FRI-UW-7408
June 1974

FISHERIES RESEARCH INSTITUTE
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PRELIMINARY ASSESSMENT OF THE EFFECTS OF GRAND COULEE PUMPED/STORAGE DEVELOPMENT ON THE ECOLOGY OF BANKS LAKE, WASHINGTON

by

Q. J. Stober, P. B. Roger, W. A. Karp, G. L. Thomas,
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ANNUAL PROGRESS REPORT

June 11, 1973 to May 31, 1974
Contract Number 14-06-100-7794 (Neg.) with

U. S. Bureau of Reclamation
Pacific Northwest Region Office
Boise, Idaho

Approved

Submitted: June 28, 1974

Robert L Burgner
Director

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1.0 SUMMARY

The overall objective of this investigation is to establish an ecological baseline for the lake, and on the basis of this knowledge, to assess the operational effects of the pump-generating units as well as irrigation drawdown on the limnology and fish community of Banks Lake. Detailed studies are focused on the physical and chemical limnology, fish abundance and distribution and entrainment of larval, juvenile, and adult fishes through the generating units.

Banks Lake supports an important sport fishery resource in eastern Washington for both salmonid and spiny ray fishes. A part of the U. S. Bureau of Reclamation Project to increase the electrical generating capacity of the Grand Coulee Dam complex includes the eventual installation of six pump-generating units (two presently installed) in the pumphouse supplying Banks Lake from Franklin D. Roosevelt Lake. The pump-generators will produce electrical peaking energy needed during the winter months from October to March by drawing some water from Banks Lake back into Roosevelt Lake.

Limnological investigations have indicated that Banks Lake is a very complex system dominated by the flow-through of irrigation water. Surface temperatures were found to increase (north to south) from 17.4 to 23.2 C, from 19.7 to 22.8 C and from 18.9 to 23.2 C during July, August, and September, respectively. Water pumped from the cool depths of Roosevelt Lake gradually

became warmed as it flowed southward toward the irrigation canal. Other factors complicating the lake environment besides irrigation input and withdrawal include basin morphometry, water level fluctuation and climatic conditions. During the remainder of the year while the lake was at maximum elevation the thermal characteristics of a typical north temperate lake predominated. The biological responses of the lake organisms to the temperature gradient throughout the 27-mile length of the lake provide a most interesting phenomenon for study. The standing crop of phytoplankton and zooplankton is being assessed along with the chemical water quality parameters of the lake.

Eighteen species of fish have been identified in Banks Lake. Of these, yellow perch, lake whitefish and kokanee were found to be most abundant, constituting 95% of the total gill net catch. The three most numerous species were selected for detailed study of relative abundance, distribution and life history factors. The sampling design and gear types which are being used in the canal entrainment studies have been reviewed.

2.0 ACKNOWLEDGMENTS

The Institute staff responsible for the various studies reported herein are listed as follows:

Dr. Q. J. Stober, Principal Investigator
Dr. R. E. Nakatani, Co-principal Investigator
Mr. P. B. Roger, Project Leader
Mr. G. L. Thomas, Ph.D. candidate, fish population studies
Mr. W. A. Karp, M. S. candidate, limnology studies
Mr. D. T. Griggs, M. S. candidate, canal entrainment studies
Dr. R. E. Thorne, Senior Research Associate, acoustic surveys
Mr. J. J. Dawson, Fishery Biologist, acoustic surveys

This investigation is being conducted under contract with the U. S. Bureau of Reclamation, Pacific Northwest Region Office, Boise, Idaho. The cooperation received from the Washington Department of Game is greatly appreciated. The assistance of Dr. R. R. Whitney, Leader of the Washington Cooperative Fisheries Unit has been valuable in accomplishing project goals and objectives. Dr. Richard Casteel of the U. W. Burke Museum provided assistance in whitefish scale analysis. Mr. Rufus Kiser was helpful in relating his early limnological observations on Banks Lake. The Western Washington Bass Club cooperated by providing largemouth bass catch statistics obtained by its membership. The hourly assistance of Messrs. C. Schaye, J. Hansen and J. Yarmouth is also appreciated.

3.0 INTRODUCTION

The present study was initiated to determine the effects of pumped/storage development on Banks Lake. This environmental impact assessment will provide data on one of the first pump/storage power generation plants to become operational in the northwest. The objectives of this comprehensive investigation include: 1) evaluation of the extent of physical and chemical changes in water quality due to seasonal and operational effects; 2) assessment of the composition, relative abundance and distribution of Banks Lake fish populations; 3) evaluation of the effects of lake water level fluctuations upon the spawners utilizing the lake littoral zone; 4) estimation of the gain or loss of fish larvae, juveniles or adults due to entrainment through the pump/generators and irrigation canal; 5) determination of the response of the recreational fishery to possible reduced fish recruitment, redistribution of fish populations and/or changes in a portion of the north Banks Lake winter ice cover. This study is designed to determine a pre- and post-operational ecological baseline.

This report covers a period (June 11, 1973 to May 31, 1974) of the baseline study prior to operation of the pump/generators for power production. Three major investigations are being conducted which include, 1) the limnology of the lake, 2) fish population assessment, and 3) canal entrainment. The former two studies will establish the existing ecological baseline conditions for the lake while the latter will assess the direct effects of fish entrainment through the feeder and irrigation canals.

3.1 Description of Study Area

Banks Lake is an artificial impoundment occupying the upper Grand Coulee, a former channel of the Columbia River, in central Washington State (Fig. 3-1). Banks Lake was created in 1951 to serve as the equalizing

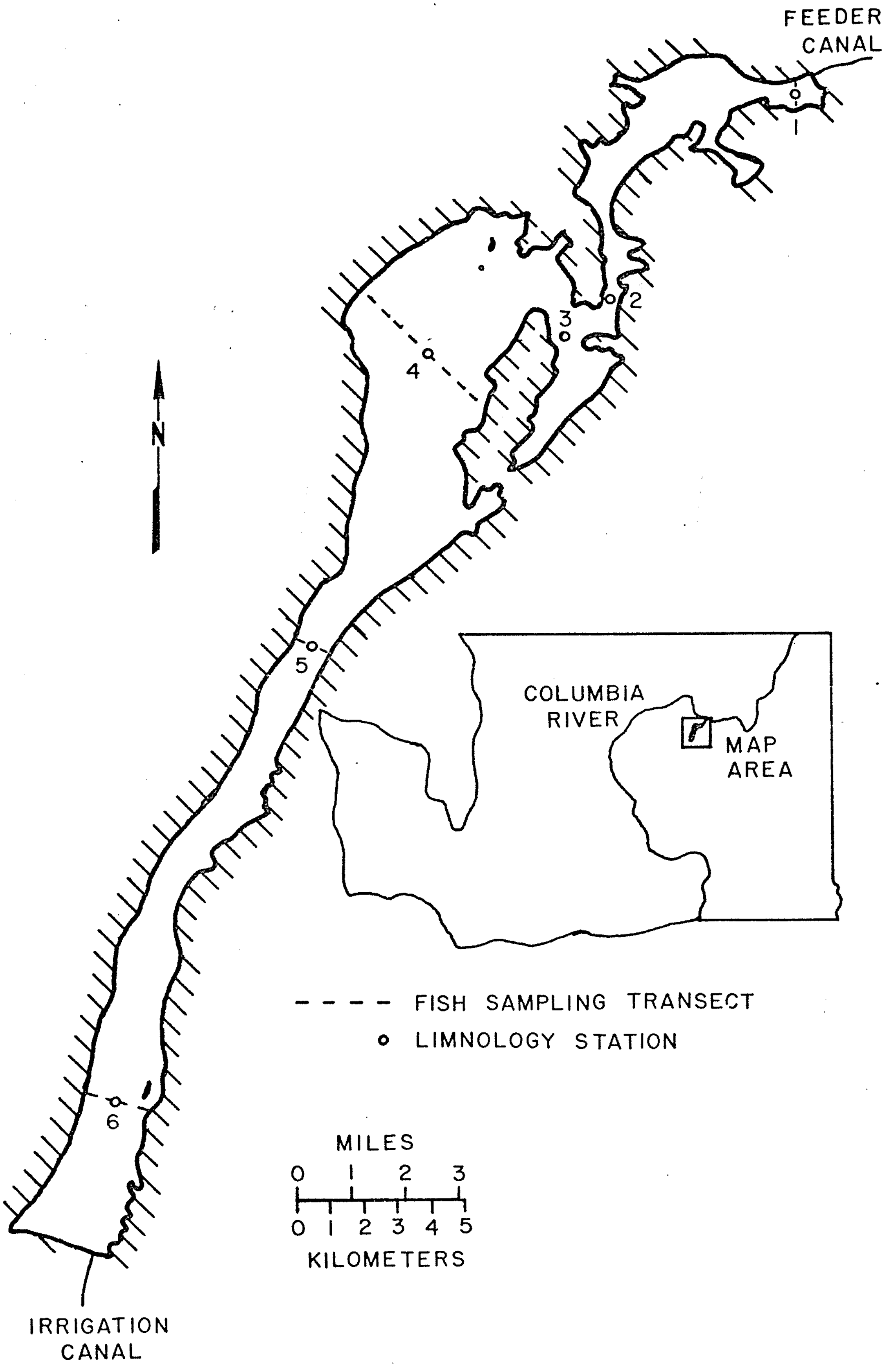

Fig. 3-1. Banks Lake showing limnology and fish sampling sites.

reservoir for the Columbia Basin irrigation project. The lake is 43.4 km (27 miles) long, contains 1.48023 x 10^5 hectare meters (1.2 million acre feet) of water covering a surface area of 11,008 hectares (27,200 acres) to a depth of about 22.9 m (75 ft) at a water level elevation of 478.5 m (1,570 ft) msl (Table 3-1).

The main features of Banks Lake include a pumping plant situated adjacent to Franklin D. Roosevelt Lake at the left forebay of Grand Coulee Dam. Water is pumped up 111.2 m (365 ft) and discharged into a 2.5 km (1.6 mile) long feeder canal which conveys water into Banks Lake. The pumping plant contains six pumps, each rated at 487.7 cubic meters per second (m^3/sec) (1,600 cubic feet/second) and two pump-generators rated at 533.4 m^3/sec (1,750 cfs). The head at the pump intake may vary 25.0 meters (82 ft) due to fluctuations in the levels of Roosevelt Lake. The North Dam and Dry Falls Dam are the containment structures for Banks Lake. Head works for the irrigation canal are located in Dry Falls Dam. Water for irrigation is withdrawn from Banks Lake through Dry Falls Dam at a maximum rate of 2,286 m^3/sec (7,500 cfs). Modifications presently being made to the irrigation canal will increase capacity to 2,407.9 m^3/sec (7,900 cfs).

Significant fluctuations occur in the surface level of Banks Lake as a result of irrigation withdrawal. The irrigation season normally begins in late March and ends in late October each year. Banks Lake typically reaches a maximum drawdown of 1.5 to 4.6 meters (5 to 15 ft) in May. Pumping into the lake increases with spring runoff in the Columbia River and full elevation in Banks Lake is usually achieved during August. This cycle varies somewhat depending on yearly variations in irrigation demand, rainfall, runoff, and power demand. Maximum fluctuations in the level of Banks Lake of 7.9 meters (26 ft) in 1963 and 7.6 m (25 ft) in 1973 resulted from drawdown required by construction, low runoff or high power demands.

Table 3-1. Morphometric characteristics of Banks Lake.

	Elevation	Area (acres)	Volume (acre-ft)	Maximum Length (mi.)	Maximum Width (mi.)	Mean Depth (ft)
Maximum Level	1,570 478.5 m	22,200 11,008ha	1,202,000 148,269 ha m	27 43.5 km	5.0 8.0 km	44.2 13.5 m
Pumped/Storage Drawdown (max.)	1,568 477.9 m				5.0 8.0 km	
Irrigation Drawdown:						
5 feet	1,565 477.0 m	26,100 10,562ha	1,068,000 131,740 ha m	27 43.5 km	5.0 8.0 km	40.9 12.5 m
15 feet	1,555 474.0 m	23,200 9,389ha	822,000 101,394 ha m	27 43.5 km	4.9 7.9 km	35.4 10.8 m
Maximum Drawdown	1,540 469.4 m	19,000 7,689ha	506,000 62,416 ha m	27 43.5 km	4.9 7.9 km	26.6 8.1 m

In the future, Banks Lake will be used as a pumped storage/power generating reservoir in addition to an equalizing reservoir for irrigation. This project will ultimately include the addition of six pump-generating units to the present six pump facility. The new units will be used to provide peaking power during the period from October through March by drawing some Banks Lake water back into Roosevelt Lake. The new pump-generating units will each produce 50,000 kw each. The first two units, P/G 7 and 8 are installed and scheduled to become operational in fall, 1974.

Pumped-storage power generation will normally occur during morning and evening peak electrical demand periods with pumpback during the night off-peak hours or during weekends. Under heavy peak power demand the units could operate nine hours per day for up to ten days before pumpback would be required. When all six pump/generators are installed, Banks Lake would be drawn down 6.1 cm (0.2 ft) per day with a normal maximum drawdown of up to 60.9 cm (2.0 ft). The normal capacity of the feeder canal for the generating mode is 3,200 m^3/sec (10,500 cfs) without modification and 3,810 m^3/sec (12,500 cfs) with modification of the canal.

3.2 Sport Fishery

Since its creation Banks Lake has supported an increasingly important sport fishery. The Washington State Department of Game lists sixteen species of fishes commonly occurring in Banks Lake of which rainbow trout (*Salmo gairdneri*), kokanee (*Oncorhynchus nerka*), yellow perch (*Perca flavescens*), and black crappie (*Pomoxis nigromaculatus*) constitute the bulk of the sport catch (Duff, 1973). A creel survey conducted in 1971-72 estimated angler usage of Banks Lake at 92,236 fisherman-days and a catch of approximately 81.6 m tons (90 tons) of fish with a direct value to the angler of approximately $1.6 million (Duff, 1973). This represents a 300 percent increase in fishing intensity since 1965. The weight of fish taken was about evenly divided between trout and spiny ray fishermen.

4.0 LAKE LIMNOLOGY

4.1 Introduction

The limnological investigations have been coordinated with the fish population and entrainment studies in a comprehensive approach to understanding the lake as an ecosystem and to examine the effects of irrigation withdrawal, water level fluctuations and pumped storage operation. The specific objectives of the limnological program are to index the spatial and temporal changes in the physical and chemical limnology and in the phytoplankton and zooplankton standing stocks. The physical and chemical parameters under investigation include the monitoring of temperature, transparency, conductivity, dissolved oxygen, pH, total alkalinity, total hardness, nitrate and phosphate levels. Preliminary studies have indicated that the standing stock of macro-invertebrate benthos in the lake is extremely low and constitutes a relatively small component of the fish diet. Therefore, this aspect is presently receiving minimal effort.

4.2 Materials and Methods

Initial limnological measurements were made during July and August 1973 which provided data necessary in the determination of the location of the sampling stations. A minimum of six stations was needed to describe the lake environment. Stations were established at maximum midlake depths along its length. From north to south sampling stations were located near (1) the feeder canal, (2) north and (3) south of the constriction near Steamboat Rock; (4) west of the southern end of Steamboat Rock; (5) adjacent to Million Dollar Mile; and (6) at the south end of the lake, near Dry Falls Dam (Fig. 3-1). Stations 1, 4, 5 and 6 were also used as fish sampling stations.

Stations 2 and 3 were selected to allow the phenomena associated with the narrowing and shoaling of the lake in this area to be examined. Water level drawdown as well as lateral narrowing and shoaling of the lake at this point all contributed to changes in the lake limnology during certain times and operating conditions which separate the lake into two generally distinct regions.

A monthly sampling program was adopted for limnological observations. On occasion it was necessary to modify this plan due to weather conditions or equipment problems. During the December sampling period severe weather conditions prevailed and observations were not taken at Stations 2 and 3. Sampling was not conducted in January 1974 or in February at station 6 due to an unstable ice cover.

4.2.1 Physical Measurements

All temperatures were taken with a thermistor probe. In the early stages of the project a Beckman Model RS-5 temperature-conductivity probe was used. Since November 1973 a Hydrolab temperature probe has been used as a replacement. Vertical temperature measurements were recorded from the surface to the bottom in 4 m depth intervals. If more precise determination of the thermocline was required, readings were taken at 0.5 or 1 meter intervals.

Transparency was measured with a standard 20 cm diameter Secchi disc (Tyler, 1968). Readings were taken by lowering the disc over the shaded side of the boat until it disappeared and then raising it until it just became visible. The mean of these two depths was then recorded. All observations were made with the aid of polarizing sunglasses.

4.2.2 Chemical Measurements

Water samples for chemical and chlorophyll 'a' analysis were taken at 3 depths at each station with three 2.5 liter Van Dorn bottles. Samples were taken at the surface, 4 meters and near the bottom.

A Hach Model DR-EL direct reading Engineers Laboratory was used to analyze the water quality samples in the field. Total hardness was determined in p.p.m. $CaCO_3$. Total alkalinity was determined by the Hach method involving titration with standard sulfuric acid against a bromocresol green-methyl red indicator and was expressed in p.p.m. $CaCO_3$.

Dissolved oxygen was determined by the Hach modification of the Winkler titration. Dissolved oxygen samples were chemically fixed in the field and titrated in the laboratory. Results were expressed in p.p.m. dissolved oxygen and percentage saturation was calculated from a table of saturation values.

A Photovolt expanded scale pH meter was used to determine the pH in the laboratory.

The conductivity of Banks Lake water was measured *in situ* with a Hydrolab temperature-conductivity instrument. This instrument was specially modified to operate at conductivity readings less than 100 μmho/cm^2 and has been employed in the field since November 1973. Readings were taken coincidentally with temperatures at the surface, at 4 meter depth intervals and near the bottom.

Water for nutrient analysis was placed in 500 ml "Nalgene" plastic bottles and frozen in the field prior to transportation to the University for analysis. The Institute's water quality laboratory became fully operational in the spring of 1974 and results of analyses are available beginning in March 1974. Banks Lake water is being analyzed for ortho, dissolved and total phosphate and for total nitrate. The methods used are modifications of standard techniques (A.P.H.A., 1971).

4.2.3 Biological Measurements

Chlorophyll 'a' concentration was determined by the spectrophotometric method described by Richards and Thompson (1952) and by using the equation of Parsons and Strickland (1963). One drop of saturated aqueous $MgCO_3$ solution was added to each one liter water sample as it was collected. Samples were taken at three depths at each station. Each sample was filtered through a Millipore type RA (1.2 μ) filter, dried and refrigerated in a darkened dessicator for later analysis. Filters were dissolved in 90 percent aqueous acetone and absorbance of light at wavelengths of 630, 645, 665, and 750 mμ was determined with a Bausch and Lomb Spectronic 20 spectrophotometer within two weeks of collection.

In order to estimate the zooplankton standing stock at each station vertical hauls were made with a 0.5 m diameter plankton net of 73 μ mesh (No. 20). Duplicate hauls were made at each station from the bottom to the surface and from 4 m to the surface. The nets were hauled with a Warn electric winch at the approximate velocity of 30 meters per minute. All samples were preserved in 10% formalin. Volume sampled was determined by multiplying the area of the net opening by the distance hauled.

Replicate milliliter subsamples from each sample were counted over a grid with a zoom stereo microscope (10 - 30 x). The numbers per cubic meter and the percentage composition of each zooplankton genus were calculated at each station. Although clogging has been a problem with the 73 μ mesh net, the fine mesh size has been retained to provide additional data for phytoplankton species composition and zooplankton instar analysis.

4.3 Results and Discussion

4.3.1 Physical Characteristics

When observations began in July 1973, stratification was evident at stations 3, 4, 5 and 6. A trend of increasing surface temperature with distance, north to south, along the lake was detected, particularly between stations 2, 3 and 4. The maximum surface temperature observed in July was 18.5 C at station 4. The surface temperature increased between stations 2 and 3 from 15.5 to 18.0 C. During this period the pumping and irrigation withdrawal rates were approaching a maximum (Fig. 4-1), which resulted in large amounts of cooler water being introduced into the lake near station 1.

The air temperature began to decrease during August (Fig. 4-2), however, the maximum water temperatures were observed reaching 24.1 C at the surface of station 4. The surface temperature increased markedly between stations 1, 2, and 3 (19.5 C, 21.7 C, 24.0 C, respectively). This trend was also reflected at 4 m. Although some vertical stratification was evident at station 2 the stratification patterns for stations 3-6 were much more pronounced. The mean surface temperature was 22.3 C. The isotherm plots for August (Fig. 4-3) show the patterns of temperature change between stations and depths and indicate that the colder water which was being pumped into Banks Lake near station 1 was well mixed throughout the water column in this area. Maximum rates of water movement through the lake were evident during this time (Fig. 4-1). As the water moved south it was gradually warmed and by the time it reached station 2 had entered the constricted area of the lake. Between stations 2 and 3, there was an apparent sinking of this cooler water below a mass of warmer, less dense water. It appears that lake basin morphometry, water level drawdown, climatic conditions and the river-run characteristics of the lake caused by the operational input and

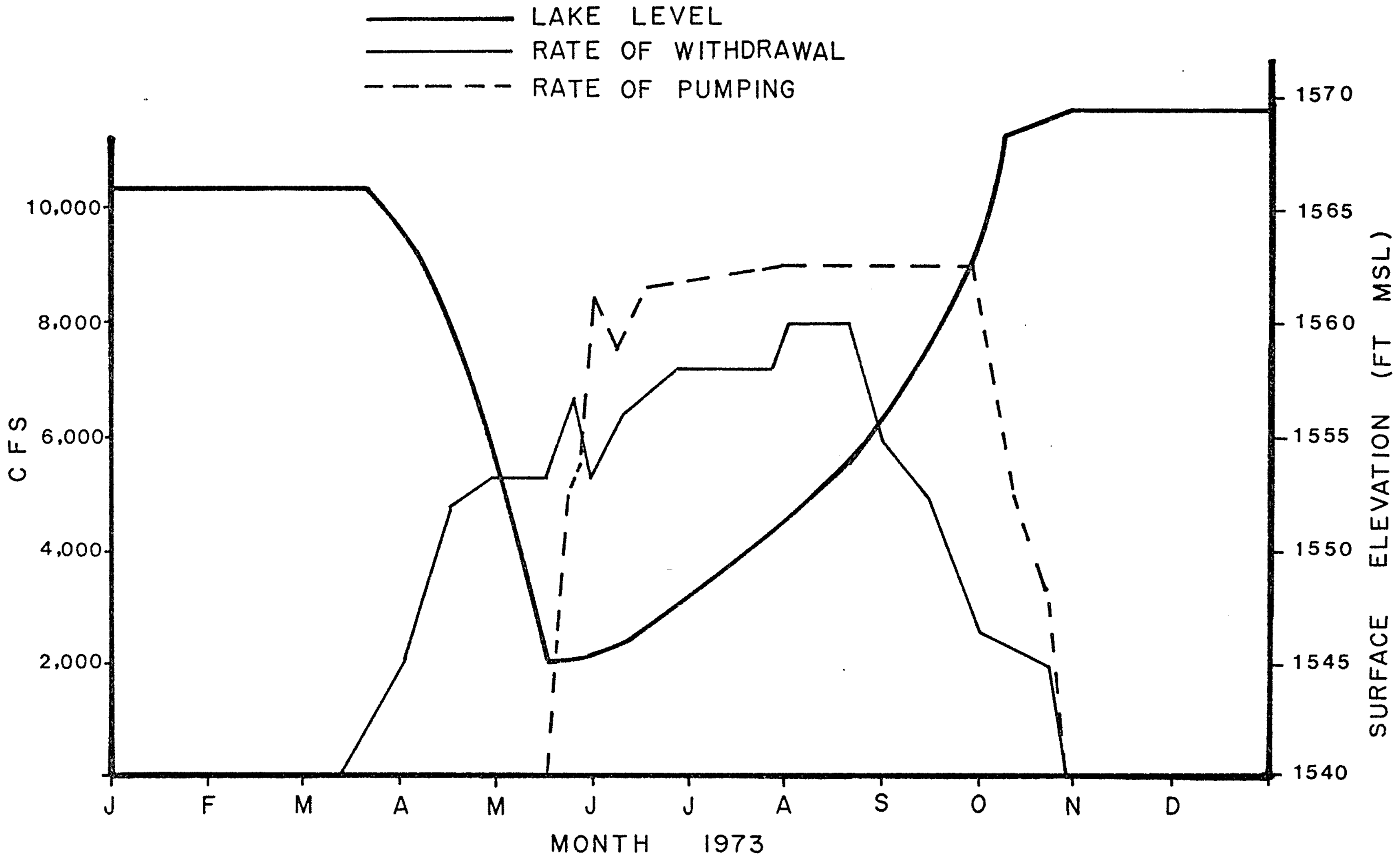

Fig. 4-1. Banks Lake surface elevation relative to rates of irrigation water input and withdrawal, 1973 (U.S.B.R.).

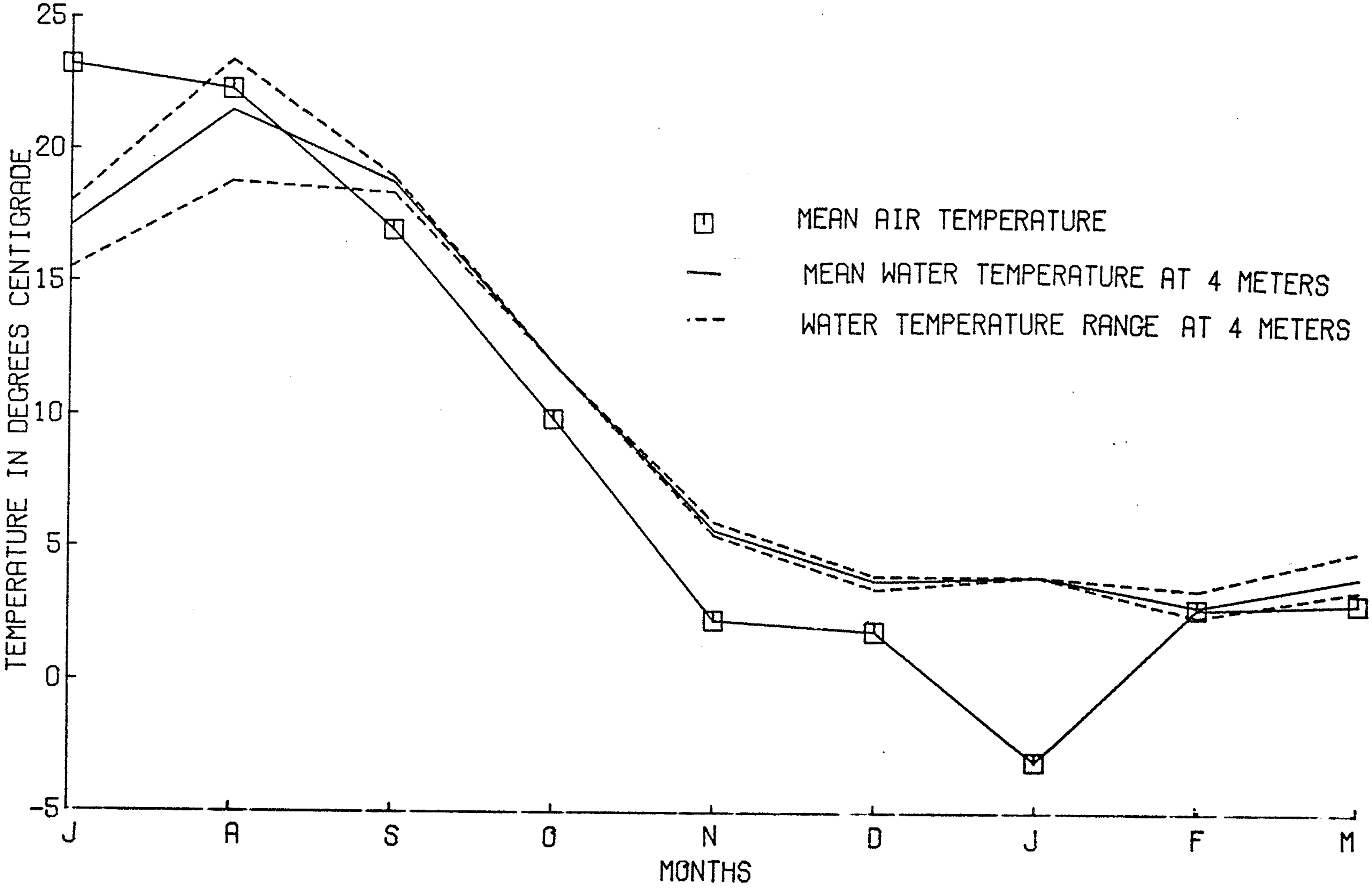

Fig. 4-2. Banks Lake mean water temperatures and range at 4 meters compared to mean monthly air temperatures for the period from July, 1973-March, 1974.

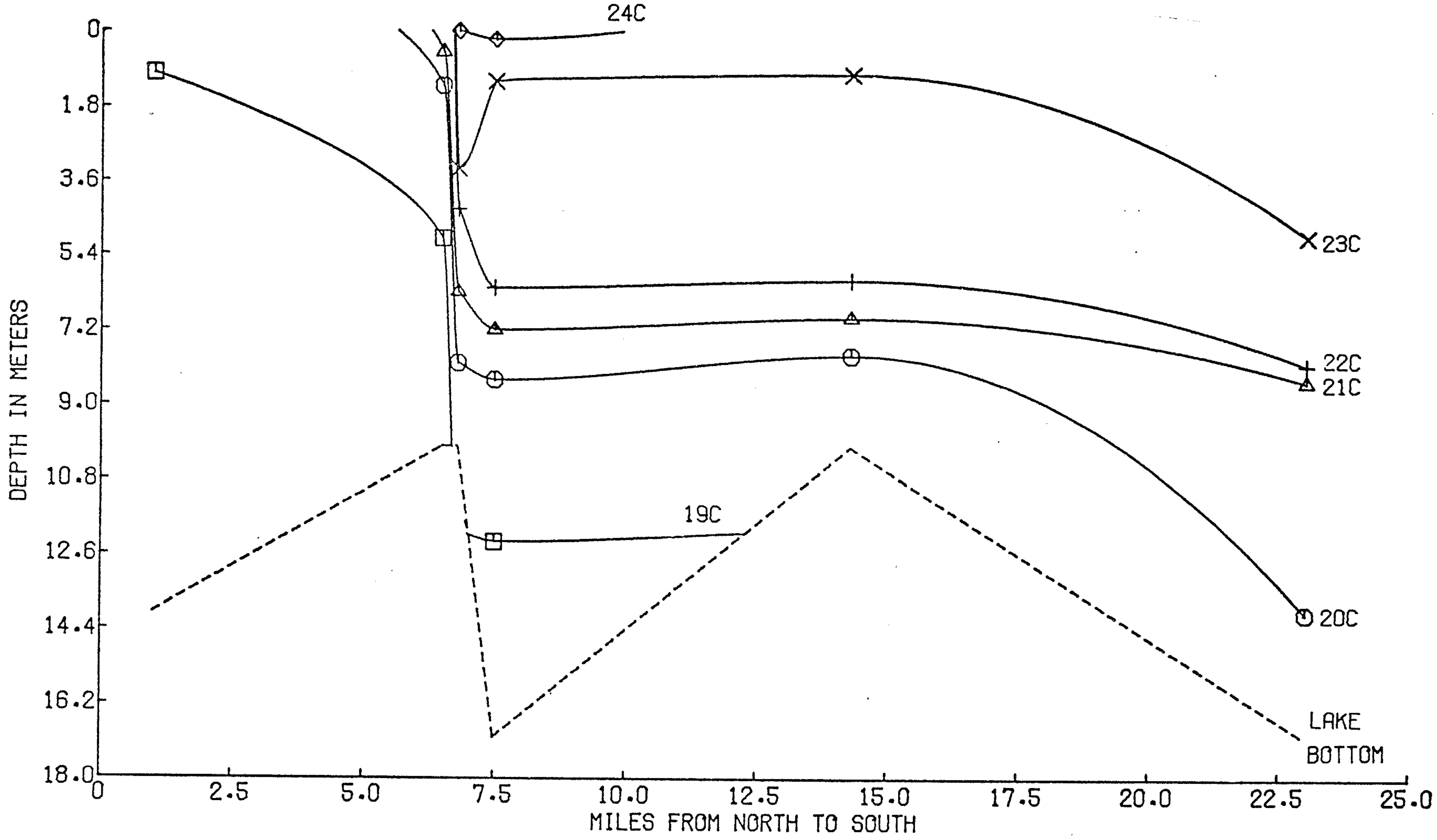

Fig. 4-3. Banks Lake isotherms (August 11, 1973) showing the convergence zone between mile 6 and 7 where the mass of cooler water from north Banks Lake was observed to sink beneath a lens of less dense warmer water south of mile 7.5.

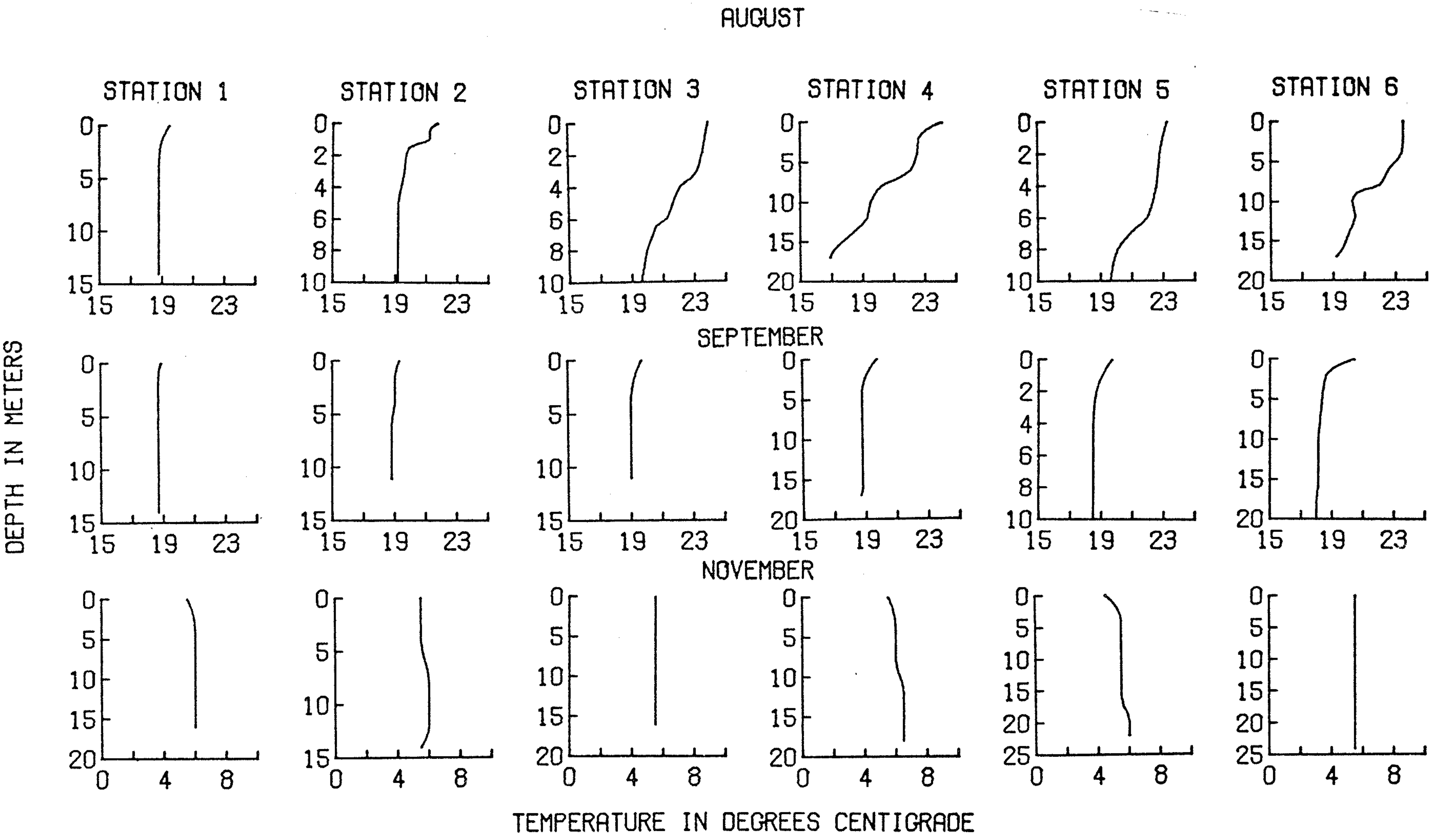

Fig. 4-4. Temperature profiles at stations 1-6 for August, September and November, 1973.

withdrawal of irrigation water contributed to the formation of a surface 'lens' of warmer water between stations 3 and 6. The colder more dense water from the north end of the lake sank beneath this lens at a convergence point between stations 2 and 3. This 'convergence zone' was clearly demarcated at the lake surface as a line across the lake at which floating detritus collected. The color and transparency of the water was often visibly different between stations 2 and 3 during the summer.

There was a decrease in surface water temperature in September (range 18.9 - 20.4 C; mean 19.6 C) and in air temperature (mean 17 C). The increase in surface temperature with distance south was still distinct as was the stratification, particularly at stations 3-6. The convergence zone was clearly evident although irrigation withdrawal was decreasing while pumped input to the lake was maintained at a maximum rate. The lake level was rising rapidly during this period.

Pumped input and withdrawal of water had virtually ceased by October (Fig. 4-1) and the air temperatures had decreased substantially (mean 9.9 C). Water temperature had decreased a considerable amount, (range 12 to 14 C). Water surface temperatures were higher at station 1 and decreased toward the south which was probably due to input of warmer water into north Banks Lake from Roosevelt Lake during the onset of a seasonal cooling trend. The convergence zone was no longer evident.

The November temperature profiles (Fig. 4-4) showed a further decrease in temperatures throughout the lake (range 4.5 - 6.5 C). Mean air temperature was 2.3 C. Some reverse stratification was observed probably due to surface cooling by wind. All pumping and withdrawals had ceased for the winter and the lake level had reached the maximum of 478.5 m (1,570 ft msl) (Fig. 4-1).

December temperature data showed patterns similar to those observed in November and a continued decrease in air temperature (mean 1.4 C). Surface water temperatures ranged from 3.0 to 3.5 C. In January the lake had complete ice cover (mean air temperature - 3.0 C). Ice cover remained only at station 6 in February. Almost no stratification was detected in February except at station 5 where the ice cover had recently disappeared and a slight reverse stratification was found.

During March, the lake was completely free of ice and surface temperatures were the same or only slightly warmer than in February. There was slight stratification at stations 1 and 6 (Fig. 4-5).

Temperature observations characterize Banks Lake as a complex river-run reservoir during the irrigation season which reverts to the thermal characteristics of a typical north temperature lake during the remainder of the year.

Secchi depth transparency data is presented for the period from July 1973 (Table 4-1). Station 6 exhibited the greatest transparency from August to March. There appeared to be a steady trend towards reduced transparency with time from September to March. Observations suggest that changes in transparency in Banks Lake may be due either to wind induced turbidity and/or phytoplankton blooms.

4.3.2 Chemical Characteristics

The observed values for total hardness ranged from 55 to 80 p.p.m. calcium carbonate. No clear patterns by station, depth or time were apparent. Kiser (unpublished, undated report) reported total hardness values of 70 to 95 p.p.m. calcium carbonate at Steamboat Rock in 1964 and 1965.

The observed values for total alkalinity ranged from 55 to 80 p.p.m.

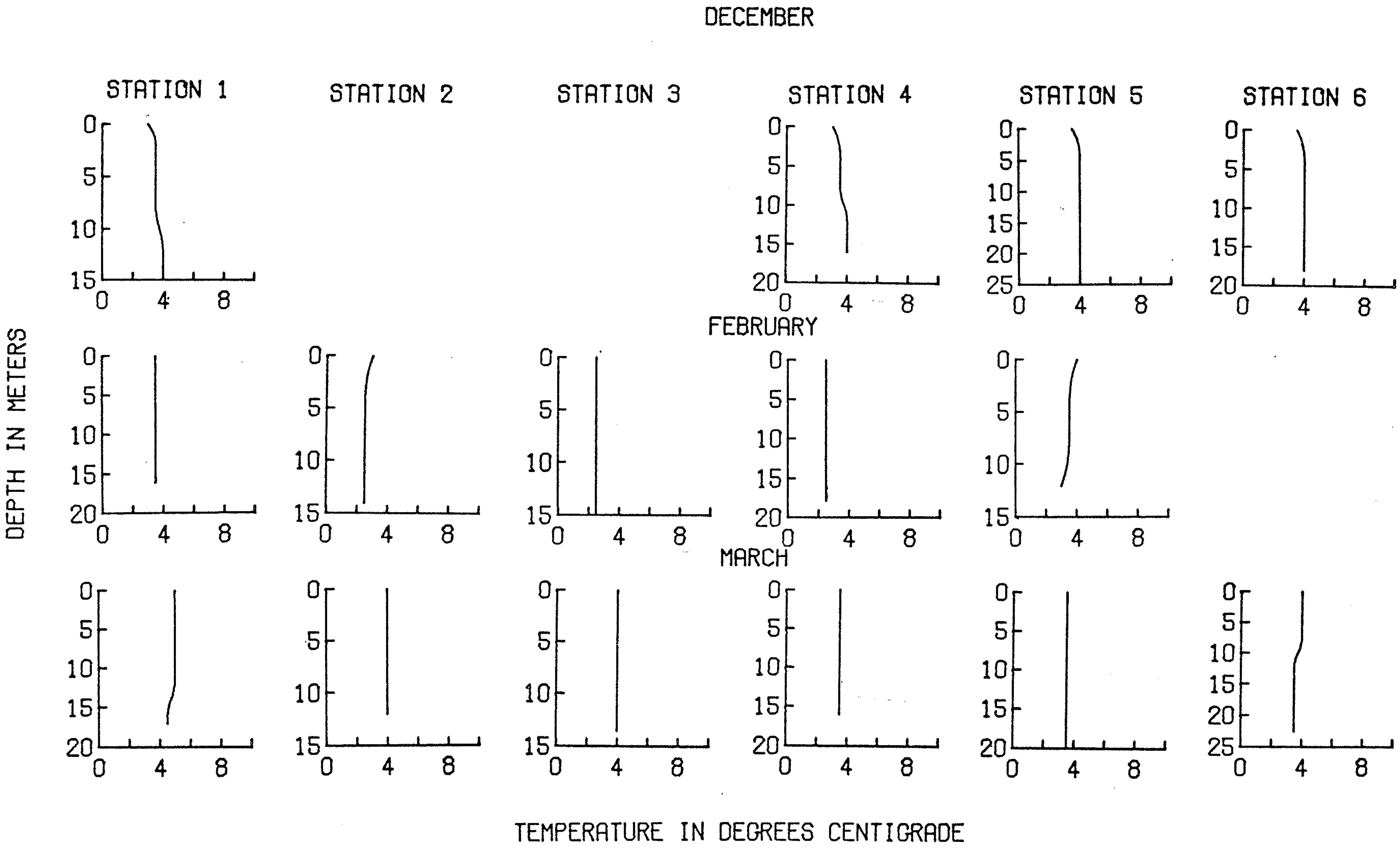

Fig. 4-5. Temperature profiles at stations 1-6 for December, 1973 and February and March, 1974.

Table 4-1. Banks Lake secchi depth transparency by station and month in feet.

Station	July	August	September	October	November	December	February	March
1	4.0	4.0	6.0	3.0	3.0	3.0	4.5	2.0
2	4.0	3.0	4.0	3.0	3.0	3.5	2.0	1.5
3	3.0	3.5	3.0	4.0	3.0	3.5	2.0	1.5
4	NA	6.0	7.0	4.0	2.0	3.5	2.0	1.8
5	3.7	6.5	3.0	5.0	3.0	4.0	4.0	2.0
6	2.0	7.0	7.0	6.0	3.0	7.0	ice	4.0

calcium carbonate. No trends in the results by station, depth, or time, could be seen. Kiser reported total alkalinity values of 64 to 80 p.p.m. calcium carbonate at Steamboat Rock in 1964 and 1965.

Saturation levels of dissolved oxygen were at least 85% or greater except for the following: in August, near the bottom at station 4 (17 m) and station 6 (18 m) had 58% and 73% saturation, respectively. Banks Lake did not experience any significant oxygen depletion during the period August 1973 to March 1974 while the lake was ice free. Although samples were not taken during the brief period of ice cover, observations made soon after the ice had thawed showed high levels of oxygen saturation.

The pH readings ranged from 7.2 to 9.0. No trends in the results, by station, depth or time were observed. Kiser reported pH values of 7.2 to 8.4 at Steamboat Rock in 1964 and 1965.

Conductivity data are available for November and December 1973 and February 1974. The observed range was 88 to 98 μmho/cm^2 through this period. At most stations, a slight increase (1 to 4 μmho/cm^2) in conductivity with depth was evident; however, other trends were lacking.

Nutrient data are only reported for March 1974 (Table 4-2). Further data is required before a trend analysis will be attempted.

4.3.3 Biological Characteristics

Chlorophyll 'a' distribution generally varied little with depth. No consistent pattern of abundance with depth was noticeable within or between stations during the period from September to March.

Chlorophyll 'a' concentrations were greatest south of Steamboat Rock (stations 4, 5 and 6) in October and were greatest in north Banks Lake (station 1) in November (Fig. 4-6). The delayed peak in abundance at station 1 was related to the cessation of pumped input and irrigation

Table 4-2. Banks Lake nitrate and phosphate analysis by station and depth for March, 1974.

Station	Depth	Phosphate Ortho ppb	Phosphate Hydrolyzable ppb	Phosphate Total ppb	Nitrate Total ppb
1	0	16.0	37.5	47.5	10.8
	4	16.0	30.0	45.0	5.4
	16	16.0	30.0	50.0	5.4
2	0	18.9	40.5	62.5	60.0
	4	18.9	32.5	60.0	25.4
	12	21.6	37.5	70.0	50.0
3	0	13.5	32.5	57.5	19.3
	4	16.0	25.0	52.5	16.9
	12	18.9	30.0	55.0	15.4
4	0	16.0	27.5	50.0	22.3
	4	13.5	30.0	50.0	15.4
	16	16.0	27.5	45.0	11.5
5	0	16.0	35.0	80.0	15.4
	4	13.5	25.0	50.0	13.0
	20	16.0	25.0	42.5	11.5
6	0	18.9	30.0	55.0	21.5
	4	21.6	30.0	75.0	14.6
	20				20.8
Mean		16.9	35.0	63.2	22.2
Minimum		13.5	25.0	42.5	5.4
Maximum		21.6	40.5	80.0	60.0

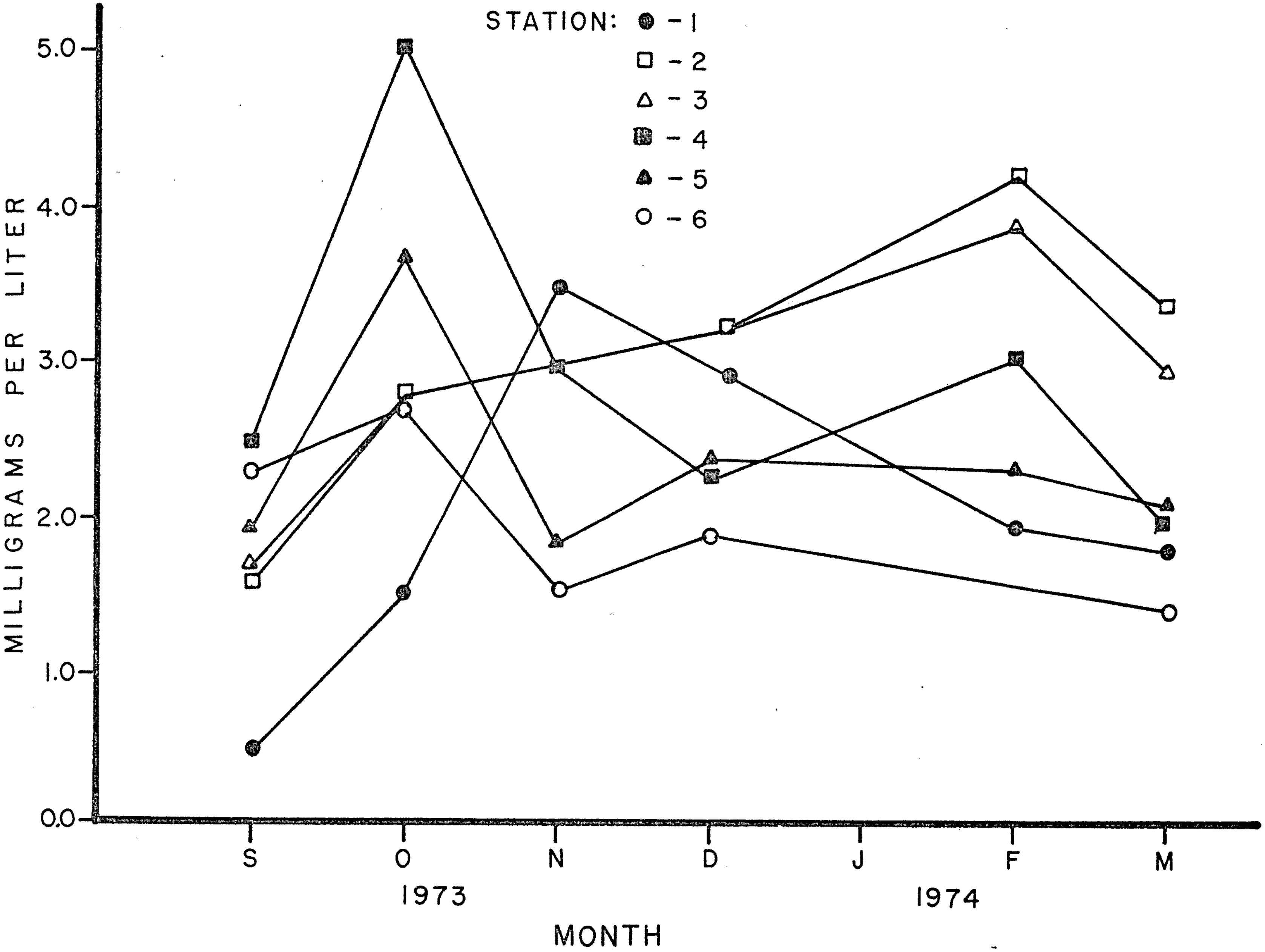

Fig. 4-6. Banks Lake chlorophyll 'a' concentrations at each sampling station for the period September, 1973-March, 1974.

withdrawals which may have resulted in retention of nutrients and/or phytoplankters in the relatively confined northern portion of the lake. A general decline in chlorophyll 'a' was noted at stations 4, 5 and 6 from October and November through March, while the trend of chlorophyll 'a' concentrations in the summer convergence area (stations 2 and 3) increased. There were no obvious chemical or physical differences between these two stations and the rest of the lake during this period and no satisfactory explanation can be given at this time for these different trends in chlorophyll 'a'.abundance.

A qualitative analysis of the phytoplankton composition showed three diatoms, *Fragillaria*, *Asterionella*, *Stephanodiscus*, and an unidentified filamentous alga predominated during this period. *Fragillaria* and the filamentous alga were much more abundant at all stations in September and October than were other genera. *Fragillaria* predominated at stations 1, 2 and 3 in October while the filamentous alga predominated at stations 4 to 6. The filamentous alga predominated at all stations in November, while *Stephanodiscus* was more abundant and *Fragillaria* was less abundant than previously. *Asterionella* completely dominated samples from all stations in February and March and was much more abundant than in any previous month. *Stephanodiscus* was present in moderate numbers at all stations while *Fragillaria* and the filamentous alga were present in insignificant numbers.

The major zooplankton groups identified from the lake were the calanoid copepod *Diaptomus*, the cyclopoid copepod *Cyclops*, copepod nauplii and the cladoceran *Daphnia*. The cladoceran *Bosmina* and the rotifers *Keratella*, *Asplancna* and *Kellicottia* were observed in smaller numbers throughout the year. *Leptodora*, *Epischura* and *Diaphanosoma* were occasionally observed during the summer months.

With minor exceptions, the trends exhibited in the 4 m to surface haul at each station were also seen in the bottom to surface haul (Fig. 4-7) at that station.

The maxima in *Diaptomus* contributions to the zooplankton standing stock varied from station to station. At station 1 this maximum occurred in September (Fig. 4-7) (52%); at station 2 (4 m to surface) it occurred in October (54%) while station 2 (bottom to surface) (Fig. 4-7) showed a decrease in *Diaptomus* relative abundance in October (28%) and increases in September (52%) and November (52%). Station 3 (4 m to surface) exhibited a high level of *Diaptomus* relative abundance in September (58%) and March (47%) and, as in stations 1 and 2, *Diaptomus* formed a major proportion of the zooplankton at all times, often in excess of 35%. Stations 2 and 3 (4 m to surface) showed, consistently, the highest proportions of *Diaptomus*. Station 3 (bottom to surface) (Fig. 4-7) did not show a *Diaptomus* maximum until December (40%). At station 4 *Diaptomus* levels remained constant at about 35% with a slight increase in March (Fig. 4-7) (41%). Stations 5 and 6 showed similar trends in *Diaptomus* with increases in relative abundance in October and decreases in November (Fig. 4-7).

The contribution of *Daphnia* to the observed zooplankton standing stock was more erratic. It showed its maximum proportions at most stations in September. Stations 1, 2 and 3 exhibited high proportions in September (37%, 33%, 49%, respectively), a sharp decrease by October (4%, 8%, 14%), slight increases in November and December at stations 2 and 3 (4 m to surface). Then at station 1 the *Daphnia* proportion dropped very low and remained at 10% or less from December through March (Fig. 4-7). At station 2 the proportion stayed close to 20% through the winter (Fig. 4-7) and at station 3 a steady decrease through the winter was observed (Fig. 4-7).

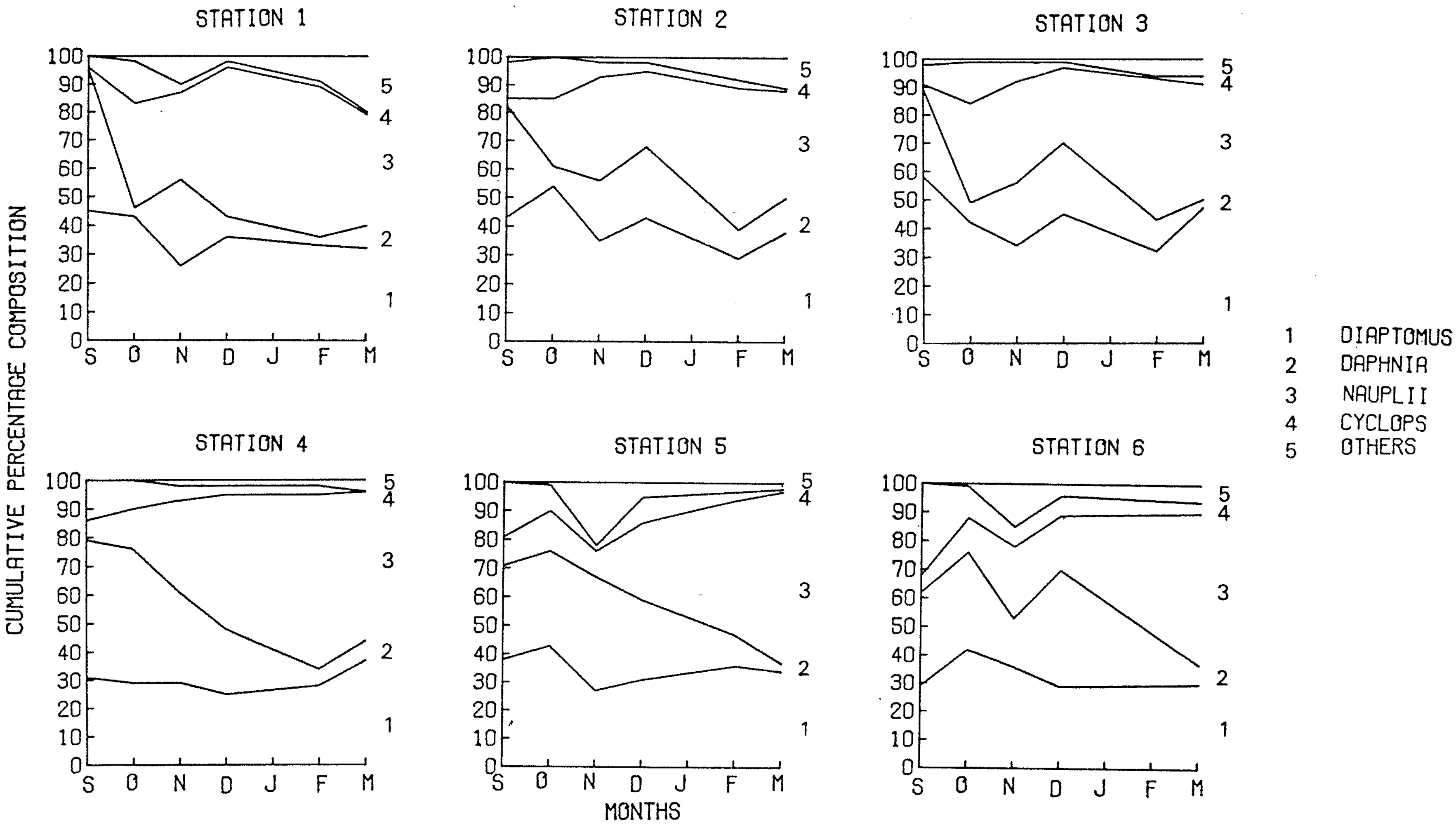

Fig. 4-7. Changes in zooplankton cumulative percentage composition by month at each station from September, 1973-March, 1974.

Stations 4 and 5 showed maxima in September (41% and 35%) and with slight fluctuations, a continuing decrease through the winter (Fig. 4-7). This trend was also true of station 6 (4 m to surface), with the exception of the decrease seen in November. Station 6 (bottom to surface) *Daphnia* levels rarely assumed the proportions seen elsewhere, particularly in the September observation (Fig. 4-7) (26%).

The contribution of copepod nauplii to the zooplankton standing stock generally increased from low levels in September to very high relative abundances throughout the winter and early spring. The changes in abundance at stations 1 and 2 were more complex; high levels of relative abundance were observed in October, abundance then decreased in November at these stations (Fig. 4-7). Then an increase in relative abundance of nauplii was observed with maximum observed proportions in February. Stations 3, 4, 5 and 6 showed steady increases in nauplii proportions during the sampling period. Stations 1, 2, 3 and 4 showed a slight decrease in March. At each station nauplii formed at least 40% of the total numbers of zooplankters in Febraury and 36% in March.

Cyclops relative abundance generally showed an increase in September and then a steady decrease through the year to very low proportions in March. This genus made up a greater proportion of the zooplankton at station 6 than elsewhere in the lake (Fig. 4-7) (36% in September, 5% in March) and was more significant at station 5 (Fig. 4-7) in September (24%) than at the stations to the north.

The contribution of other groups to the total was somewhat variable. *Bosmina* was the principal constituent of this category, although its contribution rarely exceeded 5%. *Bosmina* was responsible for an increase in percentage contribution of "other" groups in November (22% at station 5, 4 m to surface). Rotifers became apparent in February and March. The high percentage contribution of "other" groups at station 1 in March was due to rotifers (14%) (Fig. 4-7). All the zooplankton analysis was carried out through a low power microscope. Since rotifers are often difficult to see without high power magnification the data may be somewhat biased.

The observed fluctuations in total numbers of zooplankters per cubic meter were erratic (Figs. 4-8 and 4-9). In most cases the trends observed in the bottom to surface hauls were also observed in the 4 m to surface hauls. There was a general decrease in numbers from September to November and December with, in some cases, a slight increase by March. Station 4 showed this most clearly (Fig. 4-9). Increases in numbers of zooplankters in November at stations 1 and 2 corresponded with increasing proportions of nauplii. The high numbers observed in December at stations 2 and 3 (4 m to surface) (Fig. 4-8) coincided with increases in *Diaptomus* and *Daphnia* abundance. The high numbers observed in December at station 2 (bottom to surface) coincided with an increase in nauplii abundance. Maximum numbers of individuals observed were 56,000/m^3 at station 4 (4 m to surface) (Fig. 4-9) in September and 47,000/m^3 at station 1 (4 m to surface) in March (Fig. 4-8). Lowest numbers seen were 4,000/m^3 at station 6 (Fig. 4-9), in March. It is probable that many of these erratic fluctuations are due to the characteristic patchiness in the distribution of zooplankton.

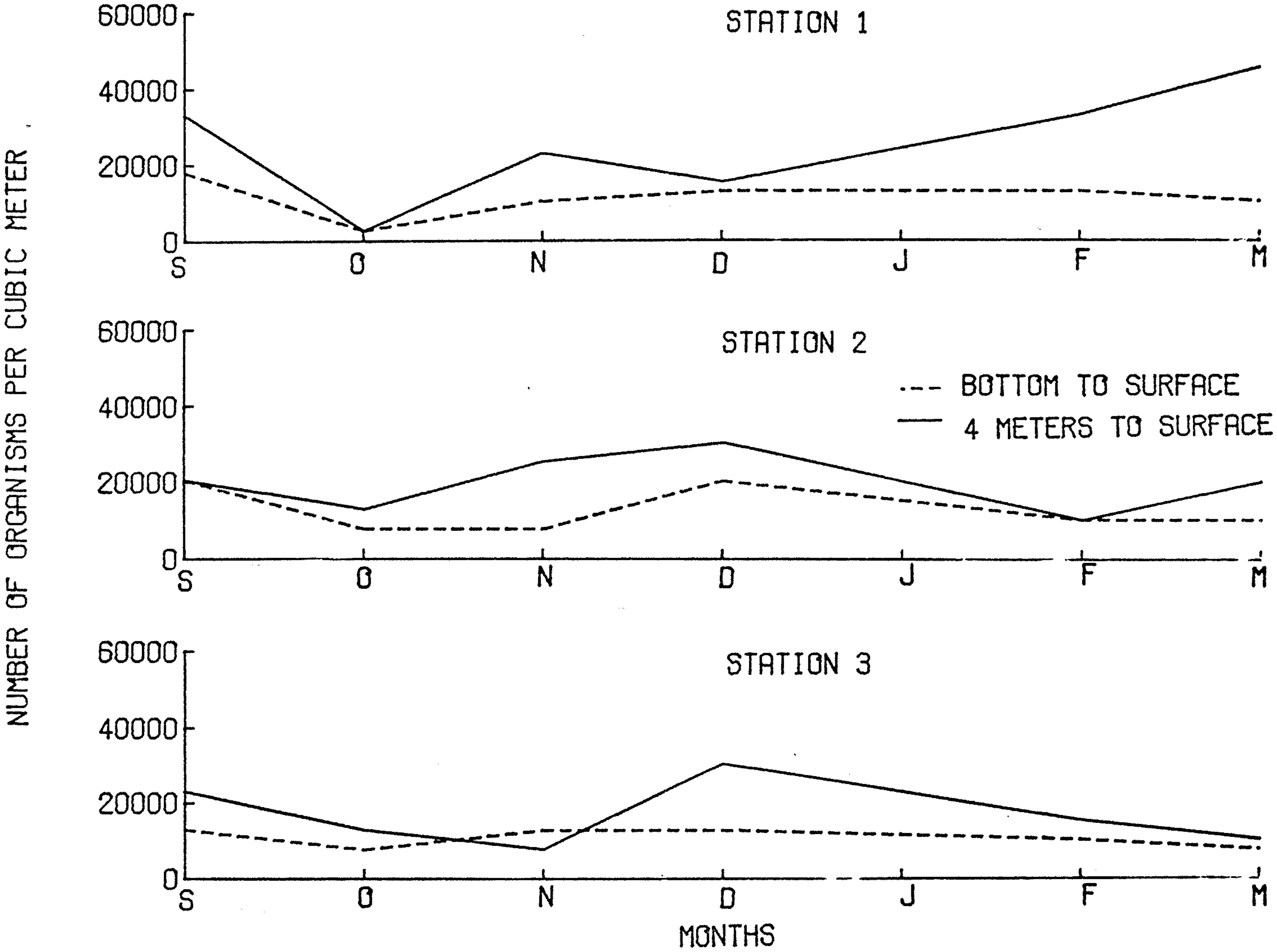

Fig. 4-8. Changes in the number of zooplankton organisms per cubic meter (stations 1-3) taken in vertical hauls from bottom to surface and 4 m to surface by month from September, 1973-March, 1974.

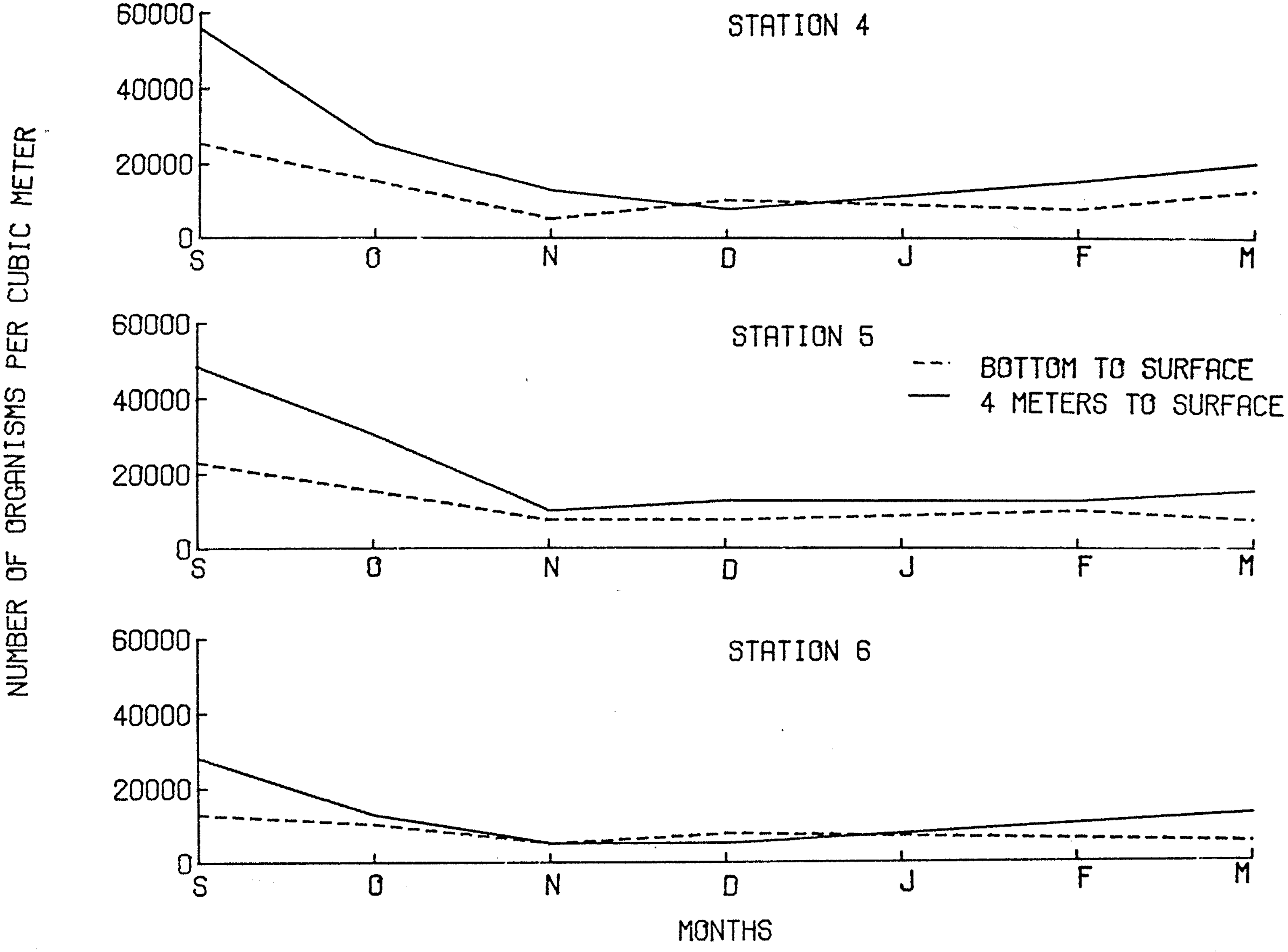

Fig. 4-9. Changes in the number of zooplankton organisms per cubic meter (stations 4-6) taken in vertical hauls from bottom to surface and 4 m to surface by month from September, 1973-March, 1974.

5.0 FISH ABUNDANCE AND DISTRIBUTION

5.1 Introduction

Banks Lake supports both cold and warm water varieties of freshwater gamefish complicating the assessment of the fish populations. The relative abundance, distribution and life history of each species is being studied, with emphasis on three dominant species, yellow perch, lake whitefish and kokanee. This report includes some of the baseline data on the fish populations in the lake prior to pump storage operation. Most of the data reported was obtained between July 1973 and March 1974.

5.2 Materials and Methods

A comprehensive sampling plan was developed to assess the distribution, relative abundance and life histories of the fish populations. Monthly sampling was designed to detect differences in the fish populations 1) along the length of the lake (north to south), 2) vertically through the water column and 3) in the littoral zone compared to the pelagic zone. The seasonal sampling, which consisted of more extensive shoreline sampling in the vicnity of each midlake station, was designed to detect differences in the fish populations across the width of the lake (east to west).

5.2.1 Sampling Gear

Three types of gear were used, the horizontal gill net, the vertical gill net and a beach seine.

The horizontal gill nets were 30.5 m (100 ft) long by 1.8 m (6 ft) deep with nine panels of variable mesh monofilament nylon. The mesh sizes ranged from 2.5 cm to 12.7 cm (1 in to 5 in) stretched graduated in 1.3 cm (1/2 in) intervals. Sets were made at the surface and bottom of the water column.

The vertical gill nets were constructed of 6.4 cm (2-1/2 in) stretched monofilament nylon 24.4 m (30 ft) deep by 3.0 m (10 ft) wide. Spreader bars of 6.4 mm (1/4 in) aluminum rod were attached at the bottom at 8 m intervals (24 ft) above the bottom and at the surface of the water column. Excess mesh was tied off at the surface.

The beach seine was 30.5 m (100 ft) long, having a center depth of 1.8 m (6 ft) tapered to 1.2 m (4 ft) on each end. The mesh size was graduated from 3.8 cm (1-1/2 in) at each end to 6.4 mm (1/4 in) (stretched) in the bunt. Rope leads 30.5 m long were attached to each end of the seine to facilitate hauling the net.

5.2.2 Sampling Design

Sampling was conducted along the length of the lake each month at stations 1, 4, 5 and 6 (Fig. 3-1). The layout of gear used at each station is shown in Fig. 5-1. Two vertical and two surface horizontal gill net sets of 24 hour duration were made at the midlake stations. Four beach seine hauls were made, two on each shore adjacent to the midlake stations.

Quarterly sampling was increased to include 24 hour gill net sets during daylight and darkness to measure diurnal differences in catch. Sampling was conducted across the width of the lake once during each quarter. Six horizontal gill net sets were made on the bottom, two sets at each midlake station and two sets along each shoreline adjacent to each midlake station.

5.2.3 Sample Processing

Relative abundance and distribution estimates are presented as catch per unit effort. Since the sampling scheme employed a constant effort, the total catch was a measure of catch per effort. Where continuous diurnal gill net sets were made, the day and night catches were combined to represent one 24 hour set. For each gill net set or beach seine haul the date,

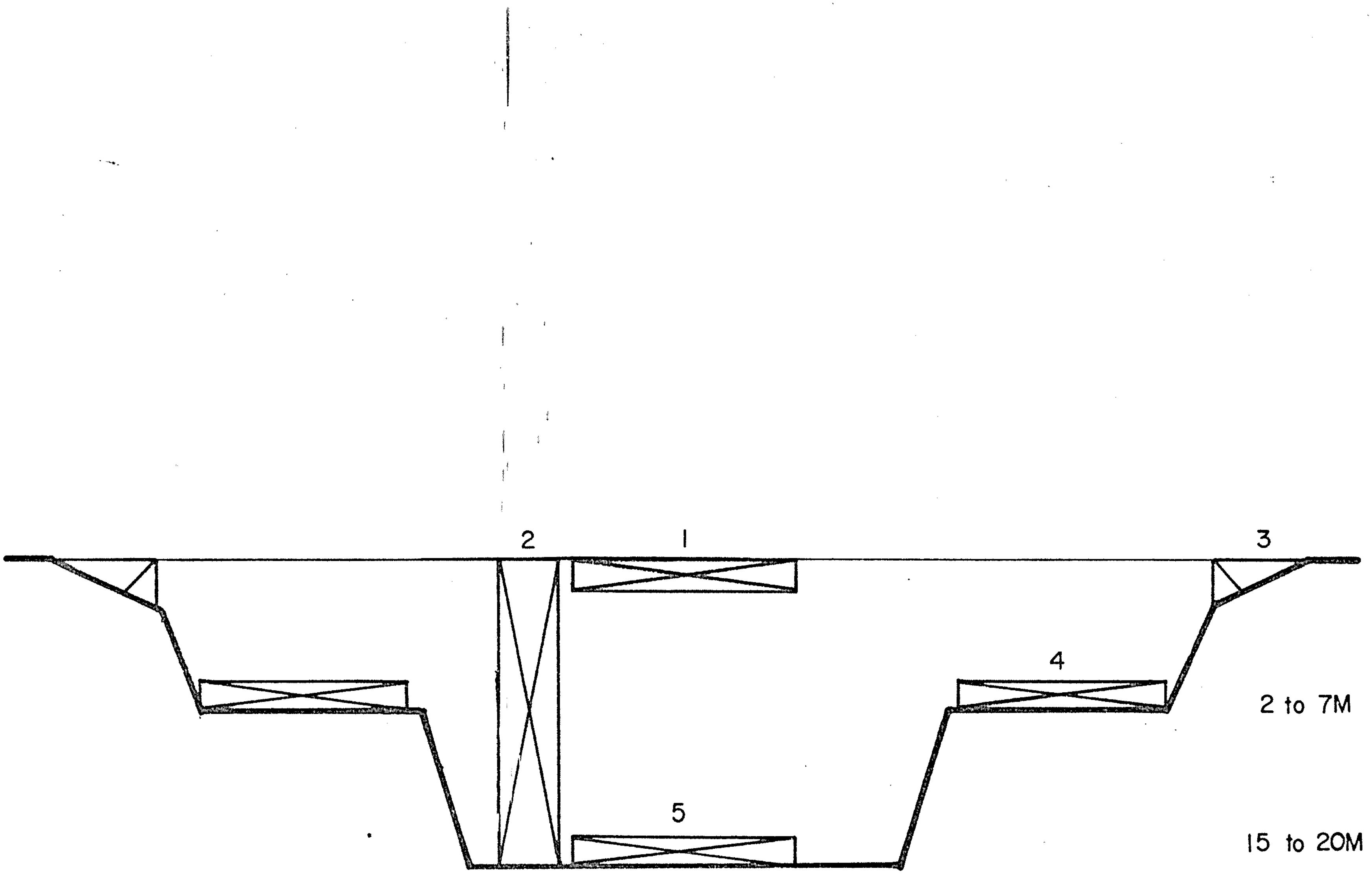

Fig. 5-1. Schematic section through one station illustrating sampling site for each gear type. 1) surface set horizontal gill nets (monthly), 2) vertical gill nets (monthly), 3) beach seine hauls (monthly), 4) shoreline bottom horizontal gill nets (quarterly), 5) midlake bottom horizontal gill nets (quarterly).

location, gear type, effort, diurnal conditions, water temperature, visibility and catch were recorded. Each fish caught was identified to species, measured to the nearest millimeter (fork length) ,weighed to the nearest gram and examined for determination of sex, maturity, stomach contents, stomach fullness and incidence of obvious parasites or disease. Scale or otolith samples were taken for aging. Stomach samples were taken for determination of food habits. Ovaries were preserved for fecundity and estimation of ova size.

Scales were taken from the right side above the lateral line. Scale samples were taken from the majority of the fish caught unless the catch exceeded 25 fish of one species for one set. A Bausch and Lomb microprojector (5 X objective, 3.5 X power) was used to examine scales which had previously been cleaned, impressed on plastic cards, and catalogued. The majority of the age determinations were by scale readings but otoliths were used on brown and rainbow trout, kokanee, burbot and walleye.

Eight food type codes and 3 stomach fullness codes were used to describe stomach contents. Microscopic examination was conducted on a subsample of the fish stomachs for identification to genus, enumeration and size estimation of food items.

Sex and maturity were recorded for each fish using Nikolsky's maturity index (Bagenal and Braum, 1968). This maturity index was used to help establish time, interval and location of spawning for the species examined. Direct observation of the shoreline to search for spawning fish, nests, eggs, spent or dying fish and type of shoreline was conducted seasonally.

5.3 Results

5.3.1 Species Composition

Eighteen species of fish have been identified in Banks Lake from June

1973 to May 1974. In order of abundance in the catch they were: yellow perch, *Perca flavescens*; lake whitefish, *Coregonus clupeaformis*; kokanee, *Oncorhynchus nerka*; largemouth bass, *Micropterus salmoides*; *Cottus* spp.; peamouth, *Myclocheilus caurinus*; black crappie, *Pomoxis nigromaculatus*; carp, *Crypinus carpio*; pumpkinseed sunfish, *Lepomis gibbosus*; longnose sucker, *Catostomus catostomus*; rainbow trout, *Salmo gairdneri*; brown bullhead, *Ictalurus nebulosus*; largescale sucker, *Catostomus machrocheilus*; walleye, *Stizostedion vitreum*; burbot, *Lota lota*; brown trout, *Salmo trutta*; the rocky mountain whitefish, *Prosopium williamsoni*; and the northern squawfish, *Ptychocheilus oregonensis*.

Yellow perch, lake whitefish, kokanee, peamouth, and longnose sucker represented 78%, 10%, 6%, 2% and 2% of the total gill net catch, respectively. Carp, pumpkinseed sunfish, black crappie, walleye, rainbow trout, brown trout, burbot, largemouth bass and largescale sucker each represented less than 1% of the total gill net catch. Brown bullhead and cottids were the only species not taken in the gill nets.

Twelve percent of the total gill net catch was taken in surface horizontal sets. Lake whitefish, kokanee, rainbow trout, peamouth, black crappie and yellow perch constituted 63%, 29%, 5%, 2%, 0.5% and 0.5% of the surface catch, respectively.

Sixty percent of the total gill net catch was taken by bottom set horizontal gill nets. Yellow perch, lake whitefish, longnose sucker, peamouth, kokanee, rainbow trout and largescale sucker constituted 68%, 24%, 3%, 2%, 2%, 0.5% and 0.5% of the bottom catch, respectively.

Twenty-eight percent of the total gill net catch was taken in vertical gill nets. Yellow perch, kokanee, lake whitefish, peamouth, rainbow trout, black crappie and largescale sucker constituted 55%, 31%, 9%, 3%, 1%, 0.5%

and 0.5% of the catch, respectively.

Yellow perch, largemouth bass, and cottids represented 94%, 2% and 2% of the beach seine catch. The lake whitefish, rocky mountain whitefish, peamouth, longnose sucker, carp, black crappie, pumpkinseed sunfish, brown bullhead and rainbow trout were taken in the beach seine but represented less than 1% of the total catch each. Walleye, burbot, northern squawfish, brown trout, and kokanee were not taken in the beach seine.

Three of the eighteen species captured, yellow perch, lake whitefish and kokanee, were selected for detailed study because these constituted 95% of the total gill net catch and represented both warm and cold water varieties of fish. The yellow perch and kokanee are the species most commonly taken by the sport fishery. The lake whitefish does not support a large sport fishery; however, it is the second most abundant species in the samples.

5.3.2 Yellow Perch

5.3.2.1 Distribution. Distribution along the length of the lake (among the midlake stations) was determined for yellow perch. Surface horizontal gill net sets were relatively ineffective for perch with a total catch of only two yellow perch. Bottom horizontal gill net sets were highly efficient at capturing yellow perch. The bottom set catches were greatest at stations 1 and 6, at the north and south ends of the lake, and were consistently lowest at stations 4 and 5 (Fig. 5-2). The vertical gill net was also effective in capturing yellow perch. Stations 4 and 5 had the highest and lowest vertical gill net catches of yellow perch, respectively (Fig. 5-3). The beach seine hauls provided information on the smaller size yellow perch (young of the year) which were not taken in the gill nets. Stations 4 and 5 had the highest beach seine catches of yellow perch. The

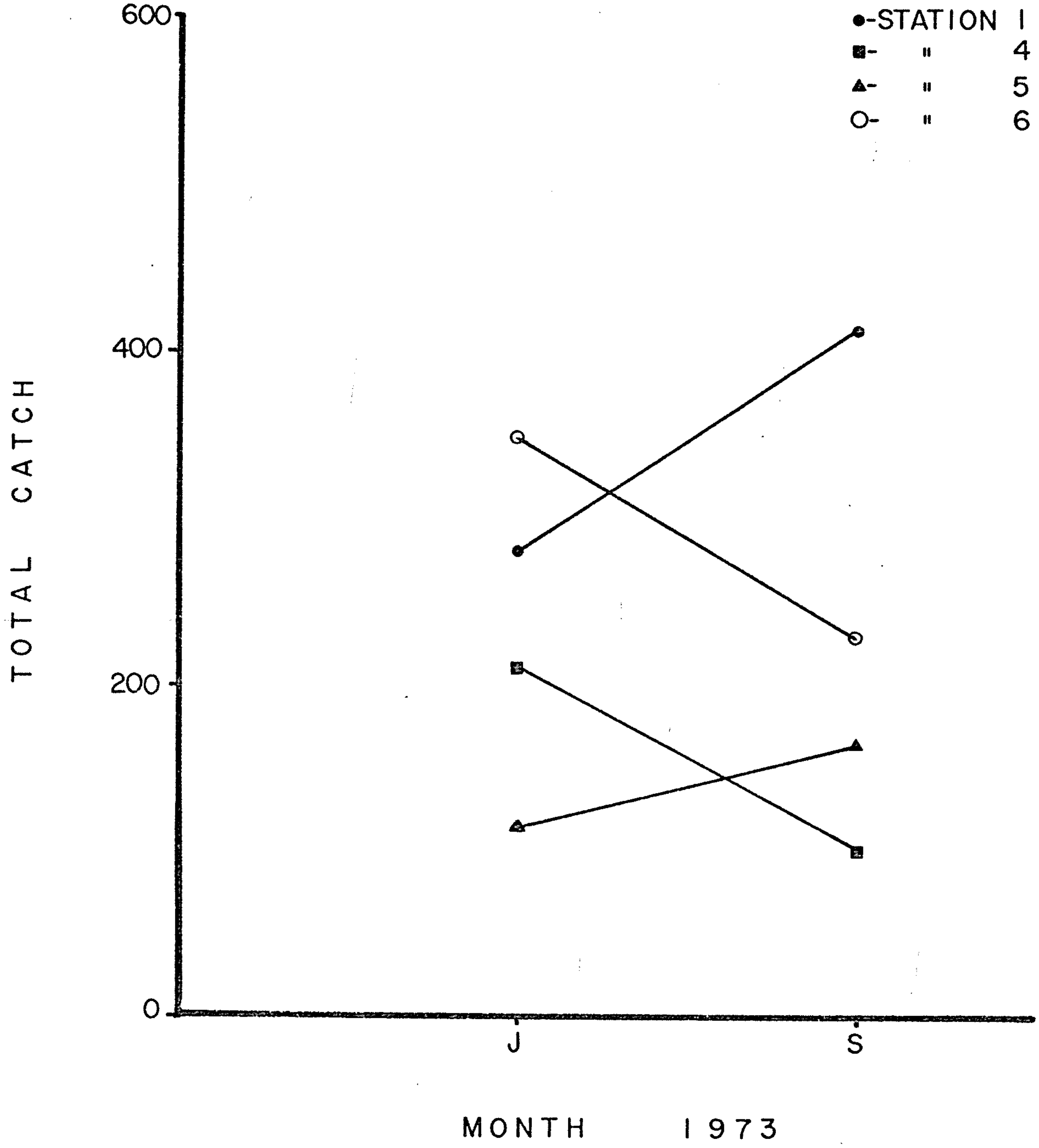

Fig. 5-2. Abundance of yellow perch captured in bottom set horizontal gill nets, July-September, 1973.

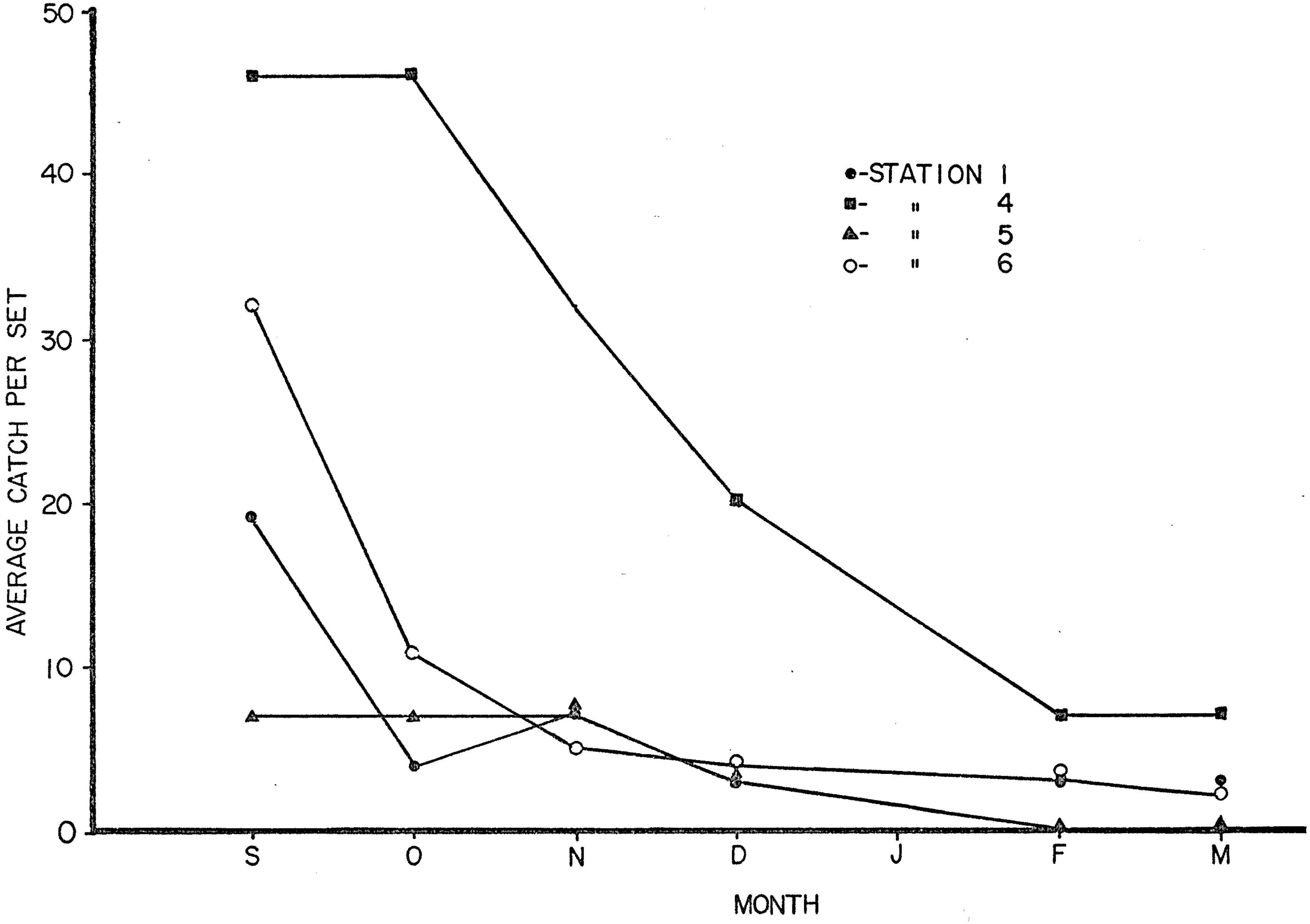

Fig. 5-3. Abundance of yellow perch captured in vertical gill nets, September, 1973-March, 1974.

beach seine catches of yellow perch at stations 1 and 6 were much smaller (Fig. 5-4).

Distribution across the width of the lake (east, midlake and west shore sites) was investigated for yellow perch. Large catches were made at all three sites at each station. Trend analysis has not yet been completed.

The depth distribution of yellow perch was determined for the midlake stations. Over 99% of the yellow perch were taken in the bottom 4 m (12 ft) of the water column. Recent catches (since March 1974) of yellow perch in the surface set horizontal gill nets and near the surface in vertical gill nets indicate that the yellow perch move into the pelagic zone in the spring.

5.3.2.2 Life History. The mean length for each year class of yellow perch among stations was computed (Fig. 5-5). Mean lengths for year class 0 were obtained from the August 7, 1973 beach seine samples. This beach seine catch represented the last large sample of juvenile yellow perch taken. Mean lengths for year classes 1 through 6 were computed from the September gill net catches. Although growth patterns were similar among stations, differences in the rate of growth and maximum size attained were suggested. Yellow perch of age 1 to 3 at station 4 were larger than those of the same age at other stations. Age 5 and 6 yellow perch were the largest at station 6. Perch at station 1 exhibited reduced growth with respect to the other stations after reaching age 3.

Yellow perch stomachs were inspected for the type of food consumed, stomach fullness, and the percentage of stomachs containing food (Fig. 5-6). Four types of food were found to be consumed, zooplankton, fish, insects and other benthic invertebrates.

The contents of the yellow perch stomachs were found to vary greatly with season. Zooplankton was the primary food source utilized and occurred

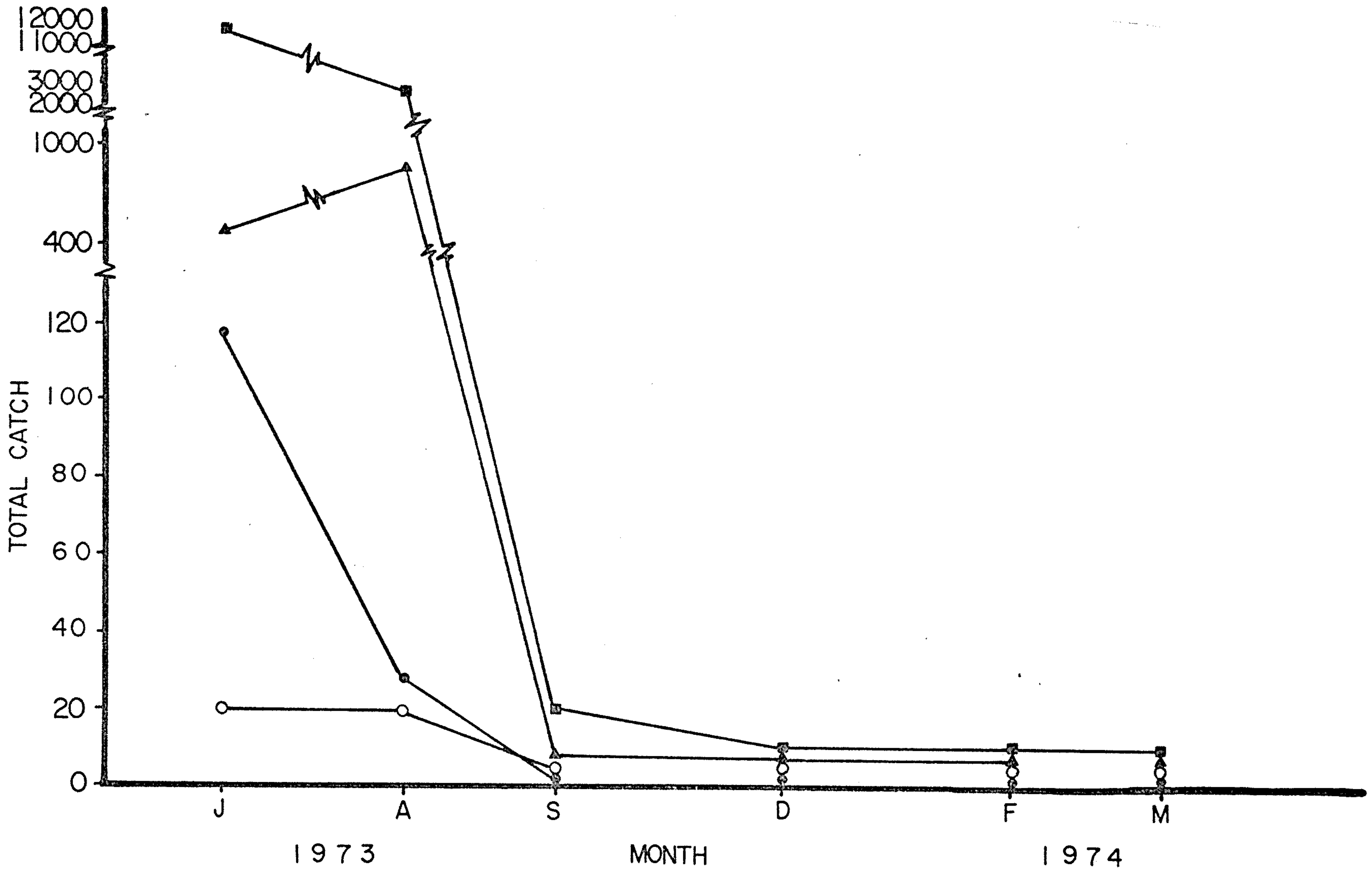

Fig. 5-4. Abundance of yellow perch captured in beach seine hauls, July, 1973-February, 1974.

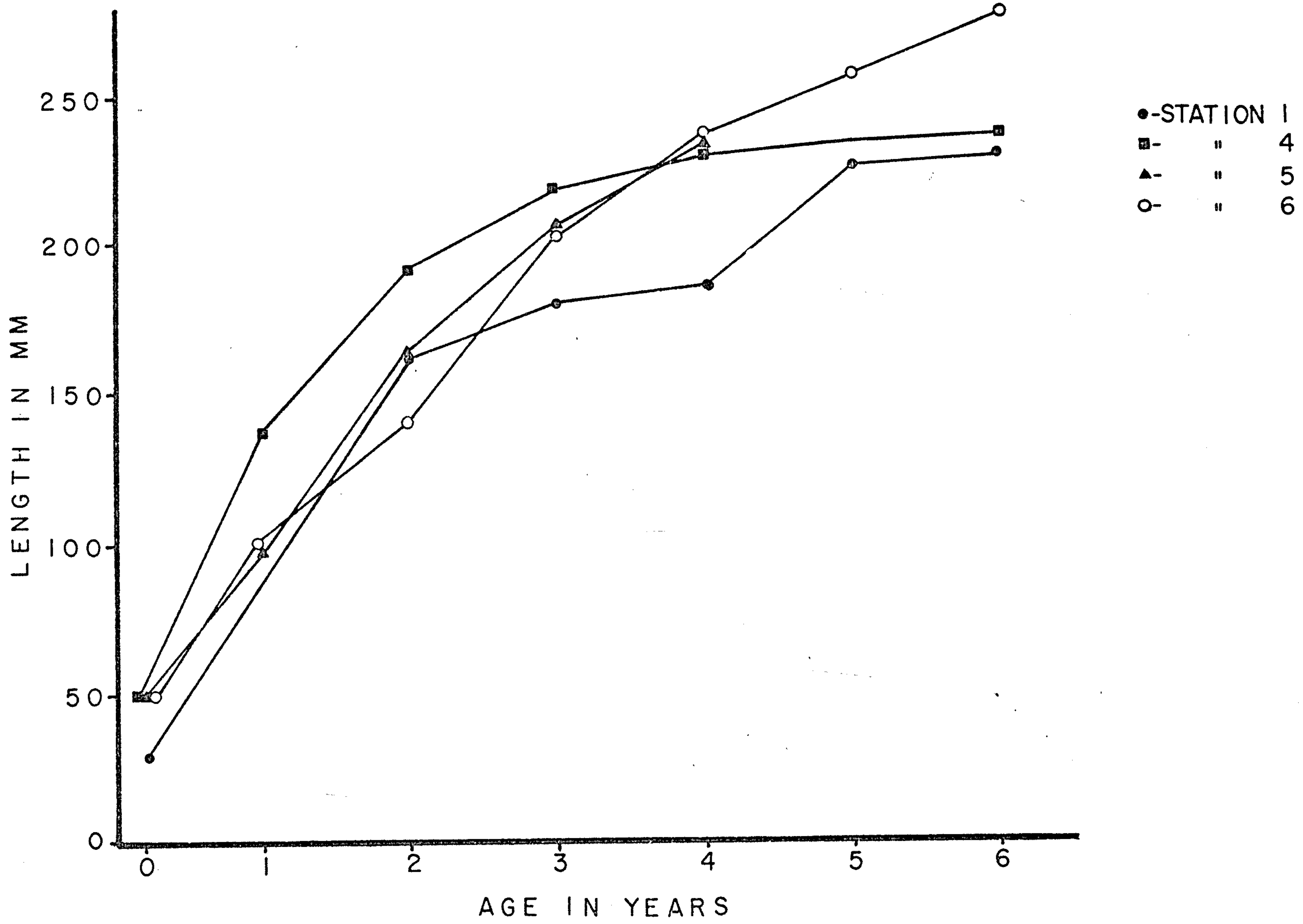

Fig. 5-5. Mean lengths at age for yellow perch caught at stations 1, 4, 5 and 6, August-September, 1973.

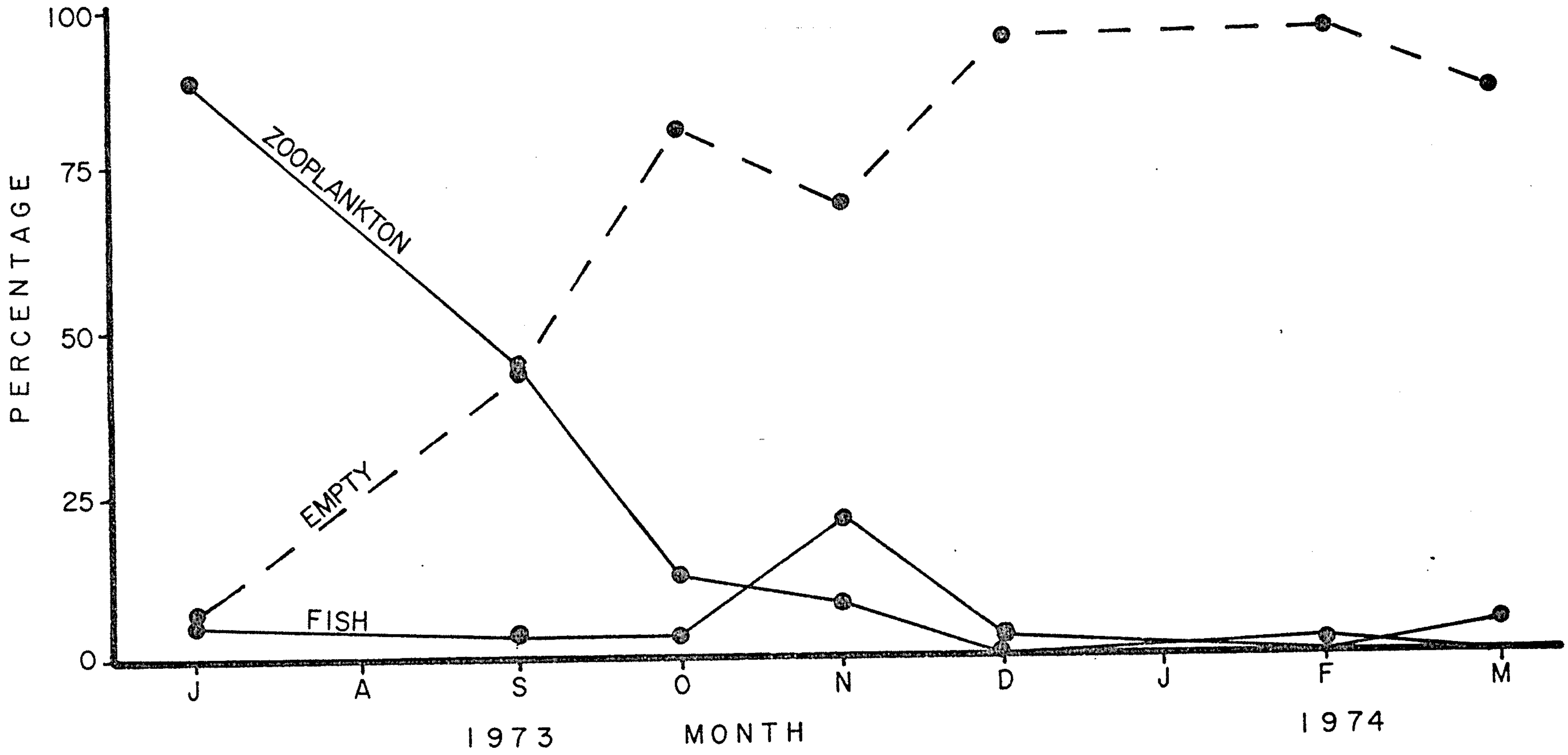

Fig. 5-6. Stomach contents of yellow perch, July, 1973-March, 1974.

in 88% of the fish stomachs in July. The dashed line in Fig. 5-6 represents the percentage of yellow perch with empty stomachs. The increased percentage of empty stomachs as the percentage of zooplankton in the stomachs decreased, may indicate a strong dependence on zooplankton as a food source. Fish were second in occurrence being utilized by less than ten percent of the yellow perch. Insects, other invertebrates and detritus were observed incidentally.

Maturity was estimated for each yellow perch and the percentage of fish at a specific stage of development was determined for each sample period. The percentage of mature yellow perch increased from 0% in July to 100% in November (Fig. 5-7). The first fish in spawning condition were observed in April. Sampling since then indicates all spawning was completed in April.

5.3.3 Lake Whitefish

5.3.3.1 Distribution. Distribution along the length of the lake (among midlake stations) was determined for lake whitefish. Surface horizontal gill net sets were effective in capturing lake whitefish. The largest surface set catches were made at station 5 in August and September, when no lake whitefish were taken at station 1 (Fig. 5-8). From October through February the largest catches were made at station 4. The largest bottom gill net catches of whitefish were made at station 4 in July and September (Fig. 5-9). The absence of lake whitefish in the catch at station 1 in July and September and their presence in the December catch at station 1 agreed with the distribution shown by the surface set nets. The vertical gill nets were the least effective gear used to catch lake whitefish. Station 4 consistently had the highest catch and no lake whitefish were taken at station 1 in July and September. The beach seine catch up to March 1974 did not take any lake whitefish. Recent (April and May) beach seine catches have taken large numbers

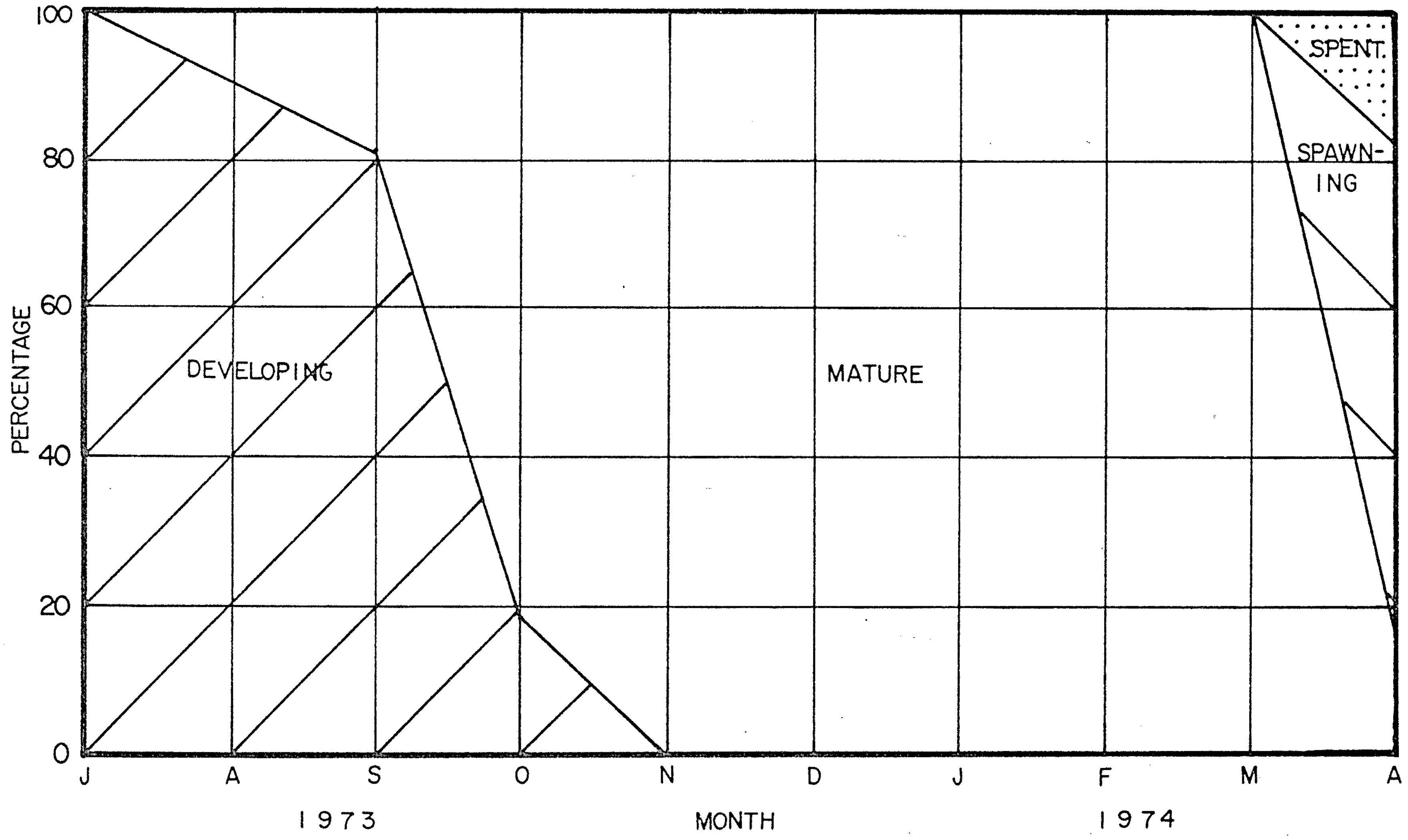

Fig. 5-7. Sexual condition of female yellow perch, July, 1973-April, 1974.

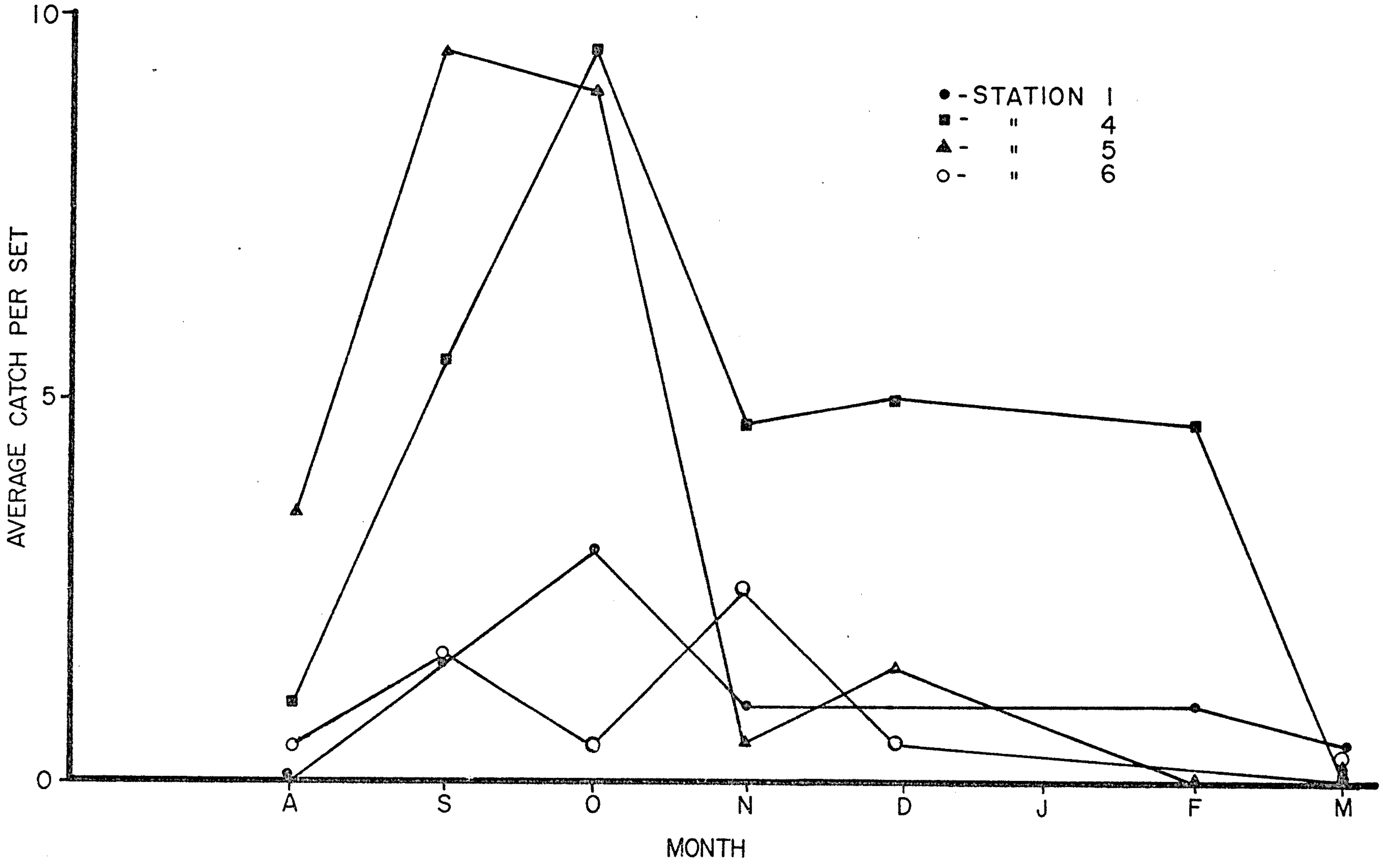

Fig. 5-8. Abundance of lake whitefish caught in surface set horizontal gill nets, July, 1973-March, 1974.

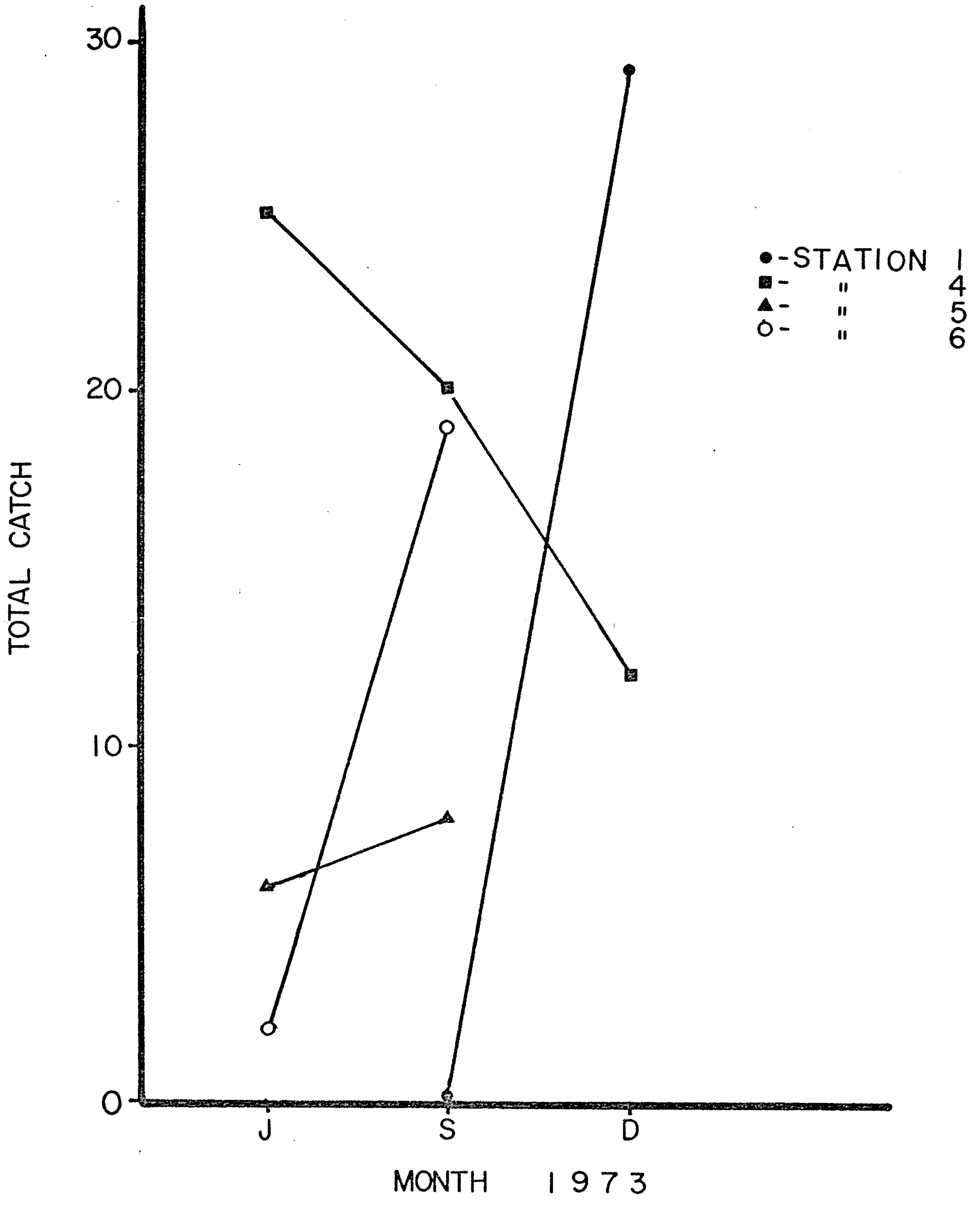

Fig. 5-9. Abundance of lake whitefish caught in bottom set horizontal gill nets, July-December, 1973.

of juvenile lake whitefish at all four stations.

Distribution of lake whitefish across the width of the lake (west, midlake and east shorelines) was investigated. The lake whitefish were taken almost exclusively at the midlake station.

The depth distribution for lake whitefish was investigated for the midlake stations. The larger lake whitefish were caught at the surface and bottom of the water column. All of the smaller lake whitefish were taken at the bottom of the water column.

5.3.3.2 Life History. The length distribution of lake whitefish in the combined gill net catch was bimodal. A smaller mode at 240 mm was distinctly separated from a larger mode at 440 mm. Aging indicated the fish in the 440 mm mode to be from 11 to 19 years old and the fish in the 240 mm mode to be approximately 2 to 5 years old. The presence of these groups of abundant year classes in the lake whitefish population is being examined with respect to the history of the lake.

Lake whitefish stomachs were inspected for the type of food consumed, stomach fullness and the percentage of fish with empty stomachs (Fig. 5-10). Zooplankton was the only food utilized by the lake whitefish from July 1973 to March 1974. Analysis of stomach fullness has not been completed. The percentage of lake whitefish in the catch utilizing zooplankton declined from 95% in July to 25% in November. The percentage of lake whitefish which utilized zooplankton increased after November. The dashed line in Fig. 5-10 represents the percentage of lake whitefish with empty stomachs, which may suggest a dependence upon zooplankton as a food source.

Maturity was estimated for each lake whitefish and the percentage of fish at a specific stage in development was determined by month. In October all of the lake whitefish had reached maturity (Fig. 5-11).

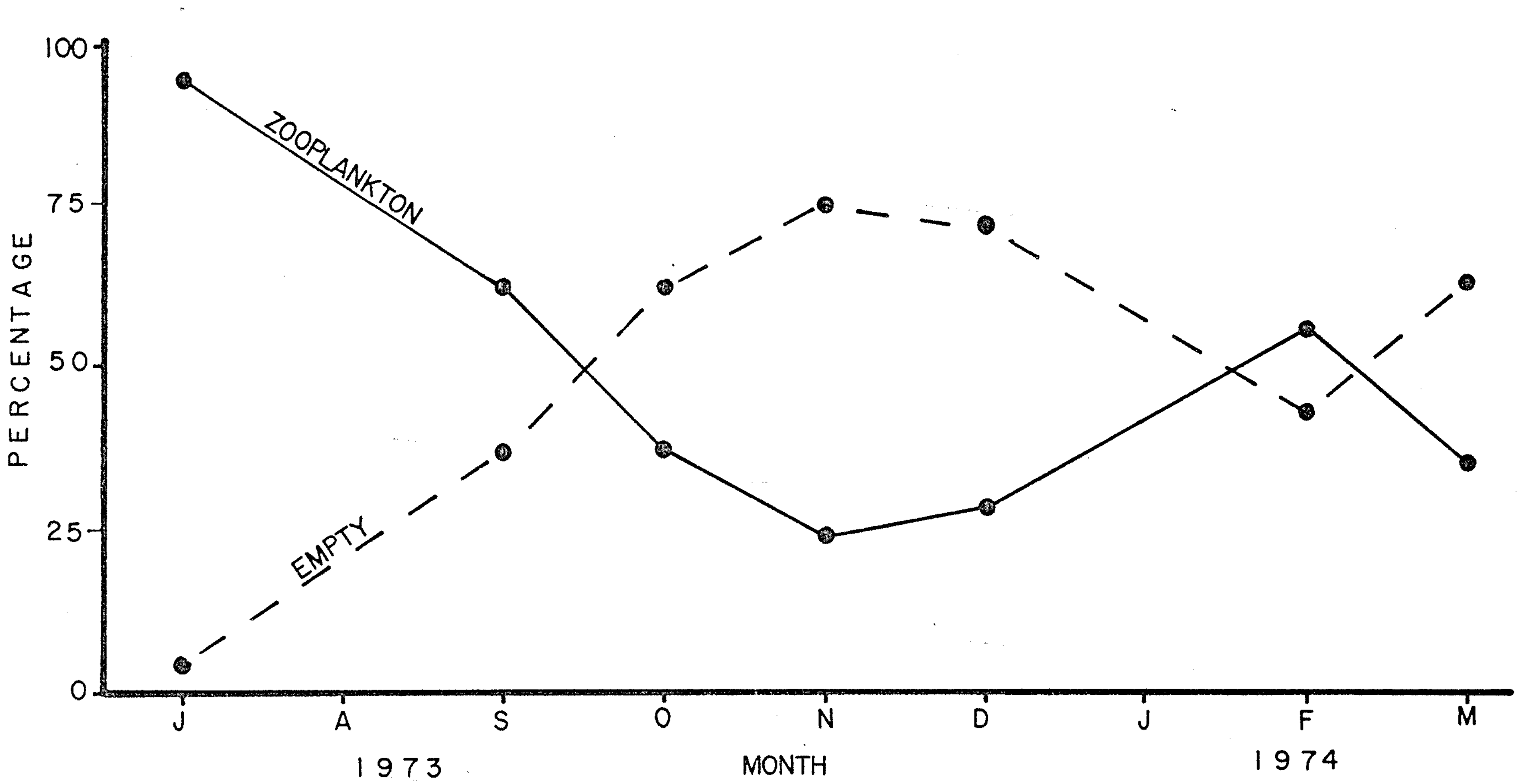

Fig. 5-10. Stomach contents of lake whitefish, July, 1973-March, 1974.

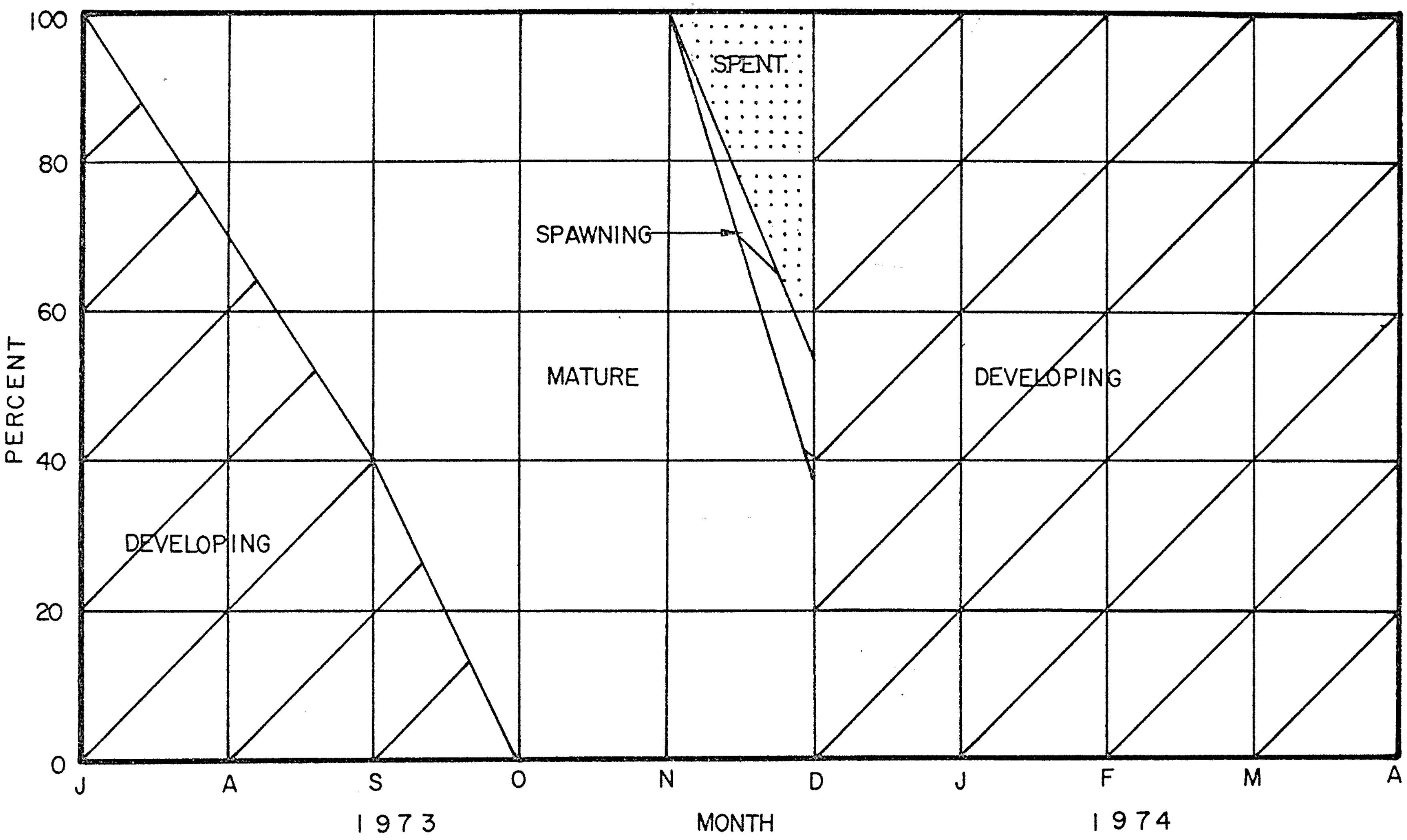

Fig. 5-11. Sexual condition of female lake whitefish, July, 1973-March, 1974.

Spawning and spent individuals were taken in the gill nets in December. Due to ice cover the next sampling was delayed until February when all of the lake whitefish were either in the resting or developing stage.

5.3.4 Kokanee

5.3.4.1 Distribution. Distribution along the length of the lake was determined for kokanee. Surface set horizontal gill nets were relatively effective in capturing kokanee. The highest catches with surface set nets were obtained at stations 1, 6, 5 and 4 for the months of August, September, October and November, respectively (Fig. 5-12). Only a small number of kokanee were taken from December to March, all at station 4. There were only two kokanee taken in bottom set horizontal gill nets, both in September at station 6. The vertical gill nets were the most effective gear for capturing kokanee (Fig. 5-13). The highest catch of kokanee from August through November agreed with the surface set horizontal catch for the stations. From December through March the vertical gill net catches were largest at station 5. Kokanee have not been taken in the beach seine.

The distribution of kokanee across the width of the lake was investigated. Over 90% of the catch was taken at the four midlake stations. The majority of the catch was made in the water column from 8 m (24 ft) above the bottom to the surface.

5.3.4.2 Life History. The kokanee stomachs were inspected for the type of food utilized, stomach fullness and the percentage of empty stomachs. The only food utilized was zooplankton (Fig. 5-14). The percentage of kokanee containing zooplankton increased from 29% in July to 58% in March (February sample, N = 2, omitted). The dashed line in Fig. 5-14 may suggest dependence on zooplankton as a food source.

Maturity of kokanee was estimated for each fish in the catch. Immature

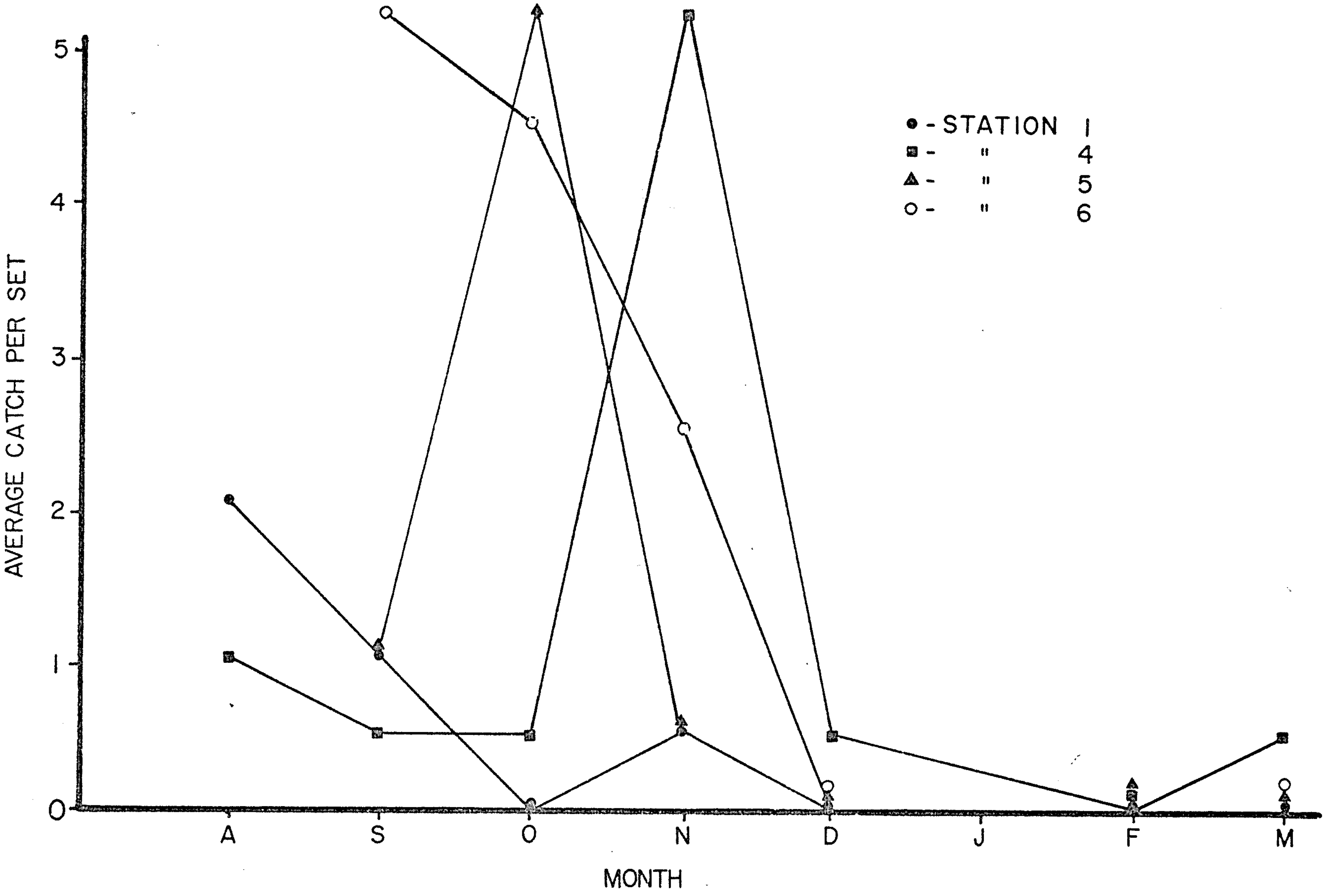

Fig. 5-12. Abundance of kokanee caught in surface set horizontal gill nets, July, 1973-March, 1974.

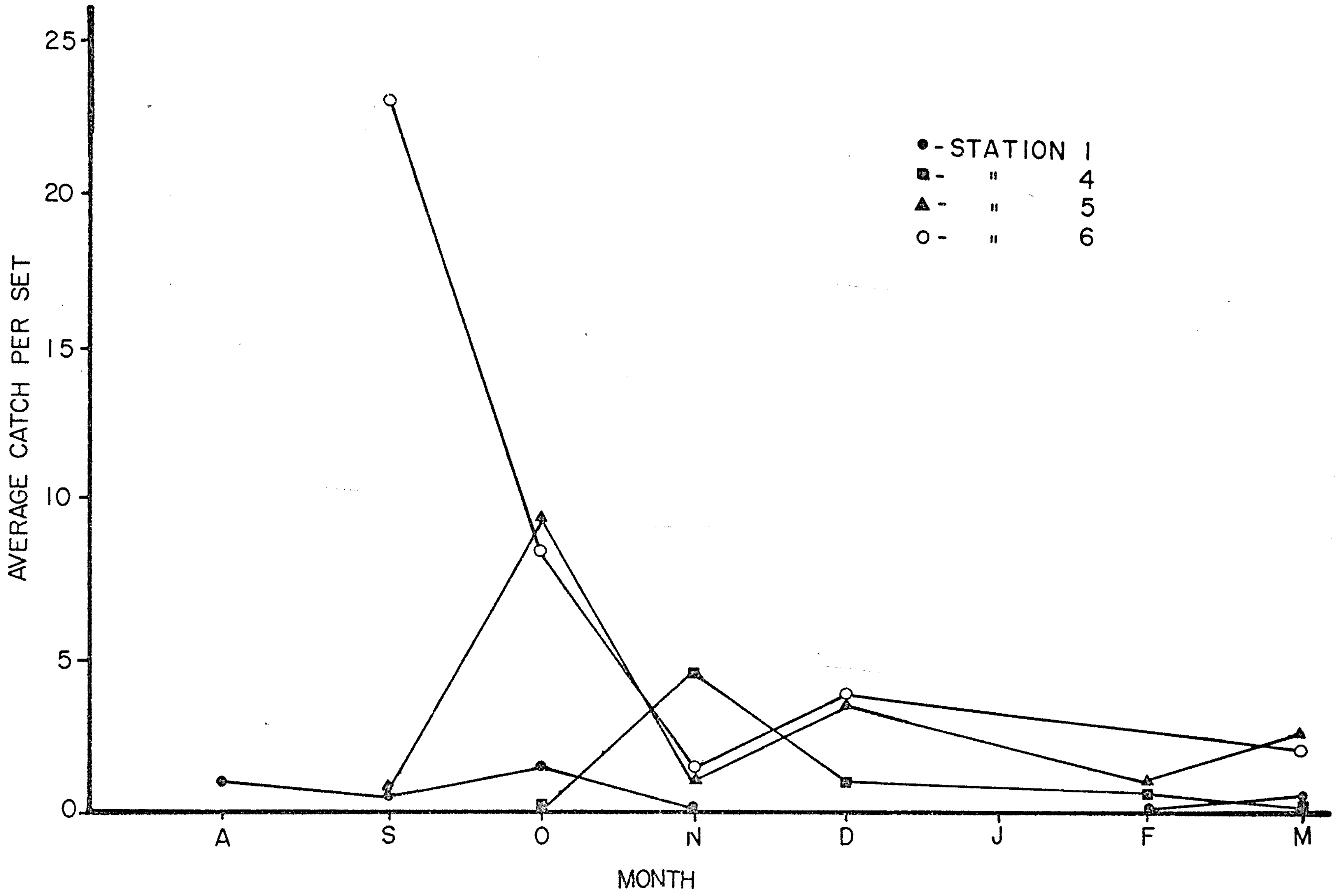

Fig. 5-13. Abundance of kokanee caught in vertical gill nets, July, 1973-March, 1974.

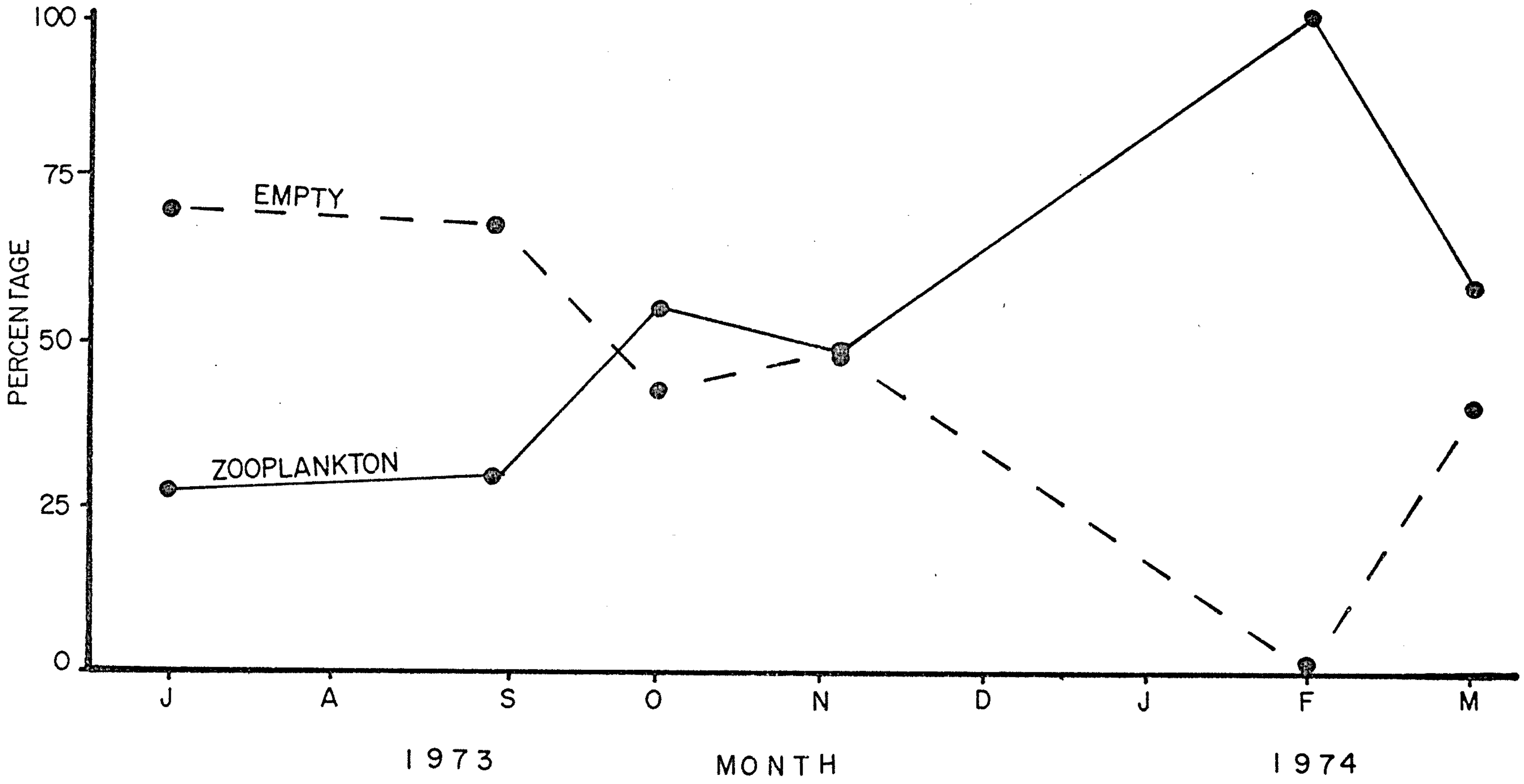

Fig. 5-14. Stomach contents of kokanee, July, 1973-March, 1974.

fish made up the majority of the catch (Fig. 5-15). In September, the developing and mature fish represented a high of 27% of the catch. In October, 13% of the catch was mature and in November the first spawning kokanee were taken. Only immature kokanee have been taken since November, 1973.

5.4 Discussion

Sixteen species were considered common to Banks Lake prior to this study (Duff, 1973). The bluegill sunfish is the only species of these 16 which has not been taken in our sampling. Two additional species, the brown trout and the rocky mountain whitefish have been taken. Two suckers, the longnose sucker and the largescale sucker, have been identified. No coho salmon, *Oncorhynchus kisutch*, have been taken although they were planted in 1971 by the Washington Department of Game.

The catch of yellow perch among stations remained fairly constant, suggesting these may be resident populations. Tagging studies by Mraz (1951) in Lake Michigan demonstrated 80% of the recaptures were at the locations of initial tagging, inferring that the yellow perch are a sedentary species. However, the fact that the largest beach seine catches of juvenile yellow perch are at stations 4 and 5 while the largest gill net catches of adult yellow perch are at stations 1 and 6 implies that significant movement and/or mortality may have occurred. This movement may have occurred at early life stages as the fish move offshore. Growth rate data supports the hypothesis that yellow perch populations are sedentary. The length at age for all stations except 1 and 6 for age 0 and station 1 for ages 1 and 6 were within the upper and lower limits reported by Coots (1965).

The lake whitefish catches suggest movement between stations. The majority of the catch of lake whitefish consisted of specimens over 400

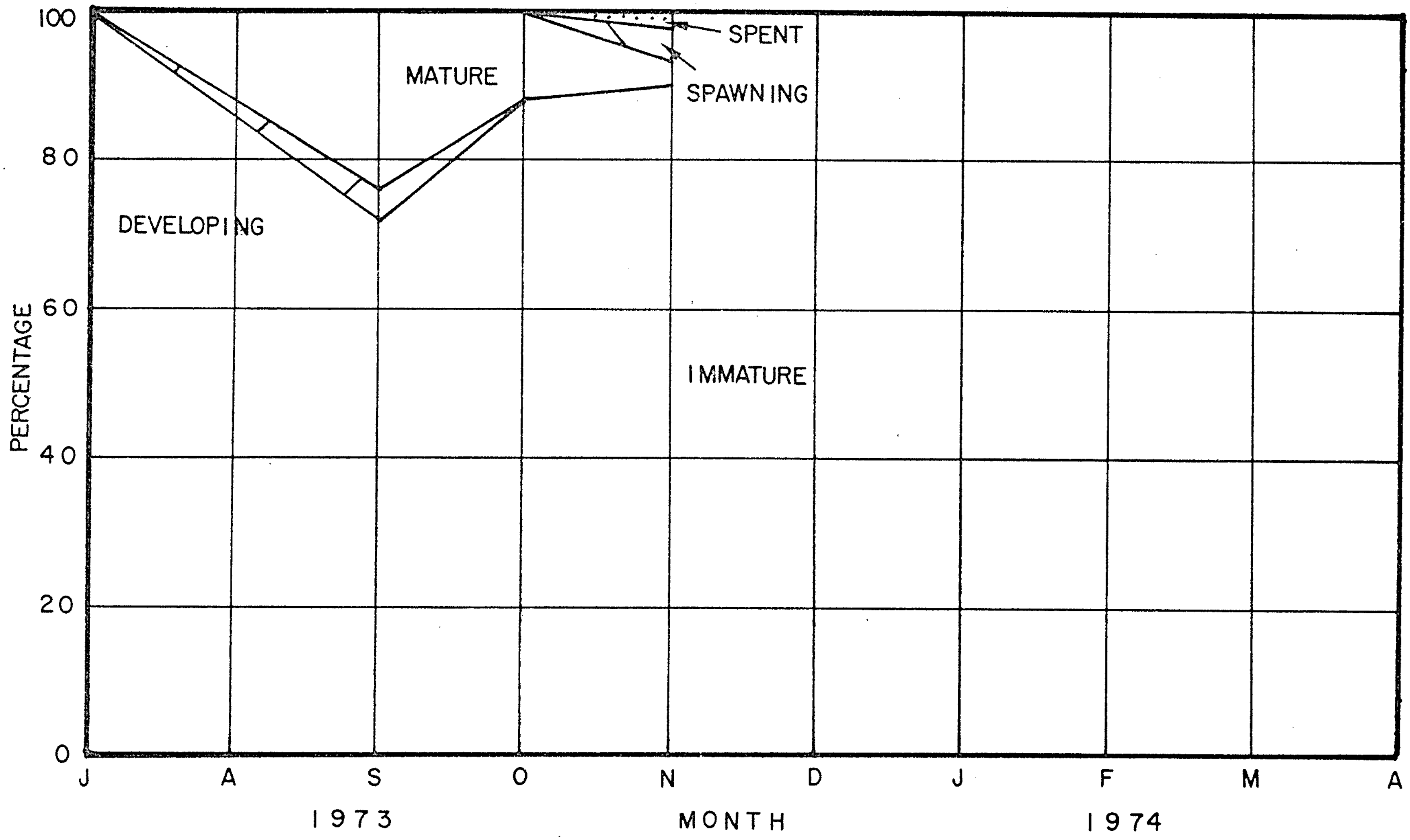

Fig. 5-15. Sexual condition of male and female kokanee, July, 1973-March, 1974.

millimeters. Preliminary aging indicates these fish to be between 11 and 19 years of age. Hart (1930) aged lake whitefish from Lake Nipigon which were 400 millimeters or larger to be 13 to 24 years old.

The kokanee catches suggest movement between stations. Aging has not been completed for the kokanee but the mature fish taken ranged from 280 to 410 millimeters which is average when compared with data taken from several lakes by Seeley and McCammon (1966).

The stomach contents analysis indicated the yellow perch, lake whitefish and kokanee are largely dependent upon the zooplankton as a primary food resource.

The distribution and growth of the yellow perch, lake whitefish and kokanee are being analyzed with respect to the temperature and zooplankton densities found throughout the lake.

The distribution, abundance and life histories of yellow perch, lake whitefish and kokanee are being established prior to pump storage operation. As pump storage operation is initiated the lake currents, water temperature and water chemistry may be affected. These changes may directly affect the distribution and abundance of fishes which the sampling program is designed to detect.

6.0 ACOUSTIC SURVEYS

6.1 Introduction

Two acoustic surveys of Banks Lake were conducted in 1973 as part of a comprehensive study of fish populations. The primary goal of the surveys was to examine the feasibility of using acoustic techniques to determine the distribution and abundance of fish in Banks Lake.

6.2 Materials and Methods

The echo sounder utilized for the surveys was a 105 kHz Ross 200 A Fineline with a transducer producing an 8.5° circular beam. The transducer was mounted on a towed vehicle for use from small boats. In addition to the echogram output, the acoustic data could be recorded on a special magnetic tape recording system for later detailed analysis. The complete data acquisition system is described by Thorne, Nunnallee and Green, (1972).

The first acoustic survey was conducted on June 5 and 6. The goals of the survey were to examine the gross distribution of fish and to establish transecting procedures. The tape recording system was not utilized. Daytime transects were run over most of the long axis of the lake, and a short night series was conducted near the feeder canal.

The second survey was conducted during August 6-8. Transecting was done only at night due to unavailability of the boat at other times. Series were run in the vicinity of Steamboat Rock and in the vicinity of the feeder canal and Electric City. A total of three hours of data were recorded on tape.

The echo signals on magnetic tape were analyzed with an oscilloscope. The number of fish targets along each transect was counted and the depth and maximum echo amplitude were recorded. Densities of fish were calculated by dividing the number of echoes by the volume sampled by the echo sounder. An 8.5° sampling cone was assumed based on sampling volume measurements with the same system in Lake Quinault (Croker, 1973). The echogram outputs were used only to examine the gross distribution in June and for a relative comparison of the two surveys. Only targets at depths greater than 3 m were counted. The extremely small sampling area of the sounder above this depth, the proximity of targets to the boat, and interference from surface turbulence and debris, all tended to minimize the usefulness of data from the near-surface region. All targets that could be resolved from the bottom were counted. Targets within 1 m of the bottom were generally not resolvable.

6.3 Results

A total of 46 targets were observed during the three hours of transects in August. The data were insufficient to establish characteristics of horizontal distribution and were combined to examine vertical distribution. The mean densities of fish in 3 m depth intervals from 3 to 18 m are presented in Table 6-1. The highest density, 0.43 fish per 1,000 m^3, was observed in the upper interval, and the second highest density, 0.33 fish per 1,000 m^3 was observed in the deepest interval. The numbers of fish per unit surface area are also presented in Table 1. The numbers reflect the greater area associated with shallower depths. The mean density for all data combined was 3.4 fish/1,000 m^2 in the depth interval between 3 m below the surface and 1 m above the bottom. If the total area of Banks Lake is assumed to be 10^8 m^2, the resulting population estimate is 340,000 fish in midwater.

Although the greater densities were observed in the shallowest interval, there was a strong association of the targets with the bottom. The number of targets as a function of distance above the bottom is presented in

Table 6-1. Vertical distribution of fish in Banks Lake during August 1973.

Depth (m)	Density (number/$10^3/m^2$)	Number/$10^3/m^3$
3-6	1.3	0.43
6-9	0.7	0.23
9-12	0.7	0.31
12-15	0.5	0.28
15-18	0.2	0.33
	3.4	

Table 6-2. Echo targets encountered in Banks Lake during August 1973 as a function of height above bottom.

Height above bottom (m)	Targets encountered
1-4	22
4-7	18
7-10	6

Table 6-2. Over 80% of the targets were observed within 7 m of the bottom.

Comparison of the echograms for the two surveys indicates considerably greater density of targets in June. As in August, most targets in June were near the surface or bottom with a noticeable shoreward bias.

Although target echo amplitudes were measured in August, target strength analysis and sizing were not attempted because the number of targets was insufficient for meaningful results.

6.4 Discussion

The results indicate that distributions during the summer are strongly biased toward surface and bottom. This trend was supported by the results of net sampling, and it is probable that many fish are located at depths less than 3 m from the surface or within 1 m of the bottom where they are not detectable with the acoustic system used on these surveys. The near surface region could be examined with a bottom-mounted transducer directed toward the surface, but the upper 1 m would still not be resolvable. A bottom-mounted system would be stationary, and thus would have a limited sampling power similar to gill nets. Possibly the primary value of such a system would be to evaluate net catching efficiency.

Efforts were made unsuccessfully during the August survey to deploy the 8.5° transducer on the bottom in an upward looking mode. The experiment indicated a need for a longer cable and an anchoring device. Experiments near the feeder canal outlet showed considerable interference from air bubbles. It was apparent that the system was not useable under these turbulent conditions.

Evaluation of the utility of the acoustic system in the Banks Lake studies must consider sampling power, costs, and requirements for absolute abundance information. Although only 46 targets were encountered during the three hours of recorded survey data, the number is considerably greater than that caught in overnight sets of the gill nets, and the sampling power could be increased by using a wider angle transducer. The acoustic system does not give species composition, but it also causes no mortality. The acoustic system cannot sample near surface or bottom, but these strata are easily sampled by horizontal gill nets.

A major advantage of the acoustic system is the ability to provide direct absolute abundance estimates. Gill nets do not directly provide absolute abundance information, although comparison of gill net catches and acoustic measurements of fish density in the vicinity could provide a mechanism for net calibration.

Further assessment of Banks Lake fish populations by acoustic methods does not appear to be feasible at this time for two reasons: 1) most of the fish caught have been within 3 m of the surface or 1 m of the bottom where the acoustic system is least effective; 2) the cost of additional acoustic sampling and data analysis are greater than the preliminary results justify at this time.

7.0 ENTRAINMENT STUDIES

7.1 Introduction

Fish entrainment through the pump/generators between Franklin D. Roosevelt Lake and Banks Lake may occur during the pumping or generation phase resulting in a net gain or loss of fish to Banks Lake. A net loss of fish can also occur during the irrigation phase of operation which has probably been a consistent effect throughout the history of the lake. It is important that each phase be investigated quantitatively so that effects of pumped storage may be determined.

Entrainment of organisms may occur in two ways: 1) by active entrainment when organisms move into an intake as the result of a behavioral response (e.g., current) or; 2) by passive entrainment when organisms are forced into an intake. The mortality that is imposed on the entrained fish may be direct, due to the pump or generator rotor or indirect by placing fish in a less favorable environment resulting in lower survival. Direct mortality rates can be calculated for the generation phase using fish length, blade separation, rpm, efficiency, pressure differentials across the blade and surge. The mortality during the pumping phase of operation will be evaluated directly. The indirect mortality may be extensive for small juveniles that are placed in bodies of water that have large populations of predators or inadequate food supplies.

The objectives of the entrainment study are to determine the relative magnitude, size, and age of the entrained species with the season. The estimation of direct mortality of the entrained fish will be undertaken based upon known mortality rates for similar types of pumps and generators.

7.2 Sampling Approach

Preliminary sampling to define the most adequate methods of evaluating fish entrainment have involved gill nets, fyke nets, plankton nets and modified beam trawls. Gill nets were used to determine the relative magnitude of large fish in the feeder and irrigation canals, areas in Banks Lake near the canals and in Trail Lake. Gill net catches from the feeder canal yielded 5 species: black crappie, peamouth, rainbow trout, longnose suckers, and lake whitefish. Thirteen fish were captured with whitefish being the most numerous. Half-meter diameter plankton nets were towed across the irrigation canal intake to determine the presence of small fish and numerous 15 mm (0.59 in) lake whitefish were captured. Fyke nets were found to be an unsuccessful sampling gear in the feeder canal during operation of the generators.

Gear was developed to sample the discharge from the existing pumps (6 units) and pump/generators (2 units) with the expectation that there will ultimately be 6 P/G units. The water velocity in the feeder canal during the generation phase will range from less that 0.3 m/sec (1 ft/sec) to 2.0 m/sec (7 ft/sec). Sufficient time and effort to develop sampling gear and procedures which can be repeated later over a wide velocity range will facilitate the comparison of the effects of operating two units to the eventual operation of 6 units. Effects over the long term after all units have been added may be of greater importance than any immediate impacts on Banks Lake fish populations.

The primary sampling gear will be of beam trawl design with a 1 by 2 meter (3.3 ft x 6.6 ft) opening. The frame, constructed from 1.9 cm (.75 in) galvanized pipe reduces the original net opening from 1.2 by 2.1 meter (4 ft by 7 ft) and increases the mouth opening to mesh ratio and maximum possible fishing velocity. The rigid net frame has several advantages: 1) it cannot collapse, 2) it maintains a constant opening which is not dependent on fishing velocity, and 3) it facilitates closing of the net while setting and retrieving. The net is of variable mesh construction with 2.5 cm (1.0 in), 1.3 cm (0.50 in), and 6.4 mm (0.25 in) mesh (stretched) in mouth, middle, and cod end, respectively. A zipper in the cod end facilitates the removal of the catch. Variable mesh trawls have been found to be more efficient because of lower back pressure allowing operation over a greater range of fishing velocities. A greater size range of fishes can also be sampled. A 0.5 meter diameter by three meter long, 223 micron mesh, plankton net is employed as an exterior sleeve enveloping the terminal 0.9 m (3 ft) of the cod end of the trawl to protect it from damage by capture of large fish. The plankton net is held open by a one-half meter steel ring sewn to the trawl. A cumulating flow meter is suspended near the center of the trawl mouth. A 4.7 mm (3/16 in) steel cable towing harness will be attached to each corner of the rectangular frame; the two leads from each side of the frame will terminate at a shackle to which the towing warps are attached. The dynamic warp, 3.9 mm (5.32 in) steel cable, will be set and retrieved using a battery powered Warn winch while the 50 meter (165 ft) static warp, 1.1 cm (7/16 in) braided nylon, will be set and retrieved by hand.

Sampling in the feeder canal during the pumping and generation phases of operation will be conducted from the bridge at the taintor gates. Two nets will be fished on 50 meters (165 ft) of wire and nylon warps and retrieved by Warn winches. The time a net is fished will be established by determining the time interval in which sampling efficiency is altered due to clogging. Since clogging is dependent upon velocity the nets will be evaluated for each phase of operation and sampling.

The sampling scheme for the irrigation canal during the irrigation phase of operation will consist of fishing two nets on 50 meters (165 ft) of wire and nylon warp from a boat anchored just upstream of the outlet. The nets will be fished in the lake as close to the outlet structure as practicable.

The combination of a fixed opening and flow measurements will allow calculation of the amount of water that passes through the net which can be extrapolated to determine the total entrainment. Even with the extreme mixing and turbulence found near the intakes certain species and sizes of fish may be distributed unevenly throughout the water column making it necessary to take replicate samples at three depths in the water column (surface, midwater and bottom). The nets will be positioned using weights and floats at the desired depths. Diurnal variance will be determined by day and night sampling.

Circulation patterns in Banks Lake near the feeder and irrigation canals will be determined using current drogues (floats) and plane table mapping techniques. The procedure will consist of releasing the drogues at known locations. The movement of these drogues will be plotted on the plane table using a telescopic alidade and staff with respect to elapsed time between sightings. The circulation study will define the movement of water masses which enter the canals and will assist the evaluation of passive fish entrainment.

Gill net sampling will be conducted with 30.5 m (100 ft) variable mesh 2.5 - 12.7 cm (1 - 5 in), monofilament nets (as described in a previous section) fished on the bottom and surface in the canals during slack water periods. These nets will be fished between the headworks and the cut and cover section in the feeder canal and between Dry Falls Dam and the Bacon siphon in the irrigation canal.

The work schedule for this irrigation season will include sampling at biweekly intervals at the irrigation canal intake and in the feeder canal when pumping commences. Further refinements in the gear and sampling procedures are being evaluated. The circulation study will be conducted twice during the summer and fall months near the feeder and irrigation canal intakes. When the irrigation phase of operation terminates, gill nets will be fished in the feeder and irrigation canals. When the generation phase begins samples will be collected on a frequency consistent with the operation of the generators. It should be stressed that close coordination and communication between Bureau personnel and the biological sampling team will be necessary to make the generating phase sampling most meaningful.

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