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ABSTRACT

Sockeye salmon (Oncorhynchus nerka) in three lakes on Afognak Island, Alaska, were studied. Ruth Lake was treated with rotenone to remove resident fish. Midarm Lake, which had no salmon, and Little Kitoi Lake, which has a small run of sockeye, were used as controls to compare survival and growth of introduced fry and natural fry with survival and growth of introduced fry in Ruth Lake. Other factors that might influence sockeye production, such as plankton and bottom fauna, were also considered.

In general, growth and survival of fry and biological productivity were greater in the treated lake. Growth and survival decreased as fry densities increased.

INTRODUCTION

Young sockeye salmon generally spend at least a year in fresh water in a lake below the spawning area--usually before migrating to sea. Most sockeye spawn in the inlet streams to the nursery lake, although a few may spawn on lake beaches that have suitable waterflows deep in the gravels. Fry emerge from these beds directly into the nursery areas. In a few locations where sockeye spawn in an outlet, the fry migrate upstream to the nursery lake.

The phase of the life cycle in the lake may be the most important to sockeye production because it takes place in the most limiting environment in the life-history sequence.

It may be desirable to control the numbers and growth of the population in the lake so that most fish migrate to sea after 1 yr. rather than remain an additional year or more. The "holding-over" of juveniles an additional year or more could increase intraspecific competition for food and even lead to predation by the older salmon on younger fish. Foerster (1938a), Barnaby (1944), and Koo (1955) demonstrated that the smaller fish tend to hold over an additional year before migrating seaward. The mortality during this extra year of fresh-water residence may override any benefits from the increased marine survival of these fish when they migrate at a larger size. Hence, longer lake residence may result in poorer survival to adulthood than would be obtained from an earlier seaward migration of larger numbers of smaller young salmon.

On the assumption that the lacustrine environment is a major factor in the production of sockeye, biologists of the Alaska Department of Fish and Game began studying the extent to which production of sockeye could be increased by controlling reproduction and providing more suitable rearing areas for juveniles before they migrate to sea. Factors considered were: the optimum density of fry recruitment for a given lake; the basic productivity of the lake (particularly the quality and quantity of food available to the young salmon); and the effects of other resident fish on the fresh-water production of sockeye. The primary aim of this phase of the investigation, however, was to study the survival and growth of sockeye fry introduced into a lake in which all potential competing and predatory fishes had been destroyed. Removal of predators and competitors from the environment should create more favorable opportunities for survival and growth of juvenile sockeye.

The importance of predation on juvenile salmon has been mentioned often in the literature. Brett and McConnell (1950), for example, attributed poor survival (0.4 to 1.1 percent) of juvenile sockeye salmon in Lakelse Lake, British Columbia, to heavy predation by northern squawfish (Ptychocheilus oregonensis). In several hundred squawfish stomachs examined, fish made up 83 percent of the contents by volume, and 31 percent of the fish were young sockeye. Ricker (1941) stated that young sockeye were an important food of predators in Cultus Lake, British Columbia. Predatory species included northern squawfish, Dolly Varden (Salvelinus malma), cutthroat trout (Salmo clarki), young coho salmon (O. kisutch), and sculpins (Cottus spp.). In general, consumption of young sockeye was proportional to their abundance. Predators consumed other foods in greater proportion in years when sockeye were scarce. Foerster (1944) reported that reduction in numbers of predator fish by gill netting in Cultus Lake resulted in an appreciably higher capacity for sockeye. More specifically, Foerster and Ricker (1941) found that reduction of predators by persistent gill netting in the lake increased survival of sockeye 3-1/3 times over prior average survival.

LOCATION AND DESCRIPTION OF STUDY AREA

Kitoi Bay, on Afognak Island, was chosen as the study area, primarily because it was near several lakes, which range between 5.2 and 144 hectares in surface area (fig. 1, table 1). Only one of these, Little Kitoi Lake, has a natural run of salmon. Big Kitoi Lake contains a few landlocked sockeye (kokanee). These fish are evidence that the lake, which is impassable to upstream migration of fish because of two major falls in the outlet stream,

Table 1.--Surface area, volume, and depth of lakes in the vicinity of the Alaska Department of Fish and Game Kitoi Bay Research station

[Present studies limited to Little Kitoi, Ruth, and Midarm Lakes]

Lake	Surface area	Volume	Average depth	Maximum depth
	Ha.	$M.^3$	M.	M.
Little Kitoi	38.6	4.174×10^7	10.8	26.8
Ruth........	19.2	1.245×10^7	6.2	17.1
Midarm......	5.2	0.340×10^7	6.6	12.2
Upper Jennifer..	40.7	4.348×10^7	10.7	26.5
Lower Jennifer..	17.9	1.811×10^7	10.1	26.2
Big Kitoi[1]..	144.1	--	--	--

[1] The volume and depth of Big Kitoi Lake have not been determined.

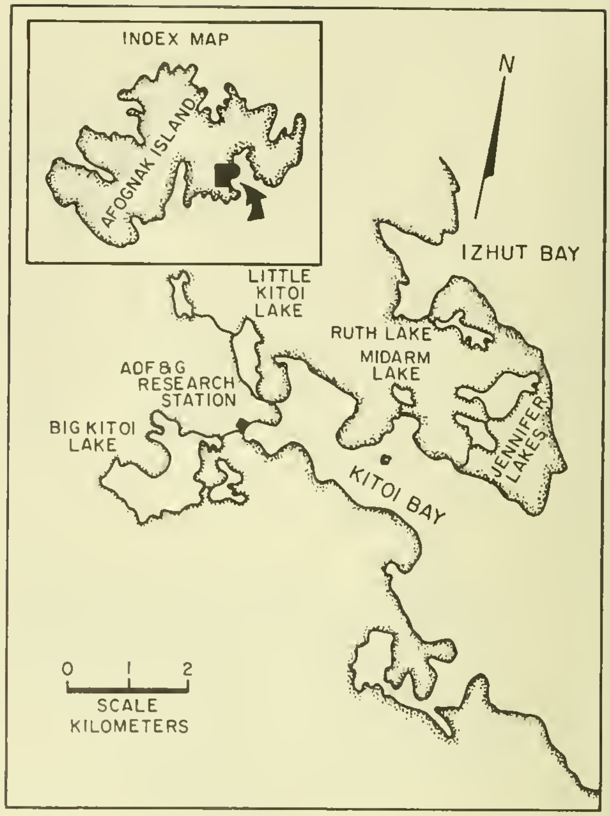

Figure 1.--Kitoi Bay area, Alaska, showing location of Research Station of Alaska Department of Fish and Game and lakes where young sockeye were studied.

was once accessible to anadromous fishes. The remaining lakes in the area have no salmon because of barriers to spawning or the absence of suitable spawning conditions. The lakes are all within a few miles of the research station and are accessible by skiff and overland trails.

Kitoi Bay is on the southeast coast of Afognak Island, about 48 km. (kilometers) north of the City of Kodiak, Kodiak Island. The coastal fringe is for the most part low--generally less than 150 m. (meters) above sea level. It is covered with a dense growth of Sitka spruce (Picea sitchensis) and an undergrowth, primarily devil's club (Oplopanax horridus), huckleberry (Vaccinium sp.), and salmonberry (Rubus spectabilis). A few alders (Alnus tenuifolia) grow on the steeper slopes and along the creek banks and deltas. The forest floor and the crotches and larger limbs of the spruce trees are heavily matted with sphagnum moss. Growth of the moss was stimulated by a 10- to 15-cm. (centimeter) layer of pumice that was spewed over the adjacent mainland and islands in 1912 during the eruption of Mt. Katmai (located on the mainland of the Alaska Peninsula about 120 km. west of Kitoi Bay). This pumice layer is readily observed in the shallow areas of the lakes as well as in the terrestrial environment, and bottom sampling has shown that the pumice is also evident at depths of 26.8 m.

The climate of the area is moderated by the Japanese Current, and the average annual precipitation of about 152 cm. is fairly evenly distributed throughout the year (Capps, 1937).

Dissolved oxygen concentrations are sufficient to sustain fish life at all times. For a few days in the early spring, concentrations at the lake bottoms may be slightly less than 3.0 p.p.m. (parts per million), the figure generally accepted as necessary for fish. Values normally range from about 14.0 p.p.m. at the surface in June to about 11.0 p.p.m. at the surface in January (Parker and Vincent, 1956). During the spring and fall overturns (generally in May and October), sufficient oxygen is circulated to the lower depths of the lakes to sustain fish through the summer and winter stagnation, when the formation of a thermocline or an ice cover prevents circulation of oxygen-rich surface waters to the depths.

Three lakes were selected for study. Little Kitoi Lake furnished the brood stock for planting the other lakes and also served as one of the control lakes. Besides runs of sockeye, coho, and pink salmon (O. gorbuscha), this lake maintains populations of threespine sticklebacks (Gasterosteus aculeatus), Dolly Varden, sculpins, and a small number of rainbow trout (Salmo gairdneri). Midarm Lake, the second control lake, maintains populations of sticklebacks and Dolly Varden. Ruth Lake was the experimental lake. It also contains sticklebacks and Dolly Varden.

METHODS

Weirs with traps and holding boxes were built at the outlets of all three lakes to facilitate accurate counting and sampling of downstream migrants.

During the summer of 1955 an application of 5 percent rotenone killed resident fish populations in Ruth Lake. A complete kill apparently resulted because no fish other than the introduced sockeye have been observed since the treatment.

Beginning in the fall of 1955, sockeye eggs were taken from beach-spawning sockeye in Little Kitoi Lake, fertilized, and placed in a hatchery for incubation and rearing. Early in July 1956, the first resulting fry were released in Midarm and Ruth Lakes. Fry were reared in the hatchery and released yearly in Ruth Lake until 1960; however, because of a lack of sufficient brood stock to incubate experimental eggs, no fry were released in Midarm Lake after 1956. The number of fry released each year and the density per surface acre are shown in table 2.

All fry releases from the Kitoi hatchery were made as soon as the yolk sacs were

Table 2.--Number and density per surface hectare of hatchery-reared sockeye fry from Little Kitoi Lake stock released in Midarm and Ruth Lakes, 1956-60

Year of release	Fry released		Fry per surface hectare	
	Midarm Lake	Ruth Lake	Midarm Lake	Ruth Lake
	Number	Number	Number	Number
1956.....	80,000	89,000	15,000	4,640
1957.....	--	66,000	--	3,440
1958.....	--	110,000	--	5,730
1959.....	--	50,000	--	2,600
1960.....	--	425,000	--	22,140

absorbed and the fish were ready to feed naturally. Each year some hatchery feeding was required before all of the fry were ready for simultaneous release. Foerster (1925) reported that other investigations have shown that only a few sockeye migrate to sea as fry; he considered this behavior when he proposed that fry be released from hatcheries into fresh water as soon as possible.

The 1958 plant offered an exception to the release of fry from Little Kitoi stock into Ruth Lake. In that year, to test the effect of increased fry planting on smolt production, and because only 55,000 fry were available from Little Kitoi Lake, 55,000 fry from Hugh Smith Lake near Ketchikan were added to provide a total release of 110,000 into Ruth Lake. Sockeye from Hugh Smith Lake were similar to those from Little Kitoi in that both races spawned in early October and both spawning lakes are adjacent to salt water. Hugh Smith Lake lies at about lat. 55° N. in Southeastern Alaska, and Little Kitoi Lake lies at lat. 58° N.

Salmon Smolts

During their seaward migration from the lakes, all sockeye smolts were counted, and at least 100 were measured (fork length) each day. They were anesthetized (during the early years of the study with urethane and later with tricaine methanesulfonate, MS 222) and placed on millimeter graph paper with the tip of the nose set on the zero line. A pin prick at the end of the midline of the caudal fin recorded the length (fig. 2). Anesthetized fish recovered in a holding pen and were then released into the outlet below the weir.

Smears of smolt scales were placed on glass microscope slides. During each week of the downstream migration, scales were sampled from 10 smolts in each 5-mm. (millimeter) size class, or from all smolts in size groups that did not contain more than 10 fish.

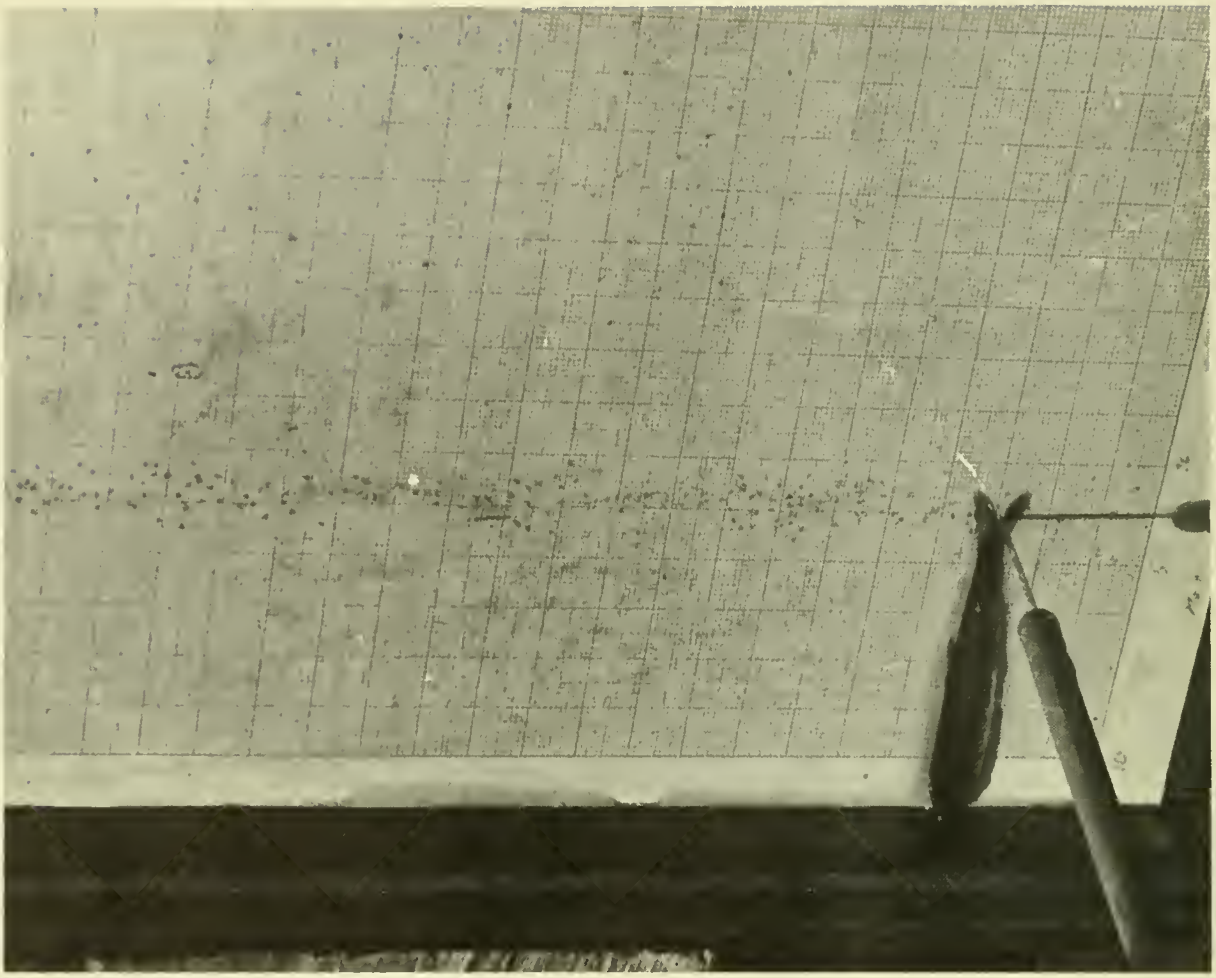

Figure 2.--Method of measuring fork length of sockeye smolts by pricking graph paper. Margin of graph paper from headboard is 10 mm.

Originally, a drop of clear Karo syrup[1] was used as an adhesive agent for the slides, but the natural mucus from the scales proved to be a better adhesive.

Scales were examined to determine growth and age composition so that brood year (year egg is fertilized) and the amount of hold-over in the lakes could be determined. The scale-reading machine gave an image with variable magnification. Ages were recorded as 1-check (or annulus), 2-check, or 3-check, depending upon the number of annular growth bands shown by the spacing of the circuli. Generally, smolts from Little Kitoi Lake departing in the spring with 1, 2, or 3 checks, and referred to as 1-, 2-, or 3-yr.-old fish, had been spawned about 20, 32, or 44 mo. (months) previously.

To compute condition factors, samples of about 30 smolts were taken from Ruth and Little Kitoi Lakes each week during the 1962 migration, transported to the laboratory in 2-l. (liter) polyethylene bags, and measured and weighed individually to the nearest millimeter and the nearest 0.1 g. (gram).

Stomachs of fish collected to determine condition factors were examined for food contents with the aid of a dissecting microscope. Organisms were identified to the lowest taxonomic group possible--often determined by the state of digestion of the organisms.

Biological Environment

No detailed plankton studies were made on Ruth Lake before it was treated in 1955. During the 1955 field season, a few plankton tows were made in various lakes in the Kitoi Bay area. Tows were made at comparable depths for a standard towing time with a 20-mesh Wisconsin net. The plankton was allowed to settle in a 55-cm.^{3} (cubic centimeter) bottle

[1]Trade names referred to in this publication do not imply endorsement of commercial products.

10 min. (minutes) for comparison of volumes of plankton.

The growth of periphyton was studied in 1956, 1957, and 1958, (Smoker, 1957, 1958, 1960). A different substrate was used each year in an attempt to discover a technique that would best facilitate handling and processing of the substrate and attached growths. During 1956 standard glass microscope slides served as collecting bases; a series of slides was strung together to cover the desired range of depths. In 1957 the microscope slides were replaced by a series of 15.2-cm.^{2} glass plates. In 1958 solid glass rods about 1.2 m. long and 12 mm. in diameter were tied end to end and suspended from moored buoys. Each rod had a total area of about 400 cm.^{2}. Each year the substrate was left untouched for 60 days in each lake. This period was selected because tests run during 1956 showed that 60 days were needed for the growth to be great enough to measure.

Throughout the 1961 field season, samples of bottom fauna were taken with a 15.2-cm.^{2} Ekman dredge from shoal and deep areas in Little Kitoi and Ruth Lakes. Shoal samples were from about 1.2 m. depths; deep samples were from the vicinity of maximum depth in each lake--26.8 m. in Little Kitoi Lake and 17.1 m. in Ruth Lake (table 1). The material was preserved in formol alcohol (equal parts of 5 percent Formalin and 70 percent ethyl alcohol) and later was sorted. The organisms were identified and counted, and the wet weight of each sample was recorded (each sample was blotted 1 min. and then weighed on an analytical balance to the nearest milligram). These data were transferred to IBM cards for tabulation and summarization.

GROWTH AND SURVIVAL OF SOCKEYE

The results of this study encompass several aspects of the life of sockeye in fresh water. The timing of migrations and the apparent effects of lake rehabilitation on survival, growth, and condition are considered in the subsections that follow.

Migration of Smolts

The numbers of all species of downstream migrants taken at the Little Kitoi Lake weir from 1955 to 1963 are shown in table 3. Migrations of sockeye, coho, and Dolly Varden changed little, although they were slightly higher in the later years of the study. Migrations of sticklebacks and sculpins especially decreased sharply throughout the study. This reduction most probably is the result of installation of the weir; no sticklebacks or sculpins have gained access to the lake from salt water since the weir was installed in 1955. The salmonids have not been deterred by the weir because they are able to gain access to an upstream weir section by means of an aluminum Denil-type fish pass and are then passed into the lake by hand.

In general, the peak migration from Little Kitoi Lake was 1 to 2 wk. (weeks) earlier for 2-annulus smolts than for 1-annulus (table 4, fig. 3). The peak migrations of 1- and 2-annulus smolts from Ruth Lake occurred about the same time (table 4, fig. 4). The peak migrations of 1- and 2-check smolts were usually 1 or 2 wk. later from Ruth Lake than from Little Kitoi Lake. The migrations from Little Kitoi Lake tended to peak a few days later as the years progressed, whereas those from Ruth Lake remained fairly consistent (table 4). The single year class of fry released in Midarm Lake departed as 1-check smolts at the same time as the 1-check smolts from Ruth Lake, and as 2-check smolts about the same time as the 2-check smolts from Little Kitoi Lake (table 4).

As shown in table 4 and figure 3, the downstream migration from Little Kitoi Lake in 1956 was unusual. The migration of 1-check smolts in 1956 had two separate peaks. The first and major one was almost a month earlier than the average for the other years, whereas the second peak was about 3 wk. later. In the

Table 3.--Downstream migrants taken at Little Kitoi Lake weir, 1955-63

Year	Sockeye salmon	Coho salmon	Dolly Varden	Sticklebacks	Sculpins
	Number	Number	Number	Number	Number
1955............	28,660	3,535	1,085	822	213
1956............	51,000	4,545	741	2,448	81
1957............	35,457	4,104	758	451	22
1958............	27,081	1,935	289	983	3
1959............	29,216	3,277	431	629	11
1960............	19,875	5,420	896	330	17
1961............	36,842	4,836	756	655	1
1962............	60,194	4,485	565	304	1
1963............	49,233	5,916	987	67	0

Table 4.--Peak periods of migration of 1- and 2-annulus sockeye salmon smolts from Little Kitoi, Ruth, and Midarm Lakes, 1955-63

Year of migration	Little Kitoi Lake		Ruth Lake		Midarm Lake	
	1-annulus smolts	2-annulus smolts	1-annulus smolts	2-annulus smolts	1-annulus smolts	2-annulus smolts
1955........	June 10-14	June 5-9	--	--	--	--
1956........	May 6-10	June 15-19	--	--	--	--
1957........	May 31 to June 4	May 31 to June 4	June 5-9	--	June 5-9	--
1958........	June 10-14	May 26-30	June 25-29	June 25-29	--	May 21-25
1959........	May 31 to June 4	May 26-30	June 10-14	June 10-14	--	--
1960........	June 5-9	June 5-9	June 15-19	May 31 to June 4	--	--
1961........	June 5-9	May 26-30	June 10-14	June 30 to July 4	--	--
1962........	June 10-14	June 5-9	--	June 10-14	--	--
1963........	June 5-9	May 26-30	--	--	--	--

early migration 41,000 of the 50,000 1-check migrants were stunted fish that averaged about 39 mm. fork length. The later group of 1-check migrants had an average length of 61 mm. The cause of this atypical condition (small size of smolts and earlier migration) is not known. The peak of the migration of 2-check smolts in 1956 was also considerably later than average. Smoker (1957), who reported this unusual migration, called attention to the severe winter of 1955-56 and noted that the ice cover was three times as thick as in the previous 2 winters and that the lake had been covered with both ice and snow more than 7 mo.

Survival

Exact comparisons of estimates of survival among the three study lakes are not possible because the available estimates are based on the egg-to-smolt stage for Little Kitoi Lake and on the fry-to-smolt stage for Ruth and Midarm Lakes. I can, however, make rough comparisons by assuming an arbitrary rate of survival from the egg-to-fry stage for Little Kitoi Lake and calculating a fry-to-smolt survival from the result. In this section I discuss my estimates of survival in the egg-to-smolt stage in Little Kitoi Lake and the fry-to-smolt stage in Ruth and Midarm Lakes with similar estimates from the literature; I present also my calculations of the fry-to-smolt survival in Little Kitoi Lake when an arbitrary figure is assumed for the egg-to-fry survival.

Fry-to-smolt stage, Midarm and Ruth Lakes.--Survival to the smolt stage of fry from the 1955 brood year of Little Kitoi Lake, released in Midarm Lake in 1956 (table 2), was 3.6 percent (table 5)--lower than the survival for Ruth Lake in any year of the study. In Cultus Lake, Foerster (1938a, 1938b) found the average survival to the smolt stage of introduced fry to be 3.24 percent. He attributed the high mortality to predation. Foerster and Ricker (1941) reported a survival of introduced fry of 13.05 percent after partial removal of predator fishes by gill netting, as compared with an average survival of 4.16 percent before gill netting. In Port John Lake, British Columbia, for the 1955 fry that migrated in 1956 and 1957, an estimated fry-to-smolt survival of 80 percent is reported, indicating a low level of predation (Fisheries Research Board of Canada, 1958). Survival to the smolt stage of fry introduced into Ruth Lake ranged from 7.3 to 46.9 percent (table 5, fig. 5). The removal of the resident fish populations probably accounted for these higher figures. Because there is only 1 yr.'s estimate for Midarm Lake, it is not considered further in this discussion.

Egg-to-smolt stage, Little Kitoi Lake.--Survival rates for potential egg deposition to the smolt stage in Little Kitoi Lake ranged from 2.0 to 8.5 percent (table 5) and are comparable to figures obtained during certain other investigations. For instance, Holmes (1934) estimated a survival of 1 percent from egg to smolt in Karluk Lake. In three separate studies in Cultus Lake, Foerster estimated egg-to-smolt survivals of 1.13 percent (1934), 2.5 percent (1936), and 1.80 percent (1938a). Brett and McConnell (1950) estimated an egg-to-smolt survival of 0.4 to 1.1 percent for sockeye in Lakelse Lake. Over a 7-yr. period in the Lakelse Lake system, the average survival from egg to smolt was 1.4 percent (Fisheries Research Board of Canada, 1956). Over a 6-yr. period in the Babine Lake system of the Skeena River area, British Columbia, the survival from egg to smolt was 0.49 to 2.49 percent (Fisheries Research Board of

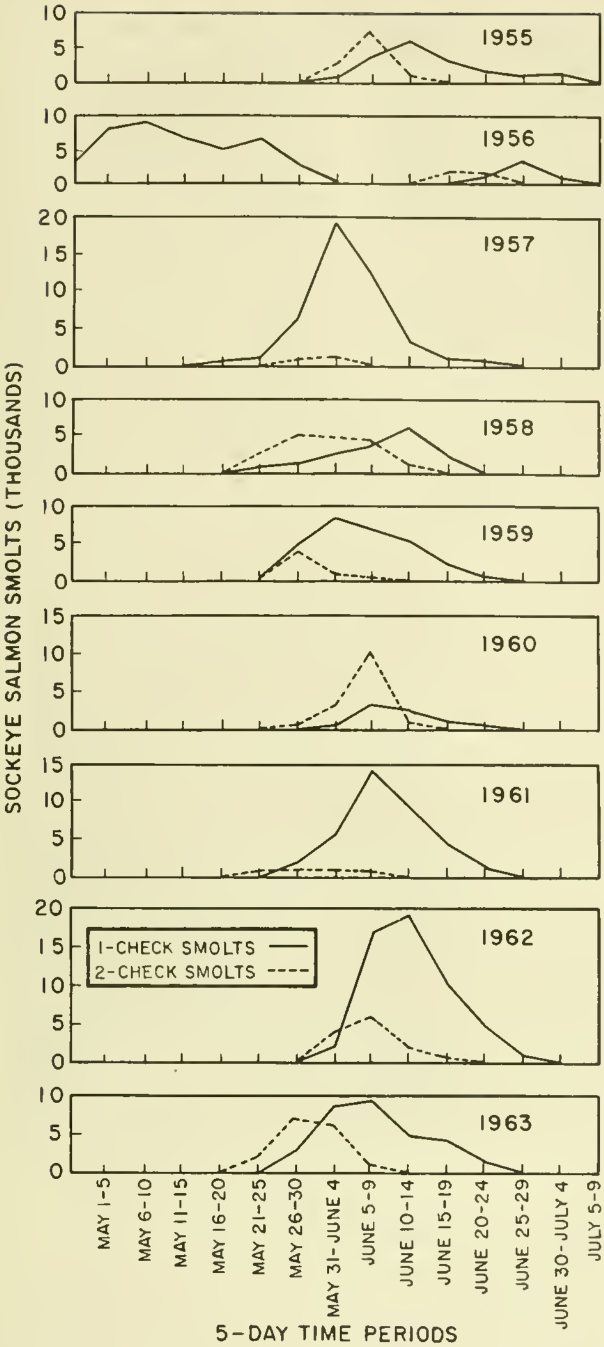

Figure 3.--Timing of migrations of 1- and 2-annulus sockeye salmon smolts from Little Kitoi Lake, 1955-63. Data grouped by 5-day periods.

Canada, 1957). In 1957, the egg-to-smolt survival in the Babine Lake system was 6.1 percent (Fisheries Research Board of Canada, 1958).

Fry-to-smolt stage, Little Kitoi Lake, assuming 30-percent egg-to-fry survival.--The fry-to-smolt survival that would result in

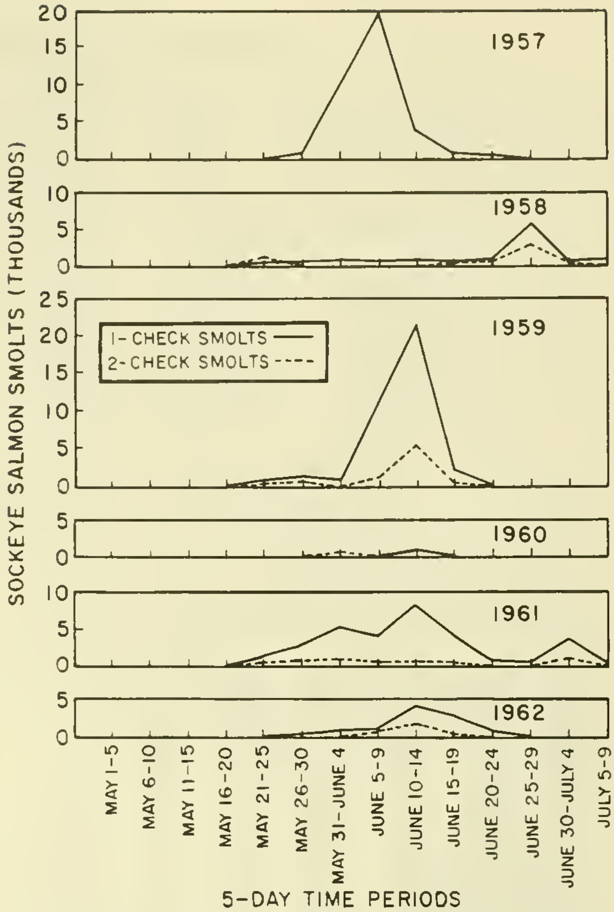

Figure 4.--Timing of migrations of 1- and 2-annulus sockeye salmon smolts from Ruth Lake, 1957-62. Data grouped by 5-day periods.

Little Kitoi Lake, if the average egg-to-fry survival is arbitrarily assumed to be 30 percent, is shown in table 6. It is highly probable that the average egg-to-fry survival could be even higher than 30 percent, which would reduce the figures on fry-to-smolt survival correspondingly. Although most studies in other areas have generally demonstrated less than 10 percent survival from egg to fry, these studies have been on stream-spawning populations. Little Kitoi Lake sockeye spawn almost entirely on lake beach sites. Data on potential egg-to-fry survival in natural beach spawning sockeye populations are not available, primarily because beach spawning areas are difficult to sample. The most comparable data are those of Quistorff (1962 and personal communication) in which survival at the Baker Lake artificial spawning beach averaged about 65 percent over a 4-yr. period. This survival in a beach incubation situation indicates that the 30-percent egg-to-fry survival assumed for Little Kitoi Lake may be conservative.

Table 5.--Number of migrants and percentage survival by age groups of sockeye smolts in migrations from Little Kitoi, Ruth, and Midarm Lakes, 1954-59 brood years

Brood year	Potential egg deposition[1]	Fry released	Smolts in migration							Survival egg-to-smolt stage	Survival fry-to-smolt stage[2]
			1-check		2-check		3-check		Total		
	Number	Number	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Percent
	Little Kitoi Lake										
1954...	2,300,000	--	50,000	97.3	1,257	2.4	153	0.3	51,410	2.2	7.3
1955...	2,000,000	--	34,200	78.3	9,452	21.7	3	0	43,655	2.2	7.3
1956...	515,000	--	17,476	80.7	4,122	19.0	54	0.3	21,652	4.2	14.0
1957...	442,000	--	25,091	66.6	12,581	33.4	2	0	37,674	8.5	28.3
1958...	250,000	--	7,240	70.7	3,000	29.3	0	0	10,240	4.1	13.7
1959...	2,226,000	--	33,840	76.6	10,304	23.3	36	0.1	44,180	2.0	6.7
	Ruth Lake										
1955...	--	89,000	31,407	75.3	8,641	20.7	1,667	4.0	41,715	--	46.9
1956...	--	66,000	9,329	61.6	5,761	38.0	59	0.4	15,149	--	23.0
1957...	--	110,000	33,733	91.9	705	1.9	2,271	6.2	36,709	--	33.4
1958...	--	50,000	841	23.0	2,637	72.0	183	5.0	3,661	--	7.3
1959...	--	425,000	28,811	81.3	6,506	18.4	108	0.3	34,425	--	8.3
	Midarm Lake										
1955...	--	80,000	1,142	39.7	1,725	60.0	10	0.3	2,877	--	3.6

[1] Based on average number of eggs per female.
[2] Estimated on basis of a 30-percent survival from egg to fry; see table 6 and later discussion for details.

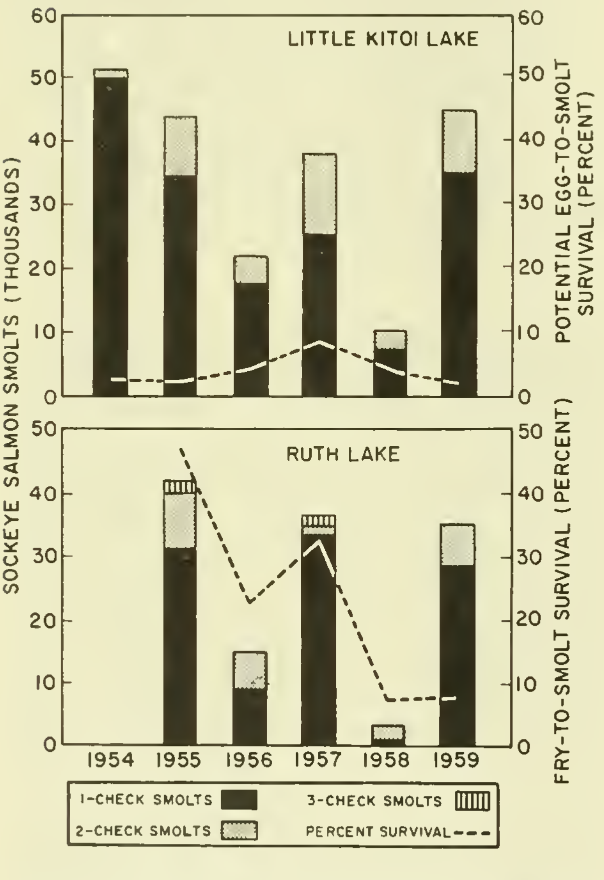

Figure 5.--Magnitude of migrations and percentage survival of sockeye salmon to smolt stage by brood year, Little Kitoi and Ruth Lakes, 1954-59.

The fry-to-smolt survival in Little Kitoi Lake would have ranged from a low of 5 percent for the 1961 brood year to a high of 28 percent for the 1957 brood year (table 6). For the same brood years 1955-59, the assumed unweighted average fry-to-smolt survival for Little Kitoi Lake would be 14 percent. This is considerably less than the actual unweighted average fry-to-smolt survival in Ruth Lake of 24 percent. If the assumed egg-to-fry survival in Little Kitoi Lake was actually greater than 30 percent, then the fry-to-smolt survival would be less than 14 percent, and Ruth Lake would appear to have provided an even greater survival for rearing juvenile sockeye.

Relation of Population Density to Survival

Survival to the smolt stage of fry planted in Ruth Lake was considerably lower in 1959 and 1960 (1958 and 1959 brood years) than in earlier years (table 5). The plant of only 50,000 in 1959 resulted in the lowest survival (as well as the greatest percentage of holdover) throughout the study. The environment may have had an adverse effect on this particular plant, or the relatively large number of fingerlings in the lake from the plant of 110,000 fry in 1958 may have depressed the survival of the 1959 plant. The relatively low survival of the heavy 1960 stocking (425,000 fry) may have been the result of overstocking, but this relation cannot be proved because of the still lower survival of the 1958 plant.

Table 6.--Fry-to-smolt survival estimated on basis of 30-percent survival from potential egg deposition to fry stage, Little Kitoi Lake, 1954-61 brood years

Brood year	Potential egg deposition	Fry produced	Fry per hectare	Smolts produced	Smolts per hectare	Fry-to-smolt survival
	Number	Number	Number	Number	Number	Percent
1954...............	2,300,000	690,000	17,870	51,500	1,330	7
1955...............	2,000,000	600,000	15,540	43,700	1,130	7
1956...............	515,000	154,500	4,000	21,700	560	14
1957...............	442,000	132,600	3,430	37,700	980	28
1958...............	250,000	75,000	1,940	10,200	270	14
1959...............	2,226,000	667,800	17,300	44,200	1,140	7
1960...............	1,466,000	439,800	11,390	66,700	1,730	15
1961...............	3,078,000	923,400	23,920	[1]42,400	1,100	5

[1] Probable total, based on average of 1- to 2-annulus smolt ratio during study.

In general, the estimated survival in Little Kitoi Lake from egg to smolt was inversely correlated with the potential egg deposition, and hence with the potential number of fingerlings in the lake: survivals to the smolt stage were about 2 percent for years when the estimated egg deposition was more than 2 million (1954, 1955, and 1959 brood years), and 4 to 8 percent for the years when potential egg deposition was 1/4 to 1/2 million (1956-58 brood years--see table 5).

The larger fry plantings in Ruth Lake resulted in a higher percentage of yearling migrants and less holdover in the lake (table 5, fig. 6). As shown in table 2, the two heaviest plants (5,730 fry per surface hectare in 1958 and 22,140 in 1960) resulted in the greatest percentage migration of the resulting smolts as yearlings; the two intermediate plants (4,640 fry per hectare in 1956 and 3,440 in 1957) yielded proportionally fewer yearling migrants; and the smallest plant (2,600 fry per hectare in 1959) resulted in the greatest holdover--the smallest percentage of migrants as yearlings (table 5, fig. 6).

The plant of about 15,000 fry per hectare in Midarm Lake in 1956 (table 2) resulted in a migration of 39.7 percent of the smolts as yearlings and a holdover for an additional year of 60.0 percent of the migrants (table 5). Ten fish (0.3 percent of the total) migrated from the lake after a residence of 3 summers.

A similar comparison in Little Kitoi Lake does not show such well-defined correlations (table 5, fig. 6). The difference is probably to some degree apparent and due to the lack of data on potential egg-to-fry survival.

Curves representing the number of smolts produced per hectare in Little Kitoi and Ruth Lakes from various fry-recruitment densities are shown in figure 7. Again a 30-percent average egg-to-fry survival is arbitrarily

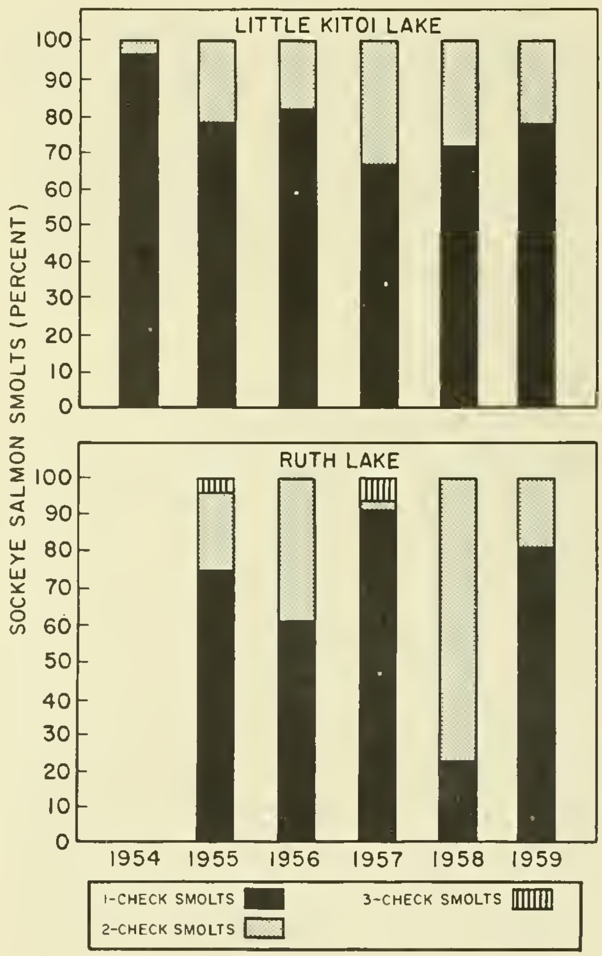

Figure 6.--Age composition of migrating sockeye smolts by brood year, Little Kitoi and Ruth Lakes, 1954-59 brood years.

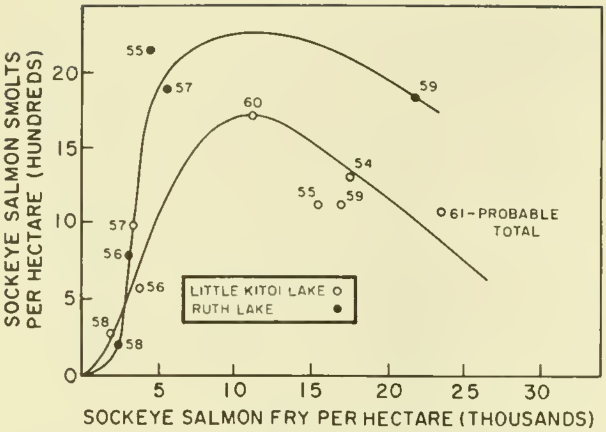

Figure 7.--Production of sockeye smolts resulting from various fry densities, Little Kitoi and Ruth Lakes, 1955-61 brood years.

assumed for Little Kitoi Lake. The shape of the curve for Little Kitoi Lake would not differ greatly from that of the curve for Ruth Lake even if the average egg-to-fry survival were actually much greater or much less than 30 percent. The maximum probably would still occur near the 5,000-fry recruitment. Hence, it appears that in both lakes the optimum density of fry, in terms of numbers of smolts produced, is about 12,400 per surface acre (I assume that the low survival of the 1960 plant in Ruth Lake was due to overstocking).[2]

Growth

The first seaward migration of sockeye smolts from Ruth Lake occurred in 1957 as a result of the fry introduced in 1956. These fish averaged 101 mm., fork length. The corresponding age group of smolts migrating from Little Kitoi Lake averaged 63 mm. (table 7), and those from Midarm Lake averaged 72 mm. (table 8). Table 7 compares the average size of smolts of various age groups from the fry plants from Ruth Lake in 1956-60 with the corresponding smolts from the naturally maintained stock in Little Kitoi Lake. Figure 8 shows the average length of smolts of all ages of each brood year from Ruth and Little Kitoi Lakes. Figure 9 shows a similar comparison based on the year of downstream migration rather than the parent brood year. This latter comparison is more suitable for studying the effects of environment. Annual fluctuations in the size of 1- and 2-check smolts are similar, but fluctuations in the size of 3-check smolts are almost directly the opposite of those of the two younger age groups. The number of 3-annulus smolts each year is small, however. The fact that in each of these two lakes the two age groups that make up the bulk of the migration each year follow the same general annual growth fluctuations suggests that the environment, as well as density of fish, plays an important part in determining growth.

The density or potential density of fry in the lakes was correlated with the size of resultant smolts in both lakes (fig. 10). The highest fry releases into Ruth Lake and the largest potential egg deposition in Little Kitoi Lake resulted in the smallest smolts of all ages, and vice versa. The single exception was offered by 3-check smolts resulting from the release of the 1959 brood year into Ruth Lake. This release, the largest in the lake, produced the largest 3-check smolts. The fry release of 1960 (1959 brood year) was the last, however, into Ruth Lake until 1963; as a result, fry that remained for 3 yr. in the lake before migrating had ideal conditions for growth during their third growing season. Only 108 smolts left Ruth Lake after 3 growing seasons, and these fish, discounting any permanent holdover as kokanee, had the entire lake to themselves during the last year--about five fish per hectare.

Smolts resulting from the fry release of 1956 in Midarm Lake had sizes generally comparable to those of smolts of similar age from Little Kitoi Lake (tables 7 and 8).

Further information on growth is supplied by the mean number of circuli laid down by juvenile sockeye in Little Kitoi and Ruth Lakes during each year of the study (tables 9 and 10; fig. 11). Smolts from Ruth Lake laid down an average of about 50 percent more circuli than did smolts from Little Kitoi Lake (table 11). The spring growth of smolts, as measured by numbers of circuli, was over 100 percent greater in Ruth Lake than in Little Kitoi Lake.

In both lakes, the mean number of circuli laid down in the spring was considerably smaller in fish that had spent 1 or 2 additional years in lake residence; the 2-annulus smolts had fewer spring circuli than had the 1-annulus smolts, and 3-annulus smolts had fewer spring circuli than had the 2-annulus smolts.

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[2] As the final work on this manuscript is being done, the migration of 1-annulus sockeye smolts from one further fry release into Ruth Lake is almost completed. In 1963, 250,000 sockeye fry (of the 1962 brood year) were released in Ruth Lake--a density of about 13,000 fry per hectare. By fall 1964, after the downstream migration of smolts resulting from this fry release was complete, 88,880 smolts had passed through the weir. The migration of 88,880 as 1-annulus smolts indicates a minimum survival from fry-to-smolt stage of 36 percent, or about 4,630 smolts per surface hectare. As shown in figure 7, this production is far above the top of the hypothetical curve and coincides with the level of optimum fry density in terms of smolt production as reflected by the Ruth Lake experiments.

Table 7.--Mean fork length and mean size difference of sockeye smolts by age group from Ruth and Little Kitoi Lakes, 1954-59 brood years

Brood year and age group	Fork length of smolts		Mean size difference	
	Ruth Lake	Little Kitoi Lake		
	Mm.	Mm.	Mm.	Percent
1954				
1-check	--	43	--	--
2-check	--	71	--	--
3-check	--	86	--	--
Brood year mean	--	44	--	--
1955				
1-check	101	63	38	59
2-check	137	78	59	57
3-check	138	83	55	60
Brood year mean	110	67	43	61
1956				
1-check	113	74	39	66
2-check	121	77	44	63
3-check	135	93	42	69
Brood year mean	116	75	42	64
1957				
1-check	98	71	27	72
2-check	135	81	54	60
3-check	142	110	32	78
Brood year mean	102	74	28	73
1958				
1-check	119	75	44	63
2-check	130	83	47	64
3-check	145	--	--	--
Brood year mean	125	77	48	62
1959				
1-check	88	58	30	66
2-check	114	67	47	58
3-check	157	104	53	66
Brood year mean	93	60	44	63

Table 8.--Mean fork length of sockeye smolts by age group, Midarm Lake, 1955 brood year

Age group	Fork length
	Mm.
1-check	72
2-check	90
3-check	90
Brood year mean	83

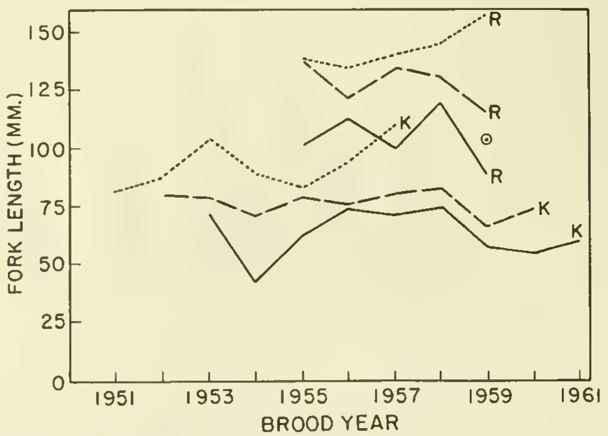

Figure 8.--Average fork length of sockeye smolts of various ages by brood year, Little Kitoi and Ruth Lakes, 1951-61 brood years. Solid lines, long dashes, and short dashes indicate 1-, 2-, and 3-check smolts, respectively. Circled dot is for 3-check smolts in Little Kitoi Lake.

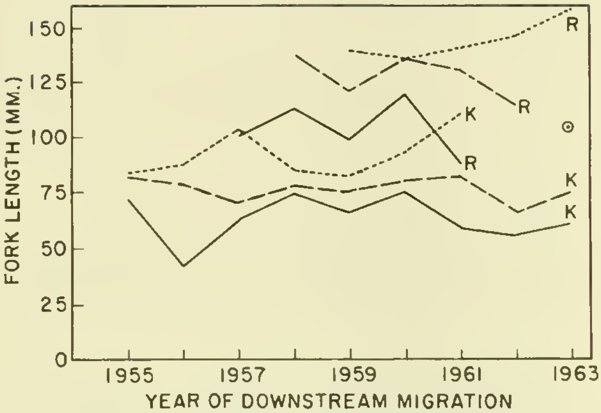

Figure 9.--Average fork length of sockeye smolts of various ages by year of downstream migration, Little Kitoi and Ruth Lakes, 1955-63. Solid lines, long dashes, and short dashes indicate 1-, 2-, and 3-check smolts, respectively. Circled dot is for 3-check smolts in Little Kitoi Lake.

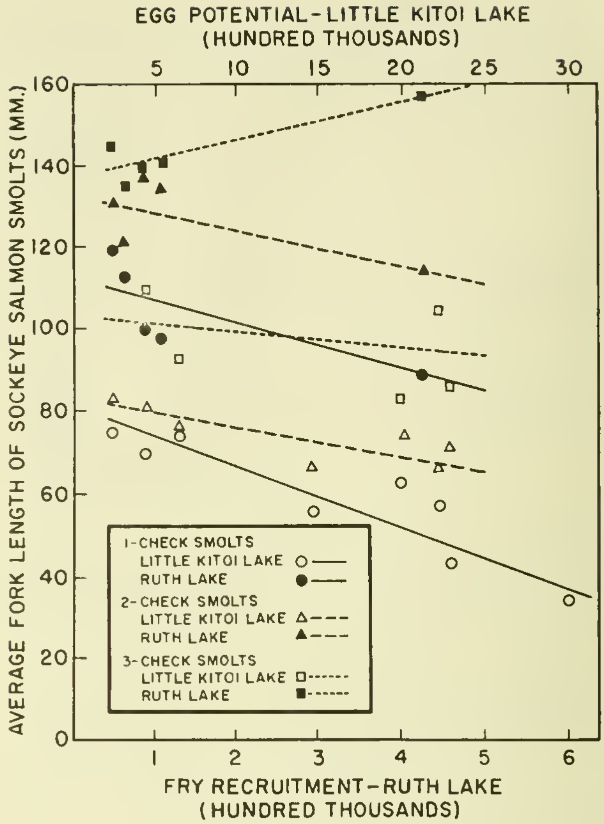

Figure 10.--Average fork length of sockeye smolts resulting from various fry-recruitment densities, Little Kitoi and Ruth Lakes, 1954-61 brood years.

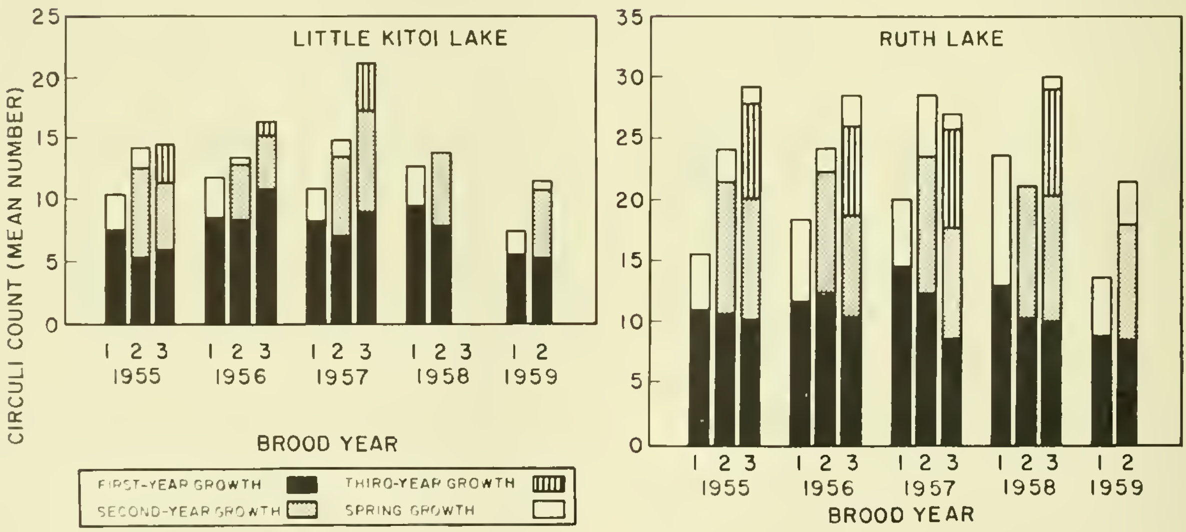

Figure 11.--Mean number of circuli laid down by sockeye smolts of various age groups by brood year, Little Kitoi and Ruth Lakes, 1955-59 brood years. The numbers 1, 2, and 3 above brood year dates indicate the age of smolts, i.e., 1, 2, and 3 annuli.

Table 9.--Mean number of circuli laid down by sockeye smolts of various age group from Little Kitoi Lake, 1955-59 brood years

[Figures in parentheses indicate spring growth]

Brood year and age group	Mean number of circuli during growing season							Total
	1956	1957	1958	1959	1960	1961	1962	
1955								
1-check..........	7.8	(2.7)	--	--	--	--	--	10.5
2-check..........	5.4	7.1	(1.6)	--	--	--	--	14.1
3-check..........	6.0	5.5	3.0	(0)	--	--	--	14.5
1956								
1-check..........	--	8.6	(3.4)	--	--	--	--	12.0
2-check..........	--	8.2	4.7	(0.2)	--	--	--	13.2
3-check..........	--	5.3	5.5	4.5	(0.8)	--	--	16.0
1957								
1-check..........	--	--	8.1	(2.8)	--	--	--	10.9
2-check..........	--	--	7.0	6.5	(1.0)	--	--	14.5
3-check..........	--	--	9.0	8.0	4.0	(0)	--	21.0
1958								
1-check..........	--	--	--	9.6	(3.2)	--	--	12.7
2-check..........	--	--	--	7.8	5.8	(0)	--	13.6
3-check..........	--	--	--	--	--	--	--	--
1959								
1-check..........	--	--	--	--	5.6	(1.5)	--	7.1
2-check..........	--	--	--	--	4.9	5.9	(0.4)	11.2
Mean								
1-check..........	7.94	(2.7)	--	--	--	--	--	10.6
2-check..........	6.7	6.0	(0.7)	--	--	--	--	13.3
3-check..........	6.8	6.3	3.8	(0.3)	--	--	--	17.2

Table 10.--Mean number of circuli laid down by sockeye smolts of various age groups from Ruth Lake, 1955-59 brood years

[Figures in parentheses indicate spring growth]

Brood year and age group	Mean number of circuli during growing season							Total
	1956	1957	1958	1959	1960	1961	1962	
1955								
1-check..........	11.3	(4.5)	--	--	--	--	--	15.8
2-check..........	10.8	10.9	(2.6)	--	--	--	--	24.3
3-check..........	10.4	10.1	7.6	(1.2)	--	--	--	29.2
1956								
1-check..........	--	12.0	(6.7)	--	--	--	--	18.6
2-check..........	--	12.7	9.9	(1.9)	--	--	--	24.4
3-check..........	--	10.8	8.2	7.3	(2.2)	--	--	28.5
1957								
1-check..........	--	--	14.9	(5.2)	--	--	--	20.2
2-check..........	--	--	12.7	11.1	(4.9)	--	--	28.8
3-check..........	--	--	9.1	9.1	8.0	(1.1)	--	27.3
1958								
1-check..........	--	--	--	13.4	(10.6)	--	--	23.9
2-check..........	--	--	--	10.7	10.7	(2.4)	--	23.8
3-check..........	--	--	--	10.6	10.1	8.5	(1.1)	30.2
1959								
1-check..........	--	--	--	--	9.2	(5.0)	--	14.2
2-check..........	--	--	--	--	8.9	9.6	(3.1)	21.5
Mean								
1-check..........	12.1	(6.4)	--	--	--	--	--	18.6
2-check..........	11.2	10.4	(3.0)	--	--	--	--	24.6
3-check..........	10.2	9.4	7.9	(1.4)	--	--	--	28.8

Table 11.--Difference in number of circuli and percentage difference between smolts of various age groups from Ruth and Little Kitoi Lakes

[Numbers in parentheses are mean percentage difference]

Years of growth and lake	Differences in-- Mean circuli from 1-check smolts	Mean circuli from 2-check smolts	Mean circuli from 3-check smolts
	Number	Number	Number
First-year growth			
Ruth Lake............	12.1	11.2	10.2
Little Kitoi Lake....	7.9	6.7	6.8
Difference.........	4.2 (52.9)	4.5 (67.6)	3.5 (51.1)
Second-year growth			
Ruth Lake............	--	10.4	9.4
Little Kitoi Lake....	--	6.0	6.3
Difference.........	--	4.4 (74.0)	3.0 (47.7)
Third-year growth			
Ruth Lake............	--	--	7.9
Little Kitoi Lake....	--	--	3.8
Difference.........	--	--	4.0 (105.2)
Spring growth			
Ruth Lake............	6.4	3.0	1.4
Little Kitoi Lake....	2.7	0.7	0.3
Difference.........	3.7 (137.4)	2.3 (358.5)	1.2 (460.0)

Condition

Condition factors were determined by use of the formula

$$K = \frac{W \times 10^5}{L^3}$$

where $\underline{W}$ = weight in grams and $\underline{L}$ = fork length in millimeters. The results for samples of smolts taken in 1962 are given in table 12. The high condition factor in Ruth Lake smolts was expected because smolts from there have always appeared more robust than have their counterparts from Little Kitoi Lake (fig. 12). The general increase in condition factor was also apparent in each lake as the migration progressed from May 28 to June 25, 1962 (table 12).

Table 12.--Average condition factor (K) of sockeye smolts from Little Kitoi and Ruth Lakes throughout the migration, 1962

Date	Little Kitoi Lake K	Little Kitoi Lake Smolts in sample	Ruth Lake K	Ruth Lake Smolts in sample
		Number		Number
May 28.................	0.729	28	0.901	25
June 4..................	.737	29	.902	27
June 12.................	.799	29	.962	28
June 18.................	.854	31	.969	40
June 25.................	.766	30	.978	7
Average K............	0.778	147	0.940	127

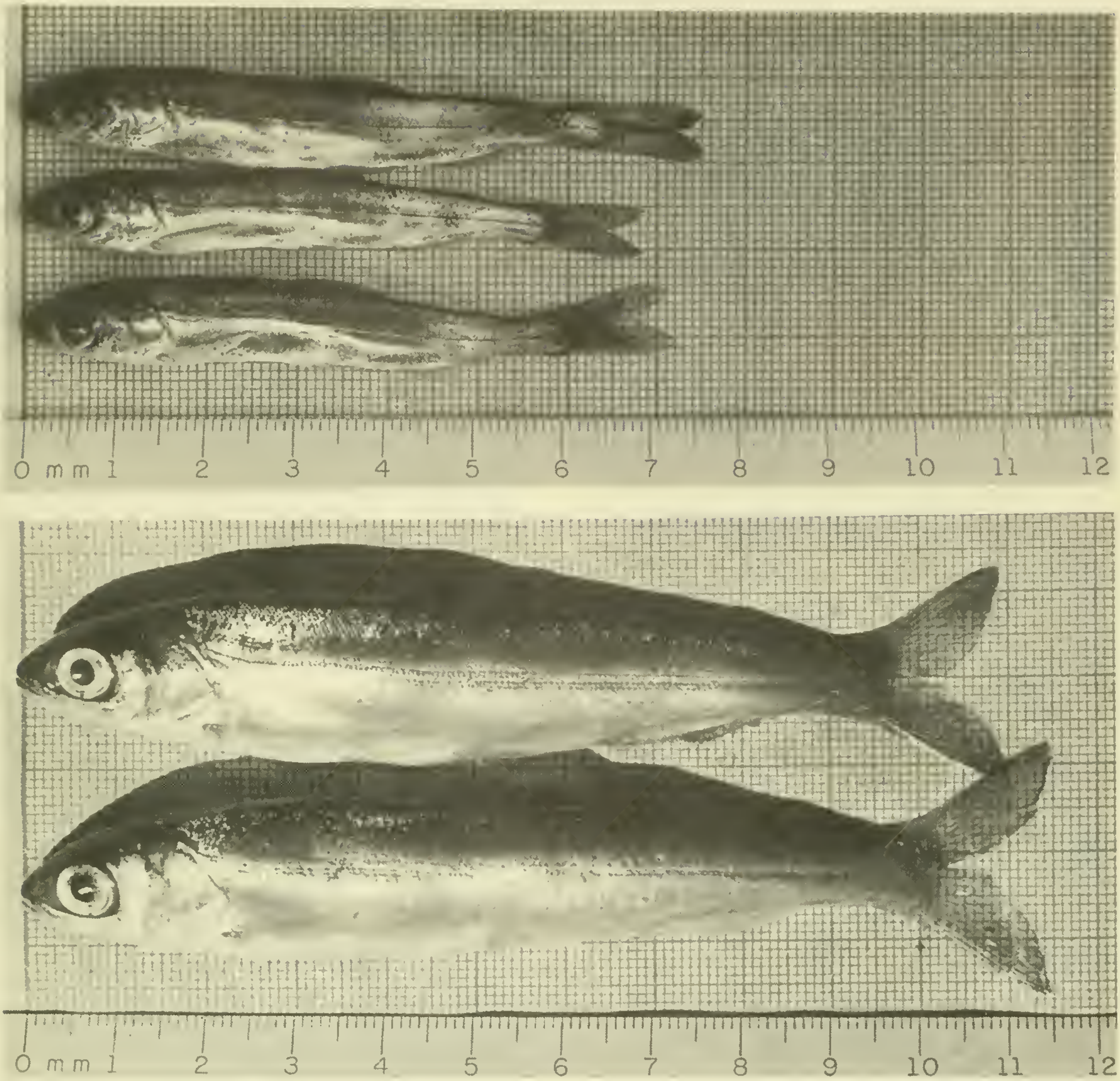

Figure 12.--Comparison of size of I-annulus smolts in 1957 from Little Kitoi Lake (upper) and Ruth Lake (lower)--1955 brood year.

TROPHIC CONDITIONS IN THE LAKES

Trophic conditions in lakes have a strong influence on the well-being of young salmon (Foerster, 1925). To ensure the greatest production, lakes with sufficient and proper food should be chosen for rearing areas. Analysis of the stomach contents of sockeye yearlings in Cultus Lake showed Cyclops to be the major food, followed in order of importance by Daphnia, Bosmina, and to a much lesser extent by Epischura. Insects were minor food items. In most lakes of the Fraser River system, cladocerans and copepods were the principal food. In the Stuart Lake district, primarily insects were taken (particularly Tendipedidae); some cladocerans were eaten also.

Although my data are not extensive, the available information on plankton, periphyton, and bottom fauna supports the view that trophic conditions influence the survival, growth, and condition of sockeye in the lakes under study.

Samples from Little Kitoi Lake, Ruth Lake, and other lakes near Kitoi Bay, taken before Ruth Lake was treated, indicated that all of the lakes had about the same low level of plankton production. Plankton production in Ruth Lake increased immediately after the rotenone treatment, and this level remained high through 1964. A quantitative and qualitative study was started in 1962 to evaluate more effectively the plankton productivity of the various lakes in the area. Samples from Ruth and Little Kitoi Lakes were taken within 1 day of each other in 1962 under similar conditions. Each sample was collected by towing a 12-in. net of 20-mesh silk bolting cloth a distance of 100 m. at a depth of 6 m. The settled volume of plankton in the Ruth Lake sample was 22 ml. (milliliter), whereas in the Little Kitoi Lake sample it was only 2 ml. Samples from Ruth Lake consisted primarily of cladocerans, whereas those from Little Kitoi Lake contained mostly rotifers. It is impossible to state exactly the cause for the shift of Ruth Lake to a higher level of plankton productivity. Both release of fertility by the destruction of resident fishes and reduction in the numbers of plankton-eating fish must have played a part.

Stomachs of most smolts from Little Kitoi and Ruth Lakes, taken within a few hours after the fish had left the lake, were empty. When they contained food, midge larvae (Tendipedidae) were the primary organisms in both lakes, although oligochaete worms were also an important food in samples from Ruth Lake. Several of the stomachs of fish from each lake contained a small amount of partly digested plankton. Nonmigratory juveniles were not sampled for stomach contents because sufficient numbers of fish were hard to get; samples from these fish would certainly be better than those from the migrating smolts to indicate feeding habits in the two lakes.

Because of the diversity of substrate for collecting periphyton each year (see "Methods"), presentation of the original data would not be useful. The relative conditions in the three lakes can be brought out, however, by comparing the accumulation in the three lakes with the amount accumulated per unit area in Ruth Lake (table 13). The comparisons showed Ruth Lake to be the more productive--usually by a wide margin.

The greater productivity of Ruth Lake is shown further in a comparison of bottom fauna there and in Little Kitoi Lake (table 14). The weight of bottom organisms per square meter in the shallow water of Little Kitoi Lake (0.624 g.) was only 38.9 percent of that in Ruth Lake (1.604 g.). In deep water, Little Kitoi Lake had 2.433 g. of organisms per square meter, or 44.5 percent of that in Ruth Lake (5.469 g.). Larvae of Tendipedidae from Ruth Lake were considerably larger than were those from Little Kitoi Lake; as a result the bottom-fauna biomass from Ruth Lake was greater than from Little Kitoi Lake, although the number of organisms per square meter was sometimes higher in Little Kitoi Lake than in Ruth Lake.

Table 13.--Accumulation of periphyton in Little Kitoi, Ruth, and Midarm Lakes expressed as percentages of the amount accumulated per unit area in Ruth Lake

Year	Little Kitoi Lake	Ruth Lake	Midarm Lake[1]
	Percent	Percent	Percent
1956..............	18	100	14
1957..............	47	100	--
1958..............	31	100	79
Average.........	32	100	46

[1] No data for 1957.

Table 14.--Average number and wet weight of bottom organisms per square meter in Little Kitoi Lake on 6 days between March 6 and September 18, 1961, and in Ruth Lake on 5 days between March 6 and September 19, 1961

Lake and depth	Tendipedidae	Oligochaeta	Others[1]	Total organisms	Wet weight
	Number	Number	Number	Number	Grams
Little Kitoi Lake:					
Shallow (1 m.)...	455	18	89	574	0.624
Deep (18 m.).....	320	0	12	332	2.433
Ruth Lake:					
Shallow[2] (1 m.)..	178	0	16	193	1.604
Deep (16 m.).....	594	65	603	1,262	5.469

[1] The major groups in this category were gastropods (*Gyraulus* sp.), pelecypods (Sphaeriidae), and amphipods (*Hyalella* sp., *Gammarus* sp.).
[2] No sample taken on March 6.

SUMMARY

Three lakes in the Kitoi Bay area of Alaska were studied to determine how removal of resident fish affects the production of sockeye introduced after removal. Ruth Lake was treated with rotenone in 1955; Little Kitoi and Midarm Lakes, untreated, served as control lakes. Little Kitoi and Midarm Lakes contain populations of Dolly Varden, sticklebacks, and sculpins; Little Kitoi Lake also maintains populations of sockeye, coho, and a few pink salmon. After Ruth Lake was treated, sockeye fry were introduced in 1956 into Ruth and Midarm Lakes. Because of subsequent limited availability of salmon fry, Midarm Lake was not stocked again. Ruth Lake was planted with sockeye fry each year in 1956-60 and in 1963.

Fresh-water survival of the fry introduced into Ruth Lake was considerably greater than the survival of fry in Midarm Lake and most probably in Little Kitoi Lake. The survival of the single brood year from fry to smolt for Midarm Lake was 3.6 percent; the average for four brood years in Ruth Lake was 17.9 percent; and the estimated average for Little Kitoi Lake was 9.7 percent. A 30-percent egg-to-fry survival in Little Kitoi Lake is assumed for comparisons between Little Kitoi Lake and the other two.

Survival and growth were considerably greater in the treated lake. The optimum number of smolts was produced from a fry stock of about 12,400 per surface hectare in both Little Kitoi and Ruth Lakes.

The average survival of fry to the smolt stage in Ruth Lake was considerably higher than survival of fry introduced into other sockeye lakes that maintained populations of predator and competing fishes.

The length of time of fresh-water residence of sockeye and the percentage survival appear to be correlated negatively with density of fry, although environmental conditions such as temperature and ice cover probably exert considerable influence during certain years.

Survival and growth of fry in both Ruth and Little Kitoi Lakes were also affected by the amount of recruitment; survival rates and average lengths of smolts decreased with increased fry density. Growth of sockeye fry introduced into treated Ruth Lake was considerably greater than growth of fry in untreated Midarm and Little Kitoi Lakes. The average length of smolts for the 1955-59 brood years for Ruth Lake was 104 mm., but for Little Kitoi Lake it was only 70 mm. The average length of smolts for the single brood year in Midarm Lake was 83 mm. From limited plankton studies it appears that, prior to treatment, Ruth Lake maintained plankton populations of about the same magnitude as did Little Kitoi Lake. Since treatment in 1955, the plankton population has increased more than tenfold. Removal of resident fishes by the treatment of Ruth Lake is held to be responsible for the higher survival and growth of introduced fry in this lake than of introduced fry in Midarm Lake and of natural fry in Little Kitoi Lake.

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As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States--now and in the future.

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