AN ABSTRACT OF THE THESIS OF

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Title Distribution of Kokanee (Oncorhynchus nerka) Fingerlings in Summer as Related to some Environmental Factors

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Natural populations of kokanee fingerlings were studied in Odell Lake, Oregon from June 1962 to September 1963. Vertical and horizontal distributions were determined in relation to temperature, zooplankton, and light during the summer of 1963. Food habits of the fingerlings were also examined.

A mid-water townet was employed for sampling the fish. Vertical series of temperatures and plankton samples were taken in conjunction with each fishing effort.

Diaptomus was taken selectively by the kokanee. *Daphnia* was taken in proportion to relative abundance. *Cyclops* was taken least in relation to relative abundance.

The fingerlings showed a disproportionate horizontal distribution with the greatest density being at the west end of the lake. This distribution appeared to be associated with the principal known spawning area, greater zooplankton numbers, and slightly lower temperatures. Currents resulting from wind action might have influenced

the horizontal distribution.

The vertical distribution of kokanee became more restricted as the summer progressed. When surface temperatures rose, the kokanee began to associate with the thermocline at about 60 feet. The mean of the temperatures found at the modes of vertical distribution was 11.1 C. A multiple regression analysis indicates there was a positive correlation with Diaptomus and with time, and a negative correlation with the product of temperature and time. The numbers of kokanee caught at the surface during August and September were positively correlated with moonlight.

DISTRIBUTION OF KOKANEE (<u>ONCORHYNCHUS NERKA</u>) FINGERLINGS IN SUMMER AS RELATED TO SOME ENVIRONMENTAL FACTORS

by

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DISTRIBUTION OF KOKANEE (ONCORHYNCHUS NERKA) FINGERLINGS IN SUMMER AS RELATED TO SOME ENVIRONMENTAL FACTORS

INTRODUCTION

Kokanee, Oncorhynchus nerka (Walbaum), are identical to the anadromous form of sockeye salmon except that they are smaller and can complete their life cycle in fresh water. Kokanee are native to lakes from Oregon to northwestern Alaska and in eastern Siberia and northern Japan.

In recent years kokanee have been introduced widely, both within and outside their native range, filling a niche in cool deep lakes not normally used by other fishes. Kokanee are pelagic in habit and usually feed on planktonic crustacea.

Although anadromous sockeye have been studied intensively, little research has been done on kokanee. Theories on the origin of kokanee were published by Ricker (29; 30; 31). Vernon (36) wrote on three distinct races of kokanee within Kootenay Lake, British Columbia. Stross (33), and Jeppson (17; 18) discussed age, growth and food habits of kokanee in Lake Pend Oreille, Idaho. Lorz (24) studied the distribution and spawning migration of maturing kokanee in Nicola Lake, British Columbia. A review of data on kokanee in California was completed by Seeley and McCammon (32).

The objective of my work was to determine the spatial distribution of kokanee of the year in relation to some environmental factors. The factors considered were temperature, zooplankton, and light. The study was conducted from June 1962 to September 1963 in Odell Lake, Oregon. The data presented in this thesis were gathered in the summer of 1963. The periodic work done in 1962 was largely of exploratory nature.

DESCRIPTION OF STUDY AREA

Odell Lake lies just east of the summit of the Cascade Range at an elevation of 4788 feet. It has 3300 surface acres, and is slightly over five miles long and a mile wide. The long axis lies west-east, the direction of prevailing winds. The lake is paralleled on the north by Oregon Highway 58. The watershed of 39 square miles is in old growth coniferous timber. Odell Creek, the outlet, has a mean annual flow of 82 cubic feet per second, equivalent to 59,370 acre feet per year (35, p. 55). The ten-year average monthly discharge from Odell Lake is shown in Appendix A. Odell Lake is mostly steep-sided with relatively little shallow area. The lake stratifies thermally in the summer with the top of the thermocline near 50 feet. Dissolved oxygen concentrations remained above 8.5 ppm throughout the year. The lake fits the oligotrophic classification.

The lake supports a good population of zooplankton. The most prominent species in summer are the cladoceran, Daphnia longispina (O. F. Muller) and the copepods Cyclops bicuspidatus thomasi Claus, and Diaptomus franciscanus Lilljeborg.

The origin of kokanee in Odell Lake is uncertain. In a survey of Central Oregon lakes, Newcomb (25, p. 106) explained that kokanee had been in Wallowa, Suttle, and Odell lakes for many years and were possibly native, but added that this theory was disputed by some people.

Although no prior stocking records are available, Newcomb (25, p. 189) found kokanee in Odell Lake in 1940. Since then annual introductions of fry or fingerlings have been made ranging from 70,000 in 1956 to 600,000 in 1960 for an average of 345,000 salmon yearly.[1]

Length-frequency distributions and scale analysis show that kokanee in Odell Lake have a four year life cycle. Length at maturity in 1963 was about 340 mm. The known spawning areas are a beach area at the west end and the outlet, Odell Creek. Kokanee spawned in Trapper Creek in 1963, apparently for the first time. Spawning continues from September to January.

Trawl samples have indicated there is significant natural contribution to the kokanee population. By relating townet catches to the lake volume in the stratum shallower than 100 feet, I estimated there were in excess of a million kokanee fry in the lake in 1963. Including hatchery fish, which are somewhat larger than natural fish of the year, there were five size groups present in lake.

Other fish found in the lake are: lake trout, *Salvelinus namaycush* (Walbaum); Dolly Varden, *Salvelinus malma* (Walbaum); rainbow

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[1] From Oregon State Game Commission stocking records.

trout, Salmo gairdneri Richardson; brown trout, Salmo trutta Linnaeus; brook trout, Salvelinus fontinalis (Mitchell); mountain whitefish, Prosopium williamsoni (Girard); and the tui chub, Siphateles bicolor (Girard).

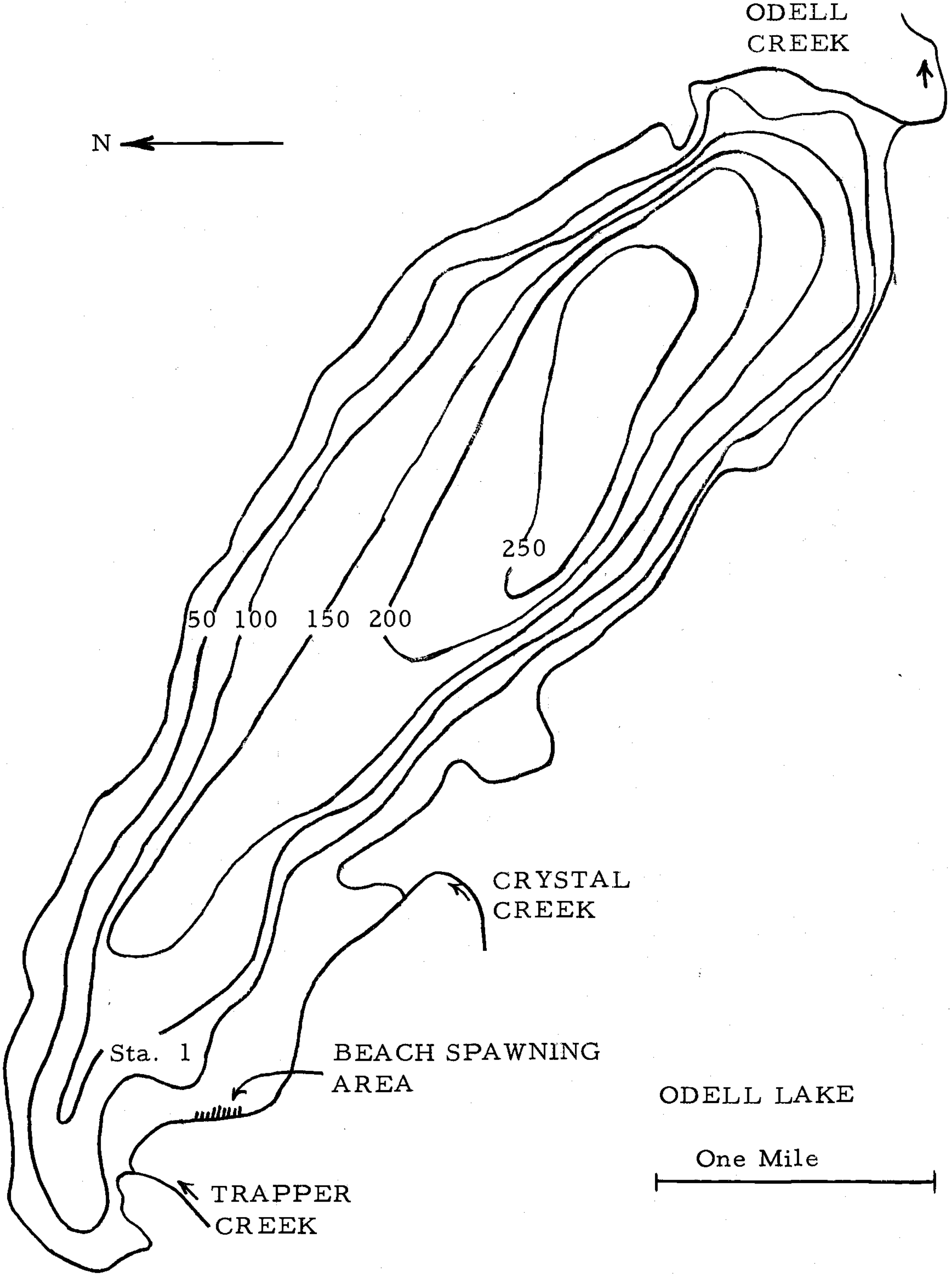

Figure 1. Map of Odell Lake.

MATERIALS AND METHODS

Fish

The kokanee studied were fish of the year from natural spawning in Odell Lake. I call them fingerlings after Davis (7, p. 305). The fingerlings were apparently free-swimming in June when sampling began, as an inspection of the principal spawning area revealed no fry in the gravel at that time. At the beginning of the sampling period in mid-June, the fingerlings had a mean fork length of 23.5 mm and had grown to about 53 mm in length by September when sampling was ceased.

Townet and Equipment

The fingerlings were sampled with a mid-water townet pulled by two outboard-powered boats. This sampling method was first used by Johnson in 1954 for catching young sockeye salmon in Lakelse Lake, British Columbia. He used a circular net three feet in diameter. Burgner (5, p. 6) designed a townet with a nine-foot square opening after abandoning a ten-foot circular net because of difficulty in interpreting the catch.

The net used in my study (Figure 2) was designed after Burgner's square net. It has an opening nine feet square and a length of

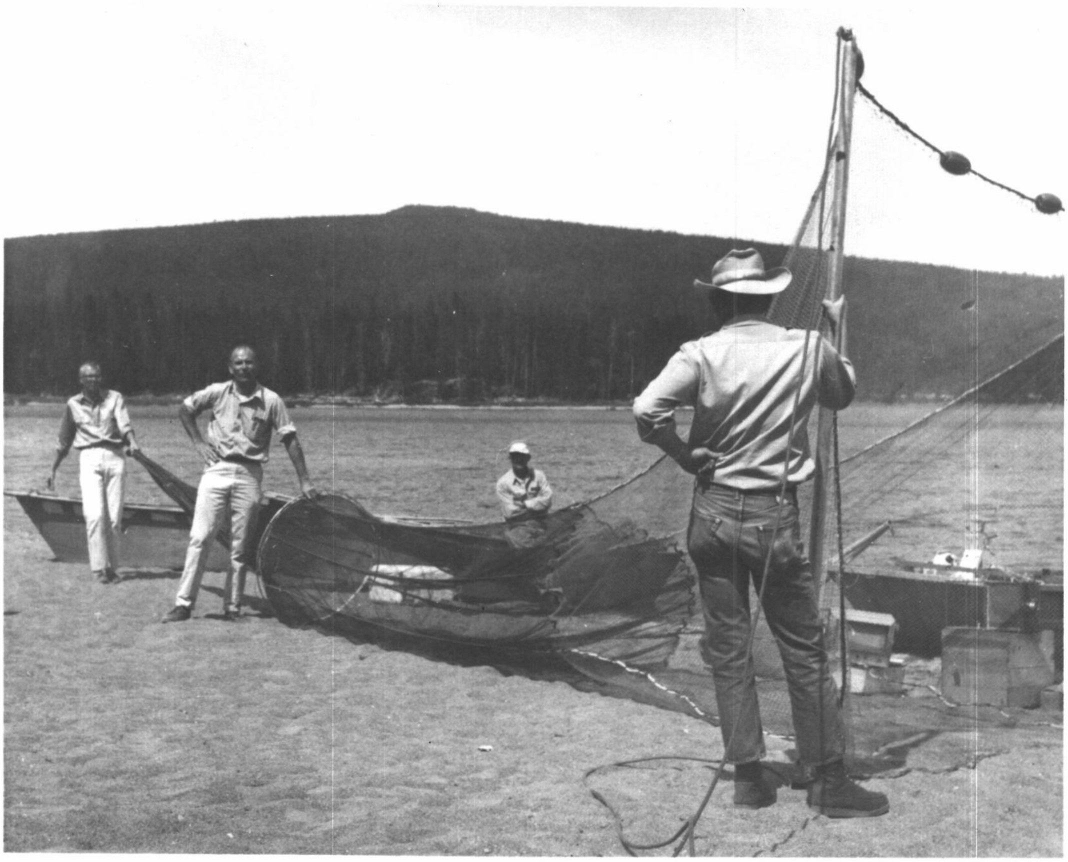

Figure 2. Midwater townet.

twenty-seven feet. It is made of woven nylon mesh varying from 1.5 inch in the lead to .25 inch stretched measure in the cod end. The cod end is fitted with a nylon zipper for easy access to catch. The net is held open vertically by nine-foot tubular aluminum bars on the sides. Floats on the top and weights on the bottom of the net aid in holding the net open while the boats keep it spread horizontally. The boats used were 14-foot aluminum barges powered by 40-horsepower outboard motors.

The towing cables were of 3/16 inch stainless steel wire-rope 600 feet long, wound on the drum of a gasoline-powered winch. The winches were mounted on 4x4 inch wooden timbers fixed in the bottoms of the boats. The cables from each winch ran through pulleys hung on brackets bolted to the transoms. Affixed to the end of each cable were steel rings to which the harnesses from the net were attached by snaps. The boats were rigged so one was "left-handed" and the other "right-handed".

I regulated depth of tow by manipulating length of tow cable, length of a float line extending from the top of the net to the water surface, and amount of weight attached to the net. A float made from a styrofoam packing case was tied to the float line. For other than surface tows, lead trolling weights were lashed to the bottoms of the spreader bars. More tow line was used for the deeper tows.

All towing was done at night because the fish are apparently able to avoid the net during the day. The boats were kept about 100 feet apart while towing so the water in the path of the net would not be disturbed. After eight minutes of towing under full power, we brought the boats together under reduced power closing the net to prevent contamination of the catch by fish from strata shallower than the depth of the tow.

The chance of catching fish from other than the desired towing depth was a primary sampling problem. Efforts were made to reduce the probability of this incidental catch. Used as another precaution, the float line kept the net from sinking deeper than necessary at the start of the tow. The extent of contamination is unknown but assumed to be minimal and constant.

All live fish in excess of five from each tow were counted and released. The fish kept were preserved whole in ten percent formalin and the bottle identified by tow number. The morning following towing we measured fork lengths of preserved fish to the nearest millimeter. Up to five stomachs per tow sample were removed and labeled with date, time, area, course, and tow number.

The towing speed was checked with a pygmy current meter and was found to be three-four feet per second. Burgner (5, p. 6) found that there was no significant decrease in catch of young sockeye when towing speed was reduced from five to three fps. He also observed the pattern of abundance of fish with a Simrad Master Sounder depth recorder and saw that catch per tow corresponded well with the numbers of fish shown on the recorder chart. With these findings in mind, I assumed that sampling with a townet gives a reliable index of the abundance of fish present in the area sampled.

Sampling Design

The sampling scheme was designed to give equal coverage to all parts of the lake to determine the horizontal as well as vertical distribution of the kokanee fingerlings. We divided the lake into three areas numbered from west to east (Figure 3). Six towing courses were laid out within each area. The plan was to sample each area at least once a week. The order in which areas were sampled was taken from a table of random numbers, as was the course to be run within each area. The order in which the depths were towed was determined by taking the first depth to be towed from a table of random numbers. From that depth the tow series proceeded downward to the deepest, then to the surface and down again until the series of five tows was completed. The planned towing depths were surface, 20, 40, 60, and 80 feet. We noted in July that the tows were not going deep enough, so we adjusted the gear until tows in August and September were deeper than previous ones.

Towing depths were estimated from the previous years experience but were not verified until the sampling period was nearly

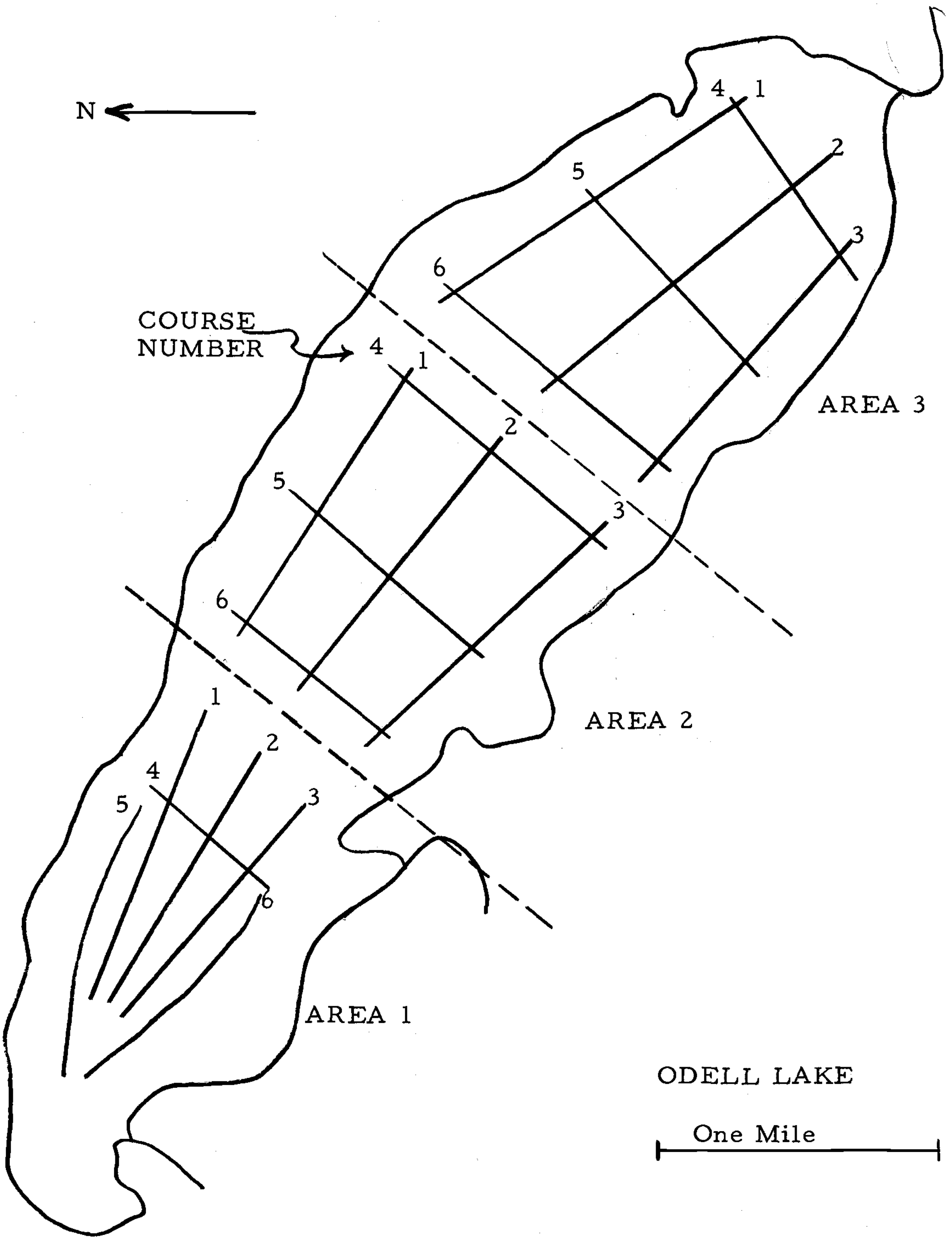

Figure 3. Map of Odell Lake showing sampling areas and courses.

completed. We determined actual towing depth by using a 20-pound test monofilament line mounted on a stout rod and reel. From a third boat, the line was tied to the top of the net and played out as the net was deployed for the tow. When the tow was well under way, the boat was maneuvered over the net and the line reeled in until perpendicular with the water surface. The monofilament was then cut at the waterline. When the net was retrieved, the line was removed and measured. This procedure was repeated for each depth of tow used in this study. A duplication of one tow depth varied three inches.

The towing depths probably varied slightly with changing weather conditions. Extent of this variation is not known but is assumed to be insignificant since we did not sample when weather conditions prohibited normal operation. Four and a half feet was added to each measurement to get the depth of the center of the net. The depths reported in this study are to the center of net opening.

Plankton Sampling

Plankton samples were obtained with a ten-liter Juday plankton trap. The structure and operation of this trap were described by Juday (22, p. 578-580).

Plankton samples were taken in conjunction with each towing series at the sampling site just prior to towing. One sample was obtained at each 20 foot interval from the surface to 80 feet.

In early July, August, and September, a 24-hour plankton trapping program was completed. A buoy was anchored at Station 1 near the west end of the lake. At that point, a series of samples was taken at ten-foot intervals to a depth of 100 feet every four hours for a period of 24 hours. This program was an effort to follow the diel distribution of zooplankters. A temperature series and observations on weather conditions were taken at the time of each series of samples.

The analysis of plankton was done mainly by total counts of the plankters in each sample. When numbers were too great to make total counts practical, several subsamples were taken with a 1 cc plunger and the proportion expanded to total number of plankters.

The contents from the anterior halves of stomachs from fingerlings in each sample were lumped together for examination. Those individuals or parts recognized as whole plankters were counted. The numbers of individual animals within a genus were expressed as a percentage of the total individuals present in the sample.

Water Temperature

Water temperatures were taken prior to each tow series and in conjunction with the 24-hour plankton sampling program. The instrument used was a battery-powered thermister. Readings were taken to the nearest .25 C, at 5-foot intervals from the surface to

100 feet. A two-pound lead weight attached to the end of the cord made it hang straight.

Light

Relative amount of light present was estimated by visual observation. There were no instruments available to us that were sensitive enough to measure the available light at night. As a substitute, observations were made on moon phase and the percentage of cloud cover. The product of assigned values for moon phases and percentage of cloud cover was used as a numerical light value. This scheme is illustrated in Appendix B. Although no Secchi disk readings were taken during the sampling period, some were taken the previous year to get an indication of the clarity of the water.

Dissolved Oxygen and Water Chemistry

We took water samples monthly at Station 1 to determine dissolved oxygen content. Samples were taken with a Kemmerer water bottle at the surface, 50 and 100 feet. The dissolved oxygen content was determined by the Modified Winkler Method (2, p. 309) in the field.

Monthly water samples were also taken for analysis of water chemistry. Total dissolved solids were determined by filtering the samples with filter paper and drying the filterable residue at 105 C

(2, p. 214-215). The stannous chloride method for orthophosphates was used to determine the total phosphates present (2, p. 198-206). Amounts of nitrogen were determined by the phenoldisulfonic acid method; elimination of interferences was not necessary (2, p. 175-178).

RESULTS

Physical Characteristics

Water temperatures remained cool throughout the summer; the surface temperature was 10.5 C in mid-June and rose to a high of 17.8 C in early September. At all times during the sampling period there was some form of a thermocline present; it was poorly defined in June but was evident in July and became more definite as the summer passed. The depth of the thermocline was generally about 50 feet at the time of sampling, just after dark.

Fluctuations in depth of the thermocline were noted when temperature readings were taken at four hour intervals over a 24-hour period. Figure 4 shows the variance found on August 2-3. These changes were apparently caused by wind-induced seiches. A westerly wind blew nearly every afternoon from June through August but was sometimes replaced by a strong east wind in September. Both winds blew directly in line with the long axis of the lake, maximizing their effectiveness in moving the water.

Dissolved-oxygen content remained high throughout the summer. The lowest content was 8.6 mg/l on September 17. The greatest difference between the surface and 100 feet was 1.2 mg/l on August 8. Since dissolved oxygen concentration remained high and uniform, it

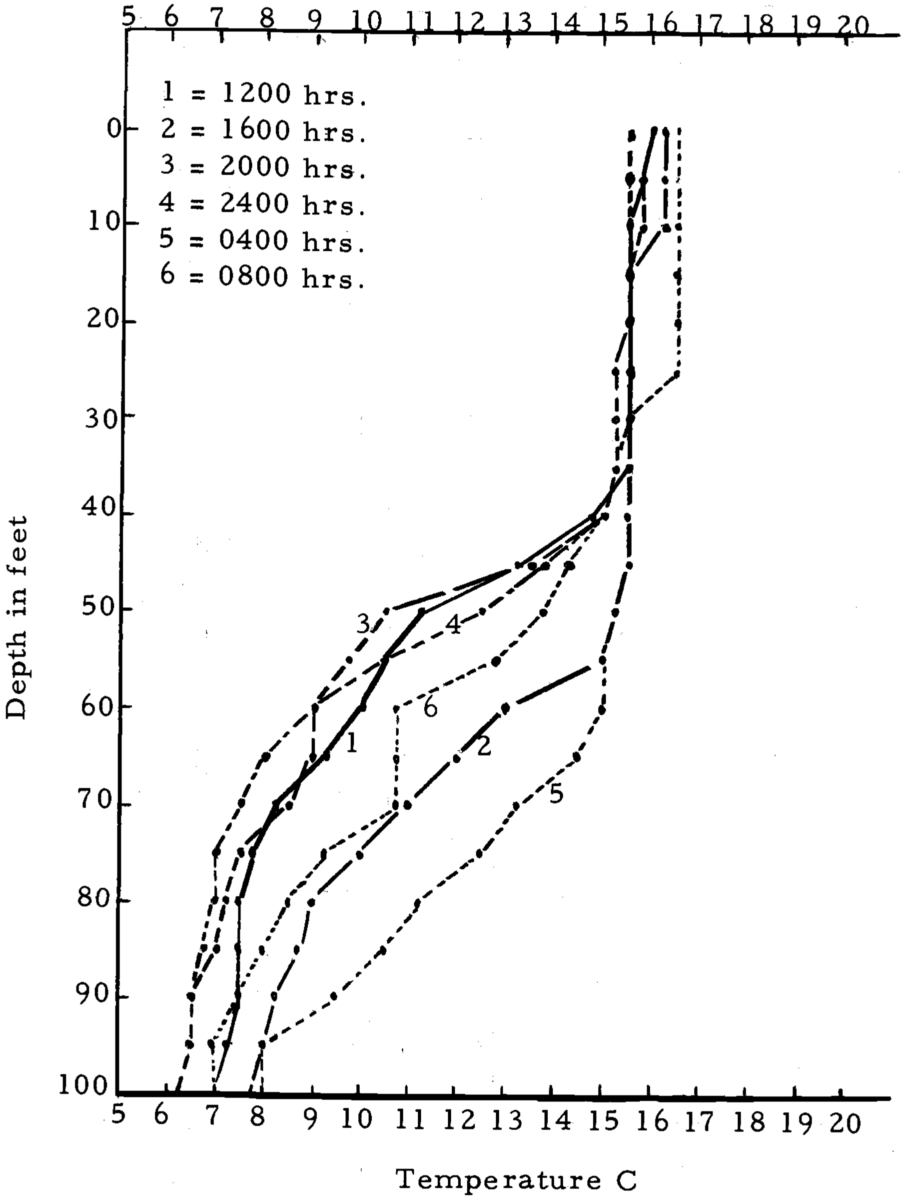

Figure 4. Thermal fluctuations at Station 1 over a 24-hour period, August 2-3, 1963.

was ruled out as a possible factor influencing the distribution of kokanee fingerlings.

The chemical constituents found in the lake water during the sampling period are given in Table 1.

Table 1. Water chemistry of Odell Lake

Date of Analysis	Total dissolved solids gm/l	Total Phosphorous ppm	Total Nitrogen ppm
June 6, 1963	0.019	0.036	$<.02$
July 25, 1963	0.020	0.032	$<.02$
Sept. 24, 1963	0.024	0.028	$<.02$

Secchi disk readings in 1962 ranged from 35 to 40 feet. Though none was taken during the sampling period in 1963, I believe water clarity was as great. On several occasions it was noted that the plankton trap was visible at a depth of 40 feet. There was a heavy algal bloom starting in mid-September that undoubtedly impaired light penetration.

Horizontal Distribution of Zooplankton

Figures 8-10 show that *Cyclops* dominated the zooplankton population during June and July, then decreased in abundance steadily through September. *Daphnia* increased in number rapidly as the summer progressed and was the most abundant plankter in

September. Densities of Diaptomus were never great, but were highest in June, declining thereafter.

Densities of zooplankters were highest in Area 1 from June thru August, and Area 3 in September, During June and July zooplankters of all genera were most abundant in Area 1 (Figure 8), with numbers declining toward Area 3. Cyclops numbers were somewhat greater early in the summer in Area 1 than in Area 3. Areas 2 and 3 had nearly equal densities of Diaptomus while Area 1 had a substantially higher density in June and July. Numbers of Daphnia were relatively low and about equal throughout the lake in early summer.

Area 1 still held the most zooplankton in August (Figure 9) while densities in Areas 2 and 3 were about equal. Diaptomus was the only genus which did not show this unequal horizontal distribution. The rise in total zooplankton numbers from July to August was the result of a rapid increase in Daphnia while other genera decreased in abundance somewhat.

In September, the pattern of horizontal distribution of plankters that had been evident was altered by a great increase in Daphnia in Areas 2 and 3 (Figure 10). The distributions of Cyclops and Diaptomus were homogenous among the three areas.

Vertical Distribution of Zooplankton

An indication of the diel vertical movement of zooplankters is provided by the results of the series of samples taken August 2 and 3 (Figure 5). The mode of the population of Cyclops seemed to be closely associated with the thermocline although there were animals living above the thermocline. There was some reaction to light by Cyclops, more pronounced in the upper group than in the thermocline dwellers. All Cyclops moved toward the surface at night and downward in day.

Daphnia appeared to be greatly influenced by light in their movements with their peak density shifting from near the surface at night to below the thermocline during the day.

Few Diaptomus were taken above 80 feet in August but their numbers increased below that depth. It was noted in June that Diaptomus were numerous in the surface waters, indicating that they may prefer colder waters than were available in late summer above the thermocline. Diaptomus were not taken in sufficient numbers to detect any vertical migration.

The seasonal change in vertical distribution of plankters can be determined from samples taken in conjunction with fish sampling (Figures 12-15). These data show the distribution of these animals just after dark. Daphnia were most abundant near the surface throughout the sampling period regardless of temperature. The distribution mode for Cyclops shifted from the surface early in the

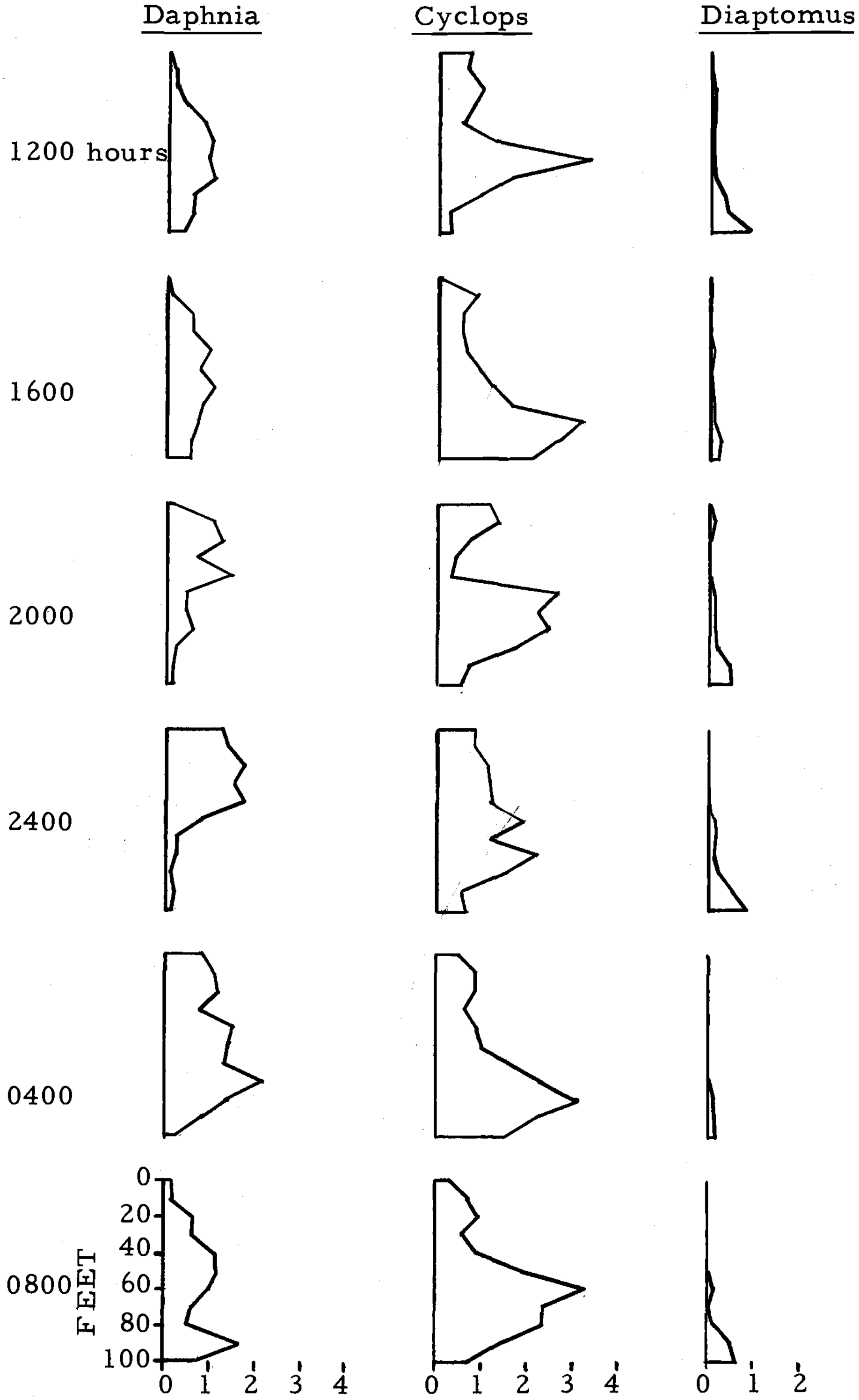

Figure 5. Diel vertical distribution of zooplankters at Station 1, August 2-3, 1963.

summer to the middle of the thermocline in August and September. As stated earlier, I found Diaptomus in deeper water as the summer passed.

Fingerling - Food Relationship

The percentages of contents from stomachs of kokanee fingerlings and corresponding plankton samples were compared in Figure 6. I computed the percentages for each month. It is apparent that the number of plankters taken by fingerlings is in proportion to the abundance of the plankters.

The percentage of Daphnia found in stomachs was nearly the same as that found in the plankton. Diaptomus percentages in the stomachs were twice those found in the plankton while the reverse situation was true for Cyclops.

Horizontal Distribution of Kokanee

Area 1 yielded larger catches of kokanee fingerlings than did Areas 2 and 3 throughout the sampling period (Figure 7). In Figures 8-10 I have graphed for each month and area the mean number of kokanee captured in tows, mean abundance of each plankter, and mean water temperature.

During June and July the fingerlings were distributed in a manner similar to the distribution of plankton organisms. All

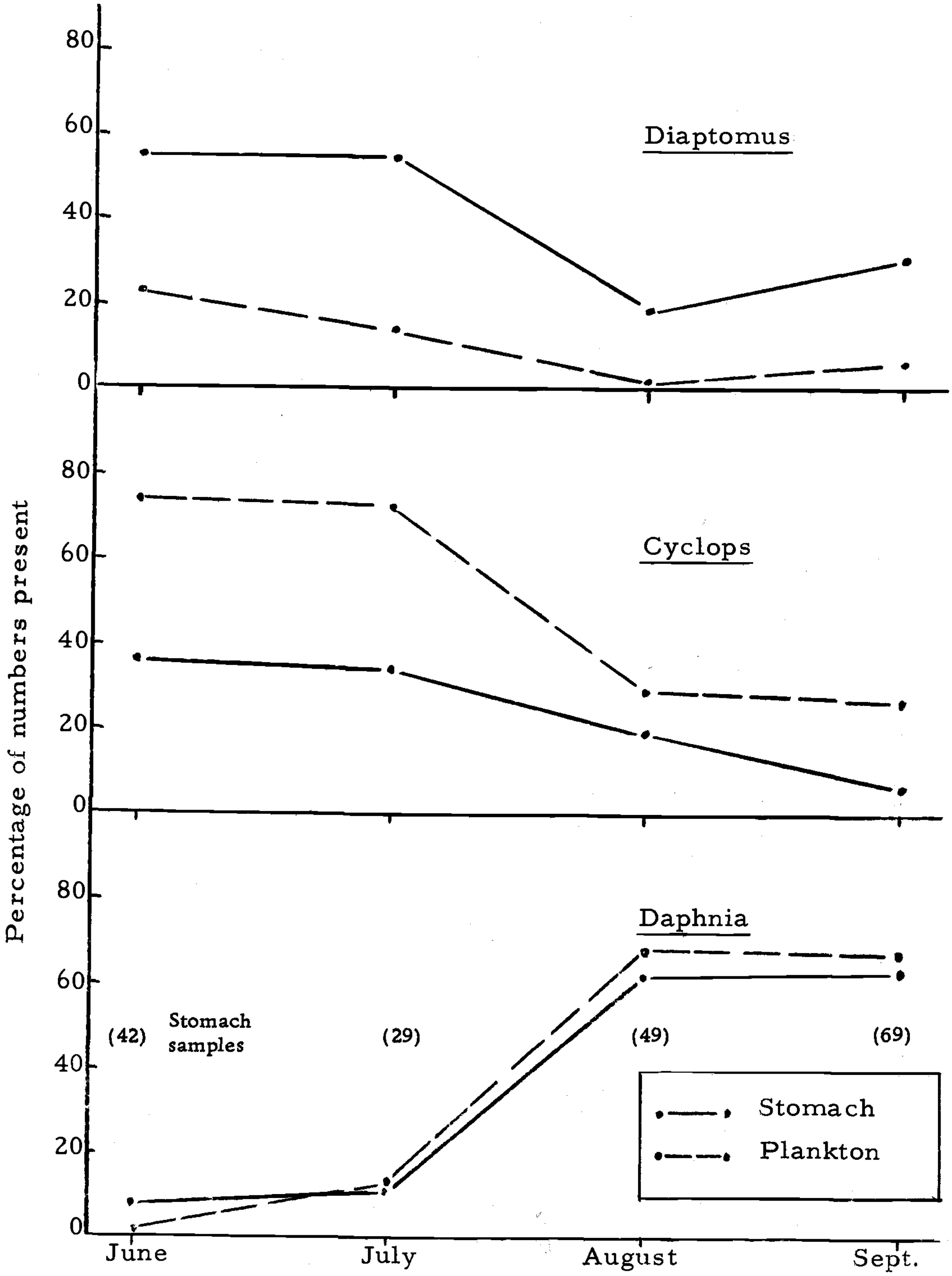

Figure 6. A comparison of the percentage composition by genera present in plankton samples and stomach contents of kokanee fingerlings from Odell Lake, 1963.

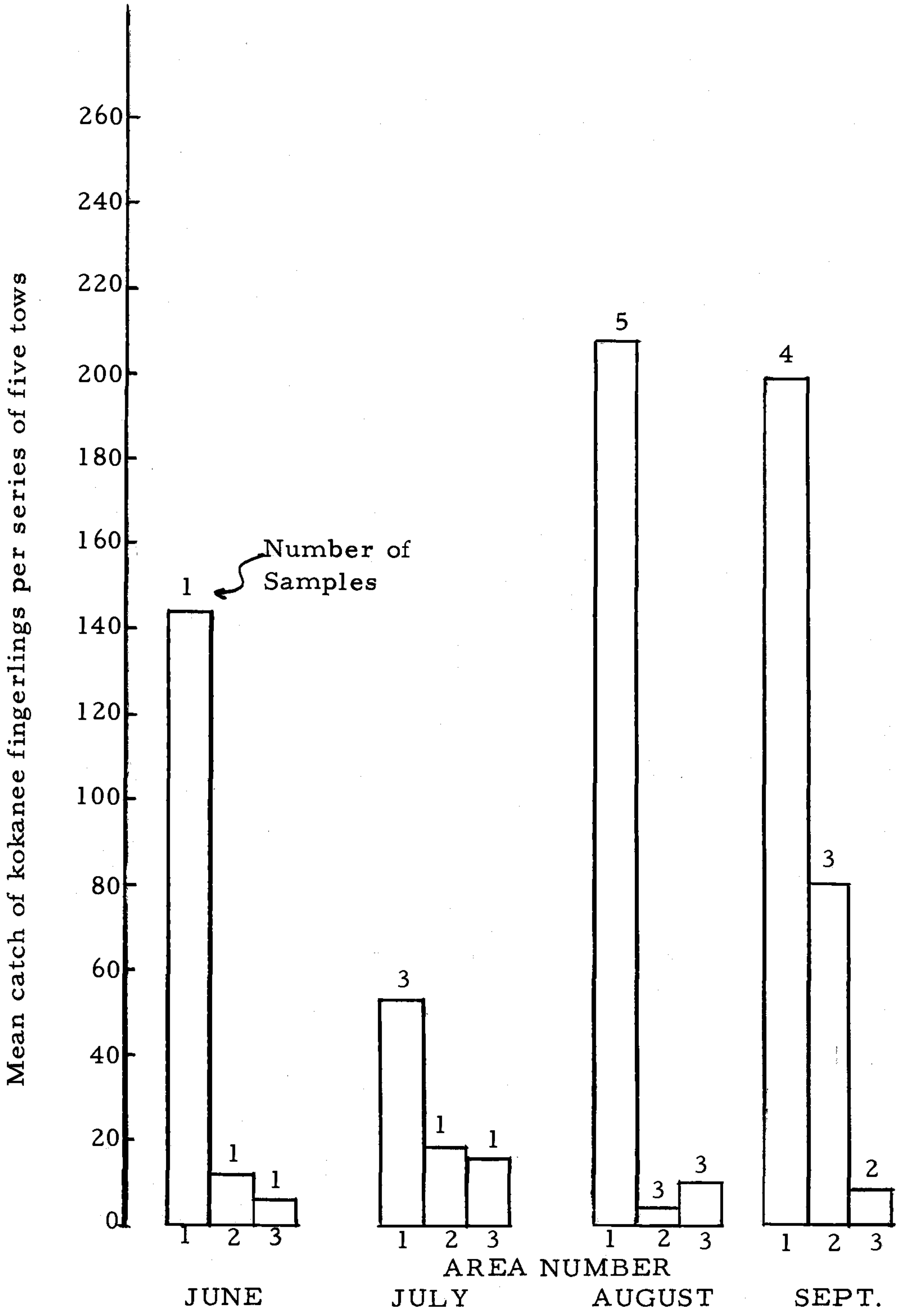

Figure 7. Horizontal distribution of kokanee fingerlings in Odell Lake, 1963.

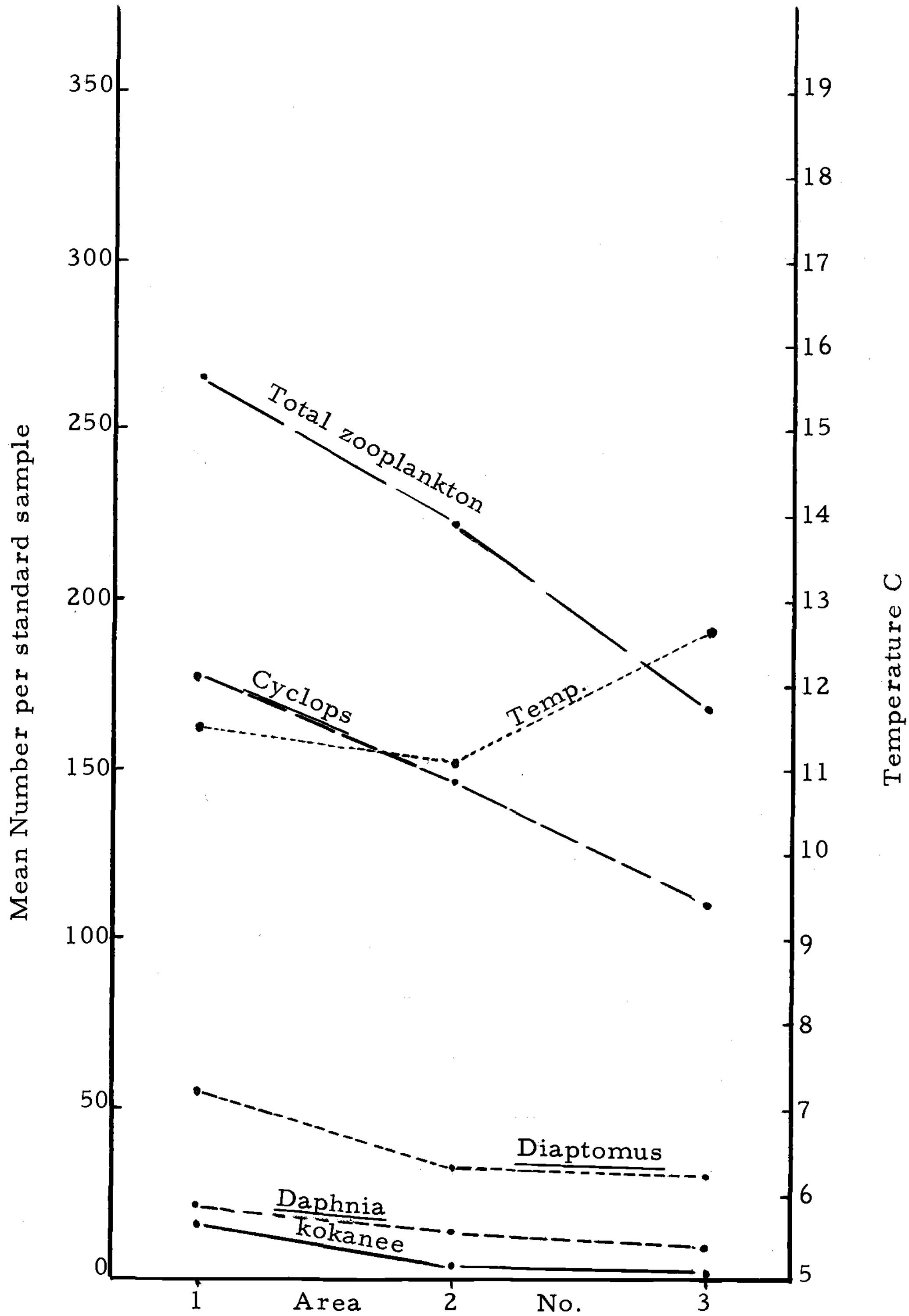

Figure 8. Mean number of animals and temperature within areas in Odell Lake during June and July, 1963.

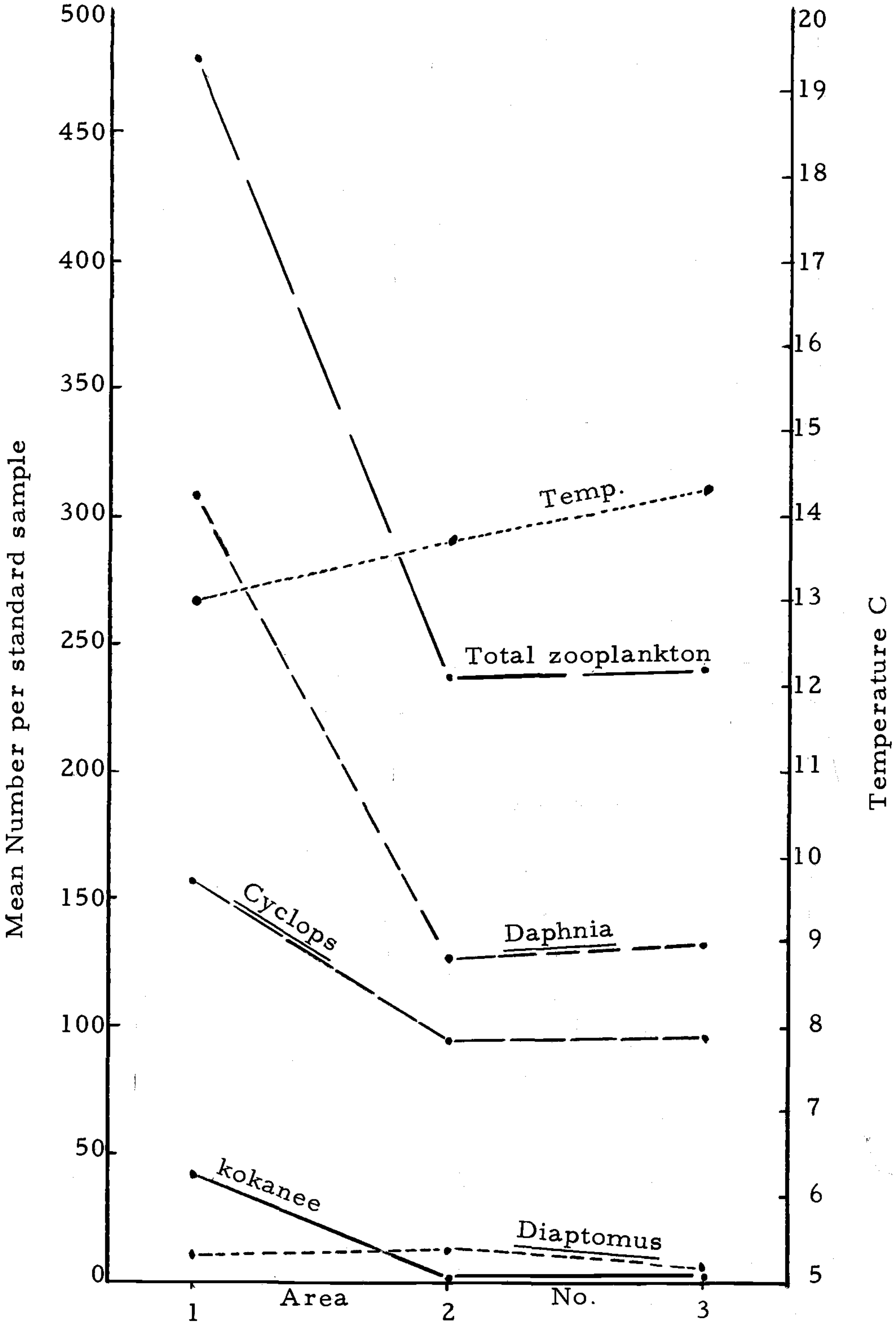

Figure 9. Mean number of animals and temperature within areas in Odell Lake during August, 1963.

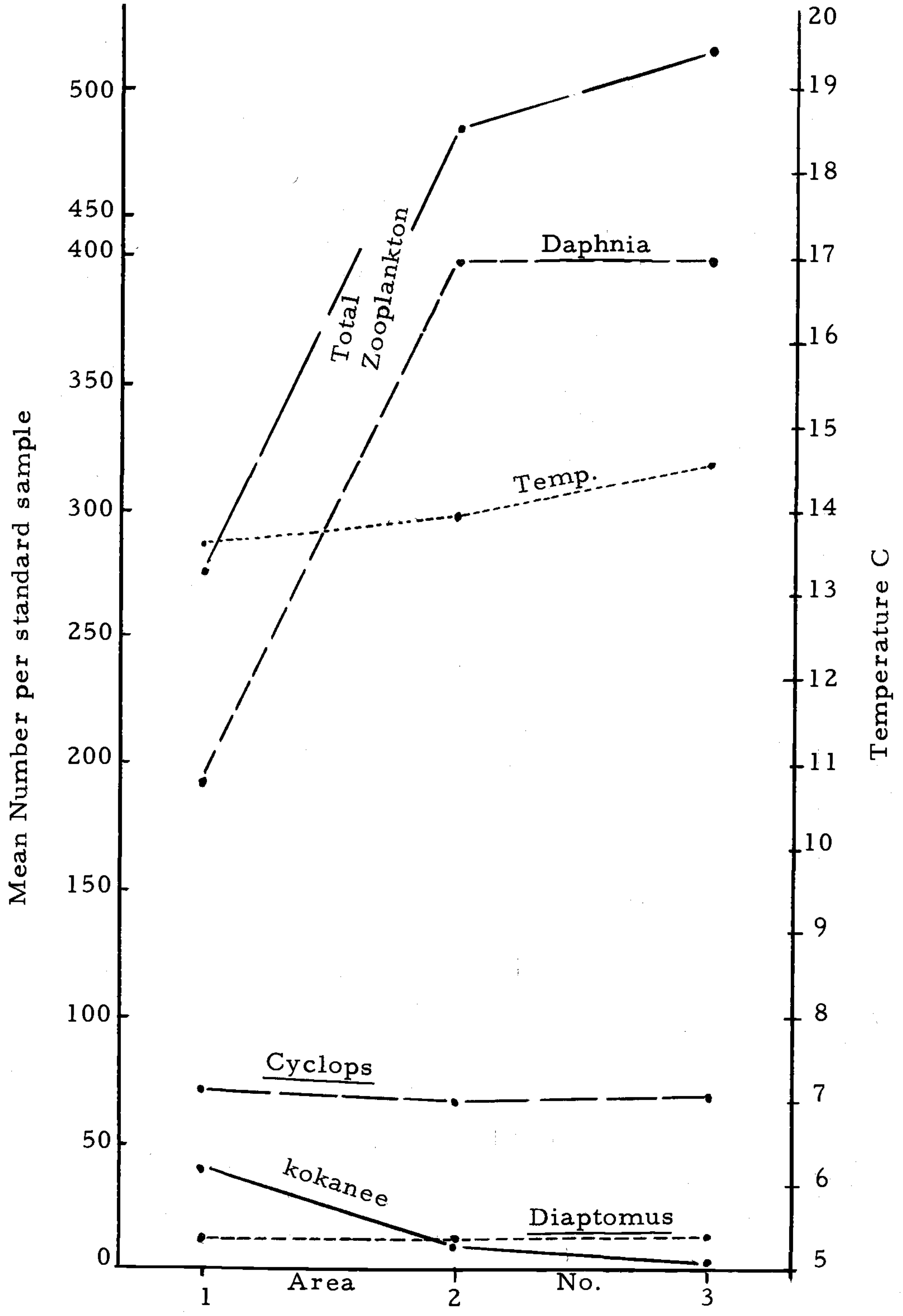

Figure 10. Mean number of animals and temperature within areas in Odell Lake during September, 1963.

of these animals were most abundant in Area 1. The catches of kokanee for this period averaged 5.8, 3.7, and 3.2 fish per tow in Areas 1, 2, and 3 respectively. The mean temperature for towing depths was 11.5 C in Area 1, one degree lower than Area 3, but 0.5 C higher than Area 2.

In August, numbers of kokanee were highest in Area 1 and appeared to be correlated with total zooplankton, Daphnia and Cyclops. Diaptomus populations in Areas 1 and 2 were about equal but a little larger than in Area 3. The temperature was 1.3 C lower in Area 1 than in Area 3 with Area 2 intermediate. The mean catch of kokanee per tow for August was 14.4 for Area 1 compared to 0.9 and 2.0 for Areas 2 and 3.

In September, the catch of kokanee in Area 2 increased to 9.4 per tow but in Area 1 the mean catch was 39.8 per tow. During this period, the greatest density of total zooplankton was in Areas 2 and 3 because of an increase in Daphnia. Cyclops and Diaptomus were distributed fairly evenly over the lake while the temperature remained about one degree cooler in the west end than in the east.

Vertical Distribution of Kokanee

The data on vertical distribution that are analyzed graphically is limited to Area 1, where fish were present in sufficient numbers to develop a vertical pattern. Examination of the figures for the other areas reveals a similar pattern to that found in Area 1. I grouped the data into monthly periods to reveal changes in vertical distribution with time.

June. On the basis of a single series of townet samples on June 27 (Figure 11), fingerling numbers appeared to be allied with *Diaptomus* as both reached their highest density at a depth of 50 feet. The temperature range from 11.5 C at the surface to 9.3 C at 70 feet probably had little influence on kokanee distribution.

July. The average of three townet series in July (Figure 12) shows the mode of kokanee distribution at 20 feet. *Cyclops* and *Daphnia* numbers declined from the surface downward. *Diaptomus* also declined to 30 feet where it began increasing again. Mean temperatures were 13 C at the surface, falling gradually to 9.8 C at 60 feet. This temperature range probably did not restrict distribution.

August. Water temperatures increased in August and a definite thermocline was at 40 feet. The results of five townet series showed the modes of distribution for kokanee fingerlings, *Cyclops* and *Diaptomus* were in the thermocline at 60 feet (Figure 13). Total zooplankton, reflecting an increase in *Daphnia*, had a sharp mode at about 22 feet. Numbers of fingerlings, *Cyclops* and *Diaptomus* appeared closely correlated.

September. Vertical distribution of kokanee in September

(Figure 14) was similar to that in August, although there were fewer fish in upper waters and more near the middle of the thermocline at 58 feet. Fingerling numbers decreased below this depth. The temperature range was about the same as in August but the thermocline became deeper and narrower. Kokanee distribution again appeared to be correlated with Cyclops and Diaptomus but not with Daphnia which was most abundant in the warmer upper layer of water.

In August and September it was possible to obtain samples from Area 1 under differing phases of the moon. The numbers of kokanee fingerlings taken at the surface were markedly different under different light conditions (Figure 15). It appears that the fish present in the surface layers above the thermocline were most influenced by light. Higher numbers were caught at the surface under full moonlight, somewhat fewer under a half moon, and least when dark. The catch of fingerlings at the surface was positively correlated with observed light values ($P < .005$, 7d. f.).

A multiple regression analysis of vertical distribution was performed on an IBM 1620 computer. The percentage taken in any one tow of the total catch per series of five tows was used as the dependent variable. The resulting t ratios for the selected independent variables are given in Table 2.

I found significant positive correlations between time (number of days after June 24) and kokanee catch; and between abundance of

Diaptomus and kokanee catch. There was a significant negative correlation between kokanee catch and the product of time and temperature.

Table 2. t ratios and significance levels for correlation between percentage of kokanee caught per tow and selected independent variables.

Independent variable		t ratio	Significance	P
X_1	Depth in feet	-.509	no	
X_2	Temperature C	.653	no	
X_3	Time $t_o + t_n$	1.804	yes	< .10
X_4	Daphnia numbers	-.940	no	
X_5	Cyclops numbers	-.203	no	
X_6	Diaptomus numbers	2.219	yes	< .05
X_1^2	$(\text{Depth})^2$	.736	no	
X_2^2	$(\text{Temp.})^2$	-.445	no	
X_1X_2	(Depth)·(Temp.)	.572	no	
X_1X_3	(Depth)·(Time)	-.427	no	
X_2X_3	(Temp.)·(Time)	-2.139	yes	< .05

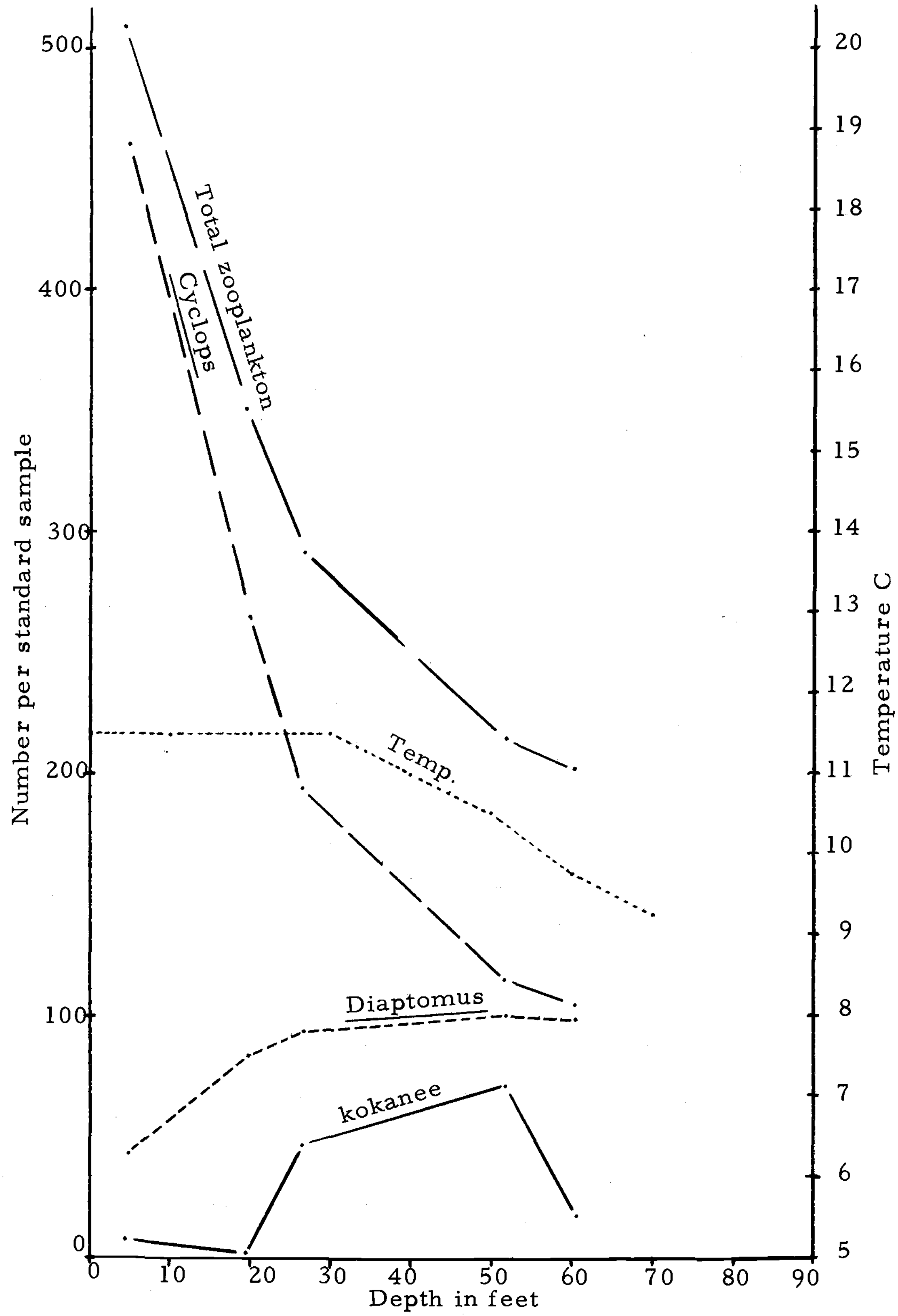

Figure 11. Vertical distribution of animals and temperature in Odell Lake, Area 1, June 27, 1963.

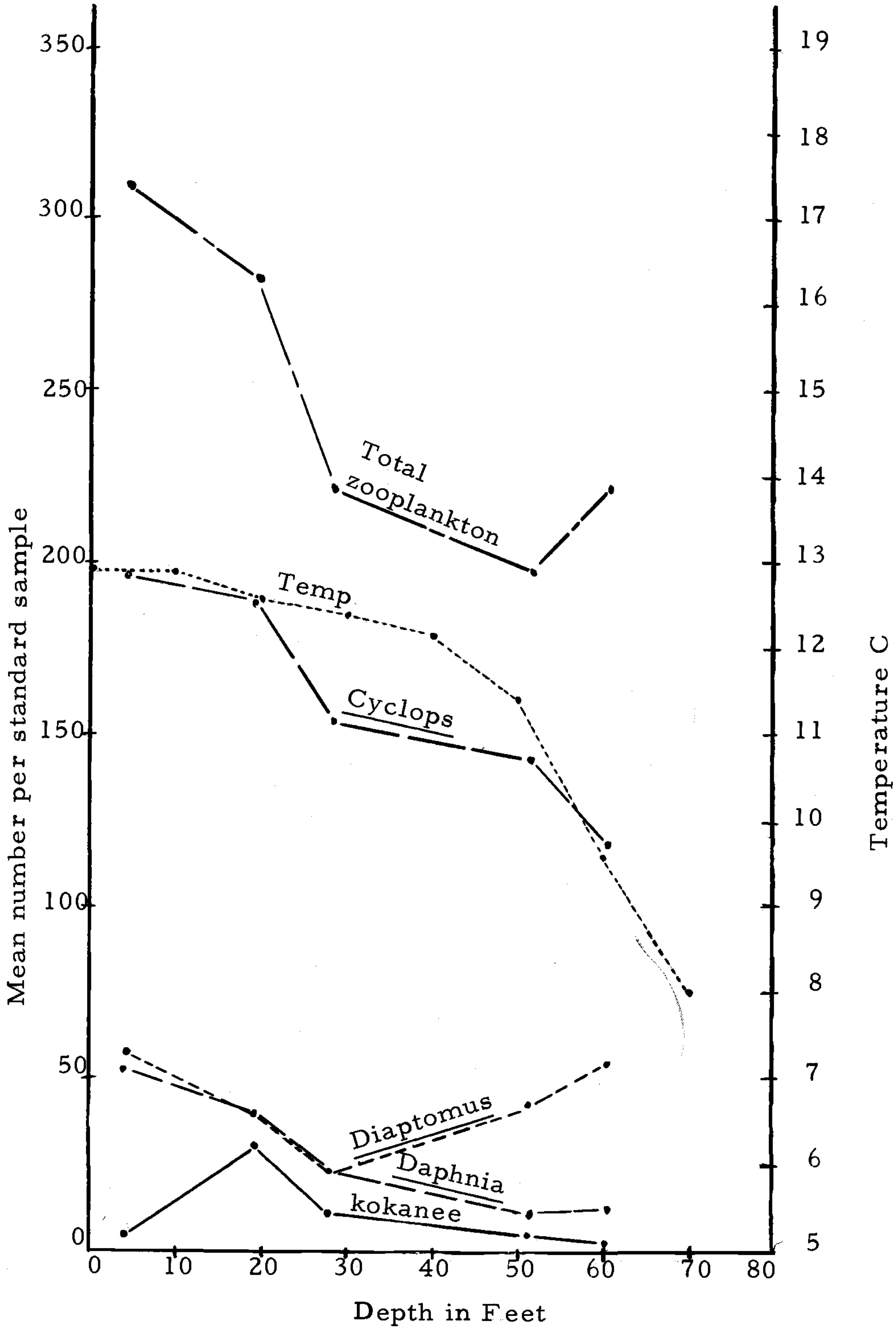

Figure 12. Vertical distribution of animals and temperature in Odell Lake, Area 1, July, 1963.

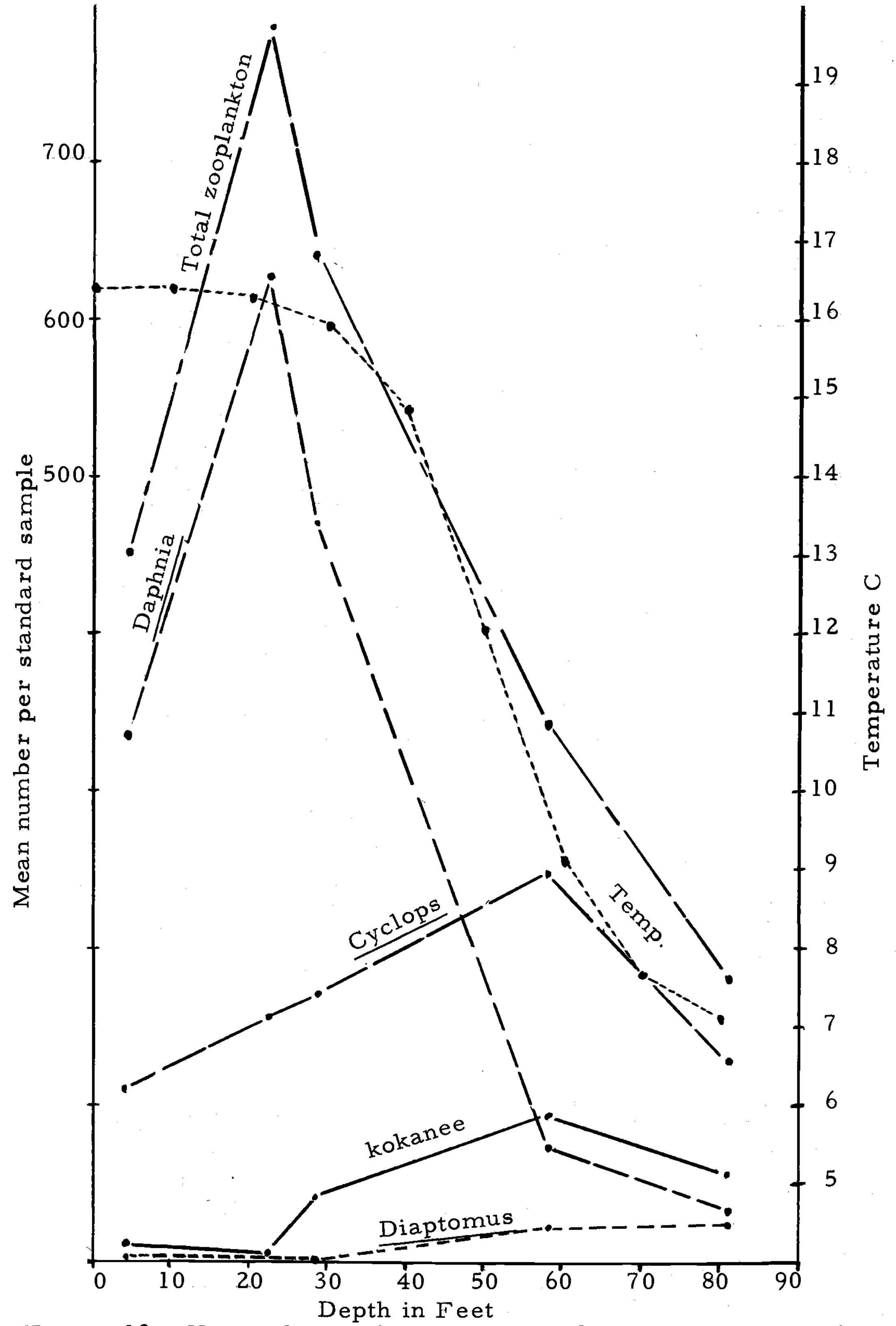

Figure 13. Vertical distribution of animals and temperature in Area 1, Odell Lake, August, 1963.

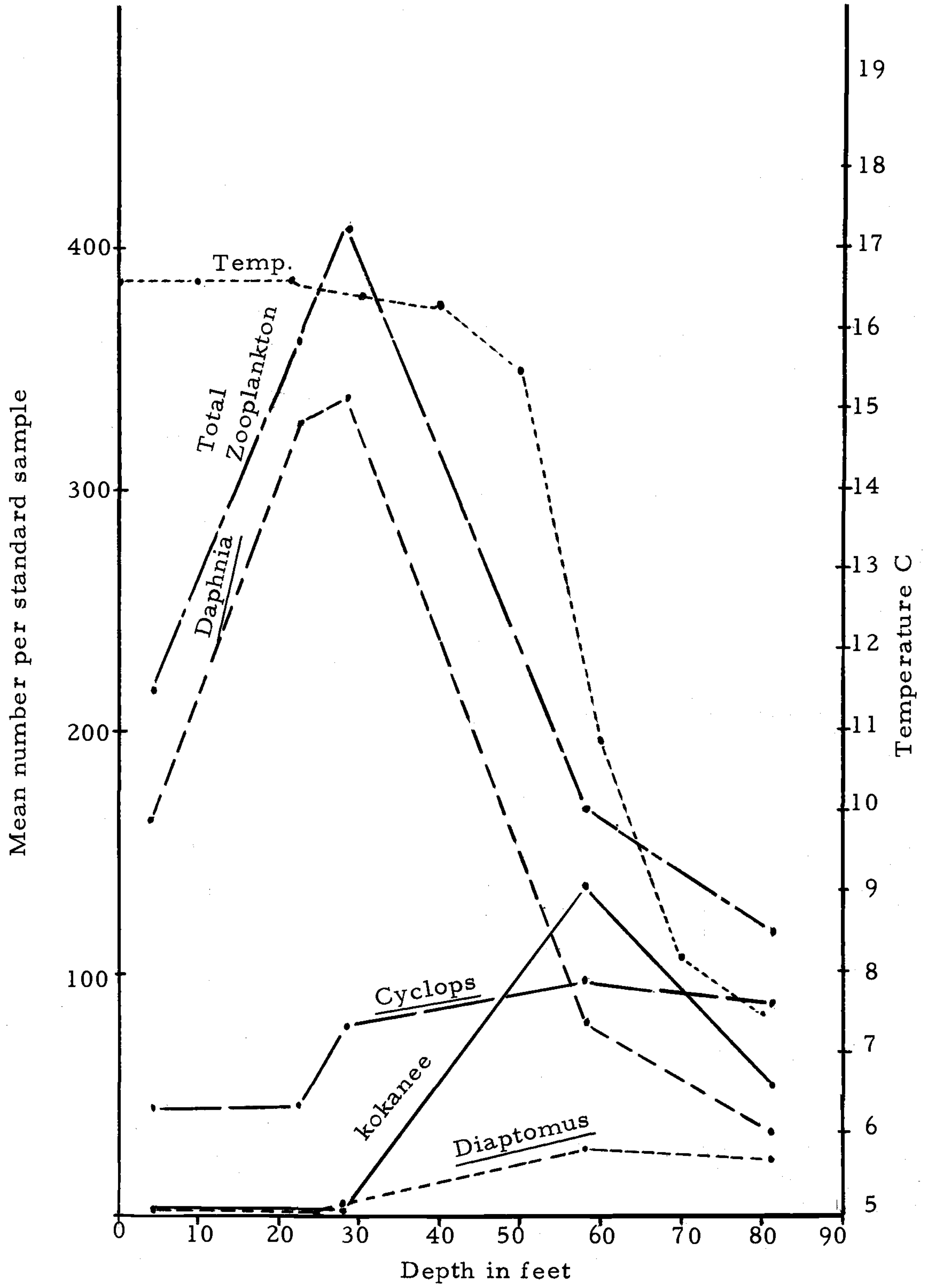

Figure 14. Vertical distribution of animals and temperature in Odell Lake, Area 1, Sept., 1963.

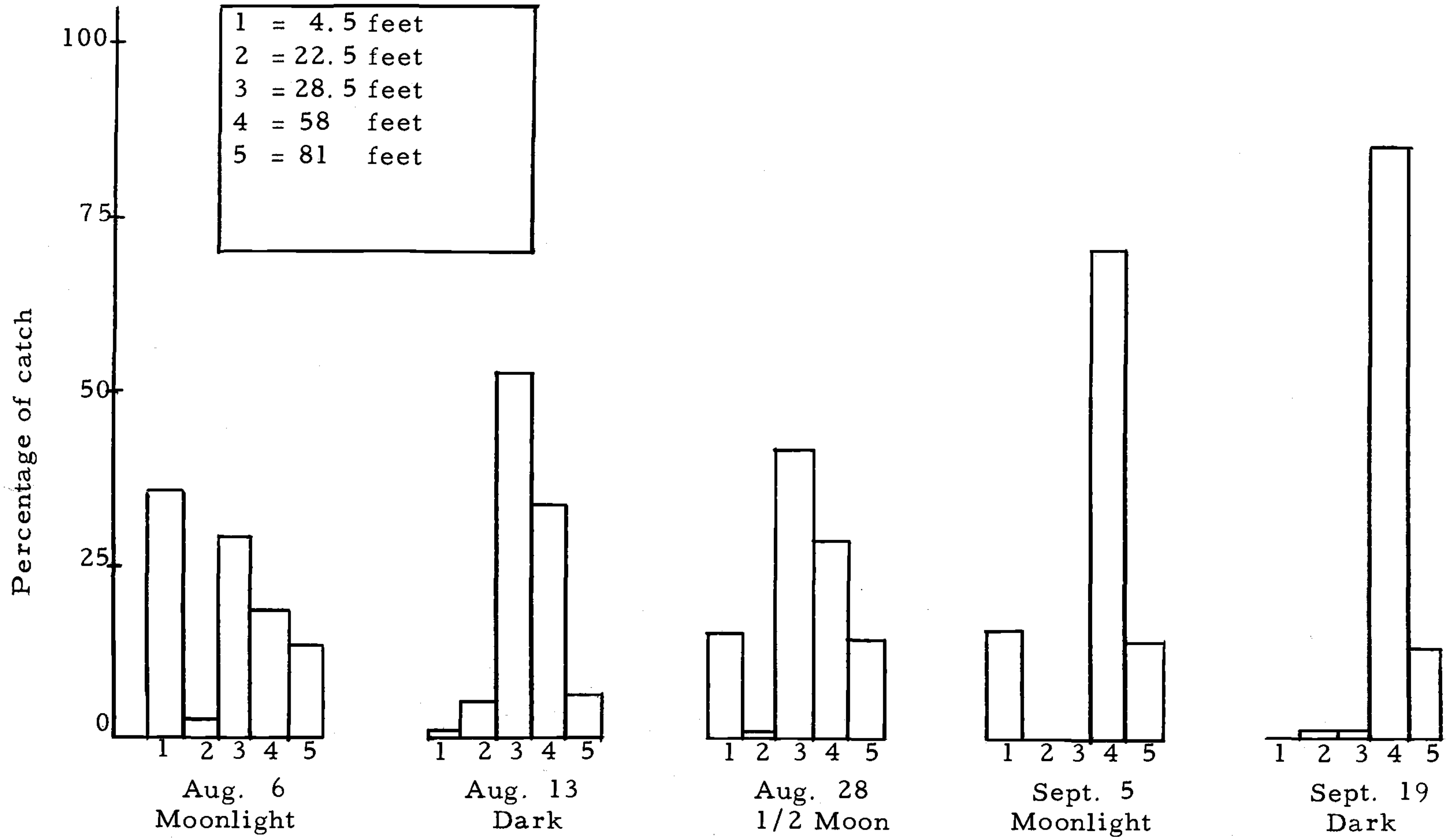

Figure 15. Vertical distribution of kokanee fingerlings under different light conditions, Area 1, Odell Lake, 1963.

DISCUSSION

Horizontal Distribution

The disproportionate horizontal distribution of kokanee fingerlings in Odell Lake might be induced by the influence of one or more factors. It may simply be that the fingerlings are slow to disperse from the spawning area from which they emerged. The area of highest fingerling density contains the main known spawning area for the lake. Kokanee are known to spawn in Odell Creek, the outlet, but it is not known if the emerging fry swim up into the lake or are carried downstream. The possibility that there might be some unknown deep-water spawning remains for further investigation before a correlation can be verified between spawning area and fingerling distribution in Odell Lake.

Johnson (19, p. 706), (20, p. 972) found limited dispersal from the nursery areas in his work with young sockeye salmon in British Columbia. The same relationship was reported by Kerns, *et al.* (23, p. 9) for Iliamna Lake, Alaska.

Johnson further noted that while the young salmon are feeding they are subject to being carried in the circulating water mass just as their planktonic food. He stated that limited dispersal seemed to be peculiar to multibasin lakes because the wind induced currents and independent circulations in multibasin systems offer no guide to remote areas. Later, Johnson (21, p. 727) found evidence of horizontal concentrations seemingly related to lake circulation, suggesting passive horizontal transport. This finding followed the theory by Ragotzkie and Bryson (27, p. 157-172) for zooplankton in Lake Mendota, Wisconsin where animals with a near-surface distribution were concentrated by the prevailing wind.

Although Odell Lake is a single basin, it seems possible that the concentration of fish and zooplankton found may have been the result of current action. But, the effective current would have to be a subsurface counter current since the concentrations are in the lee of the prevailing westerly wind. This would be effective because the vertical distribution seen in Odell Lake is somewhat deeper than the 0-5 meter range that Johnson found. Such a circulation would contribute to the cooler temperatures of Area 1 as well as the concentration of plankton. The shift in September of Daphnia from Area 1 to Area 2 may possibly be the result of the increased occurrence of easterly winds in that month. It was also in September when the first substantial increase in kokanee numbers was found in Area 2, the first evidence of dispersal.

Even discounting the influence of currents, from June through August I found an apparent positive correlation between the numbers of kokanee and zooplankton. In September when the peak of abundance of total zooplankton shifted to Area 3, the first dispersal of kokanee was noted. When tested, this relationship was shown to be non-significant, probably because of the large variation in catch of kokanee caused by their schooling habit. Kerns, et al. (23, p. 9) also found a distinct relationship between young sockeye and zooplankton in Iliamna Lake.

There also appears to be a positive, but not necessarily causal, correlation of kokanee abundance with slightly lower temperatures; this relationship was also statistically non-significant. The cooler water temperatures in Area 1 probably resulted from wind action and the flows of the main tributaries, Trapper and Crystal Creeks, which enter there.

Vertical Distribution

Since the data presented here are all from nocturnal sampling, the results describe the vertical distribution of kokanee fingerlings for a period shortly after dark. The influences and changes in distribution seen here are a seasonal trend rather than an indication of daily distribution.

Temperature has been related to fish distribution in studies by Dendy (8), Odell (26), and Hile and Juday (12). Dendy (8, p. 131-132) reported that the middle 50 percent of a species distribution fell within a certain temperature range and that distribution was uniform when the lake was homothermal. It was the opinion of Odell (26, p. 333) that the need for low temperatures is the principle factor governing the distribution of deep-water fishes. Hile and Juday (12, p. 181) found no clearcut relationship between fish distribution and temperature. These studies were complicated by a deficiency in dissolved oxygen in some cases. Lorz (24, p. 55) cited Clemens, et al. (6) and Ferguson (9) as reporting that kokanee were found in intermediate depths in lakes in the Okanagan Valley during the summer because of thermal barriers presented by thermoclines. Lorz also cited Tokui (34) as finding young kokanee near the surface in June and descending as temperatures rose. In Lake Pend Oreille, according to Jeppson (18, p. 10), kokanee are at greater depths when illumination is good and surface waters are too warm.

Lorz did his work on the diel vertical distribution of maturing kokanee in Nicola Lake, British Columbia. He concluded that since the fish made regular vertical migrations thru an unstable thermocline, temperature could not have been the factor directly controlling vertical distribution (24, p. 55).

Most of this work tends to substantiate the contention expressed by Ferguson (10, p. 607). He stated that temperature alone could determine the distribution of fishes in laboratory experiments, but light, feeding responses, and social behavior interfere with the response to temperature under natural conditions. This is undoubtedly the case in Odell Lake, but temperature is apparently the most important factor influencing the seasonal change in vertical distribution of kokanee. Although a multiple regression analysis indicates there was no significant relationship between kokanee and temperature over the period, the analysis did show a negative correlation with temperature and time taken together. This relationship probably results from the trend of descending distribution seen in the kokanee as the summer passed. This trend led to larger catches in colder water.

It is difficult for me to discount temperature as an influence on the distribution of kokanee since there is strong evidence indicating that these fish seek a limited range of temperature. As surface temperature rose, the fingerlings began grouping in the vicinity of the thermocline. The temperatures where the modes of kokanee distribution were found ranged from 9.7 to 12.6 C with mean of 11.1 C. This agrees quite well with the findings of other workers. In laboratory experiments, Brett (4, p. 300) found the preferred temperature for young sockeye salmon to be 12-14 C. Horak and Tanner (16, p. 142-143), working at Horsetooth Reservoir, Colorado, found kokanee within a range of 7.8-18.3 C with most being caught between 10.6 and 13.8 C.

The upper lethal temperature for kokanee, when acclimatized at 11 C, was reported to be 22 C by Black (3, p. 207). Brett (4, p. 305-306) recorded the ultimate upper lethal temperature as being

24.4 C for fingerling sockeye. Since the highest temperature recorded at Odell was 18 C, there theoretically should not have been any lethal thermal barrier to the distribution of kokanee.

A positive correlation between kokanee abundance and time was indicated by a t ratio of 1.804 (significant at the 10 percent level) in the multiple regression analysis. The only explanation I can offer for this relationship is that as the summer passed, the vertical distribution of kokanee became more restricted. This bunching resulted in some larger catches as the sampling period progressed.

The concentration of dissolved oxygen was discounted as a factor influencing vertical distribution in this study, since the lowest concentration found was 8.6 mg/l. It is assumed that these conditions did not influence the movements of kokanee fingerlings.

The sockeye salmon, kokanee included, are known primarily as feeders on plankton and their vertical distribution may be influenced by the movements of these food organisms. From his studies at Cultus Lake, British Columbia, Ricker (28, p. 454) postulated four factors which could account for the feeding by young sockeye on different plankters. He felt that abundance and size of the organism was important; the larger and more abundant animals were taken most frequently. Selection of habitat probably plays a part in the degree of usage in that a group of plankters that is isolated from others may not attract foraging. The characteristics of the animals such as agility, conspicuousness, and differences in diel migration of predators and prey may govern the usage. Ricker also revealed simple preferences exhibited by individual fish in choosing their food (28, p. 460). He concluded that the numerical ratio of plankters in the stomach as compared to that in the environment corresponds to the relative availability of the plankters. These findings were exemplified in the results of my study and the work done by Stross (33, p. 81-84) on Lake Pend Oreille, Idaho. Stross found that Daphnia were most often taken although Cyclops were more abundant; probably because Daphnia were larger.

Kokanee fingerlings in Odell Lake showed the greatest preference for Diaptomus. The latter are large, probably conspicuous, and select habitat similar to that of the kokanee. The smaller Cyclops, always more plentiful than Diaptomus, were taken least. Daphnia were taken in proportion to their presence in the plankton and only in August and September when they greatly outnumbered Diaptomus did did they occur more frequently in the stomach samples. Daphnia, unlike Cyclops and Diaptomus, did not show a selection of habitat similar to that chosen by kokanee.

Foerster (11, p. 402) found Cyclops confined to deeper waters in Cultus Lake and hypothesized that this tended to explain the absence of young sockeye in surface waters since Cyclops represented 75 percent of their food. Working at Lake Pend Oreille, Jeppson (18, p.

10), observed small kokanee feeding at the surface on summer evenings. He believed that they followed the plankton migration into the warmer water for brief feeding periods. He also stated that most of their foraging was between 18-50 feet, but that when surface waters were too warm the kokanee went deeper. Lorz (24, p. 59) reported some relationship between the vertical distribution of maturing kokanee and their diet. Early in the summer the fish were found at the surface feeding on emerging chironomids.

No definite conclusion can be made as to the short term effect of food organisms on the vertical distribution of kokanee on the basis of the data from my study.

The apparent seasonal correlation between kokanee and Diaptomus was verified by the multiple regression analysis. This relationship may have been caused by kokanee seeking Diaptomus, since the fingerlings did exhibit an apparent preference for the copepod, or may merely be coincidental because the predator and prey have common habitat.

At Odell Lake, densities of kokanee were found to be greater at the surface under moonlight conditions and lower in darkness. A positive phototaxis to light cannot be implied under the circumstances. It is my feeling that the fish may have been attracted to the surface by their prey in moonlight conditions, but were not attracted to feed when moonlight was not available.

Sockeye fry were found by Hoar (14, p. 91) to prefer deep water and remain under cover when exposed to strong light. He observed that sockeye smolts often came nearer to the surface than fry and suggested that the cause was the activity of the smolts resulting in wider vertical distribution especially under reduced light. Later, Hoar, Keenleyside and Goodall (15, p. 830), saw older fry rise into shallow water and brighter light but still not show a preference for stronger light. The kokanee distribution in Nicola Lake was seen by Lorz (24, p. 57) to suggest a negative phototaxis in 1961, while he saw no such relationship in 1959. He could not determine whether the response was caused directly by light or some associated factor.

In his work on Atlantic salmon, Salmo salar Linnaeus, and brook trout, Hoar (13, p. 90-101) observed little feeding during the period from 1-2 hours after sunset to 1-2 hours after sunrise, but he also found that Atlantic salmon were able to feed in complete darkness. Ali (1, p. 984) discovered that fingerling sockeye are able to feed under .0001 footcandle of light by silhouetting their prey against the light background.

With these findings in mind, it seems reasonable that the fingerlings found at the surface on light nights were taking advantage of an opportunity to feed. No clearcut relationship was evident between the stomach contents of the kokanee and the distribution of zooplankton to support this theory.

In summation, it is my contention that the horizontal distribution of kokanee fingerlings observed in this study was caused by their naturally reluctant dispersal from the spawning area being reinforced by the abundance of food and current action. Seasonally, temperature of the water exerts the primary influence on vertical distribution, with zooplankton possibly exhibiting some modifying effects.

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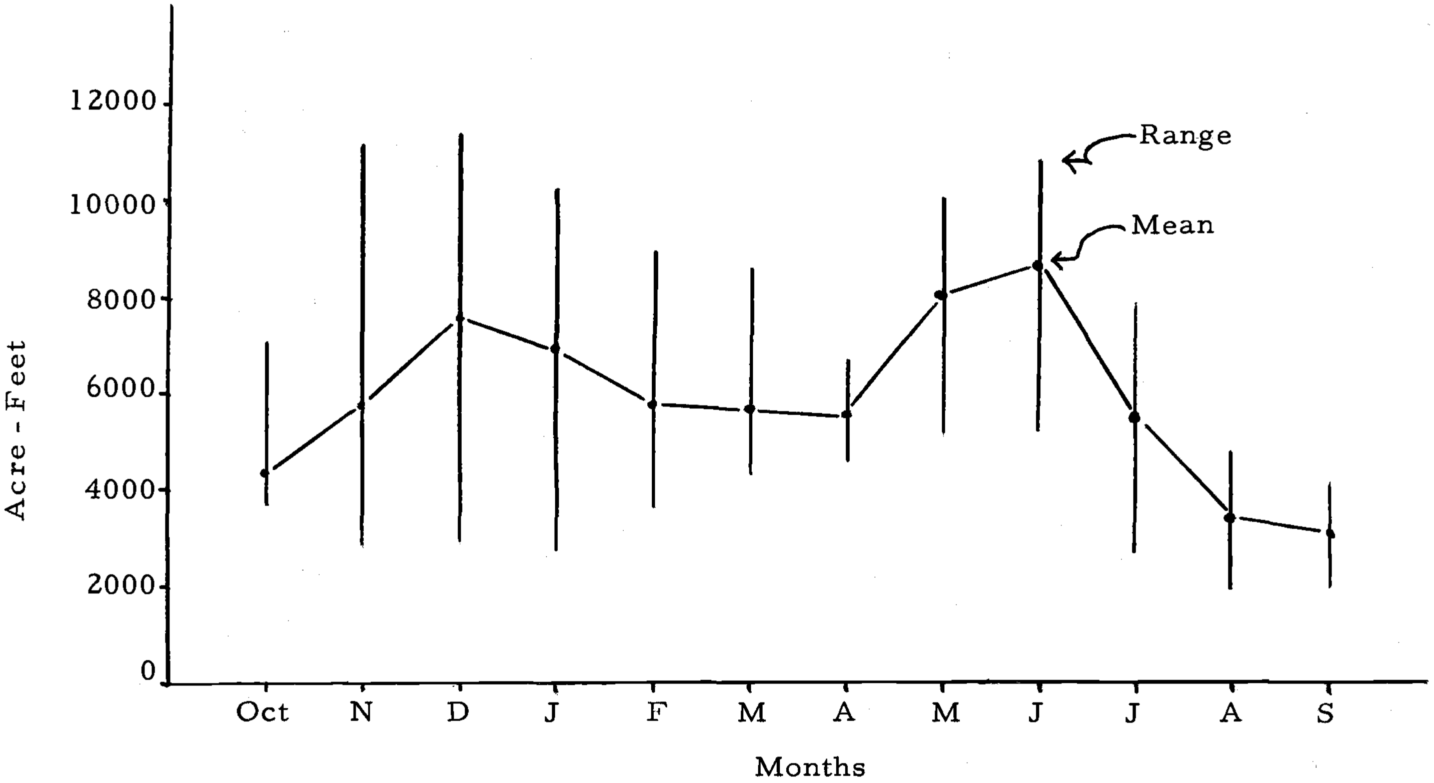
APPENDICES



Appendix A: Mean monthly discharge through Odell Creek; 1950-1960[1]

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[1] Data from U. S. Geological Survey Water-Supply Paper 1738 (34).

APPENDIX B

Light Values

Moonlight / Cloudiness	Dark = 1	1/4 Moon = 2	1/2 Moon = 3	3/4 Moon = 4	Full = 5
100% = 1	1	2	3	4	5
75% = 2	2	4	6	8	10
50% = 3	3	6	9	12	15
25% = 4	4	8	12	16	20
Clear = 5	5	10	15	20	25