ABUNDANCE AND SIZE OF JUVENILE SOCKEYE SALMON, *ONCORHYNCHUS NERKA*, AND ASSOCIATED SPECIES IN LAKE ALEKNAGIK, ALASKA, IN RELATION TO THEIR ENVIRONMENT[1]

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ABSTRACT

Juvenile sockeye salmon, *Oncorhynchus nerka,* and associated fish in the littoral of Lake Aleknagik (Bristol Bay, Alaska) were sampled systematically from spring to midsummer (1962-72) with a beach seine. Apparent mortality rate and relative abundance were estimated from catches. Juvenile sockeye salmon and threespine stickleback comprised the majority of the population, and slimy sculpin, ninespine stickleback, and Arctic char fry the remainder. The annual abundance of juvenile sockeye salmon was related to the abundance of parent spawners. No correlation was evident among the annual estimates of abundance of the five species.

Age was determined from length-frequency distributions, and growth rates were calculated for sockeye salmon (age 0), Arctic char (age 0), and threespine stickleback (age I). The mean lengths of sockeye salmon fry and char fry on 20 June were positively correlated with water temperature, whereas the mean length of threespine stickleback (age I) on this date was inversely correlated with the average catch of sockeye salmon fry in the previous year. The mean lengths of all species on 20 July were inversely correlated with the mean catch of sockeye salmon fry. A limited capacity of the Lake littoral to sustain growth of individual fish was indicated.

The annual commercial catch of anadromous sockeye salmon, *Oncorhynchus nerka* Walbaum, from the Nushagak District of Bristol Bay declined from an average of about 5 million fish in the early 1900's to only about 1 million in recent years (Mathisen, 1971). Since the early 1950's, the Fisheries Research Institute has studied the freshwater life of the stock to understand the factors controlling the average abundance and annual variation in abundance of the adult run. We have assumed that a significant portion of the variation is related to the variation in abundance and growth of juveniles, especially fry (age 0), and have concentrated effort on the Wood River lake system because it has been the major producer among the river systems in the District (Figure 1).

The sockeye salmon fry inhabit different parts of each lake from spring to fall. From mid-May to mid-June, when the ice breaks up, to mid-July, they reside along the shore and in shallow bays; in mid-July they begin to move offshore; and from mid-August through September they occupy the pelagic areas (Burgner, 1962). Accordingly, the populations are sampled during early summer through beach seining and during August and September through townetting and echo sounding (Rogers, 1967). Beach seine sampling has been conducted throughout the District but has been concentrated in Lake Aleknagik. The catch and length statistics for sockeye salmon fry from an extensive effort in the lake in 1962 were analyzed by Pella (1968), and the catch statistics for five species of fish from 1964 through 1966 were examined by Waters (1969).

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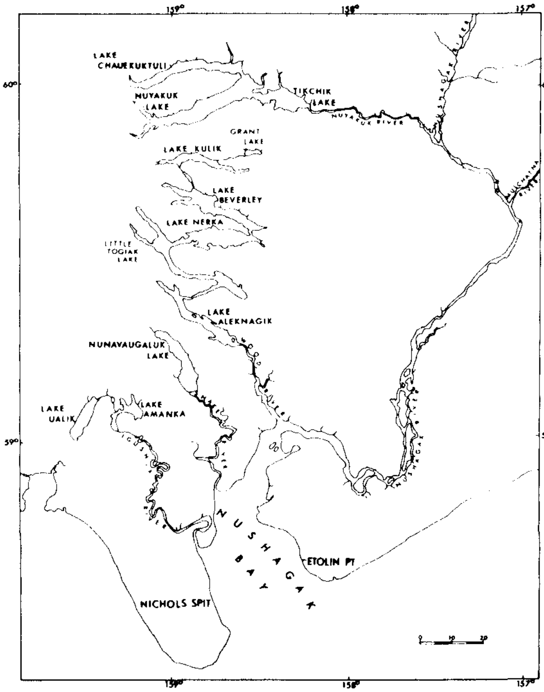

FIGURE 1.—The Wood River lake system and adjoining river systems in the Nushagak District, Bristol Bay, Alaska.

The primary objective in beach seine sampling has been to obtain periodic estimates of fish length in early summer. The secondary objectives have been (1) to estimate the annual relative abundance and growth of fish species associated with juvenile sockeye salmon to determine the effect, if any, that they may have on survival and growth of juvenile sockeye salmon and (2) to determine the relationships among relative abundance of sockeye salmon fry, abundance of parent spawners, and abundance of returning adult sockeye salmon. The data and statistical tests are detailed in Rogers (1972). The purpose of this report is to examine the relationships among annual estimates of the size and abundance of fish and the physical parameters of the environment during early summer.

MATERIALS AND METHODS

A detailed description of the gear and sampling procedures is given by Waters (1969). The seine used was 35 m in length and had a midsection of 6-mm mesh, 7.6 m long and 3.7 m deep. A 1.8-m bridle and a 17-m hauling rope were attached to each end of the net. The seine was set in a semicircle about 15 m from shore and hauled by hand, usually by two men. Catches consisting of less than 500 fish were preserved in 10% Formalin.[3] Larger catches were successively divided in half until approximately between 200 and 500 fish remained. These were preserved, and the fraction taken was recorded. For each haul the date, time, location, set direction, and surface water temperature were noted. Other physical parameters measured in connection with the beach seining were the date of ice breakup, lake level, and solar radiation.

In 1962, beach seine hauls were made at 24 stations on Lake Aleknagik in eight time periods between 20 June and 8 September. In 1963, nine of the stations were sampled on 24 July and 3 August. From 1964 through 1972, generally 10 stations (Figure 2) were sampled at five weekly intervals between 22 June and 23 July and once between 2 to 5 August. Seining was conducted at the 10 stations between 0930 and 1600 h, seldom during rough water conditions, i.e. when there were waves on shore. A description of the beach seine stations is given in Rogers (1972).

Between 1 and 7 days after collection, the fish were enumerated and measured to the nearest millimeter from tip of snout to end of middle ray of the tail. In 1962 only juvenile sockeye salmon and threespine stickleback, *Gasterosteus aculeatus* Linnaeus were measured, whereas in the remaining years fish of all species were measured. Also, only 50 sockeye salmon fry were measured in samples containing more than 75 sockeye salmon fry, and only 200 threespine stickleback were measured in samples containing over 250 of this species.

The length frequencies were plotted by species and lake area (Figure 2) and for areas combined. Partial age compositions were determined from the length frequencies, and mean lengths were calculated for those age groups

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

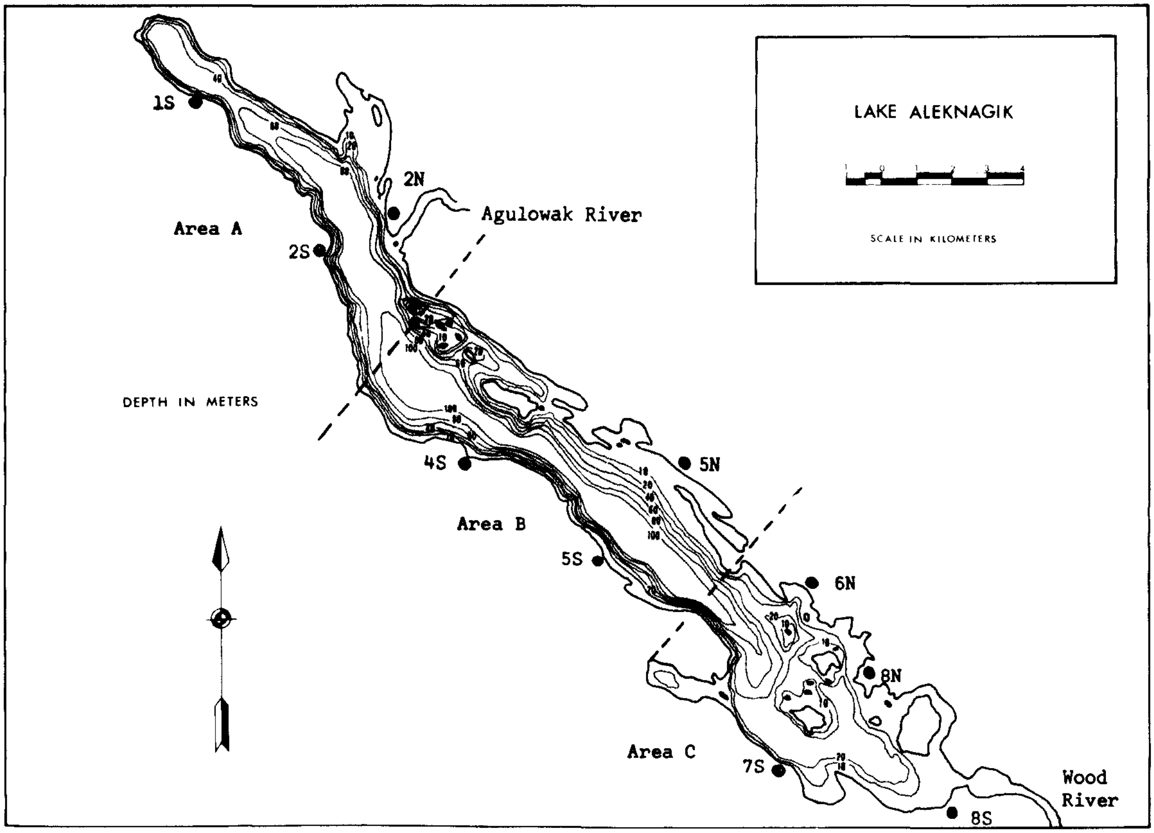

FIGURE 2.—Beach seine stations and lake sampling areas in Lake Aleknagik.

that were easily separated from the length frequencies. The mean lengths were converted to equivalent live lengths so as to adjust for the shrinkage due to preservation (Rogers, 1964). These were plotted by date and examined for determination of the most suitable growth model. A curvilinear relationship was indicated, and regressions of natural logarithm (ln) mean length on coded date (1 June = 1, 1 July = 31, etc.) were calculated through weighting the observations with geometric mean catch. A weighting procedure was used because (1) variance of the means tended to increase during the season as a result of the decline in catch (hence sample size) and (2) the accuracy of mean lengths from beach seine samples as estimates of mean length in the population tended to decrease in midsummer as the fish moved offshore. Annual growth rate and fish size in given periods were estimated from the regressions.

The beach seine catch data were analyzed through logarithmic transformation. An analysis of variance was conducted with the catches made in the first four periods of sampling (20 June-19 July) for the purpose of determining the significance of observed variation associated with location (station and lake area), date, and year. The last two periods (21 July-5 August) were excluded from the analysis since the catches of sockeye salmon fry in these periods were obviously lower than those in the other periods and age 0 fish of the longer lived species often appear at this time.

Mortality rate in a population is estimated commonly from changes in catch with time when catch per unit of effort can be reasonably assumed to be proportional at all times to true

TABLE 1.—Dates of ice breakup, surface water temperatures, and relative lake levels during beach seine sampling in Lake Aleknagik, 1962 through 1972.

Year	Date of ice breakup	Mean surface water temperature (°C) 20-24 June	20 June-19 July	21 July-5 August	Mean lake level (cm) 21-25 June	21 June-20 July	21 July-5 August
1962	1 June	9.0	11.8	12.0	157	137	89
1963	2 June	—	11.1	12.3	140	122	80
1964	15 June	7.7	9.4	11.6	150	139	82
1965	5 June	7.4	7.0	11.7	184	147	97
1966	6 June	7.6	8.5	12.8	157	148	112
1967	28 May	9.0	12.1	13.9	146	118	68
1968	31 May	10.8	13.3	14.9	102	84	50
1969	2 June	9.4	10.8	12.5	220	168	92
1970	23 May	7.8	9.8	11.2	154	134	109
1971	16 June	8.5	10.0	9.4	177	148	167
1972	8 June	4.3	7.5	12.0	191	171	108

population size. A frequent source of error is the variation in availability of the fish population to the sampling net. Beach seine catches of sockeye salmon fry and threespine stickleback decline seasonally as a result of movement offshore and mortality. Apparent mortality rates were estimated from linear regressions of ln mean catch on coded date.

The data were examined through stepwise multiple regression and linear correlation techniques for determination of significant relationships among the physical and biological parameters.

RESULTS

Climatological observations for the Wood River lake system are given in Rogers, Siler, and Croker (1970). The average date of ice breakup from 1951 to 1972 is 1 June, and the range in dates is from 14 May to 16 June. A summary of physical data collected in connection with the beach seine sampling in Lake Aleknagik is given in Table 1. Lake level usually rises rapidly after ice breakup until mid-June and declines through the summer. Inshore surface water temperatures rise gradually from ice breakup to late July and then level off. Water temperatures are lower on the average in the upper third of the lake (area A) than elsewhere. From 1962 to 1972 the average surface water temperatures during 20 June-19 July were 9.1°, 10.3°, and 10.7°C in areas A, B, and C, respectively.

Fish of 24 species have been collected in Lake Aleknagik, but only juvenile sockeye salmon and threespine stickleback have been greatly predominant in beach seine catches (Table 2). These two species are also the only ones that become pelagic in midsummer. Three other species appear in significant numbers in the catches: ninespine stickleback, *Pungitius pungitius* Linnaeus; slimy sculpin, *Cottus cognatus*

TABLE 2.—Sums of geometric mean beach seine catches of five fish species by lake area, Lake Aleknagik, 1962 through 1972.

	Area	Sockeye salmon Fry	Fingerling	Threespine stickleback	Ninespine stickleback	Sculpin	Char fry	Sum
20 June-19 July								
	A	258	1	130	8	43	15	455
	B	265	2	303	11	25	2	608
	C	86	8	160	22	23	1	300
	Total	192	3	184	12	29	4	424
21 July-5 August								
	A	36	1	132	13	23	8	213
	B	20	2	75	7	8	3	115
	C	20	2	92	14	10	2	140
	Total	24	2	97	11	12	3	149

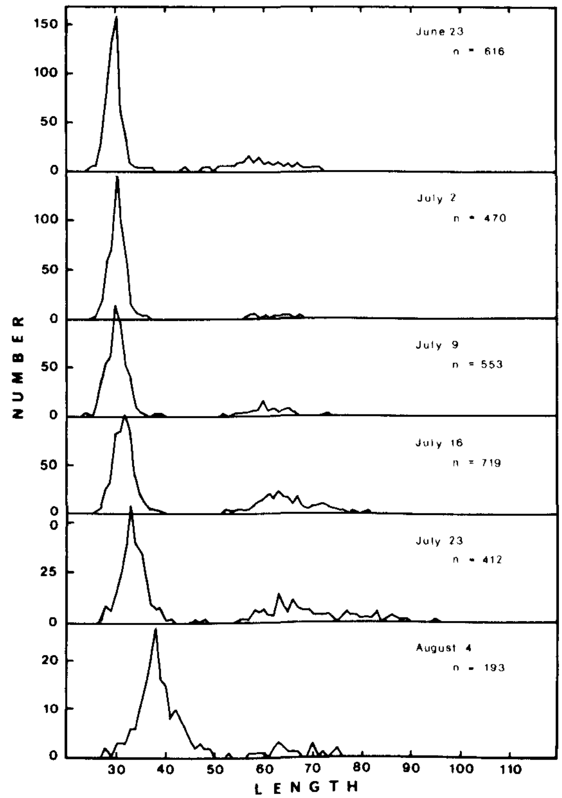

FIGURE 3.—Length-frequency distributions (mm) of sockeye salmon, 1966.

Richardson; and Arctic char fry, *Salvelinus alpinus* Linnaeus. Of primary value in the beach seine statistics are the annual estimates, since our main concern is with the source of the observed annual variation in adult sockeye salmon abundance. Geographical and temporal variations were examined and are discussed here to the extent necessary for procurement of valid annual estimates of abundance, growth and size.

Sockeye Salmon

Length-frequency distributions for juvenile sockeye salmon are shown in Figures 3 and 4 for a year in which growth was below average (1966) and a year in which growth was above average (1968). The length frequencies are based on number of fish measured and thus do not reflect variation in abundance among time periods and years. The apparent abundance of sockeye salmon fingerlings in comparison to fry is exaggerated since usually the entire sample of fingerlings, but often a subsample of fry, was measured.

Sockeye salmon fingerlings (primarily age I) ranged in length from approximately 45 to 118 mm. Many presumably originated in the upper lakes of the Wood River system and had been in Lake Aleknagik by early summer as smolts to migrate out of the lake system. Catches were significantly higher toward the lake outlet (area C) than elsewhere (Tables 3 and 4).

Sockeye salmon fry (age 0) ranged in length from approximately 25 to 60 mm. The length frequencies are symmetric and may be modeled

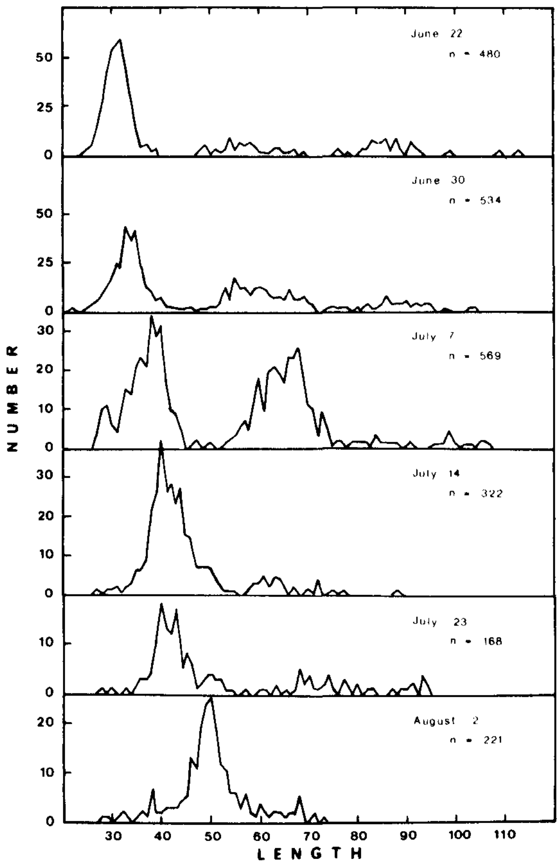

FIGURE 4.—Length-frequency distributions (mm) of sockeye salmon, 1968.

TABLE 3.—Geometric mean beach seine catches in Lake Aleknagik by area and year for the period 20 June-19 July 1962, 1964 through 1972.

Year	Area	n	Sockeye fry	Sockeye fingerling	Threespine stickleback	Ninespine stickleback	Sculpin	Char fry
1962	A	12	510.1	4.4	318.5	23.8	52.2	18.3
	B	12	384.8	0.2	301.5	6.2	28.1	4.1
	C	16	109.2	9.4	113.4	12.0	38.2	1.9
	Mean		277.8	3.1	221.7	12.1	38.3	5.6
1964	A	12	140.4	0.0	92.2	7.9	58.3	25.5
	B	12	294.3	0.9	497.2	22.3	52.3	2.1
	C	16	121.9	15.0	463.1	47.8	29.3	0.7
	Mean		171.4	2.1	276.9	20.3	44.7	4.2
1965	A	12	806.3	0.2	102.3	4.2	44.8	9.0
	B	12	1,137.0	1.6	593.8	10.7	25.5	0.9
	C	16	196.6	1.5	130.1	10.6	25.6	0.6
	Mean		564.9	1.0	199.2	7.8	30.8	2.1
1966	A	12	560.2	1.3	127.0	1.5	26.3	24.9
	B	12	446.3	3.0	705.8	5.9	13.3	4.0
	C	16	219.5	4.2	131.8	5.9	16.5	2.0
	Mean		380.0	2.6	227.8	3.7	17.9	6.3
1967	A	12	949.7	3.1	274.0	17.0	51.4	34.9
	B	12	273.7	13.0	737.1	21.6	10.8	3.0
	C	16	145.0	22.8	249.6	27.4	11.5	1.2
	Mean		335.3	10.1	369.4	21.6	18.6	5.8
1968	A	12	44.2	6.3	335.0	33.2	46.5	22.2
	B	12	17.0	4.2	151.8	12.0	17.9	2.4
	C	16	54.6	9.1	142.4	80.1	17.3	2.2
	Mean		34.5	6.3	193.5	31.7	24.3	5.3
1969	A	12	91.9	1.0	208.1	9.0	40.6	6.4
	B	12	106.9	1.9	309.2	15.6	15.8	0.3
	C	15	62.4	2.6	149.2	80.2	28.3	0.8
	Mean		84.9	1.8	212.5	22.4	26.3	1.6
1970	A	12	170.3	0.0	154.7	11.7	24.1	13.9
	B	12	100.9	1.0	95.0	9.6	30.5	2.0
	C	16	120.5	13.7	158.0	37.3	33.5	2.6
	Mean		127.5	2.1	132.4	16.1	29.1	4.4
1971	A	12	404.2	1.1	64.8	5.5	59.8	3.6
	B	12	792.1	4.0	333.8	11.8	35.6	1.3
	C	16	207.9	14.9	378.9	18.2	29.7	0.9
	Mean		405.3	4.5	201.6	10.6	39.8	1.7
1972	A	12	147.6	0.9	18.1	1.4	44.6	14.2
	B	12	721.1	2.5	94.4	4.1	47.4	2.7
	C	16	21.0	3.5	36.9	4.0	17.9	1.1
	Mean		130.7	2.1	39.8	2.8	33.6	3.5

by the normal distribution; however the variability in length in area C was more than in the other areas. This part of the lake tends to warm up earlier in the spring and has a lower abundance of fry. Mean lengths were calculated for 20 June and 20 July from the regression parameters in Table 5. These lengths represent the sizes of fish at the beginning and end of early summer, when sockeye salmon fry were abundant inshore. The fry were of similar length in the lake areas on 20 June, but had become larger in area C than in the others by 20 July (Table 6).

Sockeye salmon fry were more abundant in areas A and B than in area C, apparently because the major spawning ground, Agulowak River, is located here. They were more abundant at the stations adjacent to spawning grounds than at those stations located elsewhere. Most spawning occurs from early August to mid-September. The fry emerge from the gravel from late winter to early spring, and most are in the lake by early June.

Regressions in ln mean catch on coded date (23 June = 1, 1 July = 9, etc.) were calculated for the entire period of sampling (20 June-5 August) and for all periods except the first period (Table 7). The latter results appeared to have greater consistency than the former and indicated that fish were perhaps less available in early spring than later. Catches of sockeye salmon fry declined at a greater rate than

TABLE 4.—Geometric mean beach seine catches in Lake Aleknagik by area and year for the period 21 July-5 August, 1962 through 1972.

Year	Area	*n*	Sockeye fry	Sockeye fingerling	Threespine stickleback	Ninespine stickleback	Sculpin	Char fry
1962	A	6	12.9	2.1	64.8	5.4	26.0	9.2
	B	6	16.4	2.1	58.9	7.7	9.2	9.4
	C	8	3.2	0.0	17.2	2.4	4.5	1.6
	Mean		9.1	1.1	40.6	5.7	10.5	5.5
1963	A	6	0.3	0.4	16.5	4.9	26.7	11.9
	B	6	6.2	0.4	18.2	7.9	2.8	6.5
	C	8	6.5	1.6	40.8	1.2	4.2	7.8
	Mean		3.1	0.7	23.1	3.9	7.2	8.5
1964	A	6	25.3	0.9	395.8	26.6	20.5	21.2
	B	6	41.7	4.2	297.0	12.9	10.4	2.3
	C	8	11.2	0.3	64.6	12.9	9.7	3.4
	Mean		22.9	0.9	197.0	16.5	12.8	5.9
1965	A	3	3,476.8	4.0	756.5	13.5	16.1	15.7
	B	3	15.1	0.4	53.4	4.1	8.5	2.0
	C	4	9.0	0.0	187.8	13.2	11.0	3.2
	Mean		81.4	0.9	197.2	9.2	11.5	4.9
1966	A	6	7.4	0.3	101.4	5.6	9.7	2.1
	B	6	35.0	2.3	249.7	3.8	2.8	1.3
	C	8	26.7	6.1	175.2	7.5	15.2	0.5
	Mean		19.3	2.1	164.4	5.5	7.7	1.2
1967	A	9	127.2	9.9	337.6	15.4	20.0	14.7
	B	9	22.9	8.9	104.3	4.5	3.5	1.5
	C	12	62.2	10.5	100.5	33.3	9.3	0.4
	Mean		56.9	9.7	152.5	13.6	8.9	2.8
1968	A	6	6.1	0.4	167.7	47.5	20.5	0.7
	B	6	3.9	1.7	38.2	17.8	8.4	0.4
	C	8	7.6	1.2	81.0	99.0	14.2	0.0
	Mean		5.7	1.0	80.5	44.0	13.5	0.3
1969	A	6	28.0	0.6	370.4	36.8	39.6	10.2
	B	6	6.9	2.0	46.3	7.0	3.6	1.8
	C	8	26.9	0.7	111.7	46.8	7.9	1.1
	Mean		17.6	1.0	124.6	23.4	10.8	3.0
1970	A	6	46.7	0.0	166.7	16.4	7.0	8.3
	B	6	40.5	3.5	89.7	10.0	16.4	4.5
	C	8	62.3	1.0	221.3	37.4	13.8	3.0
	Mean		49.0	1.1	149.1	18.4	11.7	4.9
1971	A	6	102.3	0.0	43.3	8.6	57.4	4.0
	B	6	13.1	0.7	37.7	3.9	16.7	1.7
	C	8	126.8	6.4	198.3	12.3	11.1	2.0
	Mean		56.1	1.3	68.9	7.6	22.2	2.4
1972	A	6	87.1	11.0	39.9	5.1	53.3	9.0
	B	6	182.7	1.1	149.9	7.6	33.7	4.4
	C	8	25.8	11.2	62.2	7.7	26.0	2.2
	Mean		74.3	5.1	71.9	6.7	36.0	4.4

those of the other species caught by beach seining because this species moves offshore to the pelagic region in midsummer.

Threespine Stickleback

Threespine stickleback were of ages 0 to III and perhaps age IV. They ranged in length from 6 to 81 mm. In years of poor growth, the three major age groups had distinctive length frequencies (Figure 5), whereas in years of good growth, age groups II and III overlapped greatly in length distribution (Figure 6). When, also, ice broke up earlier and water temperatures were higher than average, age 0 fish appeared in the catches before mid-July; threespine stickleback spawn in June and July.

Age I threespine stickleback were usually easy to separate from other age groups from their length, especially within a given lake area. The mean lengths of age I threespine stickleback were greater in area C at both the beginning and end of early summer than in the two other areas (Table 6), but growth rates were similar among the three lake areas.

Threespine stickleback were more abundant along the north shore of the lake than the south. This shore is shallower and has more aquatic

TABLE 5.—Parameters from weighted exponential regression of ln, mean length (live equivalent) on coded date, for Lake Aleknagik beach seine sampling 16 June-5 August, 1962, 1964 through 1972.

Species	Year	Area A		Area B		Area C		Combined	
		[1] *a*	[2] *b*	*a*	*b*	*a*	*b*	*a*	*b*
Sockeye fry (Age 0)	1962	3.280	0.0070	3.271	0.0073	3.260	0.0094	3.273	0.0073
	1964	3.242	0.0068	3.293	0.0064	3.266	0.0066	3.291	0.0061
	1965	3.178	0.0087	3.353	0.0027	3.251	0.0051	3.234	0.0067
	1966	3.325	0.0033	3.308	0.0039	3.368	0.0026	3.324	0.0035
	1967	3.304	0.0044	3.229	0.0069	3.183	0.0095	3.267	0.0058
	1968	3.216	0.0097	3.291	0.0102	3.200	0.0122	3.194	0.0118
	1969	3.322	0.0059	3.213	0.0098	3.262	0.0095	3.255	0.0083
	1970	3.221	0.0093	3.236	0.0085	3.135	0.0125	3.192	0.0101
	1971	3.311	0.0040	3.369	0.0019	3.229	0.0069	3.298	0.0043
	1972	3.234	0.0062	3.288	0.0044	3.053	0.0103	3.225	0.0062
	Mean	3.263	0.0065	3.285	0.0062	3.221	0.0085	3.255	0.0070
Threespine stickleback (Age I)	1962	3.252	0.0055	3.218	0.0062	3.374	0.0040	3.269	0.0051
	1964	3.347	0.0033	3.360	0.0035	3.401	0.0029	3.392	0.0027
	1965	3.166	0.0059	3.305	0.0023	3.257	0.0048	3.256	0.0041
	1966	3.187	0.0044	3.232	0.0037	3.181	0.0053	3.215	0.0042
	1967	3.143	0.0059	3.238	0.0046	3.265	0.0057	3.262	0.0038
	1968	3.310	0.0050	3.259	0.0060	3.286	0.0075	3.302	0.0053
	1969	3.304	0.0050	3.448	0.0022	3.335	0.0056	3.399	0.0033
	1970	3.331	0.0053	3.274	0.0062	3.402	0.0050	3.344	0.0051
	1971	3.195	0.0061	3.436	0.0001	3.220	0.0064	3.268	0.0046
	1972	3.095	0.0081	3.209	0.0055	3.383	0.0024	3.216	0.0055
	Mean	3.233	0.0054	3.298	0.0040	3.310	0.0050	3.292	0.0044
Arctic char fry (Age 0)	1964	3.243	0.0049	3.291	0.0041	3.243	0.0050	3.247.	0.0048
	1965	3.238	0.0054	3.348	0.0013	3.312	0.0029	3.259	0.0047
	1966	3.324	0.0025	3.197	0.0057	3.235	0.0046	3.298	0.0032
	1967	3.216	0.0051	3.209	0.0055	3.260	0.0038	3.216	0.0051
	1968	3.332	0.0038	3.373	0.0042	3.075	0.0113	3.305	0.0048
	1969	3.206	0.0060	2.974	0.0105	3.267	0.0060	3.208	0.0061
	1970	3.266	0.0050	3.127	0.0093	3.231	0.0070	3.215	0.0066
	1971	3.270	0.0036	3.307	0.0031	3.270	0.0033	3.284	0.0033
	1972	3.187	0.0058	3.116	0.0085	3.154	0.0060	3.133	0.0074
	Mean	3.254	0.0047	3.216	0.0058	3.227	0.0055	3.241	0.0051

[1] Natural log of mean length on 31 May.
[2] Instantaneous growth rate in length.

vegetation and a larger area of mud bottom; therefore it provides a more suitable forage and spawning habitat. These fish were distributed in much the same pattern as sockeye salmon fry. The two species have common food and some common behavioral habits during the summer (Rogers, 1968). Age I and II fish usually became pelagic in midsummer, and age 0 and III fish tended to remain inshore by late summer.

Ninespine Stickleback

Ninespine stickleback were age 0 to II and perhaps age III. They ranged in length from 10 to 76 mm (Figure 7). The time of spawning and appearance of age 0 fish in the catches were similar to those of threespine stickleback, but growth was more rapid and ages I and II were not as distinctive from length frequencies.

The distribution of ninespine stickleback shows an even greater correlation with location of vegetation and mud bottom than that of threespine stickleback. At stations 2S and 4S where vegetation is sparse on the bottom, catches were always very low. Ninespine stickleback showed the lowest rate of decline in catches among the associated species (Table 7).

Slimy Sculpin

Sculpin ranged in age from 0 to perhaps V but were mostly age I from observations at Iliamna Lake of the Kvichak River system (Roger, 1971). They ranged in length from 8 to 91 mm (Figure 8). As with the sticklebacks,

TABLE 6.—Calculated mean lengths (live equivalent in mm) for 20 June and 20 July from weighted exponential regressions, 1962 through 1972.

		20 June				20 July			
Species	Year	Area A	Area B	Area C	Combined	Area A	Area B	Area C	Combined
Sockeye fry	1962	30.6	30.5	31.4	30.6	37.7	38.0	41.7	38.1
	1963[1]					39.6	45.5	44.0	44.9
	1964	29.3	30.6	29.9	30.3	35.9	37.0	36.4	36.4
	1965	27.4	30.2	28.6	29.0	35.5	32.7	33.2	35.5
	1966	29.7	29.5	30.6	29.8	32.8	33.2	33.0	33.0
	1967	29.7	29.0	29.2	29.5	34.0	35.7	38.8	35.1
	1968	30.2	32.9	31.3	30.8	40.5	44.7	45.2	43.9
	1969	31.2	30.2	31.6	30.6	37.3	40.6	41.9	39.2
	1970	30.2	30.1	29.6	29.8	39.9	38.9	43.1	40.4
	1971	29.7	30.2	29.0	29.5	33.5	32.0	35.6	33.5
	1972	28.7	29.3	26.0	28.5	34.6	33.4	35.4	34.3
	Mean[2]	29.7	30.3	29.7	29.3	36.2	36.6	38.4	36.9
	S.D.	1.05	1.07	1.68	0.75	2.63	4.05	4.33	3.45
Threespine stickleback (Age I)	1962	28.9	28.3	31.7	29.1	34.1	34.0	35.7	33.9
	1963[1]					36.7	39.3	38.4	36.9
	1964	30.3	30.9	31.8	31.4	33.4	34.3	34.7	34.0
	1965	26.7	28.5	28.6	28.1	31.9	30.5	33.0	31.8
	1966	26.4	27.3	26.8	27.0	30.2	30.5	31.4	30.6
	1967	26.1	27.9	29.4	28.2	31.1	32.1	34.8	31.5
	1968	30.3	29.4	31.1	30.2	35.2	35.2	39.0	35.4
	1969	30.1	32.8	31.4	32.0	34.9	35.1	37.1	35.3
	1970	31.1	29.9	33.2	31.4	36.4	36.0	38.6	36.6
	1971	27.6	31.1	28.4	28.8	33.0	31.2	34.4	33.1
	1972	25.9	27.6	30.9	27.8	33.0	32.6	33.1	32.8
	Mean[2]	28.3	29.4	30.3	29.4	33.3	33.2	35.2	33.5
	S.D.	2.01	1.79	1.96	1.74	1.92	2.04	2.46	1.91
Arctic char fry (Age 0)	1963[1]					35.8	36.1	32.1	35.3
	1964	28.2	29.2	28.3	28.3	32.7	33.1	33.0	32.7
	1965	28.4	29.2	29.1	28.6	33.5	30.3	31.7	32.9
	1966	29.2	27.4	27.9	28.9	31.5	32.6	32.0	31.8
	1967	27.6	27.7	28.1	27.6	32.2	32.7	31.6	32.3
	1968	30.2	31.7	27.1	30.0	33.8	36.0	38.0	34.7
	1969	27.8	24.2	29.6	27.9	33.3	33.1	35.4	33.6
	1970	29.0	27.4	29.1	28.4	33.6	36.2	35.9	34.6
	1971	28.2	29.0	28.1	28.5	31.4	31.8	31.0	31.5
	1972	27.2	26.7	26.4	26.6	32.3	34.5	31.6	33.2
	Mean[2]	28.4	28.1	28.2	28.3	32.7	33.4	33.4	33.0
	S.D.	0.92	2.08	1.01	0.93	0.91	1.91	2.47	1.12

[1]Means calculated from lengths on 24 July 1963 and growth rate in 1968.
[2]1963 excluded.

spawning occurs primarily in June and July, and the entire lifespan is spent in Lake Aleknagik.

Sculpin were the most uniformly distributed of the fish commonly caught by beach seine, but they tended to be more abundant at stations where sockeye salmon spawning occurred (Stations 2N, 5S, 6N, and 7S) than at other stations. Roger (1971) discusses the role of sculpins as predators on sockeye salmon eggs in Lake Iliamna of the Kvichak River system.

Arctic Char Fry

Arctic char spawn in late fall. They are presumably in the lake by early June, although little is known of their reproduction and early life history in Lake Aleknagik. In early summer they are in the fry stage and range in length from 25 to 50 mm. The adults are major predators of juvenile sockeye salmon and threespine stickleback (Nelson, 1966).

Char fry averaged about 1 mm shorter than sockeye salmon fry on 20 June and about 4 mm shorter on 20 July. They did not differ significantly in average length among the lake areas on 20 June, but were smaller in area A than in the other areas on 20 July (Table 6).

Arctic char fry were the most unevenly distributed of the fish caught by beach seine and occurred infrequently in catches. They were more abundant in the upper region of the lake

TABLE 7.—Regression parameters for ln mean catch on coded date (23 June = 1), 1962, 1964 through 1972.

Year	Sockeye fry		Threespine stickleback Age I		Threespine stickleback Age II +		Ninespine stickleback[1]		Sculpin[1]		Char fry[2]	
20 June-5 August	[3]*a*	[3]*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
1962	6.600	-0.1092	5.272	-0.0645	4.964	-0.0486	2.122	0.0009	4.188	-0.0472	2.294	0.0135
1964	5.924	-0.0786	5.364	-0.0191	4.844	-0.0175	3.176	-0.0105	4.353	-0.0526	3.022	0.0073
1965	6.104	-0.0239	4.173	0.0158	3.714	0.0344	2.226	-0.0057	3.748	-0.0286	1.582	0.0278
1966	7.040	-0.1012	4.548	-0.0157	4.766	0.0003	1.628	-0.0075	3.203	-0.0274	3.913	-0.0729
1967	6.392	-0.0605	5.397	-0.0454	5.169	-0.0116	2.904	-0.0102	3.250	-0.0305	3.159	-0.0055
1968	4.358	-0.0704	5.504	-0.0771	4.567	-0.0332	3.704	-0.0170	3.815	-0.0541	4.143	-0.1164
1969	4.933	-0.0507	5.106	-0.0131	3.750	-0.0024	3.365	-0.0094	3.582	-0.0311	1.695	0.0143
1970	5.679	-0.0580	3.786	0.0013	4.333	0.0057	2.894	0.0001	3.719	-0.0314	3.062	-0.0322
1971	6.722	-0.0686	4.578	-0.0208	4.633	-0.0081	2.121	0.0085	3.842	-0.0193	1.336	-0.0036
1972	5.081	-0.0275	2.687	-0.0106	3.041	0.0252	0.399	0.0456	3.343	0.0069	2.403	0.0042
Mean	5.383	-0.0649	4.642	-0.0249	4.378	-0.0056	2.454	-0.0005	3.704	-0.0353	2.661	-0.0164
30 June-5 August												
1962	7.226	-0.1299	6.007	-0.0888	5.407	-0.0632	2.721	-0.0182	4.351	-0.0524	4.206	-0.0475
1964	5.807	-0.0745	5.502	-0.0238	4.265	0.0023	3.325	-0.0156	4.248	-0.0491	3.148	0.0030
1965	7.635	-0.0783	5.050	-0.0159	4.310	0.0127	2.203	-0.0049	3.772	-0.0294	1.993	0.0138
1966	7.477	-0.1157	5.747	-0.0551	4.810	-0.0011	1.417	-0.0005	3.128	-0.0250	4.566	-0.0944
1967	6.365	-0.0597	6.666	-0.0848	6.266	-0.0458	3.705	-0.0352	3.739	-0.0457	3.837	-0.0267
1968	4.152	-0.0633	5.713	-0.0842	5.025	-0.0489	4.355	-0.0393	3.671	-0.0492	4.472	-0.1276
1969	5.187	-0.0589	5.774	-0.0346	4.254	-0.0187	3.644	-0.0184	3.781	-0.0376	1.333	-0.0260
1970	6.035	-0.0705	4.667	-0.0296	5.036	-0.0189	2.932	-0.0012	3.970	-0.0398	3.493	-0.0466
1971	7.163	-0.0834	5.338	-0.0463	5.308	-0.0306	2.655	-0.0093	4.061	-0.0265	2.143	-0.0304
1972	5.983	-0.0580	3.201	-0.0280	3.537	0.0085	0.832	0.0310	3.640	-0.0031	3.261	-0.0248
Mean	6.303	-0.0792	5.367	-0.0491	4.892	-0.0106	2.779	-0.0112	3.836	-0.0358	3.245	-0.0355

[1]Calculated from geometric mean catches except age 0.
[2]Calculated from geometric mean catches in lake area A only.
[3]The regression parameter *a* is the natural logarithm of the calculated catch on 22 June, and the parameter *b* is the instantaneous rate of decline in catch.

(area A) than in the middle section and the outlet with the exception of station 7S. They were never caught at station 8N. Their distribution in early summer probably reflected the distribution of parent spawners in the previous fall.

Catches of char fry tended to increase during the first four periods of sampling and then to decrease in the last two periods. They may not have been as available to the beach seine as early in the spring as sockeye salmon fry because of later emergence from the spawning grounds.

Annual Variation in Abundance

The geometric mean of the annual mean catches in each area during 20 June-19 July was considered the best estimate of the relative abundance in Lake Aleknagik during the period of the summer when sockeye salmon fry were concentrated inshore. On the average, juvenile sockeye salmon were the most abundant species in the littoral and also exhibited the greatest annual absolute as well as relative variation (coefficient of variation) over the years. Significant differences were detected in the mean catches by year for all species, but the relative annual variations in catches for the next two most abundant species (threespine stickleback and slimy sculpin) were low compared to that of juvenile sockeye salmon.

Linear correlation coefficients were calculated for the purpose of examining relationships among annual estimates of abundance, apparent mortality rates, and selected physical parameters. A total of 84 pairs of variables was examined for correlation and statistically significant correlations at the 5% level were found among 38 pairs. Obviously some caution is needed in the biological interpretation of these data. It is expected that 5% of the tests would reject the null hypothesis that they are independent. Some partial correlation coefficients were examined; however, none were found statistically significant. The notable results of the correlation analysis were: (1) significant positive correlations between water temperature and apparent mortality rate for threespine stickleback (age I), ninespine stickleback, and sculpin ($n = 10, r = 0.80, 0.84,$ and 0.76, respectively); (2) significant correlation between apparent mortality rates of ninespine stickleback and sculpin ($r = 0.86$); and (3) lack of significant correlations involving sockeye salmon fry. The correlations between water temperature and apparent mortality rate suggest that ninespine stickleback and sculpin populations (which do not become pelagic) experience higher mortality rates at higher water temperatures. The higher mortality may be the result of increased spawning rate and/or rate of predation. Since sockeye salmon fry constitute a major portion of the inshore fish community and exhibit greater annual variation in abundance than the rest,

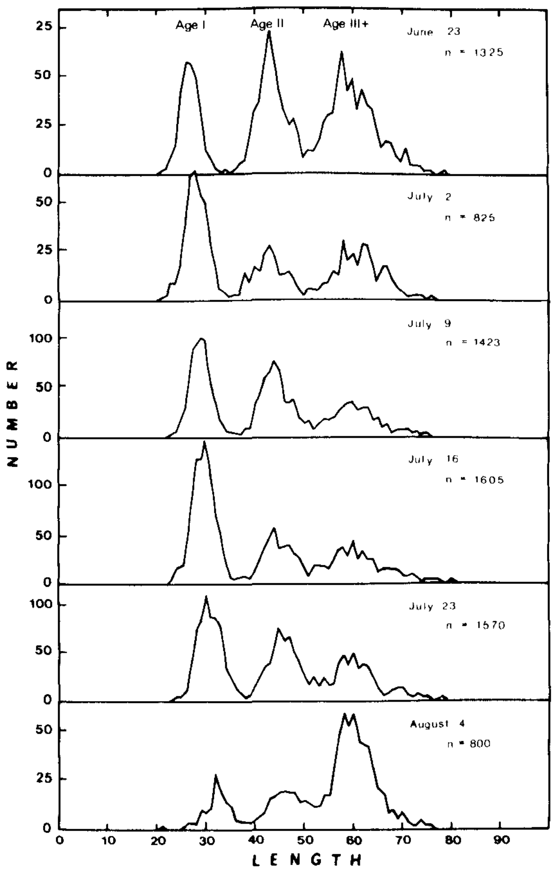

FIGURE 5.—Length-frequency distributions (mm) of threespine stickleback, 1966.

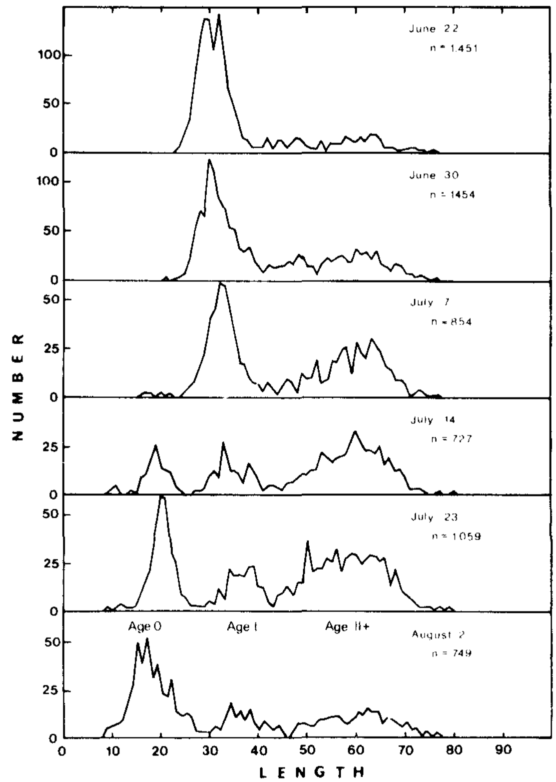

FIGURE 6.—Length-frequency distributions (mm) of threespine stickleback, 1968.

they would appear to have the greatest potential for affecting the abundance of fish of other species. The depressing effect of high abundance of sockeye salmon fry on the abundance of other species was suggested by Parr (1972), but such an effect may be observable only after a time lapse and would be detectable only with observations from a greater number of years. No significant correlation was detected between the catches of sockeye salmon fry and the catches of other species in the same year or in the following year.

A significant, although highly variable, relationship was apparent between the abundance of parent spawners and mean catch of sockeye salmon fry in Lake Aleknagik ($r = 0.62$, $n = 11$). A comparison of the density of sockeye salmon spawners with mean catch of sockeye salmon fry in the Nushagak District is given in Table 8. A positive relation between density of adult

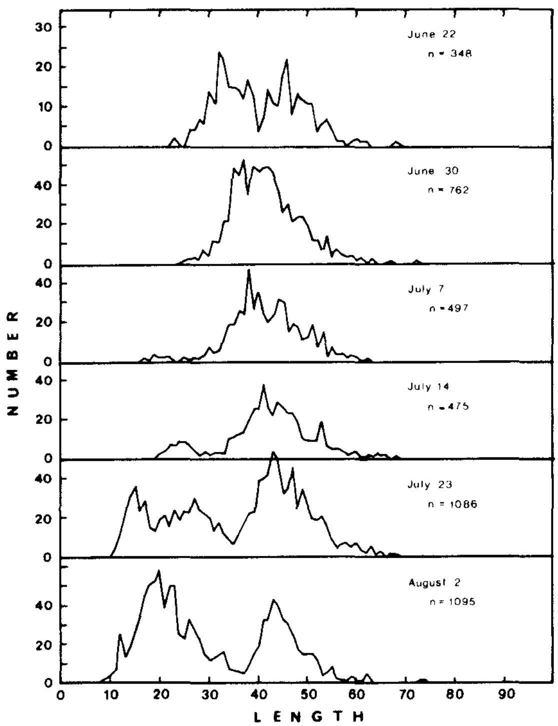

FIGURE 7.—Length-frequency distributions (mm) of ninespine stickleback, 1968.

spawners and density of fry progeny among years and lakes is indicated. The relation between the abundance of fry and the abundance of returning adults is of primary interest because of the possible value in forecasting the magnitude of adult runs. More years of observations are necessary, however, before this relation can be adequately defined.

Annual Variation in Length

Estimates of the average size of the fish in Lake Aleknagik are more precise than estimates of abundance from catches. The annual relative variation in mean length is much less, moreover, than the relative variation in catch. For example, the coefficients of variation in annual mean catches and mean lengths (20 July) for sockeye salmon fry were 67 and 9%, respectively.

The annual estimates of mean length on 20 June and 20 July, which represent the sizes of the fish at the beginning and end of early summer, were examined for determination of the major factors regulating growth. Annual mean lengths of sockeye salmon fry, threespine stickleback (age I), and char fry on 20 June were not significantly correlated. A significant part of the annual variation in lengths of sockeye salmon fry and char fry at this time was explained by the surface water temperatures on 20-24 June (Figure 9). Water temperature on 20 June is largely a function of the date of ice breakup and amount of solar radiation. Thus the annual growth attained in the spring by sockeye salmon fry and char fry is primarily a function of climatological conditions. The mean length of age I threespine stickleback was most closely correlated, however, with the abundance of sockeye salmon fry in the previous year. The best rela-

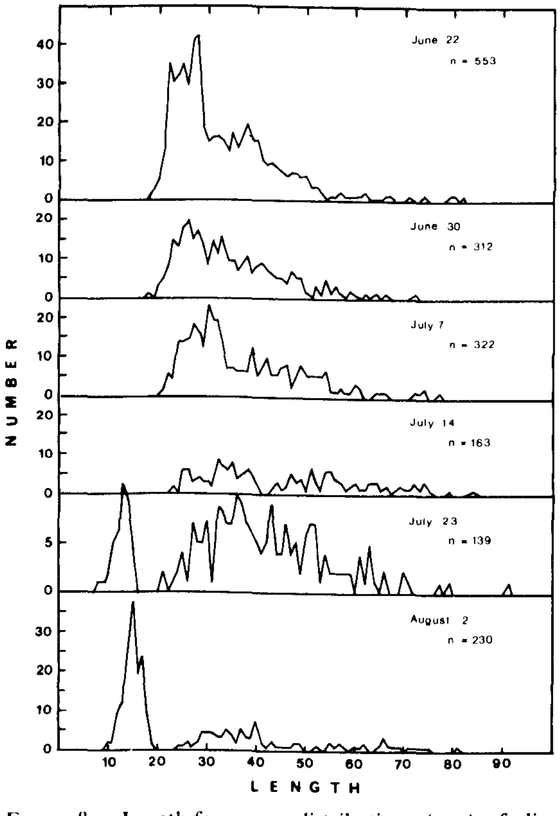

FIGURE 8.—Length-frequency distributions (mm) of slimy sculpin, 1968.

TABLE 8.—Densities of parent spawners and mean beach seine catches of sockeye salmon fry for years and lakes in which six or more seine hauls were made during 20 June-19 July for 1962 through 1972.

Lake	Year (i)	Sockeye salmon escapement in year i-1 (thousands)	Escapement density (number per km² of surface area)	Mean catch of sockeye salmon fry in year i	Adult sockeye salmon returns in years i+3-5 (thousands)
Tikchik lakes	1964	166	595	45	160
Igushik lakes	1965	129	1,743	163	640
Nunavaugaluk	1965	13	146	17	—
	1966	12	135	16	—
Kulik	1969	31	689	36	—
	1970	17	378	50	—
	1971	55	1,222	234	—
	1972	66	1,447	77	—
Beverley	1969	112	1,244	78	—
	1970	27	300	59	—
	1971	238	2,644	71	—
	1972	245	2,722	85	—
Aleknagik	1962	153	1,840	278	497
	1963	48	580	42	203
	1964	31	370	171	321
	1965	155	1,867	565	375
	1966	220	2,646	380	604
	1967	287	3,464	335	262
	1968	92	1,102	34	—
	1969	117	2,129	85	—
	1970	160	1,931	127	—
	1971	302	3,639	405	—
	1972	182	2,193	131	—

tionship was obtained by regressing the mean length on the logarithm of catch (Figure 10). Thus the mean length of threespine stickleback at age I is largely determined by the abundance of their main competitor when they were age 0.

The annual mean lengths on 20 July among

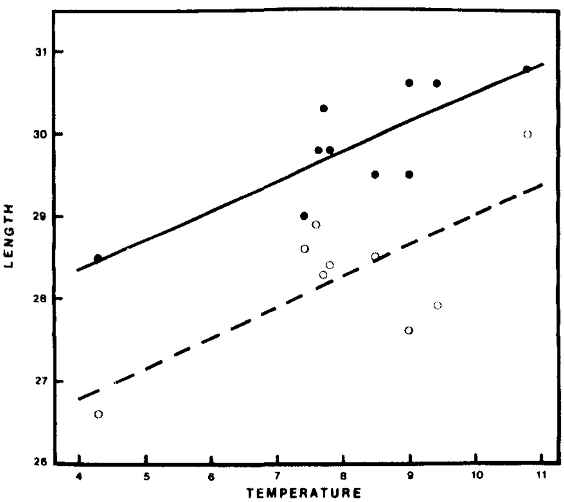

FIGURE 9.—Relationships between mean length (mm) on 20 June and mean surface water temperature from 20 to 24 June. Sockeye salmon fry (0): $Y = 26.93 + 0.36\ X$ ($r = 0.82$). Arctic char fry (0): $Y = 25.31 + 0.37\ X$ ($r = 0.71$).

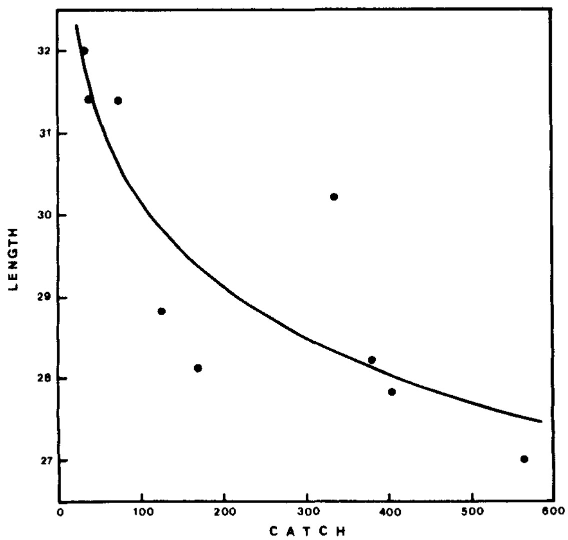

FIGURE 10.—Relationship between mean length (mm) of age I threespine stickleback on 20 June and mean catch of sockeye salmon fry in the previous year (20 June-19 July). $Y = 37.24 - 3.53 \log_{10} X$.

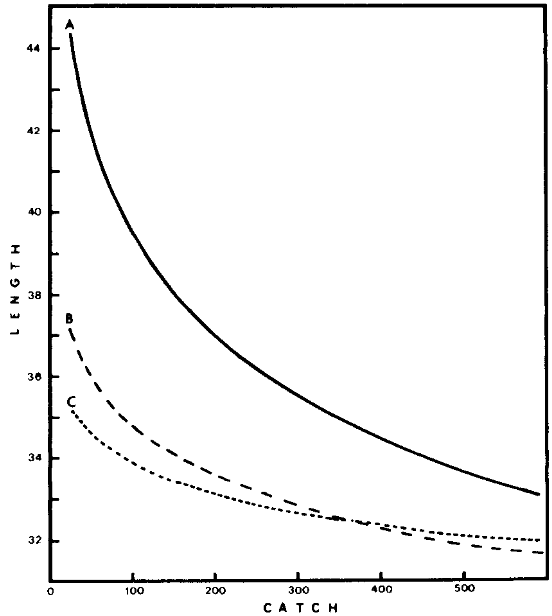

FIGURE 11.—Relationships between mean length on 20 July and mean catch of sockeye salmon fry from 20 June-19 July. A. Sockeye salmon fry: $Y = 56.82 - 8.62 \log_{10}X$ ($r = -0.86$). B. Age I threespine stickleback: $Y = 42.95 - 4.11 \log_{10}X$ ($r = -0.80$). C. Char fry: $Y = 38.93 - 2.56 \log_{10}X$ ($r = -0.85$).

the three species were significantly correlated but were most highly correlated between sockeye salmon fry and char fry ($r = 0.990$). Some correlation was evident between length and (1) date of ice breakup (small size — late date, large size — early date) and (2) average water temperature (small size — cold water, large size — warm water); however the highest correlations were between mean length and the mean catch of sockeye salmon fry. The last relationship appeared to be curvilinear, and regressions of mean length on logarithm of mean catch were significant at the 1% level (Figure 11).

Our main concern is with relationships involving sockeye salmon fry and threespine stickleback, as these are the most abundant species in the littoral. An increasing abundance of sockeye salmon fry results in a decreasing growth of these fish as well as of associated species in early summer. These data suggest a limiting capacity in the lake for growth of individual fish in the populations during the early summer but do not demonstrate a limiting capacity for the number of fish.

Annual variation in the relative abundance of other species did not appear to affect the growth of juvenile sockeye salmon; however, since growth of these species was density dependent (on juvenile sockeye salmon) and these species share a common food supply (primarily aquatic insects), there presumably was competition for food. If larger changes in the abundance of other species occurred in Lake Aleknagik, there would probably be corresponding changes in the growth of juvenile sockeye salmon. This question could best be examined by a comparison of growth and abundance among the lakes of the Wood River system.

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