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College of Fisheries
University of Washington
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COLLECTION AND ANALYSIS OF BIOLOGICAL DATA FROM THE WOOD RIVER
LAKE SYSTEM, NUSHAGAK DISTRICT, BRISTOL BAY, ALASKA

FERTILIZATION OF LITTLE TOGIAK LAKE

by

Donald E. Rogers

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INTRODUCTION

Little Togiak Lake, with a surface area of 6 km², is a small lake in the Wood River system (425 km²). This lake system is the major producer of sockeye salmon in the Nushagak District of Bristol Bay. The catches of sockeye in the Nushagak have declined greatly since the initial buildup of the fishery in the late 1800's. The most recent decline, from an annual average catch of near 3 million (1919-1948) to just under 1 million (1949-present), began when five successive brood years with above-average escapements (1944-1948) produced very small returns.

The Fisheries Research Institute has been investigating the sockeye salmon populations in the Nushagak since 1946. The major emphasis has been on identifying the factors which limit or control the production of salmon from the Wood River lakes because these lakes offer a greater potential for increased production than do the other lakes in the Nushagak District. We identified freshwater growth of juveniles as one important controllable factor in the production of adults; therefore, in 1970, we began studies in two bays on the feasibility of artificial fertilization as a method of increasing the growth of juveniles by increasing their food supply (Rogers et al. 1973). The fertilization of Bear Bay in Lake Aleknagik caused an increase in phytoplankton abundance in the Bay that was followed by increases in the abundance of midges and zooplankton in 1971. Because juvenile sockeye move out of Bear Bay and into the main lake by mid-summer, the effect of the fertilization on their growth was limited.

In August 1974 and 1975, we added commercial fertilizer, primarily diammonium phosphate, to the upper end of Little Togiak Lake. This lake was chosen for experimentation because it is relatively small and the sockeye populations had a history of high density and poor growth relative to the populations in the other Wood River lakes. The fertilizer was added in August because, at that time, 1) water temperature is warmest and there is a thermocline, 2) phytoplankton biomass is low but net primary production is high, 3) the abundance of herbivorous zooplankters is higher than earlier in the summer and the populations are increasing, and 4) the natural input of nutrients from salmon carcasses occurs in late summer or fall. The major disadvantages in adding fertilizer in August were in terms of evaluating the effects on zooplankton, insects, and the growth of the fish. Budgetary and personnel restrictions limited field observations to June through September and much of the effects of fertilization may take place beyond 30 days following the additions of nutrients. Thus, in 1976 we fertilized the lake in mid-July.

A summary of fertilization experiments in lakes containing populations of sockeye salmon is given in Table 1. The results of these experiments were variable as were the conditions in the lakes. Added nutrients caused an increase in the standing crop of phytoplankton in

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all experiments except Great Central Lake; however, in that experiment there was a significant increase in primary production and this production was probably cropped by the increased abundance of zooplankton (LeBrasseur and Kennedy 1972). An increase in the abundance of secondary producers (zooplankton and insects) tended to occur in the year following fertilization in the Bare Lake and Fern Lake experiments (Nelson and Edmondson 1955; Donaldson et al. 1971). A significant increase in the size of smolts was demonstrated only in the Bare Lake experiment; however, in that experiment as well as in the Great Central Lake experiment, there were significant increases in the returns of adult fish and this is the desired end result of fertilization.

Fertilization can be expected to increase the production (abundance) of adult sockeye salmon only to the extent that survival and growth of juveniles in freshwater subsequently limits or controls survival to the adult stage. Likewise, added nutrients will increase growth and survival of sockeye juveniles only to the extent that nutrients (e.g., phosphates) limit or control the production of sockeye food, and that growth and survival of the juveniles is limited by the abundance of food. Under natural conditions it is difficult to determine the effect of nutrients on fish growth because the input of nutrients is either difficult to measure or there is relatively little annual variation. Thus by adding phosphates to Little Togiak Lake, we can test the validity of nutrients as a factor controlling the growth and/or survival of the sockeye salmon in the Wood River Lakes.

Our major objectives in 1976 were to determine 1) the effects of fertilization of the entire lake on standing crops of phytoplankton and zooplankton, and the growth of fish during the summer; and 2) the effects of the fertilizations in 1974 and 1975 on the size and age compositions of the smolts that migrated from the lake in the spring of 1976.

METHODS

A technical grade of diammonium phosphate was added to Little Togiak Lake in July. The dates and amounts added are given in Table 2. We added a total of 1,341 kg of diammonium phosphate over most of the lake surface; whereas, in 1974 and 1975, we had added 661 kg and 220 kg, respectively, to the upper end of the lake. The fertilizer was dissolved in water in a 55-gal drum and then sprayed over the lake from a moving boat. The chemical composition of the fertilizer used in 1976 is compared with that used in 1975 in Table 3. The technical grade of diammonium phosphate cost about the same as commercial grades but the cost per kilogram of phosphate was considerably cheaper, especially at the point of application. We have used fertilizers that were high in phosphates because chemical analyses of water from the Wood River lakes in 1962 and 1963 indicated that sufficient concentrations of nitrogen were present during the summer, 0.1 to 0.3 mg/l of nitrate nitrogen; likewise silicates did not appear to be limiting to phytoplankton growth as the averages for the lakes ranged from 2.1 to 3.5 mg Si/l during the summer. However, concentrations of phosphate phosphorus were never greater than .02 mg P/l and were usually lower than the detectable limit of .006 mg P/l during the summer.

Concentrations of phosphorus and nitrogen were measured before, during, and after the application of fertilizer in 1976. Two samples of water were collected at 5, 15, and 20 m at each of two stations and the chemical determinations were done in Seattle. Likewise, water samples were collected from five creeks which drained into Little Togiak Lake and from Little Togiak River on July 1, and from Lake Nerka (about 1 km from Little Togiak River) on July 25. Solar radiation and lake level were measured continuously from June through September, and surface water temperature was measured with all field sampling so that observations were taken at two-three day intervals throughout the summer.

The standing crop of phytoplankton was estimated by the density of chlorophyll a. In past years, we have calculated the concentration of chlorophyll a using the Richards and Thompson equations; however, this year we recalculated concentrations based on the Parsons and Strickland equations because they are more generally used and considered to be more accurate estimates. The R and T equations estimate the concentration of chlorophyll a with a bias of plus 25%.

The abundance of zooplankton was estimated from vertical hauls from 20 to 60 m with a 1/2-m net of No. 6 mesh. The volume of plankton was measured after the sample had settled for 1/2 hour in a graduated cylinder. The number of organisms was determined from the expanded average counts of two-three subsamples. The abundance of individual species or categories of zooplankton was then calculated in terms of the number per m² of surface area. The No. 6 mesh does not retain many of the small zooplankters, e.g., nauplii stages of copepods and most rotifers, but it does sample most of the zooplankton eaten by the fish. Zooplankton and phytoplankton sampling were conducted weekly at established stations along with Secchi depth and temperature profiles (Fig. 1).

Emergent insect traps were placed in the lake at five stations as soon as they were clear of ice and the traps were checked at two-three day intervals until the end of September. Bottom samples were collected with an Eckman sampler at two stations, biweekly, to estimate the relative abundance of midge larvae and other benthic organisms.

The relative abundance and average size of fish in the littoral zone during the early summer was measured from beach seine hauls at seven stations. Hauls were made at weekly intervals between June 27 and August 2. The catches or subsamples of large catches were preserved in 10% Formalin and then enumerated and lengths of the fish were measured. Mean lengths were calculated for the major age groups and these were then converted to the equivalent lengths of live fish by multiplying by a shrinkage factor (1.031 for sockeye and char fry and 1.015 for threespine stickleback).

The relative abundance and size of pelagic fish were measured from tow-net sampling conducted during the nights of July 30, August 16, and September 2. We used a 9x9 ft. tow net and made hauls at the surface for 5 to 10 min. All catches were adjusted to a 5-min haul. Six hauls were made on the first two nights and 9 hauls were made on September 2. The tows were spread evenly along the long axis of the lake.

The number of smolts that migrated from Little Togiak Lake in 1976 was estimated from expanded fykenet catches. The opening of the net was 8 ft wide at the wings. Two locations in the river were used, one where the river was 160 ft wide (4 stations) and another where it was 48 ft wide (2 stations). Sampling was moved to the narrower, upriver, site in early July because water velocity had declined below 3 ft/sec at our original sampling location and some smolts were probably able to avoid capture by the net. The catch for a 24-hr period was multiplied by 20 or 6 to estimate the total number of smolts. Daily samples of smolts were collected to determine the size and age composition in the migration. Sampling began on June 19, two days after ice was clear from the main part of the lake, and terminated on August 14 because catches of adult sockeye (river spawners) prohibited effective sampling for smolts.

Samples of smolts migrating from Lakes Kulik, Beverley, and Nerka were collected by Mr. J. Burke; and samples of smolts were collected at the outlet of the lake system (Mosquito Point, L. Aleknagik) by the Alaska Department of Fish and Game (Mr. P. Krasnowski). The length statistics from these samples were kindly provided by Mr. Burke.

The number of adult sockeye salmon that migrated into Little Togiak Lake was estimated from expanded 1/2-hour counts made during daylight hours. The age composition of the escapement was estimated from otoliths that were collected from spawned-out fish in September, and the runs for each age group were estimated by multiplying the number of fish in the escapement by the ratio of run to escapement in the Nushagak District.

RESULTS

Figure 2 shows the major physical conditions that prevailed during the summers of 1973-1976. Spring weather was exceptionally warm in 1974, ice breakup was early, water level was low, and temperatures were unusually high in that year. Conditions in 1973 were typical of those in prior years, whereas ice breakup in 1975 and 1976 was later than normal and water temperatures in 1976 were colder than temperatures in the other years.

Primary Productivity

When fertilizer was applied in mid-July of 1976 lake level was higher, thus the outflow of water was greater than during the fertilizations in 1974 and 1975 and there was a potentially greater loss of fertilizer from this cause. Moreover, water temperatures were colder and a thermocline had not yet developed by mid-July of 1976, so there was also a potentially greater loss of fertilizer to the hypolimnion. Conversely, there was a greater amount of solar radiation during July because the period of daylight is longer than in August, therefore primary production could occur over a longer period (Fig. 3). Net primary production in Lake Aleknagik was measured during the years 1961-1970. The measurements made during the mid-day period were not significantly

correlated with the variation in mid-day solar radiation from June through September; however, primary production only occurred during daylight. Variation in daily solar radiation is probably not a major factor limiting primary production during the summer months except for very low overcast days.

When fertilizer was added in 1976 the concentration of phosphorus in the upper 20 m increased whereas the concentrations of nitrate nitrogen decreased (Table 4). The determinations of total nitrogen appeared unreliable because the variation between replicate samples was as great as the variation among dates and depths, and total nitrogen should have been as great or greater than the nitrogen in the form of nitrates. Although the concentrations of phosphorus increased at both stations during fertilization, only at Station 5 were the values significantly greater than the range in natural concentrations. Two weeks after fertilization the concentration of phosphorus was back to normal. The phosphorus content in central Lake Nerka shortly after fertilizer was added to Little Togiak Lake was somewhat higher than normal at 5 m; however, no observations were made prior to fertilization.

Prior to fertilization the ratio of nitrogen to phosphorus in the lake (upper 20 m) was about 12 parts nitrogen to 1 part phosphorus. During and after fertilization the ratio was about 4 to 1, which is within the range required by algae (Nelson and Edmondson 1955).

The responses of the phytoplankton to the fertilization in July of 1976 were somewhat different than those from fertilizations in August of 1974 and 1975. Although there was an almost immediate increase in the concentration of chlorophyll in the upper 10 m and a decrease in Secchi depth in all years, the concentration of chlorophyll in 1976 declined to the usual mid-summer level within 25 days following fertilization (Fig. 4 and Table 5). The concentration of phosphate added to the upper end of the lake (Station 1 in Area A) was nearly the same in 1975 and 1976 (about one-third of that added in 1974). There were relative increases in chlorophyll concentrations of 100% in the first ten days following fertilization in both years, but the concentration subsequently increased in 1975 and decreased in 1976. The different responses were probably caused by differences in the abundance of zooplankton in 1975 and 1976.

Secondary Production

The purpose of artificial fertilization is to increase the food supply for juvenile sockeye, i.e., zooplankton and aquatic insects (primarily chironomids) and hence the growth of the fish. The standing crop of zooplankton is controlled by their rates of growth, reproduction, and mortality. If growth and reproduction are limited by the abundance of phytoplankton then the production of zooplankton should increase with an increase in phytoplankton and the abundance of zooplankton should also increase unless mortality rates equally increase, e.g., from predation by fish.

There were no obvious increases in the abundance of zooplankton within 40 days following the fertilizations in August of 1974 and 1975 that could be attributed to the fertilizer; however, an increase could have occurred after our observations terminated at the end of September. The large forms of zooplankton are particularly vulnerable to predation by fish, and in 1976 their abundance increased substantially to a peak density about 50 days after fertilization (Fig. 5). The abundance of zooplankton is greater in the main basin of the lake (Areas B and C) where the mean depth is 34 m and the maximum depth is 85 m than in the upper basin (Area A) where mean depth is 18 m and maximum depth is only 25 m. The largest increase in abundance occurred in the main basin of the lake and this part of the lake was directly fertilized only in 1976.

The high abundance of zooplankton from mid-August to late-September in 1976 (Fig. 6) probably caused the relatively low standing crop of phytoplankton that was observed. Although no direct measurements of zooplankton reproduction were made, the rate in 1976 must have been much greater than in previous years because the abundance of fish in 1976 was similar to the abundance in 1975 and greater than the abundances in 1973 and 1974. The abundance of Daphnia has been consistently low in the Wood River lakes whenever the abundance of sockeye was high. In 1976 fish abundance was high throughout the lake system and the abundance of Daphnia was correspondingly low in all lakes except Little Togiak.

There has been no significant change in the catches of emergent chironomids in Little Togiak Lake since fertilization began in 1974. The average daily catches from June through August were 9, 4, 4, and 5 for the years 1973, 1974, 1975, and 1976 respectively, whereas the average catches in Lake Aleknagik in the same years were 29, 11, 27, and 12. The relatively low abundance of chironomids in Little Togiak Lake is probably caused by the limited amount of suitable midge habitat in the lake. There is relatively little shallow (less than 5 m) area with mud bottom. Most of the shallow areas of the lake have rock or gravel on the bottom; thus fertilization is probably ineffective in increasing the production of midges in Little Togiak Lake. A final evaluation will be made when bottom samples collected in 1976 are processed.

Abundance and Size of Fish During Summer

The mean catches of sockeye fry and threespine stickleback from beach seine and tow-net sampling in Little Togiak Lake are shown in Figure 7. Beach-seine catches of sockeye fry are probably a better measure of their relative abundance than are tow-net catches because the latter are more affected by variation in availability of the fish (Rogers 1967, 1973).

Sockeye fry were more abundant in 1976 when the parent escapement was 30,000 than in 1975 when parent escapement was 48,000; however in both years their abundance was greater than in 1973 and 1974 when parent escapements were 14,000. The abundance of threespine stickleback increased from 1973 through 1976 but this also occurred in the other Wood River lakes so the increased abundance in Little Togiak was unlikely caused by the fertilization of the lake.

The fertilizations in 1974 and 1975 could not have greatly affected the size of the fish on September 1 which is about the time of our last sampling of the populations; however, the growth of the fish after that date could have been affected if, as postulated, there were increases in the abundance of zooplankton in October of those years. Although water temperature usually declines after early September, the temperature remains about 4°C until the end of October, and a considerable amount of growth can occur during September-October. Sockeye fry in the Wood River lakes typically increase 20 to 30 mm in length from September 1 to June of the following year.

The fertilization in July of 1976 apparently increased the growth of sockeye fry during August (Fig. 8). Since the abundance of fish was about equal in 1975 and 1976, ice breakup was later in 1976, and water temperatures were colder, we would expect growth to be no better and perhaps poorer in 1976 than in 1975. The sockeye fry in 1976 were actually larger than the fry in 1975. On September 1, they were about 14% longer or 33% heavier than the fry in 1975. However the growth in 1976 may not be entirely related to fertilization because the fry in Lake Aleknagik were also somewhat larger than expected from the abundance of parent spawners (Fig. 9).

The growth of age I threespine stickleback in the Wood River lakes is correlated with the growth of sockeye fry, and the length of both species is inversely correlated with the abundance of sockeye (Rogers 1973). Age I stickleback were quite scarce in Little Togiak in 1973, and we obtained a poor estimate of their growth in that year. In the subsequent years the age I fish were abundant and their growth in 1976 was intermediate between their growth in 1974 and 1975. They were very small in June 1976 as a result of poor growth when they were age 0 fish in 1975, and that was probably caused by the high abundance of sockeye in 1975. By September 1, 1976, the age I stickleback had increased about 15 mm in length, whereas the increases in length for comparable periods in 1974 and 1975 were 19 and 10 mm, respectively. Although they were not significantly larger on September 1, 1976, than they were in previous years, the growth rate of age I stickleback during August was slightly greater than expected from the abundance of sockeye. However, fertilization apparently did not affect the growth of stickleback as much as that of juvenile sockeye.

Tow-net catches of age I sockeye are probably a reliable measure of their relative annual abundance in Little Togiak Lake because they seldom reside inshore during the summer and are thus more available to pelagic sampling than are the age 0 sockeye. Mean catches and lengths of yearling sockeye are listed according to abundance of parent spawners in Table 6. The relative abundance of yearlings in 1976 (1974 brood year) was considerably lower than expected from the abundance of parent spawners (also from the catches of fry in 1975) and their average length on September 1 was larger than expected from their length when they were age 0 in 1975. The fertilization in 1975 apparently increased the growth of sockeye fry in the fall and this caused a significantly greater-than-normal proportion of the fry to smoltify in the spring of 1976.

Abundance and Size of Smolts

Average fyke-net catches of smolts and some physical conditions during the 1976 migration are given in Table 7. From about June 26 to July 4 the fishing efficiency of the nets was reduced, particularly during daylight, because the water velocity in the river declined. Catches during this period were multiplied by the average ratio of catches that were made from nets fished simultaneously during July 6-9 at an upstream site and at the downstream sites used prior to July 5 to obtain comparable catches for this period. We then multiplied the daily catches by the reciprocal of the percentage of the river's width that was fished by the net to obtain an estimate of the number of smolts that migrated daily (Fig. 10).

Migrations usually occurred during evening (twilight) and at night (dark); however, on July 15 there was a substantial daytime migration. The length and age composition of the smolts did not change significantly during the migration of a particular day (Table 8), but both changed during the season. About 50% of the age II smolts migrated by June 25 and 90% by July 5. At that time, only 50% of the age I smolts had migrated and 90% of them had not migrated until July 30. The timing of the migration in 1976 was later and more prolonged than the migration in 1961, the only other year when extensive sampling was conducted in Little Togiak River. In 1961, 90% of the migration had occurred by July 9 or within 30 days following ice breakup (Rogers 1976).

The estimated numbers of smolts in the 1976 migration were 167,000 age I and 20,000 age II, and they were produced from parent escapements of 48,000 and 14,000 respectively. The smolt estimates are probably too low because 1) it was unlikely that the efficiency of the fykenets was 100% and 2) the fact that age I smolts were still migrating out of Little Togiak Lake on August 14 when we had to terminate our sampling. The estimated numbers of smolts in the 1961 migration were 650,000 age I and 6,000 age II and these were produced from parent escapements of 40,000 and 16,000 respectively.

The primary purpose of our sampling in Little Togiak River was to estimate the size of the smolts and to compare their size in 1976 (after a portion of the lake was fertilized in 1974 and 1975) with the size of smolts in previous migration from Little Togiak and in migrations from the other lakes in 1976. These comparisons, along with the size of the fish when they were age 0, were used to determine the effect of fertilization in Little Togiak on the growth of the juvenile sockeye to the smolt stage.

Smolts begin migrating out of Little Togiak and the other lakes about the time of ice breakup. The smolts from Little Togiak reach the outlet of the lake system (Wood River), a distance of about 65 km, in about 11 days (Burgner 1962). The total abundance of sockeye in Little Togiak Lake is small relative to the populations in the other, much larger, lakes of the system and the smolts from Little Togiak become mixed with smolts from the upper lakes (North Nerka, Beverley, and Kulik) during their migration through Lakes Nerka and Aleknagik.

The size of the age I smolts that migrate from each of the individual lakes tends to decrease from the beginning of the migration to the peak and then increase towards the end of the migration. The larger individuals in a lake tend to migrate earlier and the size of the smolts usually increases in July as a result of their growth. This seasonal change in length is often not so evident at the outlet of the lake system because the size of the smolts there is influenced by the abundance and size of fish in the individual lakes and the timing of the migrations. However, the earliest smolts to leave the lake system are those from Lake Aleknagik where ice breakup is usually at least a week earlier than in the other lakes.

The mean lengths of age I smolts in the Wood River lakes during 1976 are shown by date of sampling in Fig. 11 and by days after ice breakup in Fig. 12. The smolts from Little Togiak were obviously larger than those from the other lakes. The difference was even more pronounced when the mean lengths of the age I smolts were compared to the lengths of the fish when they were age 0 in 1975 (Tables 9 and 10). The fry in Little Togiak Lake were significantly smaller on September 1, 1975, than the fry in all of the other Wood River lakes yet the age I smolts were larger. This indicates that the growth of fry in Little Togiak after September 1, 1976, was considerably greater than the growth of fry in the other lakes. However, such comparisons may be invalid because 1) all of the fry do not migrate at age I and the proportion that do migrate is variable and probably size dependent, and 2) growth in the fall may be typically greater in Little Togiak than in the other lakes.

Our sampling of the juveniles in Little Togiak Lake during 1976 indicated that the holdover of juveniles from the 1974 brood year was much less than normal for that lake. If we assume that the smaller fish in the population are the ones that tend to holdover (migrate at age II), then we would expect the age I smolts from Little Togiak to be smaller in 1976 relative to other years unless they experienced unusually good growth. Seasonal growth patterns are shown in Fig. 13 for the brood years when data on both fry and smolts were collected from Little Togiak. The curves were drawn by eye with the assumptions that 1) growth rates in September and October were the same in 1975 (1974 brood year) but different in the other years, 2) growth ceased by December in all years, and 3) nearly all of the fry migrated at age I. The latter was obviously not true for the 1959 brood year (Table 11), thus the actual growth of the fry in the fall of 1960 was somewhat less than indicated in Fig. 13.

The growth rate (in length) of the fry in the fall of 1975 was at least 60% greater than the growth rate in the fall of 1960 (a year with comparable fish abundance) and the growth rate in weight was at least 70% greater in 1975 if a constant weight-length relationship is assumed. The condition of the age I smolts tended to increase during the migration from Little Togiak in 1976, e.g., at an average length of 85 mm the mean weight was 4.99 g in June and 5.40 g in July. Weight-length statistics were not available from other years in Little Togiak nor from other lakes in 1976; however, smolts that were 85 mm at the outlet of the lake system averaged 4.84 g (annual range, 4.38 to 5.23) over the years 1954 to 1961.

The effect of fertilization on the size of smolts from Little Togiak was also evaluated based on the relationship between the mean length of age I smolts and the density of parent spawners (Fig. 14). The mean length of age I smolts during the first 30 days of the 1976 migration was 82.4 mm (85.3 mm for the total migration); and compared to observations taken within 30 days of ice breakup in past years, the smolts from Little Togiak in 1976 were 6% longer than predicted ($\alpha = .10$). In terms of weight, the smolts were 28% heavier than expected.

The age II smolts from Little Togiak had a mean weight of 8.0 g in 1976. Their mean weight on September 1, 1975, when they were juveniles was 4.0 g, thus they increased 200% in weight during the fall of 1975. The average relative increase in weight for the entire lake system in past years was 46% and the annual range in estimates was 0 to 120% (Tables 11 and 12). The age I smolts from Little Togiak (first 30 days in 1976) had a mean weight of 4.75 g (5.5 g for entire migration), and as age 0 fish on September 1 they averaged 0.8 g. They increased about 594% in weight, whereas the average increase in the lake system was 191% and the annual range was 131 to 291%.

Adult Escapement to Little Togiak Lake

The escapement into Little Togiak Lake in 1976 was estimated from sample counting in the river to provide an additional comparison with the aerial method. The escapement in 1961 was estimated by three methods: sample counting in the river (10,500), tag and recapture (10,100 - 11,100), and aerial survey (11,000). In 1975 the escapement was estimated by sample counting (30,000) and by aerial survey (21,600). The aerial survey was conducted by Mr. Mike Nelson, Alaska Department of Fish and Game.

The daily and cumulative estimates of the escapement in 1976 are given in Table 13. The escapement was bimodal with a small early peak on July 9 and a large later peak on July 15. The sockeye require about 9 days to migrate from Wood River (Lake Aleknagik) to Little Togiak River and about 10% of the fish entering the lake may move back out of the lake to spawn in Lake Nerka (Finn 1961). Although there was a net movement of 18,620 fish into the lake by July 24, our final estimate of the escapement was 18,000 because the downstream movement was probably not completed by that date.

Samples from the beach spawning grounds in Little Togiak Lake indicated that 59 % of the fish were four years old (1972 brood year), 31% were five years old (1971 brood year), and 10 % were six years old (1970 brood year).

SUMMARY

Diammonium phosphate was added to the upper end of Little Togiak Lake in August of 1974 and 1975 to determine whether artificial fertilization would increase productivity and hence the growth of juvenile sockeye salmon. There were immediate increases in the standing crops of

phytoplankton and these increases were partially sustained through the month of September. Although we could not demonstrate subsequent increases in the abundance of zooplankton nor the growth of the fish during those summers, the smolts that migrated from Little Togiak Lake in the spring of 1976 were significantly larger than expected. The fertilization in 1975 had increased the growth of the fish in the fall (September-October) and also caused a higher-than-normal proportion of the fish to migrate out of the lake at age I. Both effects are considered beneficial to the eventual production of adult sockeye salmon.

Diammonium phosphate was added to the entire lake in July 1976 and again there was an immediate increase in the standing crop of phytoplankton. This increased production caused a significant increase in the abundance of the larger forms of zooplankton from mid-August through September and an increase in the growth of juvenile sockeye during August. However, the age 0 sockeye were still small on September 1, 1976, relative to past years and the smolts that migrate in 1977 will have to be sampled to determine the full effect of the fertilization on the growth of the fish.

Although a final evaluation cannot be made until the adult salmon return (1977-1980), the observed effects of fertilization in Little Togiak Lake are close to those predicted if indeed phosphates are a major factor in limiting the growth and production of sockeye in the Wood River lakes. Therefore, experimental fertilization should be continued in the lake system by 1) fertilizing one of the larger lakes (preferably Aleknagik) and 2) fertilizing Little Togiak Lake in both July and August. The former should be done to achieve the maximum benefits of an increase in adult returns and to evaluate the effects of fertilization where there is a substantial data base. Little Togiak Lake should be used to test alternate schedules of fertilizations and to determine any cumulative effects of fertilization that may occur as a result of repeated annual applications.

Lake Aleknagik and the north arm of Lake Nerka are logical choices for fertilization in 1977 because the density of juvenile sockeye will be higher there than in the other lakes. The biological data base for Lake Aleknagik is more detailed and extensive than in the other lakes; and, since it is the lowest lake in the system, the fertilizer would not affect productivity in the rest of the system. The latter is an advantage in evaluating the effects of fertilization. Although artificial fertilization has shown great promise as a method of enhancing sockeye salmon production (Bare, Great Central, and Little Togiak Lakes), the methodology is still in its infancy; therefore, future additions of nutrients should be accompanied by an evaluation that is as complete as available funds will permit.

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Table 1. Summary of fertilization experiments in lakes with sockeye salmon

Location	Surface area (km) ²	Max. depth (m)	Mean sockeye escapement	Fertilizer		Ratio of nitrogen to phosphorus
				Type of fertilizer	Amount added (kg)	
Bare Lake (Kodiak Is.)	0.5	7.5	300	Sodium nitrate and diammonium phosphate	1,400 to 4,100	5 to 1
Fern Lake (Washington State)	0.1	7	none (planted fingerlings)	1) Non-commercial mixture with primarily N and P 2) Ammonium phosphate, 11-48-0	7,900 7,900 400	8/19-9/4, 1965 at 4 5-day intervals 6/24-7/10, 1968 at 4 5-day intervals vals 6/19-8/28, 1969 at 10 weekly intervals vals (spread over entire lake)
Bear Bay in L. Aleknagik	0.6 (83)	11 (105)	3,000 (173,000)	Commercial fertilizer 21-53-0	544	6/12-7/3, 1970 at 10-day intervals (spread over entire lake)
Anvil Bay in North Nerka	1.4 (86)	35 (90)	19,000 (181,000)	"	1,270	6/16-7/8, 1970 at 10-day intervals (spread over most of bay)
Great Central (Vancouver Is.)	51	280	50,000	Commercial fertilizer, 27-14-0	90,720	June-Oct, 1970-1973 at weekly intervals (spread over 8 km ² near center of lake)

Table 1. Summary of fertilization experiments in lakes with sockeye salmon, cont'd

Location	Surface area (km) ²	Max. depth (m)	Mean sockeye escapement	Fertilizer		Ratio of nitrogen to phosphorus
				Type of fertilizer	Amount added (kg)	
Little Togiak	6	85	22,000	1) Commercial fertilizer, 21-53-0	1,361	1 to 1.1
				2) Diammonium phosphate technical grade	454	
					1,361	
				Aug 13-29, 1974 at 1-3 day intervals		
				Aug 13-20, 1975 at 3 day intervals (spread over 1 km ² at upper end of lake)		
				July 12-21, 1976 at 1-4 day intervals (spread over 5 km ² of lake)		

Table 2. Schedules of fertilizations in Little Togiak Lake and the densities of applications with diammonium phosphate to the actual surface area applied on a given date

1974	Area A	Date	8/13	8/14	8/17	8/18	8/22	8/23	8/28	8/29	Total
		kg	123	88	88	80	71	106	48	57	661
		kg/km ²	246	176	176	160	142	212	96	114	661
1975	Area A	Date	8/13		8/17		8/20				
		kg	88		66		66				220
		kg/km ²	88		66		66				220
1976	Area A	Date	7/12	7/13	7/18	7/19					
		kg	133	45	133	89					400
		kg/km ²	78	64	78	127					235
	Area B	Date	7/12	7/13	7/14	7/18	7/19				
		kg	89	89	44	89	89				400
		kg/km ²	99	99	49	49	99				222
Area C	Date	7/13	7/14	7/19	7/21						
	kg	89	178	44	223					534	
	kg/km ²	99	119	49	149					356	

Table 3. Compositions of fertilizers used in Little Togiak Lake in 1975 and 1976

	1975		1976	
	Percent	Weight (kg)	Percent	Weight (kg)
PO ₄	34.7	157.5	71.0	966
NH ₄	13.8	62.7	26.9	366
NO ₃	0.54	2.5	0	0
Ca	0.02	0.1	0.6	8
Mg	0.012	0.05	0	0
Fe	< 0.03	< 0.1	0.07	1
Other (inert material)	<u>50.9</u>	<u>231.0</u>	<u>1.5</u>	<u>20</u>
Total	100	454	100	1,361
P	11.2	51	23.1	315
N	10.8	49	20.9	285
Type	Commercial diammonium phosphate fertilizer (21-53-0)		Diammonium phosphate (98-99%) and tricalcium phosphate (1-2%), a drying agent	
Cost at Seattle	\$ 370		\$ 1,080	
Cost at Bristol Bay	\$ 588		\$ 1,733	
Cost at Little Togiak	\$ 738		\$ 2,183	
	(\$ 4.69 per kg of PO ₄)		(\$ 2.26 per kg of PO ₄)	

Table 4. Concentrations (ppm or mg/l) of phosphorous and nitrogen in unfiltered water. Values are the means from two samples collected at each date, depth, and station

Location	Date	Depth (m)	Total phosphorus (P)		Nitrate nitrogen (NO ₃ -N)		Total nitrogen (N)	
			Sta. 1	Sta. 5	Sta. 1	Sta. 5	Sta. 1	Sta. 5
Little Togiak Lake	7/8	5	.007	.016	.141	.106	.118	.146
		15	.007	.014	.143	.139	.078	.097
		20	<u>.014</u>	<u>.008</u>	<u>.114</u>	<u>.124</u>	<u>.124</u>	<u>.086</u>
		mean	.009	.013	.133	.123	.107	.110
	7/14	5	.022	.054	.119	.120	.191	.057
		15	.022	.026	.093	.099	.111	.276
		20	<u>.020</u>	<u>.030</u>	<u>.086</u>	<u>.139</u>	<u>.186</u>	<u>.129</u>
		mean	.021	.037	.099	.119	.163	.154
	7/22	5	.020	.023	.097	.101	.086	.075
		15	.023	.054	.124	.093	.104	.130
		20	<u>.017</u>	<u>.026</u>	<u>.088</u>	<u>.107</u>	<u>.103</u>	<u>.225</u>
		mean	.020	.034	.103	.100	.098	.143
	8/3	5	.021	.020	.089	.091	.097	.099
15		.027	.023	.102	.112	.084	.072	
20		<u>.019</u>	<u>.025</u>	<u>.104</u>	<u>.130</u>	<u>.086</u>	<u>.057</u>	
mean		.022	.023	.098	.111	.089	.076	
Central Lake Nerka	7/25	5	.029		.127		.096	
		15	.024		.124		.098	
		20	<u>.018</u>		<u>.132</u>		<u>.064</u>	
		mean	.024		.128		.086	
Little Togiak Cr.	7/1		.022		.144		.105	
Waterfall Cr.	7/1		.021		.126		.092	
A Creek	7/1		.021		.112		.045	
C Creek	7/1		.015		.117		.169	
Island Creek	7/1		.024		.061		.176	
Little Togiak River	7/1		.018		.123		.094	

Table 5. Secchi depth (m) and density of chlorophyll "a" in the upper 10 m (mg/m^3) at two stations in Little Togiak Lake by days after ice breakup and date, 1973-1976

1973						1974					
Days	Date	Sta. 1		Sta. 5		Days	Date	Sta. 1		Sta. 5	
		Secchi	Chloro.	Secchi	Chloro.			Secchi	Chloro.	Secchi	Chloro.
12	6/20	6.5	1.6	9.5	1.3	24	6/20	8.0	1.4	8.0	1.4
19	6/27	6.5	1.1	9.5	1.4	31	6/27	10.0	0.9	9.5	0.9
25	7/3	--	1.3	--	1.5	38	7/4	--	0.9	--	0.7
33	7/11	9.5	1.3	9.0	1.4	45	7/11	--	0.7	--	--
40	7/18	--	1.3	--	0.9	51	7/17	10.0	1.0	11.0	0.9
48	7/26	9.0	1.4	8.0	1.0	59	7/25	10.0	0.9	14.0	0.7
56	8/3	8.5	0.7	8.0	0.5	67	8/2	11.0	1.1	13.5	0.6
63	8/10	--	1.2	8.5	0.7	74	8/9	11.5	1.2	14.0	0.5
70	8/17	12.0	1.1	14.0	0.6	81	8/16	9.5	2.6	16.0	0.7
78	8/25	11.0	1.3	11.5	0.9	83	8/18	7.5	--	15.0	--
85	9/1	12.0	1.1	12.0	0.9	89	8/24	4.0	7.8	11.0	1.0
91	9/7	12.0	1.5	11.5	1.3	92	8/27	4.0	--	--	--
97	9/13	10.0*	1.3	12.5	1.3	97	9/1	4.5	1.8	11.0	0.9
103	9/19	4.0*	1.2	10.0*	1.3	103	9/7	5.0	2.8	12.0	0.7
109	9/25	4.5*	1.0	6.5*	1.4	110	9/14	9.0	2.2	13.0	0.8
						117	9/21	9.0	2.2	13.0	0.8

1975						1976					
Days	Date	Sta. 1		Sta. 5		Days	Date	Sta. 1		Sta. 5	
		Secchi	Chloro.	Secchi	Chloro.			Secchi	Chloro.	Secchi	Chloro.
5	6/20	8.0	1.0	11.0	0.9	9	6/26	9.5	1.2	10.5	0.9
15	6/30	3.0	2.4	9.0	1.9	16	7/3	10.5	1.5	9.5	1.6
20	7/5	5.0	2.0	8.0	2.3	23	7/10	8.5	1.0	10.0	1.0
26	7/11	6.5	1.3	8.0	1.7	27	7/14	9.5	1.6	10.5	1.1
33	7/18	8.0	1.4	9.5	1.6	28	7/15	7.5	--	9.0	--
40	7/25	7.5	1.7	11.0	1.0	30	7/17	9.0	1.4	10.0	1.3
47	8/1	11.0	1.3	--	1.0	35	7/22	6.5	3.0	7.5	2.2
54	8/8	10.0	1.5	9.5	1.1	39	7/26	6.0	2.3	7.5	1.0
61	8/15	9.0	1.7	12.5	1.1	45	8/1	8.5	1.7	10.0	1.2
63	8/17	--	2.3	--	1.1	52	8/8	9.5	1.6	10.0	1.1
68	8/22	6.0	2.1	13.0	0.8	59	8/15	11.5	1.4	12.5	0.7
72	8/26	7.0	--	12.0	--	66	8/22	11.5	1.2	14.5	0.7
75	8/29	8.5	2.1	11.5	1.3	73	8/29	7.5*	1.7	12.0	0.7
84	9/7	8.5	2.2	11.0	1.3	81	9/6	8.0	1.7	11.5	0.6
102	9/25	9.5	2.3	13.0	1.1	88	9/13	9.5	1.5	12.5	1.0
109	10/2	8.0	3.0	11.0	1.4	95	9/20	6.5*	1.3	12.5	0.9

* white color from runoff of heavy rainfall.

Table 6. Mean tow net catches and lengths on September 1 of age I juvenile sockeye salmon in Little Togiak Lake according to abundance of parent spawners and sampling area

Escapement (thousands)	Brood Year	Age 0 mean length	Age I							
			Geometric mean catch				Mean length (mm)			
			A	B	C	mean ¹	A	B	C	mean ²
6	1957	60	3.0	0.8	0.8	1	107	105	104	106
10	1962	61	8.3	3.5	0.2	3	97	96	94	97
10	1967	56	2.3	0.3	1.0	1	99	105	95	98
11	1961	57	0.0	4.6	0.7	2	105	100	102	100
14	1972	56	0.7	0.2	0.5	0.5	85	87	82	84
14	1973	54	2.5	0.7	0.3	1	79	77	90	80
15	1964	51	11.3	7.4	3.5	7	80	92	88	86
16	1958	63	8.3	0.7	0.4	3	95	100	99	96
17	1960	55	13.5	10.5	2.9	8	90	92	87	90
20	1956	--	1.7	0.3	1.2	1	102	96	93	97
20	1968	51	3.3	0.0	0.0	1	91	--	--	91
20	1969	54	4.0	1.9	1.7	2	87	91	88	88
21	1963	54	9.9	4.2	8.1	7	86	85	88	87
22	1966	53	15.1	0.9	0.7	5	87	90	90	87
24	1971	49	2.4	14.7	5.3	7	82	85	86	85
26	1965	45	4.4	9.0	1.2	4	86	86	91	87
40	1959	55	12.7	17.0	26.0	20	86	90	87	88
48	1974	45	1.3	1.6	2.1	2	88	88	90	89
55	1970	47	7.0	52.6	102.1	60	76	79	77	77

¹weighted by surface area, i.e., $(\bar{C}_A \times 1.7) + (\bar{C}_B \times 1.8) + (\bar{C}_C \times 2.5) \times 1/6$.

²weighted by surface area times mean catch.

Table 7. Average fyke-net catches of sockeye smolts in Little Togiak River by time period in 1976

Date	Catch per hour				Nerka lake level (cm)	Water temperature (c)	Nighttime Cloud cover	Weather Darkness
	1200- 2100	2100- 2400	0000- 0300	0300- 1200				
June 19-20	*	0	27	*	139	4.0	Clear	2330-0200
20-21	*	0.3	76	*	138	4.0	Overcast	2330-0200
21-22	*	0	213	*	138	4.6	Scattered	0000-0200
22-23	*	0	78	1	137	5.5	Overcast	0030-0200
23-24	0	0	108	2	137	6.2	Clear	0100-0200
24-25	0.2	0	39	6	136	4.7	Clear	0100-0200
25-26	*	0	10	0	135	5.0	Clear	0100-0200
26-27	0	0	11	--	134	6.0	Clear	twilight
27-28	0	0	120	--	133	6.0	Clear	twilight
28-29	*	0	12	0	132	5.5	Clear	twilight
29-30	0	0	5	2	130	6.5	Scattered	twilight
30-1	*	1	31	4	129	6.5	Broken	twilight
July 1-2	0	0	23	--	128		Overcast, rain	0030-0200
2-3	0.4	0	9	--	127		Overcast, rain	0030-0200
3-4	0	0	11	--	125	7.0	Overcast	0030-0200
4-5	0.1	*	97	--	123		Overcast	0030-0200
5-6	*	66	108	0.2	121	6.8	Overcast	0030-0230
6-7	*	8	47	0.4	119	4.8	Broken	0030-0230
7-8	*	16	200	1	117	5.5	Scattered	0030-0200
8-9	12	33	113	2	115	10.5	Broken	0000-0200
9-10	0	23	22	0.3	113		Clear	0000-0200
10-11	5	5	14	2	111	11.0	Scattered	2330-0230
11-12	0	6	16	1	109	9.8	Scattered	2330-0230
12-13	*	667	47	1	107	9.0	Overcast	2300-0230
13-14	1	3	17	--	105		Clear	2300-0230
14-15	0.4	2	19	10	103	10.0	Clear	2300-0230
15-16	98	34	85	1	100	11.0	Scattered	2300-0230
16-17	1	20	7	8	98		Clear	2300-0230
17-18	0.2	12	4	0	96	13.5	Clear	2300-0230
18-19	1	3	3	0	94		Scattered	2230-0300
21-22	*	--50	--	0.2	95	11.0	Overcast	2230-0300
23-24	*	--19	--	3	96		Overcast, rain	2230-0300
26-27	0	--1	--	0	94	12.7	Overcast	2230-0300
29-30	*	--244	--	0.1	94		Overcast	2200-0330
30-31	0.1	--42	--	5	94	12.8	Overcast	2200-0330

* No sampling conducted.

Table 8. Mean lengths and age compositions of smolts from Little Togiak River on dates when three or more samples were collected. June 20-22 at site 2 and July 5-8 at sites 5 and 6

Date	Time	Mean length (mm)		Age composition (%)		Sample Size	Total Catch
		age I	age II	age I	age II		
6/20	0000-0100	81.6	97.1	90	10	49	49
	0100-0200	82.4	97.5	76	24	85	85
	0200-0300	81.8	98.7	70	30	94	94
6/21	0000-0100	80.9	97.3	79	21	61	196
	0100-0200	82.1	100.7	74	26	50	270
	0200-0300	81.7	99.1	83	17	54	174
6/22	0000-0100	81.1	97.9	83	17	23	23
	0100-0200	82.7	99.6	66	34	53	133
	0200-0300	81.9	99.6	78	22	64	70
7/5	2200-0000	81.2	99.6	91	9	102	199*
	0000-0100	79.1	97.9	96	4	104	216*
	0100-0200	79.1	105.2	99	1	96	76*
	0200-0300	79.3	101.6	97	3	61	33*
7/7	2100-0000	80.0	104.2	96	4	49	49
	0000-0030	81.4	93.8	98	2	49	94
	0030-0100	81.4	96.4	96	4	52	250
	0100-0130	80.6	--	100	0	51	172
	0130-0200	80.4	94.8	98	2	52	53
	0200-0230	82.0	99.3	86	14	21	21
7/8	1230-1700	81.3	93.8	98	2	50	61
	2100-0000	80.6	104.2	98	2	48	100
	0000-0030	79.6	95.9	97	3	38	39
	0030-0100	79.4	--	100	0	41	41
	0100-0130	80.1	101.1	93	7	46	46
	0130-0200	80.9	101.6	96	4	52	52
	0200-0230	80.1	99.0	96	4	53	80
	0230-0300	82.8	102.1	96	4	52	81

* Mean catch of two nets.

Table 9. Mean lengths of sockeye fry (age 0) by sampling area and smolts (age I) by lake for the 1974 brood year

Lake	Number of spawners in 1974	Spawner density in 1974	Sampling area of lake	Estimated number of fry in 1975 (millions)	Mean catch of fry in 1975	Mean length of fry on Sept. 1, 1975	Mean length of age I smolts in 1976 (6/19-7/10)
Kulik	337,000	7489	C	1.7	18	41.3	
			B	3.5	26	48.3	
			A	4.4	36	45.6	76.4
Beverley	410,000	4556	A	3.5	24	42.8	
			B	3.8	32	44.8	
			C	16.0	45	57.9	70.8
North Nerka	242,000	2801	C	0.2	5	54.2	
			B	0.4	5	47.7	
			A	1.5	15	54.8	
Little Togiak	48,000	8000	A		9	44.9	
			B		13	44.8	
			C		18	43.2	81.7
Central Nerka	141,000	2749	A	1.3	14	54.7	
			B	2.2	22	52.9	
			C	0.4	8	57.9	
South Nerka	236,000	3728	A	1.1	12	56.7	
			B	0.5	10	60.7	
			C	0.04	1	62.0	
Aleknagik	242,000	2916	A	0.4	7	54.4	
			B	0.7	8	56.6	
			C	0.8	10	54.4	78.7

Table 10. Mean lengths of sockeye fry (age 0) and smolts (age 1) in the Wood River lakes for the 1974 brood year

Lake	Number of Spawners in 1974	Spawner density in 1974	Number of fry in 1975 (millions)	Mean length of fry on Sept. 1, 1975 (mm)	Mean length of age 1 smolts (in 1976 (mm)
Kulik	337,000	7489	9.5	45.8	76.4 (July 4)
Beverley	410,000	4556	23.2	53.5	70.8 (June 20-July 2)
Little Togiak	48,000	8000	0.2	44.0	81.7 (June 19-July 10) 85.3 (June 19-Aug. 14)
Nerka	619,000	3080	7.7	54.7	79.9 (July 9-19)
Aleknagik	242,000	2916	1.8	55.2	78.7 (June 1-25)
Lake system	1,709,000	4021	42.4	52.0	80.6 (June 11-July 10) 82.6 (June 1-August 9)

Table 12. Annual escapements of sockeye salmon, mean weights of juveniles, and the adult returns to the Wood River lakes, 1957-1976. Numbers in parenthesis are preliminary estimates

Brood year (y)	Escapement (thousands) Sept. 1 in y+1	Mean weight of age 0 on Sept. 1 in y+1 (gm)	Mean weight of age I smolts in y+2 (gm)	Apparent Growth		Adult returns of ages 1.2 and 1.3 (thousands)	Mean weight of age I on Sept. 1 in y+2 (gm)	Mean weight of age II smolts in y+3 (gm)	Absolute Growth (gm)	Relative Growth (%)	Adult returns of ages 2.2 and 2.3 (thousands)
				Absolute (gm)	Relative (%)						
1957	289	2.11	5.6	3.49	165	332	8.51	11.3	2.79	33	43
58	960	1.98	5.8	3.82	193	2216	4.91	7.7	2.79	57	120
59	2209	1.39	4.3	2.91	209	1230	5.64	7.9	2.26	40	414
60	1016	1.66	4.2	2.54	153	2100	6.66	9.3	2.64	40	176
1961	461	1.74	5.1	3.36	193	1125	7.96	8.5	.54	7	47
62	874	1.83	4.8	2.97	162	1380	4.74	9.9	5.16	109	132
63	721	1.44	5.6	4.16	289	1194	5.16	7.5	2.34	45	87
64	1076	1.36	4.3	2.94	216	573	5.09	6.2	1.11	22	358
1965	675	1.15	4.5	3.35	291	1212	3.17	7.0	3.83	120	198
66	1209	1.57	3.6	2.03	129	1553	6.60	6.1	.50	0	52
67	516	2.42	5.6	3.18	131	743	7.93	10.2	2.27	29	31
68	649	2.05	5.3	3.25	159	731	9.03	--	--	--	20
1969	604	2.02	--	--	--	438	6.11	--	--	--	273
70	1162	1.67	--	--	--	2306	5.96	--	--	--	230
71	851	1.46	--	--	--	937	6.64	--	--	--	(250)
72	431	1.99	--	--	--	(900)	7.08	10.1	3.02	43	--
1973	330	2.33	5.1	2.77	219	--	5.95	(8.0)	2.05	34	--
74	1709	1.28	(4.0)	(2.72)	(213)	--	(5.04)	--	--	--	--
75	1207	(1.08)	--	--	--	--	--	--	--	--	--
76	817	--	--	--	--	--	--	--	--	--	--
Means 1957-1968		1.72	4.89	3.17	191		6.03	8.33	2.30	46	

Table 13. Little Togiak River adult enumeration in 1976¹

Time	7/8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0000-0100	(106)		(29)	(77)	(2)	(0)	(39)	(90)	(0)	(53)	(14)	(5)					
0100-0200	(106)		(29)	(77)	(2)	(0)	(39)	(90)	(0)	(53)	(14)	(5)					
0200-0300	(106)		(29)	(77)	(2)	(0)	(39)	(90)	(0)	(53)	(14)	(5)					
0300-0400	(106)		(29)	(77)	(2)	(0)	(39)	(90)	(0)	(53)	(14)	(5)					
0400-0500		152	50	24	0	0	22	72	20	110	52	8					
0500-0600		218	100	0	0	28	0	88	18	40	10	0					
0600-0700		26	86	70	0	10	0	156	42	12	-2	16					
0700-0800		272	136	24	0	0	0	360	314	20	20	0					
0800-0900		34	66	28	0	20	0	392	108	188	142	8					
0900-1000		104	268	0	0	32	168	2	152	28	6	-14					
1000-1100		168	28	0	54	12	574	488	94	-54	16	0					
1100-1200		164	(146)	136	0	-54	0	44	-24	0	48	18					
1200-1300		18	264	48	28	-12	6	854	292	-132	100	-10		0	0	0	6
1300-1400		0	98	0	0	0	762	338	162	-8	70	0		0	-24	18	6
1400-1500		174	0	0	6	198	-10	208	36	134	.2	-16		0	0	74	40
1500-1600	80	150	196	22	0	410	76	-30	102	-54	8	0		0	4	102	92
1600-1700	80	46	0	10	18	102	472	-42	-28	92	-2	4		0	8	46	-26
1700-1800	76	68	82	2	0	149	23	87	63	142	0	6		0	66	0	
1800-1900	107	(42)	(69)	(1)	(93)	(75)	(70)	(41)	(32)	(202)	(1)	(3)		2	2	2	
1900-2000	(83)	16	56	0	186	2	116	-6	2	262	2	0		0	0	0	
2000-2100	(84)	0	82	0	-18	0	0	116	160	8	0	0		0	0	0	
2100-2200	60	0	0	18	4	26	142	200	164	24	2	0		0	0	0	
2200-2300	(106)	8	130	4	0	78	120	0	-4	-24	(5)	0		0	0	0	
2300-0000	(106)	(29)	(77)	(2)	(0)	(39)	(90)	(0)	(53)	(14)	(5)	(0)		0	0	0	
Daily total	1,382 ²	2,123	2,050	697	379	1,115	2,748	3,698	1,758	1,216	541	43	0	36 ³	92 ³	530 ³	212 ³
Cumulative total	1,382	3,505	5,555	6,252	6,631	7,746	10,494	14,192	15,950	17,166	17,707	17,750	17,750	17,786	17,878	18,408	18,620

¹Numbers in parentheses are estimates of missing observations.

²Includes estimate of 600 for prior hours. No fish were observed during afternoon counts from July 2 through July 7.

³Geometric mean for hours counted was multiplied by number of uncounted hours.

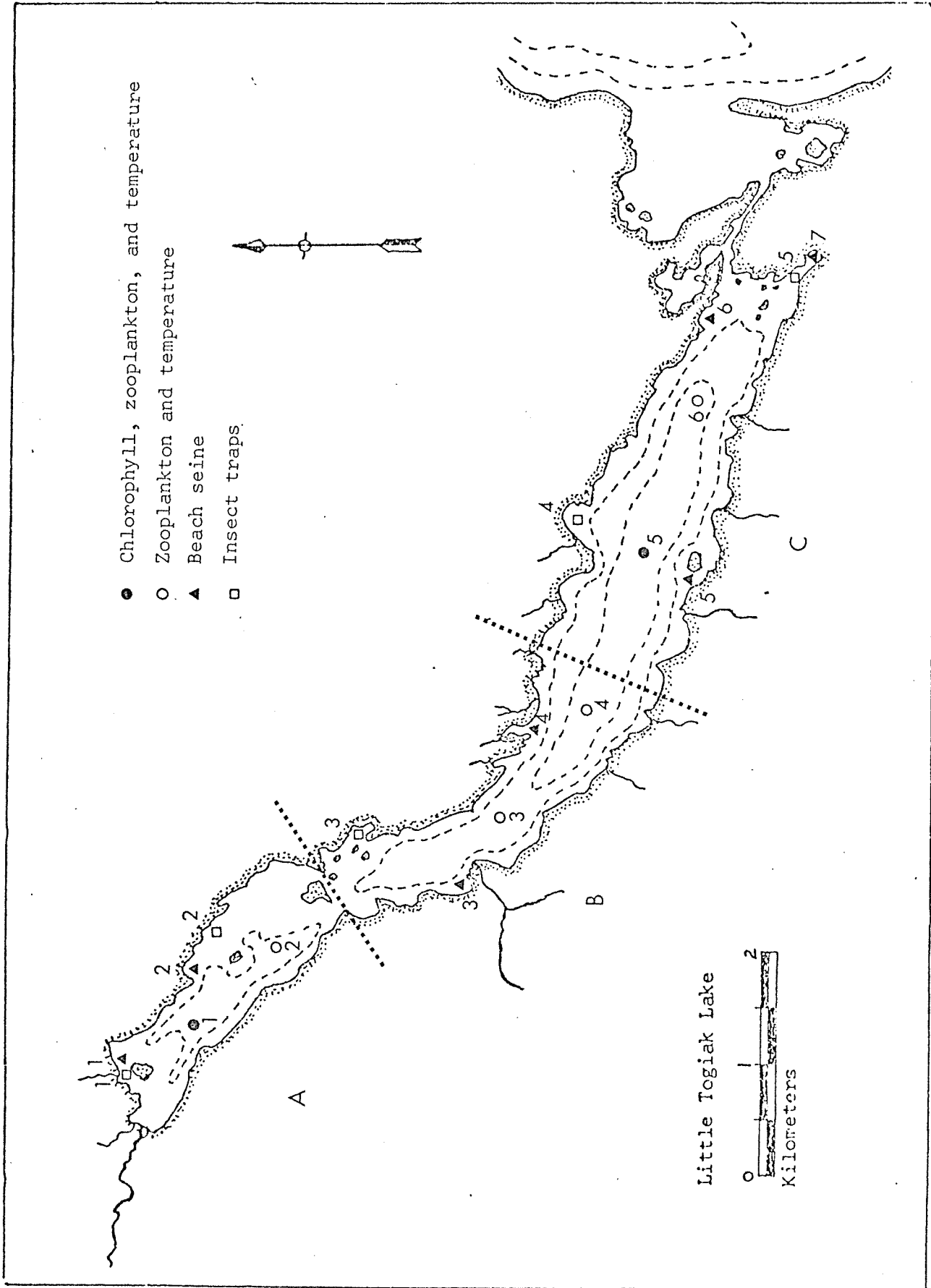


Fig. 1. Sampling stations in Little Togiak Lake. Depth contours at 20 m and 60 m indicated by dashed lines.

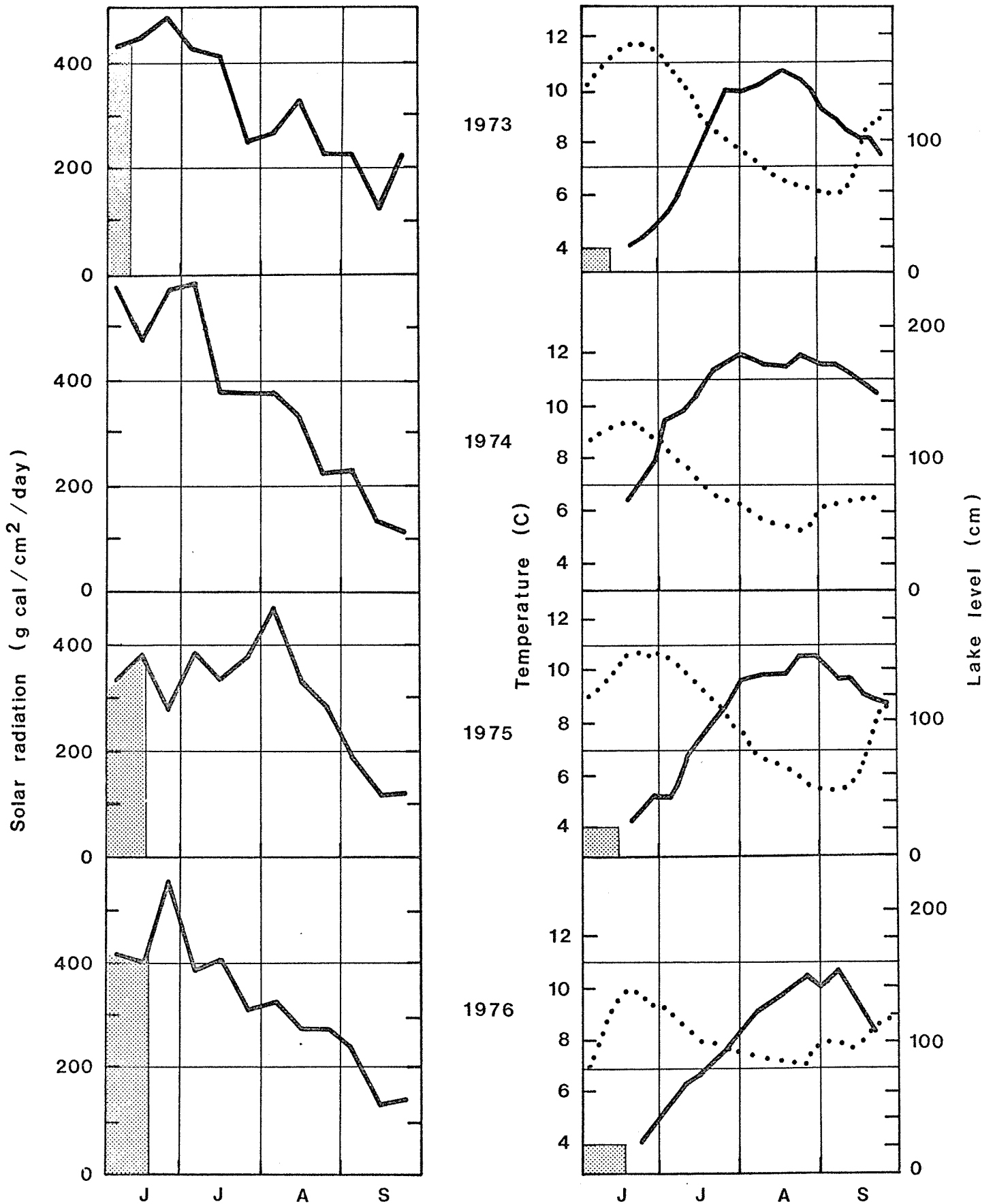


Fig. 2. Solar radiation (10-day means), mean temperature (solid line) in the upper 20 m of Little Togiak Lake, and relative lake level (dotted line) of Lake Nerka during summers of 1973-1976. The shaded area is the period of ice cover.

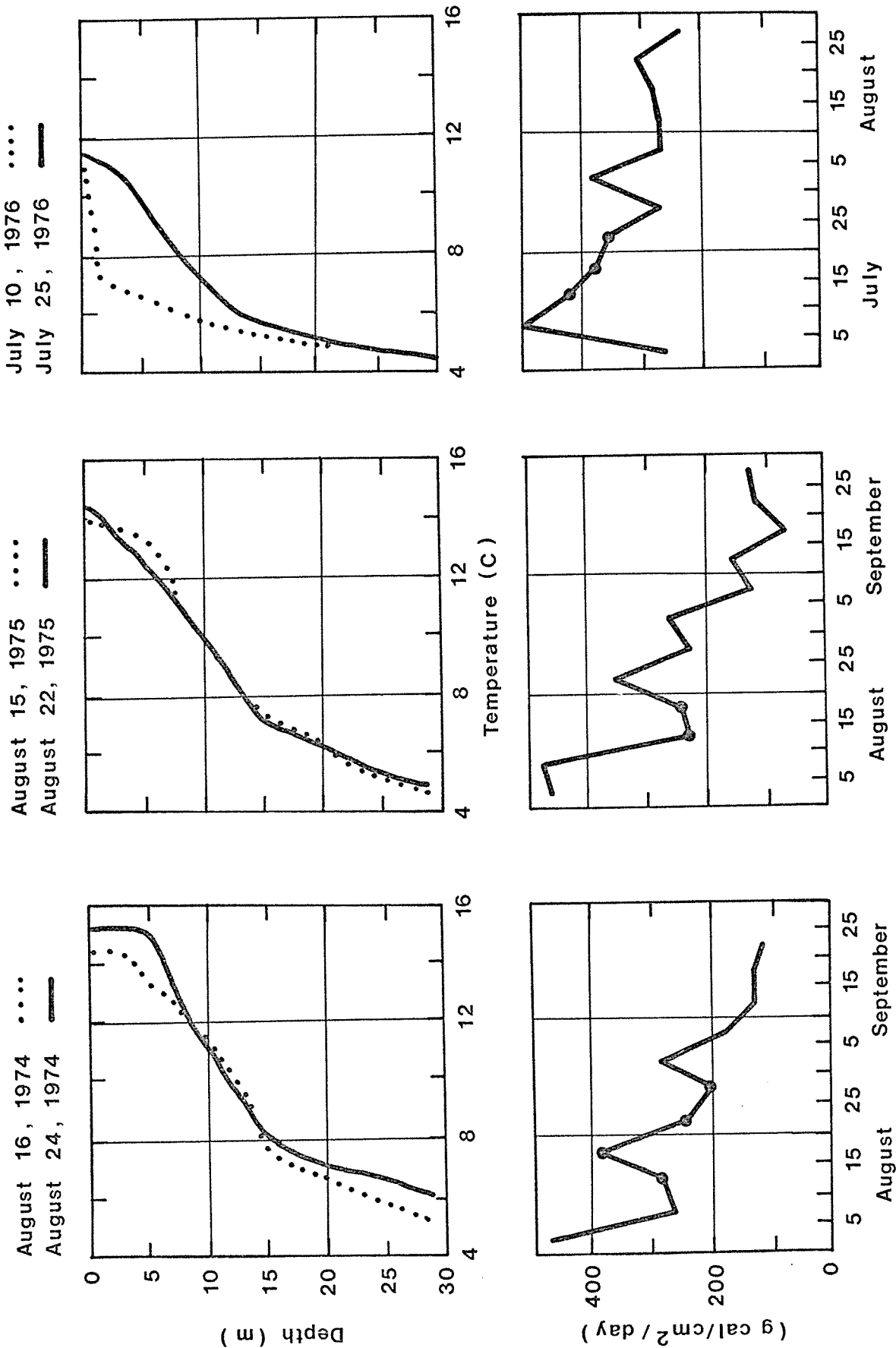
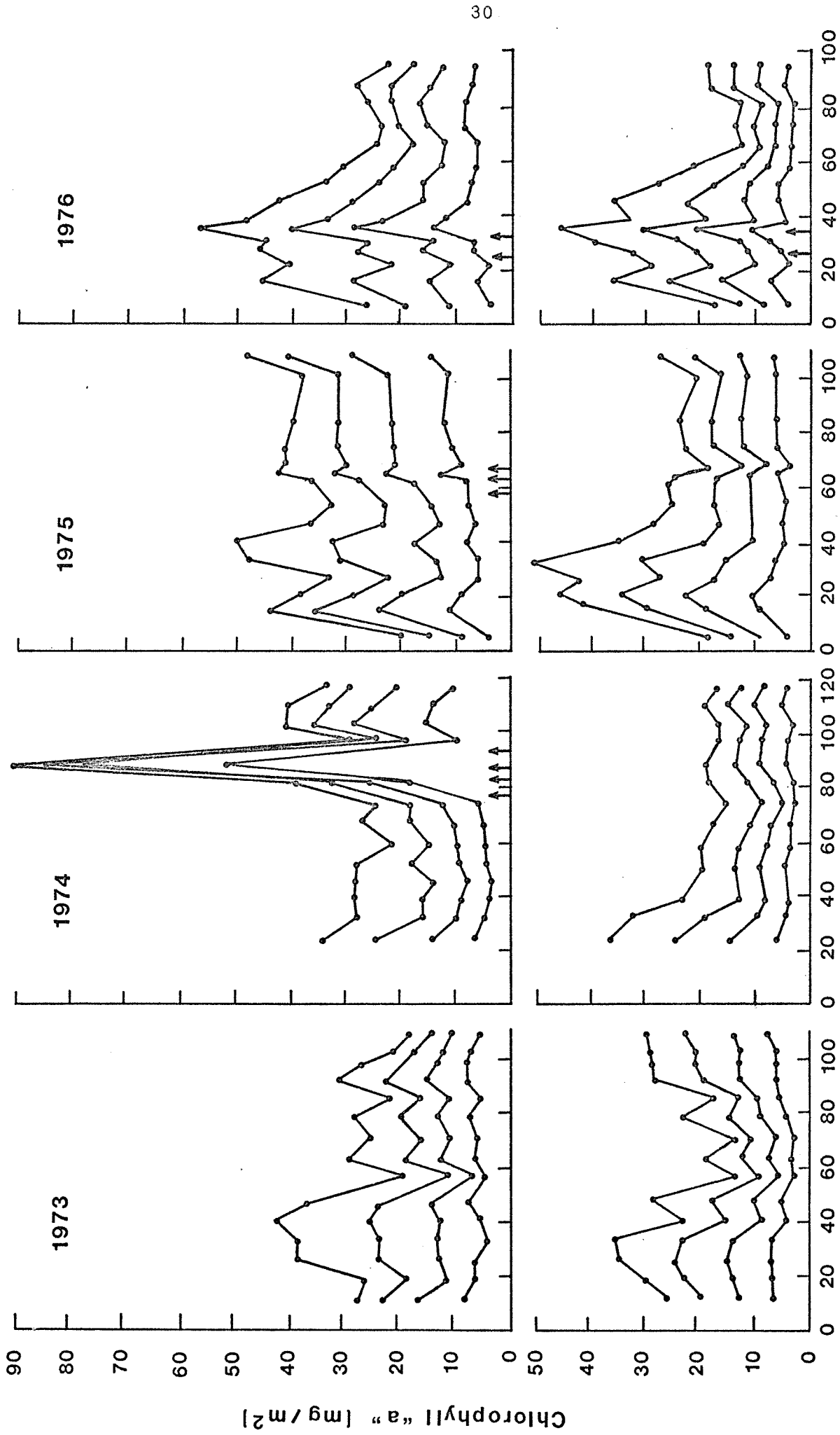


Fig. 3. Temperature profiles during fertilizations in Little Togiak Lake (upper) and mean daily solar radiation by 5-day periods (bottom).



Days after ice breakup

Fig. 4. Amount of chlorophyll a in Area A (upper) and Area C (lower) of Little Togiak Lake calculated from the surface to 5, 10, 15, and 20-m depths. Arrows indicate applications of fertilizer.

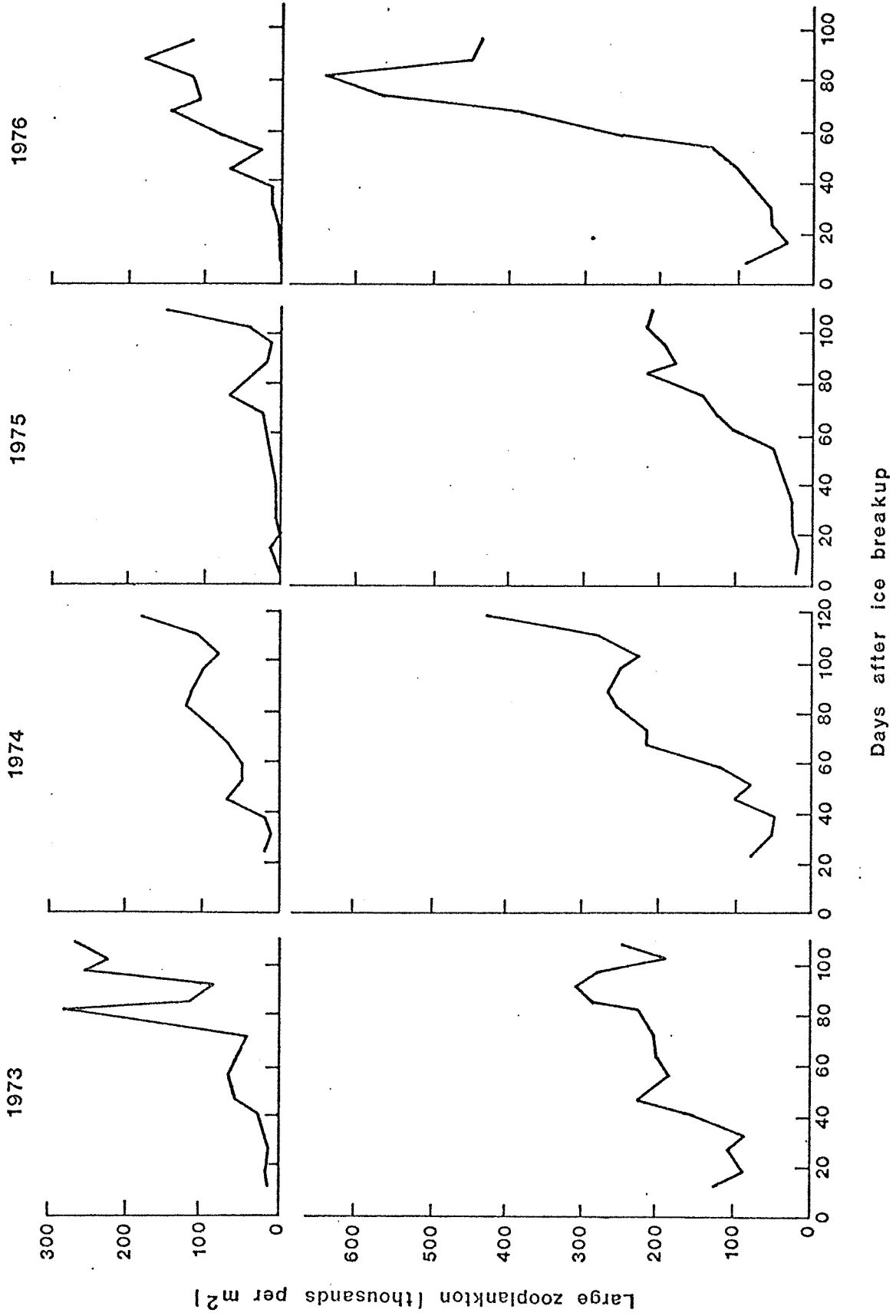


Fig. 5. Abundance of large zooplankters (Daphnia, Holopedium, and calanoid copepods) in Area A (upper) and Areas BC (lower) of Little Togiak Lake.

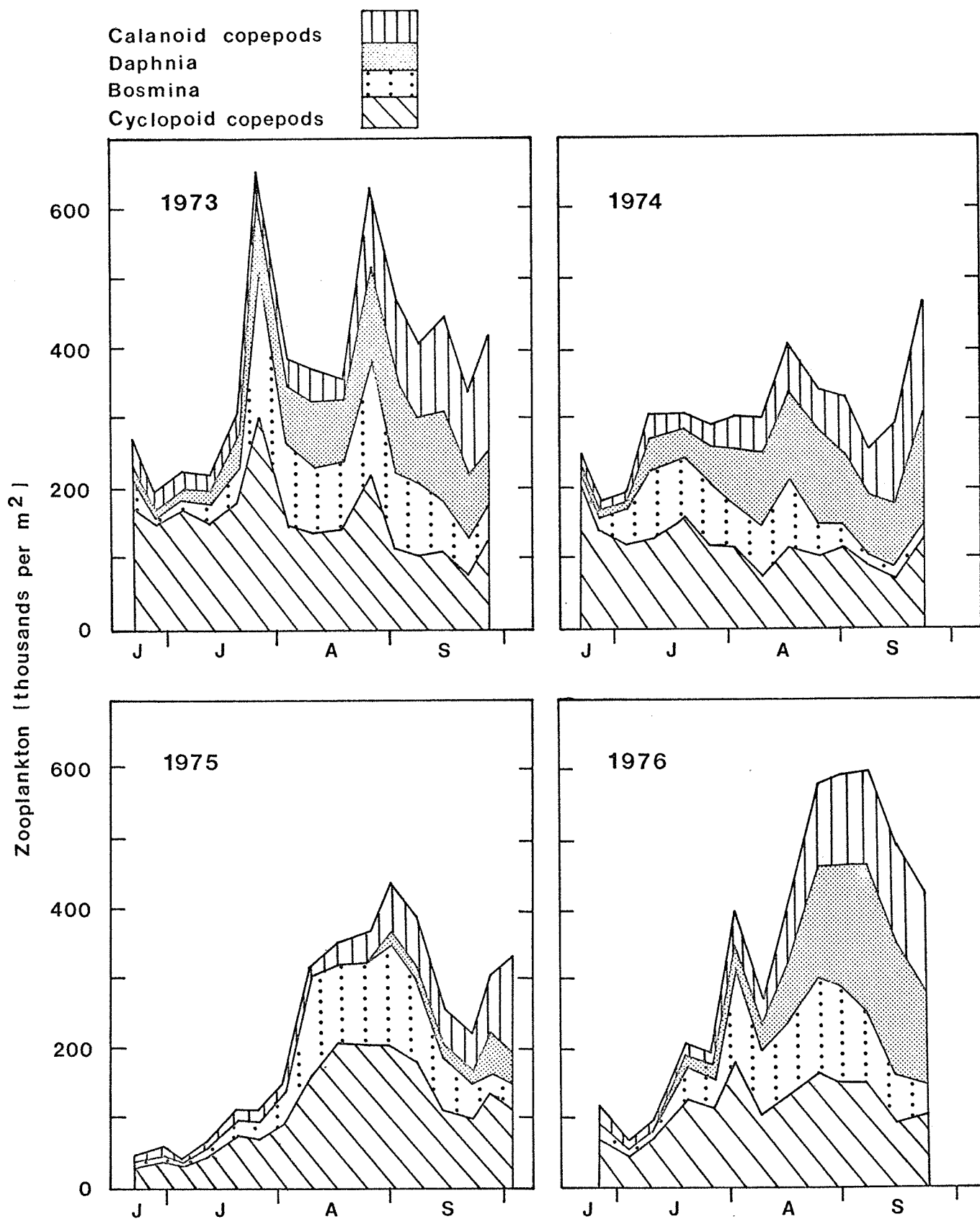


Fig. 6. Abundance of zooplankton in Little Togiak Lake, 1973-1976.

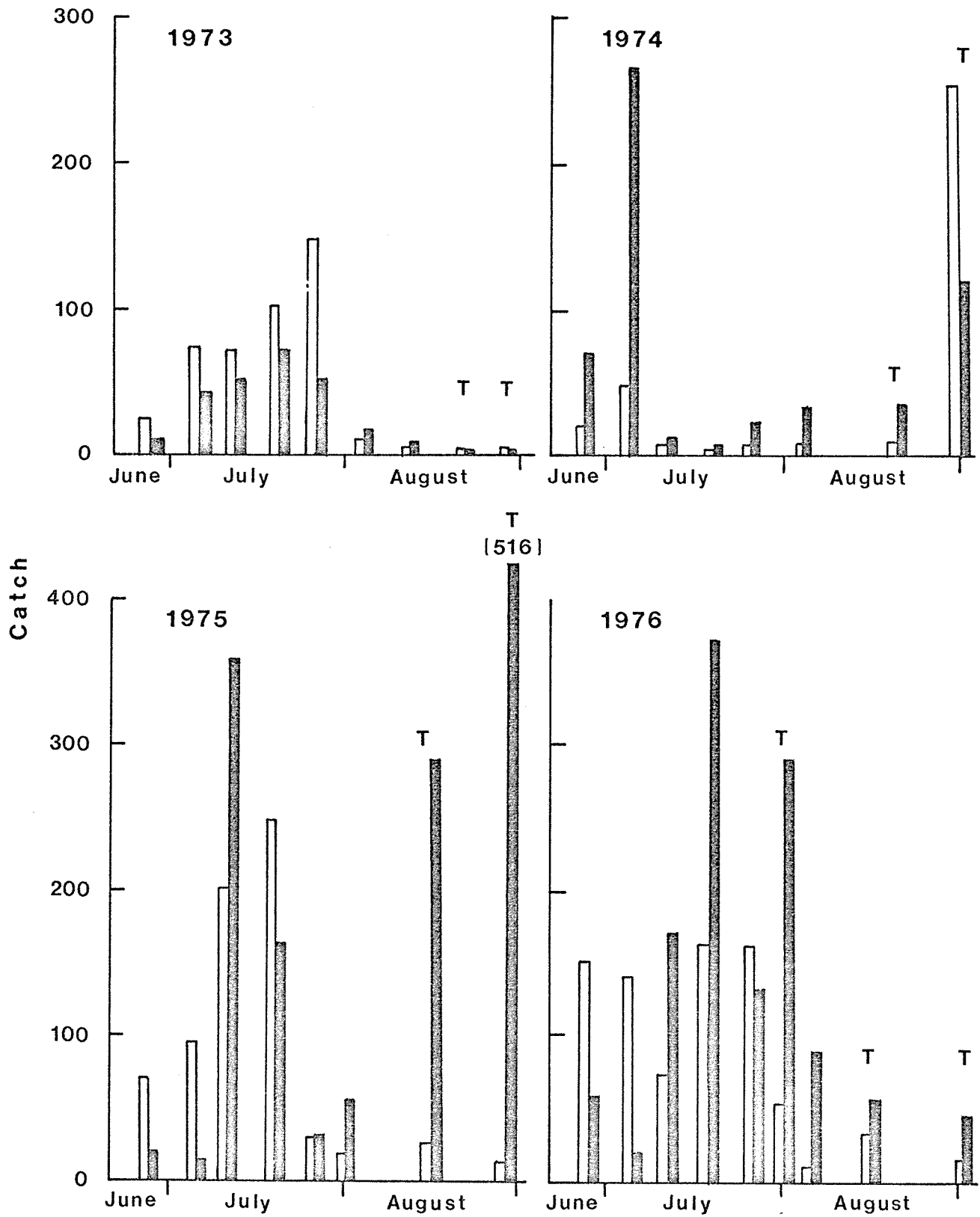


Fig. 7. Geometric means of the catches of sockeye salmon fry (open bars) and threespine stickleback (solid bars) from beach seining and tow netting (T) in Little Togiak Lake, 1973-1976.

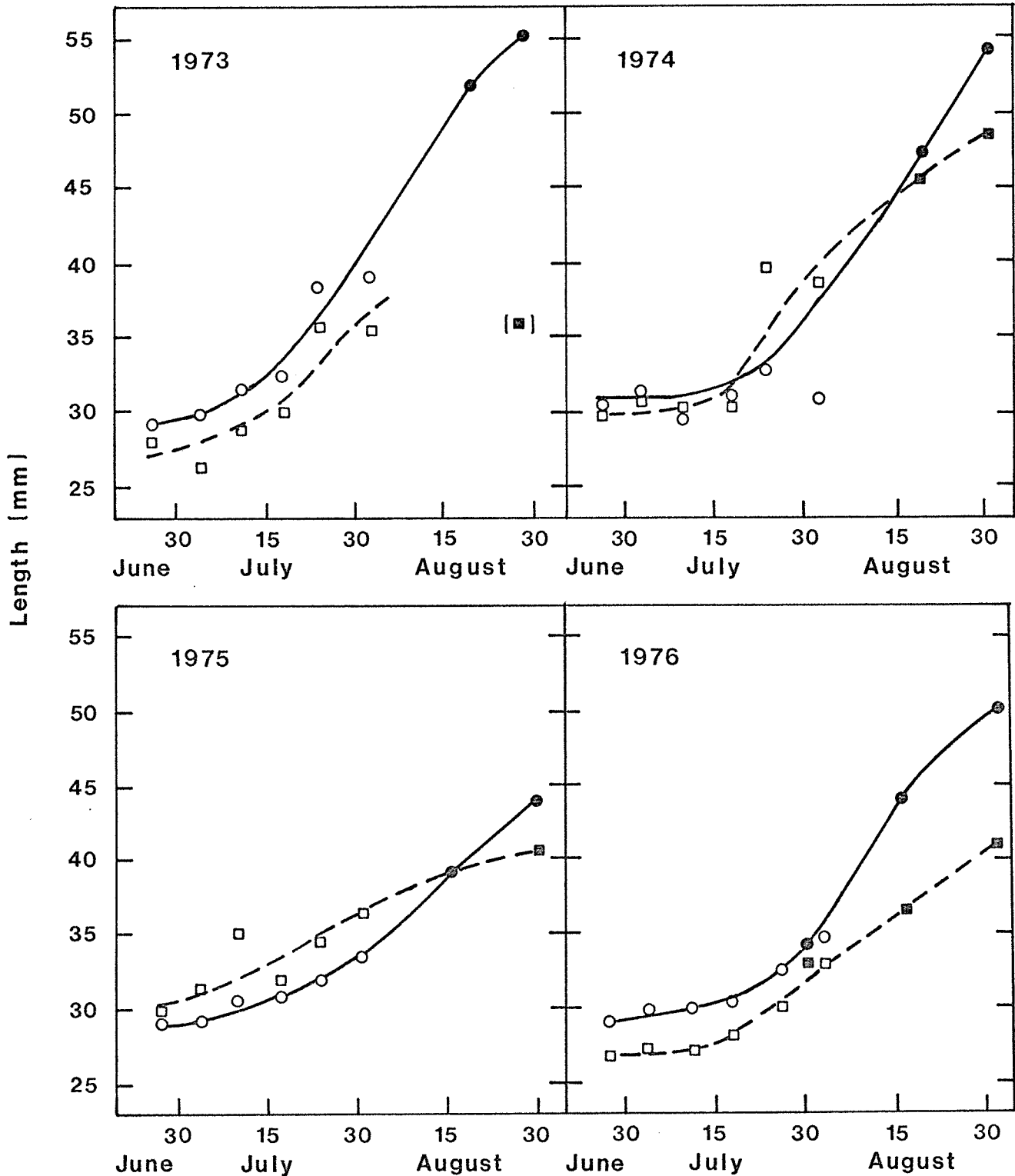
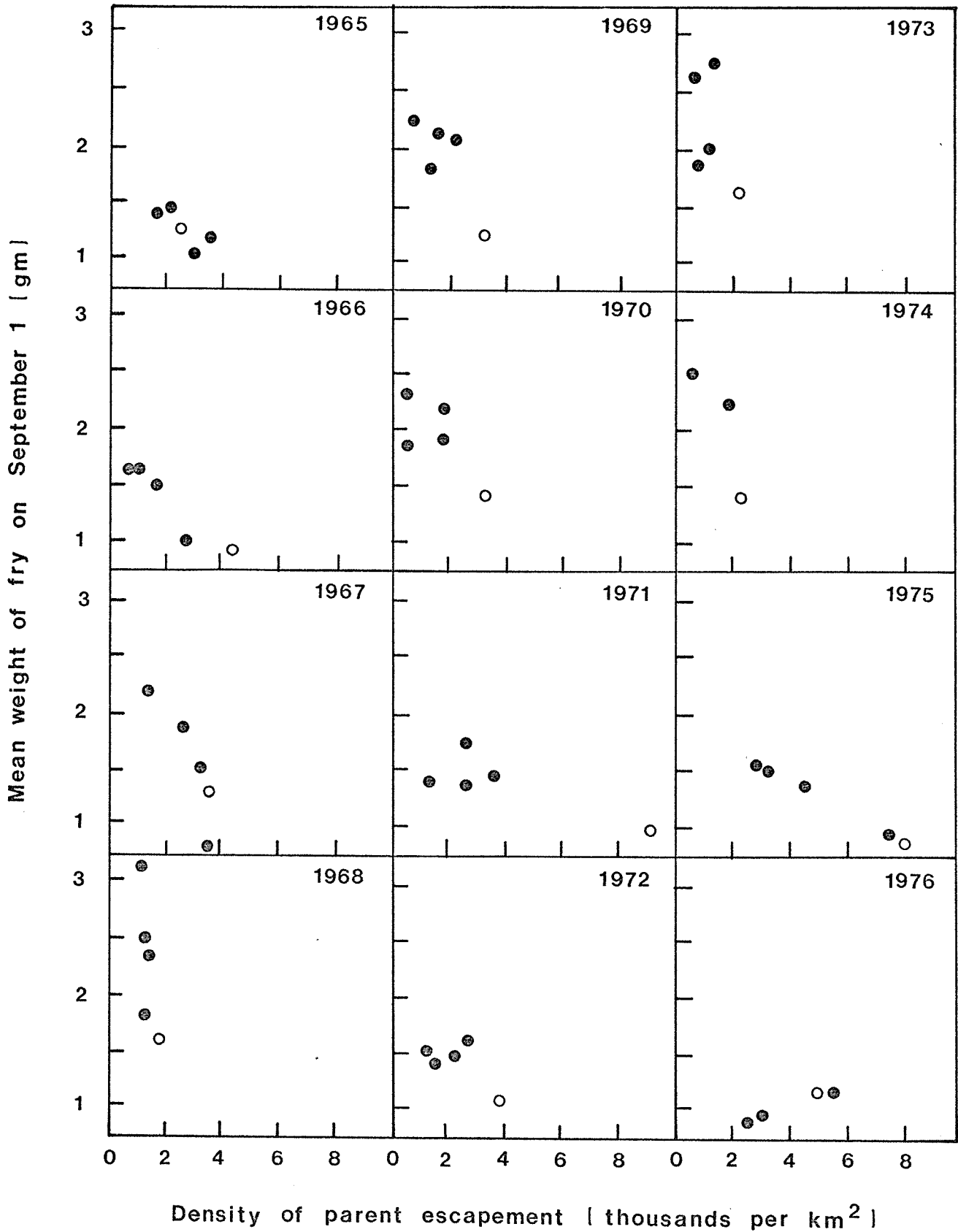


Fig. 8. Mean lengths of sockeye salmon fry (circles) and age I threespine stickleback (squares) from periodic sampling by beach seine (open) and tow net (solid) in Little Togiak Lake, 1973-1976. Curves were fitted by eye to sample means using the average catches as weighting factors.



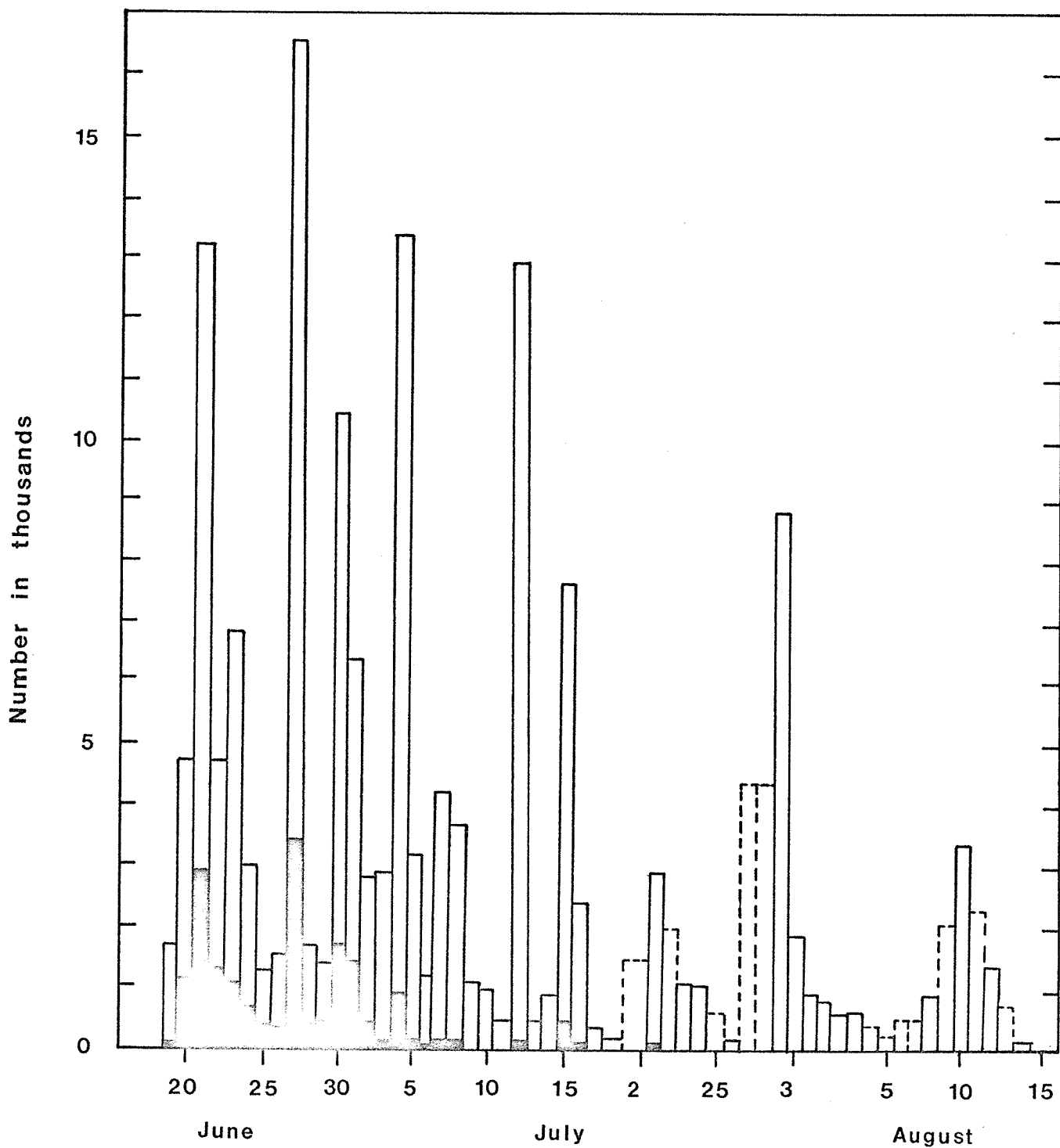


Fig. 10. Estimates of the number of smolts migrating from Little Togiak Lake by date in 1976. Open bars for age I and solid bars for age II.

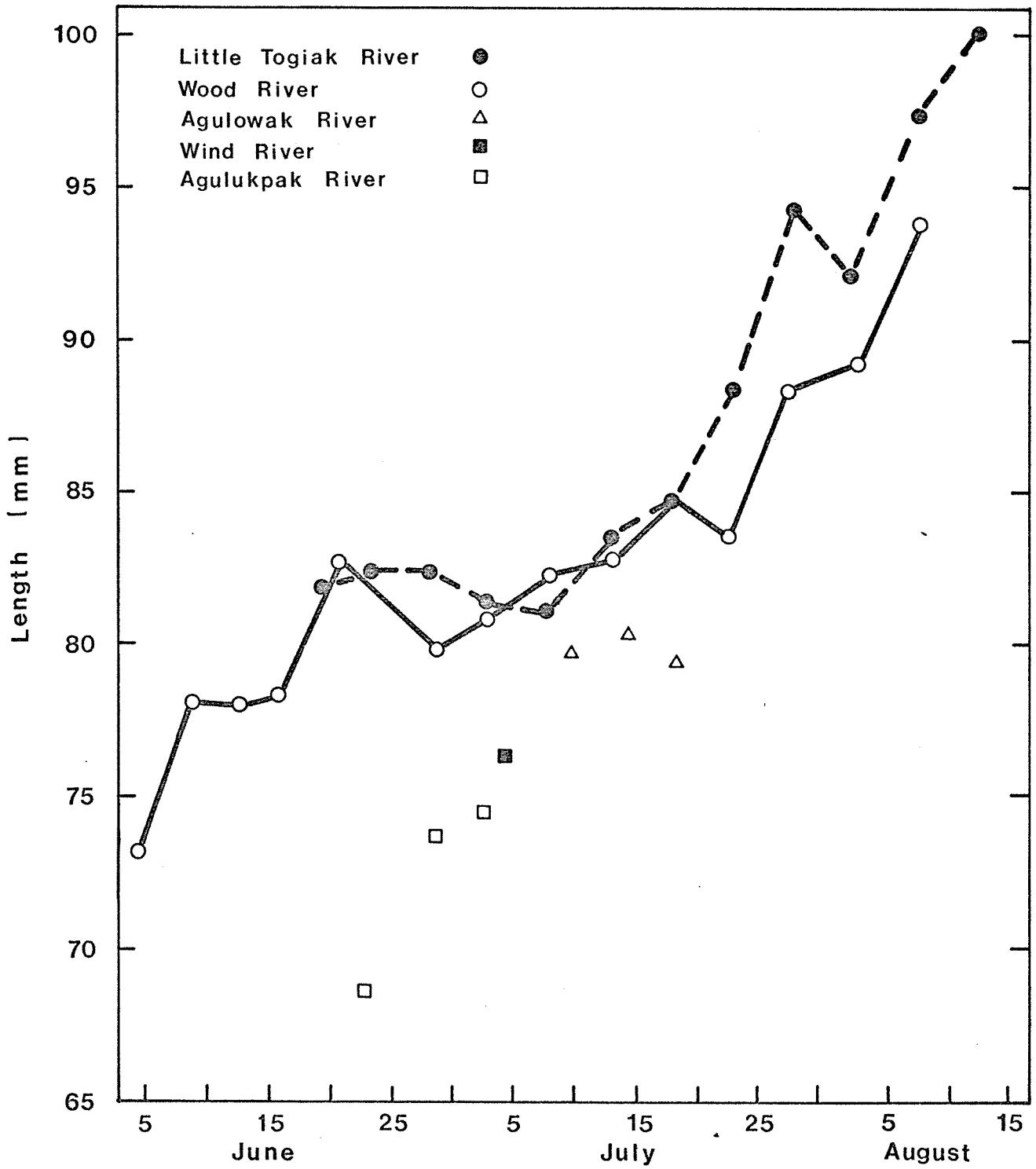


Fig. 11. Mean lengths of age I smolts in the Wood River lakes by date in 1976.

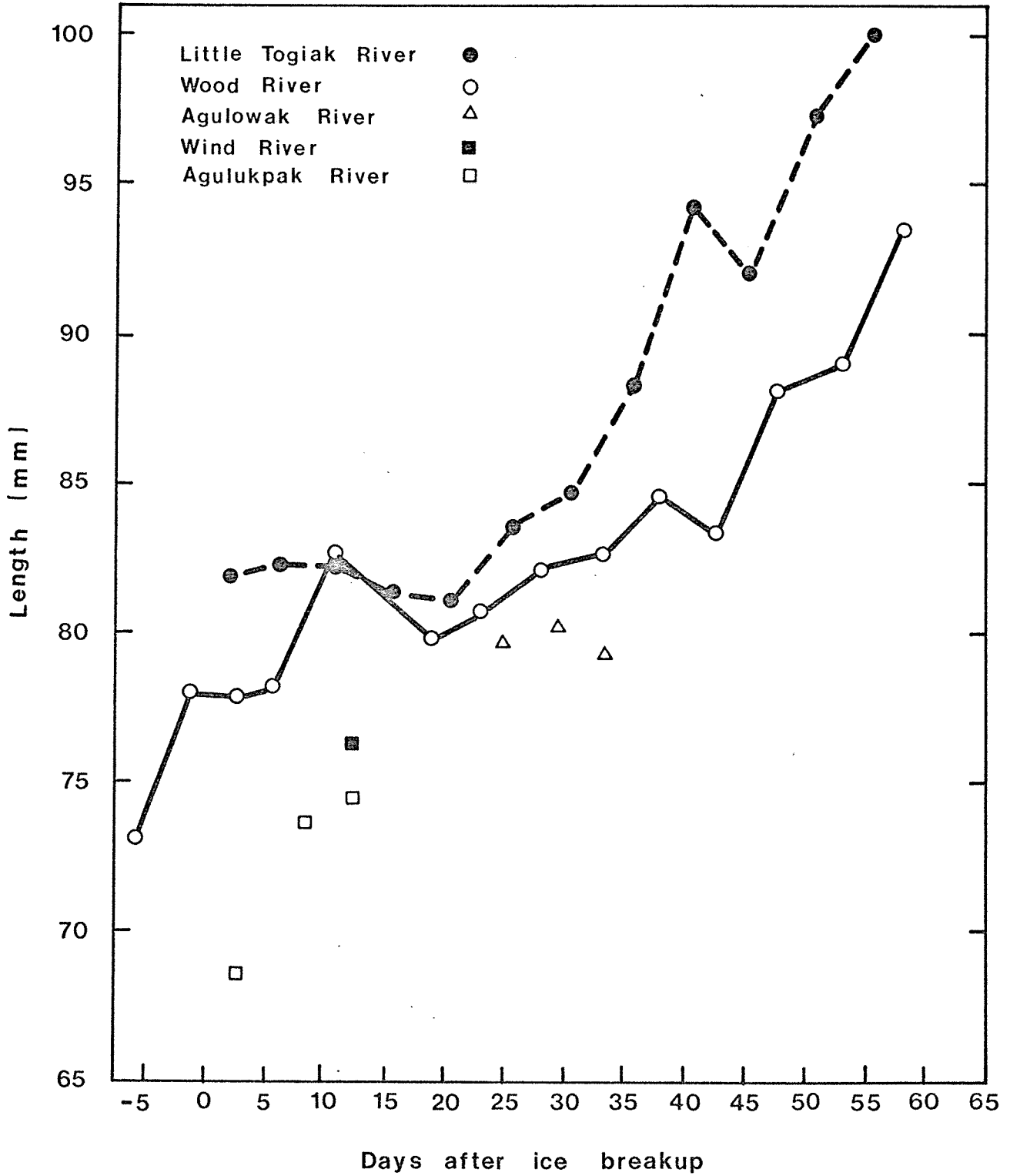


Fig. 12. Mean lengths of age I smolts in the Wood River lakes by days after ice breakup.

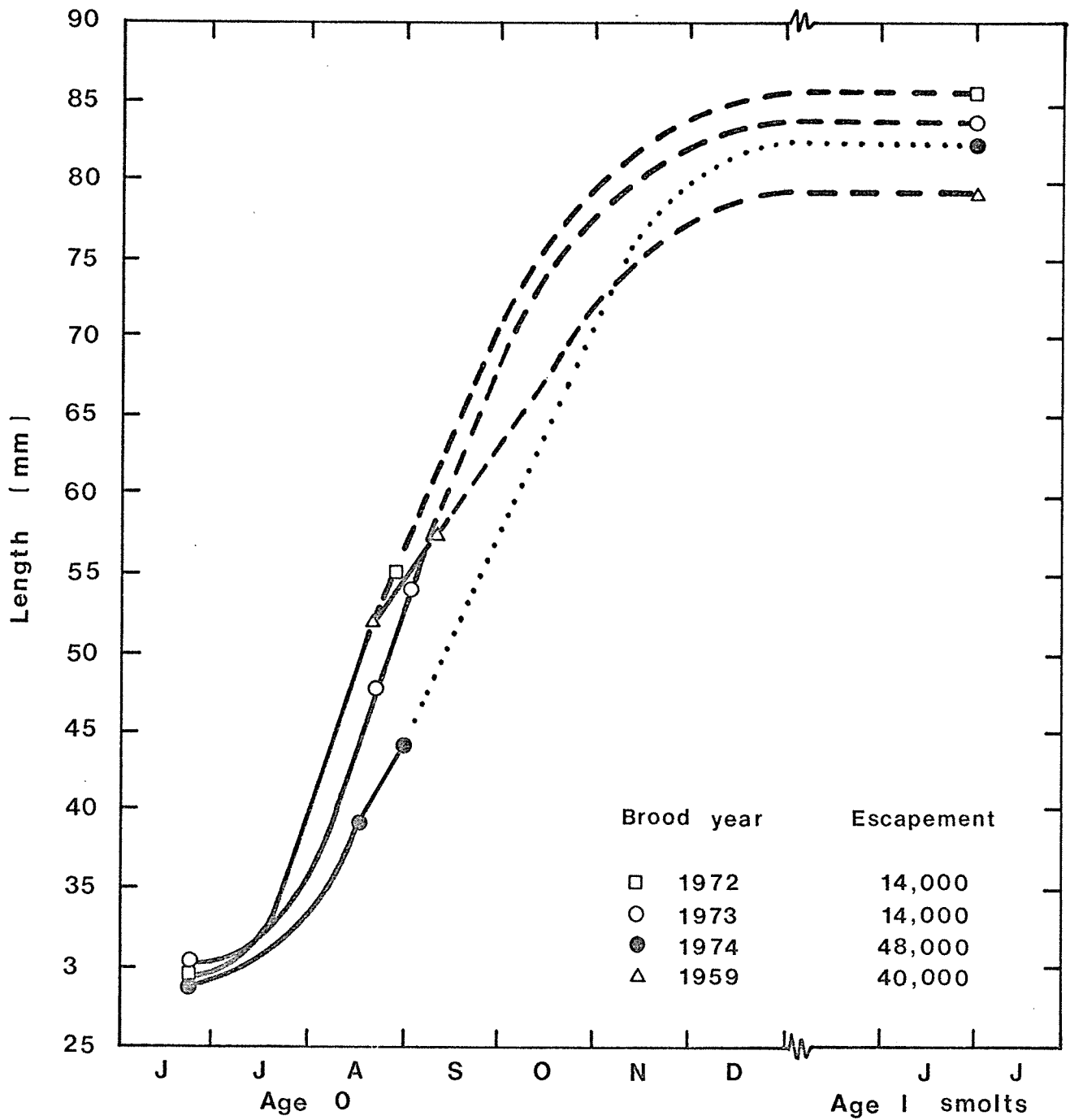


Fig. 13. Growth in length of juvenile sockeye salmon in Little Togiak Lake.

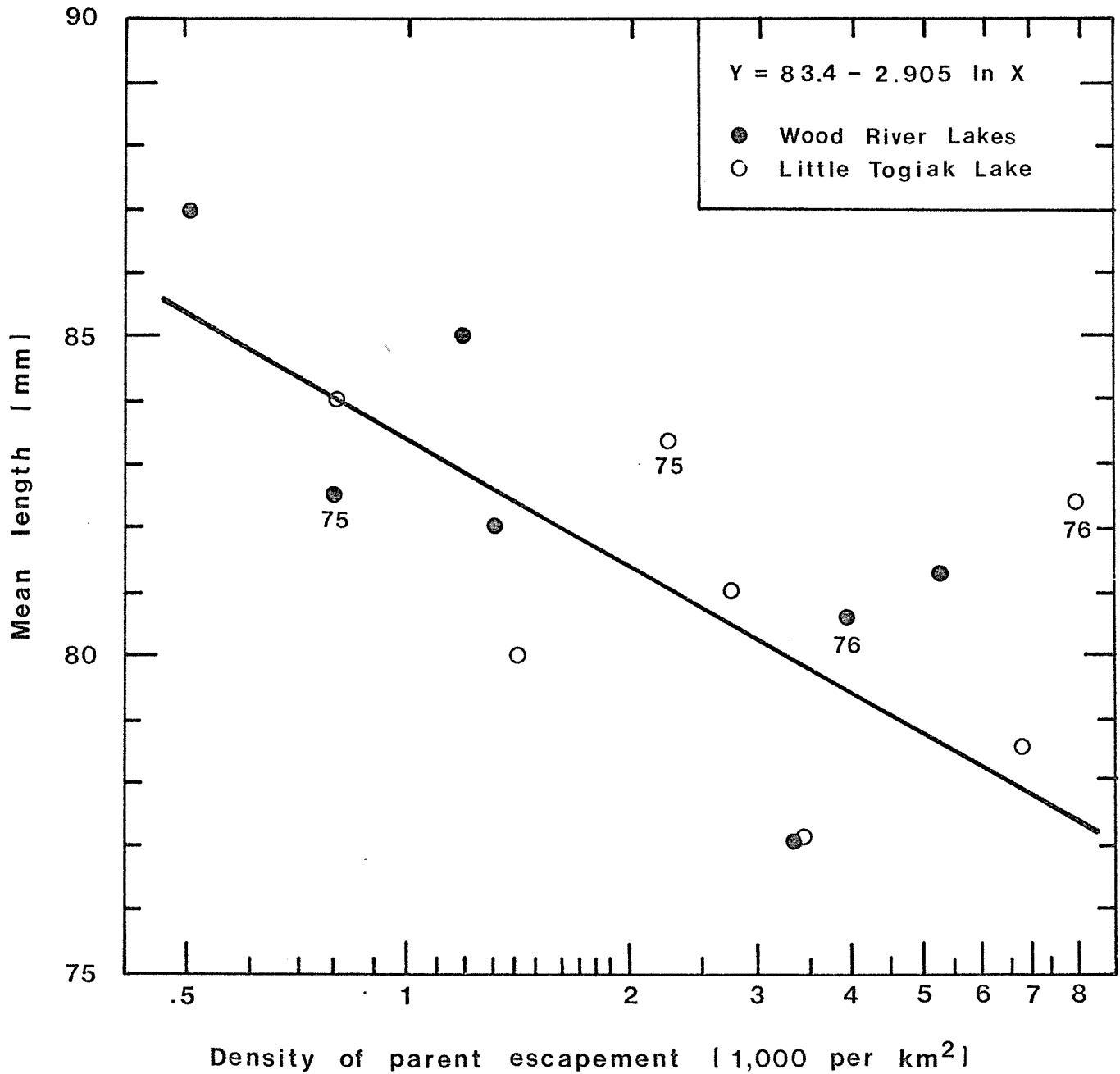


Fig. 14. Relationship between the mean length of age I smolts and the density of parent spawners (logarithmic scale). Observations from years in which length measurements were made both at Little Togiak Lake and at the outlet of the Wood River system. Regression fitted to all observations except those from 1976.