

FRI-UW-7716  
October 1977

FISHERIES RESEARCH INSTITUTE  
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Seattle, Washington 98195

THE PRODUCTION OF SOCKEYE SALMON IN THE KVICHAK RIVER SYSTEM  
DURING PEAK CYCLE YEARS

by

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FINAL REPORT  
August 1, 1976 to June 30, 1977  
Alaska Department of Fish and Game  
Association of Pacific Fisheries

Approved

Date Submitted: October 17, 1977

  
Director

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THE PRODUCTION OF SOCKEYE SALMON IN THE KVICHAK RIVER SYSTEM  
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INTRODUCTION

The Kvichak River system in western Alaska is the world's largest single producer of sockeye salmon. Observations of sockeye salmon runs to the system have been made for more than 70 years. Iliamna Lake (2,612.6 km<sup>2</sup>) and Lake Clark (266.8 km<sup>2</sup>) are the major nursery grounds in the system. Since 1961, the cyclic runs of sockeye salmon to the Kvichak River system have been studied intensively by the Fisheries Research Institute. In order to explain cyclic changes in abundance, observations of adult escapement and distribution in the spawning beds, primary and secondary production, relative abundance and growth of juveniles, and general character of the environment, have been made over three 5-year cycles. Presently, these studies are supplementing management programs developed and maintained by the Alaska Department of Fish and Game (ADF&G).

In 1969 and 1974, in an effort to broaden the Kvichak cycle to include a peak and an adjacent subdominant peak year, ADF&G regulated the commercial fishery so as to achieve a substantial escapement in 1969 of 8.4 million, and 4.4 million in 1974, prior to the peak years of 1970 and 1975, with 13.9 and 13.1 million spawners, respectively. The production from the 1969 escapement was dampened by 2 consecutive years of severe winter conditions. The 1974 escapement produced approximately 120 million age I smolts in 1976. This large migration of age I smolts was not anticipated and the question remained as to the size of the holdover populations in Iliamna and Lake Clark from the 1974 escapement.

In the Kvichak River system the hypothesis that the cycle originates in freshwater and can be manipulated by changes in the size of the escapement has been confirmed. One of the operating feedback mechanisms is the periodic introduction of biogenic elements through the salmon carcasses in the peak years, which eventually affects the food supply of juvenile sockeye salmon.

In late January 1976 the volcano on St. Augustine Island in Lower Cook Inlet, 80 miles east of Iliamna Lake (Fig. 1), underwent a series of eruptions which resulted in depositing the equivalent of .1 to 3 mm of ash over frozen Iliamna Lake and much of its basin. The timing of this event coincided with a peak year in cyclic salmon abundance in the Kvichak system. The ashfall, therefore, came in addition to the biogenic elements brought into the system by the 13.1 million salmon carcasses from the 1975 escapement. Thus, a situation was created whereby the effects of fertilization by volcanic ash could be studied.

The progeny of peak year spawners typically show a slower mean growth rate than nonpeak-year juveniles. Competition for limited food supplies by higher densities of juveniles is proposed as a major factor responsible for differential growth between year classes. The slower growth results in a higher proportion of peak year juveniles remaining 2 years in the nursery area. It is possible that the fertilization due to volcanic ashfall could influence the food supply, and hence the growth rate, of juvenile salmon. As a result, if the progeny of the 1975 escapement do not experience the usual decline in growth rate associated with peak year abundance, it could result in a substantial number of smolts migrating to sea in 1977 instead of 1978. The resulting implications to management are important, since it is conceivable that the Kvichak cyclic pattern, and hence management strategies during the late 1970's, will change.

The following report summarizes the results from studies conducted by the Fisheries Research Institute in the Kvichak River system during 1976. The emphasis is directed toward studies concerning the growth and relative survival of the progeny from the 1974 and 1975 brood years, and the impact of ashfall on biological processes in Iliamna Lake. The 1976 programs were supported by funds procured under contract with the Alaska Department of Fish and Game, and supplemented with additional funds from the Bristol Bay canning industry through the Association of Pacific Fisheries, the National Science Foundation as part of the Western Forest Biome, Analysis of Ecosystems, and the University of Washington.

## 1976 STUDIES

### Winter Sampling

The Institute, in collaboration with the Institute of Marine Studies, University of Alaska, organized a sampling trip to ice-covered Iliamna Lake from March 19 through 26, which gathered information regarding: 1) the distribution of ashfall in the Kvichak watershed; 2) the surface layers of lake sediment; 3) the abundance of primary and secondary producers; and 4) water chemistry and thermal conditions prior to the ashfall going in the lake.

### Spring Sampling

A second sampling program was conducted during ice breakup from May 21 through June 7. Data were obtained for: 1) ash deposition; 2) primary and secondary production; 3) thermal conditions; and 4) water chemistry and transparency. Studies concerned with the growth of littoral periphyton, the seasonal solar radiation, and the lake level, were also initiated.

### Summer-Fall Sampling

A third sampling program was conducted from July 4 through September 30. Efforts were directed toward: 1) obtaining indices of relative abundance, distribution and growth of juvenile sockeye salmon and major competitor

species in Iliamna Lake and Lake Clark; 2) determining the summer abundance of primary and secondary producers; 3) determining the temperature regime in Iliamna Lake; and 4) measuring the production of periphyton in littoral areas in the eastern end of Iliamna Lake.

### Ash Fallout

On January 22, 1976, Mount St. Augustine began its latest series of eruptions. Previous documented eruptions occurred in 1812, 1883, 1902, 1935, and 1963-64. The eruptions of January 22 through January 25 deposited the equivalent of .1 to 3 mm of ash on frozen Iliamna Lake and much of the surrounding watershed. The major eruptions of Mount St. Augustine lasted through mid-February.

### Distribution

It was estimated that from 6.6 to 13.9 million metric tons of ash were deposited over approximately 13,000 km<sup>2</sup> of the Kvichak watershed (Table 1). Iliamna Lake is approximately 150 km long and the heaviest ashfall occurred in the eastern part and along the south shore to midlake (Figs. 2 and 3). Initially, the density of ash at the eastern end of the lake was approximately 1.1 to 2.1 kg/m<sup>2</sup> (Table 1), but subsequently most of this ash was wind-blown and became irregularly distributed over the frozen lake surface and along the adjacent shoreline. Ash density decreased rapidly from midlake west, with the result that much lighter ash deposition occurred in the western half of the lake. However, it is in the eastern and midportions of the lake where the primary and secondary production important for the maintenance of the salmon cycle take place.

Many of the concentrations of ash observed on frozen lake surfaces during late March were reported to have gone through the ice in early April, 6 to 8 weeks prior to the breakup of lake ice.

Typically during late May and early June much of the terrain at the eastern end of the lake was coated with a thin, dust-like layer of ash. Although concentrations of drifted ash in some areas were observed at depths of up to 18 to 25 cm, this phenomenon was very rare and typically where patches of ash were found (Fig. 4), they were generally 1 to 2 mm in depth. This condition remained until the first week in June, when the area received its first heavy rainfall since snowmelt.

### Composition

The bulk chemical composition of an ash sample collected in Iliamna Lake is given in Table 2. Estimates of the total contribution of silicon and phosphorus to the lake, and the total affected area of the Kvichak watershed, are given in Table 3. The composition is typical of other volcanic ashfalls in western Alaska with Si, Al, Mg, Ca, Na, and Fe being the most common elements (Detterman 1968). The ash differs from nitrate-

phosphate fertilizers by the high content of silica, and absence of nitrogen.

#### Grain Size

A grain size analysis of Augustine ash collected by Bruce L. Reed, geologist (Alaska Branch of the U.S. Geological Survey) at Knutson Bay, 64.5 km northwest of the Mount St. Augustine volcano, showed that 50 percent of the ash was less than .045 mm.

#### Discussion

The estimated contribution of 594 to 1,816 metric tons of phosphorus to Iliamna Lake from the ashfall (Table 3) exceeds the estimated contribution of 169 metric tons from the 24.3 million sockeye salmon carcasses of the 1965 peak cycle escapement (Donaldson 1967). Laboratory analyses indicate that although the phosphorus content in the ash was 654 ppm, the ash contained only .09 ppm of the water soluble form, ortho phosphate ( $PO_4 - P$ ).

The ultimate contribution of the ash to the nutrient loading of Iliamna Lake depends on the relative solubility, and the time rate of release, of such important biogenes as phosphorus and silicate. Since the ash was predominantly very fine-grained, it is not unreasonable to assume that the elements that are readily soluble would be easily incorporated into the system. Additionally, the buffering effect of the environment in delaying the release of nutrients from the watershed to the lake suggests itself as the mechanism for any prolonged effects on tertiary production.

#### Physical Environment

Although the differential production of juvenile sockeye salmon in the Kvichak system is linked to the Kvichak salmon cycle, and, hence, the numerical size of the escapement, changes in freshwater production are also linked to changes in environmental conditions which affect the food base of juvenile salmon. Favorable environmental conditions during the period between emergence of juvenile salmon from the gravel and movement into the littoral zone of the lakes and the subsequent commencement of feeding are critical to early survival.

#### Ice Breakup

The 1976 spring breakup of lake ice was later than average (Table 4). Pile and Knutson Bays opened up May 15-18, and Pedro Bay was mostly clear of ice by May 21. Iliamna Lake was still more than 50 percent covered on May 29. By June 5, the lake was clear of ice except along the shore at the extreme west end.

It was concluded that the ashfall from the Mount St. Augustine volcano resulted in accelerating the breakup of lake ice in the eastern portion of Iliamna Lake.

### Lake Level

Lake level remained below average from late May through mid-September (Table 5 and Fig. 5) and was the second to third lowest observed since continuous observations began in 1961 (Fig. 6).

### Precipitation and Air Temperature

The 1976 precipitation and air temperature data are summarized in Tables 5 and 6. The summer was drier than normal with the precipitation in August being well below average.

### Solar Radiation

Solar radiation following the late ice breakup was above average for the period July 15 through September 10. (Table 7).

## Lake Thermodynamics

### Iliamna Lake Heat Budget

The heat budget for Iliamna Lake is calculated each year from data on water temperature collected by vertical bathythermograph hauls. Since 1961 casts have usually been made at 22 to 30 stations spatially distributed throughout Iliamna Lake. Bathythermograph casts, until recent years, have generally been made in late June to early July, mid- to late July, and mid- to late August.

In 1976, bathythermograph casts were made at: 1) 10 stations in early June; 2) 22 stations throughout July; 3) 3 stations during August; 4) 9 stations in September. The distribution of the 1976 sampling for Iliamna Lake is shown in Fig. 7, and a summary of bathythermograph cast locations and dates appears in Table 8. Lake section and whole lake heat budgets for the years 1961-76 are listed in Table 9. In 1976 there was inadequate sampling in lake sections 1-4 and 10-11 during late August and early September; therefore, the 1976 annual heat budget was expanded to represent the entire lake by using the following equation:

$$\text{Estimated heat budget} = \frac{\text{Observed heat budget sections 5-9}}{\text{Mean \% from sections 5-9 for years 1961-75}}$$

entire lake

The 1976 heat budget for Station 149 is presented in Table 10. The thermodynamics of Station 149 are further illustrated in Fig. 8, which shows temperature isotherms for the summer of 1976.

The negative heat budgets observed in June 1976 (Table 10) reflect the early sampling date, right at the time of ice breakup. Because ice did not leave the lake in 1976 until relatively late in the year (Table 4), the July heat budget was slightly below the mean value for all other years in spite of a rather high insolation rate during July 1976 (Table 9). High September insolation rates, coupled with frequent wind during this month, caused much heat to be driven into the water and resulted in a higher than average heat budget.

### Transparency

During the 1976 ice breakup, Secchi disk readings were below past mean values in certain areas in the eastern end of Iliamna Lake. Clouded water in littoral areas was observed as much of the fine ash concentrated on shore ice and along lake beaches washed into the lake. This was a short-term effect since most areas seemed to return to near-normal levels 5-7 days after ice breakup which was concurrent with the first heavy rainfall of the spring.

## Water Chemistry

### Mineral Content

Results from water samples taken during ice breakup failed to reveal any detectable changes in environmental levels of important nutrients (Table 11). Since the volume of water in Iliamna Lake is so great, the amount of nutrient resulting from the Mount St. Augustine ashfall would be so greatly diluted as to preclude any possible chance of detecting changes in the mineral content of the water.

### pH

During the spring breakup, Iliamna Lake water was checked for possible changes in pH. Due to the low buffering capacity of the lake water, initial readings made in the field with a good quality pH paper were erroneous. Subsequent readings were made utilizing electronic pH meters which showed pH levels to be normal.

## Primary Production

### Periphyton Studies

It has been hypothesized that the magnitude of the peak year returns of sockeye salmon to the Kvichak River system is in part determined by the survival of the island beach spawning stocks. The progeny of island beach stocks stay close to shore for 1 to 2 months after emergence from the gravel before moving into pelagic areas. While in the littoral, it has been

hypothesized that juvenile salmon feed primarily on insect larvae, which depend on periphyton and detritus for their food. Since dense concentrations of juvenile salmon occur in littoral areas during the spring months of some years, high food production is necessary for favorable survival (Miller, 1970).

Periphyton growth has been monitored at selected locations on island beaches since 1969. During the summer of 1976 periphyton growth was monitored at 5 stations (Fig. 9). During late May, 1976, periphyton slides were put out at the 5 stations prior to ice breakup (designated as 'early' in Table 12) and the resulting input of volcanic ash. This procedure was designed to test whether the addition of nutrients by the ash would result in an increased abundance of periphyton similar to that caused by carcasses. At the time of its deposition on the frozen lake surface the ash was distributed quite evenly. However, wind soon redistributed and concentrated the ash on the beaches. Because of the final distribution of ash, it was believed that the most obvious effects on primary production would be large periphyton blooms such as those observed by Donaldson (1967) following the decay of great numbers of salmon carcasses during years of peak spawning abundance.

Results. The abundance of periphyton at the five stations, indexed by determining the content of chlorophyll a of periphyton from glass culture slides, is summarized and compared to observations from previous years in Table 12. An early bloom of periphyton in response to the ash was not observed at any of the stations (Fig. 10). The chlorophyll a values followed the usual seasonal trend, typically low early in the season, gradually increasing as the summer progressed. Interestingly, Station W2, which has no beach spawning in its vicinity and typically has low periphyton production, received large amounts of ash but still remained unproductive. All these observations point to the conclusion that, unlike salmon carcasses, the volcanic ash had little nutritive value to the periphyton. Whether this was because of the chemical composition of the ash or due to low solubility is not known.

#### Standing Crop of Phytoplankton

The food chain leading from inorganic nutrients to production of juvenile salmon is complicated by many factors. Studies at the primary trophic level are necessary to understand how cyclic changes in escapement level affect the food base and hence the survival rate and growth rate of juvenile salmon in the Kvichak system. One hypothesis has been that the biogenic elements released by decomposed adult carcasses enrich the productivity of the nursery lakes of the system and thereby enhance the survival rate of juvenile salmon proportional to the size of the escapement.

Since 1961 the summer primary production of Iliamna Lake has been indexed by estimation of the standing crop of phytoplankton by measuring the amount of chlorophyll a in the water at Stations 19, 107, and 143 (Fig. 11). No. 20 net (73 $\mu$ ) plankton hauls were also taken at these stations during

most years. These stations were initially chosen to represent three distinct physical regions in Iliamna Lake (Table 13). Station 19, average depth 27 m, represents Section A, the lower end and shallow part of Iliamna Lake. Station 107 in Section B, or midlake area, has an average depth of 110 m. Station 143 represents Section C, the eastern end of the lake.

Monitoring the primary production by measuring the amount of chlorophyll a in the water was continued in 1976 on a regular basis at Stations 107, 143, and 149. Weighting factors used in chlorophyll a calculations are summarized in Tables 14 and 15. No. 20 net samples collected during the 1976 field season were used to determine the phytoplankton species composition and abundance in Iliamna Lake. Phytoplankton samples were counted as described by Miller (1969).

Results. The results of the 1976 phytoplankton chlorophyll a sampling appear along with values from other years in Table 16 and Figs. 12-14. The 1976 phytoplankton chlorophyll a levels were exceptionally high throughout the summer, exceeding expectations for a year following a peak in the Kvichak River salmon cycle. A single observation made during 1976 at Station 19 was also unusually high. Standard phytoplankton volumes were also exceptionally high during 1976 (Fig. 15). An unusually high abundance of *Melosira* sp. was largely responsible for this increase. Figure 16 illustrates that at the time of the observed maximum standard volume in 1976 *Melosira* sp. accounted for 75 percent of the total volume, while in 1966 and 1971 *Melosira* sp. accounted for only 33 percent and 16 percent of the total, respectively. The nutrients introduced into Iliamna Lake from the decaying salmon carcasses have been shown to be an important source of nutrients for primary producers in this extremely oligotrophic lake (Donaldson 1967; Miller 1970). Since 1975 was a peak year in the spawning cycle, phytoplankton production would be expected to be high during 1976 due to an abundance of nutrients from the many decayed carcasses. The unexpectedly high phytoplankton abundance may have resulted from the summed effects of carcasses and volcanic ash. The ash could have contributed large amounts of phosphorus and silica, along with other elements, to the lake. Despite the low water solubility of phosphorus and other minerals in the ash, tremendous amounts of nutrients may still have been contributed to the lake due to the sheer mass of the ash. These nutrients may have complemented those from the salmon carcasses and resulted in the noticeable stimulation of primary production.

#### Secondary Production

Secondary production studies in Iliamna Lake have sought to determine the point at which the lake zooplankton production becomes a limiting factor in the production of juvenile sockeye salmon. Studies of the limnetic zooplankton community of Iliamna Lake were initiated in 1961 and since 1963 zooplankton samples have been taken at 22 to 30 stations throughout the lake. Sampling rounds have generally been made in June, July, and August,

although budget limitations in the last four years have somewhat reduced the scope of the sampling.

Vertical hauls have been systematically taken with a flowmeter equipped No. 6 mesh (223 micron) nylon conical plankton net of 1/2 meter mouth aperture. Annual and seasonal abundances of several zooplankton species over ecologically distinct areas of Iliamna Lake and for the lake as a whole have been determined. To date, no strong correlation has been shown between estimated zooplankton standing crop and the growth or abundance of sockeye salmon juveniles (Mathisen, 1969), although obviously some such relationship exists.

Zooplankton sampling stations for the 1976 field season are shown in Fig. 17. Much of the 1976 sampling effort was expended at the east end of the lake.

Results. The abundance and distribution of the major zooplankton species in Iliamna Lake during the summer of 1976 are presented in Table 17. Zooplankton standing crop estimates by lake section and sampling period for the years 1963 through 1976 appear in Table 18. The seasonal trends in zooplankton abundance at Station 149 (Section C) for the years 1966, 1971, and 1976 are depicted graphically in Figs. 18-20. Station 149 was selected for special attention because it is in an area which received a large input of ash and because observations on it were available for 1966 and 1971, two other years following peak escapements.

As is usually the case in Iliamna Lake, *Cyclops scutifer* was numerically the most abundant species, especially early in the season and in the deeper, colder east end of the lake (Table 17, Fig. 20). The July 1976 standing crop of *C. scutifer* was the highest ever recorded. Cladocerans, which are generally most abundant late in the season and in the west end of the lake, followed this general pattern but did not reach the levels of abundance they had exhibited during other years (Appendix A). Total zooplankton abundance during the summer of 1976 (Table 18) was about average when compared to other years, although the June and September values were low compared to the mean values for all years for these periods. The low June standing crop may in part be attributed to the early date of sampling--right at the time of ice breakup. The low September standing crop of zooplankton may have been the result of intensive cropping of the zooplankton population by juvenile sockeye salmon which were especially abundant in 1976 because 1975 was a peak spawning year in the Kvichak system.

#### Effects of Ashfall on Secondary Production

As measured by zooplankton standing crop, the 1976 ashfall from St. Augustine had no detectable effect on secondary production in Iliamna Lake. Zooplankton abundance may have been kept low by heavy grazing by juvenile sockeye salmon while actual production rates were high. Because zooplankton fecundity, closely tied to production rate, depends largely on food supply

as well as temperature, it was suspected that an increase in primary production due to ash fertilization effects would cause an increase in zooplankter brood size. In Fig. 21 *Cyclops* fecundity at Station 149 (Section C) has been plotted against the days after ice breakup for the years 1968-71 and 1976. Although the 1976 values are at the high end of the observed range, they are not markedly different from other years.

The fact that secondary producers in Iliamna Lake have shown no detectable response so far to the 1976 ashfall does not mean that such a response will not occur in subsequent years. Following the 1956 eruptions of Mount Besymjanny on Kamchatka, Kurenkov (1966, 1975) found that although primary production increased by two orders of magnitude during the first year following the ashfall, the abundance of *C. scutifer* actually declined immediately after the eruption and did not increase until three years later, with a peak abundance of 8 times the pre-eruption value occurring seven years after the original ash deposition. Such a lagged response in secondary production may well occur in Iliamna.

#### STUDIES OF JUVENILE SOCKEYE SALMON AND MAJOR COMPETITOR SPECIES

Since 1962 the Institute has conducted studies to determine the relative abundance, distribution and growth of juvenile sockeye salmon in Iliamna Lake and Lake Clark. These studies provide the first indication of the success of spawning of each brood year and provide a yardstick for measuring and understanding the interactions between juvenile salmon and biotic and abiotic factors operating in the ecosystem that affect their production. Continuous, comparable data over several Kvichak salmon cycles now exist and provide an essential input when evaluating the productive capacity of the Kvichak system and formulating future management alternatives.

In 1976 the fourth peak year abundance of juvenile sockeye salmon occurred in the nursery lakes of the Kvichak system since the Institute initiated its lake studies in 1961. Interest in the survival and growth rate of the progeny from the 1974 and 1975 brood years concurrent with any effects of the 1976 Mount St. Augustine ashfall on the Iliamna system resulted in the continuation of juvenile salmon studies in the Kvichak system in 1976. Results of these studies follow.

#### TOWNETTING

Indexes of relative abundance, distribution and growth of juvenile sockeye salmon and threespine sticklebacks in Iliamna Lake and juvenile salmon and least ciscos in Lake Clark were obtained in 1976. Townetting was conducted from August 17-20 in Lake Clark and August 6 to September 21 in Iliamna Lake. The standard 2.7m x 2.7m Burgner towner was used as in past years. The net was towed during darkness between either two outboard-powered skiffs or between a power boat and an outboard-powered skiff at a velocity of approximately 4.3 ft/sec. The standard shallow and deep

20 minute Kvichak tows were made with the net fishing either the 0-3m strata or the 4.6-7.6m strata. Of the 98 tows made in the Kvichak system in 1976, 58 percent or 57 of them were surface tows. The distribution of the townetting effort in Iliamna Lake and Lake Clark is shown in Fig. 22. The towing effort in Lake Clark was the same pattern followed since 1968. Towing in Iliamna Lake was the most extensive since 1972. Coverage in Iliamna Lake was adequate except for sections 1-3 where towing efforts were very minimal.

### Index of Abundance

Townet catches of the major groups of fishes from all towing in Iliamna Lake and Lake Clark are presented in Table 19. The weighted arithmetic mean catches of resident fish from index towing for Iliamna Lake, Lake Clark, and the Kvichak system are summarized in Table 20. Since the movement of age 0 sockeye salmon from the littoral to the pelagic areas of Iliamna Lake was not essentially complete until after September 1, the index towing conducted from September 5-21 in Iliamna Lake was considered to be more representative of the relative abundance and hence is used in computing the index for the Kvichak system. The towing data for the period September 5-21 is also summarized in Table 20.

#### Lake Clark

Age 0 sockeye salmon represented 94 percent of the townet catch in Lake Clark in 1976. The relative abundance of age 0 sockeye salmon was 355 percent higher than any other year following a peak year escapement in the Kvichak system (Table 21). The 1976 age 0 index of 182.5 is essentially the same as the 1975 index, which was the largest observed since townetting was initiated in 1962. In 1975, like 1974, very little early season commercial fishing on Kvichak stocks probably favored the return to Lake Clark. Spawning ground surveys indicated large returns to the Lake Clark system both in 1974 and 1975. The townet catches of age 0 sockeye salmon in Lake Clark in 1975 and 1976 reflect the large returns in 1974 and 1975.

Age I sockeye salmon represented 3 percent of the catch in Lake Clark in 1976. The townet index of age I sockeye salmon of 5.0 was about average (Table 22), therefore, indicating that the major movement of age I sockeye salmon from Lake Clark to nursery areas of Six Mile Lake and/or Iliamna Lake had occurred prior to the commencement of towing operations on August 17, 1976.

Least ciscos accounted for 3 percent of the catch having a townet index of 5.9. The relative abundance of ciscos was only 60 percent of the past mean value and was the lowest observed since 1972 (Table 23).

#### Iliamna Lake

The index of abundance of age 0 sockeye salmon in Iliamna Lake in 1976 was 92.6. Age 0 sockeye salmon accounted for 61 percent of the total

catch. In comparing the 1976 index in Iliamna Lake to other years following a peak escapement in the Kvichak system (Table 21), several things are noteworthy. First, the 1976 index of 92.6 is lower than both the 1961 and 1966 indexes of 137.0 and 146.5, respectively, but higher than the 1971 index of 55.4. In order to more adequately interpret these results, several things must be considered. The peak year escapements of 1960, 1965, 1970 and 1975 that produced the above indexes were 14.6, 24.3, 13.9, and 13.1 million spawners, respectively. It is possible that the 1961 index was underestimated due to incomplete towing using comparable methods in Iliamna Lake and no towing in Lake Clark. In addition, the 1971 index reflects the extremely adverse environmental conditions that occurred during the 1970-71 winter and the following spring and summer. Secondly, since environmental conditions in 1966 and 1976 were similar it seems more appropriate to make comparisons between these years rather than comparisons of 1976 results to either 1961 or 1971. The comparison of 1976 to 1966 shows the 1976 density of age 0 sockeye salmon in Iliamna Lake to be 63 percent of the density found in 1966. A measure of the relative production of age 0 sockeye salmon in Iliamna Lake from the brood years 1965 and 1975 shows a mean catch of 6.03 and 7.07 age 0 sockeye salmon per million spawners, respectively. One important consideration in the above comparison is that the relative production of age 0 in Iliamna Lake in 1976 was probably considerably higher since a much larger proportion of the Kvichak escapement went to Lake Clark in 1975 than in 1965.

The 1976 index of age I sockeye salmon in Iliamna Lake was 4.9, which is only 25 percent of the 1962-1975 mean of 19.3. In 1976 age I sockeye salmon represented 3 percent of the townet catch in Iliamna Lake. Therefore, results from townetting indicate that the holdovers from the 1974 escapement of 4.4 million were considerably less than expected and well below the abundance of holdovers resulting from the 1969 escapement of 8.4 million, the only other pre-peak cycle year having an escapement in excess of 4 million (Table 24).

Sticklebacks accounted for 36 percent of the townet catch in Iliamna Lake in 1976. The index of threespine sticklebacks in Iliamna Lake in 1976 was 34.0, which is 65 percent of the 1962-1975 mean of 52.0 (Table 23).

#### Distribution

The weighted total index catch by individual fish group in each lake section of Iliamna Lake and Lake Clark is shown in Figs. 23 and 24. The major portion of the total index of age 0 and age I sockeye salmon in Iliamna Lake came from sections 4-6, while the distribution of threespine sticklebacks was more uniform throughout the lake with the largest index occurring in section 7 (Fig. 23 and Table 20). The distribution of juvenile salmon and least ciscos in Lake Clark followed the normal pattern with the highest concentrations of age 0 and age I juvenile salmon occurring in section 12 and the greatest density of least ciscos occurring in sections 13 and 14 (Fig. 24 and Table 20).

### Growth in Length

The daily growth rates of juvenile sockeye salmon and age I threespine sticklebacks were computed from the data summarized in Table 25 as shown in Table 26. The estimated daily growth rates of juvenile salmon and age I threespine sticklebacks in the eastern portion of Iliamna Lake for the years 1962-1976 are summarized in Table 27. Growth curves established for age 0 and age I sockeye salmon and age I threespine sticklebacks in the eastern portion of Iliamna Lake are illustrated in Fig. 25. A comparison of the 1976 growth rates of age 0 and age I juvenile sockeye salmon to growth rates determined in 1966, the only other year following a peak escapement in the Kvichak system for which there was similar environmental conditions and comparable data, shows that the 1976 growth rates for age 0 and age I sockeye salmon are 21 and 36 percent lower, respectively.

The mean live lengths of juvenile salmon and major competitors by lake section for Iliamna Lake and Lake Clark in 1976 are presented in Table 28. The weighted mean lengths of juvenile salmon and competitors in Iliamna Lake and Lake Clark for the years 1962-1976 are presented in Table 29. In the Kvichak system in 1976 the mean length of age 0 and age I sockeye salmon was 7 and 6 percent smaller, respectively, than the mean length for the years 1962-1975. In comparing the size of age 0 sockeye salmon in Iliamna Lake in 1976 to other years following peak escapements in the Kvichak system, results show that the 1976 age 0 were 2 percent smaller than in 1966 but 15 percent larger than in 1971. In making the same comparison for Lake Clark, we find that in 1976 the age 0 were 7 percent smaller than in 1966 but 28 percent larger than in 1971. For the Kvichak system as a whole, the 1976 age 0 sockeye salmon were 3 percent smaller than in 1966 and 15 percent larger than in 1971. The comparison of the size of age 0 sockeye salmon in 1976 to 1971 is not very meaningful due to the drastic differences in environmental conditions. The size of age 0 sockeye salmon in 1976 and 1966 is much more comparable due to more similar climatic conditions, even though there were considerable differences in the size of the escapements and the density of juveniles in the nursery lakes. All things considered, we would have expected the size of age 0 sockeye salmon in the Kvichak system in 1976 to be somewhat larger than observed.

### Weight

In 1976 only the length-weight relationships of juvenile sockeye salmon in Iliamna Lake sections 6, 7, 8, and 9 were studied. The weighted mean weight of age 0 sockeye salmon adjusted to September 1 was 1.15g or 32 percent less than the mean weight on September 1 for the years 1962-1975 (Table 21). In comparing the weight of age 0 sockeye salmon in 1976 to other years following peak escapements in the Kvichak system, we find that in 1976 the weighted mean weight of age 0 juvenile salmon was 13 percent less than in 1966 and 49 percent greater than in 1971. The weighted mean weight and mean length of Iliamna Lake age 0 sockeye salmon adjusted to September 1 for the brood years 1961-1975 is presented in Fig. 26. The length-weight relationship

for Iliamna Lake age 0 sockeye salmon in 1976, representing the 1975 brood year, follows the usual decline associated with peak year abundances of juvenile salmon in the nursery lakes of the Kvichak system.

#### BEACH SEINING

Sampling by beach seine was conducted as usual in the eastern portion of Iliamna Lake to follow both the early size and growth of age 0 sockeye salmon and sticklebacks and the timing of the movement of these fishes from littoral nursery areas to pelagic rearing areas of the lake. The 1976 sampling stations are shown in Fig. 27. The catch data indicate that the movement of age 0 sockeye salmon and sticklebacks into the pelagic areas of Iliamna Lake was not essentially complete until after September 1 (Table 30).

#### HYDROACOUSTIC SURVEYS

Systematic hydroacoustic surveys were made in conjunction with tow-netting operations in Iliamna Lake and Lake Clark from 1971 through 1975. In 1976 chart recordings were made in conjunction with the tow-netting program on Iliamna Lake. Results show the major concentrations of age 0 and age I sockeye salmon were found in lake sections 4-8 and section 11.

#### DISCUSSION

When comparing the production of juvenile sockeye salmon from different years in the Kvichak salmon cycle the general character of the environment as well as the size and distribution of the escapements must be considered. Comparable indexes of the relative production of juvenile salmon in the Kvichak system obtained from the tow-netting programs are now available for 3 five-year cycles.

A multiple regression analysis of parameters collected from towing and other lake studies conducted by the Institute indicates that the summer abundance of age 0 juvenile sockeye salmon in the Kvichak system is most highly correlated with the egg deposition of the parent escapement followed by the thermal conditions in the lakes, which reflect the general character of the environment. The four variables, egg deposition, heat budget, date of ice breakup and weight of age 0 sockeye salmon on September 1, explain 94 percent of the variation in the relative abundance of age 0 sockeye salmon observed in the Kvichak system as measured through the tow-netting program for the years 1962-1976 (Fig. 28).

Results from a similar analysis comparing the size of age 0 sockeye salmon in different years of the Kvichak cycle shows size on September 1 to be more strongly correlated with the character of the environment than with the size of the parent escapement. This would suggest that, although density dependent growth causes the progeny of peak year spawners to typically have a slower mean growth rate than nonpeak year juveniles, extreme deviations

from normal environmental conditions in some years probably has a greater affect on fish size than density-dependent growth mechanisms. The three variables, heat budget, date of ice breakup and parent egg deposition explain 86 percent of the variability in the size of age 0 juvenile salmon on September 1 observed from the townetting programs for the years 1962-1976 (Fig. 29).

The relative production of age 0 juvenile sockeye salmon in the Kvichak system as measured from townetting programs in Iliamna Lake and Lake Clark for the years 1962-1976 is illustrated in Fig. 30. The recent increase in the production of Lake Clark is noteworthy and can be logically explained by the distribution of the Kvichak escapements in 1974 and 1975. In both 1974 and 1975 there were large returns to the spawning beds of the Lake Clark system.

Comparison of the production from three peak cycle years in the Kvichak system can now be made. In comparing the production of the 1975 and 1965 peak year escapements of 13.1 and 24.3 million spawners, respectively, the 1975 escapement was only 54 percent of that in 1965 but the index of age 0 abundance from the 1975 brood year of 100.9, or 7.68, age 0 per million spawners, was 73 percent of the index from the 1965 brood year of 137.7, or 5.66 age 0 per million spawners. The progeny from the 1965 and 1975 brood years experienced quite similar environmental conditions so the disparity in production is mainly attributed to high-spawning densities that occurred in 1965 and resulted in overdeposition of eggs in many of the spawning areas. The escapements for the peak years 1970 and 1975 of 13.9 and 13.1 million spawners, respectively, were very comparable in size but the production of age 0 sockeye salmon from these two brood years was extremely different. The 1971 index of age 0 juvenile salmon was only 55 percent of that in 1976. Whereas the 1975 spawning produced an index of 7.68 age 0 per million spawners, while the 1970 spawning produced an index of only 3.77 age 0 per million spawners. The large disparity in production is the direct result of extremely unfavorable environmental conditions during the winter of 1970-1971 and the following spring and summer.

Comparison of the distribution of age 0 sockeye salmon in Iliamna Lake and Lake Clark for all years with special reference to the years following peak escapements in the Kvichak system are shown in Figs. 31 and 32. Concerning Iliamna Lake it can be seen that the very large return to the island beaches in 1965 is reflected in the distribution of the townet index in 1966. In 1971 most of the townet index came from section 6 while in 1976 the largest concentrations of age 0 sockeye salmon were found in sections 4-6. In Lake Clark the 1971 and 1976 distributions of age 0 sockeye salmon were very similar with the density being the highest at the western end of the lake. The 1966 distribution shows the largest concentrations of age 0 juvenile salmon in the mid and eastern sections of Lake Clark.

One of the major objectives of the 1976 studies was to determine any effects of the Mount St. Augustine ashfall on the early survival and subsequent summer growth of juvenile sockeye salmon in Iliamna Lake.

Observations conducted in littoral areas during spring ice breakup showed no signs of abnormal mortalities of emerging age 0 sockeye salmon. Juvenile salmon did not seem to be affected by the clouded water along beach areas where wind blown accumulations of ash were being washed into the lake as a result of rising lake level and heavy spring rains. The early summer growth and gradual movement from littoral to pelagic rearing areas did not seem to be affected either. Information gathered on the density and distribution of ash throughout the affected areas of the watershed showed no instances where ash accumulations were great enough to significantly affect the survival of the salmon fry emerging from the spawning gravels of the Kvichak system.

There was no evidence that fertilization due to the ash increased the food supply in Iliamna Lake as a whole and hence the growth rate of juvenile salmon in Iliamna Lake in 1976. Although the observed abundance and size of age 0 juvenile salmon were somewhat lower than predicted (Figs. 28 and 29) the differences were not significant. The production of the Kvichak system in 1976 was about as expected and the mean length, weight, and growth rate of age 0 juvenile salmon were below average, thereby following the usual decline associated with peak year abundances. (Table 21).

#### SUMMARY

Studies conducted by the Fisheries Research Institute in the Kvichak system in 1976 were directed toward determining the growth rate and relative survival of the progeny from the 1974 and 1975 brood years and the impact of the Mount St. Augustine ashfall on biological processes in Iliamna Lake. A brief summary of the results follows.

1. There was no measurable change in the mineral content of the water resulting from an estimated 6.6 to 13.9 million metric tons of ash being deposited over the Kvichak watershed.
2. There was an immediate response in primary production as measured by the concentration of chlorophyll a and by the volume of selected larger diatom species monitored in past years; however, a similar response was not exhibited by the littoral periphyton communities studied in past years.
3. Although the abundance of age 0 sockeye salmon for the Kvichak system as a whole was somewhat less than predicted, it did not differ significantly from other years following peak escapements considering the general character of the environment.
4. The mean length, weight and growth rate of juvenile salmon were below average, thereby following the usual decline associated with peak year abundances in the Kvichak system.
5. The abundance of age I holdovers from the 1974 escapement was less than expected in both Iliamna Lake and Lake Clark.

6. Although the abundance of age 0 sockeye salmon in Lake Clark was 3.55 times greater than any other year following a peak year escapement in the Kvichak system, this could logically be explained by the distribution of the 1975 peak escapement.

7. There was no evidence that fertilization due to the ash increased secondary production and/or the food supply and hence the growth rate of juvenile salmon in 1976.

8. The slow release of nutrients from the large surrounding watershed should enhance primary production in Iliamna Lake for a number of years which may cause a lagged response in secondary production and hence increase the food supply of juvenile salmon.

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Table 1. Ashfall to Iliamna Lake and the Kvichak watershed

Area	Ashfall	
	Metric tons	kg/m <sup>2</sup>
<u>Kvichak watershed</u>		
(12,588 to 13,537 km <sup>2</sup> )	6,646,412 to 13,857,804	.53 to 1.02
<u>Iliamna Lake</u>		
Eastern end (Lake sections 6-9)	345,560 to 691,120	1.06 to 2.12
Entire lake, (2,621.6 km <sup>2</sup> )	907,518 to 2,777,450	.35 to 1.06

Table 2. Composition of a sample<sup>1</sup> of Mount St. Augustine ash fall collected at Knutson Bay, Iliamna Lake

Composition of ash <sup>2</sup>	
Measurement	Per cent by weight
SiO <sub>2</sub>	63.30
Al <sub>2</sub> O <sub>3</sub>	16.34
Fe <sub>2</sub> O <sub>3</sub>	2.52
FeO	2.78
MgO	2.98
CaO	6.40
Na <sub>2</sub> O	3.53
K <sub>2</sub> O	1.10
TiO <sub>2</sub>	.61
P <sub>2</sub> O <sub>5</sub>	.15
MnO	.107
CO <sub>2</sub>	.02
Cl	.105
S as S	.100

<sup>1</sup> Represents the chemical composition of a composite sample of different size fractions.

<sup>2</sup> Collected and analyzed by the U.S. Geological Survey.  
L. Espos, Analyst  
X-ray Spectroscopy.

Table 3. Estimated contributions of the elements silicon and phosphorus to Iliamna Lake and the total affected area of the Kvichak watershed.

Area	Silicon Range		Phosphorus Range	
	Metric tons	kg/m <sup>2</sup>	Metric tons	kg/m <sup>2</sup>
Kvichak watershed (12,588 - 13,537 km <sup>2</sup> )	1,965,543 - 4,098,168	.16 - .30	4,347 - 9,063	.0004 - .0007
Iliamna Lake				
East end (Lake sections 6-9)	102,192 - 204,385	.31 - .63	226 - 452	.0007 - .0014
Entire lake (2,621.6 km <sup>2</sup> )	268,380 - 821,375	.10 - .31	594 - 1,816	.0002 - .0007

Table 4. Estimated date<sup>1</sup> of the breakup of lake ice in three sections<sup>2</sup> of Iliamna Lake, 1961-1976

Year	Section A		Section B		Section C	
	Calendar date	Julian date	Calendar date	Julian date	Calendar date	Julian date
1961	5/26	147	5/16	137	5/12	133
1962	5/31	152	5/23	144	5/20	141
1963	6/01	153	5/16	137	5/06	127
1964	6/21	173	6/11	163	6/07	159
1965	5/22	143	5/15	136	5/08	129
1966	6/18	170	6/03	155	6/02	154
1967	5/21	142	5/19	140	5/14	135
1968	5/23	144	5/17	138	5/17	138
1969	5/31	152	5/24	145	5/18	139
1970	4/15	106	4/15	106	3/19	79
1971	6/17	169	6/16	168	6/06	158
1972	6/11	163	6/07	159	6/05	157
1973	6/05	157	5/20	141	5/15	136
1974	5/24	146	5/23	144	5/19	140
1975	6/10	162	6/07	159	5/28	149
1961-1975 Mean	5/31	152	5/24	145	5/17	138
1976	6/06	158	5/31	152	5/20	141

<sup>1</sup>Source of data: Personal logs of FRI biologists and correspondence and/or personal diaries of residents of the Iliamna area.

<sup>2</sup>Primary production division of Iliamna Lake. Section A is at the outlet end, section C at the head of the lake.

Table 5. Daily precipitation, solar radiation, and lake level at Porcupine Island, May 23 through May 31, 1976

Month	Date		Precipitation (inches)	Solar radiation (cal/cm <sup>2</sup> )	Lake Level (mm below reference point)			
	Julian				1976	1961-75 <sup>1</sup> Mean	Number of years	Deviation from mean
23	144		.00	363	2743	*		
24	145		.06	339	2703	*		
25	146		T	524	2715	*		
26	147		.00	512	2683	2522	1 - 161	
27	148		.00	363	2671	2514	1 - 157	
28	149		.00	488	2678	2503	1 - 175	
20	150		.00	649	(2675) <sup>2</sup>	2516	1 - 159	
30	151		.00	553	2671	2496	1 - 175	
31	152		.00	506	2683	2460	2 - 223	
Total			.06	4297	Lake Rise 60	62	- 175	Mean Dev. (-6.89 in)

T = Trace of precipitation.

No observation.

<sup>1</sup>Calculated from years where either actual or estimated values are given.

<sup>2</sup>Values in parentheses are linear estimates between days of observation.

Table 5. Daily precipitation, solar radiation, and lake level at Porcupine Island, June 1976 - Continued

Date		Precipitation (inches)	Solar radiation (cal/cm <sup>2</sup> )	Lake Level (mm below reference point)			
Month	Julian			1961-75 <sup>1</sup> 1976	Mean <sup>1</sup>	Number of years	Deviation from mean
1	153	.00	608	(2672) <sup>2</sup>	2456	2	- 220
2	154	.02	412	2670	2450	2	- 220
3	155	.00	268	2663	2467	2	- 196
4	156	.00	496	2698	2427	2	- 271
5	157	.91	249	2663	2408	2	- 255
6	158	*	338	(2650)	2413	3	- 237
7	159	*	622	(2638)	2405	5	- 233
8	160	*	268	(2625)	2391	5	- 234
9	161	*	388	(2612)	2371	5	- 241
10	162	*	489	(2600)	2352	5	- 248
11	163	*	557	(2587)	2337	6	- 250
12	164	*	593	(2574)	2323	6	- 251
13	165	*	570	(2562)	2298	6	- 264
14	166	*	382	(2549)	2322	8	- 227
15	167	*	228	(2537)	2310	8	- 227
16	168	*	228	(2524)	2269	10	- 255
17	169	*	243	(2511)	2248	10	- 263
18	170	*	639	(2499)	2229	10	- 270
19	171	*	732	(2486)	2210	10	- 276
20	172	*	578	(2473)	2223	11	- 250
21	173	*	581	(2461)	2208	11	- 263
22	174	*	435	(2448)	2196	11	- 252
23	175	*	460	(2435)	2161	12	- 274
24	176	*	549	(2423)	2143	12	- 280
25	177	*	623	(2410)	2134	12	- 276
26	178	*	652	(2397)	2112	12	- 285
27	179	*	544	(2385)	2100	12	- 285
28	180	*	566	(2372)	2086	12	- 286
29	181	*	587	(2359)	2067	12	- 292
30	182	*	464	(2347)	2060	12	- 287
Monthly Total		.93 <sup>3</sup>	14,448	329	396		- 256 (-10.06 in.)

\* No observation.

<sup>1</sup> Calculated from years where either actual or estimated values are given.

<sup>2</sup> Values in parentheses are linear estimates between days of observation.

<sup>3</sup> Represents only relative precipitation (local residents reported very dry weather after FRI personnel left on June 6).

Table 5. Daily precipitation, solar radiation, and lake level at Porcupine Island, July 1976 - Continued

Month	Date		Precipitation (inches)	Solar radiation (cal/cm <sup>2</sup> )	Lake Level (mm below reference point)			
	Julian				1961-75 <sup>1</sup> 1976	Mean	Number of years	Deviation from mean
1	183		*	228	(2334) <sup>4</sup>	2049	12	- 285
2	184		*	272	(2321)	2059	14	- 262
3	185		*	473	(2309)	2047	14	- 262
4	186		*	217	(2296)	2042	14	- 254
5	187		.35 <sup>2</sup>	293	(2284)	2027	14	- 257
6	188		.00	394	2271	2015	14	- 256
7	189		.00	428	2250	2000	14	- 250
8	190		.00	694	2239	1987	14	- 252
9	191		.00	549	2250	1978	14	- 272
10	192		.00	720	2243	1971	14	- 272
11	193		.00	525	2233	1963	14	- 270
12	194		.09	530	2238	1943	14	- 295
13	195		.00	675	2213	1921	14	- 292
14	196		*	635	2195	1908	14	- 287
15	197		*	352	(2176)	1895	15	- 281
16	198		.36	285	2158	1883	15	- 275
17	199		*	296	(2150)	1878	15	- 272
18	200		*	559	(2142)	1863	15	- 279
19	201		*	709	(2134)	1849	15	- 285
20	202		*	259	(2125)	1846	15	- 279
21	203		*	502	(2117)	1831	15	- 286
22	204		*	449	(2109)	1827	15	- 282
23	205		*	553	(2101)	1806	15	- 295
24	206		.40 <sup>3</sup>	595	2093	1790	15	- 303
25	207		.00	599	2108	1784	15	- 324
26	208		.00	361	2118	1780	15	- 338
27	209		T	365	2153	1780	15	- 373
28	210		.09	372	2163	1770	15	- 393
29	211		.31	320	2073	1768	15	- 305
30	212		.00	510	2073	1754	15	- 319
31	213		.01	450	2043	1749	15	- 294
Monthly Total			1.61	14,169	291	300		- 289 (-11.38 in.)

\* No observation.

T = Trace of precipitation.

<sup>1</sup> Calculated from years where either actual or estimated values are given.

<sup>2</sup> Represents precipitation that occurred from 6/05 to 7/05 (local residents reported most occurred in early July so assigned precipitation to July).

<sup>3</sup> Includes precipitation which may have occurred on the previous series of days with missing observations.

<sup>4</sup> Values in parentheses are linear estimates between days of observation.

Table 5. Daily precipitation, solar radiation, and lake level at Porcupine Island, August 1976 - Continued

Date		Precipitation (inches)	Solar radiation (cal/cm <sup>2</sup> )	Lake Level			
				(mm below reference point)			
Month	Julian			1961-75 <sup>2</sup> 1975	Mean	Number of years	Deviation from mean
1	214	.06	345	2038	1737	15	- 301
2	215	T	386	2033	1731	15	- 302
3	216	.00	593	2023	1723	15	- 300
4	217	.00	561	2348	1719	15	- 329
5	218	.01	312	2043	1708	15	- 335
6	219	.06	289	2023	1699	15	- 324
7	220	.00	407	2048	1677	15	- 371
8	221	.00	257	2018	1674	15	- 344
9	222	T	285	2008	1661	15	- 347
10	223	.00	587	1993	1648	15	- 345
11	224	.00	508	1993	1635	15	- 358
12	225	T	295	1983	1627	15	- 356
13	226	.01	306	1983	1615	15	- 368
14	227	.16	264	1973	1614	15	- 359
15	228	*	350	1967	1614	15	- 353
16	229	*	500	(1962) <sup>3</sup>	1601	15	- 361
17	230	*	183	(1956)	1596	15	- 360
18	231	*	301	(1950)	1576	15	- 374
19	232	*	371	(1945)	1569	15	- 376
20	233	*	376	(1939)	1578	15	- 361
21	234	*	532	(1934)	1569	15	- 365
22	235	.95 <sup>1</sup>	483	(1928)	1552	15	- 376
23	236	.00	468	(1923)	1545	15	- 378
24	237	T	310	(1983)	1538	15	- 445
25	238	.35	217	1963	1529	15	- 434
26	239	.08	350	1903	1524	15	- 379
27	240	.01	559	1913	1528	15	- 385
28	241	.04	412	1903	1511	15	- 392
29	242	.01	384	1903	1520	15	- 383
30	243	T	414	1908	1508	15	- 400
31	244	.00	325	1943	1496	15	- 447
Monthly Totals		1.74	11,930	Lake 95 Rise	241		- 365 (14.37 in.)

T = Trace of precipitation.

\* No observation.

<sup>1</sup> Includes precipitation which may have occurred on the previous series of days with missing observations.

<sup>2</sup> Calculated from years where either actual or estimated values are given.

<sup>3</sup> Values in parentheses are linear estimates between days of observation.

Table 5. Daily precipitation, solar radiation, and lake level at Porcupine Island, September 1 through September 22 - Continued

Date		Precipitation (inches)	Solar radiation (cal/cm <sup>2</sup> )	Lake Level (mm below reference level)			
Month	Julian			1961-75 <sup>2</sup> 1976	Mean	Number of years	Deviation from mean
1	245	.15	261	1918	1495	15	- 423
2	246	105	285	1913	1482	15	- 431
3	247	104	468	1868	1481	15	- 387
4	248	100	547	1883	1480	15	- 403
5	249	*	483	(1883) <sup>3</sup>	1474	15	- 409
6	250	*	392	(1883)	1481	15	- 402
7	251	*	369	(1883)	1487	15	- 396
8	252	.20 <sup>1</sup>	394	1883	1493	15	- 390
9	253	*	462	(1916)	1499	15	- 417
10	254	.16 <sup>1</sup>	217	1928	1487	15	- 441
11	255	T	238	1913	1456	13	- 457
12	256	T	154	1943	1445	13	- 498
13	257	.01	116	1938	1447	12	- 491
14	258	.40	336	1958	1447	12	- 511
15	259	.32	251	1958	1426	10	- 532
16	260	.20	137	1993	1451	9	- 542
17	261	1.44	129	2063	1433	9	- 630
18	262	.62	342	1918	1505	8	- 413
19	263	.04	287	1903	1510	8	- 393
20	264	1.15	112	1883	1517	8	- 366
21	265	.16	238	1863	1422	6	- 441
22	266	.41	192	1843	1434	6	- 409
23	267	*	194	*			
Total, 9/1-22		5.35	6,604 <sup>4</sup>	Lake Rise 75	61		- 445 (-17.52 in.)

\* No observation.

<sup>1</sup> Includes precipitation which may have occurred on the previous series of days with missing observations.

<sup>2</sup> Calculated from years where either actual or estimated values are given.

<sup>3</sup> Values in parentheses are linear estimates between days of observation.

<sup>4</sup> Total solar radiation 9/01-9/23.

Table 6. Daily maximum and minimum air temperatures ( $^{\circ}$ F), Porcupine Island, May 23 through June 5, 1976

May				June				
Date		Temperature		Date		Temperature		
Month	Julian	Maximum	Minimum	Month	Julian	Maximum	Minimum	
	23	144	62 <sup>1</sup>	-22 <sup>1</sup>	1	153	*	*
	24	145	48	38	2	154	*	*
	25	146	48	30	3	155	62 <sup>2</sup>	31 <sup>2</sup>
	26	147	44	35	4	156	58	41
	27	148	43	33	5	157	48	43
	28	149	49	38				
	29	150	*	*				
	30	151	55	36				
	31	152	61	31				

<sup>1</sup>Represents maximum and minimum temperature for the period 9/15/75 through 5/23/76.

<sup>2</sup>Represents maximum and minimum temperature for the period 6/01/76 through 6/03/76.

\* No observation.

Table 6. Daily maximum and minimum air temperatures ( $^{\circ}\text{F}$ )<sup>1</sup>, Porcupine Island, July 7 through September 22, 1976 --Continued

July				August				September			
Date		Temperature		Date		Temperature		Date		Temperature	
Month	Julian	Max.	Min.	Month	Julian	Max.	Min.	Month	Julian	Max.	Min.
				1	214	54	49	1	245	50	47
				2	215	56	48	2	246	54	46
				3	216	66	50	3	247	58	38
				4	217	75	58	4	248	53	44
				5	218	63	56	5	249	56	32
				6	219	63	53	6	250	(55)	(32)
7	189	68	40	7	220	62	53	7	251	(53)	(45)
8	190	68	44	8	221	56	52	8	252	52	37
9	191	67	46	9	222	60	51	9	253	53	(46)
10	192	68	48	10	223	70	40	10	254	(51)	45
11	193	70	53	11	224	70	42	11	255	52	34
12	194	61	51	12	225	60	51	12	256	54	47
13	195	62	50	13	226	60	50	13	257	56	46
14	196	70	(46)	14	227	56	51	14	258	54	48
15	197	(66)	(44)	15	228	(57)	(47)	15	259	54	42
16	198	(62)	(48)	16	229	(63)	(41)	16	260	48	41
17	199	(68)	(46)	17	230	(53)	(48)	17	261	46	44
18	200	(68)	(42)	18	231	(55)	(47)	18	262	52	47
19	201	(62)	(52)	19	232	(52)	(46)	19	263	(48)	(36)
20	202	(57)	(50)	20	233	(62)	(42)	20	264	(52)	(36)
21	203	(66)	(48)	21	234	(65)	(40)	21	265	48	34
22	204	(64)	(48)	22	235	(67)	(40)	22	266	45	40
23	205	(62)	(47)	23	236	63	46				
24	206	(65)	(44)	24	237	57	43				
25	207	68	40	25	238	54	49				
26	208	60	50	26	239	62	50				
27	209	64	52	27	240	61	50				
28	210	59	52	28	241	64	48				
29	211	60	53	29	242	62	46				
30	212	64	42	30	243	66	42				
31	213	65	52	31	244	56	46				
				<u>7/07-31</u>		<u>Monthly</u>		<u>9/01-22</u>			
Max. and Min. Temperature				70	40	75	40	58	32		
Mean Max. and Min. Temperature				65	48	61	48	52	41		

<sup>1</sup>Temperatures in parentheses were estimated from recording thermograph charts.

Table 7. Total solar radiation ( $\text{cal}/\text{cm}^2$ ), mean radiation per day, and percentage of total summer radiation by month, July 15 to September 10, 1966 through 1976, Iliamna Lake, Alaska.

Year	PERIOD									
	July 15 - 31			August 1 - 31			September 1 - 10			
	Total	Mean/Day	Percent	Total	Mean/Day	Percent	Total	Mean/Day	Percent	
1966	7,719	454	44.7	7,366	238	42.6	2,195	220	12.7	17,280
1967	5,964	351	34.7	9,395	303	54.7	1,818	182	10.6	17,177
1968	9,239	543	38.0	11,776	380	48.5	3,266	327	13.5	24,281
1969	6,018	354	28.8	12,230	395	58.6	2,629	263	12.6	20,877
1970	7,394	435	36.5	9,523	307	47.0	3,333	333	16.5	20,250
1971	3,933	231	31.8	6,247	202	50.5	2,199	220	17.7	12,379
1972	7,210	424	38.6	9,213	297	49.4	2,233	223	12.0	18,656
1973	6,227	366	31.7	10,650	344	54.3	2,739	274	14.0	19,616
1974	8,033	473	34.9	11,785	380	51.1	3,217	322	14.0	23,035
1975	5,999	353	28.7	12,188	393	58.3	2,707	271	13.0	20,894
1966-75 Mean	6,774	398	34.8	10,037	324	51.6	2,634	263	13.6	19,445
1976	7,536	443	32.3	11,930	385	51.1	3,878	388	16.6	23,344

Table 8. Summary of bathythermograph sampling in Iliamna Lake, 1976<sup>1</sup>

Date	Cast #	Station
5/26	1	149
5/28	2,3	145,152
5/31	4,5	143,149
6/1	6,7	107,90
6/2	8-11	126,124,136,138
6/3	12	149
7/10	13	149
7/11	14	143
7/12	15-18	152,145,138,136
7/14	19,20,21	107,126,124
7/18	22-26	90,92,94,110,67
7/22	27-34	19,17,15,32,34,36,65,63
7/25	35	149
8/9	36	149
8/23	37	149
9/6	38,39	152,145
9/10	40	138
9/13	41,42	143,149
9/15	43-46	107,126,90,92
9/21	47	149

<sup>1</sup> BY #6167 use for all casts less than 65 meters and BT #LL4452 used for all casts greater than 65 meters in depth.

Table 9. Amounts of stored heat in excess of 4°C (cal/cm<sup>2</sup>)  
in Iliamna Lake, June 1961-1976

Year	JUNE				Weighted lake heat budget
	Lake sections				
	1-4	5-6	7-9	10-11	
1961	*	*	*	*	*
1962	*	*	*	*	*
1963	*	*	*	*	*
1964	4,765	-1,251	-8,868	9,481	1,274
1965	4,527	4,496	-894	6,150	4,261
1966	5,109	-1,619	-1,291	7,535	3,692
1967	7,623	993	6,508	5,470	5,511
1968	7,687	5,882	2,466	8,573	6,479
1969	6,009	4,940	7,729	5,393	5,945
1970	10,640	8,897	4,021	8,597	9,152
1971	-6,099	-9,438	-8,639	-1,387	-6,285
1972	4,692	1,196	-4,690	-3,348	851
1973	x	x	6,349	x	x
1974	x	x	x	x	x
1975	x	x	x	x	x
1961-75					
mean	4,995	1,566	269	5,193	3,431
1976	-2,233	-10,000	-21,454	x	*

\* Data insufficient for determination of values for comparative purposes.

x Data not taken.

Table 9. Amounts of stored heat in excess of 4°C (cal/cm<sup>2</sup>)  
in Iliamna Lake, July 1961-1976 - Continued

Year	JULY				Weighted lake heat budget
	Lake sections				
	1-4	5-6	7-9	10-11	
1961	*	*	*	*	*
1962	*	*	*	*	*
1963	*	*	*	*	*
1964	11,233	8,974	2,549	10,713	9,331
1965	11,116	13,111	8,058	9,221	11,203
1966	13,377	13,660	12,908	13,217	13,389
1967	17,434	23,602	18,727	20,980	19,207
1968	18,346	18,434	12,966	14,204	17,633
1969	14,947	17,474	23,823	14,204	16,895
1970	x	x	x	x	x
1971	x	x	x	x	x
1972	x	x	x	x	x
1973	18,215	18,045	19,414	11,996	18,129
1974	24,168	29,703	29,117	17,254	26,165
1975	x	x	x	x	x
1961-75 mean	16,105	15,802	15,945	13,974	16,498
1976	11,989	15,997	18,414	10,328	15,942

\* Data insufficient for determination of values for comparative purposes.

x Data not taken.

Table 9. Amounts of stored heat in excess of 4°C (cal/cm<sup>2</sup>)  
in Iliamna Lake, August and September 1961-1976 -  
Continued

AUGUST and SEPTEMBER					
Year	Lake sections				Weighted lake heat budget
	1-4	5-6	7-9	10-11	
1961	24,883	35,775	41,390	18,459	30,175
1962	21,805	30,031	35,220	17,031	25,882
1963	22,335	28,798	19,790	17,988	23,635
1964	21,474	29,560	27,751	18,053	23,688
1965	19,895	22,670	23,760	17,273	20,389
1966	20,912	24,772	28,448	13,637	22,835
1967	24,211	29,115	26,193	19,267	25,212
1968	24,909	28,837	27,618	18,534	26,163
1969	19,387	27,636	22,087	18,250	22,011
1970	23,433	29,879	27,800	13,942	25,514
1971	12,546	16,237	23,290	15,038	15,168
1972	21,386	14,087	21,263	21,786	21,161
1973	20,379	25,986	24,229	15,119	23,005
1974	26,427	36,582	37,789	21,245	30,669
1975	20,232	27,352	22,864	13,367	22,342
1961-75 mean	21,614	27,154	27,633	17,266	23,890
1976	x	30,909	29,395	x	25,150 <sup>1</sup>

<sup>1</sup> Estimated heat budget =  $\frac{\text{Observed heat budget sections 5-9}}{\text{Mean \% from sections 5-9 for years 1961-75}}$   
entire lake

x Data not taken.

Table 10. Amounts of stored heat in excess of 4°C (cal/cm<sup>2</sup>) for Station 149, 1976.<sup>1</sup>

Date	Stored Heat
5/26	-16,875
5/31	-15,352
6/3	-14,521
7/10	10,838
7/25	15,029
8/9	9,682
8/23	18,842
9/13	17,596
9/21	20,171

<sup>1</sup>Calculated to 160 m.

Table 11. Comparison of chemical analyses of Section C, Iliamna Lake water<sup>1</sup> taken at Station 149, 1961-1962 and 1976

Measurement	Concentrations in ppm	
	1961-1962	1976
Phosphate	0.01	0.01
Sodium	1.27	1.20
Potassium	0.50	0.50
Magnesium	0.77	0.90
Nitrate nitrogen	0.047	0.04
Silica	1.5	1.3
Calcium	5.5	5.3

<sup>1</sup>1961-1962 are arithmetic mean values of the following:

- (1) 1961-composite samples taken from 3 m depth on August 22 and September 15.
- (2) 1962-composite samples taken from 5 and 15 m depths on November 23.

1976 values are from composite samples from 5 m depth (analysis performed by U.S. Geological Survey).

Table 12. Chlorophyll a (mg/m<sup>2</sup>) amounts in periphyton samples in Iliamna Lake, Alaska, 1969-76

Date	Stations				
	P 1	P 2	P 3	W 2	W 3
7/31/69	1,521	238	*	*	*
9/05/	12,185	9,669	*	*	*
7/16/70	1,987	224	*	*	*
7/28/	4,015	1,201	*	*	*
8/06/	3,796	2,642	*	*	*
8/12/	1,356	1,957	*	*	*
8/23/	5,162	2,771	*	*	*
8/26/	11,100	3,892	*	*	*
9/04/	9,665	4,026	*	*	*
7/09/71	232	204	*	*	*
7/24/	925	972	529	*	*
8/09/	6,669	3,339	8,964	*	*
8/18/	4,323	9,595	18,109	*	*
8/28/	*	3,646	11,224	*	*
7/13/72	186	112	313	24	595
7/27/	639	347	1,670	183	2,575
8/10/	1,140	272	5,773	157	3,050
8/25/	1,490	690	5,216	451	6,336
9/12/	3,631	503	9,227	205	8,766
8/06/73	83	92	290	63	331
8/25	*	479	1,594	435	1,921
9/09/	1,272	4,164	1,117	710	8,800
8/06/74	160	46	269	172	180
8/18/	294	208	1,174	225	358
9/15/	*	1,981	42,003	280	7,723
8/05/75	562	243	439	183	662
8/31/	4,751	2,120	6,884	484	12,132
9/13/	44,833	11,431	53,302	2,199	44,540
7/08/76	(709) <sup>1</sup>	(685)	(543)	(62)	(347)
7/27/	(1,234)	(1,228)	(4,813)	(308)	(507)
	*	321	2,631	152	249
8/13/	(*)	(*)	(10,073)	(449)	(5,279)
	*	*	5,285	388	4,050
8/27/	(3,477)	(3,619)	(13,216)	(947)	(11,962)
	2,722	2,001	5,993	577	5,334
9/21/	(8,384)	(4,379)	(19,844)	(1,828)	(*)
	7,609	2,679	17,364	1,590	7,745

\*No observations.

<sup>1</sup>(Early) - prior to ice breakup, late May 1976.

Table 13. Physical measurements and characteristic features of three sampling areas in Iliamna Lake

Measurement	Section A	Section B	Section C	Total
Area (km <sup>2</sup> )	1,858.0	610.0	154.0	2,622.0
Per cent of total	70.9	23.2	5.9	100.0
Volume (km <sup>3</sup> )	62.4	36.3	16.6	115.3
Percent of total	54.1	31.5	14.4	100.0
Maximum depth (m)	40.0	240.0	393.0	
Mean depth (m)	33.6	39.6	107.6	44.0
Sampling station	19	107	143	
<u>Potential spawning ground (km<sup>3</sup>)</u>				
Streams	0.66	0.57	1.51	2.74
Beaches			0.33	0.33
Total	0.66	0.57	1.84	3.07
Per cent of total	21.0	19.0	60.0	100.0

Source: Low (1972).

Table 14. Weighting factors used for computations of mean chlorophyll a concentrations ( $\text{mg}/\text{m}^3$ ) at Stations 19, 107, and 143<sup>1</sup>

Sample depth (i)	Chlorophyll <u>a</u> concentrations	
	Station 19	Stations 107 and 143
	Depth stratum (m)	Depth stratum (m)
1	1.5	1.5
2	1.0	1.0
3	1.0	1.0
4	1.0	1.0
5	1.5	1.5
7	2.5	2.5
10	4.0	4.0
15	7.5	7.5
25	5.0	10.0
35		10.0
45		5.0
Sum	25	45

<sup>1</sup>Data from Low, 1972.

Table 15. Weighting factors used for computation of weighted yearly mean concentration of chlorophyll a ( $\text{mg}/\text{m}^3$ ), Iliamna Lake, Alaska <sup>1</sup>

Lake section	Sampling station	Weighting factor	
		Volume ( $\text{km}^3$ )	% of total volume
A	19	62.4	54.1
B	107	36.3	31.5
C	143	16.6	14.4
	Total	115.3	100.0

<sup>1</sup>Data from Low, 1972.

Table 16. Concentrations of chlorophyll  $a$  ( $\text{mg}/\text{m}^3$ ) in June, July, and August at Stations 19, 107, and 143, Iliamna Lake, 1961-1976

Year	Station 19			Station 107			Station 143					
	June	July	Aug.	Mean	June	July	Aug.	Mean	June	July	Aug.	Mean
1961	0.74*	0.49	0.65	(0.63)	0.80	0.65	0.77	(0.74)	0.65	0.71	0.66	(0.67)
Date		7/21	8/23		6/29	7/13	8/23		7/16	8/06	8/24	
1962	0.85	0.59	0.17	(0.54)	0.78	0.77	0.46	(0.67)	0.79	0.65	0.27	(0.57)
Date	6/06	7/18	8/15		6/05	7/14	9/09		6/03	7/17	8/18	
1963	0.54*	0.34*	0.27	(0.38)	0.74	0.62	0.24	(0.53)	0.59	0.54	0.49	(0.54)
Date			8/16		6/14	7/09	8/06		6/13	7/07	8/12	
1964	0.60	0.45	0.27	(0.44)	0.76	0.52	0.65	(0.64)	0.69	0.61	0.73	(0.68)
Date	7/01	7/23	8/14		6/25	7/18	8/11		6/23	7/11	8/07	
1965	0.74	0.48	0.65	(0.62)	0.87	0.37	0.69	(0.64)	0.59	0.68	0.64	(0.64)
Date	6/24	7/21	8/29		6/30	7/14	8/06		6/24	7/18	8/02	
1966	0.78	0.56	0.36	(0.57)	0.68	0.56	0.37	(0.54)	1.07	0.90	0.62	(0.86)
Date	6/28	7/17	8/14		6/26	7/15	8/11		6/25	7/13	8/10	
1967	0.63	0.33	0.50	(0.49)	0.45	0.61	0.44	(0.50)	0.84	0.61	0.69	(0.71)
Date	6/26	7/28	8/22		6/20	8/02	8/27		6/18	8/06	8/29	
1968	0.56	0.50	0.76	(0.61)	0.92	1.00	0.55	(0.82)	0.92	0.92	0.86	(0.91)
Date	6/22	7/21	8/20		6/24	7/24	8/23		6/20	7/25	8/26	
1969	1.07	0.62	0.38	(0.69)	1.06	0.93	0.85	(0.95)	0.91	1.38	0.89	(1.06)
Date	6/23	7/22	8/22		6/28	7/29			7/01	8/01	8/30	
1970	0.95*	0.82	0.86	(0.88)	0.76	0.96	0.44	(0.72)	1.31	1.14	0.77	(1.07)
Date		7/17	8/16		6/23	7/18	8/24		6/24	7/19	8/22	
1971	1.16	1.20	1.01	(1.12)	0.87	1.39	1.05	(1.10)	1.53	1.42	1.33	(1.43)
Date	6/25	7/26	8/11		6/27	7/28	8/12		6/27	7/29	8/31	
1972	0.91	0.37	0.52	(0.60)	0.91	0.97	0.62	(0.83)	1.12	0.98	1.11	(1.07)
Date	7/09	8/03	9/08		7/02	8/02	8/28		7/07	8/01	9/05	
1973	**	0.90	0.42	(0.66)	**	1.09	0.52	(0.81) <sup>†</sup>	**	1.38	0.86	(1.12) <sup>†</sup>
Date		7/28	8/16		**	7/24	8/17	9/05 0.62	**	7/29	8/20	9/05 0.70
1974	**	0.34	0.42	(0.38)	**	0.41	0.39	(0.40)	**	0.59	0.54	(0.56)
Date		8/03	9/02		**	7/31	9/08		**	8/07	9/14	
1975	**	**	0.15	(0.15)	**	**	(0.12)	(0.12)	**	**	0.26	(0.26)
Date			9/02				9/07				8/20	
1976		1.10			0.92	1.11	0.84	(0.96)	1.65	1.96	1.41	(1.67)
Date		7/22			6/01	7/14	9/15		5/31	7/11	9/13	

\* Missing observations estimated by randomized block method from Snedecor, 1969, p. 317 (Low, 1972).

\*\* No sampling in June, 1973.

<sup>†</sup> Concentrations of chlorophyll  $a$  taken on 9/05/73 not used in calculation of station means.

Table 17. Abundance (geometric mean number per cubic meter) and distribution of major zooplankton species from number 6 net (223  $\mu$  mesh size) catches, Illiamna Lake, 1976<sup>1</sup>

Lake stations	Sample period	Sampling dates	Number of stations sampled	Number of samples collected	Copepoda			Cladocera			Total
					Calanoids	Cyclops	Bosmina	Daphnia	Holopedium		
4	March	3-25	1	2	458	3026	15	40	0	3540	
2	June	6-1	1	2	220	1096	15	5	0	1393	
3	June	6-1/6-2	5	10	432	3073	69	5	0	3681	
4	June	5-28/5-31	4	8	98	1131	9	1	0	1281	
Whole lake <sup>2</sup>	June	5-28/6-2	10	20	*	*	*	*	*	2502	
1	July	7-10/7-22	6	12	893	6751	1013	379	547	10225	
2	July	7-10/7-22	6	12	902	6870	399	68	329	8969	
3	July	7-10/7-22	6	12	391	5147	45	4	41	5757	
4	July	7-10/7-22	4	8	249	4189	13	1	2	4555	
Whole lake	July	7-10/7-22	22	44	648	5922	420	132	259	7726	
Whole lake <sup>3</sup>	Aug.	*	*	*	*	*	*	*	*	8838	
2	Sept.	9-15	2	2	1075	541	2076	606	36	4627	
3	Sept.	9-10/9-15	3	4	408	1674	918	152	53	3566	
4	Sept.	9-6/9-21	4	5	440	3541	528	33	30	4857	

<sup>1</sup> Section values weighted by the percentage of total lake volume which they represent for calculation of whole lake values.

<sup>2</sup> Estimated from mean ratio of July to August whole lake values (11 years of data).

<sup>3</sup> Estimated from ratio of section 2-4 values to whole lake values (10 years of data).

\* Data lacking.



Table 19. Catches of juvenile sockeye salmon, sticklebacks and least ciscos from all towing in Iliamna Lake and Lake Clark, 1976

Lake section	Sockeye salmon		Sticklebacks		Least ciscos	Number of tows
	Age 0	Age I	3-spine	9-spine		
<u>Iliamna Lake</u>						
1	9	0	9	0	0	1
2	72	1	37	11	0	2
3	54	1	63	9	0	2
4	1,181	118	339	115	4	10
5	1,710	335	542	39	0	12
6	2,638	209	263	55	1	12
7	3,674	148	4,833	42	0	9
8	6,187	370	4,390	439	0	13
9	2,342	66	1,168	147	6	7
10	442	36	105	22	0	3
11	719	25	250	71	0	3
Total:	19,028	1,309	11,990	950	11	74
<u>Lake Clark</u>						
12	3,088	88	0	0	12	9
13	859	21	1	1	65	10
14	396	9	0	0	67	5
Total:	4,343	118	1	1	144	24
Grand Total:	23,371	1,427	11,991	951	155	98

Table 20. Weighted arithmetic mean catches of resident fish from index tows for Iliamna Lake, Lake Clark, and the Kvichak system, 1976

Lake section	Sockeye salmon		Sticklebacks		Least ciscos	Weighting factor	Number of index tows
	Age 0	Age I	Three-spine	Nine-spine			
<u>Iliamna Lake (all tows 8/06-9/21)</u>							
1	1.917	.000	.000	.000	.000	.2130	1
2	6.613	.092	3.398	1.010	.000	.1837	2
3	5.225	.097	6.095	.871	.000	.1935	2
4	15.684	1.567	4.502	1.527	.053	.1328	10
5	13.594	2.663	4.309	.310	.000	.0954	12
6	15.015	1.190	1.497	.313	.006	.0683	12
7	4.572	.184	6.014	.052	.000	.0112	9
8	3.998	.239	2.837	.284	.000	.0084	13
9	12.178	.343	6.074	.764	.031	.0364	7
10	4.847	.395	1.151	.241	.000	.0329	3
11	5.872	.204	2.042	.580	.000	.0245	3
Total:	89.515	6.974	37.919	5.953	.090	1.0001	74
<u>Iliamna Lake (tows 9/05-9/21)</u>							
1	1.917	.000	.000	.000	.000	.2130	1
2	6.613	.092	3.398	1.010	.000	.1837	2
3	5.225	.097	6.095	.871	.000	.1935	2
4	15.684	1.567	4.502	1.527	.053	.1328	10
5	19.414	1.252	3.065	.405	.000	.0954	8
6	17.444	.594	1.325	.239	.000	.0683	10
7	7.116	.284	9.108	.034	.000	.0112	5
8	3.342	.039	2.727	.050	.000	.0084	6
9	5.081	.335	.619	.066	.000	.0364	5
10	4.847	.395	1.151	.241	.000	.0329	3
11	5.872	.204	2.042	.580	.000	.0245	3
Total:	92.555	4.860	34.032	5.023	.053	1.0001	55
<u>Lake Clark</u>							
12	130.657	3.723	.000	.000	.508	.3808	9
13	36.413	.890	.042	.042	2.755	.4239	10
14	15.468	.352	.000	.000	2.617	.1953	5
Total:	182.537	4.965	.042	.042	5.880	1.0000	24
<u>Iliamna Lake</u>							
	83.994	4.410	30.884	4.558	.048	.9075	55
<u>Lake Clark</u>							
	16.885	.459	.004	.004	.544	.0925	24
Total:	100.879	4.869	30.888	4.562	.592	1.0000	79

<sup>1</sup>Weighted mean catches: (Iliamna Lake index)(.9075) + (Lake Clark index)(.0925) for Kvichak system.

Table 21. Relative abundance, length, weight, growth rate and relative production of age 0 sockeye salmon, Iliamna Lake, Lake Clark, and Kvichak system, 1962-1976

Year of sampling	SOCKEYE SALMON AGE 0								
	Iliamna Lake			Lake Clark		Kvichak System			
	Index of abundance	Mean <sup>1</sup> length (mm)	Mean <sup>1</sup> weight (g)	Growth rate (mm/day)	Index of abundance	Mean <sup>1</sup> length (mm)	Index of abundance	Mean length (mm)	Mean catch per million spawners
1961 <sup>2</sup>	137.0 <sup>3</sup>								
1962	21.6	55.1	1.57	.33	22.3	50.3	21.7	54.6	5.84
1963	28.3	58.4	1.90	.30	72.9	49.9	32.4	56.7	12.56
1964	0.9	55.5	1.62	.43	6.5	50.4	1.4	54.0	4.11
1965	3.9	62.7	2.24	.51	2.2	50.2	3.7	61.3	3.85
1966 <sup>2</sup>	146.5	53.3	1.32	.42	51.4	52.5	137.7	53.1	5.66
1967	66.0	60.8	2.06	.50	22.5	44.7	62.0	60.2	16.40
1968	38.8	64.1	2.34	.45	84.7	59.3	43.0	63.3	13.35
1969	8.1	58.1	1.88	.54	22.1	50.4	9.4	56.4	3.67
1970	98.2	63.2	2.35	.36	17.4	55.4	90.7	63.1	10.81
1971 <sup>2</sup>	55.4	45.5	0.77	.26	25.3	38.0	52.6	45.1	3.77
1972	1.7	52.4	1.18	.29	23.3	40.6	3.7	45.5	1.54
1973	1.8	57.5	1.88	.37	36.7	47.8	5.0	51.2	4.95
1974	1.7	68.1	2.96	.57	24.4	57.3	3.8	61.6	16.52
1975	49.0	55.9	1.55	.47	182.6	54.8	61.4	55.5	14.18
1962-1975 mean	37.3	57.9	1.70	.41	42.4	50.2	37.8	55.8	8.39
1976 <sup>2</sup>	92.6	52.3	1.15	.33	182.5	48.7	100.9	51.7	7.68

<sup>1</sup>Lengths and weights adjusted to September 1.

<sup>2</sup>Indicates production of a peak cycle year.

<sup>3</sup>Estimated from incomplete towing in conjunction with echogram counts.

Table 22. Relative abundance, length and growth rate of age I sockeye salmon, Iliamna Lake, Lake Clark, and the Kvichak system, 1962-1976

Year of sampling	Sockeye salmon age I									
	Iliamna Lake			Lake Clark			Kvichak System			
	Index of abundance	Mean <sup>1</sup> length (mm)	Growth rate (mm/day)	Index of abundance	Mean <sup>1</sup> length (mm)	Index of abundance	Mean length (mm)	Index of abundance	Mean length (mm)	Mean catch per million spawners
1962 <sup>2</sup>	87.8	89.9	.18	0.0	86.3	79.7	89.9	5.45		
1963	11.2	97.6	.20	1.5	86.2	10.3	97.5	2.78		
1964	21.1	95.8	.37	0.9	83.3	19.2	95.9	7.44		
1965	2.7	108.6	.58	1.2	80.0	2.6	106.7	7.70		
1966	0.9	112.0	.56	0.7	100.7	0.9	108.9	.94		
1967 <sup>2</sup>	75.3	89.9	.27	3.5	94.1	68.7	89.9	2.82		
1968	20.5	109.6	.33	19.8	99.0	20.4	108.8	5.42		
1969	2.4	98.2	.31	11.6	95.5	3.3	95.9	1.03		
1970	4.8	100.8	.53	12.1	108.6	5.5	101.9	2.16		
1971	20.7	92.8	.21	5.5	88.3	19.3	92.7	2.30		
1972 <sup>2</sup>	20.7	74.0	.30	6.4	83.7	19.4	74.2	1.39		
1973	1.9	100.6	.46	2.2	93.9	1.9	99.9	.79		
1974	0.3	112.2	.79	2.6	109.6	0.5	110.9	.50		
1975	0.5	111.1	.39	4.1	97.1	0.9	109.0	3.91		
1962-1975 mean	19.3	99.5	.39	5.2	93.3	18.0	98.7	3.2		
1976	4.9	91.8	.36	5.0	97.0	4.9	92.5	1.13		

<sup>1</sup>Lengths adjusted to September 1.

<sup>2</sup>Indicates production of a peak cycle year.

Table 23. Relative abundance of juvenile sockeye salmon, threespine sticklebacks and least ciscos in the Kvichak River system and the relative production of age 0 sockeye, 1962-1976

Year of sampling	Index of abundance <sup>1</sup>									Mean catch of Age 0 per million spawners
	Iliamna Lake			Lake Clark		Least Ciscos	Kvichak system <sup>2</sup>			
	Age 0	Age 1	Threespine sticklebacks	Age 0	Age I		Age 0	Age I		
1962	21.6	87.8	132.3	22.3	0.0	2.4	21.7	79.7	5.84	
1963	28.3	11.2	26.6	72.9	1.5	4.5	32.4	10.3	12.56	
1964	0.9	21.1	95.3	6.5	0.9	3.6	1.4	19.2	4.11	
1965	3.9	2.7	91.2	2.2	1.2	2.4	3.7	2.6	3.85	
1966	146.5	0.9	36.7	51.4	0.7	10.6	137.7	0.9	5.66	
1967	66.0	75.3	37.0	22.5	3.5	13.6	62.0	68.7	16.40	
1968	38.8	20.5	90.3	84.7	19.8	12.6	43.0	20.4	13.35	
1969	8.1	2.4	80.6	22.1	11.6	22.5	9.4	3.3	3.67	
1970	98.2	4.8	31.0	17.4	12.1	17.4	90.7	5.5	10.81	
1971 <sup>3</sup>	55.4	20.7	39.5	25.3	5.5	16.4	52.6	19.3	3.77	
1972	1.7	20.7	5.9	23.3	6.4	6.1	3.7	19.4	1.54	
1973 <sup>3</sup>	1.8	1.9	17.8	36.7	2.2	2.1	5.0	1.9	4.95	
1974 <sup>3</sup>	1.7	0.3	5.0	24.4	2.6	14.9	3.8	0.5	16.52	
1975 <sup>3</sup>	49.0	0.5	38.5	182.6	4.1	8.9	61.4	0.9	14.18	
1962-1975 Mean	37.3	19.3	52.0	42.4	5.2	9.9	37.8	18.0	8.37	
1976	92.6	4.9	34.0	182.5	5.0	5.9	100.9	4.9	7.68	

<sup>1</sup>Weighted mean catches of juvenile sockeye salmon, threespine sticklebacks and least ciscos per standard tow (all the above indices are derived from the computer program FRK 317R which uses the 1968 method of computing indices of abundance and defining lake sections).

<sup>2</sup>Iliamna index given a weight of 0.9075 and Lake Clark index a weight of 0.0925, based on total surface area.

<sup>3</sup>Indices estimated from incomplete towing.

Table 24. Abundances, sizes, and relative production of juvenile salmon in freshwater and adult escapements, total inshore returns, returns per indexed smolt ratio, and returns per spawner ratio for sockeye salmon of the Kvichak River system, brood years 1952 through 1975

Brood year	Index of abundance			Average length (mm)			Escapement x 10 <sup>6</sup>	Relative production			Adult return		
	By fyke net Age 0	By fyke net Age I	By fyke net Age II	By ton net Age 0	By ton net Age I	By fyke net Age II		By ton net Age 0 per million spawners	By fyke net Total smolt index per million spawners	By ton net Total inshore return	By ton net Total return (indexed)	Ret./ smolt spawner	Ret./ return
1952				7.3			109.0	5.97				15.6	2.6
1953		0.6		1.4	2.0		89.0	.32			6.25	3.5	1.6
1954		0.9		0.3	1.2		92.0	.24			5.00	0.7	3.1
1955		0.7		2.0	2.7		96.0	.25			10.80	1.3	5.1
1956		98.0		83.3	181.3		84.0	9.44			19.21	33.1	3.5
1957		2.6		16.6	19.2		80.0	2.96			6.49	3.6	1.3
1958		1.8		0.3	2.1		91.0	.53			3.96	0.3	0.5
1959		0.8		2.2	3.0		92.0	.63			4.41	0.5	0.7
1960		33.9		123.5	157.4		92.0	14.63			10.76	48.9	3.3
1961		21.7		10.3	51.5		83.0	3.71			13.68	3.1	0.8
1962		32.4		19.2	66.1		87.0	2.58			25.62	4.8	2.2
1963		1.4		2.6	2.6		90.0	.34			7.65	0.9	2.5
1964		3.7		0.9	14.3		91.0	.86			14.90	4.9	5.1
1965		127.7		65.7	250.2		86.0	24.33			10.28	40.1	1.7
1966		62.0		20.4	16.2		88.0	3.78			9.42	5.6	1.5
1967		43.0		3.3	26.8		92.0	3.22			8.32	1.3	0.4
1968		9.4		5.5	9.3		91.0	2.56			3.63	0.4	0.2
1969		90.7		19.35	96.3		90.0	8.39			11.48	5.6	0.64
1970		52.6		19.45	36.2		80.0	13.94			2.60	1.2	0.2
1971		3.7		1.925	18.0		85.6	2.39			8.08	5.6	0.64
1972		5.05		0.55			93.0	1.01					
1973		3.85		0.9			111.1	.23					
1974		61.4		4.9			55.9	4.33					
1975		100.9					51.7	13.14					

1. PFI weighted mean catches of juvenile sockeye salmon Age 0 and Age I per standard tow.  
 2. ADWG Igiugig 24-hr indices of smolt abundance (one index point = 33,340 smolts).  
 3. Lengths adjusted to September 1.  
 4. Estimated returns of six year-old fish determined from average percentage that returned after six years in past years.  
 5. Indices estimated from incomplete towing.

Table 25. Live length information from which daily growth rates (in mm) of juvenile sockeye salmon and age I threespine sticklebacks were determined in 1976

Fish type	Date	Type of sampling	Location of sampling		Mean live length	Sample size
			Area	Lake section		
<b>Sockeye salmon</b>						
age 0	7/13*	Beach seine	W3 and P3	6 and 8	33.45	337
	8/01		W3 and P2	6 and 8	36.35	306
	8/13		P2 and P3	7	39.32	433
	8/27		P2, P3 and W3	6 and 8	40.75	175
	8/06	Townet	149	8	43.51	110
	8/10*		143	7	41.49	280
	8/10*		141 and 144	7	42.46	157
	8/11*		149	8	42.42	473
	8/14		123 and 124	5	41.64	82
	8/14		136	6	45.55	84
	8/27		149	8	47.25	645
	9/13		124	5	58.05	260
	9/14		149	8	53.73	368
	9/20*		149	8	54.92	364
	9/21*	144	7	57.39	402	
	<b>Sockeye salmon</b>					
age I	8/06	Townet	149	8	82.13	86
	8/10*		141 and 144	7	80.14	21
	8/11*		149	8	80.26	180
	8/14		123 and 124	5	87.63	177
	8/14		136	6	86.20	122
	8/27		149	8	85.12	68
	9/20*		149	8	95.45	22
	9/21*		144	7	94.16	88
<b>Threespine stickle-</b>						
backs age I	7/13*	Beach seine	P3 and W3	6 and 8	32.78	238
	8/27		149	8	39.36	134
	9/14	Townet	149	8	41.16	179
	9/20*		149	8	41.62	465

\* Samples actually used to determine growth rates.

Table 26. Estimated daily growth rates (in mm) of juvenile sockeye salmon and age I threespine sticklebacks in the eastern portion of Iliamna Lake, 1976

Fish species	Date	Sample size	Mean live length	Length increment	No. days between sampling	Average increase per day
<u>Sockeye salmon age 0</u>						
Pedro Bay	7/13	337	33.45			
(beach seine-townd)	9/20	364	54.92	21.47	69	.31
Pedro Bay	8/11	473	42.42			
(townt)	9/20	364	54.92	12.50	40	.31
Pedro-Knutson	8/10	157	42.46			
(townt)	9/21	402	57.39	14.93	42	.36
Knutson Bay	8/10	280	41.49			
(townt)	9/19	482	54.27	12.79	40	.32
						<u>Mean = .33</u>
<u>Sockeye salmon age I</u>						
Pedro Bay	8/11	180	80.26			
(townt)	9/20	22	95.45	15.19	40	.38
Pedro-Knutson	8/10	21	80.14			
(townt)	9/21	88	94.16	14.02	42	.33
						<u>Mean = .36</u>
<u>Threespine sticklebacks Age I</u>						
(beach seine-townt)	7/13	238	32.78			
	9/20	465	41.62	8.84	69	.13

Table 27. Estimated daily growth rates (in mm) of juvenile sockeye salmon and sticklebacks in the eastern portion of Iliamna Lake, 1962 - 1976<sup>1</sup>

Year of towing	Sockeye salmon		Sticklebacks
	Age 0	Age 1	Age 1
1962	.33	.18	.09
1963	.30	.20	.18
1964	.43	.37	.24
1965	.51	.58	.12
1966	.42	.56	.22
1967	.50	.27	.17
1968	.45	.33	.02
1969	.54	.31	.04
1970	.36	.53	.09
1971	.26	.21	.06
1972	.29	.30	.29
1973	.37	.46	.17
1974	.57	.79	.30
1975	.47	.39	.13
1962-1975 mean:	.41	.39	.15
1976	.33	.36	.13

<sup>1</sup>Sources of data for estimated daily growth rates (in mm) of juvenile sockeye salmon and age I 3-spine sticklebacks for the years 1962-1975 are Kerns (1965, 1966 and 1968), Mathisen (1970), Mathisen, Poe and Roger (1971), Roger (MS, 1973), Poe (MS, 1975), Poe et al (1975), and Poe, Cortner, and Mathisen (1976).

Table 28. Mean live lengths<sup>1</sup> (in mm) and numbers measured of juvenile sockeye salmon, total threespine sticklebacks, ninespine sticklebacks, and least ciscos, Iliamna Lake and Lake Clark, 1976 (lengths adjusted to Sept. 1 for all species except least ciscos)

Lake section	Sockeye salmon				Threespine sticklebacks <sup>4</sup>		Ninespine sticklebacks <sup>4</sup>		Least ciscos <sup>5</sup>	
	Age 0 <sup>2</sup>		Age I <sup>3</sup>		Size	#meas.	Size	#meas.	Size	#meas.
<u>Iliamna Lake</u> (index period 9/05-9/21)										
1	47.2	(9)	-	-	-	-	-	-	-	-
2	55.1	(71)	93.0	(2)	47.9	(37)	50.7	(11)	-	-
3	52.3	(54)	102.4	(1)	51.3	(63)	46.7	(9)	-	-
4	53.9	(1102)	95.3	(115)	51.9	(298)	55.9	(80)	91.0	(4)
5	53.2	(1628)	90.5	(105)	46.8	(257)	48.8	(34)	-	-
6	49.5	(1621)	86.1	(81)	48.2	(177)	46.4	(32)	-	-
7	49.3	(1026)	87.4	(108)	45.1	(676)	51.1	(6)	94.0	(1)
8	48.7	(1229)	88.0	(24)	40.2	(821)	48.9	(26)	-	-
9	45.5	(635)	87.4	(46)	40.1	(85)	45.0	(9)	-	-
10	57.9	(441)	92.2	(36)	49.1	(105)	51.2	(22)	-	-
11	59.8	(719)	97.2	(25)	51.1	(250)	48.1	(71)	-	-
Lake mean <sup>6</sup>	52.3	(8535)	91.8	(543)	47.7	(2769)	50.9	(300)	91.0	(5)
<u>Lake Clark</u>										
12	49.3	(1955)	97.4	(88)	-	-	-	-	129.0	(12)
13	47.2	(859)	95.4	(21)	59.8	(1)	44.2	(1)	143.8	(64)
14	47.3	(395)	96.4	(9)	-	-	-	-	148.6	(67)
Lake mean <sup>6</sup>	48.7	(3209)	97.0	(118)	59.8	(1)	44.2	(1)	144.7	(143)

Data Source: FRK 317R computer output (arithmetic mean run)

<sup>1</sup>Mean live lengths for all species except least ciscos (preserved lengths). Most of the measurements taken from catches from index tows in 1976 were taken from fish that had been preserved in formalin and preserved lengths were converted to live lengths by multiplication with the following factors (Rogers, 1964).

Sockeye fry k = 1.031

Sockeye yearlings k = 1.042

3-sp. sticklebacks k = 1.015

9-sp. sticklebacks k = 1.015

<sup>2</sup>Lengths adjusted to September 1 by addition or subtraction of 0.33 mm/day.

<sup>3</sup>Lengths adjusted to September 1 by addition or subtraction of 0.36 mm/day.

<sup>4</sup>Lengths adjusted to September 1 by addition or subtraction of 0.13 mm/day.

<sup>5</sup>Preserved lengths.

<sup>6</sup>Lake mean is total of section means weighted by section indexes.

Table 29. Weighted mean live lengths<sup>1</sup> (in mm) of juvenile sockeye salmon, threespine sticklebacks, and weighted mean preserved lengths of least ciscos, 1962 - 1976<sup>2</sup>

Year of towing	Iliamna Lake				Lake Clark		Kvichak system		
	Sockeye salmon Fry	Sockeye salmon Yearlings	Threespine sticklebacks Total	Threespine sticklebacks Age I 3	Sockeye Salmon Fry	Sockeye Salmon Yearlings	Least Ciscos	Sockeye salmon Fry	Sockeye salmon Yearlings
1962	55.1	89.9	52.0	42.8	50.3	86.3	----	54.6	89.9
1963	58.4	97.6	54.8	44.0	49.9	86.2	165.0	56.7	97.5
1964	55.5	95.8	54.3	45.1	50.4	83.3	153.9	54.0	95.9
1965	62.7	108.6	56.5	44.3	50.2	80.0	----	61.3	106.7
1966	53.3	112.0	59.2	44.0	52.5	100.7	136.4	53.1	108.9
1967	60.8	89.9	51.3	43.7	44.7	94.1	159.9	60.2	89.9
1968	64.1	109.6	50.6	47.3	59.3	99.0	157.2	63.3	108.8
1969	58.1	98.2	54.6	47.9	50.4	95.5	166.1	56.4	95.9
1970	63.2	100.8	52.9	44.9	55.4	108.6	171.5	63.1	101.9
1971	45.5	92.8	54.8	37.3	38.0	88.3	156.8	45.1	92.7
1972	52.4	74.0	51.5	44.4	40.6	83.7	146.7	45.5	74.2
1973	57.5	100.6	60.1	45.4	47.8	93.9	167.4	51.2	99.9
1974	68.1	112.2	43.7	50.6	57.3	109.6	163.5	61.6	110.9
1975	55.9	111.1	56.2	43.9	54.8	97.1	162.1	55.5	109.0
1962 - 1975 mean:									
	57.9	99.5	53.8	44.7	50.1	93.3	158.9	55.8	98.7
1976	52.3	91.8	47.7	--	48.7	97.0	149.7	51.7	92.3

<sup>1</sup> Lengths adjusted to September 1 for all species except least ciscos (data were not available on the effect of formalin on least ciscos nor on the growth rates of least ciscos with age).

<sup>2</sup> Source of data for all weighted mean lengths except those of Age I threespine sticklebacks for the years 1962-1970 and 1972 are from the arithmetic mean computer output from program No. FRK 317R (Roger, 1972).

<sup>3</sup> Sources of data for weighted mean lengths of Age I threespine sticklebacks for the years 1962-1970 and 1972 are Kerns (1965, 1966 and 1968), Mathisen (1970), Mathisen, Poe, and Roger (1971), Roger (MS, 1973), Poe (MS, 1975), Poe et al. 1975, and Poe, Cortner, and Mathisen (1976).

<sup>4</sup> Weighting procedure:

$$\left[ \frac{(\text{Iliamna Lk. index}) (0.9075)}{\text{Kvichak system index}} \right] \text{mean live length Iliamna Lake} + \left[ \frac{(\text{Lk. Clark index}) (0.0925)}{\text{Kvichak system index}} \right] \text{mean live length Lk Clark}$$

Table 30. Beach seine catches from sampling in the eastern end of Iliamna Lake, 1976

Date	Area	Sample number	Catch					
			Sockeye salmon		Sticklebacks		Sculpins	Arctic char fry
			Age 0	Age I	Threespine	Ninespine		
7/13	74(W3)	701	351	0	1869	95	0	0
7/13	84(P3)	702	3714	0	288	66	0	0
8/01	74(W3)	703	167	0	149	12	5	0
8/01	83(P2)	704	542	0	103	5	0	0
8/01	84(P3)	705	2	0	44	0	0	0
8/13	84(P3)	706	137	0	461	3	1	19
8/13	83(P2)	707	655	0	21	2	0	18
8/27	74(W3)	708	40	0	1112	5	0	2
	84(P3)	709	15	0	174	0	2	3
	83(P2)	710	120	0	5	0	0	7

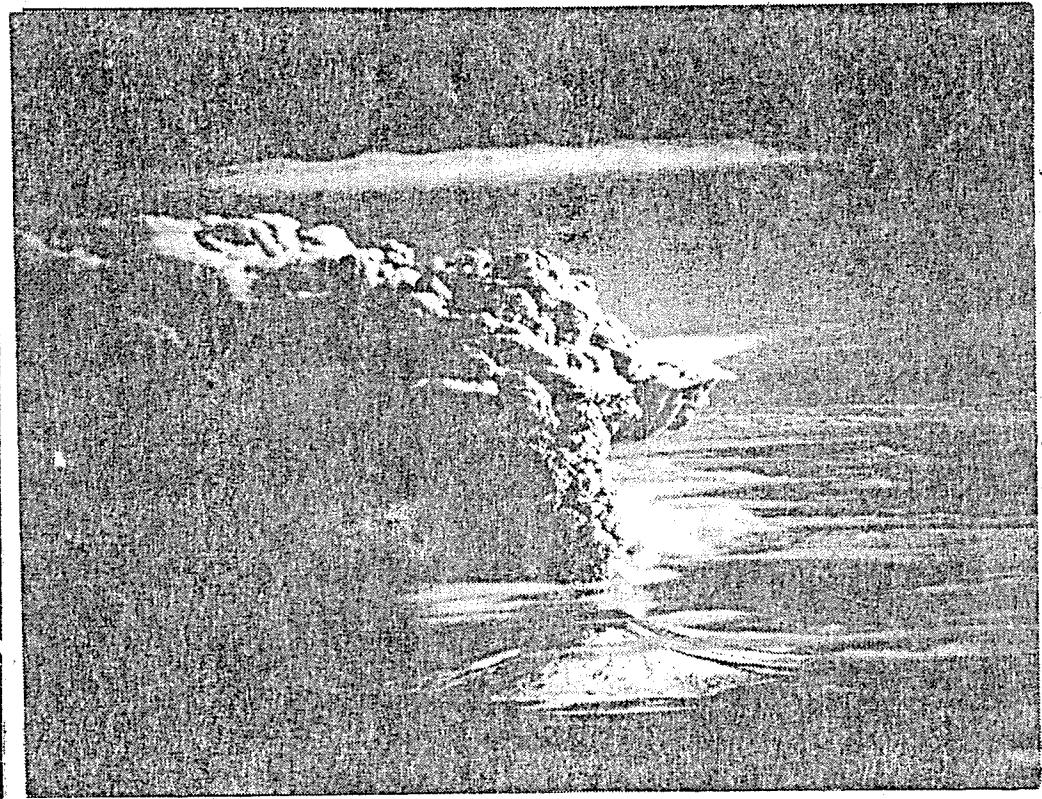
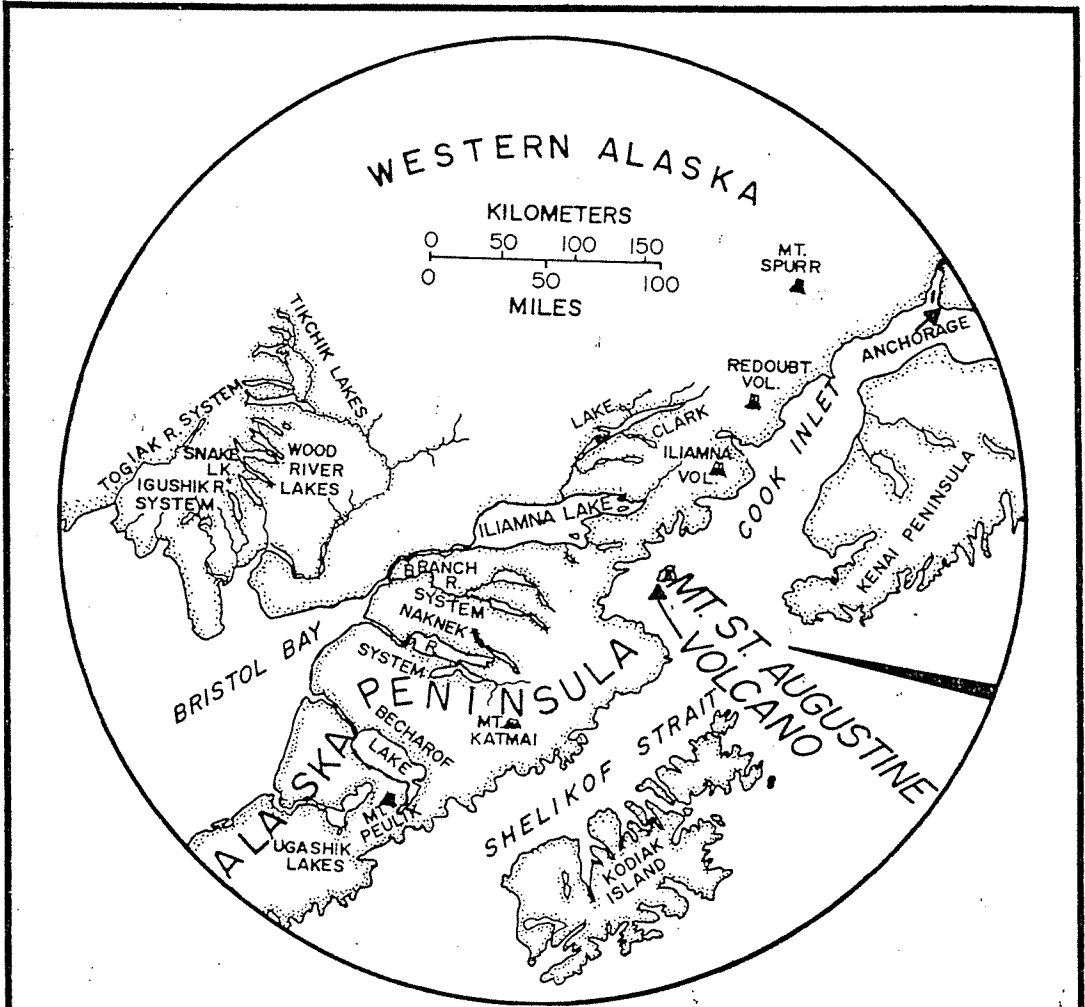


Fig. 1. Location of Iliamna Lake and the Mount St. Augustine volcano in western Alaska and one of the eruptions of February 6, 1976.

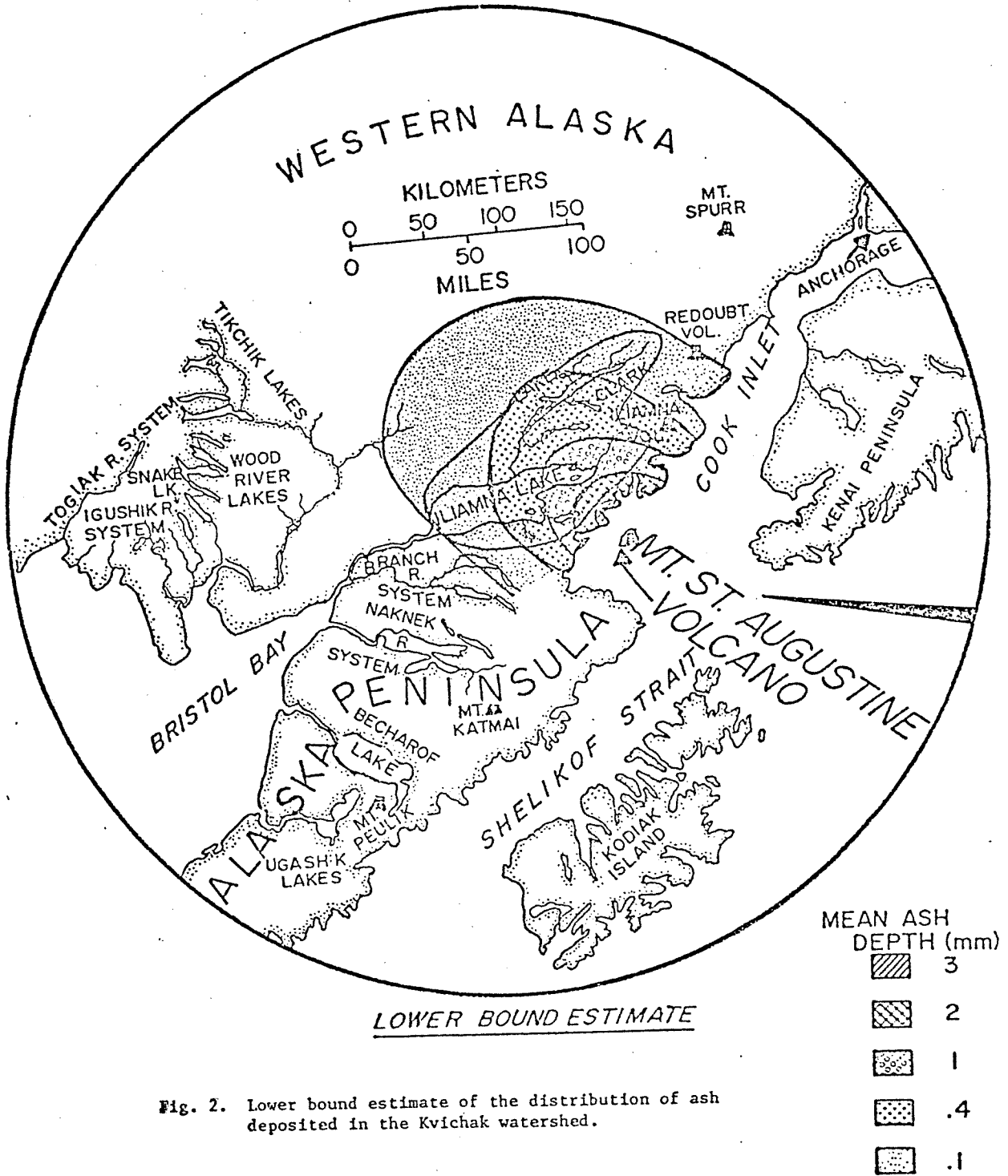


Fig. 2. Lower bound estimate of the distribution of ash deposited in the Kvichak watershed.



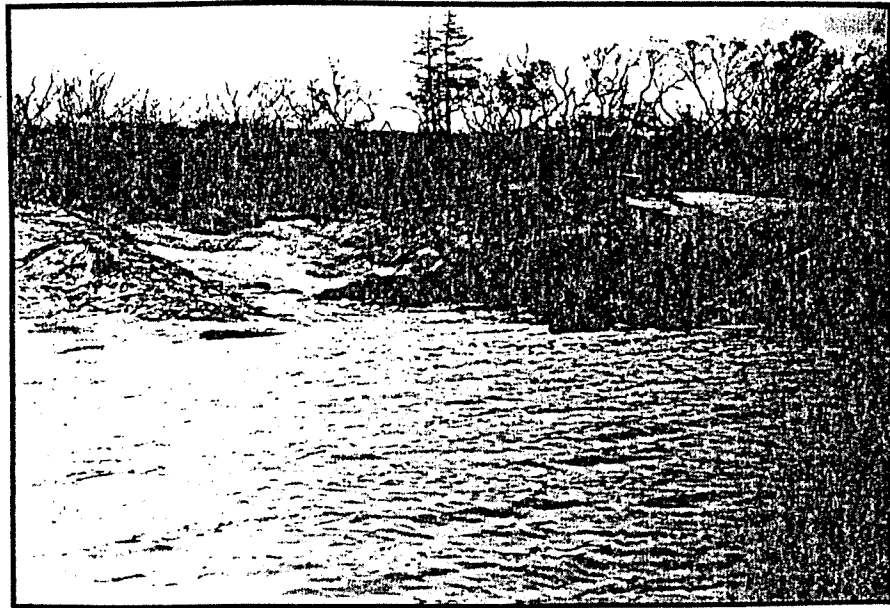
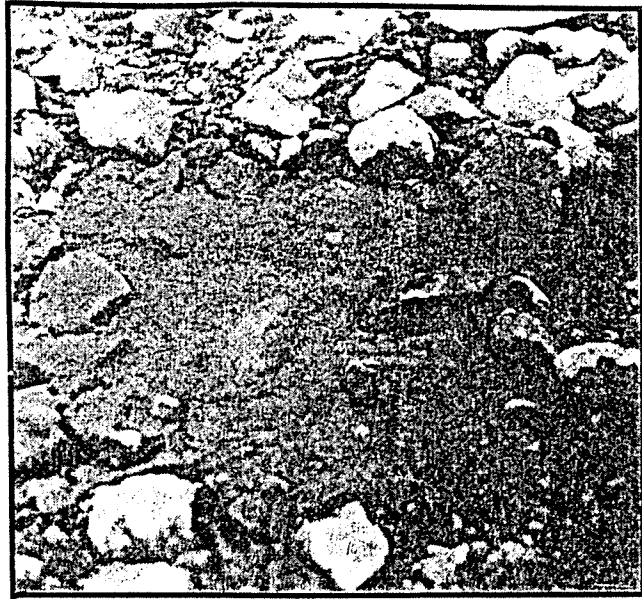


Fig. 4. Ashfall on Iliamna Lake from the 1976 Mount St. Augustine eruptions. Typically, patches of ash were 1 to 2 mm in depth (upper photo). Occasionally found were concentrations of drifted ashfall of up to 18 to 25 cm (lower photo).

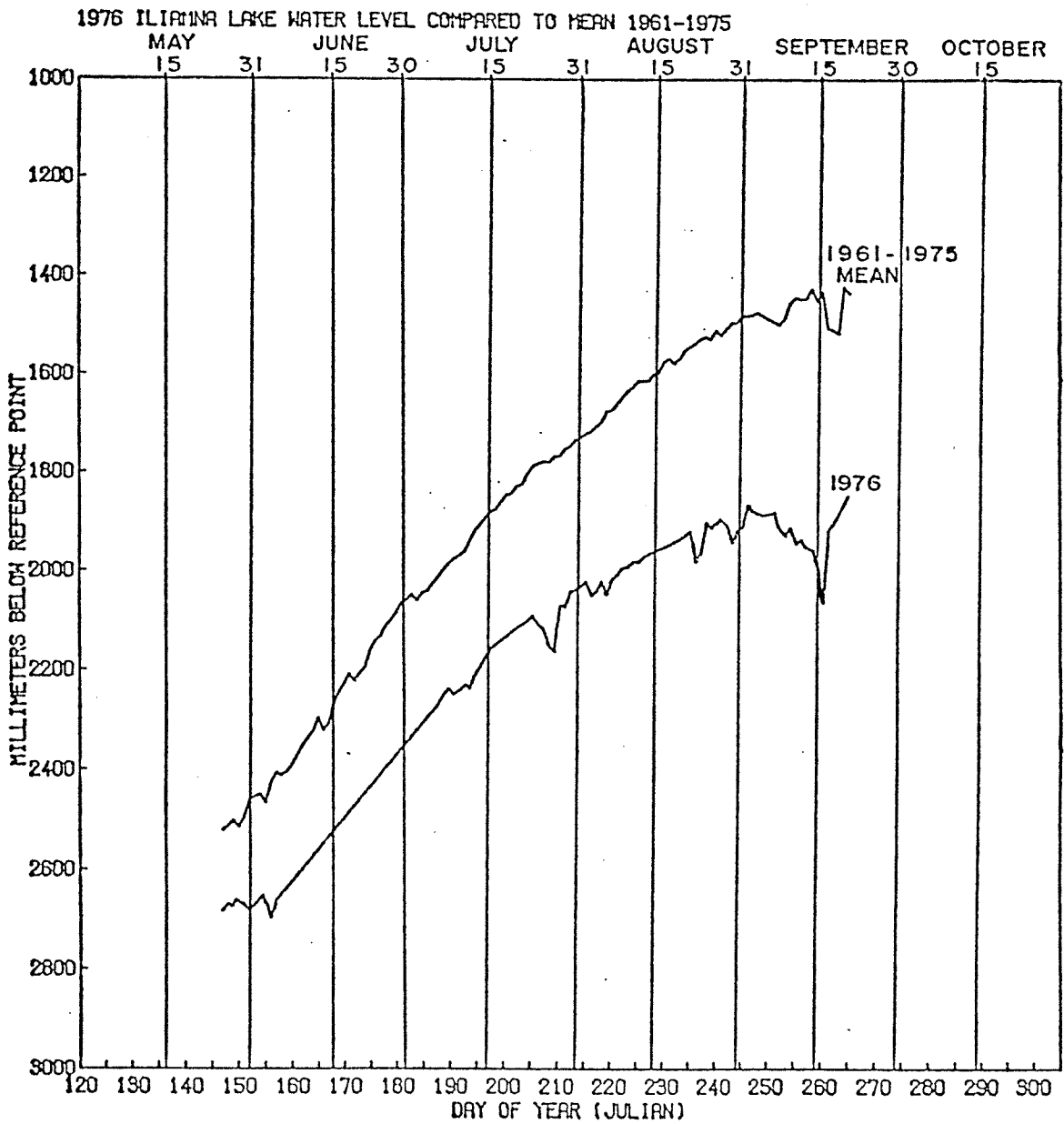


Fig. 5. Iliamna Lake water level compared to mean, 1961-1975.

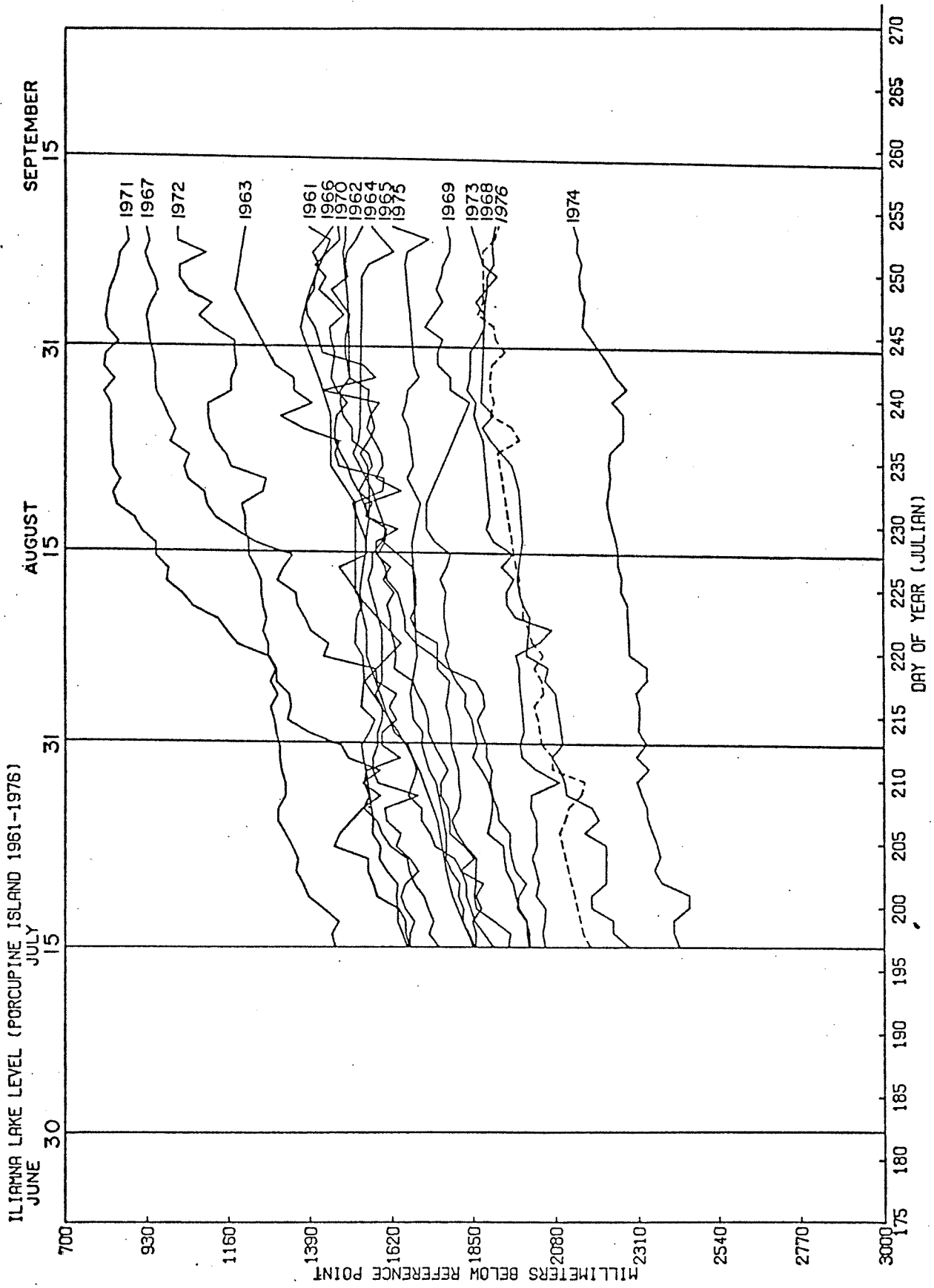


Fig. 6. Iliamna Lake level [Porcupine Island, 1961-1976].

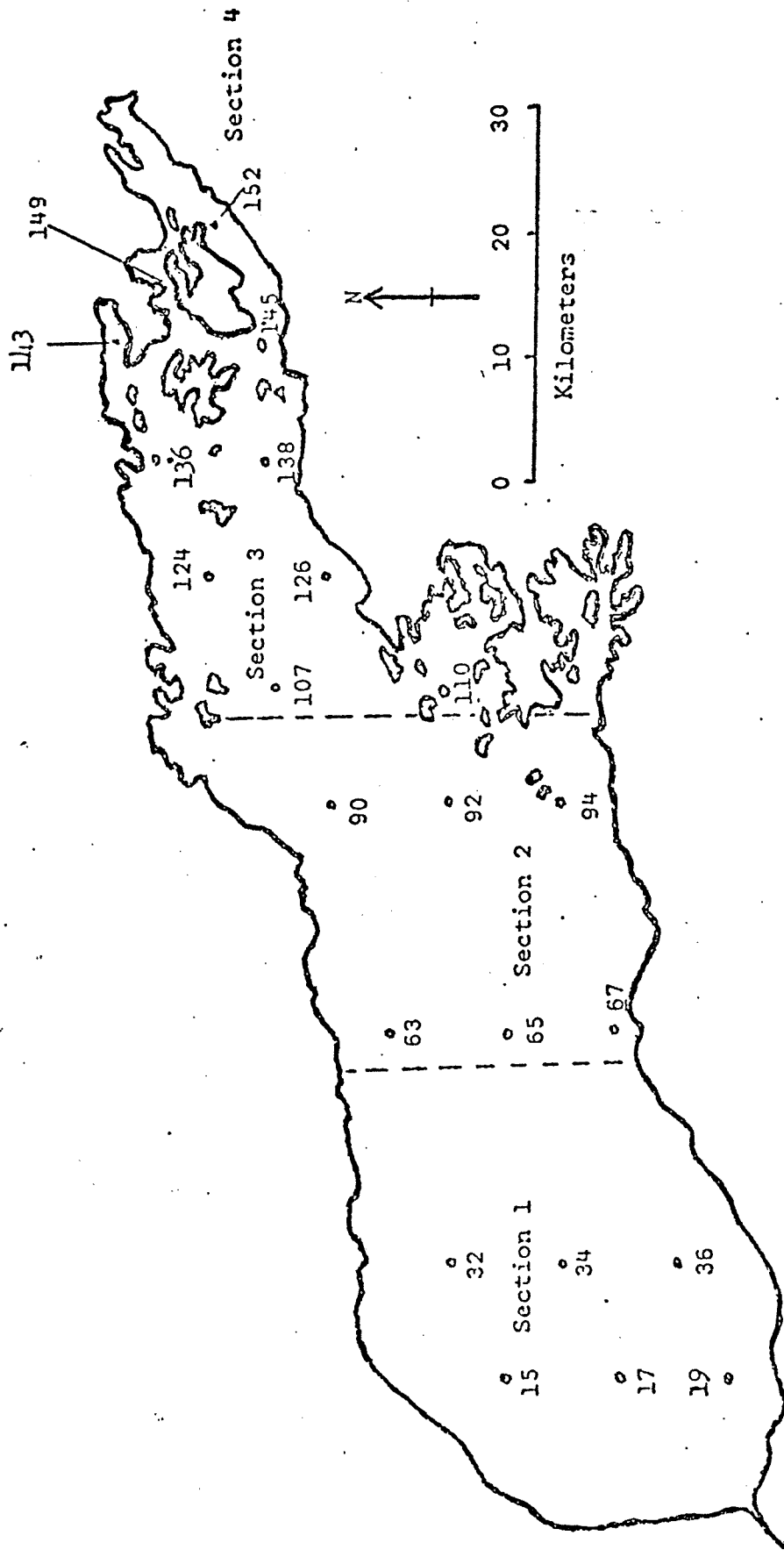


Fig. 7. Map of Iliamna Lake showing the 22 stations where bathythermograph casts were made in 1976.

TEMPERATURE ISOTHERMS, STATION 149, 1976

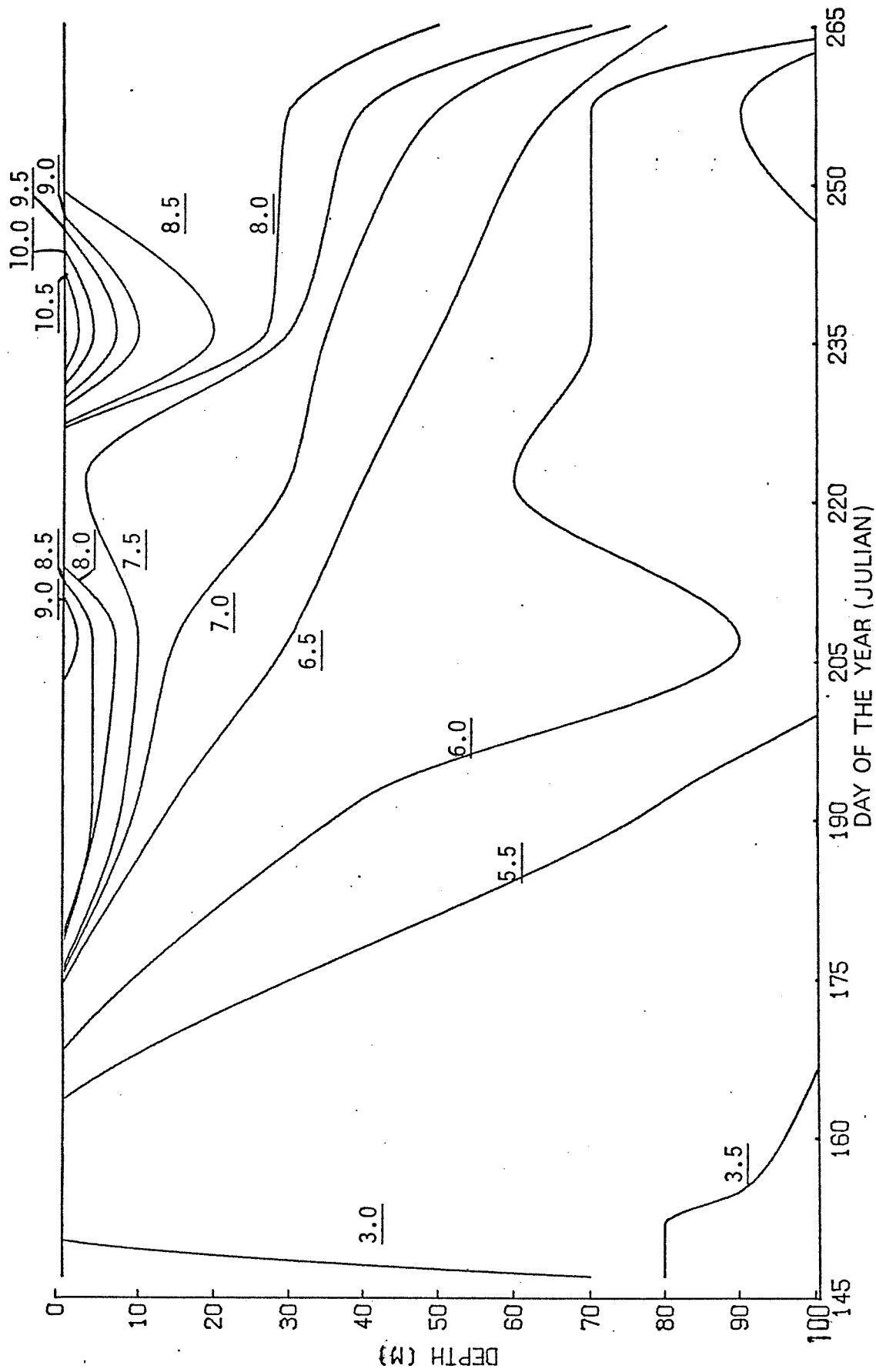


Fig. 8. 1976 temperature isotherms at Station 149, Iliamna Lake, by one-half °C increments. Each line represents the upper boundary of the temperature that it is labeled.

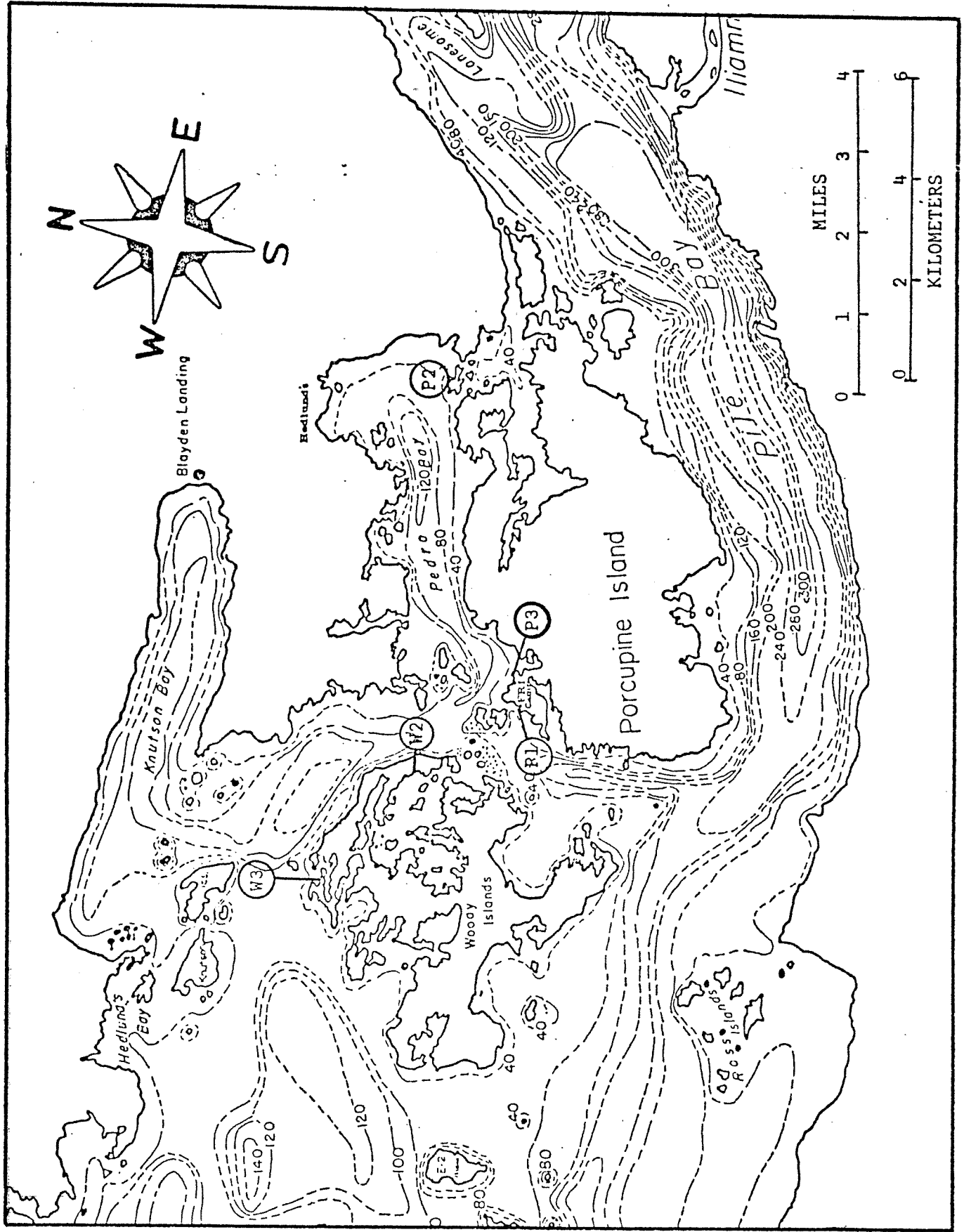


Fig. 9. Locations of the five periphyton stations sampled in 1976.

CHLOROPHYLL A IN PERIPHYTON SAMPLES FROM 5  
STATIONS IN THE EASTERN END OF ILIAMNA LAKE, 1976

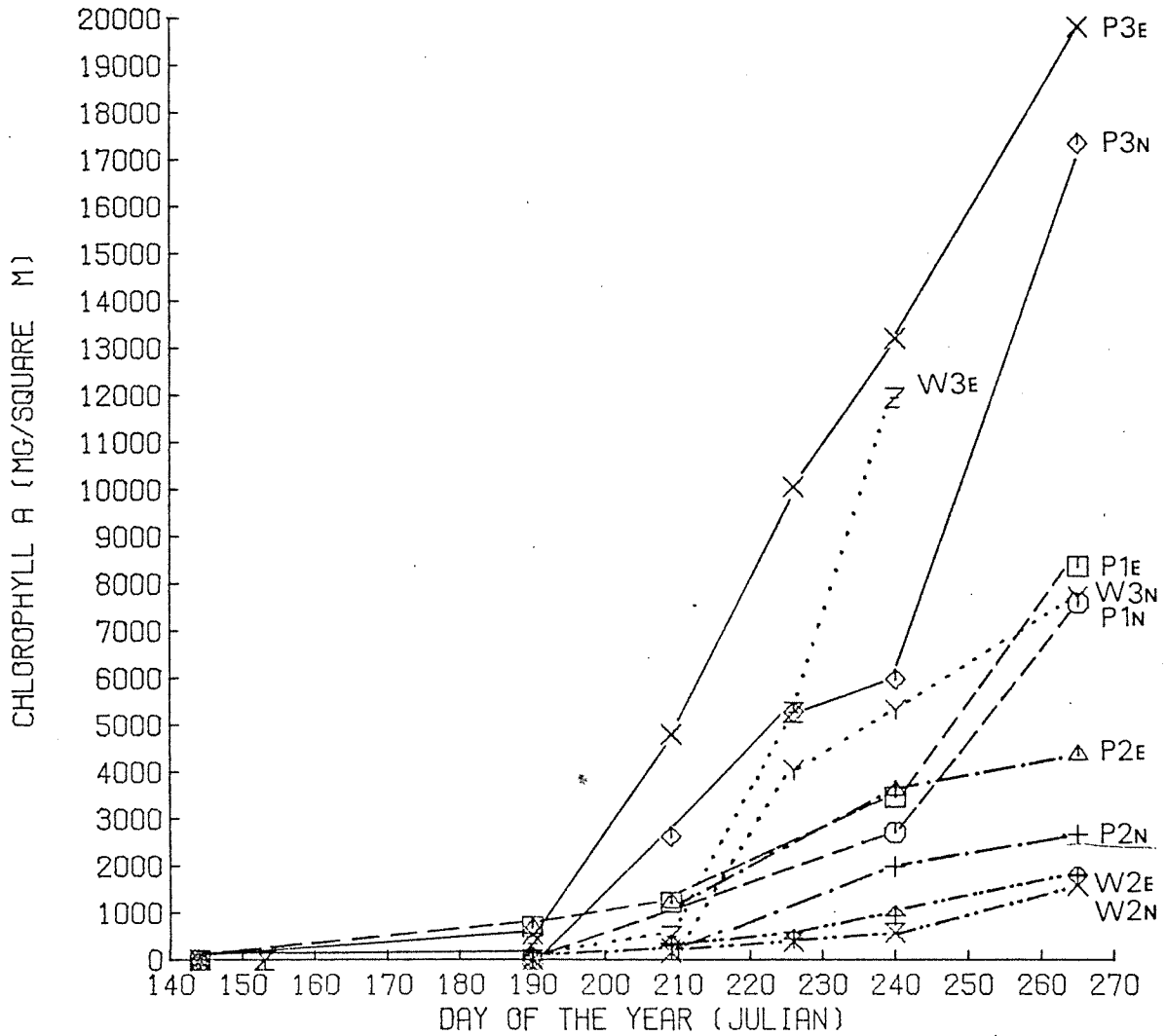


Fig. 10. Chlorophyll  $a$  ( $\text{mg}/\text{m}^2$ ) amounts in periphyton samples from Iliamna Lake, Alaska, 1976. At each of the 5 stations slides were put out both before ice breakup (E) and after ice breakup (N).

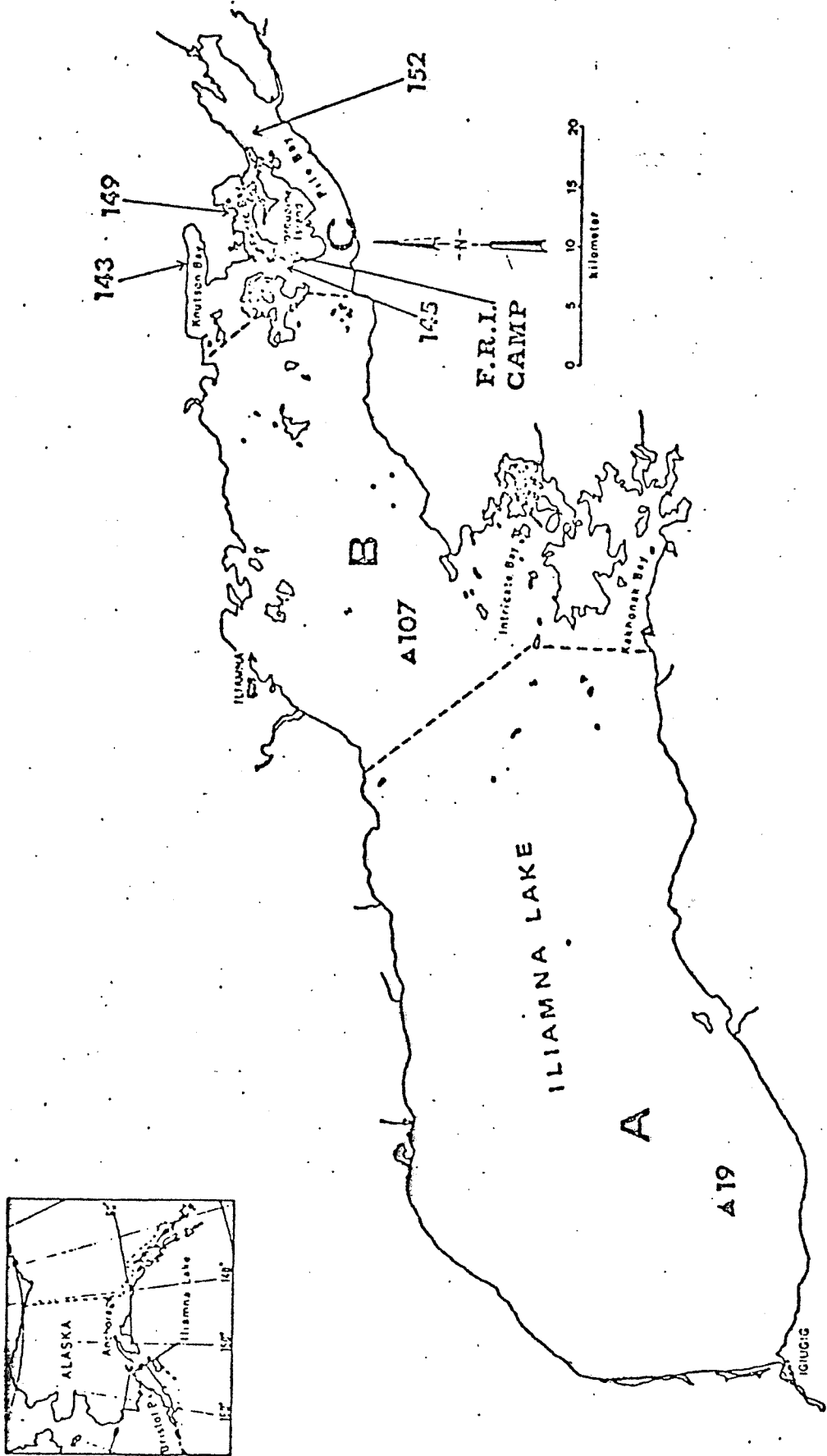


Fig. 11. Map of Iliamna Lake showing the divisions between the three major areas and the positions of stations for measurements of primary production.

## CHLOROPHYLL A, STATION 107, 1961-1976

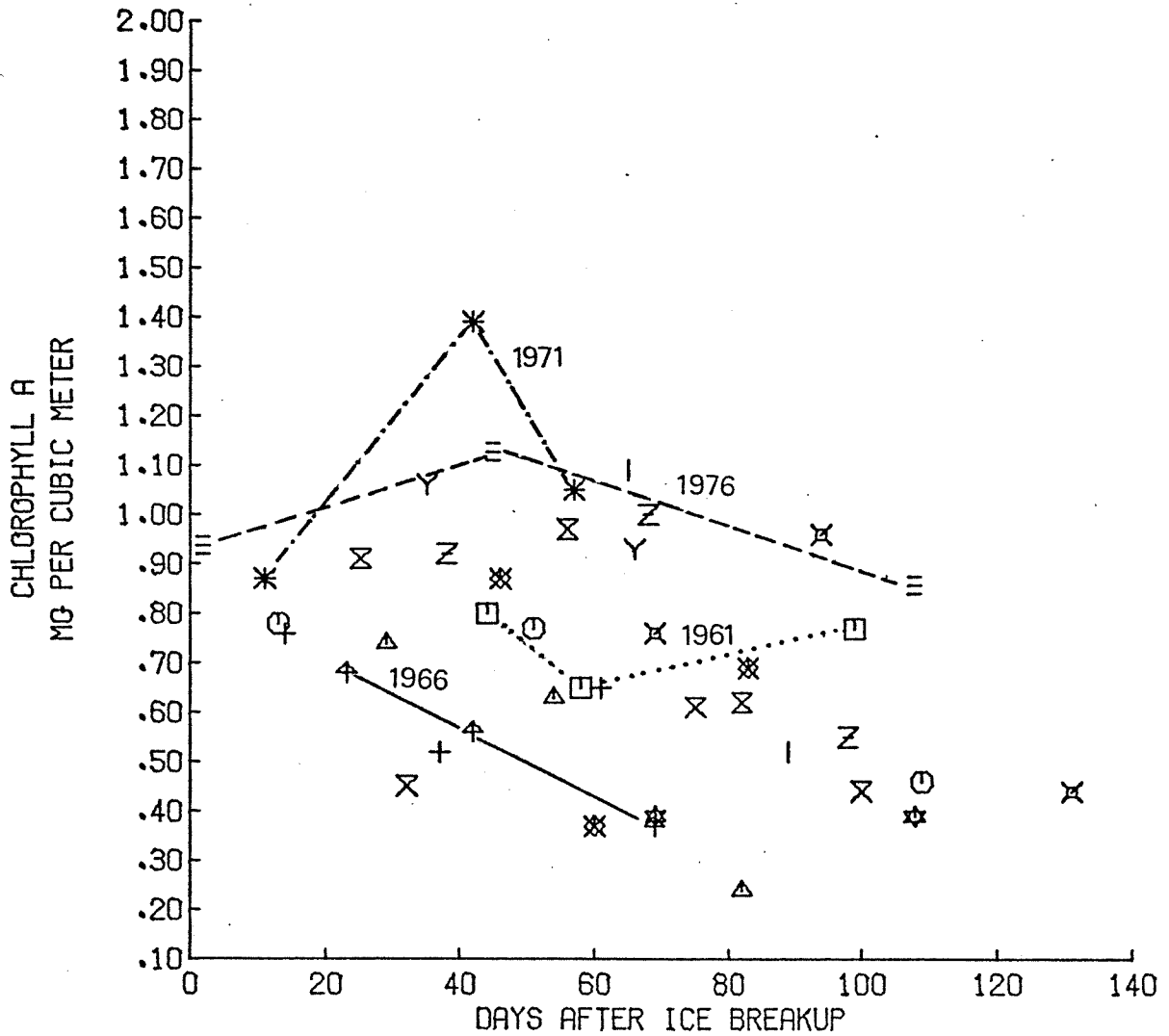


Fig. 12. Mean concentration of chlorophyll a (0-45 m) at Station 107 (Section B), Iliamna Lake, years 1961-1976, by days after ice breakup. Observations from years following a peak year of the sockeye salmon cycle have been joined by lines.

CHLOROPHYLL A, STATION 143, 1961-1976

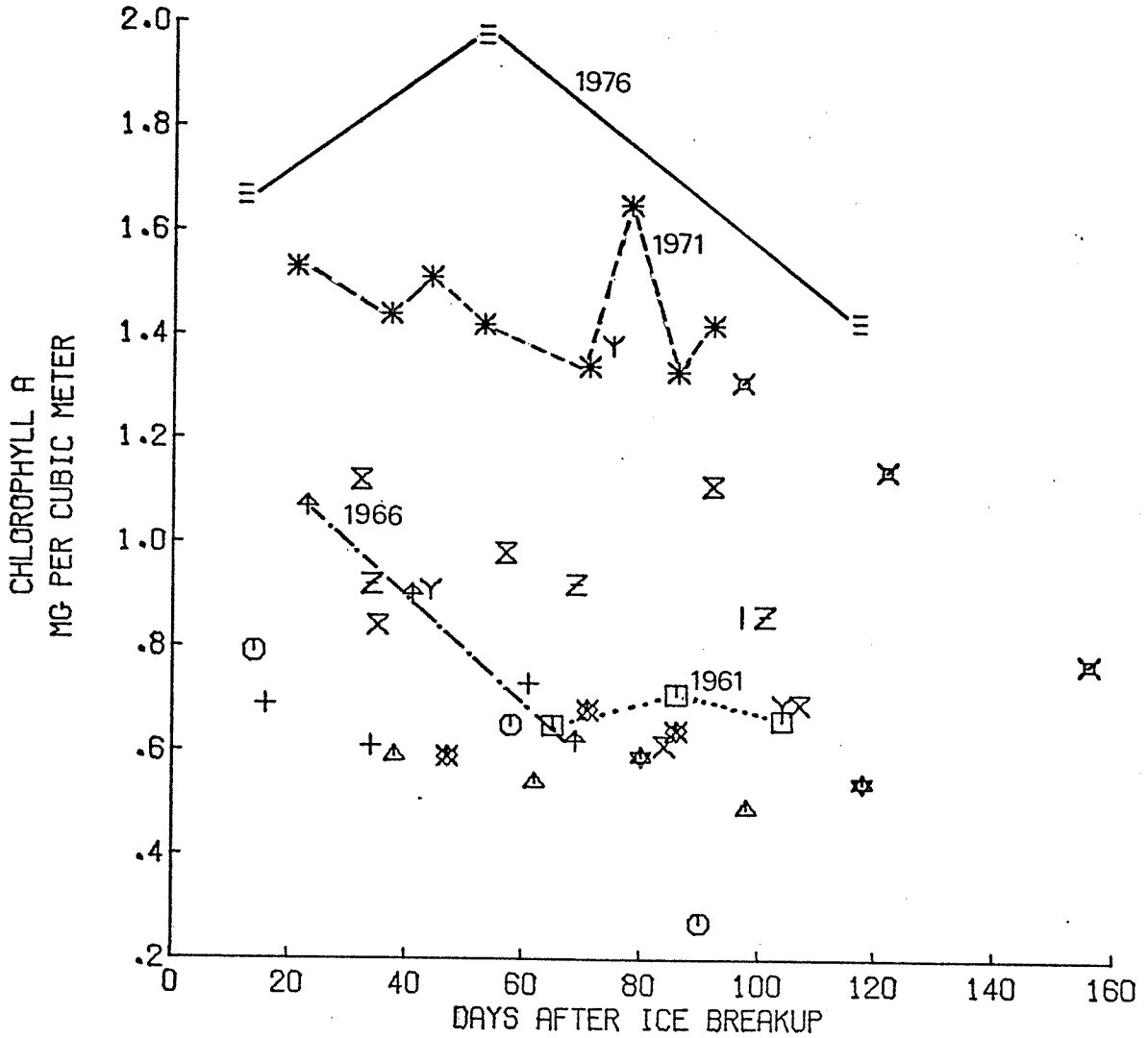


Fig. 13. Mean concentration of chlorophyll a (0-45 m) at Station 143 (Section C), Iliamna Lake, by days after ice breakup. Observations from years 1961-1976 have been included. Data points for years following a peak year of the sockeye salmon cycle have been joined by lines.

## CHLOROPHYLL A, STATION 149, 1970, 1972, 1976

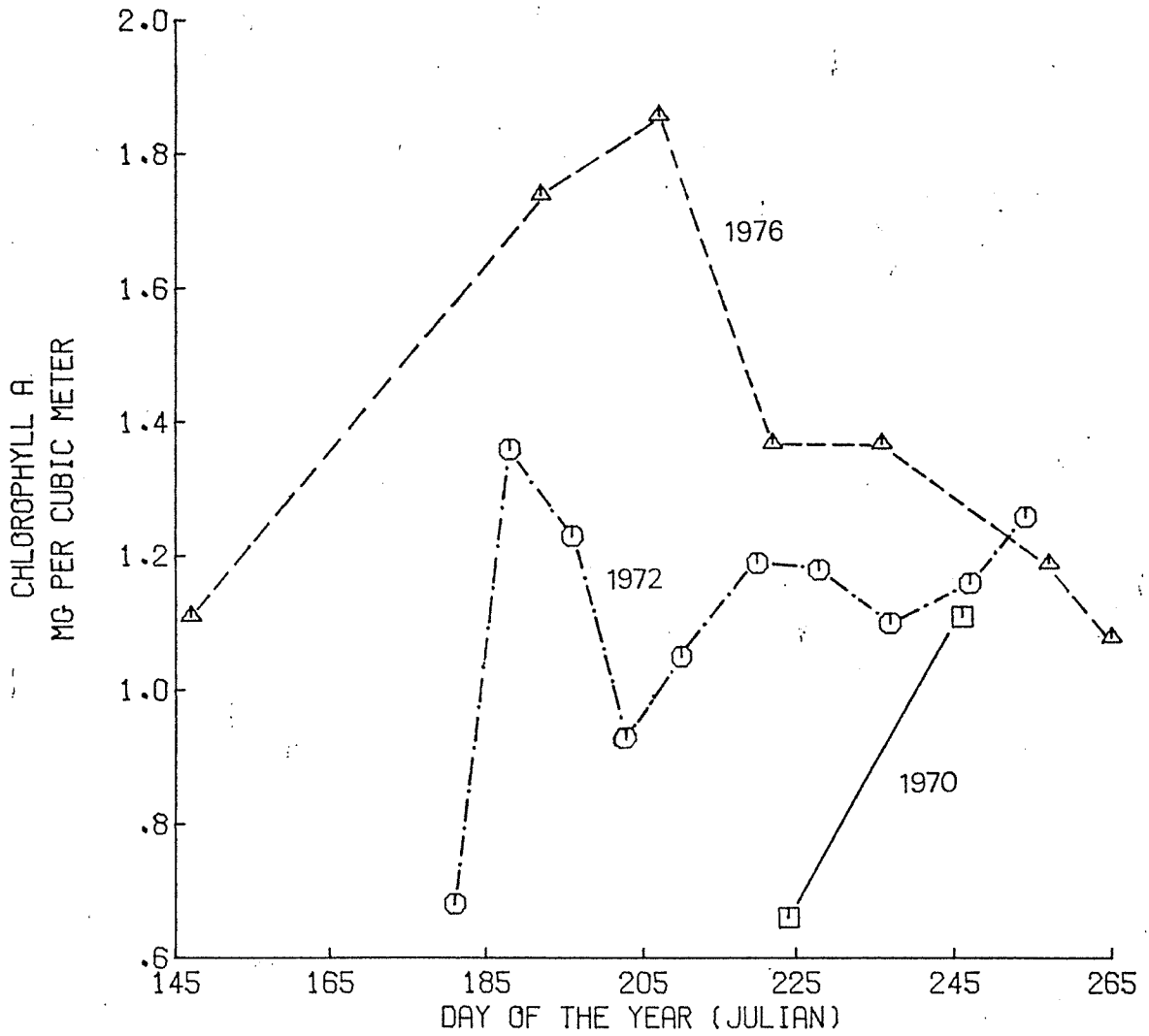


Fig. 14. Mean concentration of chlorophyll a (0-45 m) at Station 149 (Section C), Iliamna Lake, by Julian date.

PHYTOPLANKTON VOLUME- SECTION C  
 POST PEAK CYCLE YEARS- 1966, 1971, 1976

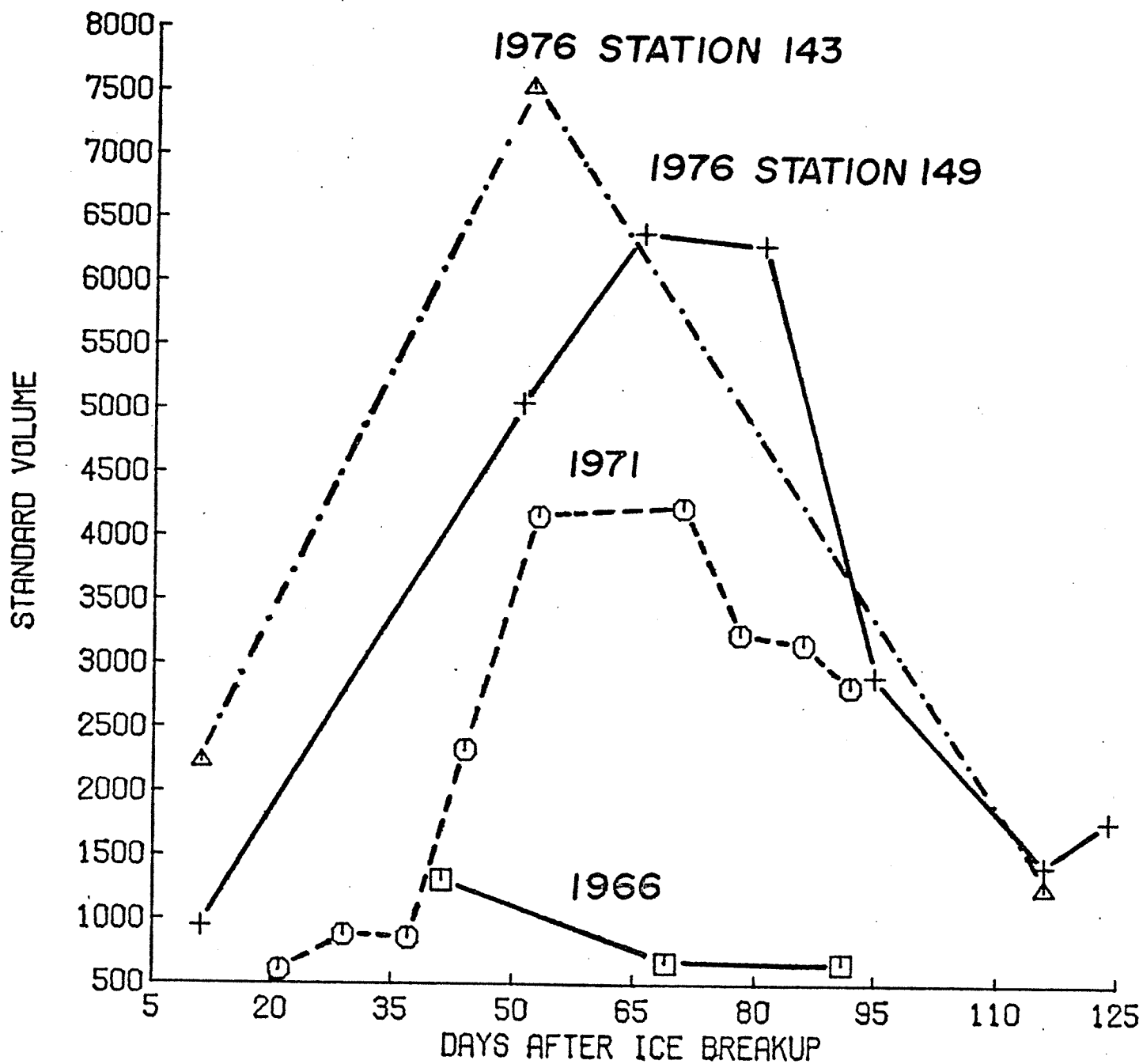


Fig. 15. Total cell volume of phytoplankters per liter collected with a #20 net (mesh aperture 73  $\mu$ ) in the east end of Iliamna Lake in years following a peak<sub>3</sub> year of the sockeye salmon cycle (standard volume equals  $\mu^3 \times \text{liter}^{-1} \times 8000^{-1}$ ).

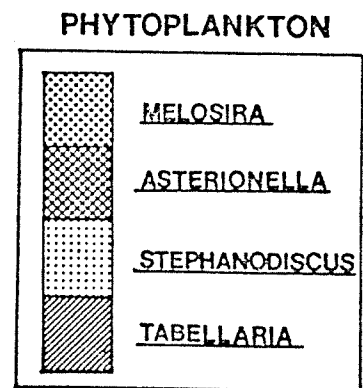
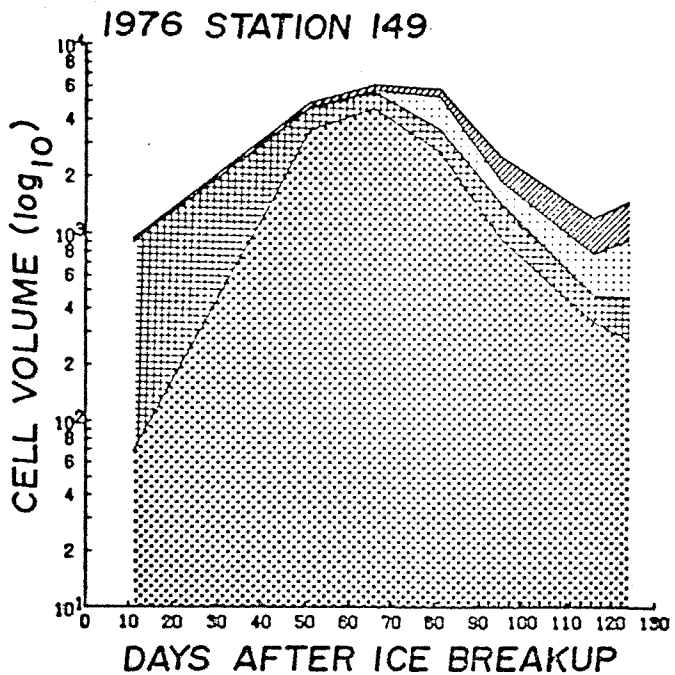
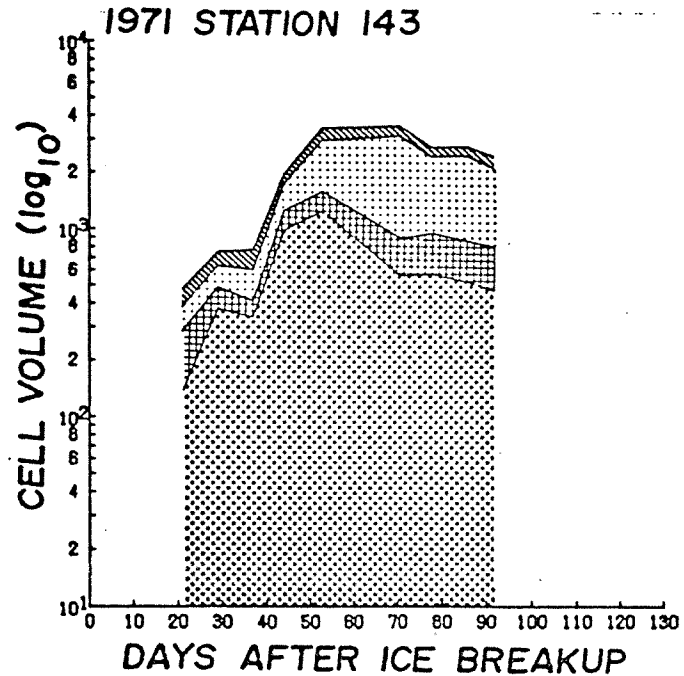
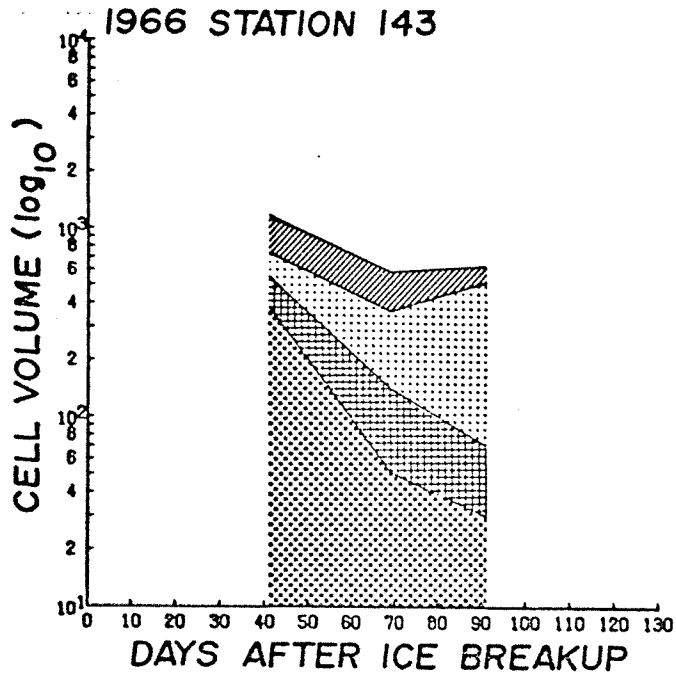


Fig. 16. Abundance of major phytoplankters in samples from the east end of Iliamna Lake in years following a peak year of the sockeye salmon cycle.

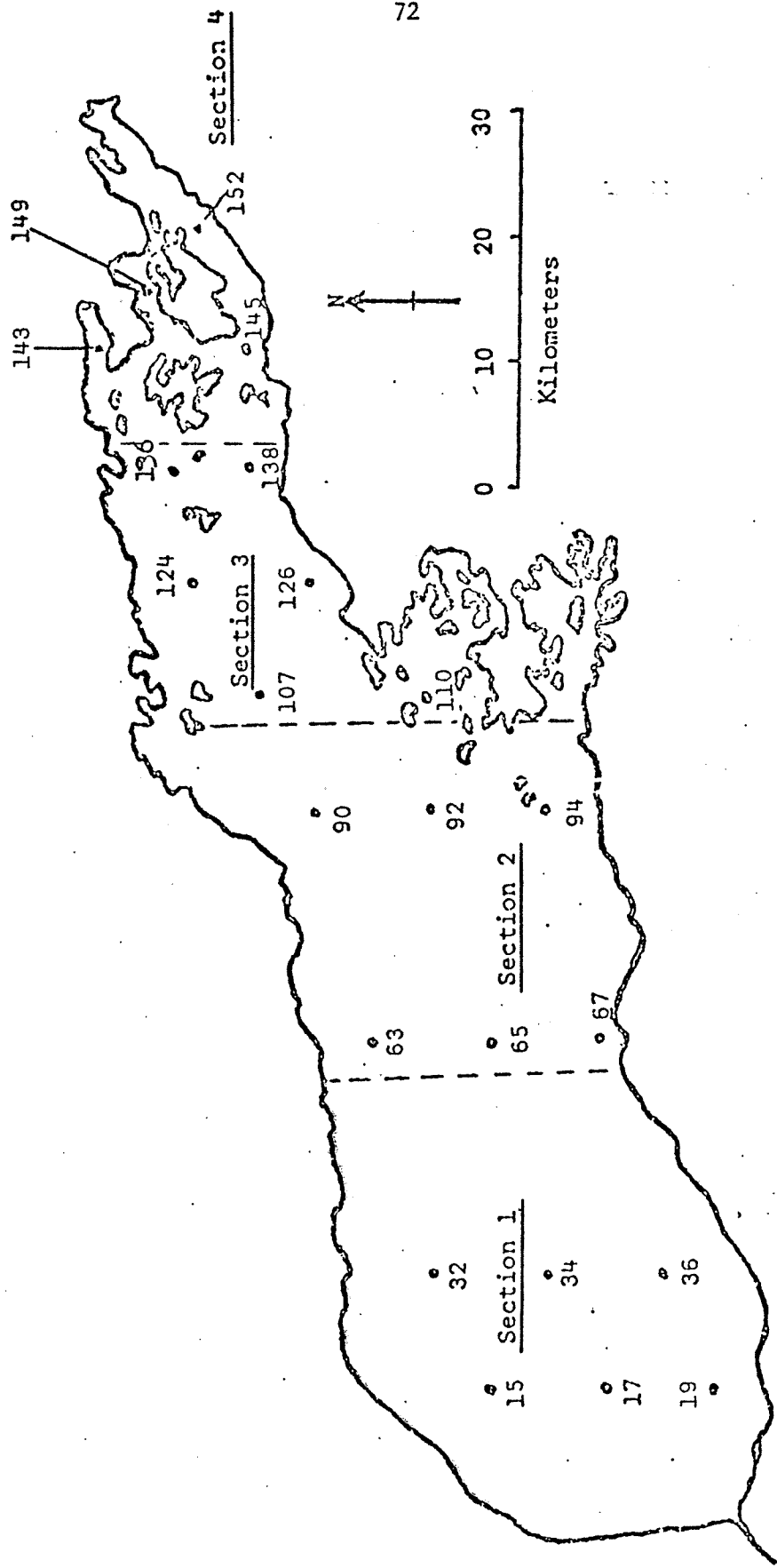
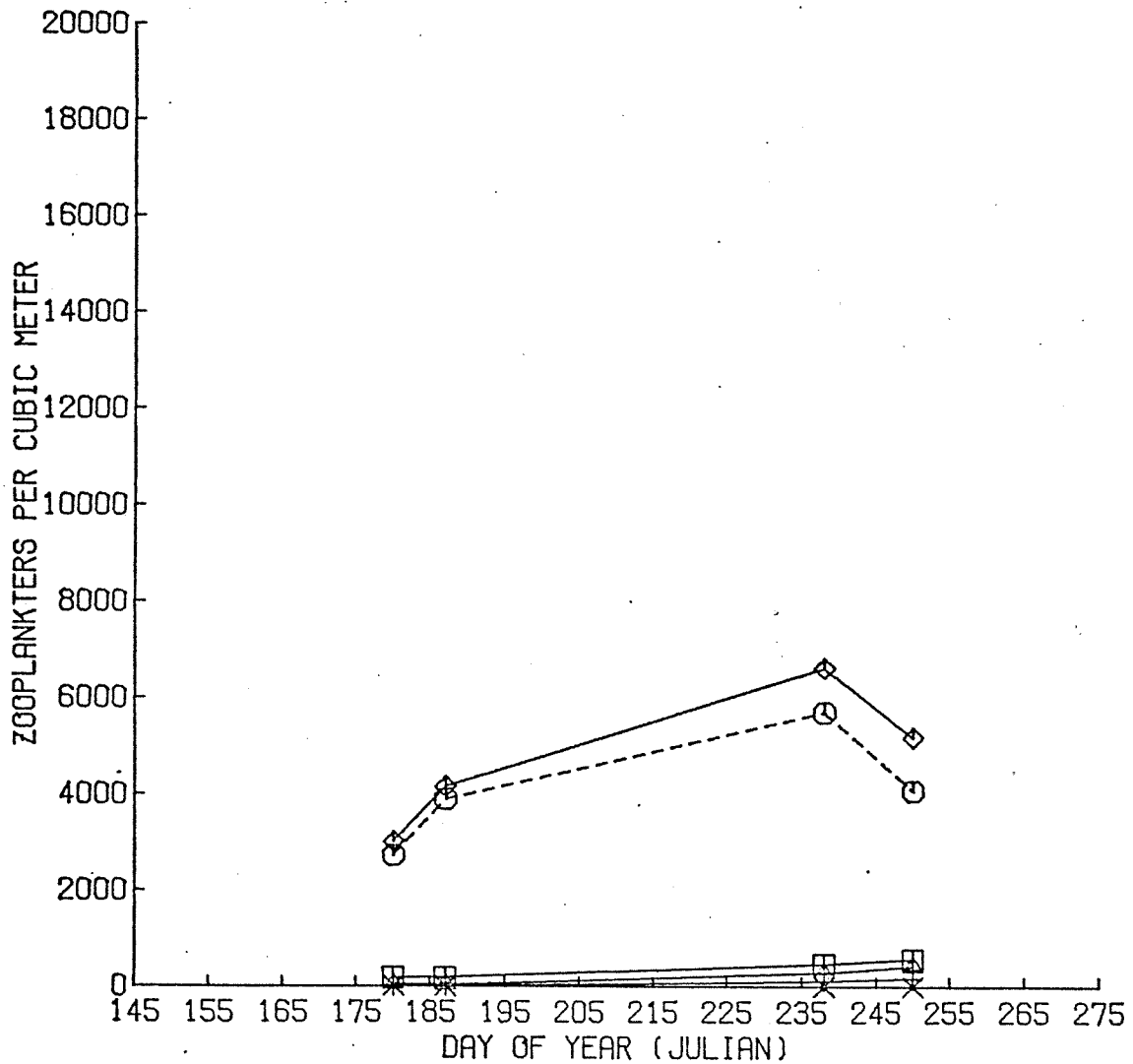


Fig. 17. Map of Iliamna Lake, showing the four limnological lake sections and the distribution of the 22 zooplankton stations sampled in 1976.

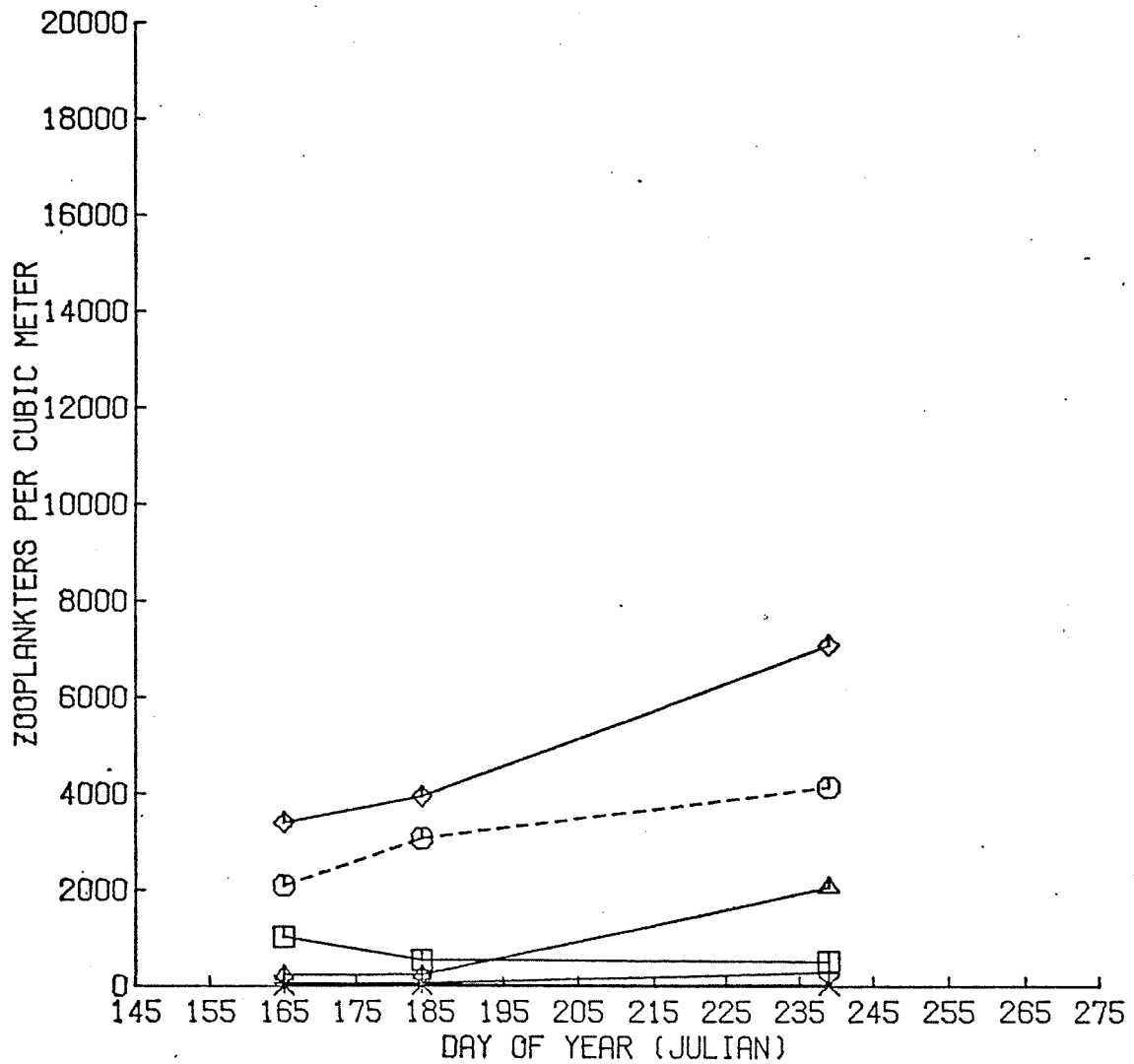
## NO 6 NET ,STATION 149



- |   |      |                     |          |
|---|------|---------------------|----------|
| □ | DATE | VERSUS CALANOIDS    | 4 VALUES |
| ○ | DATE | VERSUS CYCLOPS      | 4 VALUES |
| △ | DATE | VERSUS BOSMINA      | 4 VALUES |
| + | DATE | VERSUS DAPHNIA      | 4 VALUES |
| × | DATE | VERSUS HOLOPEDIDIUM | 4 VALUES |
| ◇ | DATE | VERSUS TZOOPS       | 4 VALUES |

Fig. 18. Seasonal abundance (geometric mean number per  $m^3$ ) of major zooplankter types and total zooplankton at Station 149, Iliamna Lake, 1966, from No. 6 net (223  $\mu$  mesh) sampling.

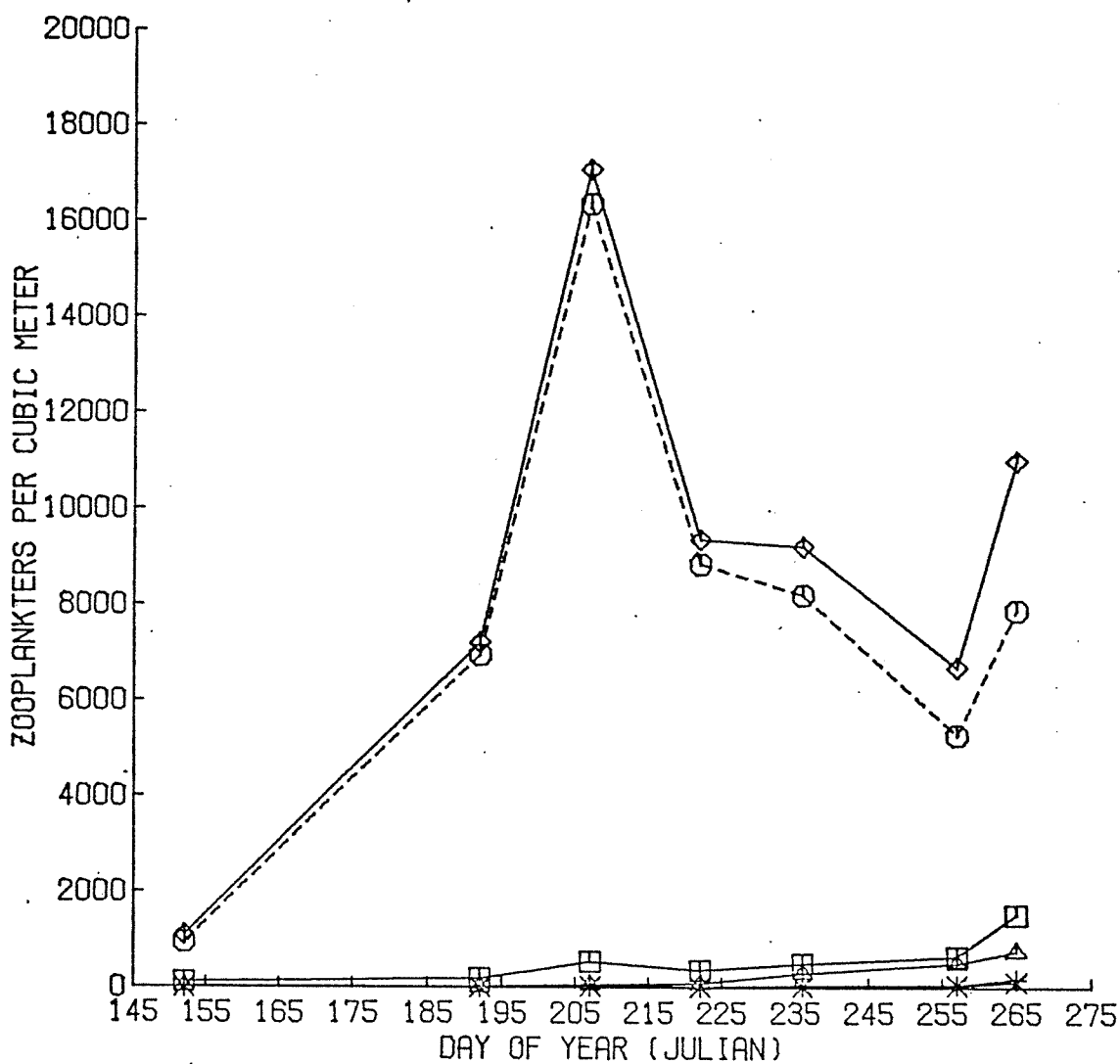
## NO 6 NET ,STATION 149



- DATE VERSUS CALANOIDS 3 VALUES
- ⊙ DATE VERSUS CYCLOPS 3 VALUES
- △ DATE VERSUS BOSMINA 3 VALUES
- + DATE VERSUS DAPHNIA 3 VALUES
- × DATE VERSUS HOLOPEIDIUM 3 VALUES
- ◇ DATE VERSUS TZOOPS 3 VALUES

Fig. 19. Seasonal abundance (geometric mean number per  $m^3$ ) of major zooplankton types and total zooplankton at Station 149, Iliamna Lake, 1971, from No. 6 net (223  $\mu$  mesh) sampling.

## NO 6 NET ,STATION 149



□ DATE VERSUS CALANOIDS      7 VALUES  
 ⊙ DATE VERSUS CYCLOPS      7 VALUES  
 △ DATE VERSUS BOSMINA      7 VALUES  
 + DATE VERSUS DAPHNIA      7 VALUES  
 × DATE VERSUS HOLOPEDIUM      7 VALUES  
 ◇ DATE VERSUS TZOOPLANKTERS      7 VALUES

Fig. 20. Seasonal abundance (geometric mean number per  $m^3$ ) of major zooplankter groups and total zooplankters at Station 149 (Section C), Iliamna Lake, from 1976 No. 6 net (223  $\mu$  mesh) sampling.

## CYCLOPS FECUNDITY ILIAMNA LAKE (1968, 1969, 1970, 1971 AND 1976)

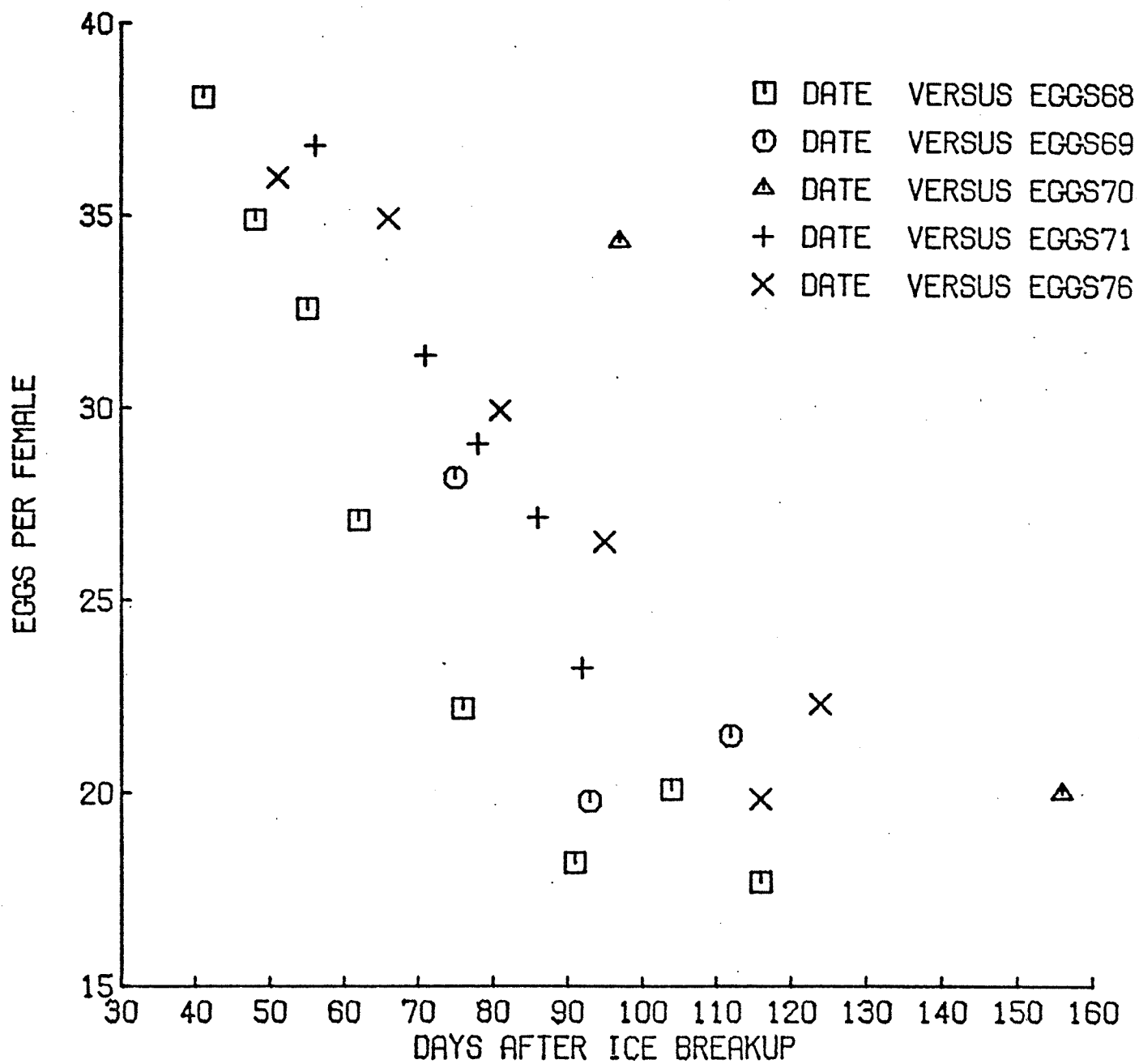


Fig. 21. Fecundity (eggs per female) of *Cyclops scutifer* (Sars) throughout the summer seasons, 1968-1971 and 1976.

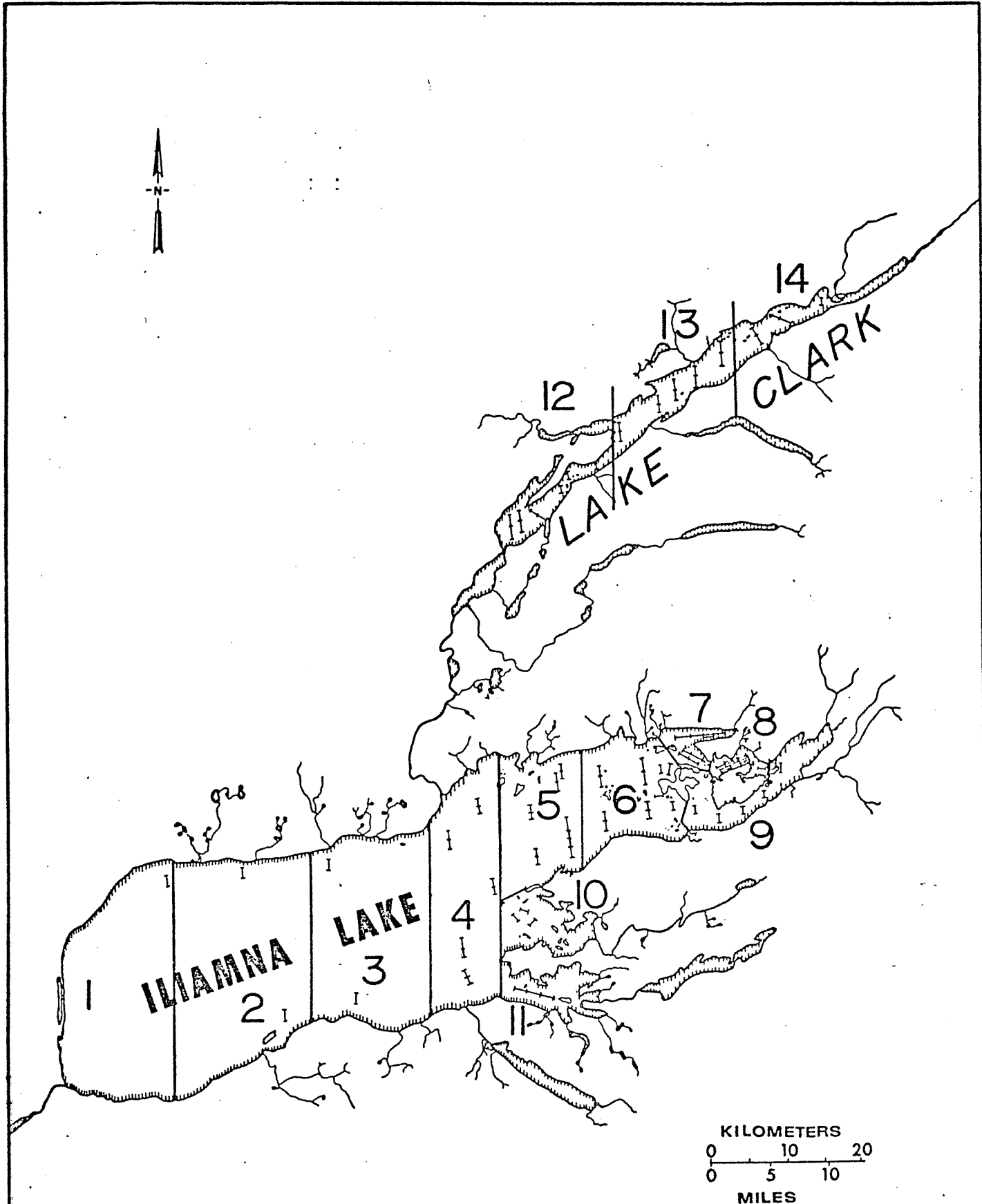


Fig. 22. Distribution of the tow netting programs in Iliamna Lake and Lake Clark, 1976.

DISTRIBUTION OF AGE 0 AND AGE 1 SOCKEYE SALMON  
AND 3-SPINE STICKLEBACKS IN ILIAMNA LAKE, 1976



Fig. 23. The distribution of juvenile sockeye salmon and three-spine sticklebacks in Iliamna Lake in 1976 as determined from townet catches.

DISTRIBUTION OF AGE 0 AND AGE 1 SOCKEYE SALMON  
AND LEAST CISCOS IN LAKE CLARK, 1976

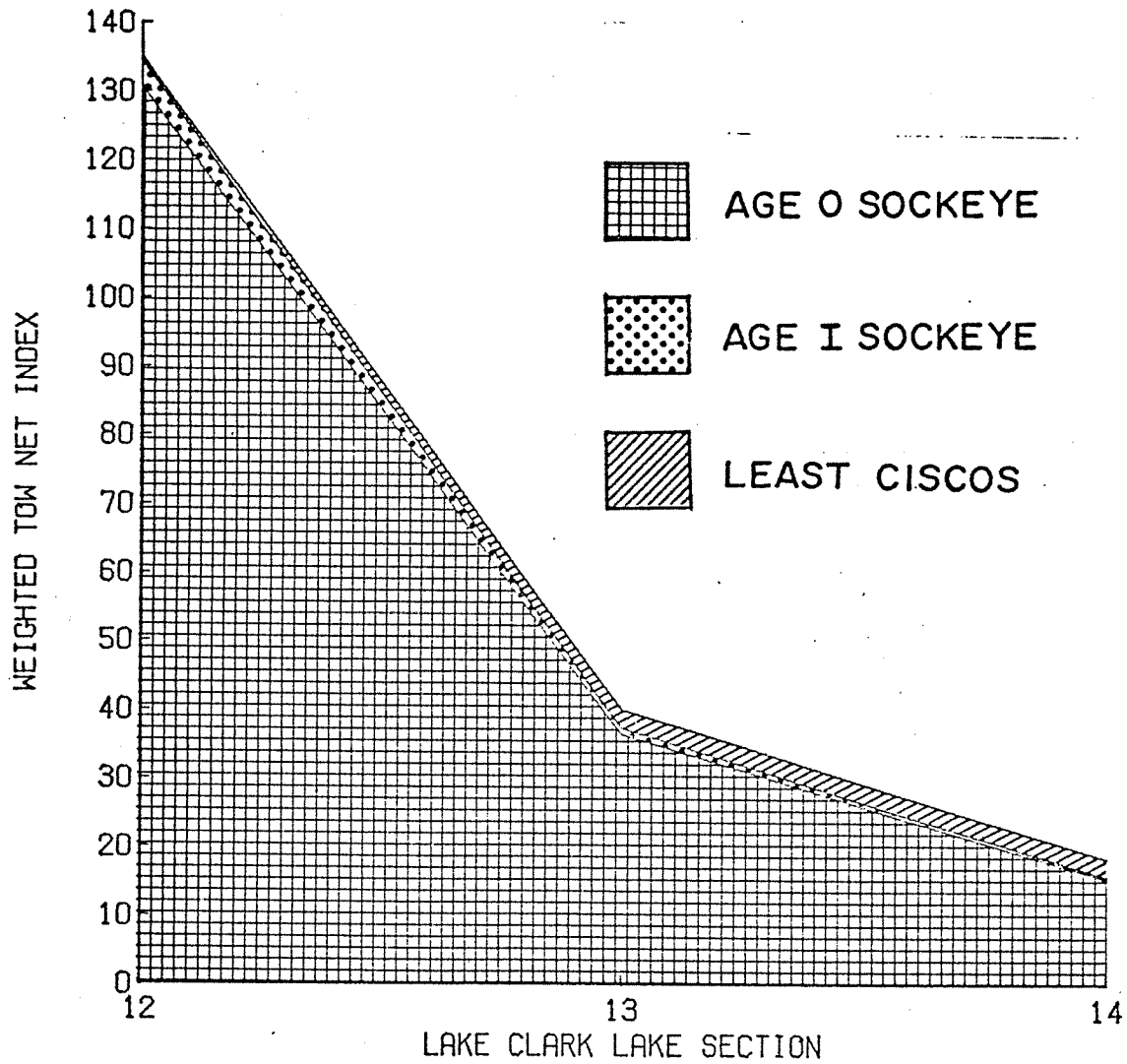


Fig. 24. The distribution of juvenile sockeye salmon and least ciscos in Lake Clark in 1976 as determined from townet catches.

INCREASE IN SIZE OF AGE 0 AND AGE 1 JUVENILE SALMON AND AGE 1  
THREESPINE STICKLEBACKS IN SECTIONS 5-8, ILIAMNA LAKE, 1976

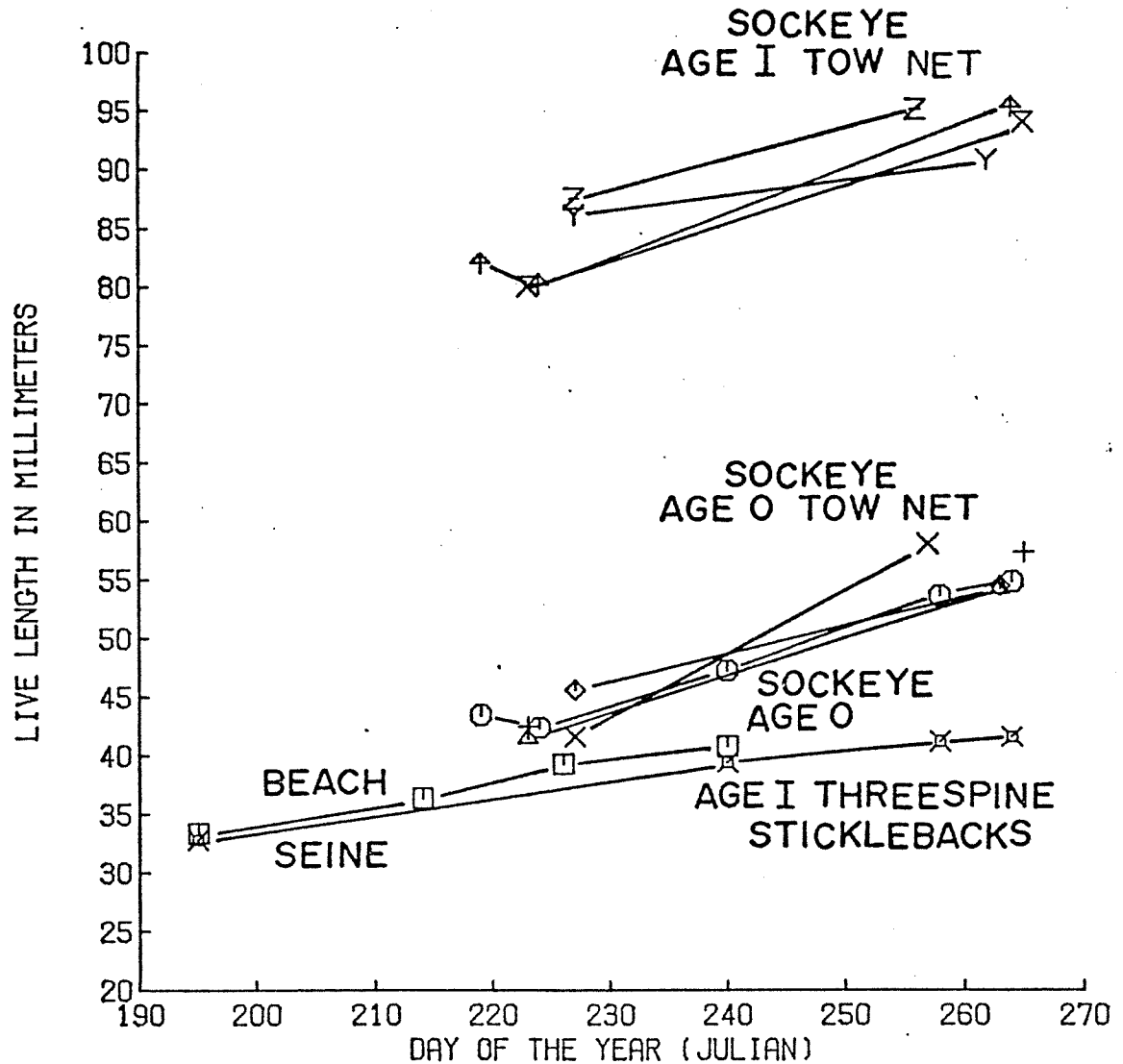


Fig. 25. Increase in length of juvenile sockeye salmon and age I threespine sticklebacks in sections 6-8 in the eastern end of Iliamna Lake, 1976.

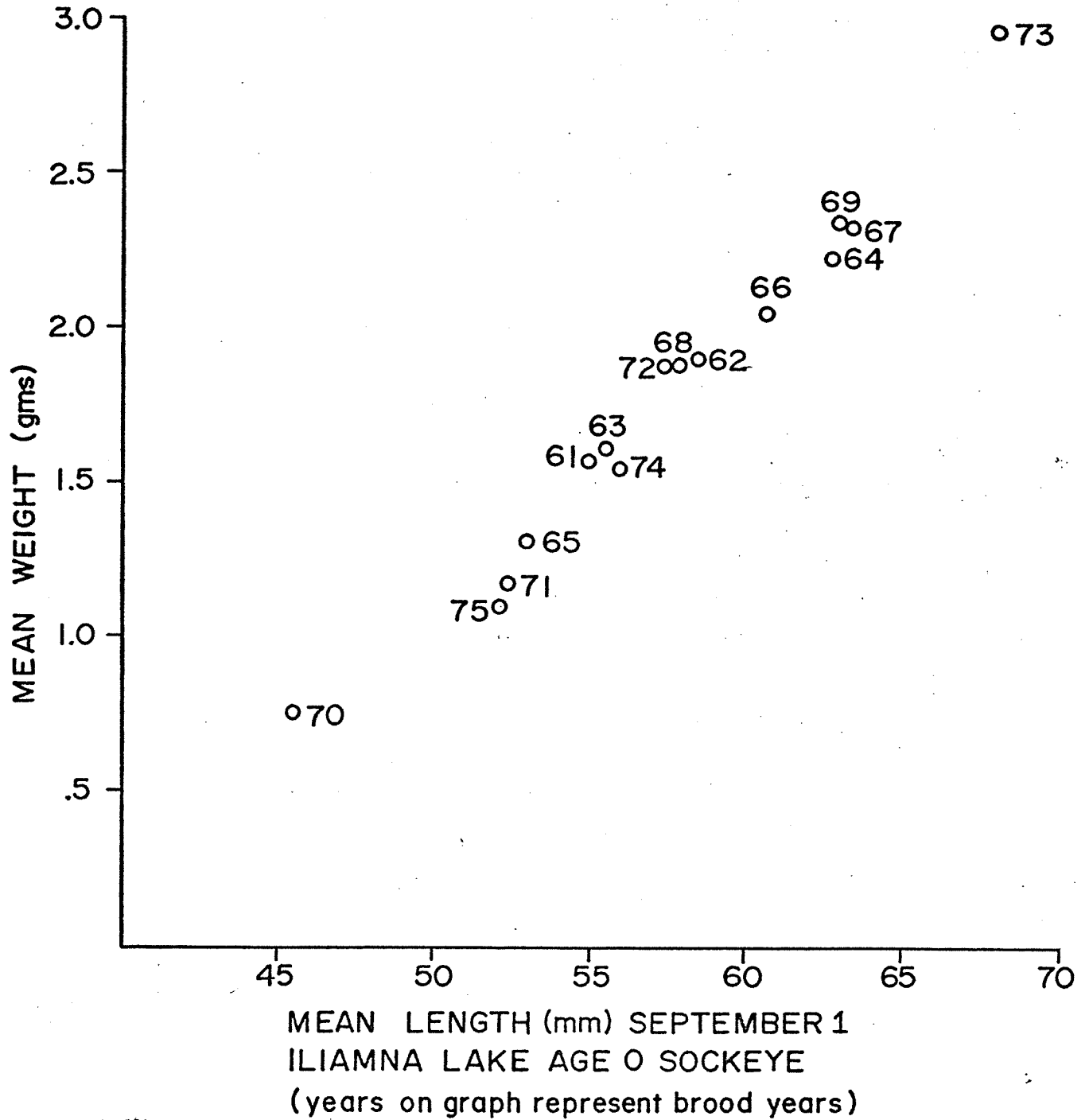


Fig. 26. Weighted mean weight and mean length of Iliamna Lake age 0 sockeye salmon on September 1, from townetting programs, 1962-1976.

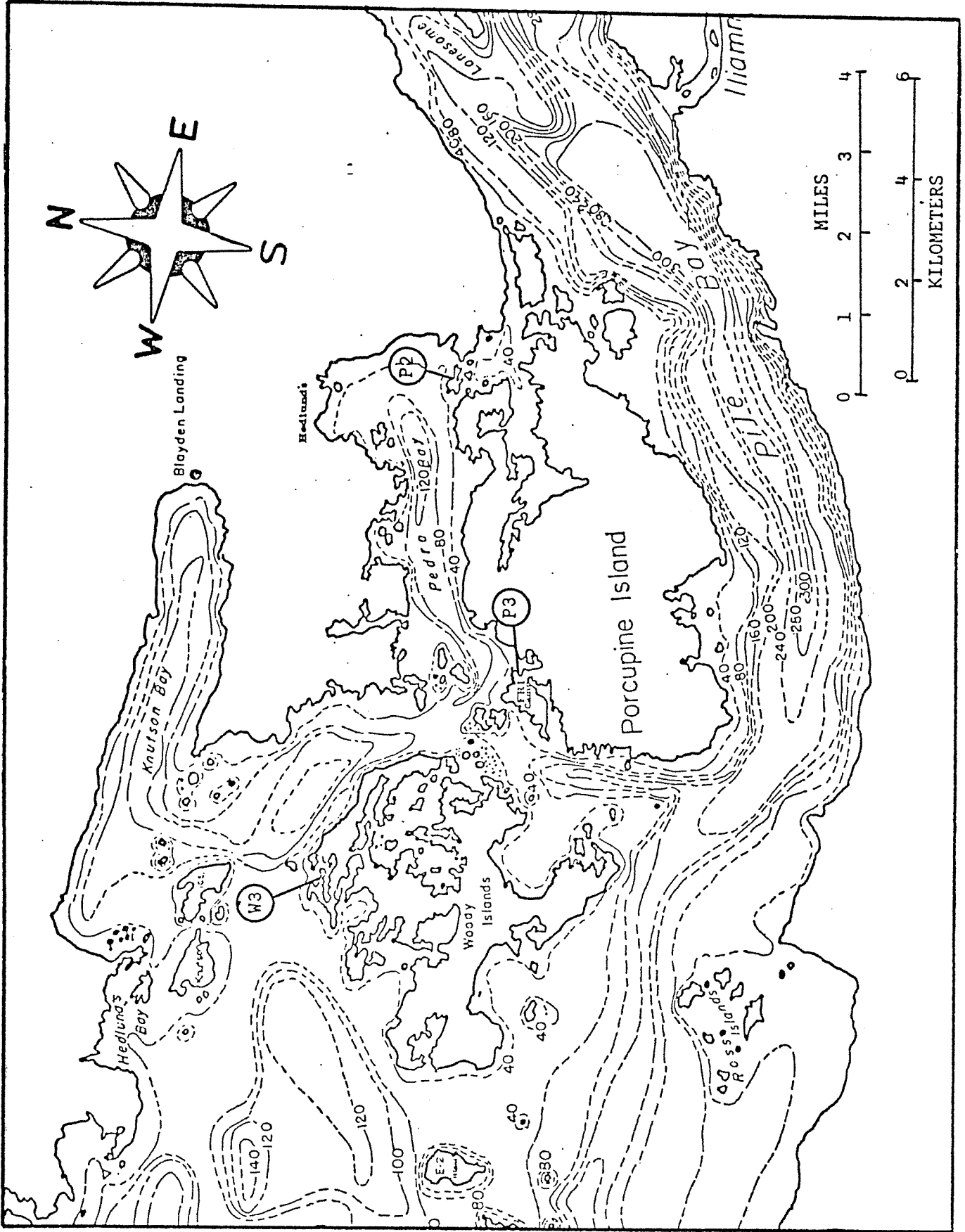
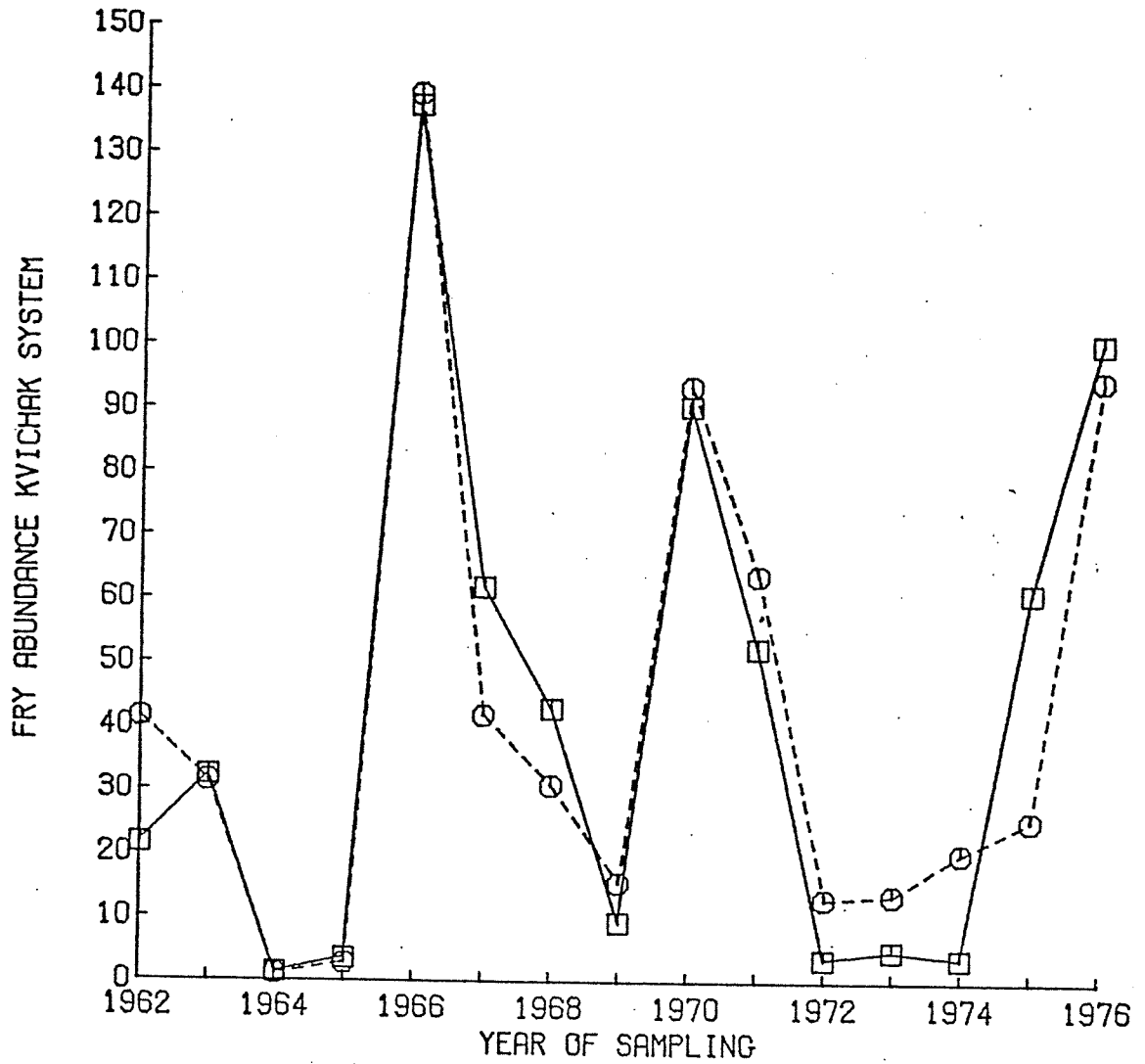


Fig. 27. Beach seine sites during the 1976 field season.

TOW NET INDEX (OBSERVED VERSUS PREDICTED)  $Y = 43.839 + 2.6151(X1) + .00386(X2) - .70664(X3) - 14.803(X4)$   $R = .94$

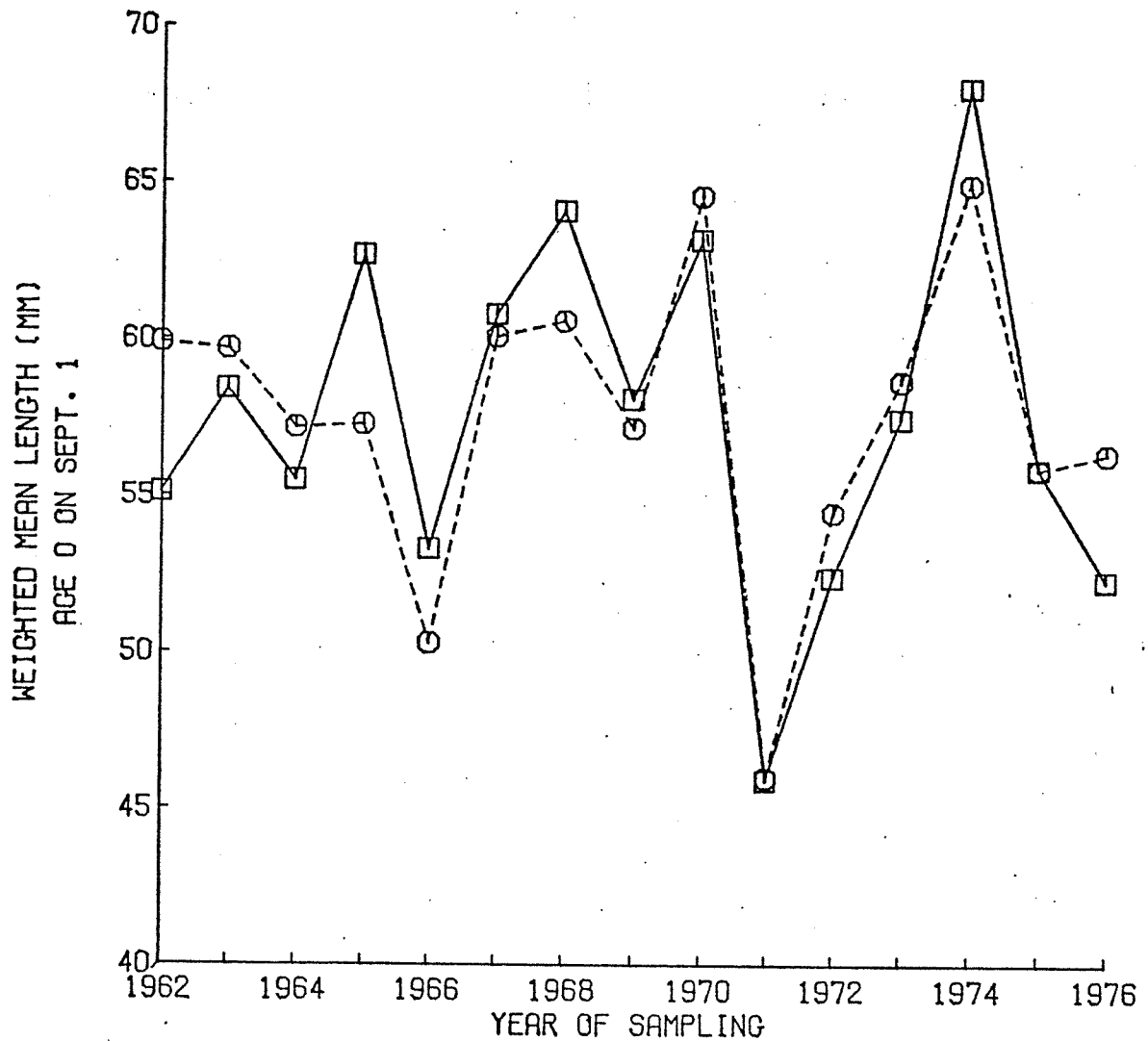


□ YEAR VERSUS OBSERVED  
 ○ YEAR VERSUS PREDICTED

Fig. 28. Observed weighted mean tow net index of juvenile sockeye salmon age 0 for the Kvichak system, 1962-1976, and the predicted relative abundance from multiple regression  $Y = 43.839 + 2.6151(x_1 \text{ Egg deposition year } n-1) + .00386(x_2 \text{ Heat budget}) - .70664(x_3 \text{ Date ice breakup Section C}) - 14.803(x_4 \text{ Fry weight } 9/01)$ .

MEAN LENGTH AGE 0 SEPT. 1 (OBSERVED VERSUS PREDICTED)

$$Y = 53.123 + .00084(X_1) - .09117(X_2) - .13006(X_3) \quad R = .86$$



- YEAR VERSUS OBSERVED  
 ○ YEAR VERSUS PREDICTED

Fig. 29. Observed mean lengths of juvenile sockeye salmon age 0 in Iliamna Lake on September 1, 1962-1976 and the predicted mean lengths from multiple regression  $Y = 55.123 + .00084(x_1 \text{ Heat budget}) - .09117(x_2 \text{ Date ice breakup Section C}) - .13006(x_3 \text{ Egg deposition year } n-1)$ .

RELATIVE ABUNDANCE OF SOCKEYE SALMON AGE 0  
ILIAMNA LAKE AND LAKE CLARK, KVICHAK SYSTEM, 1962-1976

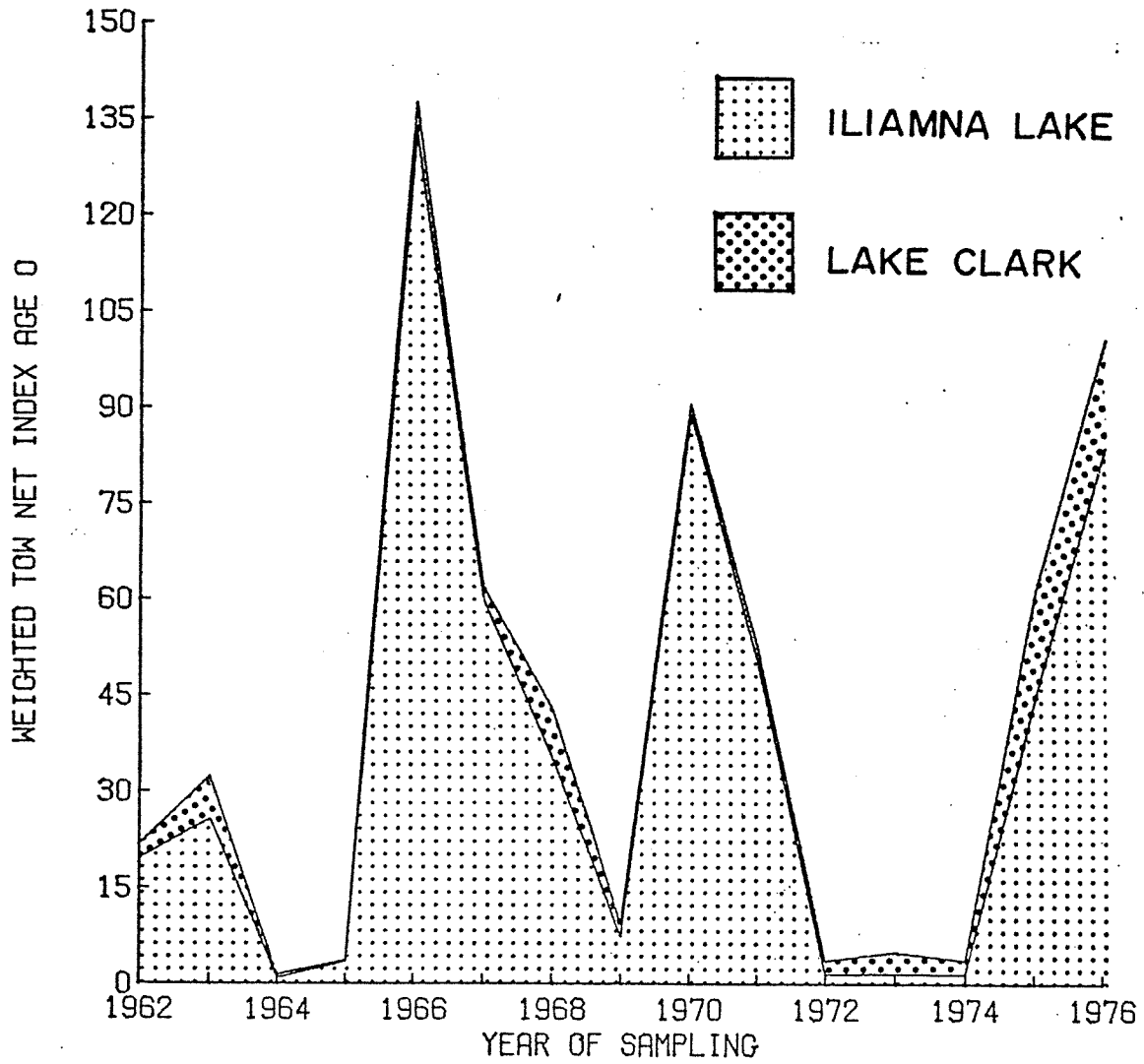


Fig. 30. The relative production of age 0 sockeye salmon in the Kvichak system as measured from tow netting programs in Iliamna Lake and Lake Clark, 1962-1976.

WEIGHTED TOW NET CATCH OF AGE 0 JUVENILE  
SCKEYE SALMON BY LAKE SECTION, 1962-1976

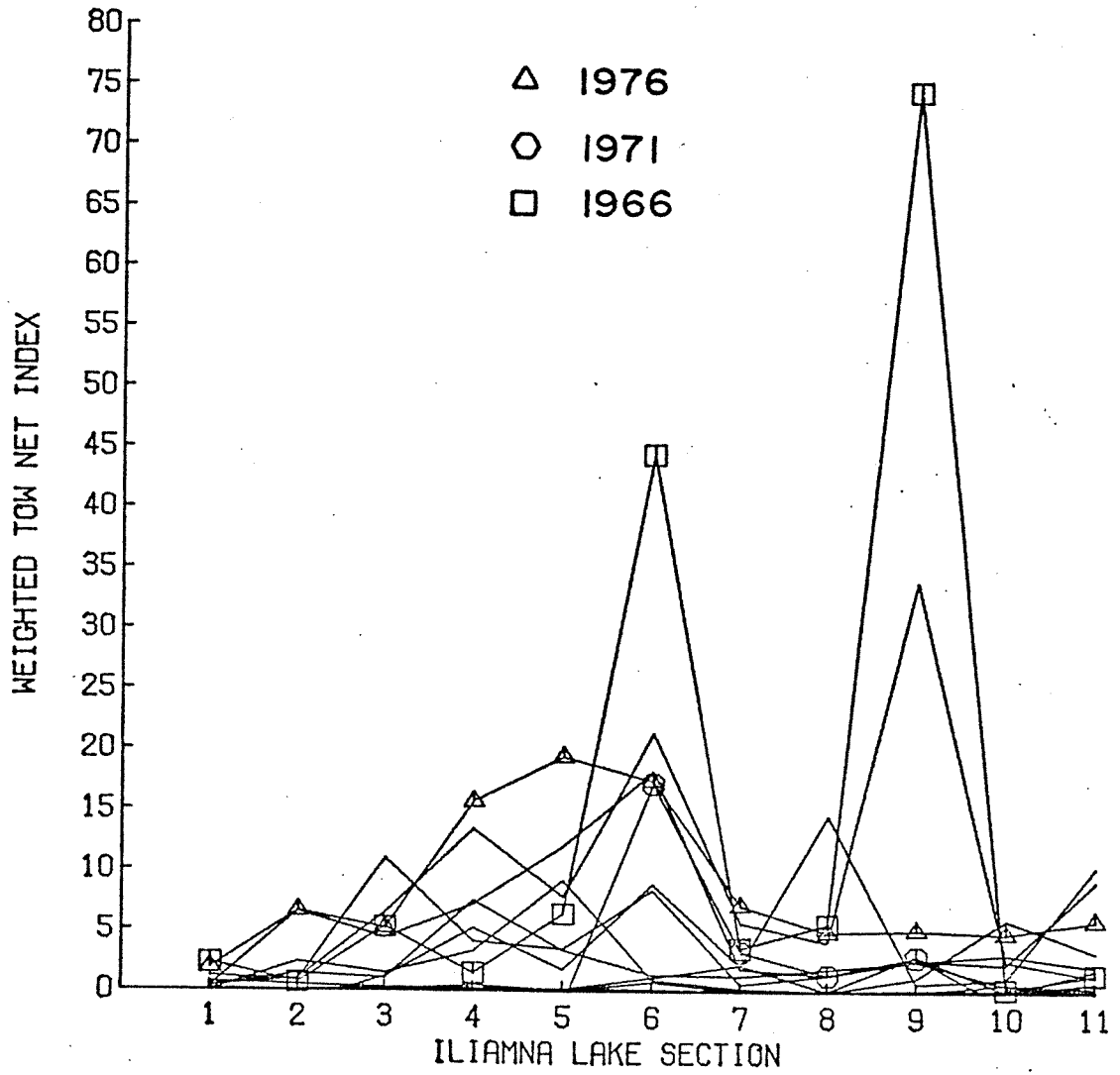


Fig. 31. Distribution of age 0 sockeye salmon in Iliamna Lake, 1962-1976.

WEIGHTED TOW NET CATCH OF AGE 0 JUVENILE  
 SOCKEYE SALMON BY LAKE SECTION, 1962-1976

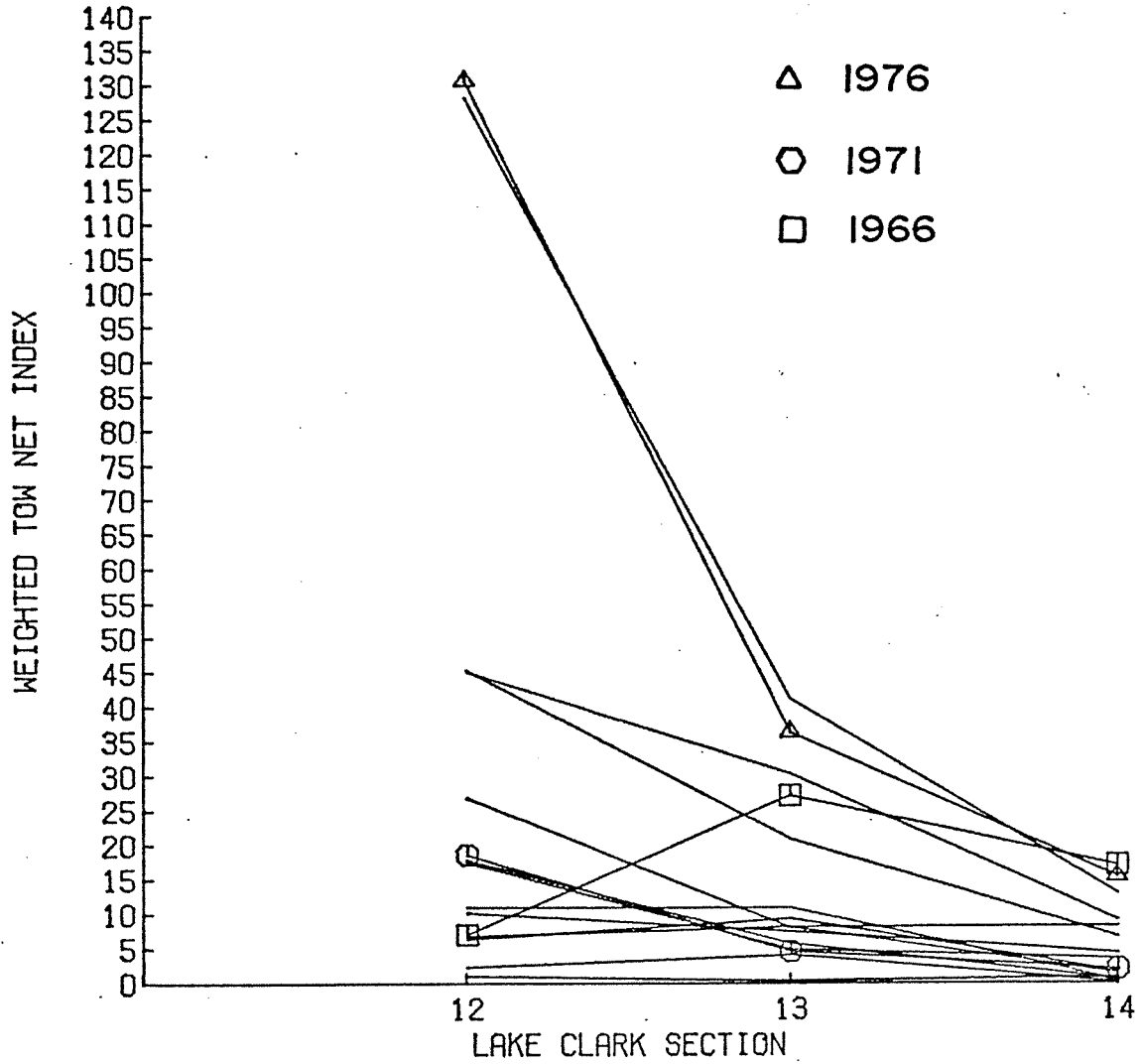


Fig. 32. Distribution of age 0 sockeye salmon in Lake Clark, 1962-1976.

APPENDIX A

## APPENDIX A

Geometric means (number/m<sup>3</sup>) by sampling period and Iliamna Lake section, and weighted lake mean<sup>1</sup>(in number/m<sup>3</sup>) *Cyclops scutifer* Sars, Iliamna Lake, 1963-1975 regional sampling rounds

Lake section	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	<u>JUNE</u>												
1	1,264	5,633	4,371	5,059	3,970	4,678	4,687	4,695	2,167	3,106	*	*	*
2	1,777	4,972	4,044	5,574	3,747	4,039	3,572	4,429	3,194	2,802	*	*	*
3	1,160	2,746	3,101	3,868	3,486	3,613	3,964	6,951	2,492	2,115	*	*	*
4	1,143	632	2,960	3,078	2,746	4,608	2,336	4,378	2,382	2,200	5,023	*	*
Lake mean	1,341	3,866	3,697	4,537	3,592	4,180	3,854	5,284	2,552	2,595	X	*	*
	<u>JULY</u>												
1	2,877	7,857	4,370	6,878	4,188	3,770	4,205	*	*	*	3,924	*	4,563
2	2,520	6,636	3,622	8,227	2,105	2,616	3,941	*	*	*	4,619	*	*
3	2,509	4,610	3,665	4,723	2,585	3,487	3,697	*	3,263	*	2,508	*	*
4	3,672	3,332	2,870	4,018	1,426	2,791	3,182	*	3,140	*	3,416	4,391	5,115
Lake mean	2,787	5,908	3,754	6,138	2,785	3,258	3,837	*	X	*	3,585	X	X
	<u>AUGUST</u>												
1	1,740	4,718	4,602	5,703	2,268	1,540	3,730	2,147	5,196	5,601	2,630	6,490	5,115
2	1,952	4,422	4,292	4,298	744	1,291	2,305	1,750	4,449	5,423	2,545	5,174	4,115
3	904	5,107	2,625	3,328	2,485	1,864	2,733	2,823	3,599	5,526	2,276	5,369	3,249
4	631	2,030	2,508	3,657	1,922	2,642	2,726	2,986	2,941	6,222	2,869	5,741	2,487
Lake mean	1,376	4,385	3,616	4,330	1,910	1,735	2,927	2,377	4,197	5,622	2,533	5,711	3,918
	<u>SEPTEMBER</u>												
1	*	*	*	*	*	*	*	*	*	*	*	3,831	*
2	*	*	*	*	*	*	*	*	*	*	*	2,680	*
3	*	*	*	*	*	*	*	*	2,949	*	1,844	3,035	*
4	*	*	*	*	*	*	*	*	3,014	*	1,903	2,961	4,644
Lake mean	*	*	*	*	*	*	*	*	X	*	X	3,177	X

<sup>1</sup> Section values weighted by the percentage of the total lake volume represented by the section volume.

\* Data not taken.

X Data insufficient for determination of lake mean.

Data source: FRM 298 computer output, Iliamna Lake zooplankton, 1963-1974, 1975 - FRM 347

Notes on methods of sampling: computer output.

- (1) 1963 - Vertical hauls were taken from 30 m to the surface or the bottom to the surface if the station depth was less than 30 m.
- (2) 1964 - Vertical hauls were taken from the bottom to the surface or 40 m to the surface if the station was deeper than 40 m.
- (3) 1965-1975 - Vertical hauls were taken from the bottom to the surface or 100 m to the surface if the station was deeper than 100 m.

## APPENDIX A - Continued

Geometric means (number/m<sup>3</sup>) by sampling period and Iliamna Lake section, and weighted lake mean<sup>1</sup> (in number/m<sup>3</sup>) Calanoid Copepods (*Diaptomus gracilis* Sars and *Eurytemora yukonensis* Wilson), Iliamna Lake, 1963-1975 regional sampling rounds

Lake section	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
<b>JUNE</b>													
1	415	1,263	1,296	1,218	705	329	1,308	823	892	837	*	*	*
2	620	956	964	1,116	519	1,216	942	730	998	749	*	*	*
3	436	1,143	722	846	347	421	481	1,016	650	440	*	*	*
4	495	176	778	725	178	545	231	688	338	155	686	*	*
Lake mean	484	996	963	1,008	473	607	809	841	765	596	X	*	*
<b>JULY</b>													
1	1,086	1,405	957	740	557	1,272	1,058	*	*	*	1,171	*	609
2	776	1,201	806	828	777	935	1,174	*	*	*	1,392	*	*
3	944	966	656	409	719	623	568	*	728	*	921	*	*
4	1,244	468	568	650	334	280	489	*	420	*	539	782	448
Lake mean	988	1,086	771	646	630	847	854	*	X	*	1,059	X	X
<b>AUGUST</b>													
1	612	673	1,064	951	1,415	890	800	1,005	1,111	990	733	1,148	1,150
2	744	927	869	680	1,077	806	921	1,179	759	063	769	1,169	732
3	546	1,266	500	469	1,377	907	859	1,053	509	631	579	768	612
4	996	521	389	403	868	646	749	780	395	526	917	677	389
Lake mean	679	898	745	657	1,242	840	841	1,031	736	806	720	969	772
<b>SEPTEMBER</b>													
1	*	*	*	*	*	*	*	*	*	*	*	1,016	*
2	*	*	*	*	*	*	*	*	*	*	*	952	*
3	*	*	*	*	*	*	*	*	454	*	791	803	*
4	*	*	*	*	*	*	*	*	619	*	639	508	965
Lake mean	*	*	*	*	*	*	*	*	X	*	X	862	X

<sup>1</sup> Section values weighted by the percentage of the total lake volume represented by the section volume.

\* Data not taken.

X Data insufficient for determination of lake mean.

Data source: FRM 298 computer output, Iliamna Lake zooplankton, 1963-1974, 1975 data from FRM 347 computer output.

Notes on methods of sampling:

- (1) 1963 - Vertical hauls were taken from 30 m to the surface or the bottom to the surface if the station depth was less than 30 m.
- (2) 1964 - Vertical hauls were taken from the bottom to the surface or 40 m to the surface if the station was deeper than 40 m.
- (3) 1965-1975 - Vertical hauls were taken from the bottom to the surface or 100 m to the surface if the station was deeper than 100 m.

## APPENDIX A - Continued

Geometric means (number/m<sup>3</sup>) by sampling period and Iliamna Lake section, and weighted lake mean (in number/m<sup>3</sup>) *Bosmina coregoni*, Iliamna Lake, 1963-1975

Lake section	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
<u>JUNE</u>													
1	168	275	454	731	296	392	160	533	119	439	*	*	*
2	191	204	279	535	139	392	128	396	195	309	*	*	*
3	119	93	275	307	38	94	57	359	80	167	*	*	*
4	23	11	224	232	21	106	27	61	56	69	189	*	*
Lake mean	138	164	323	480	138	259	101	378	117	270	X	*	*
<u>JULY</u>													
1	2,913	749	1,240	2,946	2,030	3,907	1,186	*	*	*	2,497	*	1,107
2	1,603	577	1,103	3,194	1,701	2,610	1,158	*	*	*	4,492	*	*
3	768	213	743	1,100	390	694	395	*	142	*	853	*	*
4	112	76	587	874	42	231	195	*	160	*	585	361	319
Lake mean	1,528	445	960	2,142	1,174	2,070	794	*	X	*	2,210	X	X
<u>AUGUST</u>													
1	3,012	2,810	4,033	5,014	2,936	3,934	4,357	6,021	1,361	5,520	5,874	4,216	8,011
2	4,525	1,707	3,026	4,303	2,950	4,698	3,070	6,618	877	7,256	4,624	5,790	3,968
3	2,819	823	2,187	2,680	1,760	4,077	1,745	5,088	399	1,686	3,179	3,470	2,359
4	821	103	1,009	1,424	897	1,945	659	2,021	342	699	3,178	1,897	869
Lake mean	3,016	1,538	2,784	3,606	2,286	3,886	2,705	5,313	799	4,078	4,348	4,045	4,248
<u>SEPTEMBER</u>													
1	*	*	*	*	*	*	*	*	*	*	*	4,136	*
2	*	*	*	*	*	*	*	*	*	*	*	3,404	*
3	*	*	*	*	*	*	*	*	1,004	*	3,933	3,263	*
4	*	*	*	*	*	*	*	*	666	*	3,631	2,041	2,971
Lake mean	*	*	*	*	*	*	*	*	X	*	X	3,388	X

<sup>1</sup>Section values weighted by the percentage of the total lake volume represented by the section volume.

\* Data not taken.

X Data insufficient for determination of lake mean.

Data source: FRM 298 computer output, Iliamna Lake zooplankton, 1963-1974, 1975 - FRR 347 computer output.

Notes on methods of sampling:

- (1) 1963 - Vertical hauls were taken from 30 m to the surface or the bottom to the surface if the station depth was less than 30 m.
- (2) 1964 - Vertical hauls were taken from the bottom to the surface or 40 m to the surface if the station was deeper than 40 m.
- (3) 1965-1975 - Vertical hauls were taken from the bottom to the surface or 100 m to the surface if the station was deeper than 100 m.

## APPENDIX A - Continued

Geometric means (number/m<sup>3</sup>) by sampling period and Iliamna Lake section, and weighted lake mean<sup>1</sup> (in number/m<sup>3</sup>) *Holopedium gibberum* Zaddach, Iliamna Lake, 1963-1975 regional sampling rounds

Lake section	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	<u>JUNE</u>												
1	0	2	393	4	280	34	299	386	2	362	*	*	*
2	0	1	77	38	192	142	266	196	3	199	*	*	*
3	3	0	42	8	81	9	97	114	1	2	*	*	*
4	0	0	1	7	9	1	9	17	1	1	0	*	*
Lake mean	1	1	151	14	158	48	187	202	2	159	X	*	*
	<u>JULY</u>												
1	341	240	13	135	427	634	1,172	*	*	*	590	*	138
2	129	37	26	200	1,013	938	1,029	*	*	*	597	*	*
3	85	4	11	44	161	177	152	*	10	*	52	*	*
4	11	5	11	26	15	6	81	*	5	*	14	139	3
Lake mean	163	83	15	107	431	479	666	*	X	*	343	X	X
	<u>AUGUST</u>												
1	697	244	276	641	730	811	1,272	588	207	1,197	1,487	1,248	320
2	564	241	207	407	545	376	799	502	146	1,544	1,453	1,967	595
3	603	208	105	95	285	330	221	281	44	338	350	978	277
4	53	33	110	37	211	136	86	77	8	23	331	410	110
Lake mean	544	202	182	328	473	459	661	399	113	850	962	1,223	345
	<u>SEPTEMBER</u>												
1	*	*	*	*	*	*	*	*	*	*	*	128	*
2	*	*	*	*	*	*	*	*	*	*	*	41	*
3	*	*	*	*	*	*	*	*	*	*	196	32	*
4	*	*	*	*	*	*	*	*	55	*	151	14	48
Lake mean	*	*	*	*	*	*	*	*	X	*	X	61	X

<sup>1</sup> Section values weighted by the percentage of the total lake volume represented by the section volume.

\* Data not taken.

X Data insufficient for determination of lake mean.

Data sources: FRM 298 computer output, Iliamna Lake zooplankton, 1963-1974, 1975 - FRM 347 computer output.

Notes on methods of sampling:

- (1) 1963 - Vertical hauls were taken from 30 m to the surface or the bottom to the surface if the station depth was less than 30 m.
- (2) 1964 - Vertical hauls were taken from the bottom to the surface or 40 m to the surface if the station was deeper than 40 m.
- (3) 1965-1975 - Vertical hauls were taken from the bottom to the surface or 100 m to the surface if the station was deeper than 100 m.

## APPENDIX A - Continued

Geometric means (number/m<sup>3</sup>) by sampling period and Iliamna Lake section, and weighted lake mean<sup>1</sup> (in number/m<sup>3</sup>) *Daphnia longiremis* Sars, Iliamna Lake, 1963-1975

Lake section	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	<u>JUNE</u>												
1	41	20	300	135	83	92	19	34	91	24	*	*	*
2	68	13	233	158	69	147	20	60	43	2	*	*	*
3	62	2	143	106	30	40	11	111	49	3	*	*	*
4	41	2	112	53	4	19	10	55	18	2	106	*	*
Lake mean	54	10	208	120	52	79	15	68	56	9	X	*	*
	<u>JULY</u>												
1	339	176	353	391	252	689	143	*	*	*	738	*	65
2	216	110	264	437	469	769	182	*	*	*	1,031	*	*
3	413	54	229	190	148	234	50	*	60	*	289	*	*
4	103	3	124	140	23	74	64	*	17	*	216	602	37
Lake mean	298	97	260	305	241	481	113	*	X	*	597	X	X
	<u>AUGUST</u>												
1	724	214	890	931	886	1,132	263	295	565	353	1,304	1,355	1,745
2	640	220	1,085	752	915	868	236	432	507	300	1,285	1,646	1,369
3	1,259	232	429	371	509	743	217	614	159	90	550	879	381
4	760	17	253	221	380	402	167	327	124	41	820	936	178
Lake mean	874	193	705	613	705	843	228	432	362	214	997	1,220	1,007
	<u>SEPTEMBER</u>												
1	*	*	*	*	*	*	*	*	*	*	*	1,172	*
2	*	*	*	*	*	*	*	*	*	*	*	1,181	*
3	*	*	*	*	*	*	*	*	226	*	962	548	*
4	*	*	*	*	*	*	*	*	252	*	719	440	736
Lake mean	*	*	*	*	*	*	*	*	X	*	X	877	X

<sup>1</sup>Section values weighted by the percentage of the total lake volume represented by the section volume.

\* Data not taken.

X Data insufficient for determination of lake mean.

Data source: FRM 298 computer output, Iliamna Lake zooplankton, 1963-1974, 1975 - FRR 347 computer output.

Notes on methods of sampling:

- (1) 1963 - Vertical hauls were taken from 30 m to the surface or the bottom to the surface if the station depth was less than 30 m.
- (2) 1964 - Vertical hauls were taken from the bottom to the surface or 40 m to the surface if the station was deeper than 40 m.
- (3) 1965-1975 - Vertical hauls were taken from the bottom to the surface or 100 m to the surface if the station was deeper than 100 m.