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LITTLE TOGIAK LAKE FERTILIZATION

by

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FINAL REPORT

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INTRODUCTION

This study of the sockeye salmon runs to the Nushagak District of Bristol Bay is a continuation of a research program that began in 1946 with financial support from the Alaska Salmon Industry. It is currently supported by the National Marine Fisheries Service ($50,000 annually) and the Alaska Department of Fish and Game (ADF&G) ($4,000). The emphasis of this program has been a comparative ecological study of the lake systems to determine: 1) causes of annual and long-term variations in abundance of adult sockeye salmon; 2) the effects of abundance, distribution, and age composition of spawners on the production of juveniles and adults in the Wood River lake system (the major producer of sockeye in the District); and 3) methods for management of the freshwater environment to increase production of adult salmon by enhancing the growth and survival of juveniles. Our present program is largely directed toward this last objective.

We are investigating the potential of artificial fertilization as a means of increasing freshwater growth and survival of juvenile sockeye and thus increasing their survival to the adult stage. An experiment is being conducted in Little Togiak Lake (6 km^2) of the Wood River system (425 km^2) to determine the effects of added phosphates on the growth and abundance of sockeye as well as of other species of fish. Diammonium phosphate was added to the upper end of the lake (1 km^2) in late August of 1974 and 1975, and over most of the lake in mid-July 1976-1978. No fertilizer was added in 1979 and one of our primary objectives this year was to determine whether the biological conditions in the lake would return to normal, i.e., pre-fertilization.

METHODS

Since the experimental fertilization of Little Togiak Lake was conducted under natural, and thus uncontrolled, environmental conditions it was important that we had several long-term measurements of environmental parameters so the effects of fertilization could be separated from natural annual variation. Although intensive sampling in Little Togiak Lake did not begin until 1973 for some parameters, e.g., chlorophyll and zooplankton abundance, we had long-term measurements in Lake Aleknagik. Annual estimates of the growth of sockeye fry (mean length or calculated weight September 1) were available for each of the Wood River lakes since 1958, and estimates of their relative abundance (from the abundance of parent spawners) and spawner-return statistics were available for each lake since 1946. Monthly temperature and precipitation data have been collected at Dillingham since 1919 so we

could determine if the weather during the years of the experiment was typical or exceptional. Spring (April-May) weather determines when the ice breaks up and thus the biological timing of such events as smolt migrations and phytoplankton blooms.

Our methods for measuring the effect of fertilization are to compare measurements between 1) fertilized and unfertilized areas of Little Togiak Lake within a year, 2) fertilized and unfertilized years in Little Togiak, and 3) Little Togiak and Lake Aleknagik (and to some extent other lakes) in normal years compared to years of fertilizing.

Detailed methods for field collection of observations and laboratory procedures for fish and fish food (zooplankton and insects) are given by Rogers (1979) and those for phytoplankton by Hardy (1979). These papers also present the respective results of the effects of fertilization through 1977. This report will emphasize the results of our observations in 1978-1979.

RESULTS

The 1979 field season was shortened because funding was reduced from that available in past years. A full field crew was not available until mid-June and field work terminated on September 6, whereas in past years, field work continued until at least September 20.

Physical environment

There have been some significant changes in the weather in Bristol Bay over the past 60 years. The most pronounced changes have been in the average air temperature during the winter months (November-March). Winter temperatures dropped in the mid-1940's from the averages of the 1920's and 1930's, and there were six consecutive cold winters from 1970 through 1975. Then the winter of 1976-1977 was the warmest on record and the next two winters were relatively mild (Fig. 1). Cold winters may adversely affect the survival of salmon eggs on lake beaches when the density is high (Rogers 1975). The pattern of winter air temperatures roughly corresponds to the abundances of the Nushagak sockeye runs but a significant correlation is not evident for the individual years, e.g., there were large returns from spawning in 1973-74.

Average air temperatures during the summer (June-August) and fall (September-October) have not varied much over the past 25 years but have been generally cooler than the long-term average. There were successive cold springs in 1964-1966, 1971-1972, and 1975-1977 and, consequently, late ice breakups in all years except 1977 when, because of the preceding mild winter, the date of ice breakup was about average. The winter of 1978-1979 was very mild until February and this was followed by exceptionally warm temperatures during March-May

(Fig. 2). Ice breakup in the spring was in mid-May and comparable to the exceptionally early date in 1958 (May 14). The early breakup along with above-average solar radiation during June and July resulted in the warmest water temperatures recorded about September 1 in the Wood River lakes during the past 20 years (Table 1). However, temperatures in the surface waters (above 20 m) were not much different than in 1978 and not as warm as in 1974.

Dates of ice breakup and inshore surface water temperatures in Little Togiak Lake are given in Table 2. Ice breakup has been about one week later than in Lake Aleknagik and the dates for 1974 and 1979 were estimated from the dates reported for Aleknagik by personnel of ADF&G. The surface temperature in Little Togiak Lake was usually at a maximum in early August, whereas the average temperature in the upper 20 m usually reached a maximum in late August, then the lake began cooling in September. The maximum temperature in 1979 occurred in the second week of August (Table 3; Fig. 3). Solar radiation was relatively high in 1974, low in 1975, and for late August to early September, it was exceptionally high in 1979. Maximum surface temperatures occurred in 1978 when there was unusually clear weather in late July and early August. Warm temperatures in the spring and early summer generally enhance the growth of the juvenile sockeye, and the timing of their movement offshore is affected by the water temperature.

Lake level typically peaks in June about 2-3 weeks after ice breakup, declines during July and early August, and then increases in late August or September from rainfall. Lake level was exceptionally high in August 1977 and it was also high in August 1979. High lake levels in late summer or fall generally correspond to high turbidity (low secchi depths) which probably reduces the amount of light for photosynthesis by phytoplankton (Fig. 4).

Specific conductance (conductivity), which is a measure of the concentration of ionized substances in the water, has not varied much over the years except in 1977. In that year the values were normal at the beginning of the summer, then unusually low in July and early August, and unusually high in late August and early September. No significant changes were observed to correspond with applications of diammonium phosphate to Little Togiak Lake whereas water transparency declined with the increases in phytoplankton that were caused by fertilization.

Phytoplankton and Zooplankton

The biomass of phytoplankton (as measured by chlorophyll *a*) in Little Togiak Lake returned to normal during 1979 (Table 4, Fig. 5). In each of the previous years in which phosphates were added there was a significant increase in the amount of chlorophyll *a*. In 1974 and

1975 the increases occurred only in the upper (west) end of the lake (Area A) as fertilizer was only added there. In the other fertilized years (1976-1978) there were increases throughout the lake even though fertilizer was not applied at the upper end of the lake in 1977 or 1978.

The early summer peak in chlorophyll in Little Togiak (prior to fertilizer application) was correlated with the amount of phosphorus in salmon carcasses the previous fall (Fig. 6). The large escapement of sockeye in 1974 was followed by a high amount of chlorophyll in July 1975; however, the volume of zooplankton during June and early July was very low that year; thus the high biomass of phytoplankton may have been caused by a low rate of predation rather than a high availability of nutrients. Similarly, the high biomass of chlorophyll in 1977 corresponded to a low volume of zooplankton.

Compared to the chlorophyll values from Lake Aleknagik the main increases in the biomass of phytoplankton from fertilization in Little Togiak Lake occurred during July and August. In 1979, when no fertilizer was added to Little Togiak Lake, the amount of chlorophyll during July and August was lower than in Lake Aleknagik. This was also the case in the prefertilized year 1973 (Fig. 6).

The mean volume of zooplankton from late June to early August was greater in Lake Aleknagik than in Little Togiak Lake in each year from 1973 through 1977, about equal in 1978, and then greater in Little Togiak Lake in 1979. In late August and September there has been a consistently greater volume of zooplankton in Little Togiak Lake, although in 1973 (prior to fertilization) the difference between the lakes was small (Fig. 7). The early summer differences between the lakes is probably caused by the earlier ice breakup (warmer temperatures) in Lake Aleknagik and generally higher densities of planktivorous fish in Little Togiak Lake.

In 1973 and 1977 there were very small escapements of sockeye to the upper lakes of the system (Beverley and Kulik); subsequently, in 1974 and 1978 there were high volumes of zooplankton in these lakes during late August. In contrast, there were large escapements to all of the lakes in 1978 and the mean volume of zooplankton for the lake system in 1979 was the lowest observed since observations began in 1968. The volume of zooplankton in Little Togiak Lake was higher during June-July in 1979 than in past years, but it was relatively low in August. Perhaps if the lake had been fertilized, the volume of zooplankton would not have declined so soon.

Abundance and Growth of Fry

The abundance of sockeye fry in the Wood River lakes is usually directly related to the abundance of parent spawners and their growth

is usually inversely related to the abundance of spawners. Estimates of the relative abundance of fry have been made annually in each of the lakes since 1958 from townet sampling in late August-early September. Following the large escapement of sockeye in 1978 (about 2.3 million), there were generally large catches of fry in 1979 (Table 5). As usual the densities of fry were greater in lakes Aleknagik and Little Togiak than in the other lakes. There were relatively few yearling sockeye from the 1977 brood year but the catches of threespine sticklebacks were well above average.

The catches of sockeye fry are somewhat dependent on the distribution of the fish as well as on their abundance, which is what we want to estimate. Ice breakup was very late and water temperatures were quite cold in 1971; subsequently, the townet catches of sockeye fry were small relative to the abundance of parent spawners and the early summer beach seine catches of fry in Lake Aleknagik. Most of the fry had apparently not moved offshore in August as they typically do. By contrast, in 1974 and 1979, there was an early ice breakup and warm temperatures. The beach seine catches of fry during June 24 to July 17 were low relative to the abundance of parent spawners (Fig. 8). In warm years the fish move offshore earlier and are thus more available to townet sampling and less available to beach seine sampling.

Beach seine catches of sockeye fry relative to the density of parent spawners (thousands per km^2 of lake surface area) were generally lower in Little Togiak Lake than in Lake Aleknagik. It may be that sockeye fry in Little Togiak Lake are not as available in the spring (spawning and presumably emergence is later) and move offshore earlier because the littoral zone of the lake is very limited compared to that in Lake Aleknagik. Nevertheless, the annual mean catches in the lakes generally reflect the abundances of the fry (numbers of spawners in Lake Aleknagik for 1977 and 1978 are not yet available from ADF&G). The abundance of fry in Little Togiak Lake was relatively low in 1973 and 1974 but has been consistently high since then.

The mean lengths of the sockeye fry on September 1, 1979 were generally lower than average in Lake Aleknagik and the central (west end) Lake Nerka, about average in the remainder of Lake Nerka and in Lake Kulik, and larger than average in Little Togiak Lake (Table 6). The size of the fry in 1979 was relatively large considering their abundance and the low volumes of zooplankton in late August. However the early ice breakup in 1979 made the length of the growing season (to September 1) longer than in any year since 1958, when the fry were also large but their abundance was relatively low).

The mean lengths of age I threespine sticklebacks in 1979 were below average in Lake Aleknagik and Little Togiak but above average in the other areas of the system. Their growth is usually dependent on the abundance of sockeye fry; thus their mean lengths are correlated with the mean lengths of the fry.

The growth rate of sockeye fry in Little Togiak Lake was greater in 1979 than in any prior year (since 1973) and their mean length on September 1, 1979 was exceeded only in 1958, 1959, and 1962. The parent escapements for those years were small (6 to 16 thousand) whereas the parent escapement for the fry in 1979 was large (45 thousand). The abundance of sockeye fry in Little Togiak Lake has been high for the past 5 years, yet their growth was above average in both 1978 and 1979. In addition, their growth rate in 1979 was greater than the growth rate of fry in Lake Aleknagik (Table 7). Although the growth of sockeye fry in Little Togiak has increased the past 2 years, there has not been a comparable increase in the growth of threespine sticklebacks, which are their competitor for food.

Annual statistics on the relative abundance and size (calculated mean weight) of sockeye fry, volume of zooplankton, water temperature, and amount of chlorophyll in Lake Aleknagik and Little Togiak are summarized in Figure 9. After fertilization the average amount of chlorophyll during mid-June to mid-August increased in Little Togiak Lake. The volume of zooplankton did not increase relative to Lake Aleknagik until 1978, but in 1979 it was considerably higher in Little Togiak Lake. Consequently, the sockeye fry were considerably larger in Little Togiak Lake in 1979.

Abundance and Size of Smolts

The smolt sampling in Little Togiak River got started late and some dates in June were not sampled because of budgetary restraints. Consequently, at least the first 2 weeks of the migration were missed and most of the age II smolts were probably not sampled (Table 8). Estimates for missing dates between June 16 and 27 were made from data on adjacent dates and the estimated number of smolts migrating after June 16 was 136,000. (Table 9). Mean weights were estimated from length-weight statistics (Table 10). The age I smolts at the beginning of our sampling in 1979 were larger than the smolts at comparable times in past years (Fig. 10).

The size of the age I smolts from Little Togiak Lake has increased relative to the size of smolts from the lake system since we began fertilizing the lake; however, the size of smolts from the lake system in 1979 is not yet available.[1] Increases in the growth of junvenile sockeye in Little Togiak Lake have come largely after September 1 because the fry have generally been smaller than those in the other lakes at that time.

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[1]Statistics for smolts from the Wood River lakes after 1975 are provided by the Alaska Department of Fish and Came.

The relative growth rate from fry on September 1 to age I smolts during the first 20 days of migration (i.e., prior to spring growth) has increased since fertilization in Little Togiak Lake. By comparison there has been no increase for fish from Lake Aleknagik, e.g., fish from the 1976 brood year increased 495% in weight in Little Togiak Lake and only 160% (about average) in Lake Aleknagik (Tables 11 and 12). Of course not all fry on September 1 will migrate the following spring so this growth rate may be in error if a significant proportion of the fry hold over to migrate at age II. This is most likely to occur when the growth of the fry has been relatively poor. The growth from age I juveniles to age II smolts would provide a better criterion for measuring the effects of fertilization; however age II smolts are not abundant in most years so the data base is poor. The growth rates from yearlings on September 1 to age II smolts were higher in Little Togiak than in Lake Aleknagik for the 1974 brood year (68% to 47%) and the 1975 brood year (113% to 60%); however, we do not have a good prefertilization data base for Little Togiak (i.e., years when age II smolts were relatively abundant).

Adult Escapements and Runs

Spawning ground surveys were conducted in 1979 as in past years except we were unable to collect otoliths from the late beach spawners in the upper lakes of the system. High water levels in late August also prohibited us from making counts of spawners in Moose creek and Grant River and impaired visibility in Stovall and Kema creeks. The numbers of spawners in the small creeks of the system were generally above average but not exceptional (Table 3).

The escapement to Little Togiak Lake has been enumerated in 6 years (Fig. 11). In other years (since 1946) the escapements were estimated by aerial surveys alone. The patterns of the daily escapements to Little Togiak Lake generally follow the patterns of escapement into the lake system. Thus, fish bound for Little Togiak Lake are probably mixed with other stocks in the run and are equally represented in early and late segments of the run. The timing of the 1979 run was the earliest on record as the spring weather was exceptionally warm.

The first adult returns from juveniles that were in Little Togiak Lake when the entire lake was fertilized (1976) came in 1979, age 1.2 and 2.2 returns. These were the two most abundant age groups in the 1979 escapement to the lake (30% and 38%, respectively), although there was a significant difference in the age compositions by sex: males 34, 17, 44, and 5%; females 26, 34, 33, and 7% for ages 1.2, 1.3, 2.2, and 2.3, respectively. The preliminary adult returns to Little Togiak Lake were calculated by assuming equal numbers of males and females and preliminary rates of exploitation by the Nushagak fishery. The escapement was 44,000 and the run was about 87,000. Both were slightly

smaller than in 1978 (45,000 and 93,000) but well above average. However, the escapements and runs to the lake system were also very large in 1978 and 1979, so the escapements to Little Togiak Lake were not exceptional.

The Nushagak sockeye runs in 1978 and 1979 were exceptionally large compared to the runs since 1950 (Fig. 12). The run in 1978 was exceptional when compared to the runs to the other districts in Bristol Bay; however, there were unusually large runs to all districts in 1979. The runs to the Wood River system in 1978 and 1979 were large but comparable to historical runs (e.g., 1946-1948) and the run in 1959 (Fig. 13). The production from these past large escapements was relatively poor (i.e., return per spawner less than one), so the large escapements in 1978 and 1979 may result in only average or below-average runs in 1982-1983.

The runs to Little Togiak have averaged 2.4% (range .7 to 4.6%) of the runs to the Wood River system. The effect of the fertilization of Little Togiak Lake on the production of adult sockeye will be determined by comparing the runs and relative production (return per spawner) between Little Togiak and the other lakes in the system. A complete evaluation will not be possible until about 1983, although we should have a fair measure of the effect after the returns in 1981.

LITERATURE CITED

Hardy, F. J. 1979. Effects of inorganic fertilization on phytoplankton in Little Togiak Lake, Alaska. M.S. Thesis, Univ. Washington, Seattle. 108 pp.

Rogers, B. J. 1979. Responses of juvenile sockeye salmon and their food supply to inorganic fertilization of Little Togiak Lake, Alaska. M.S. Thesis, Univ. Washington, Seattle. 112 pp.

Rogers, D. E. 1975. Systems modeling of sockeye salmon in the Wood River lakes. Univ. Washington, Fish. Res. Inst. Annu. Rep. FRI-UW-7511. 51 pp.

Table 1. Summary of physical measurements in the Wood River lake system in 1979 and the long-term means and ranges from prior years.

Measurement	1979	Long-term Mean	Long-term Range	Number of years
Date of ice breakup in Lake Aleknagik	5/16	6/1	5/14,6/16	30
Mean water temperature 0-20 m in Lake Aleknagik on:				
June 21	7.0	5.3	3.6,7.6	17
July 12	9.8	8.1	5.7,11.3	17
August 3	14.0	10.6	7.7,13.1	17
Sept. 2	12.2	11.2	9.3,12.9	17
Mean water temperature about Sept. 1 in the lake system				
0-10 m	12.2	10.8	8.6,12.4	20
total water volume	8.2	7.1	6.1, 7.9	20
Mean daily solar radiation (g cal/ cm^2) during:				
June	437	421	293,542	15
July	448	388	308,489	17
August	275	283	229,329	18
Sept. 1-15	270	215	114,300	18
Sept.16-30	-	155	122,216	8
Mean lake level (cm) at Lake Nerka in				
June	159	145	103,203	27
July	112	117	67,176	27
August	123	82	32,178	27
Sept. 1-15	111	81	43,130	27
Sept.16-30	-	89	45,176	24

Table 2. Dates of ice breakup and the average surface temperatures at insect traps in Little Togiak Lake by 5-day periods, 1973-1979.

	1973	1974	1975	1976	1977	1978	1979
Date of ice breakup	6/8	5/27	6/15	6/17	6/13	6/2	5/24
June 3	0.0	-	0.0	0.0	0.0	-	-
8	0.0	-	0.0	0.0	0.0	-	-
13	-	-	0.0	0.0	1.5	6.9	-
18	3.2	8.6	4.0	1.0	6.0	7.2	8.2
23	-	-	4.3	5.0	8.8	7.9	9.1
28	8.2	11.6	5.7	8.4	10.7	8.2	9.3
July 3	10.7	15.9	6.2	7.9	9.2	7.5	11.3
8	10.3	14.7	9.7	10.4	10.1	8.3	10.4
13	10.2	12.8	11.4	11.6	12.1	10.3	10.6
18	11.5	12.3	11.5	13.0	11.9	10.0	13.7
23	13.1	15.7	13.0	11.7	12.3	11.1	12.4
28	11.5	15.2	13.5	12.0	12.2	14.3	13.8
Aug 2	13.5	13.6	13.7	13.7	11.2	17.6	14.1
7	13.0	13.9	14.6	12.6	11.4	17.4	14.0
12	13.1	14.4	14.9	13.1	11.3	15.4	13.3
17	13.0	14.7	13.7	12.4	11.3	14.7	11.3
22	12.2	13.8	13.8	13.5	13.2	14.5	11.8
27	10.2	13.1	12.9	13.0	14.2	14.6	12.1
Sep 1	10.0	13.2	11.5	11.2	13.8	14.0	10.9
6	9.5	13.0	-	11.6	12.6	12.4	10.2
11	9.4	12.3	10.5	10.4	12.2	11.7	-
16	-	11.4	10.2	9.9	-	11.2	-
21	-	10.1	9.9	8.1	-	-	-
26	-	-	9.4	-	-	-	-

Table 3. Average water temperatures in the upper 20 m of Little Togiak Lake, 1973-1979.

Date	1973	1974	1975	1976	1977	1978	1979
June 19-20	4.1	6.8	-	-	4.1	6.0	6.2
26-28	4.6	7.8	5.1	4.8	5.7	7.0	7.6
July 3-5	5.5	9.4	5.2	-	7.0	7.0	9.0
9-11	6.5	9.8	6.8	6.1	7.3	7.7	9.2
16-18	8.3	-	7.8	-	8.1	8.4	10.3
23-26	9.9	11.5	8.5	7.6	9.7	9.1	11.5
July 30-Aug. 3	9.8	11.8	9.6	8.6	-	10.5	11.2
Aug 7-10	10.2	11.5	9.8	9.4	-	11.1	12.3
15-18	10.6	11.4	9.7	9.8	-	11.3	11.7
21-24	-	11.9	10.4	10.5	-	10.7	11.5
28-29	9.7	-	10.5	10.1	-	11.6	11.3
Sept 1-4	9.1	11.5	-	-	10.9	-	-
5-7	8.8	11.5	9.7	10.7	-	11.0	11.0
12-14	8.2	11.2	9.7	9.9	10.9	10.6	-
19-21	8.2	10.9	9.0	8.4	-	10.1	-
25	7.5	-	9.0	-	-	-	-
Oct 2	-	-	8.8	-	-	-	-

Table 4. Density of chlorophyll *a* (mg/m^3) for 0-10 and 10-20 m depth intervals and the amount in the upper 20m, (mg/m^2) at two stations in Little Togiak Lake and Lake Aleknagik during 1979.

Lake	Date	Days after ice breakup	Station 1			Station 5		
			0-10	0-20	0-20	0-10	10-20	0-20
Little Togiak	6/20	27	1.4	2.3	36	1.6	2.2	38
	26	33	1.1	1.7	28	1.1	2.2	33
	7/ 4	41	.9	1.7	26	.9	1.1	19
	11	48	.8	1.2	20	.5	1.2	17
	17	54	.8	1.4	22	.6	.9	15
	24	61	1.4	1.6	30	1.0	1.3	23
	30	67	1.1	1.3	24	.7	1.0	17
	8/ 7	75	1.2	1.3	25	.7	1.1	18
	15	83	1.3	1.2	26	.8	.7	15
	21	89	1.3	.8	21	.8	.8	16
	28	96	1.4	.9	23	1.5	1.1	26
	9/ 5	104	1.1	.5	16	1.1	.8	19
Aleknagik	6/21	36	1.3	1.6	29	1.4	1.5	29
	7/12	57	1.0	1.4	24	1.1	1.1	22
	8/ 3	79	1.1	1.1	22	1.3	1.3	26
	9/ 2	109	1.9	1.9	38	1.9	1.7	36

Table 5. Geometric means of townet catches by sampling area in the Wood River lake system in 1979 and the means and ranges in means from previous years.

Lake		Sockeye fry (age 0)			Sockeye (age I)			Threespine stickleback		
		1979	1958-1978		1979	1958-1978		1979	1958-1978	
		mean	mean	range	mean	mean	range	mean	mean	range
Aleknagik	A	308	21	1-377	0	1.4	0-42	86	38	2-377
	B	99	25	1-478	0	1.4	0-43	48	50	1-502
	C	18	36	5-521	0	1.4	0-31	24	54	7-196
South	A	1	8	0-260	0	1.4	0-14	32	5	0-114
Nerka	B	4	8	1-101	0	1.1	0-12	48	6	0-95
	C	5	3	0-15	0	0.8	0-5	9	2	0-26
Central	A	74	3	0-37	7.5	0.9	0-15	30	2	0-99
Nerka	B	8	10	0-65	0	1.1	0-13	46	7	0-125
	C	2	10	0-60	0	0.9	0-8	170	6	0-278
North	A	107	19	0-69	0	0.8	0-4	132	12	0-243
Nerka	B	5	30	3-490	0	0.4	0-5	22	9	0-112
	C	30	17	2-140	0	0.5	0-3	34	14	0-83
Beverley	A	-	13	0-163	-	1.3	0-10	-	12	0-68
	B	-	6	0-117	-	1.0	0-11	-	6	0-69
	C	-	5	0-68	-	0.6	0-7	-	10	1-108
Kulik	A	24	8	0-92	0.3	1.2	0-52	38	9	0-107
	B	73	8	0-42	2.0	1.3	0-28	53	6	0-63
	C	3	16	0-130	0	2.1	0-31	69	6	1-108
Little	A	53	37	0-555	0.8	4.7	0-15	30	21	2-252
Togiak	B	238	38	3-304	2.5	3.4	0-53	143	56	4-1657
	C	124	21	3-145	1.3	2.5	0-102	221	38	2-245

Table 6. Mean lengths (live equivalent in mm on Sept. 1) by sampling area in the Wood River lake system in 1979 and the means and ranges in means from previous years.

Lake		Sockeye fry (age 0)			Sockeye (age I)			Threespine stickleback (age I)		
		1979	1958-1978		1979	1958-1978		1979	1958-1978	
		mean	mean	range	mean	mean	range	mean	mean	range
Aleknagik	A	52.0	54	42-62	-	86	70-108	42.1	42	38-49
	B	50.6	57	44-65	-	89	70-112	42.3	43	40-51
	C	50.4	58	44-69	-	92	69-114	42.8	44	40-51
South	A	59.4	59	52-67	-	99	85-111	47.2	45	42-49
Nerka	B	62.4	60	46-72	-	100	81-120	48.0	45	39-51
	C	66.7	63	54-75	-	100	86-107	49.2	46	42-54
Central	A	53.0	55	42-70	72.3	97	77-115	47.1	45	41-52
Nerka	B	55.7	58	50-65	-	96	77-110	46.5	44	38-49
	C	56.9	58	48-64	-	99	80-114	44.4	44	40-48
North	A	57.7	57	46-65	-	94	73-115	46.9	43	39-50
Nerka	B	56.1	58	45-69	-	92	78-114	47.5	43	37-51
	C	60.2	58	44-67	-	95	79-105	47.2	44	40-52
Beverley	A	-	54	43-61	-	91	75-104	-	44	38-48
	B	-	55	45-66	-	89	77-112	-	44	40-48
	C	-	61	48-69	-	91	81-98	-	44	37-47
Kulik	A	56.0	56	43-69	91.4	89	81-105	41.2	42	37-48
	B	60.9	57	46-72	93.5	90	81-99	44.7	44	40-48
	C	49.5	58	41-66	-	90	80-106	45.1	43	37-47
Little	A	53.3	52	44.63	89.6	90	76-107	41.8	42	37-48
Togiak	B	60.0	53	45-62	95.6	91	77-105	42.5	43	36-48
	C	58.0	55	43-66	97.8	91	77-104	41.2	43	39-49

Table 7. Growth rates of sockeye salmon fry and age I threespine stickleback from June 20 to September 1, 1962-1979.

	Sockeye fry (age 0)						Threespine stickleback (age I)					
	Aleknagik			Little Togiak			Aleknagik			Little Togiak		
Year	6/20	9/1	mm/day	6/20	9/1	mm/day	6/20	9/1	mm/day	6/20	9/1	mm/day
1962	30.6	54.1	.32		57.3		29.1	43.6	.20		43.6	
1963	-	62.1	(.43)		60.6		-	46.7	(.22)		47.5	
1964	30.3	60.4	.41		54.0		31.4	43.0	.16		42.9	
1965	29.0	53.6	.34		51.1		28.1	39.5	.16		42.8	
1966	29.8	47.5	.24		44.8		27.0	39.4	.17		41.7	
1967	29.5	43.4	.19		53.0		28.2	41.3	.18		40.8	
1968	30.8	57.9	.37		56.4		30.2	43.4	.18		43.2	
1969	30.6	61.4	.42		50.6		32.0	44.0	.16		45.1	
1970	29.8	59.0	.40		54.2		31.4	42.6	.15		45.0	
1971	29.5	54.6	.34		47.3		28.8	42.9	.19		39.2	
1972	28.5	54.8	.36		48.8		27.8	44.4	.23		42.1	
1973	28.0	66.7	.53	28.5	56.3	.38	29.0	49.5	.28	27.0*	42.0*	.21
1974	35.9	62.8	.37	30.5	53.9	.32	32.8	50.1	.24	30.5	48.5	.25
1975	28.5	55.3	.37	28.5	44.6	.22	31.1	42.3	.15	29.5	41.0	.16
1976	28.6	49.8	.29	29.0	49.0	.27	26.3	39.6	.18	26.5	41.0	.20
1977	29.5	48.0	.25	25.5	45.4	.27	28.2	40.8	.17	25.0	38.5	.18
1978	32.4	62.5	.41	29.5	54.9	.35	30.5	47.5	.23	27.5	41.1	.19
1979	31.4	51.5	.28	29.8	58.5	.39	33.0	42.3	.13	28.6	41.6	.18
Means												
1962-72			.35						.18			
1973-79			.36			.31			.20			.20

*From very small sample sizes.

Table 8. Daily estimates of the number and size of sockeye salmon smolts from Little Togiak River in 1979.

Date	Number			Mean length (mm)		Mean weight (g)	
	Total	Age I	Age II	Age I	Age II	Age I	Age II
June 17	8,192	8,062	130	83.5	97.0	5.3	8.4
18	18,024	16,582	1,442	85.2	101.6	5.6	9.3
19	7,752	7,752	0	84.6	-	5.5	-
20	no sampling						
21	no sampling						
22	8,504	8,504	0	82.9	-	5.2	-
23	4,592	4,500	92	84.0	104.2	5.4	10.3
24	6,545	6,545	0	84.0	-	5.4	-
25	8,085	8,085	0	82.4	-	5.1	-
26	no sampling						
27	no sampling						
28	1,729	1,729	0	82.3	-	5.1	-
29	1,932	1,886	46	82.2	114.6	5.1	13.8
30	658	658	0	82.5	-	5.1	-
July 1	1,155	1,155	0	82.6	-	5.1	-
2	6,671	5,784	887	93.2	107.8	7.2	11.6
3	2,121	2,121	0	83.5	-	5.6	-
4	1,519	1,519	0	83.7	-	5.7	-
5	1,883	1,883	0	82.6	-	5.5	-
6	665	665	0	84.9	-	5.9	-
7	938	938	0	83.2	-	5.6	-
8	476	476	0	-	-	-	-
9	1,155	1,155	0	85.9	-	6.1	-
10	1,295	1,295	0	86.5	-	6.2	-
11	315	315	0	-	-	-	-
12	294	294	0	87.4	-	6.3	-
13	1,350	1,350	0	89.1	-	6.5	-
14	324	324	0	-	-	-	-
15	1,374	1,374	0	93.1	-	7.1	-
16	2,046	2,046	0	88.0	-	6.1	-
17	414	414	0	-	-	-	-
18	612	612	0	90.2	-	6.5	-
19	438	438	0	88.8	-	6.3	-
20	324	324	0	-	-	-	-
21	108	108	0	92.3	-	7.1	-
22	30	30	0	-	-	-	-
23	228	228	0	97.8	-	8.7	-
24	2,640	2,640	0	92.8	-	7.1	-
25	738	708	30	93.2	123.0	7.0	17.2
26	204	204	0	97.0	-	7.7	-
27	168	168	0	94.2	-	7.4	-
28	198	198	0	96.5	-	8.1	-

Table 9. Estimates of the abundance and size of sockeye salmon smolts from Little Togiak Lake by 5-day periods in 1979.

Date	Number (hundreds)			Mean length (mm)		Mean weight (g)	
	Age I	Age II	Total	Age I	Age II	Age I	Age II
6/1-5	No sampling						
6-10	"						
11-15	"						
16-20	540	26	566	84.6	101.2	5.5	9.2
21-24	357	1	358	83.3	104.2	5.3	10.3
26-30	134	1	135	82.4	114.6	5.1	13.8
7/1-5	125	9	134	87.8	107.8	6.3	11.6
6-10	45	0	45	85.2	-	6.0	-
11-15	37	0	37	90.5	-	6.7	-
16-20	38	0	38	88.8	-	6.3	-
21-25	37	+	37	93.2	123.0	7.2	17.2
26-30	10	0	10	95.9	-	7.8	-
TOTAL	1323	37	1360	85.0	103.7	5.6	10.1

Table 10. Length-weight statistics for sockeye salmon smolts from Little Togiak Lake, 1979.

Length interval (mm)	June 18-25 Mean length (mm)	June 18-25 Mean weight (g)	June 18-25 Sample size	July 8 Mean length (mm)	July 8 Mean weight (g)	July 8 Sample size	July 22-29 Mean length (mm)	July 22-29 Mean weight (g)	July 22-29 Sample size
73-77	76.7	4.20	10						
78-82	80.1	4.62	31	80.4	5.14	14	79.0	4.95	1
83-87	84.0	5.41	21	84.2	5.79	17	86.0	5.62	12
88-92	90.3	6.60	3	88.7	6.31	4	90.1	6.45	52
93-97	97.0	8.36	1				94.5	7.39	58
98-102							100.1	8.71	26
103-107							104.1	10.17	23
108-112							109.2	12.00	6
123							123.0	17.18	1

Table 11. Summary of statistics on sockeye salmon from Little Togiak Lake.

Brood year	Spawners (1,000s)	Fry (Age 0) Catch B.S.	Fry (Age 0) Catch T.N.	Fry (Age 0) Mean weight	Yearlings (Age I) Catch B.S.	Yearlings (Age I) Catch T.N.	Yearlings (Age I) Mean weight	Smolts Age I No.	Smolts Age I W	Smolts Age II No.	Smolts Age II W	Adult returns (1,000s) 1.2	1.3	2.2	2.3	Total
1957	6	-	33	1.97	-	1	9.7	-	-	-	-	3	5	*	0	8
58	16	-	162	2.26	-	2	6.9	-	-	16	10.2	20	13	2	*	35
59	40	-	115	1.53	-	19	5.3	650	3.9	-	-	24	5	7	*	36
60	17	-	177	1.51	-	7	5.9	-	-	-	-	18	8	16	3	45
61	11	-	20	1.70	-	1	8.0	-	-	-	-	18	15	1	*	34
62	10	-	75	2.01	-	2	7.2	-	-	-	-	18	9	*	0	27
63	21	-	23	1.42	-	7	5.2	-	-	-	-	11	21	2	0	34
64	15	-	105	1.20	-	6	4.7	-	-	-	-	10	5	3	2	20
65	27	-	12	.90	-	3	5.7	-	-	-	-	23	15	15	1	54
66	22	-	36	1.34	-	2	5.4	-	-	-	-	45	28	2	1	76
67	10	-	56	1.61	-	1	7.7	-	-	-	-	11	8	2	1	22
68	20	-	3	1.17	-	+	6.0	-	-	-	-	9	15	0	0	24
69	20	-	39	1.44	-	2	5.6	-	-	-	-	2	18	15	1	36
70	55	-	9	.95	-	39	3.8	-	-	-	8.5	25	13	24	5	67
71	24	-	9	1.05	0	6	4.9	-	4.4	-	9.9	1	6	5	12	24
72	14	63	6	1.60	1	+	4.7	-	5.1	-	9.1	16	11	6	5	38
73	14	12	39	1.41	0	2	4.0	-	4.7	20	7.6	8	60	1	3	72
74	48	135	24	.80	0	3	5.6	167	4.7	144	9.4	27	19	33		
75	30	125	31	1.06	2	5	4.5	366	5.4	62	9.6	32				
76	18	118	15	.84	0	1	6.3	479	5.0	4+	9.2					
77	26	99	22	1.49	0	1	7.1	129+	5.5	-	-					
78	45	94	119	1.80		-	-	-	-	-	-					
79	44		-	-		-	-	-	-	-	-					

Beach seine catch is the mean of geometric mean catches by lake area during 6/26-7/18.
Townet catch is the mean of geometric mean catches by lake area and mean weights are on Sept. 1.
Number of smolts in thousands and mean weight for first 20 days of migration only.

Table 12. Summary of statistics on sockeye salmon from Lake Aleknagik.

Brood year	Spawners (1,000s)	Fry (age 0) Catch B.S.	Fry (age 0) Catch T.N.	Fry (age 0) Mean weight	Yearling (age I) Catch B.S.	Yearling (age I) Catch T.N.	Yearling (age I) Mean weight	Smolts* Mean weight Age I	Smolts* Mean weight Age II	Adult returns (1,000s) 1.2	1.3	2.2	2.3	Total
1957	88	-	13	2.15	-	+	10.4	4.8	-	3	61	0	0	64
58	63	-	13	2.22	-	+	6.1	5.6	8.2	80	35	0	1	116
59	205	-	102	1.54	-	14	5.7	4.2	6.7	26	136	18	11	191
60	85	-	88	1.79	3	2	5.6	4.1	8.1	176	321	18	33	548
61	153	278	53	1.43	-	+	6.2	4.3	8.5	36	434	3	24	497
62	48	-	20	2.15	2	1	8.6	5.0	10.3	83	119	0	1	202
63	31	171	22	1.98	1	+	7.4	4.9	8.1	57	252	2	1	312
64	155	565	96	1.39	3	38	4.3	3.5	-	45	82	145	57	329
65	220	380	175	.97	10	6	2.7	-	-	58	395	31	117	601
66	287	335	49	.74	6	+	4.0	-	-	38	216	8	35	297
67	92	35	9	1.75	2	+	5.3	-	-	14	40	2	0	56
68	177	85	54	2.09	2	+	6.6	-	-	70	198	1	1	270
69	160	127	41	1.85	4	+	5.7	-	-	3	108	77	39	227
70	302	405	13	1.46	2	1	8.0	-	-	103	462	23	29	617
71	182	131	7	1.48	3	1	5.6	-	-	41	347	112		
72	97	22	2	2.72	1	+	5.4	-	-	152				
73	162	26	39	2.23	1	0	-	5.1	8.6					
74	242	97	8	1.52	2	1	5.3	4.1	7.8					
75	459	204	338	1.11	4	8	3.0	2.7	4.8					
76	340	174	17	1.00	4	+	4.7	2.6						
77		34	5	2.22	0	0	-							
78		160	78	1.23	-	-	-							

*Mean weight for first 10 days of migration from the lake system.

Table 13. Ground survey counts of creek spawning populations of sockeye salmon in 1979.

Location	Date of Survey	Estimated number off mouth	Number live in creek	Number dead	Total	1952-1978 Median	1952-1978 Range
Aleknagik							
Yako Cr.	8/1	600	1,367	358	2,325	900	100-4,000
Whitefish Cr.	8/10	0	303	154	459	1,000	50-4,200
Eagle Cr.	8/9	300	2,941	228	3,469		
Hansen Cr.	7/31	500	2,678	1,705	4,883	2,900	200-15,700
Happy Cr.	8/6	200	2,691	1,666	4,557	1,500	200-5,700
Bear Cr.	8/4	700	2,393	1,574	4,667	2,900	1,200-10,200
Ice Cr.	8/7	0	1,951	4,344	6,295	6,600	2,200-18,000
South Nerka							
Fenno Cr.	8/11	0	236	1,016	1,252	1,900	400-17,000
Lynx Cr.	8/17	0	4,430	596	5,026	1,600	100-15,000
Stovall Cr.	8/20	0	524	63	587	-	
Central Nerka							
Pick Cr.	8/13	20	8,932	3,014	11,966	7,600	2,400-78,200
Elva Cr.	8/12	30	340	2	372	-	
North Nerka							
Hidden Lake Cr.	8/18	0	1,444	771	2,215	1,300	100-16,300
Kema Cr.	8/22	0	412	303	715	-	
Little Togiak							
A Cr.	8/21	0	41	4	45	-	
C Cr.	8/21	15	133	167	315	-	

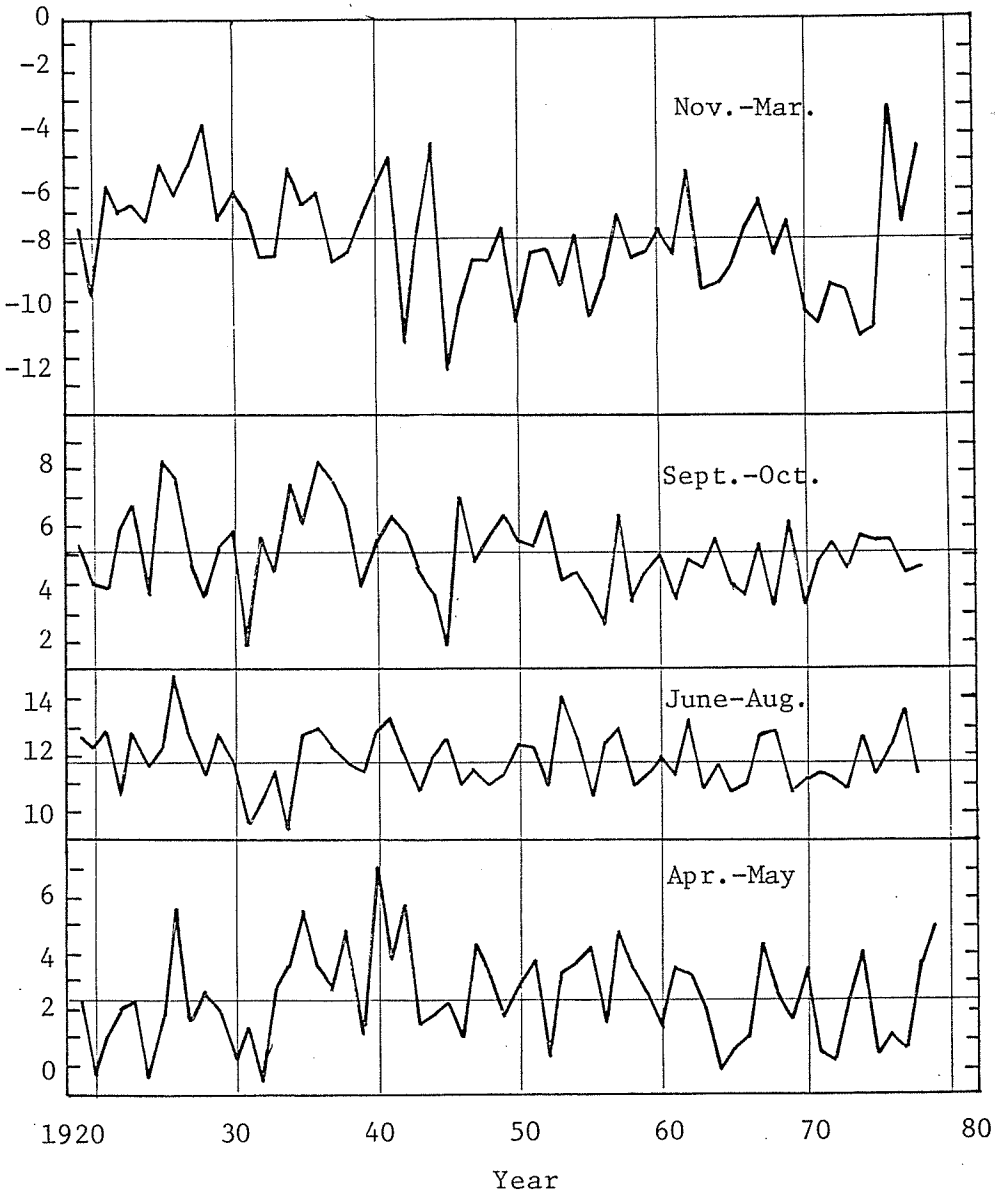

Fig. 1. Annual mean air temperatures (C) at Dillingham by season 1919-1979. Long-term means are indicated by horizontal lines.

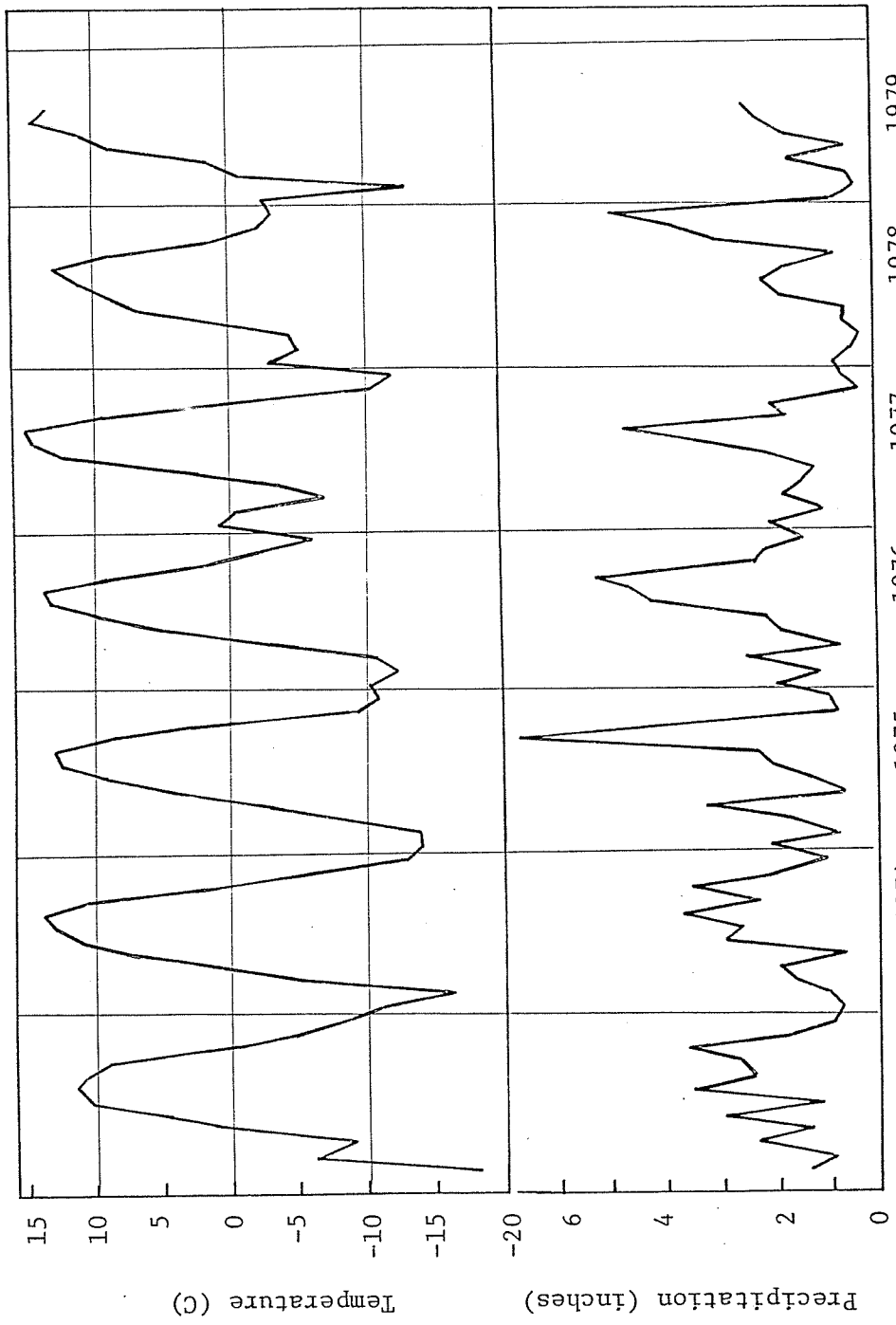

Fig. 2. Monthly mean air temperatures and precipitation at Dillingham, 1973-79.

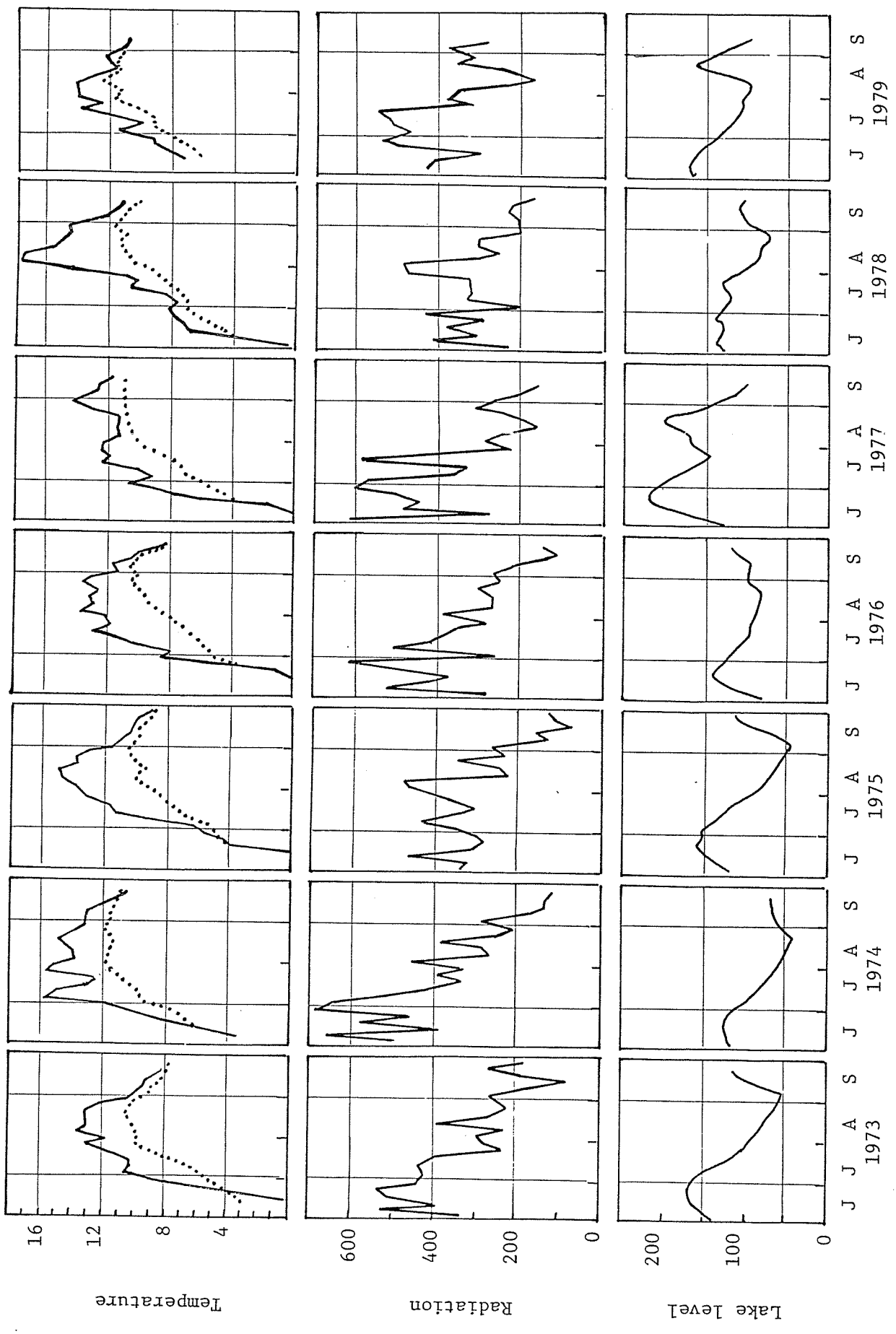

Fig. 3. Average water temperature (C) at the surface and 0-20 m, and 5-day means of daily solar radiation (gm cal/cm^2); and relative lake level (cm) during summers of 1973-1979.

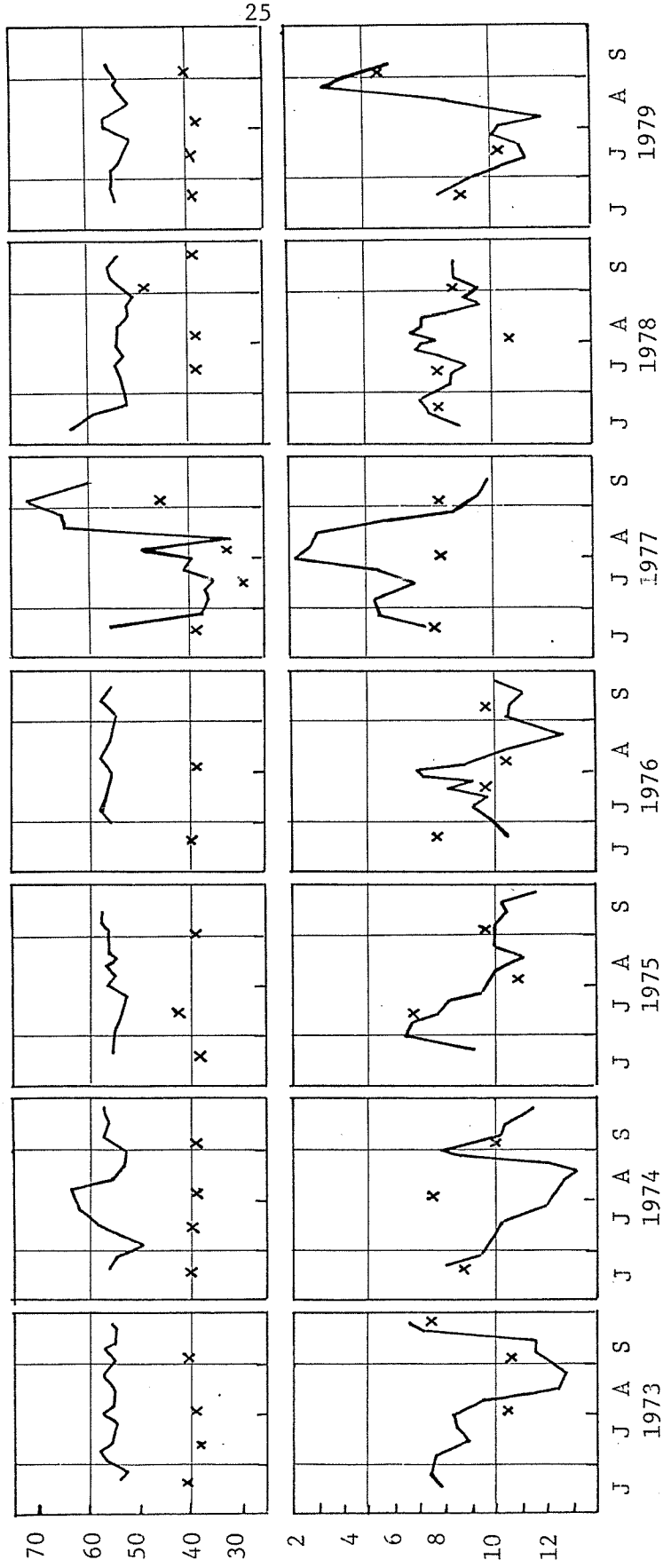

Fig. 4. Conductivity (micromhos/cm) and secchi depth (m) in Little Togiak Lake and Lake Aleknagik (x) during the summers of 1973-1979.

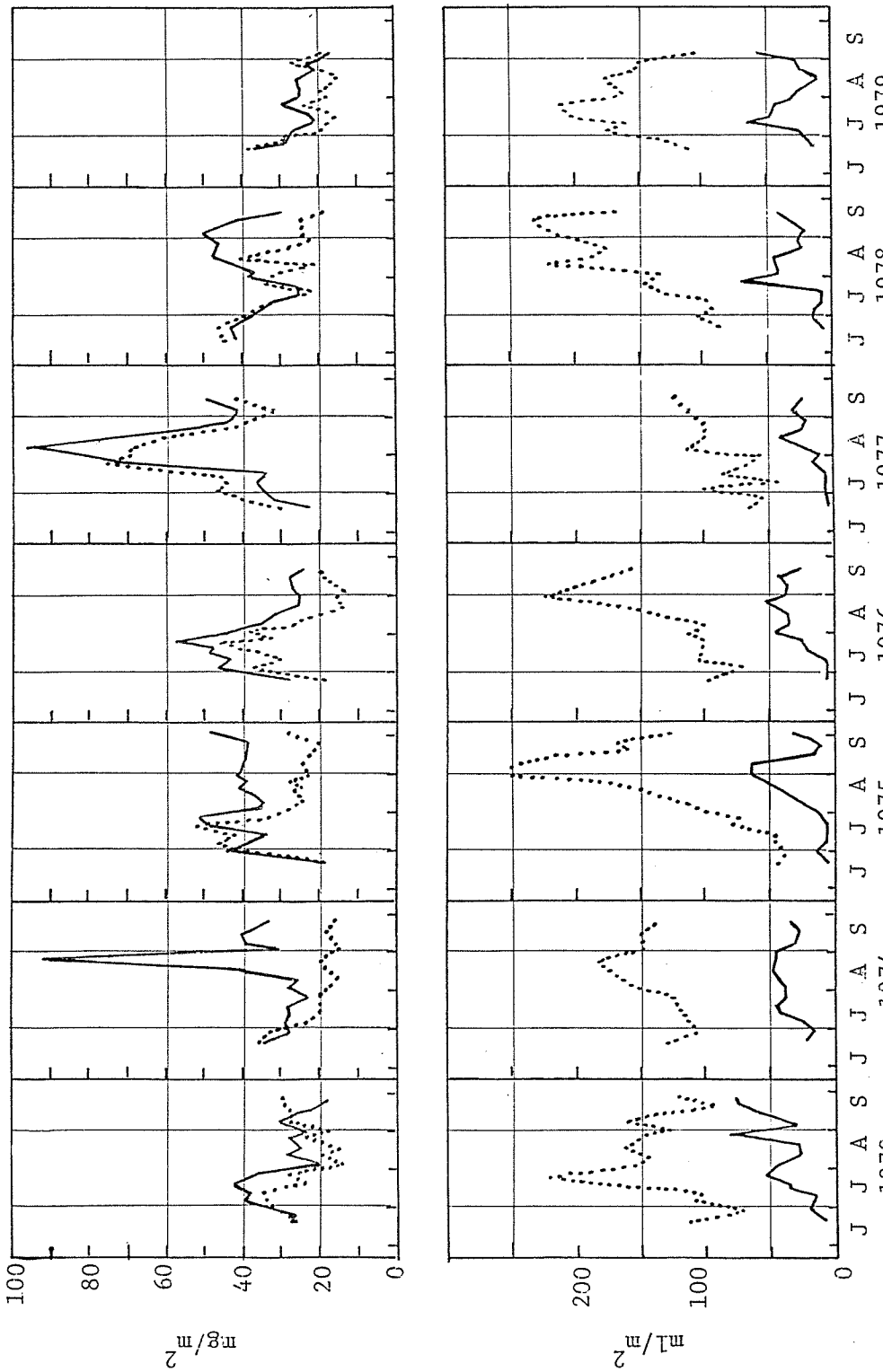

Fig. 5. Amounts of chlorophyll a 0-20 m (top) and volumes of zooplankton (bottom) in the upper basin (solid line) and lower basin (dotted line) of Little Togiak Lake during summer 1973-1979.

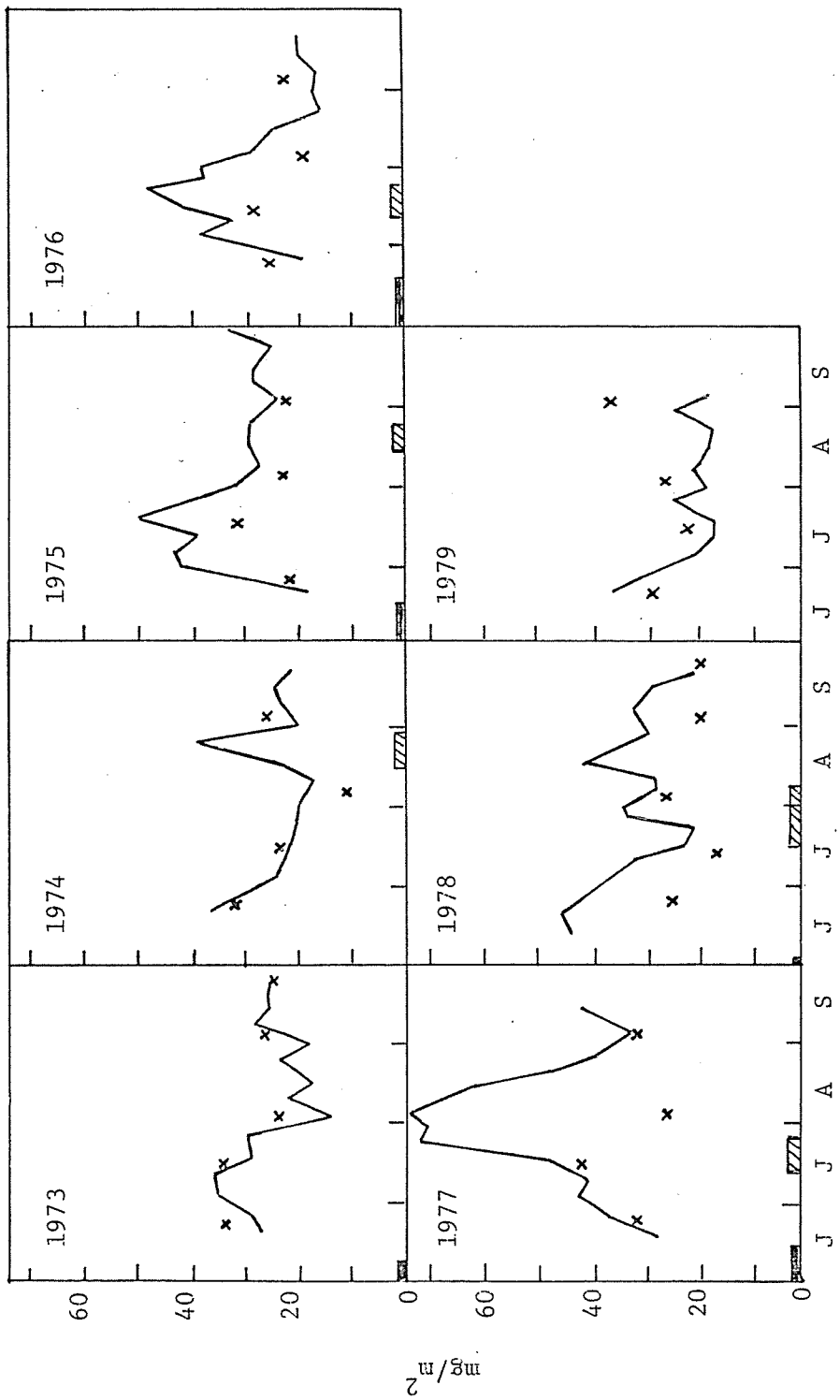

Fig. 6. Amount of chlorophyll a (mg/m^2) in the upper 20 m in Little Togiak Lake and Lake Aleknagik (X), 1973-1979.

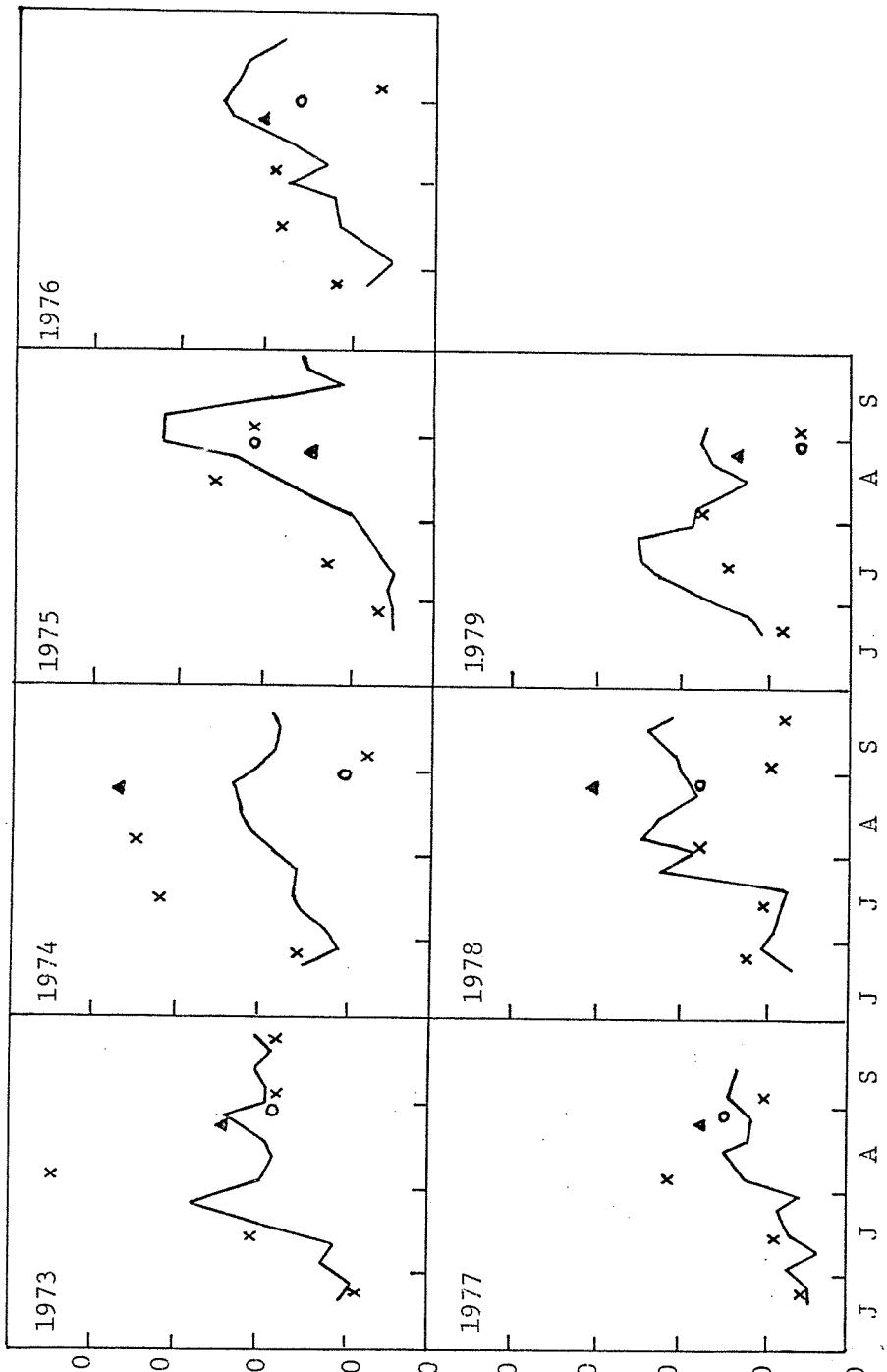

Fig. 7. Settled volume of zooplankton (ml/m^2) in Little Togiak Lake at weekly intervals and in Lake Aleknagik (X), Nerka (O) and Beverley and Kulik (Δ).

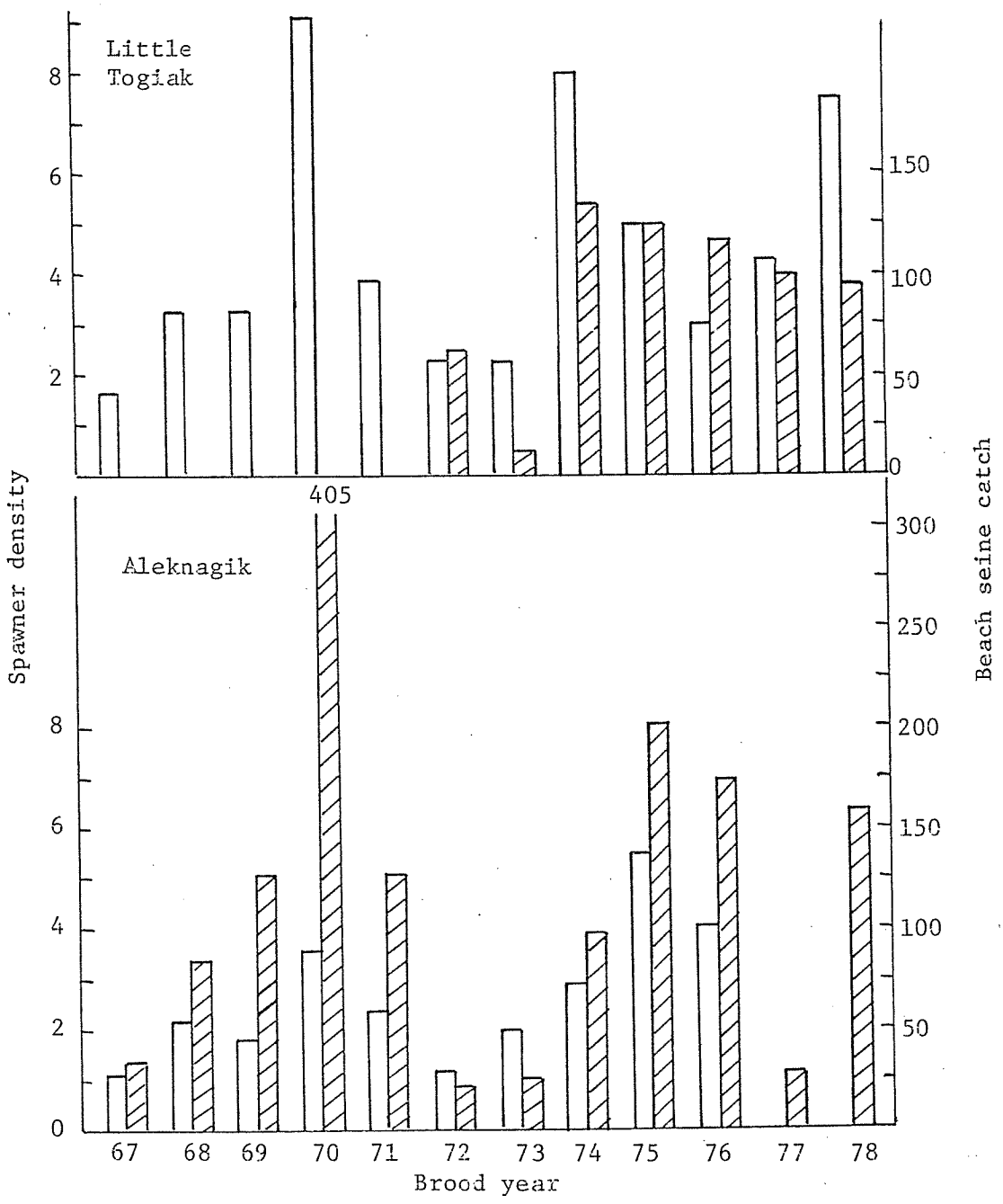

Fig. 8. Spawner density (1,000's per km^2 of lake area) and subsequent geometric mean catch of sockeye fry during June 27-July 17 in Little Togiak and Aleknagik.

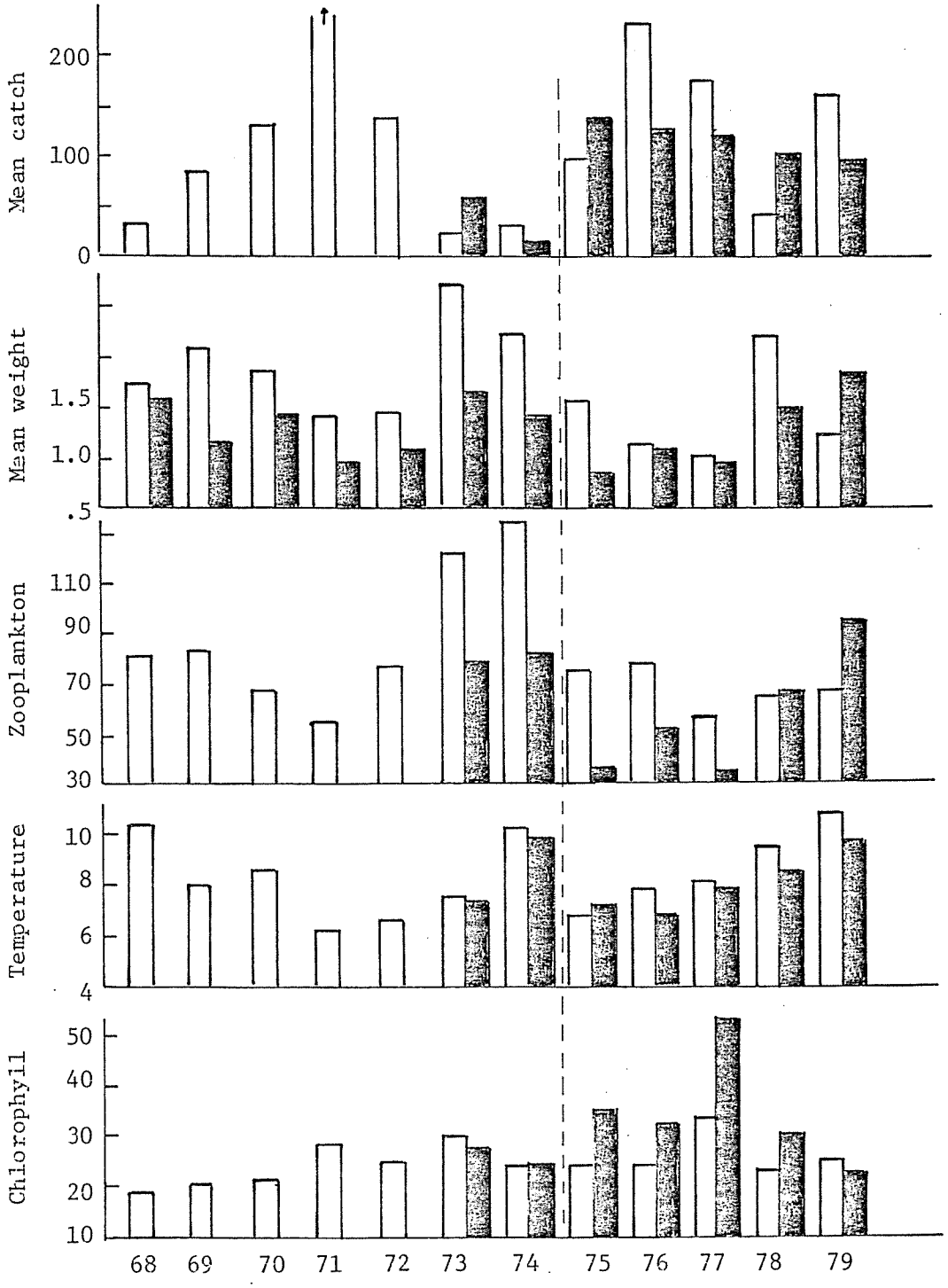

Fig. 9. Abundance of sockeye fry (mean beach seine catch), men weight of fry on September 1 (gm), and the average volume of zooplankton (ml/m^2), water temperature (0-20m), and chlorophyll a (mg/m^2, 0-20m) during mid-June to mid-August in Lake Aleknagik (open bars) and Little Togiak Lake (solid bars).

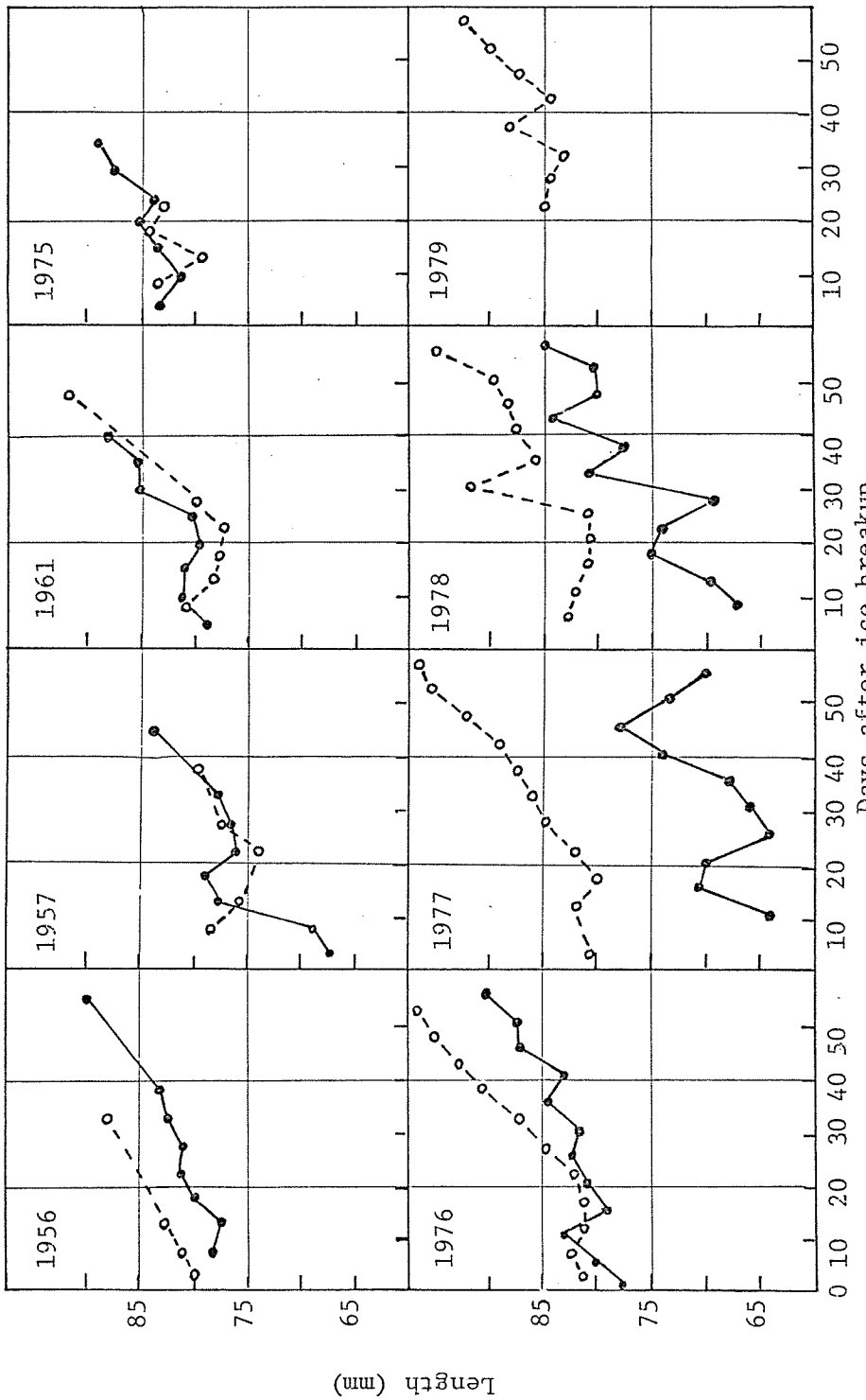

Fig. 10. Mean lengths of age I smolts in migrations from Little Togiak (O) and the Wood River lakes at the outlet of Lake Aleknagik (o).

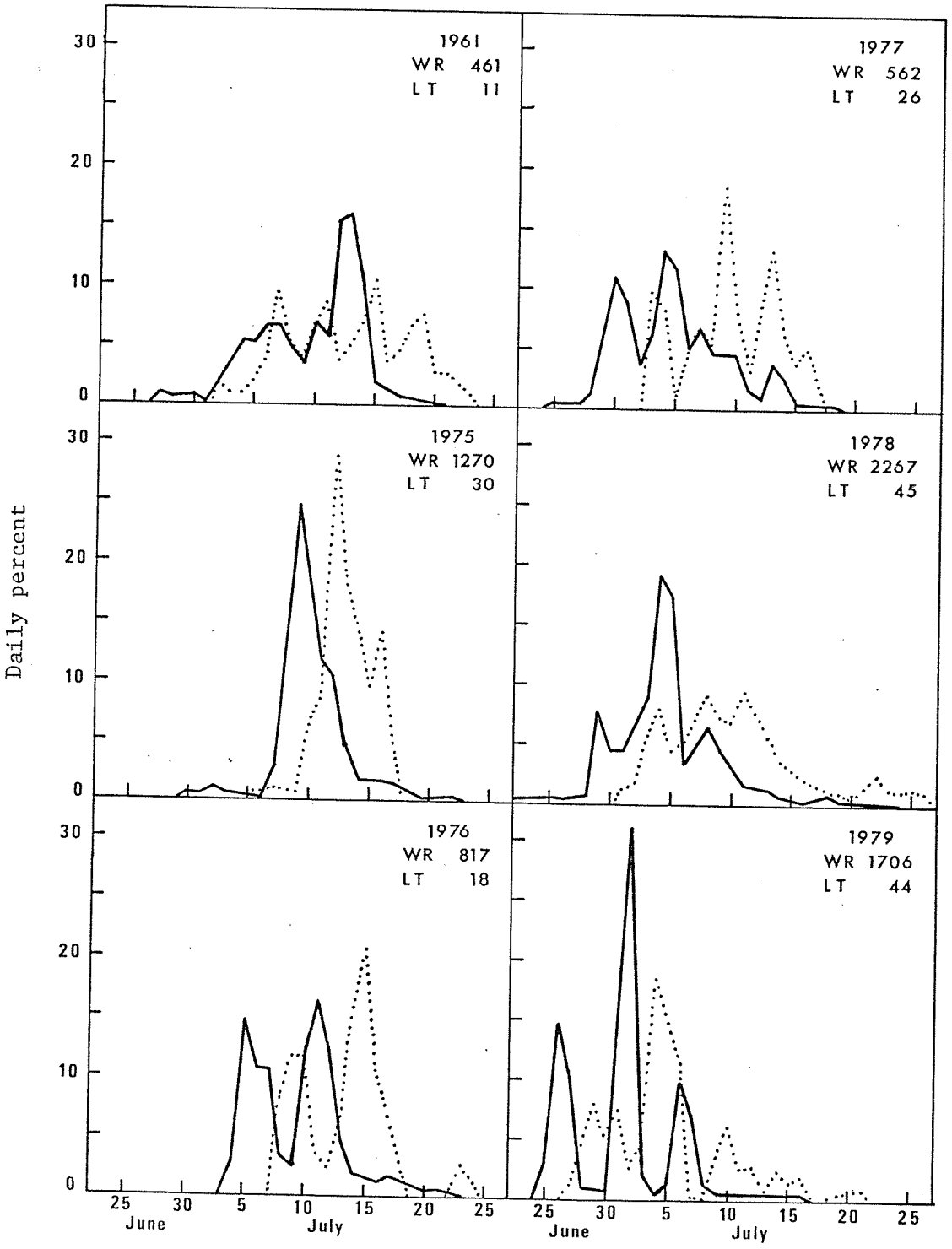

Fig. 11. Daily escapements (percent of total) to the Wood River lakes and Little Togiak Lake (dotted).

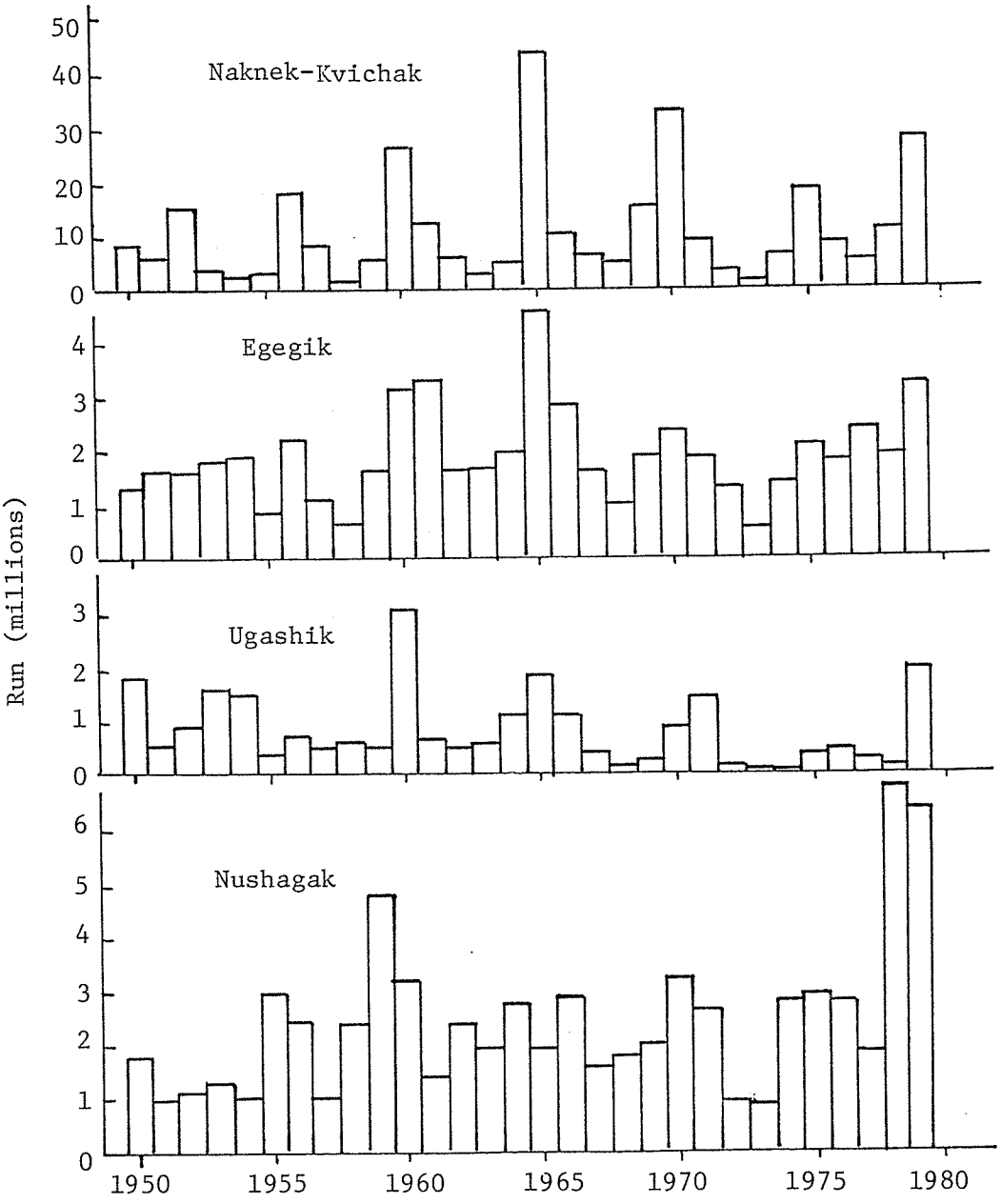

Fig. 12. Annual runs of sockeye salmon to the major fishing districts of Bristol Bay.

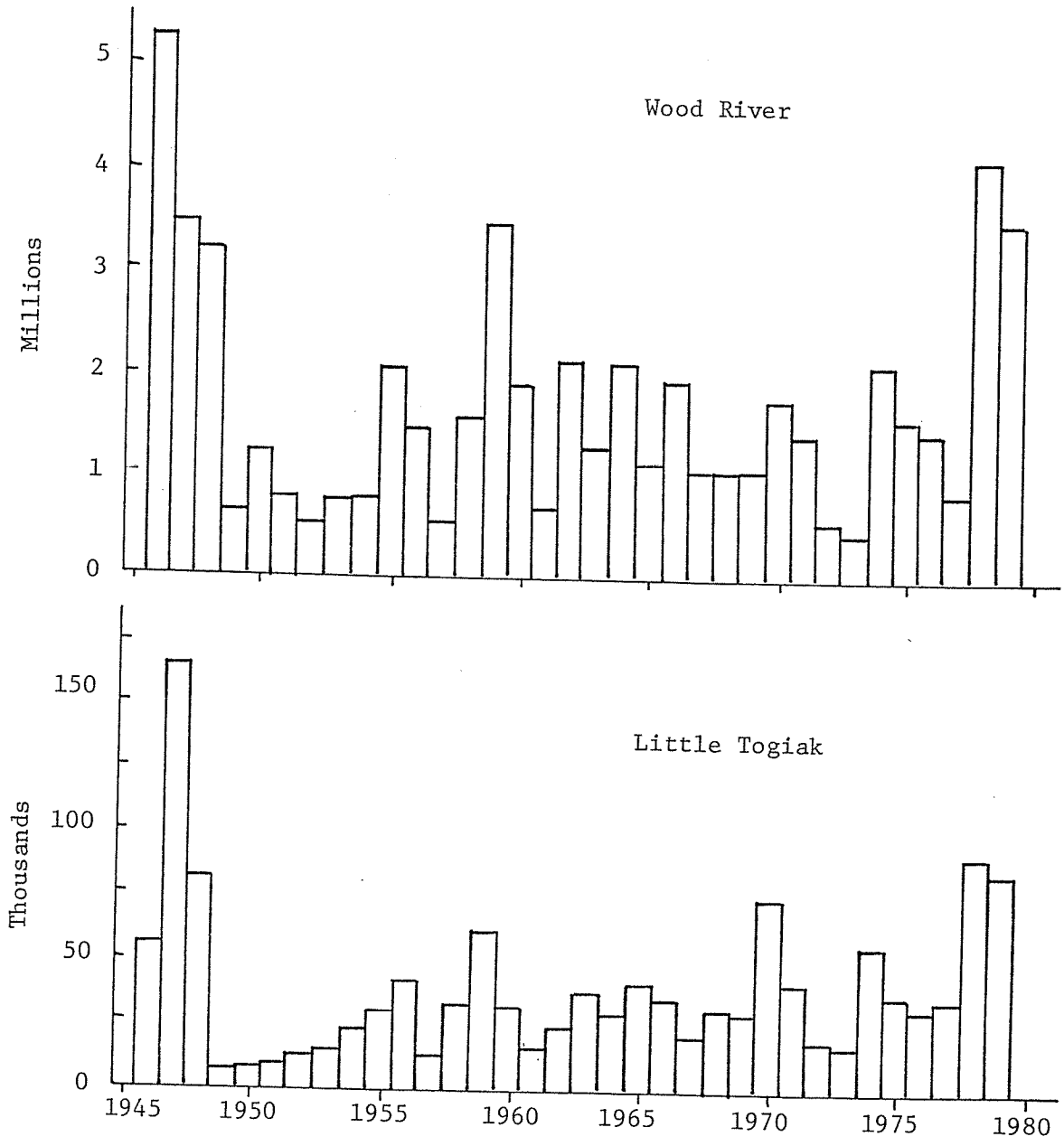

Fig. 13. Annual runs of sockeye salmon to the Wood River lake system and Little Togiak Lake, 1946-1979.