsic factors suggested as influencing the downstream migration of salmonid juveniles include size and age of fish (Elson, 1957) although these apparently are variable in migrating spring chinook salmon juveniles (Wallis, 1968; Wagner, Conte, and Fessler, 1969). Changes in water flow and temperature may be associated with movements. Wallis (1968) in reviewing literature concerning this subject found a number of authors who cited elevations in water temperature as correlated with downstream movements of Pacific salmon smolts. Emigration of sockeye salmon juveniles from Cultus and other lakes typically follows ice break up and rising temperatures (Foerster, 1968).

Migrants from Happy Valley Reservoir varied in size from 25 to 188.9 g and included fish of both age class I and class II (Table 4). The migrants appeared similar in size and condition to fish taken from the reservoir for growth studies. Migrations occurred between February and May of 1962 and 1963 at varying temperatures and outflow volumes. In 1962, no temperature relation was evident; but migrations in 1963 occurred only at temperatures above 10°C.

In 1962, 196 fish of age class I emigrated. On different days during a 6-wk period, groups of 30, 37, and 33 left when temperatures were 3.5° to 5°C, and outflows were 0.141 to 0.283 $m^3/s$ (5 to 10 cfs). During an 18-day period when temperatures were increasing from 6° to 15°C and outflows were less than 0.056 $m^3/s$ (2 cfs), migrations of 5 to 15 fish occurred on 7 nights. Outflow through the iron tube, used on 13 days when temperatures were 11.5° to 24°C, attracted one migration of 17 fish at a temperature of 13°C.

In 1963, a mid-February to mid-March spill volume of 0.141 $m^3/s$ (5 cfs) maximum, at temperatures below 5°C, brought no migration. By late April, water temperatures were 10° to 13°C, and a new spill of 0.141 to 0.283 $m^3/s$ (5 to 10 cfs) occurred. Approximately 500 salmon including both age classes exited. An additional 56 age class II and 498 age class I

TABLE 4.—Comparison of size and condition of migrating salmon with salmon in reservoir population.

| Year of migration | Year class | Sample size | Migrants: Fork length (cm) Mean | Range | Weight (g) Mean | Range | Condition factor Mean | Range | Reservoir population[1]: Fork length (cm) Mean | Weight (g) Mean | Condition factor Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1962 | 1961 | [2]117 | 16.5 | 13.2-28.2 | 55.7 | 25.0-188.9 | 1.10 | 0.67-1.37 | 17.5 | 65 | 1.15 |
| 1963 | 1961 | [3]13 | 20.0 | 19.1-22.2 | — | — | — | — | [4]22.5 | — | — |
| | 1962 | [3]13 | 14.1 | 13.3-15.9 | — | — | — | — | [4]14.5 | — | — |

[1] From Figures 12, 13, and 14; mean is for midpoint of sampling period.
[2] Taken between 2/27/62 and 5/27/62.
[3] Taken 5/7/63.
[4] By extrapolation of Figure 12.

salmon left when temperatures were 11° to 14.5°C, and spill was 0.014 to 0.056 $m^3/s$ (0.5 to 2 cfs).

## CONCLUSIONS

The high productive capacity of the reservoir was seen in the rapid growth, high condition factor, and high net production achieved during the summer by planted chinook salmon. High mortalities were caused primarily by predation. Severe summer conditions also caused deaths, indicating that the reservoir and others similar to it in thermal and chemical qualities should be considered marginal for use in natural rearing of salmon smolts.

Emigration by salmon was limited, but indicated that substantial voluntary movement may occur at appropriate temperatures and outflows, and that migrations by both age classes I and II including fish in excess of 100 g in weight are possible.

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