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

by

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1.0 SUMMARY

1.1 Ecological Baseline

The overall objective of this investigation was to establish an ecological baseline for the multiple uses of Banks Lake as an irrigation water equalizing reservoir, a pumped storage forebay reservoir, and an important sport fishery resource. Study to date has determined the characteristics of the lake induced by irrigation water input and withdrawal, the primary function of the lake in the Columbia Basin Irrigation Project. Routine operation of pump generation units (P/G 7 and 8) has not occurred due to technical difficulties. Preliminary testing of the units has yielded a minimal amount of ecological data on which to predict environmental impacts. Detailed studies have focused on the physical and chemical limnology, fish abundance and distribution, and entrainment of larval, juvenile, and adult fishes through the P/G units.

Limnological investigations have indicated that Banks Lake is a very complex system dominated by the flow-through of irrigation water. The temperature regime is one of modified dimixis possessing properties of both a stratified lake and a river-run reservoir. The turbulent inflow of cool irrigation water from Franklin D. Roosevelt Reservoir restricts the summer water temperatures in the north end of the lake. Thermal stratification occurs south of a convergence zone emphasized by a morphometric constriction of the lake basin. A horizontal surface temperature gradient increased toward the south during the summer, however, during the fall, winter, and early spring the gradient reserved, probably due to greater wind induced cooling in southern Banks Lake.

Secchi depth transparencies indicated the entire lake was often within the euphotic zone at maximum drawdown. Turbidity due to phytoplankton standing stock, sediment and turbulence due to pumping generally decreased from north to south.

Water quality measurements indicated a range for conductance from 78 to 100 μmho/cm^2. Total alkalinity averaged 68 ppm $CaCO_3$. Dissolved oxygen was generally greater than 70 percent saturation. Orthophosphates ranged from 2.5 to 25.0 ppb, hydrolyzable phosphate 5.0 to 26.3 ppb, and total phosphate 5.0 to 35 ppb. Total nitrate levels ranged from 0 to 21.6 ppb.

Chlorophyll *a* measurements indicated two functionally separate regions within the lake. Phytoplankton standing stocks were greater in the north end of the lake and showed responses to operational input of irrigation water. Changes in chlorophyll *a* were less dramatic and levels were consistently lower in the south half of the lake. The clear distinction between northern and southern regions of the lake, perpetuated by morphological and operational characteristics of the system, was further substantiated by the changes in the distribution and abundance of zooplankton.

Specific objectives of the fish population studies included assessment of the relative abundance, distribution in time and space, and life history of each of the 19 species in the lake. Emphasis was placed on yellow perch, lake whitefish, and kokanee which constituted 28.6, 34.5, and 13.3 percent of the fish biomass, respectively. Colder summer water temperatures in the north end of the lake were probably responsible for a reduction found in the growth rates of yellow perch. Horizontal temperature regimes and water velocities due to pumping apparently induced behavioral responses in kokanee and lake whitefish resulting in shifts in abundance between north and south lake sectors.

Major spring water level fluctuations have prevented successful reproduction of the rainbow trout, a spring spawner. Rainbow trout occurring in the lake are dependent on artificial stocking. The successful salmonid species are the fall spawning kokanee and lake whitefish. During the fall to spring period the lake is normally held at full pool allowing successful reproduction. Spring drawdown may also limit walleye reproductive success, however, other spiny rays are not as severely affected. Yellow perch are best adapted to the present conditions under which the lake is operated.

The food chain is predominantly plankton-to-fish for the major species investigated. Benthic production in the lake is minimal and does not appear to contribute to a significant degree in the major fish species. Benthos in the littoral zone is discouraged annually by spring water level reductions.

Fish entrainment studies began with an array of complex gear development problems. Fish sampling of bidirectional canal discharges at water velocities ranging from 1-8 fps, over a wide range of fish sizes and species-specific behavioral responses has only recently met with some success. Several methods and gear types were tested. Observations of P/G fish entrainment were only possible with underwater closed circuit TV monitoring. Test monitoring during three periods in January, February, and March 1975 indicated that TV monitoring is a viable technique. Delay in routine operation of P/G 7 and 8 over the entire season (November to March) precludes detailed assessment to date.

1.2 Preliminary P/G Impact Assessment

Based on the latest engineering design supplied by the U.S.B.R. (June 2, 1975) on Grand Coulee feeder canal modifications, the minimum water level at which P/G will occur is 1,563.1 ft. Seasonal water level fluctuations during P/G will range 6.9 ft between 1,563.1 and 1,570 ft. Since P/G will be used for peaking, daily and weekly fluctuations of 0.35 ft and 1.8 ft, respectively, will result. Each P/G unit will operate at 2,400 cfs. This will amount to a total discharge rate of 14,400 cfs (six P/G units on line) which can potentially be withdrawn from Banks Lake. Irrigation and P/G pumpback utilizing units 1-12 could attain a discharge rate of 20,640 cfs into Banks Lake. Physical modifications of the canal will bypass the cut-and-cover, widen the canal bottom 10 ft, and increase the elevation of the canal berms to prevent surge overflow. The present full pool elevation of Banks Lake will remain at 1,570 ft.

The pre-operational ecological baseline data describing Banks Lake under its original use as an irrigation storage reservoir provides the data which will be compared with that from the post P/G operational period. Since operation of P/G units 7 and 8 has been delayed by technical problems the opportunity for measuring the effects of P/G was limited to three tests during mid-winter 1975. In these tests the entrainment of fishes was observed by closed circuit TV during 35.5 hr of generation and 5 hr of pumpback. Since these tests were of short duration during mid-winter the numbers of fish observed may underestimate fish loss which may occur in November-December; and therefore, must be considered very preliminary.

Observations of entrained fishes by means of closed-circuit television indicated that roughly 4.7 fish per hr per P/G unit were entrained from Banks Lake to Roosevelt Lake during three tests in late January, February, and early March and that most of these fish were small rainbow trout which had been stocked during fall 1974. Other species were tentatively identified as whitefish, chinook salmon, and yellow perch. No fish were observed during 5 hr of pumpback. The entrainment rate of fish from FDR Reservoir should be low during the winter when Roosevelt Lake is at or near full pool because the depth of the intake exceeds the depth of normal occurrence for most species.

There are factors which complicate the use of these data in determination of a rate of entrainment. The first of three tests indicated a decreasing rate of entrainment with time, the actual rate under prolonged P/G may be less than 4.7 fish per P/G unit per hr; however, it may be greater earlier in the P/G operational period (November-December) when the fish are more active. The ice and snow cover which blanketed Banks Lake continuously during the tests probably inhibited the movement of fish and thereby minimized the observed rate of entrainment. The entrainment rate during ice-free conditions at the north end of the lake may be substantially greater. The discharge passing through the canal did not exceed a maximum of 3,500 cfs during TV monitoring, therefore creating problems of scale-up to 1,400 cfs. The species concentrated at the north end of the lake during P/G operations appears to be the lake whitefish. Fall or winter plants of rainbow trout and other salmonids at the north end of the lake are not recommended.

The effects of water flows on the ice cover of Banks Lake were observed during the first P/G test in order to determine whether significant melting occurred. Preliminary observations indicated that ice breakup began to occur in the Narrows after three days of operation of P/G units 7 and/or 8. Melting of the ice also occurred immediately offshore from the mouth of the feeder canal into Banks Lake. The sustained operation of six P/G units would probably remove solid ice cover from the entire northern end of Banks Lake southward to the Narrows. The actual extent of ice removal could only be determined by testing of longer duration.

The greatest potential hazard of P/G to the fishes is the exposure of incubating eggs due to drawdown. The fall spawners (kokanee, lake whitefish, and mountain whitefish) will be the species affected since they spawn between October and December and emergence does not take place until March and April. Kokanee spawning has been observed along the shoreline as high as elevation 1,569 ft and the average depth was estimated at 1,562 ft. A winter drawdown of 6.9 ft could substantially reduce kokanee and whitefish reproduction. Lake whitefish and mountain whitefish spawning occurs over the same areas utilized by kokanee. Since spring-summer irrigation drawdown already negatively impacts the natural reproduction of spring spawning species (rainbow trout) the lake fishery with winter drawdowns could be relegated to total dependence on artificial stocking.

It has been observed that irrigation operations influence the phytoplankton standing stock in north Banks Lake. Since the pumped storage operations will disrupt the water column in this region of the lake it is likely that primary production will be modified under such conditions. Changes in the nutrient dynamics of the lake will be of particular importance. It is probable that any apparent changes in primary production and phytoplankton standing stock resulting from pumped storage operations will occur only in the north end of the lake.

It is also probable that changes observed in the distribution and abundance of zooplankton in north Banks Lake during the irrigation season were due, largely, to operational effects. Thus, it is likely that pumped storage operations will influence the zooplankton standing stock in this region of the lake. Changes in the species composition may occur if species are exchanged with Lake Roosevelt or if the habitat changes sufficiently to favor a change in the zooplankton community. It is possible that flushing effects will reduce the magnitude of zooplankton production in north Banks Lake during pumped storage operations. There is not sufficient data available to comment on the potential effects of these changes in the plankton community or on the possible effects on growth rates of the fish populations of the lake.

In order of priority the fish habitat and entrainment aspects are most critical and ones which can be controlled to some degree. Effects on the limnology, and primary and secondary production are much more difficult to interpret and to predict.

2.0 ACKNOWLEDGMENTS

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

Dr. Q. J. Stober, Principal Investigator

Dr. R. E. Nakatani, Co-Principal Investigator

Mr. R. W. Tyler, Project Leader

Mr. M. Pease, Field Project Biologist

Mr. G. L. Thomas, Pre-Doctoral Research Associate, fish population ecology

Mr. W. A. Karp, Research Assistant, limnology

Mr. D. Smith, Research Assistant, canal entrainment

This investigation is being conducted under contract with the U.S. Bureau of Reclamation, Pacific Northwest Regional Office, Boise, Idaho. The cooperation received from the Washington Department of Game in planting marked populations of rainbow trout, and kokanee salmon are greatly appreciated. The Washington State Department of Fisheries assisted by the loan of coded wire tagging machines. Mr. Rufus Kiser provided valuable taxonomic assistance in the identification of zooplankton species. Mr. Frank Dimmick, U.S.B.R., provided essential engineering liaison and assisted in TV monitoring studies. The U.S.B.R. diving team provided able assistance in the underwater spawning bed surveys. The assistance of Dr. R. R. Whitney, Leader of the Washington Cooperative Fisheries Unit, has been valuable in accomplishing project goals and objectives. The Western Washington Bass Club cooperated by providing largemouth bass catch statistics obtained by its membership. The hourly assistance of Mr. John Knutzen and Ms. Leslie Jensen is greatly appreciated.

3.0 PREFACE

This report contains the scientific results of the ecological studies of Banks Lake conducted by the Fisheries Research Institute on the pump-generation power development project at Grand Coulee Dam. The organization of this report is by sub-project dealing with the limnology of the lake, fish population ecology, and canal fish entrainment. Results are reported through December 1974 for lake limnology and through March 1975 for the remaining sub-projects. This is the second annual report submitted to the U.S.B.R. Due to the delay in routine operation of P/G 7 and 8 this contract has been extended and expanded to include a continuation of present baseline studies, fish loss through the irrigation canal, a 12-month fisherman creel survey as well as sampling during P/G operation in the fall-winter of 1975-1976. An effort has been made to include most of the significant results of the baseline studies of the lake under operational conditions relating to irrigation water input and withdrawal. Complete analysis, synthesis, and reporting of all the data will be deferred to the final report scheduled for submission on June 30, 1976.

4.0 LAKE LIMNCLOGY

4.1 Introduction

The limnology of impounded waters has received considerable attention (Hubbel 1967; Beckmann and Kutkuhn 1953; Hall 1971; Fraser 1972). This is not surprising, considering the fact that the United States has 5.25 million hectares (13 million acres) of artificial waters at maximum pool levels (Stroud 1966). As the requirements for water and energy increase new impoundments will be established and existing reservoirs will be expanded. Biological information is needed, not only to improve our knowledge of the behavior of aquatic ecosystems, but also to provide vital background for the establishment of effective resource management programs, particularly where recreational use of artificial waters is important.

A comprehensive study of the limnology of Banks Lake was begun to establish a data base for the assessment of the environmental impact of a pumped storage power generation facility at Grand Coulee Dam utilizing Banks Lake as the forebay reservoir. This data base will also be of use in the assessment of changes imposed on the lake by its primary function as the equalizing reservoir for the Columbia Basin Irrigation Project. Determination of an ecological baseline under present operating conditions describing the effects of the input and withdrawal of irrigation water was of primary importance prior to the implementation of pumped storage power generation. Specific objectives of the limnological studies were to document the temporal and spatial changes in certain aspects of the physical and chemical limnology (temperature, transparency, conductivity, pH, total hardness, total alkalinity, dissolved oxygen, and the major plant nutrients), in the distribution and abundance of chlorophyll *a* as an index of phytoplankton abundance and in the distribution and abundance of zooplankton. A 16-month period of this investigation, from September 1973 to December 1974, is reported.

4.2 Description of Study Area

Banks Lake was established in 1951 by flooding 10,926.5 hectares (27,000 acres) along a 46.5 km (28.9 mile) section of the upper Grand Coulee between two earth fill dams (Wolcott 1964) (Fig. 4-1). The Grand Coulee gorge is located in the high scrub desert of Central Washington. It was cut from the massive plain of lava flow by the Columbia River which was temporarily diverted from its present course by an ice blockage during recent glaciation. The gorge is characterized by steep basalt cliffs and extensive talus slopes. The present day climate is one of hot, dry summers and cold dry winters. Average summer daytime temperatures range from 23.9° to 29.4°C (75° to 85°F). January temperatures average from -9.4° to -1.1°C (15° to 30°F) with occasional extremes of -28.9°C (-20°F). Annual rainfall averages 27.5 cm (11 inches)(U.S.B.R. 1974). An ice cover lasting one to three months may develop on Banks Lake during severe winters.

The North Dam constitutes the northern boundary of the lake. Dry Falls Dam contains the southern end of the lake. The pumping plant located at the left forebay of Grand Coulee Dam pumps water from Franklin D. Roosevelt Reservoir up 111.2 m (365 ft) into the 2.5 km (1.6 mile)

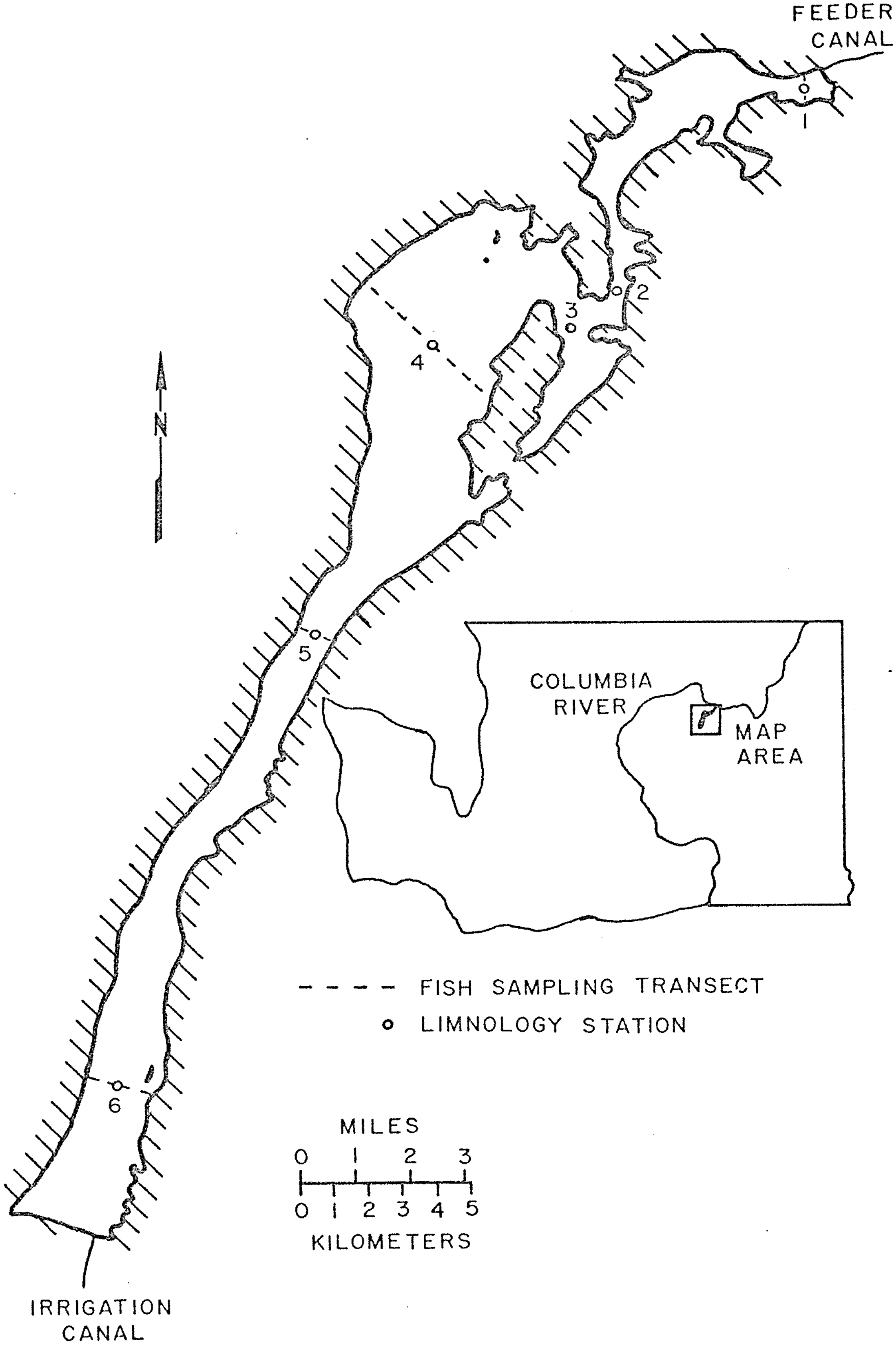

Fig. 4-1. Banks Lake showing limnology and fish sampling sites.

long feeder canal which supplies water to Banks Lake adjacent to the North Dam. Some runoff and spring water enter Banks Lake but the volume of water contributed to the system from these sources is negligible compared with the pumped water supply.

The pumping plant contains six pumps, each rated at 487.7 m^3/sec (1,600 cfs) and two pump generators, each rated at 533.4 m^3/sec (1,750 cfs) in the pumping mode. Water for irrigation is withdrawn from Banks Lake through the irrigation canal headworks at Dry Falls Dam to supply the agricultural requirements on 202,000 hectares (500,000 acres) of farmland in the Columbia Basin. The maximum rate of irrigation withdrawal is 2,407.9 m^3/sec (7,900 cfs). Variations in the operational rates of water supply and withdrawal to Banks Lake result in water level fluctuations of the lake. Rates of irrigation water input and withdrawal and changes in water level elevation during 1973 and 1974 are presented in Fig. 4-2. Maximum surface elevation is 478.5 m (1,570 ft) (Table 4-1) and at maximum drawdown the surface elevation is 469.4 m (1,540 ft). The annual drawdown does not normally exceed 4.6 m (15 ft) but during the study period drawdown reached 7.6 m (24.9 ft) and 7.2 m (23.6 ft) during the spring of 1973 and summer of 1974 (Fig. 4-2). The maximum width of Banks Lake is 8 km (5 miles); however, the mean width is considerably less. The mean lake depth at maximum elevation is 16.5 m (54.1 ft) and the maximum depth greater than 25 m (86.0 ft). The mean depth at surface elevation 496.4 m (1,540 ft) is 8.1 m (26.6 ft) (Table 4-1).

The lake perimeter is 131.5 km (81.7 miles) at maximum elevation and 155.9 km (96.8 miles) at maximum drawdown. Shoreline development (Welch 1948) is 3.53 at maximum elevation and 5.01 at maximum drawdown.

is this reversed?

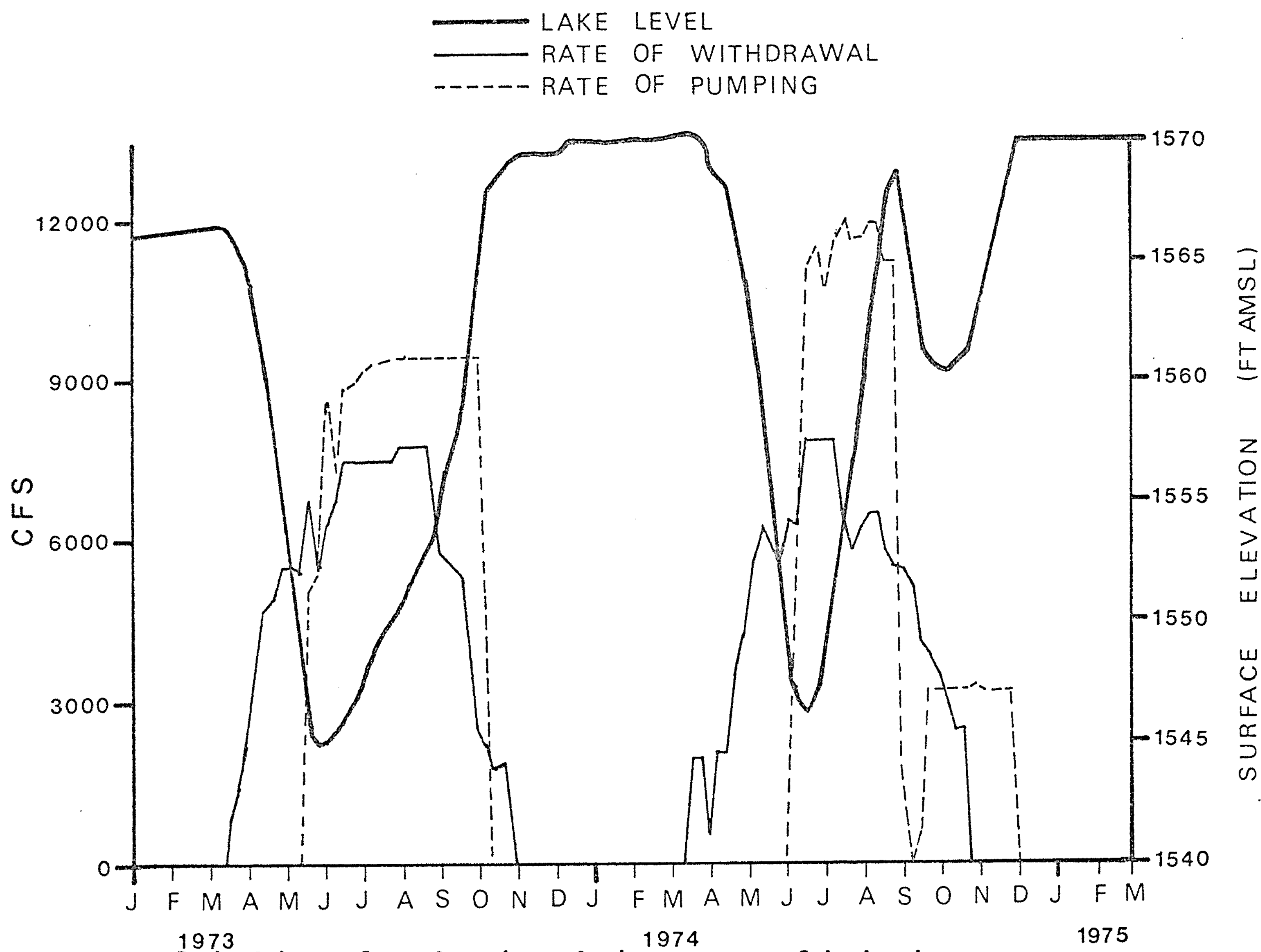

Fig. 4-2. Banks Lake surface elevation relative to rates of irrigation water input and withdrawal, 1973-1974 (U.S.B.R.).

Table 4-1. Morphometric Characteristics of Banks Lake.

	Elevation (ft)	Area (acres)	Volume (acre-ft)	Maximum Length (mi)	Maximum Width (mi)	Mean Depth (ft)	Perimeter (mi)	Shoreline Development *
Maximum level	1,570 478.5 m	27,200 11,008 ha	1,202,000 148,269 ha m	28.9 46.5 km	5.0 8.0 km	44.2 13.5 m	81.7 131.5 km	3.53
Irrigation drawdown:								
- 5 ft	1,565 477.0 m	26,100 10,562 ha	1,068,000 131,740 ha m	28.9 46.5 km	5.0 8.0 km	40.9 12.5 m		
-15 ft	1,553 474.0 m	23,200 9,384 ha	822,000 101,394 ha m	28.9 46.5 km	4.9 7.9 km	35.4 10.8 m		
-30 ft (maximum)	1,540 469.4 m	19,000 7,689 ha	506,000 62,416 ha m	28.9 46.5 km	4.9 7.9 km	26.6 8.1 m	96.8 155.9 km	5.01

*Shoreline Development = $\frac{\text{Shoreline length}}{2\sqrt{\text{Surface area } \pi}}$

Flushing time (lake volume ÷ rate of withdrawal) was determined for various elevations at different rates of withdrawal (Fig. 4-3). Under given conditions estimated flushing times ranged from 30 days to 2 years. The volume of water passing through the lake in a season was determined by irrigation requirements. This annual requirement has been approximately 271,366 hectare meters (2,200,000 acre feet) in recent years. This represents effective replacement of the storage capacity approximately three times each year and effective replacement of the total lake capacity approximately twice each year (U.S.B.R. 1974).

Initial limnological investigations, carried out during July and August 1973, indicated that a minimum of six sampling stations were required to document the limnology of the reservoir. A monthly sampling schedule was established. On occasion, severe weather conditions precluded a partial or complete set of observations. No samples were obtained in January and April 1974. In December 1973 and February 1974 incomplete sets of samples were obtained.

Stations were established at midlake locations. Station 1 was located 0.2 km (0.1 mile) from the North Dam near the feeder canal discharge point. Station 2 was 10.8 km (6.7 miles) from the North Dam, in the area of the morphometric constriction. Station 3 was 11.9 km (7.4 miles) from the North Dam, south of the morphometric constriction. Station 4 was 18.0 km (11.2 miles) from the North Dam, west of the southern end of Steamboat Rock. Station 5 was 33.3 km (20.7 miles) from the North Dam, adjacent to Million Dollar Mile. Station 6 was 41.7 km (25.9 miles) from the North Dam, about 4.8 km (3.0 miles) from the irrigation water discharge structure.

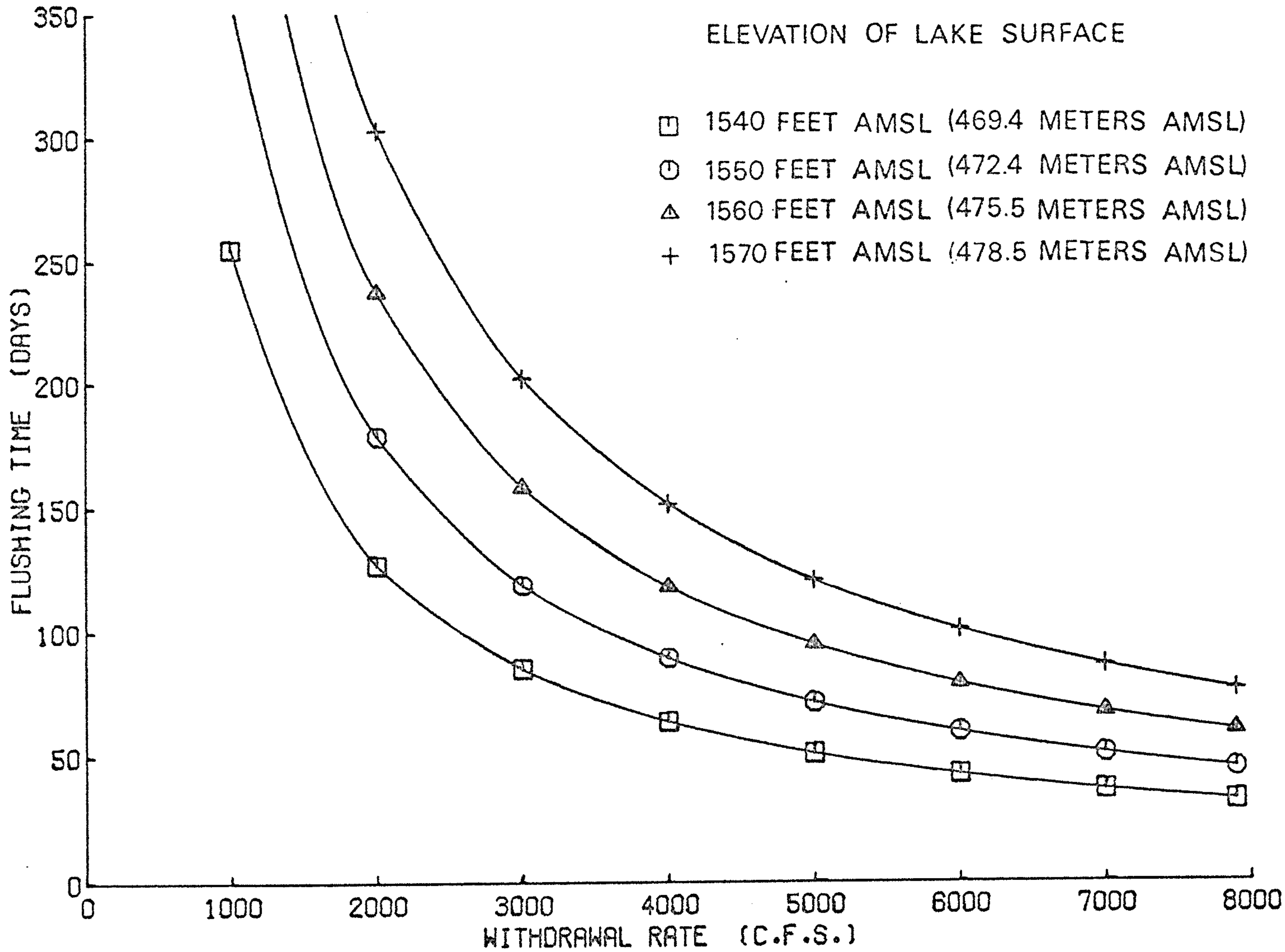

Fig. 4-3. Estimated flushing time for Banks Lake at four water level elevations.

4.3 Materials and Methods

4.3.1 Physical Measurements

Initial *in situ* temperature measurements were made with a Beckman RS-5 temperature/conductivity probe. This instrument was replaced in November 1973 with an Applied Research temperature/conductivity probe. Vertical temperature profiles were recorded at each station beginning at the surface and at 4 m depth intervals. During stratification, observations were made at closer intervals to characterize the metalimnion.

Transparency was measured with a standard 20 cm Secchi disc (Welch 1948). 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 recorded. All observations were made with the aid of polarizing sunglasses.

4.3.2 Chemical Measurements

Water samples for chemical and chlorophyll *a* analysis were taken at three depths using three 2.5 l Van Dorn bottles. Samples were taken at the surface, 4 m and near the bottom.

Total hardness and total alkalinity were determined by standard techniques (A.P.H.A. 1971), modified according to the methods manual of the Hach Chemical Company. Total hardness (mg/l $CaCO_3$) was determined by titration with EDTA against Eriochrome Black T indicator. Total alkalinity was determined by titration with sulfuric acid against bromocresol green-methyl red indicator and expressed in mg/l $CaCO_3$.

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

The conductivity of Banks Lake water was measured *in situ* with an Applied Research temperature/conductivity probe. The instrument utilized a temperature compensated four electrode A.C. cell with pure nickel electrodes. Observations were made at each station, at the surface, and at 4 m depth intervals.

Dissolved oxygen was determined by the azide modification of the Winkler titration, titrating with phenyl arsine oxide (USEPA 1974).

Water for nutrient analysis was placed in 500 ml "Nalgene" plastic bottles and acidified with one drop of concentrated hydrochloric acid. Samples were packed in ice and transported to the Fisheries Research Institute water quality laboratory for analysis within 24 hours of collection. Ortho, hydrolyzable and total phosphate was determined spectrophotometrically as phosphorus according to standard techniques (USEPA 1974). Total nitrate nitrogen was determined by hydrazine reduction (Kamphake, Hannah, and Cohen 1967). A modification of this technique, in which a chelating agent (Chelex) was used to complex metal ions which may have interfered with the determination, was carried out for comparative purposes in May 1975.

4.3.3 Biological Measurements

Phytoplankton standing stock measurements were made by the determination of chlorophyll *a* concentrations according to the spectrophotometric method of Richards and Thompson (1952). One liter water samples were taken at three depths at each station. One drop of saturated aqueous magnesium carbonate solution was added to each sample immediately after collection. The samples were kept cold and dark during transportation to the field laboratory where each was filtered through a Millipore PA (1.2 μ) filter under slight vacuum. The filters were dried and refrigerated in a darkened dissicator for analysis. Storage of samples before analysis varied from several days to three months. The filters were dissolved in 90 percent aqueous acetone. Light absorbance of the resultant solutions was determined at wave lengths of 480, 510, 630, 645, 665, and 750 μ with a Bausch and Lomb Spectronic 20 colorimeter. Plant pigment concentrations were calculated according to the equations of Parsons and Strickland (1963).

Zooplankton standing stock estimates for each station were determined from data obtained by vertical hauls of a 0.5 m diameter plankton net of 73 μ (No. 20) mesh (Edmondson and Winberg 1971). Duplicate hauls were made at each station from near the bottom to the surface and from 4 m to the surface. The net was hauled with a Warn electric winch at an approximate speed of 30 m/min. Samples were preserved in 10 percent formalin through April 1974, later samples were preserved in 90 percent ethanol. Net clogging is frequently significant with this type of gear and since it was impossible to quantify the degree of clogging during this study it was assumed to be constant in all determinations of relative abundance.

Zooplankton samples were diluted in the laboratory to a concentration of 100-200 organisms per ml. From two to four one-milliliter subsamples from each sample were counted with a low power stereo microscope

(10 - 30 X magnification) over a grid etched on a glass dish. Numbers of each genus of cladoceran and copepod and of copepod nauplii were recorded. The volume of water sampled was calculated by multiplying the net mouth area by the distance hauled. The number of each zooplankton genus per m^3 was calculated. Taxonomic identification of the zooplankton crustacean species was carried out by Mr. Rufus Kiser (personal communication).

The quantity of zooplankton pumped into Banks Lake during the irrigation season was estimated by assuming that the concentration of zooplankton at Station 1 during pumping was equivalent to the concentration of zooplankton in the water pumped from FDR Reservior.

Thus

$$T_Z = \sum_{m=1}^{K} (V_m \times Z_m)$$

T_Z = number of individuals of zooplankton group Z pumped in during the season

K = duration of pumping season (months)

V_m = volume of water pumped in (m^3) during month m

Z_m = estimated concentration (numbers/m^3) of zooplankton group Z at Station 1 during month m

In the same manner the quantity of zooplankton removed from Banks Lake with the irrigation withdrawal was estimated by assuming that the concentration of zooplankton at Station 6 during irrigation withdrawal was equivalent to the concentration of zooplankton in the water withdrawn from the lake.

4.4 Results

4.4.1 Water Temperature

The predominant pattern of seasonal water temperature change in Banks Lake was directly related to the annual air temperature cycle (Fig. 4-4). Maximum summer air temperatures averaged 0.7°C lower in 1974 than in 1973 resulting in a decrease in the mean maximum water temperatures observed at 4 m depth of 2.1°C from 1973 to 1974. Maximum mean air temperatures occurred in July 1973 and in August 1974. Similar thermal trends were observed at all stations (Fig. 4-5), although there were important differences between stations, particularly during summer stratification when irrigation water was being pumped into and withdrawn from the lake.

During the summer a pattern of thermal stratification modified by the flow of irrigation water was observed. In the late spring as the air temperature increased, stratification was observed at all stations. When pumping of water through the feeder canal began the stratification at Stations 1 and 2 disappeared due to turbulent mixing. However, stratification was maintained at Stations 3-6 until air temperatures began to decrease in September.

In 1973 only the late stages of this sequence were observed. On August 11, 1973 when observations began, temperatures ranged from 19.0° to 24.0°C. The water was homothermous and 19.0°C at Stations 1 and 2. Vertical stratification was greatest at Station 4 but this stratification was similar to that observed at Stations 3, 5, and 6. A convergence

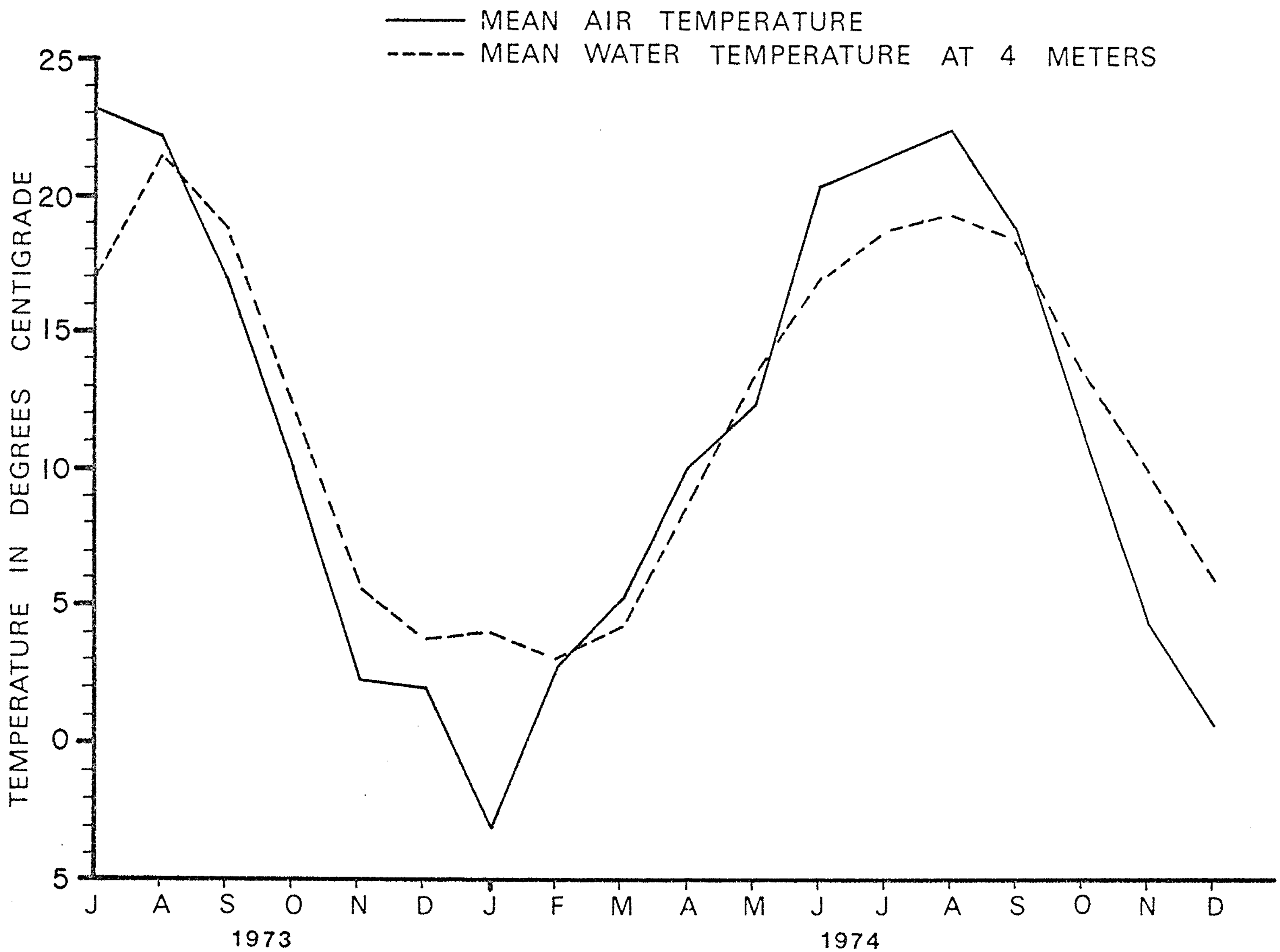

Fig. 4-4. Banks Lake mean water temperatures at 4 meters compared to mean monthly air temperatures for the period from July, 1973 - December, 1974.

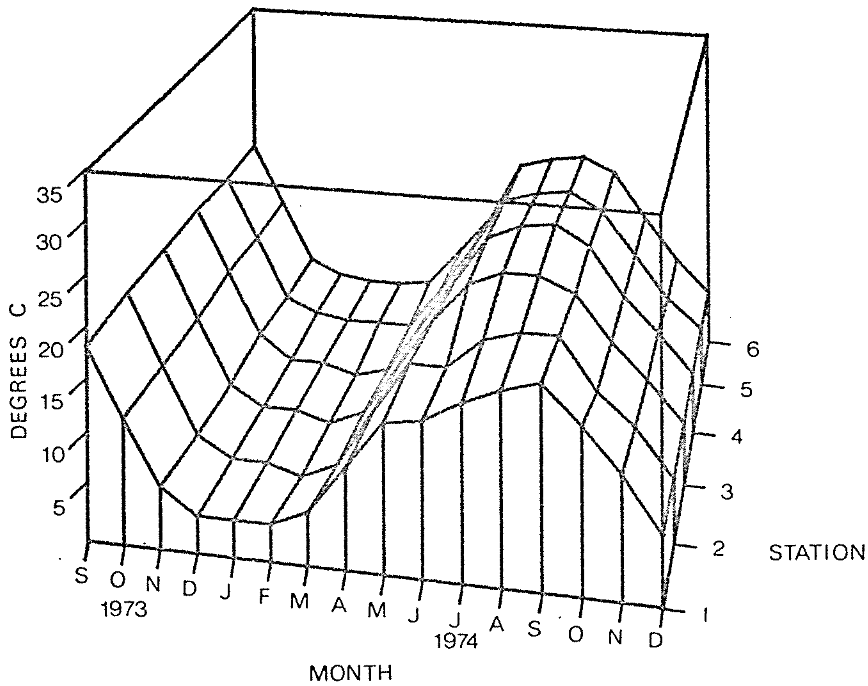

Fig. 4-5. Temporal and spatial changes in water temperature at 4m depth in Banks Lake.

zone was established between Stations 2 and 3 where the cool water pumped into the lake came into contact with the warmer eplimnetic water in the southern portion of the lake. At this point the cooler water sank toward the bottom and flowed southward toward the outlet (Fig. 4-6).

During 1974 it was possible to observe this phenomenon over a longer period of time (Fig. 4-7 to 4-12). Stratification was evident at all stations in May when temperatures ranged from 10.0° to 15.0°C (Fig. 4-13). In June, after pumping had begun, stratification had essentially broken down at Stations 1 and 2 where temperatures ranged from 14.0° to 16.0°C (Figs. 4-7 and 4-8) but was more marked at the southern stations where temperatures ranged from 15.0° to 21.0°C. Station 3 had the most pronounced degree of stratification (Fig. 4-9). Similar conditions prevailed in July but a change had occurred by August. The point of convergence had migrated north of Station 2 and the surface temperature gradient between Stations 3 and 6 had decreased. By September, when air temperatures were lower and pumping had slowed down substantially, the lake was essentially homothermous and all temperature observations were within the range 18.0° to 19.0°C.

During the summer stratification period there was also a significant horizontal stratification in lake surface temperatures created by the input of cooler irrigation water affecting Stations 1 and 2 contrasting with the warm eplimnetic water in the southern portion of the lake. In the early autumn, as the lake cooled and the rates of water supply and withdrawal were reduced, the reservoir began to assume the characteristics

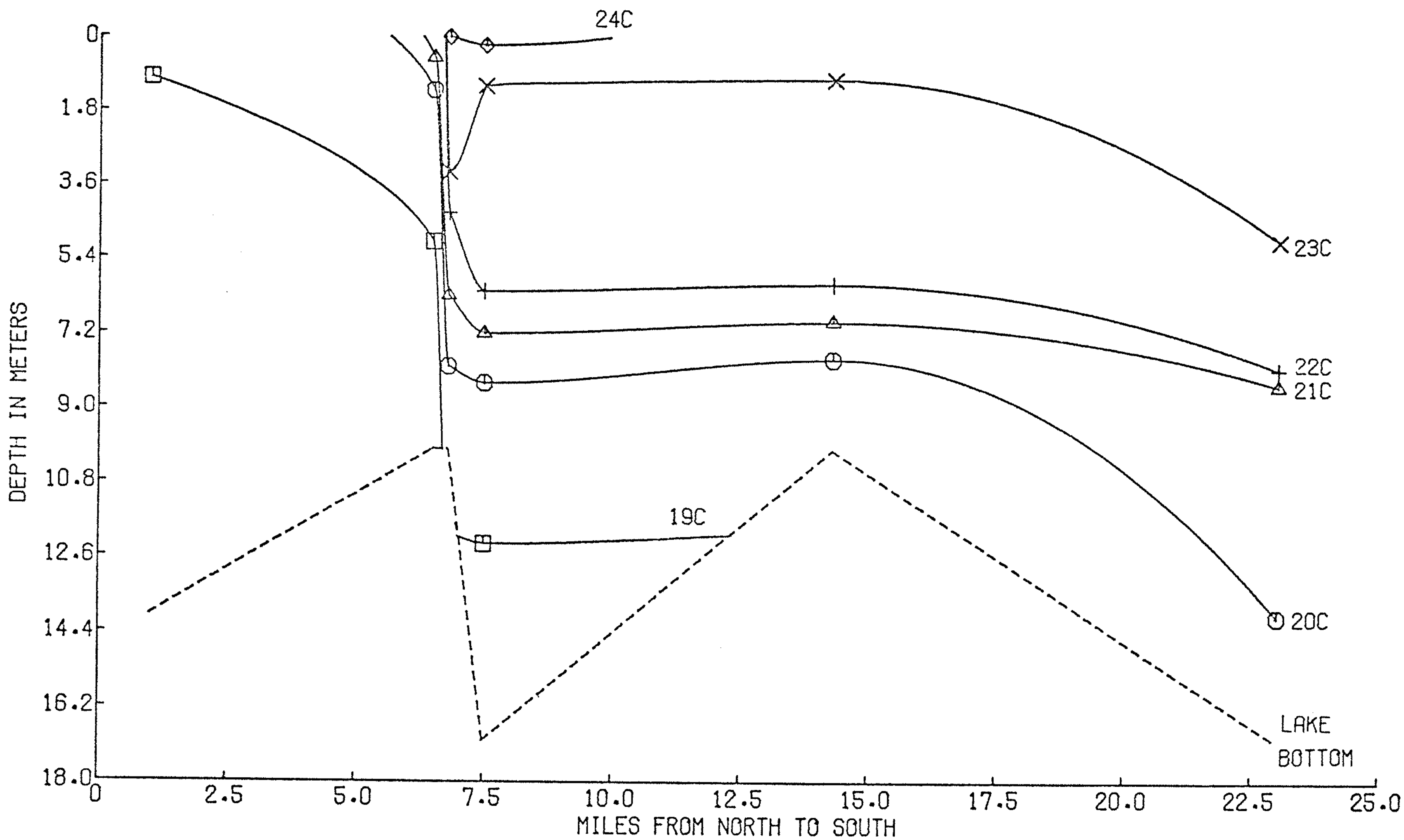

Fig. 4-6. Banks Lake isotherms (August 11, 1973) showing the convergence zone between mile 6 and 7 where the mass of cooler water from north Banks Lake was observed to sink beneath a lens of less dense warmer water south of mile 7.5.

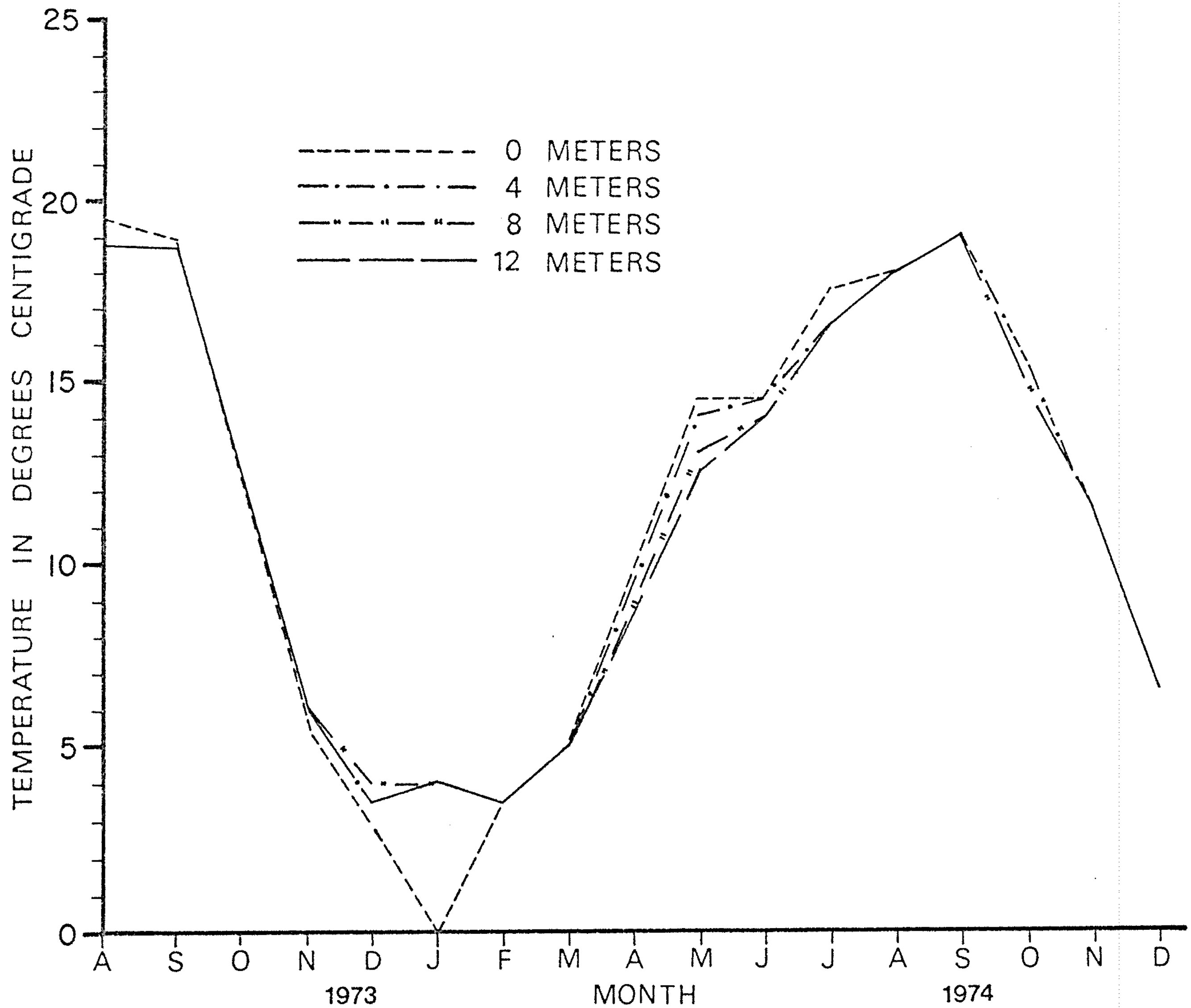

Fig. 4-7. Station 1: Monthly changes in water temperature at 4 meter depth intervals.

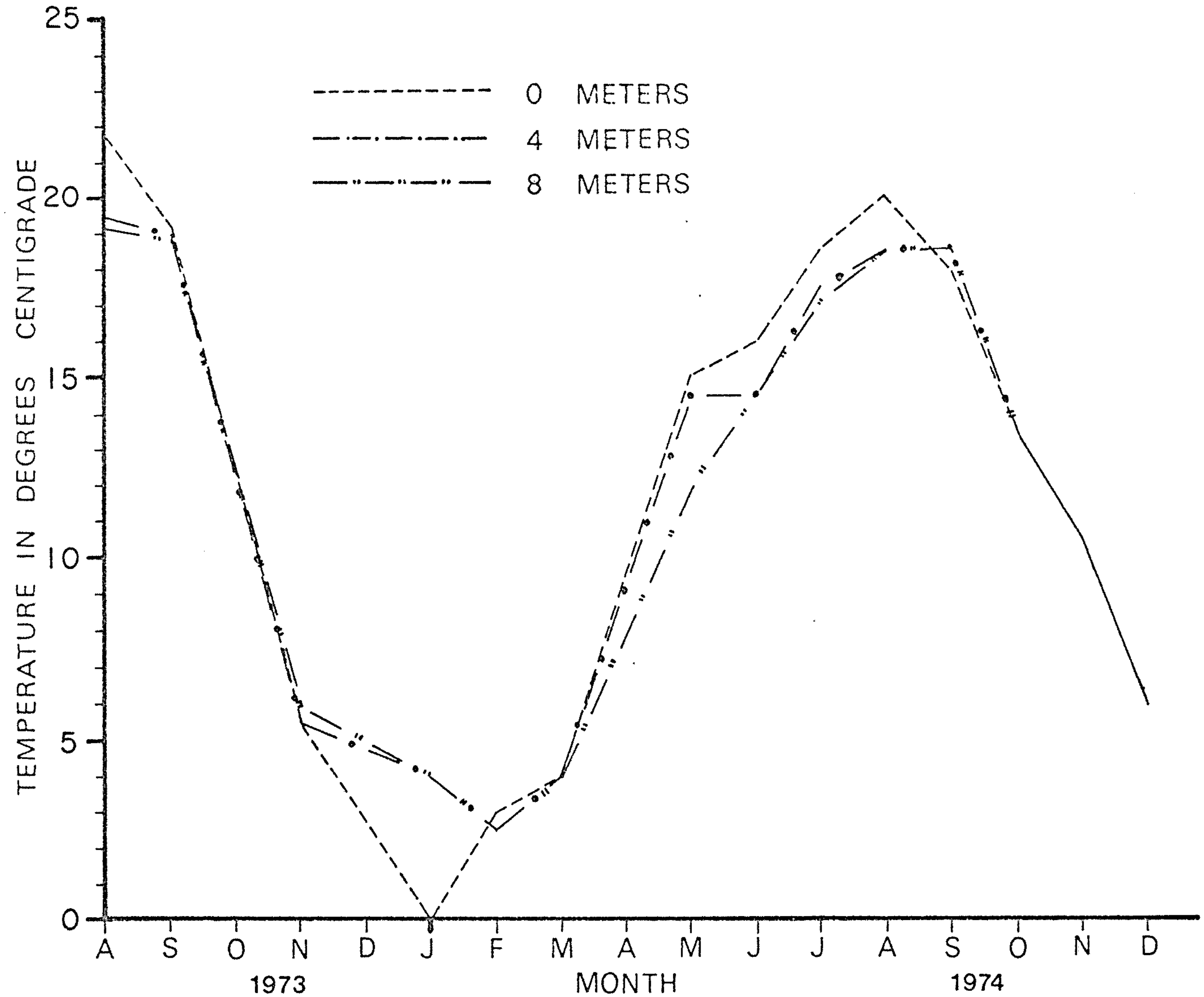

Fig. 4-8. Station 2: Monthly changes in water temperature at 4 meter depth intervals.

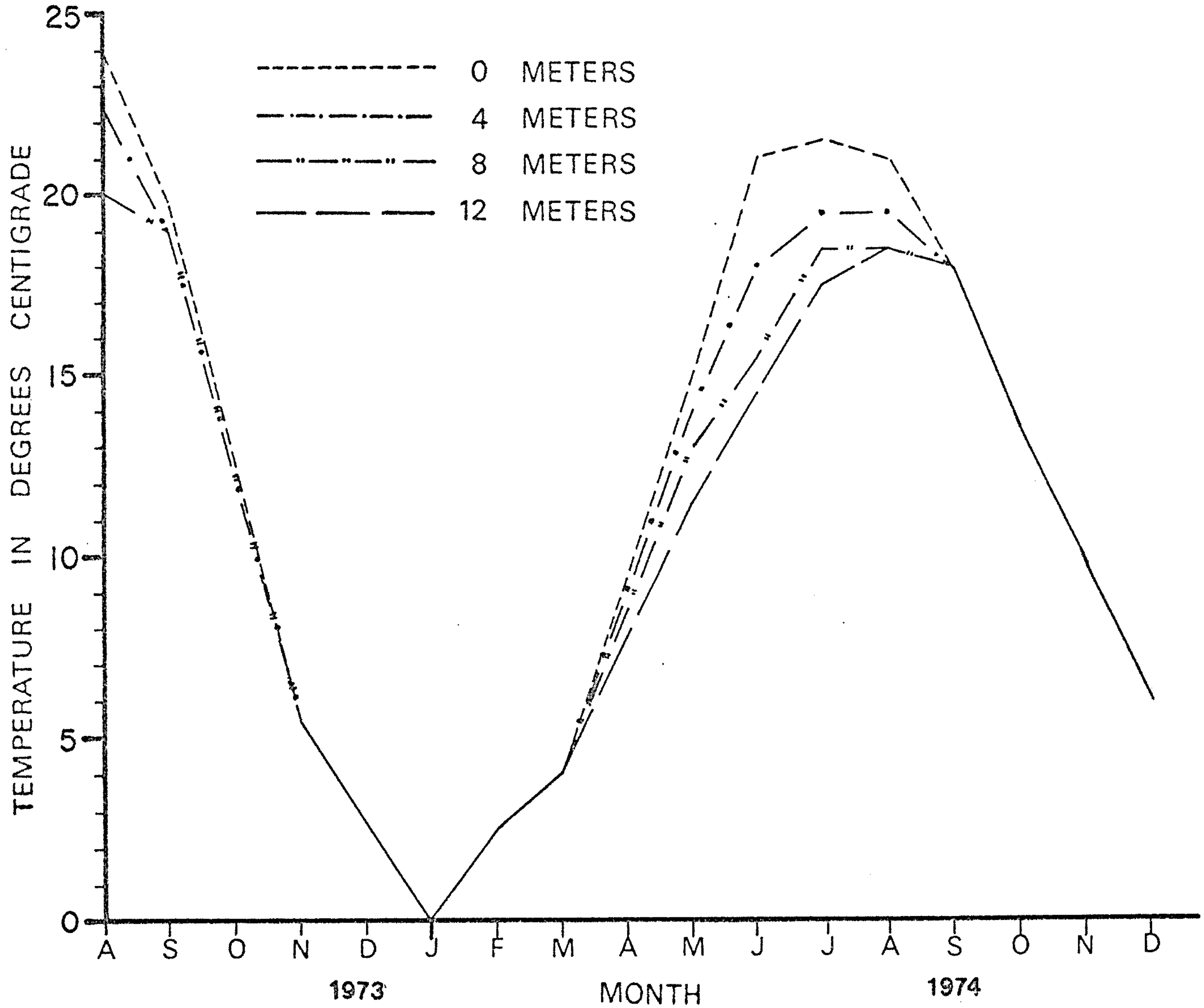

Fig. 4-9. Station 3: Monthly changes in water temperature at 4 meter depth intervals.

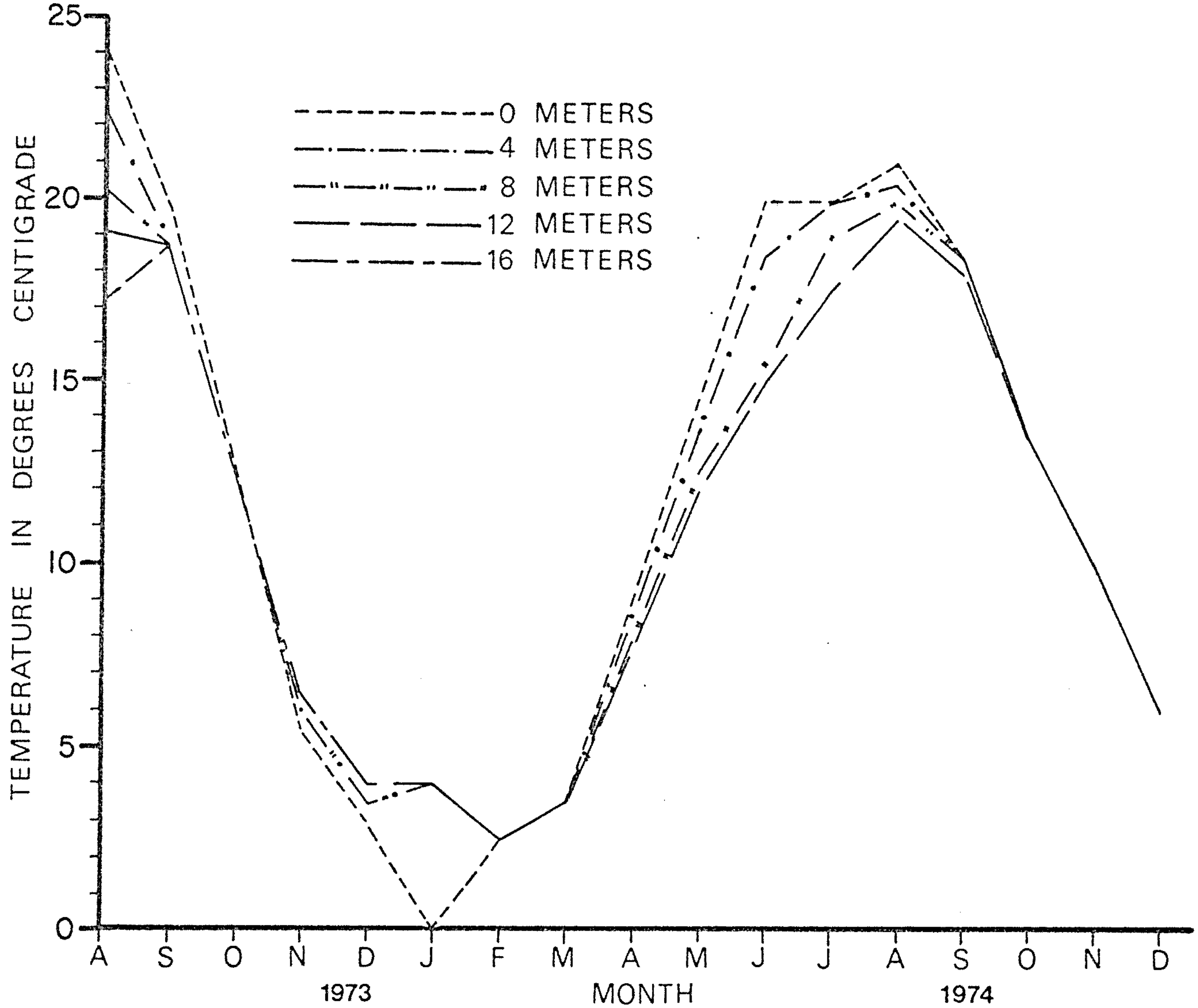

Fig. 4-10. Station 4: Monthly changes in water temperature at 4 meter depth intervals.

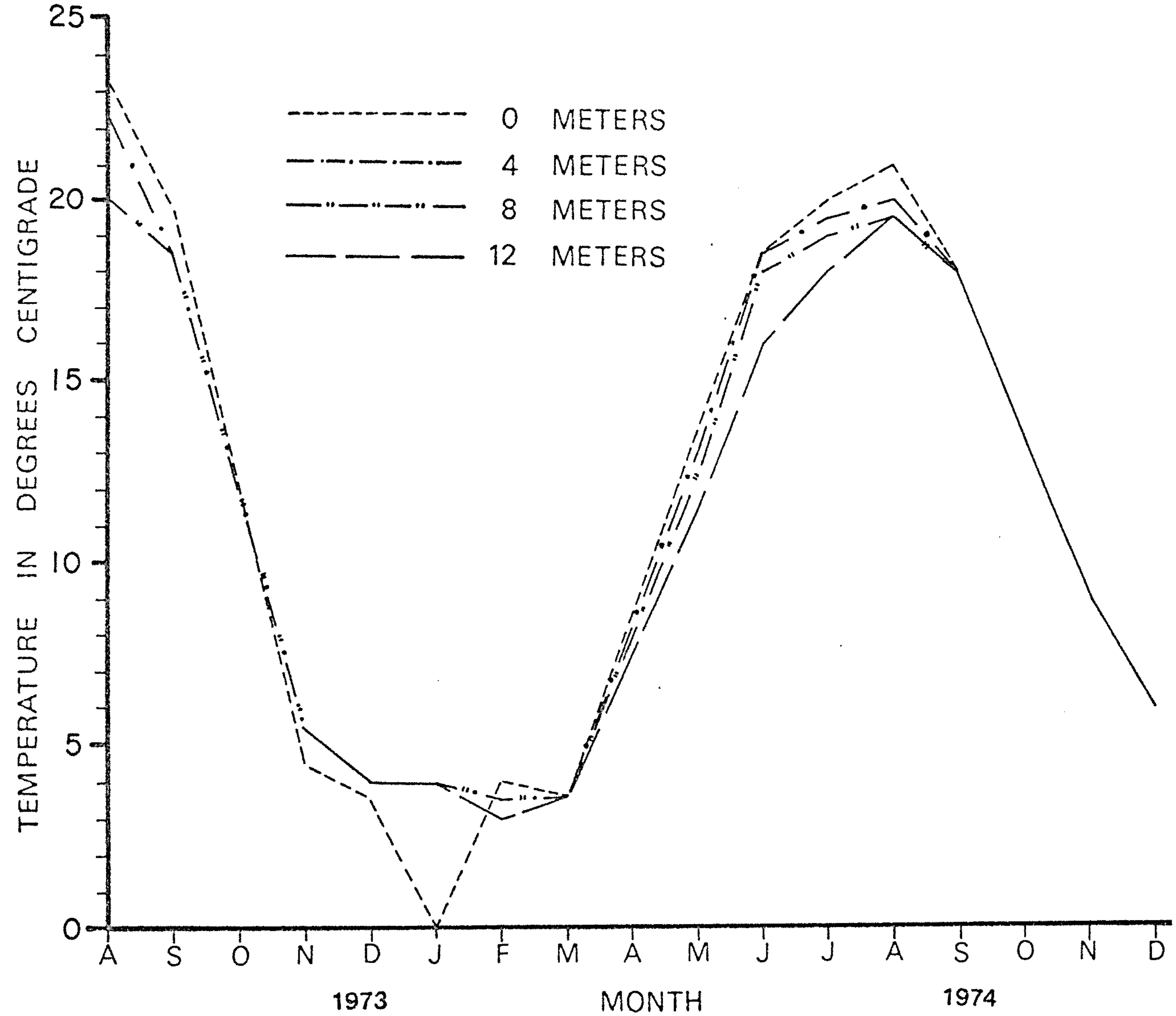

Fig. 4-11. Station 5: Monthly changes in water temperature at 4 meter depth intervals.

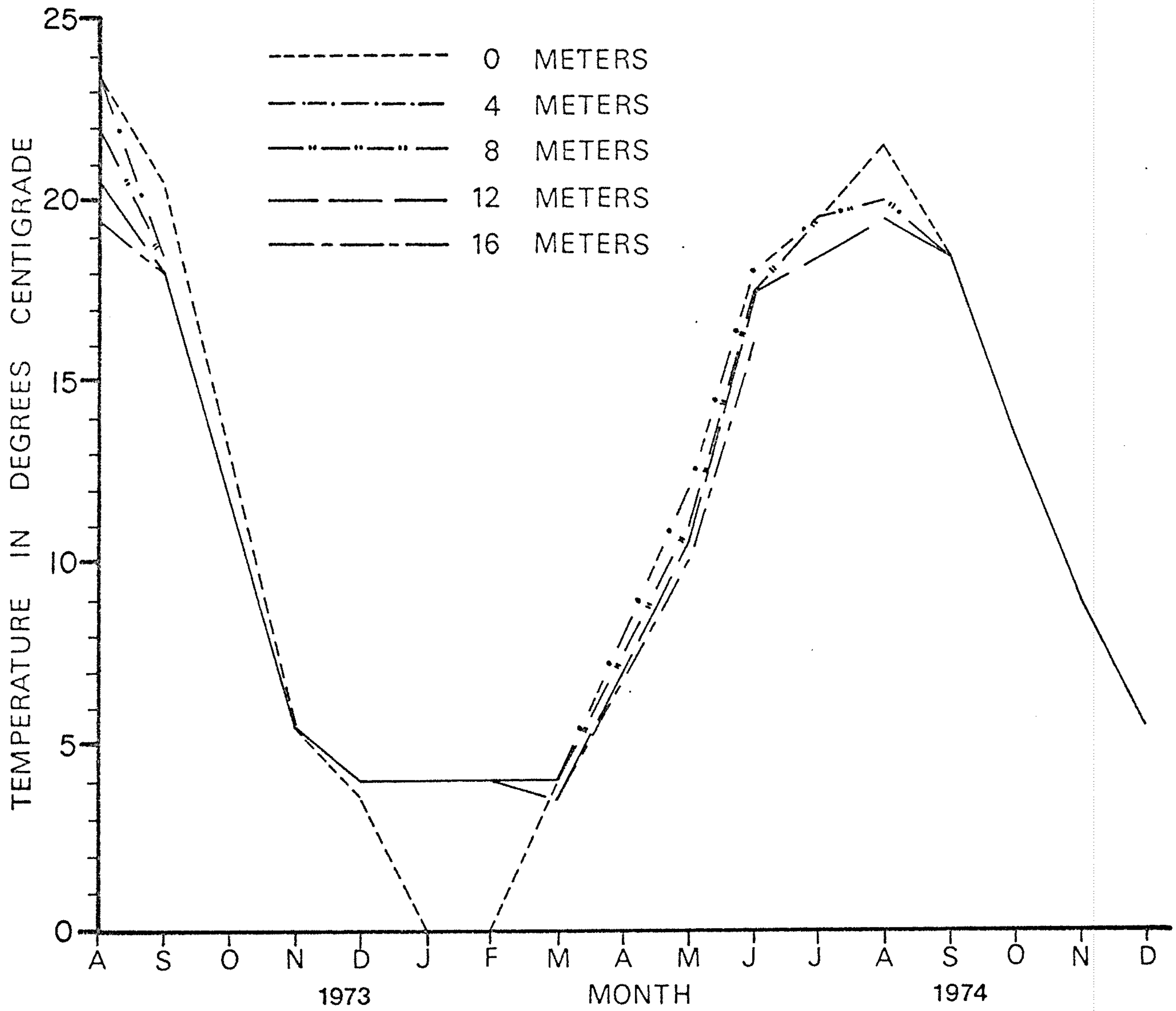

Fig. 4-12. Station 6: Monthly changes in water temperature at 4 meter depth intervals.

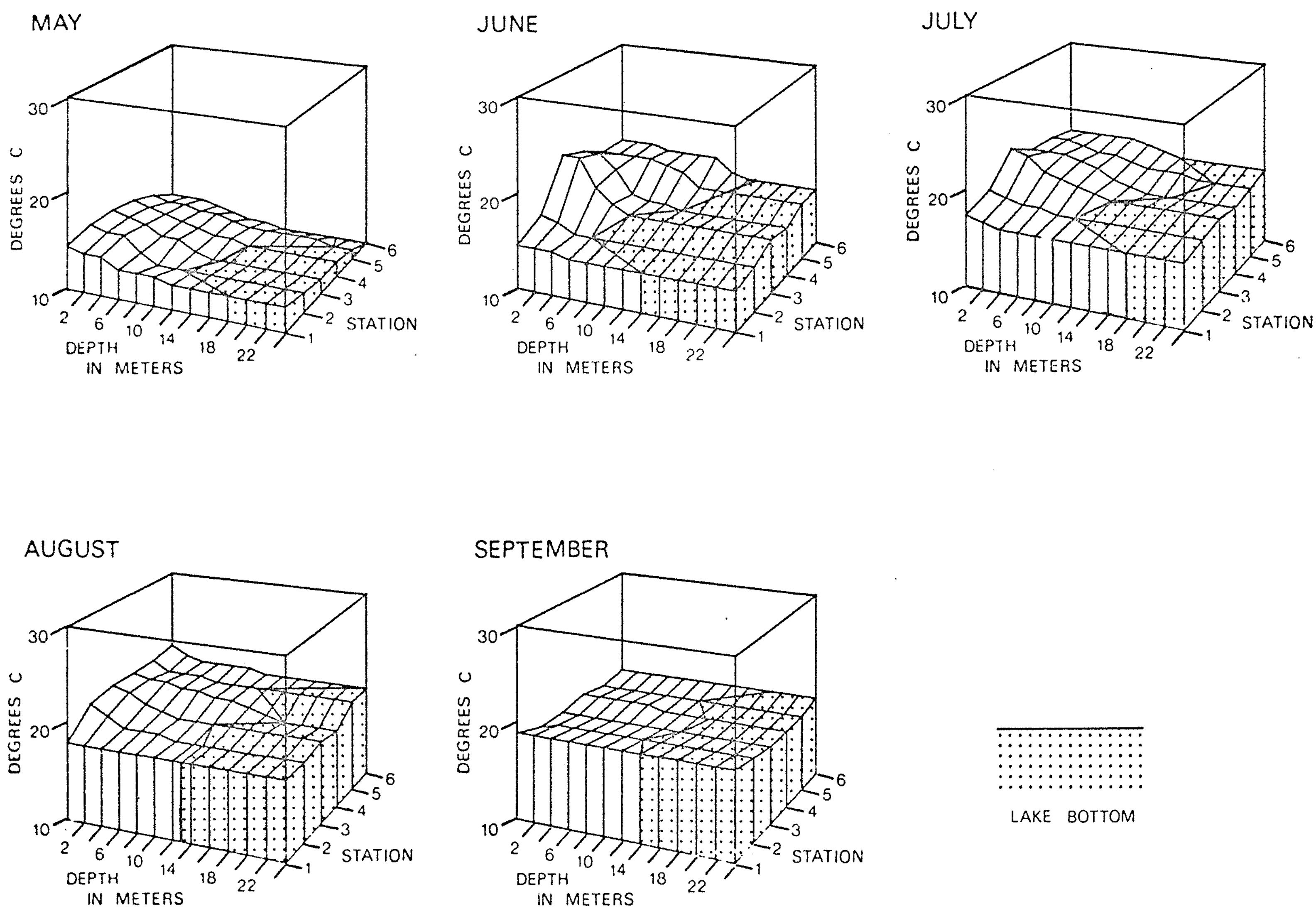

Fig. 4-13. Changes in Banks Lake thermal stratification during the period May - September 1974.

of a lake undergoing the fall overturn, in 1973 and 1974 this overturn had occurred by mid-September. On September 17, 1973 lake temperatures ranged from 17.5° to 19.0°C. On September 17, 1974 lake temperatures ranged from 18.0° to 19.0°C. As the air temperature began to drop lake water temperatures decreased during the autumn. The rate of water temperature decrease was greater in 1973 than in 1974 (Fig. 4-4). Frequently during the autumn and winter a horizontal thermal stratification, decreasing from north to south, was observed. For example, in October 1974, surface temperatures were 11.5°, 10.5°, 10.0°, 10.0°, 9.0°, and 9.0°C at Stations 1, 2, 3, 4, 5, and 6, respectively, although the water was homothermous at each station. It is probable that this phenomenon was related to wind mediated surface cooling.

There was a complete ice cover during January and early February 1974. As the ice thawed, north Banks Lake became accessible first and the southern section of the lake was the last to become ice free. The lake then began to warm up, surface temperatures ranged from 5.0°C at Station 1 (Fig. 4-7) to 3.5°C at Station 6 (Fig. 4-12) in March 1974 and from 14.5°C at Station 1 to 12.0°C at Station 6 in May 1974 when all stations demonstrated some stratification (Fig. 4-13).

4.4.2 Transparency

The transparency of Banks Lake, as determined by Secchi disc depth, showed marked temporal and spatial variation. Observations ranged from 1.5 to 8.0 m during the study period (Fig. 4-14).

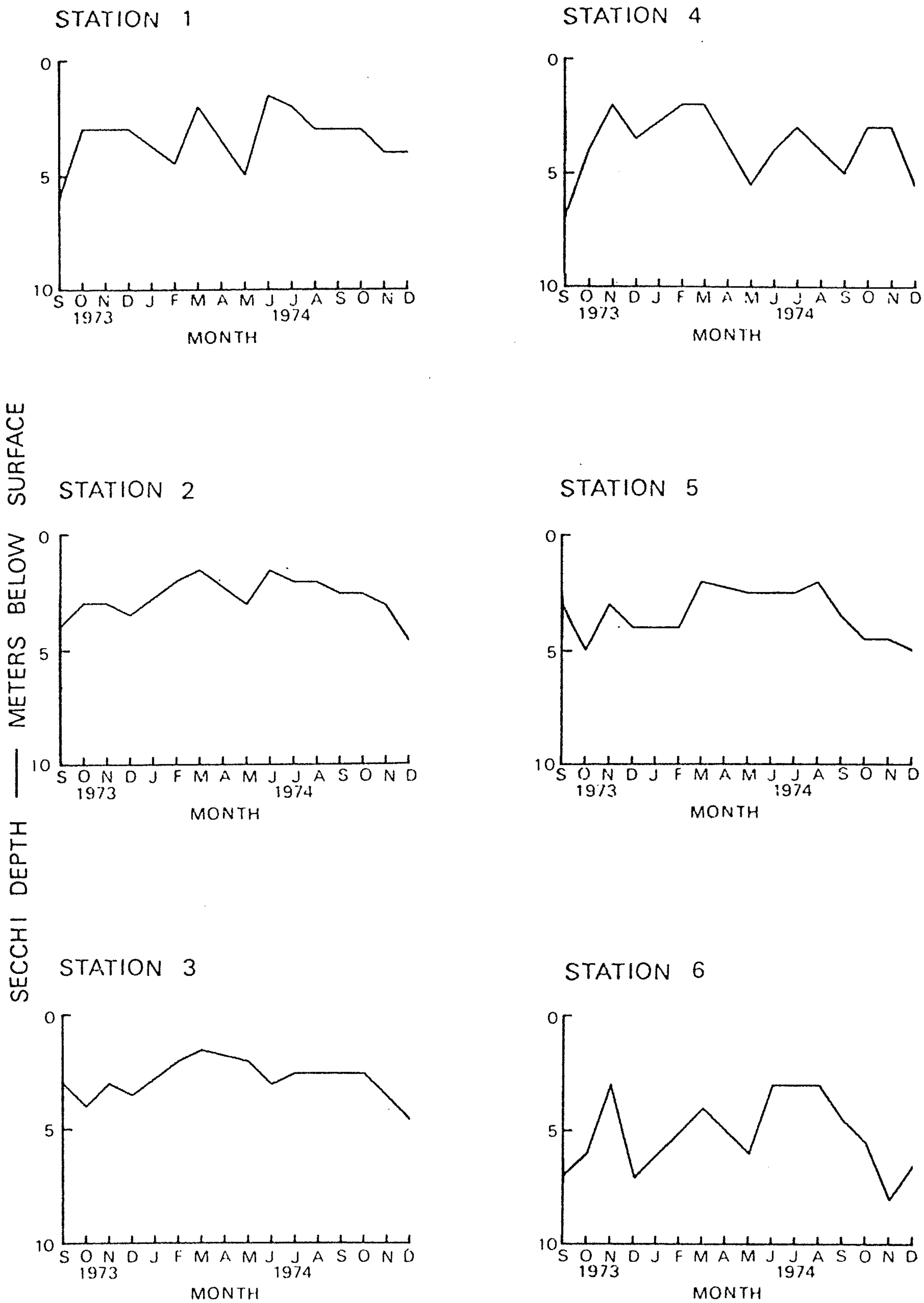

Fig. 4-14. Monthly changes in Secchi depth transparency for each station in Banks Lake from September 1973 to December 1974.

Station 6 generally exhibited the greatest transparency (Fig. 4-14). Most transparency observations were relatively high at Station 4 (Fig. 4-14). The lake demonstrated a trend of decreasing transparency with time for the period September 1973 to March 1974, a peak in May 1974 followed by a marked reduction in transparency in June and then a steady increase in Secchi depth from August to December 1974.

4.4.3 Water Chemistry

Conductivity data collected during the study period covered the range 78 to 110 μmho/cm^2. There were no distinguishable temporal or spatial trends in this parameter. In most cases, however, a small increase in conductivity with depth was recorded.

The observed values for total alkalinity ranged from 35 to 120 ppm $CaCO_3$ (mean 68 ppm). The only distinguishable trends in this data are recordings of below average values for December 1973, November 1974, and December 1974 (Table 4-2).

The observed values for total hardness ranged from 40 to 80 ppm $CaCO_3$. There were no distinguishable trends with station or depth. Values obtained for the months May 1974 to August 1974, however, were slightly lower than those obtained during the rest of the study period (Table 4-3).

The pH readings ranged from 5.7 to 9.0 (Table 4-4). No trends in these data were observed by station or depth. In December 1973 all pH readings were higher than previously recorded. The mean monthly values had decreased slightly by February (from pH 8.5 to 7.8) but observations

Table 4-2. Total alkalinity measurements (in mg/l $CaCO_3$), Banks Lake, September 1973 to December 1974.

Station	Depth (m)	1973 Sept	Oct	Nov	Dec	1974 Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Means for each depth	Water column means
1	0	70	65	80	59		70	70		60	65	60	75	60	60	60	35	64	
	4	60	60	70	51		75	80		70	70		55	60	85	60	65	66	65
	*m	60	75	80	55		75	70		60	70			65	80	55	55	67	
2	0	65	80				70	90		60	70	55	70	60	60	50	50	65	
	4	60	70		60		70	70		60	70		60	60	60	50	40	60	65
	*m	55	70		75		70	110		70			100	65	80	60	50	73	
3	0	60	70				70	70		60	80	60	70	70	65	60	60	71	
	4	60	80		57		70	70		60	70	50		60	75	55	60	64	67
	*m	60	70		58		70	110		60	70	55		55	80	50	50	66	
4	0	70	70	80	50		75	90		60	70	60	80	60	65	55	55	67	
	4	60	70	75	47		70	70		60	75	60	75	55	70	55	35	63	66
	*m	60	70	75	55		65	70		60	80	60	70	120	70	55	65	70	
5	0	60	60	70	50		75	60		60	75	65		65	65	60	55	71	
	4	65	70	70	50		75	60		60	70	60	90	60	60	60	50	64	67
	*m	60	70	70	50		70	60		60	70	60	70	70	70	65	60	65	
6	0	65	70	70	49			50		60	70	65	80	65	75	55	50	75	
	4	70	70	80	50			50		60	75	65	100	60	75	50	60	67	68
	*m	70	70	70	50			60		60	80	70	80	50	75	60	40	64	
Monthly mean for each depth	0	65	69	75	52		72	72		60	72	61	93	63	65	57	51	66	
	4	63	71	74	52		72	67		62	72	59	72	59	71	55	52	70	68
	*m	61	71	74	57		70	80		62	74	61	80	71	76	58	53	68	
Monthly water column means		63	70	74	54		71	73		61	72	60	82	64	71	56	52		

*m = maximum depth samples

Table 4-3. Total hardness measurements (in mg/l $CaCO_3$), Banks Lake, September 1973 to December 1974.

Station	Depth (m)	1973 Sept	Oct	Nov	Dec	1974 Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Means for each depth	Water column means
1	0	60	80	75	60		70	70		50	40	50	55	60	60	70	60	61	
	4	60	75	70	70		65	80		50	40		60	60	65	65	60	63	62
	*m	60	80	70	75		65	60		50	45		60	60	55	65	60	62	
2	0	60	80				70	70		40	50	50	50	60	65	70	50	56	
	4	60	75		60		70	60		50	45		55	80	55	60	70	62	61
	*m	60	70		75		65	70		50			55	60	60	65	70	64	
3	0	60	70				75	70		60	55	60	55	60	60	65	55	62	
	4	60	70		65		75	70		60	40	55	50	60	60	60	60	60	61
	*m	60	60		60		75	70		60	40	55	50	60	65	60	60	60	
4	0	60	70	80	70		65	80		40	50	60	60	60	60	60	60	58	
	4	60	60	75	70		65	65		50	40	55	60	70	70	70	65	63	61
	*m	60	60	75	70		65	60		40	50	60	55	70	65	70	70	62	
5	0	60	60	60	70		65	80		40	50	60	55	60	65	70	60	61	
	4	60	70	70	70		60	80		40	50	50	55	80	65	70	70	64	63
	*m	60	70	60	70		70	80		50	50	60	60	70	70	70	55	64	
6	0	60	60	70	70			70		40	55	55	55	60	65	60	60	60	
	4	60	70	70	70			70		40	50	60	60	50	65	60	55	57	60
	*m	60	60	70	70			75		40	55	60	60	60	65	65	65	62	
Monthly means for each depth	0	60	70	71	68		67	73		45	50	56	55	60	63	66	58	62	
	4	60	68	71	68		67	71		48	44	55	57	67	63	64	63	62	62
	*m	60	66	69	70		68	69		48	48	59	57	63	63	66	63	62	
Monthly water column means		60	68	71	68		67	71		67	67	56	56	63	63	65	61		

*m = maximum depth sampled

Table 4-4. Observations of pH, Banks Lake, September 1973 to December 1974.

Station	Depth (m)	1973 Sept	Oct	Nov	Dec	1974 Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Means for each depth	Water column means
1	0	7.7	7.6	7.5	8.0		7.9	8.0		8.0	7.7	8.1	7.0	6.9	7.0	6.9	6.0	7.4	
	4	7.9	7.7	7.5	8.2		7.9	8.1		8.0	7.7		6.9	6.2	7.3	6.8	6.0	7.4	7.4
	*m	7.6	7.7	7.5	8.1		7.9	8.0		7.9	7.7		6.9	6.3	7.2	7.0	6.0	7.4	
2	0	7.8	7.7				7.9	8.0		7.9	7.9	7.6	6.4	6.8	7.0	6.9	6.0	7.3	
	4	7.9	7.7		8.1		7.9	8.4		7.9	7.7		5.9	7.6	7.0	6.8	6.0	7.4	7.3
	*m	7.6	7.5		8.1		7.9	8.0		8.1			7.0	6.6	7.0	5.7	6.0	7.2	
3	0	7.2	7.8				7.6	8.0		7.9	7.7	7.7	7.2	6.7	7.0	6.8	6.0	7.4	
	4	7.9	7.6		8.1		7.9	8.3		8.0	7.7	7.5	6.9	7.6	7.2	6.8	6.0	7.5	7.4
	*m	7.6	7.5		8.1		7.3	8.0		7.6	7.8	7.9	6.6	7.2	7.3	7.1	6.0	7.4	
4	0	8.0	7.4	7.5	7.9		7.4	8.0		7.1	7.8	7.8	7.4	5.7	7.3	6.9	6.0	6.8	
	4	8.0	7.7	7.5	8.9		8.0	7.8		8.0	7.8	7.6	7.1	6.5	7.1	6.8	6.0	7.5	7.4
	*m	8.1	7.5	7.5	8.9		7.8	8.2		7.9	7.8	7.8	6.2	6.5	7.4	6.8	6.0	7.5	
5	0	7.7	7.4	7.4	9.0		7.8	8.1		7.8	7.7	7.9	6.9	6.9	6.8	6.9	6.0	7.5	
	4	7.9	7.6	7.5	8.9		7.9	8.1		8.0	7.8	8.6	7.3	7.0	6.9	7.1	6.0	7.6	7.5
	*m	7.5	7.5	7.5	8.9		7.9	8.1		7.8	7.8	7.6	7.3	7.0	7.3	6.8	6.0	7.5	
6	0	7.9	7.2	7.4	8.9			7.6		7.9	7.7	7.5	6.8	6.8	7.0	6.1	6.0	7.3	
	4	8.0	7.3	7.4	8.9			7.6		7.8	7.8	7.5	7.1	7.2	7.2	6.8	6.0	7.5	7.4
	*m	8.0	7.3	7.4	8.9			7.7		7.9	7.8	7.5	7.1	7.5	7.1	7.1	6.0	7.5	
Monthly means for each depth	0	7.8	7.5	7.5	8.5		7.7	8.0		7.9	7.8	7.8	7.0	6.6	7.0	6.8	6.0		
	4	7.9	7.6	7.5	8.4		7.9	8.1		8.0	7.8	7.8	6.9	7.0	7.1	6.9	6.0		
	*m	7.7	7.5	7.5	8.5		7.9	8.0		7.9	7.8	7.7	6.9	6.9	7.2	6.8	6.0		
Monthly water column means		7.4	7.5	7.5	8.5		7.8	7.8		7.9	7.8	7.8	6.9	6.8	7.1	6.8	6.0		

*m = maximum depth sampled.

remained relatively high until August 1974 (mean pH 6.9). Similar observations were recorded in September, October, and November but the mean pH for December 1974 was 6.0.

Most dissolved oxygen observations represented high levels of saturation (Table 4-5). No values of less than 42 percent oxygen saturation were obtained. Fourteen out of a total of 236 observations were of less than 70 percent oxygen saturation. Three low values were observed in July 1974 and six low values were observed in December 1974 (Table 4-5).

4.4.4 Nutrients

Nutrient data are available for the period July 1974 to December 1974 (Table 4-6). Orthophosphate levels ranged from 2.5 to 62.5 ppb (as P). Hydrolyzable phosphate levels ranged from 5.0 to 65.0 ppm (as P). Total phosphate levels ranged from 5.0 to 63.8 ppb (as P). Total nitrate levels ranged from 0 to 21.6 ppb (as N). On a number of occasions high phosphate concentrations were recorded at the deepest sampling points. To minimize the effect of sediment contamination in unfiltered samples the data were analyzed omitting samples taken near the bottom. This reduced the nutrient ranges to: orthophosphate 2.5 to 25.0 ppb, hydrolyzable phosphate 5.0 to 26.3 ppb and total phosphate 5.0 to 35.0 ppb. The range in total nitrates remained the same.

In June 1975 a series of experiments was carried out to investigate the sensitivity and accuracy of the nitrate assay technique. The technique utilized during 1974 was suspected of being susceptible to interference by magnesium ions present in Banks Lake water. Six water samples

Table 4-5. Percentage saturation of dissolved oxygen, Banks Lake, August 1973 to December 1974.

Station	Depth (m)	1973 Aug	Sept	Oct	Nov	Dec	1974 Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Means for each depth	Water column means
1	0	108	96	84	90	84		99	92		96	112	109	101	83	88	83	93	95	
	4	104	102	82	90	90		102	92		92	112		101	89	92	87	90	95	94
	*m	107	100	84	90	90		98	97		81	110		99	96	86	81	88	93	
2	0	112	102	92				101	95		98	104	43	104	93	96	90	80	93	
	4	106	102	94		91		101	56		96	106		104	85	97	90	77	92	92
	*m	102	96	87		91		102	85		91			101	90	88	86	80	92	
3	0	105	96	97				99	93		98	98	96	102	101	94	87	64	94	
	4	108	98	91		90		101	93		98	122	104	102	91	98	88	51	95	92
	*m	106	96	89		86		98	95		89	112	67	100	63	77	78	56	87	
4	0	106	96	95	90	90		102	95		102	100	104	98	85	93	88	63	94	
	4	105	97	92	92	88		101	95		90	117	98	96	87	89	83	80	94	91
	*m	56	96	93	92	85		101	96		93	94	91	57	72	84	84	91	86	
5	0	102	96	94	87	90		101	95		96	91	93	96	88	91	89	86	94	
	4	100	91	94	88	89		99	96		96	98	76	89	84	90	89	59	89	91
	*m	93	93	93	87	89		96	95		96	94	94	98	63	88	83	93	90	
6	0	100	97	94	90	90			93		94	91	91	105	91	96	82	91	93	
	4	97	95	94	83	92			93		96	104	91	91	89	87	85	93	93	89
	*m	73	94	87	90	89			95		88	91	56	70	84	73	88	67	82	
Monthly mean each depth	0	106	97	92	89	89		100	94		97	99	89	101	90	93	88	80	94	
	4	103	98	91	90	90		101	88		94	110	92	97	88	92	87	75	93	
	*m	90	96	89	90	88		99	94		91	100	77	88	78	84	83	79	88	
Monthly water column means		100	97	91	90	89		100	92		94	103	86	95	85	90	86	78		

*m = maximum depth sampled

Table 4-6. Nutrients. Means of 0 and 4 m depth observations for the period July to December 1974 (as phosphorus and nitrogen).

	Orthophosphate µg/l						Hydrolyzable Phosphate µg/l					
	Stations						Stations					
1974	1	2	3	4	5	6	1	2	3	4	5	6
July	7.5	25.0	6.3	6.3	7.5	3.8	11.1	11.1	9.7	11.1	12.5	8.3
Aug	5.0	5.0	6.3	5.0	8.8	10.0	6.3	7.5	5.6	6.3	10.0	11.3
Sept	5.0	8.8	8.8	7.5	5.0	8.8	7.5	8.8	13.8	10.0	6.3	12.5
Oct	10.5	11.9	10.5	13.2	13.2	10.5	10.5	13.2	10.5	17.2	14.5	13.2
Nov	10.5	18.4	14.5	19.7	18.4	13.2	15.8	18.4	14.5	10.6	21.0	18.4
Dec	13.8	16.3	17.5	18.8	18.8	21.3	20.0	25.0	22.5	22.5	22.5	20.0

	Total Phosphate µg/l						Total Nitrate µg/l					
	Stations						Stations					
1974	1	2	3	4	5	6	1	2	3	4	5	6
July	13.9	8.3	13.9	11.5	12.5	11.1	0	0	0	0	0	0
Aug	6.3	7.5	8.8	8.2	11.3	12.5	5.9	2.8	2.2	2.5	1.4	1.9
Sept	7.5	11.3	13.8	10.0	7.5	8.8	4.3	3.6	3.6	1.3	1.5	1.8
Oct	17.2	17.1	17.0	21.1	21.1	18.5	8.8	1.8	7.9	1.4	1.0	2.4
Nov	13.2	13.2	16.5	19.7	18.4	18.4	20.1	16.7	15.7	9.3	5.9	5.9
Dec	28.3	27.5	23.3	30.0	31.0	33.3	18.3	17.2	17.8	14.6	7.8	6.3

were analyzed by the hydrazine reduction technique both before being passed through a column of the chelating agent "Chelex" as had been carried out in 1974 and after passage through a "Chelex" column which was designed to remove any interfering metal ions from the water. Samples passed through the chelating agent were analyzed to contain between 2.1 and 5.1 (mean 4.5) times more nitrate nitrogen than the untreated samples. It is likely that the magnitude of this discrepancy varied during 1974 as the concentrations of metal ions in the system fluctuated. A recent evaluation (Asrani 1973) of chemical techniques utilized in nitrate analysis indicated the above technique was preferred but that no technique was completely free of limitations.

A trend of increasing concentrations of phosphates and nitrate with time, during the period July 1974 to December 1974, was evident from the data (Table 4-6). Nitrate concentrations demonstrated a decreasing trend from north to south during the months August 1974 to December 1974.

4.4.5 Chlorophyll *a*

The chlorophyll *a* data indicate two functionally separate regions within the lake. The changes observed at Stations 1, 2, and 3 demonstrated marked similarities while the changes observed at Stations 4,5, and 6, although different from the observations at the northern stations, were similar to each other (Fig. 4-15).

At the three northern stations chlorophyll *a* concentration increased gradually with time during autumn and winter 1973-74, peaking at Station 1

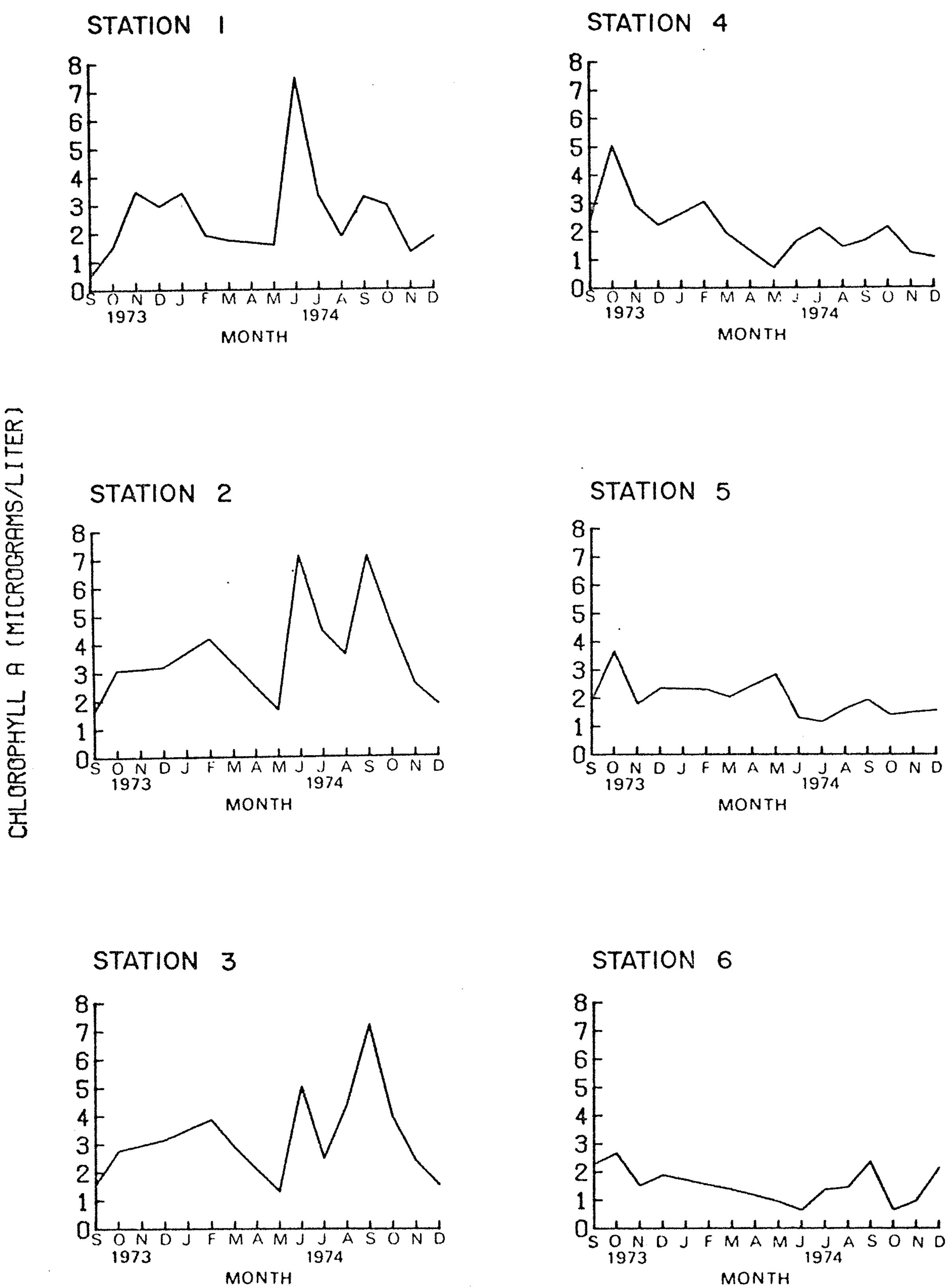

Fig. 4-15. Chlorophyll *a* mean concentrations in Banks Lake at Stations 1-6 for the period September 1973 to December 1974.

in November 1973 after pumped input had ceased and at Stations 2 and 3 in February 1974, after ice breakup. Chlorophyll *a* concentrations then began to decrease, reaching very low concentrations at all three stations in May and increasing substantially in June, after the initiation of pumping, when the mean chlorophyll *a* concentration at Station 1 peaked at 7.48 μg/liter, the highest mean value obtained during the study. July and August observations were, however, substantially lower but another peak was observed in September. On this occasion the peaks were greater at Stations 2 and 3 than at Station 1 and a surface concentration of 11.24 μg/liter chlorophyll *a* was measured at Station 3. From October to December 1974 chlorophyll *a* concentration generally decreased at the three northern stations although there was a slight increase at Station 1 between November and December.

Changes in chlorophyll *a* abundance were less dramatic at Stations 4, 5, and 6 than at Stations 1, 2, and 3.

Concentrations of chlorophyll *a* were consistently lower and exhibited a general decreasing trend with increasing distance southward in the lake. Peaks were observed at the three southern stations in October 1973 and abundance was then observed to decrease and fluctuate slightly during the winter. Station 4 demonstrated a spring peak in February 1974, a peak occurred at Station 5 in May while concentrations at Station 6 continued to decrease until June. Slight peaks were observed at Station 4 in July and October, at Stations 5 and 6 in September and at Station 6 in December. Because the peaks of abundance at these southern stations did not coincide, it appears that phytoplankton blooms were somewhat localized in the southern section of the lake.

A qualitative analysis of the phytoplankton composition showed three diatoms, *Fragillaria, Asterionella,* and *Stephanodiscus*, and an unidentified filamentous alga predominated during 1973. *Fragillaria* and the filamentous alga were much more abundant at all stations in September and October than were other genera. *Fragillaria* predominated at Station 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 1974 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.

4.4.6 Zooplankton Composition and Abundance

Sixteen species of crustacean zooplankton were identified from the samples (Kiser 1974, personal communication). Ten of these species were cladocerans and six were copepods (Table 4-7). In addition, the rotifers *Keratella, Asplancna* and *Kellicotia* were observed in small numbers.

The most frequently observed cladocerans were *Daphnia pulex* and *Bosmina longirostris*. The most frequently observed copepods were *Diaptomus ashlandii* and *Cyclops bicuspidatus thomasi*. Many of the species listed were encountered only rarely.

Quantitative analysis included five groups: *Diaptomus* spp. *Cyclops* ssp., copepod nauplii, *Daphnia* spp. and *Bosmina* sp. With minor exceptions,

Table 4-7. Species of crustacean zooplankton identified from Banks Lake samples. (Courtesy of Mr. Rufus Kiser).

Cladocera

Daphnia schodleri Sars 1862
Daphnia pulex Leydig 1860 emend Richard 1896
Daphnia galeatea mendotae Birge 1918
Diaphanosoma brachyurum (Lieven) 1848
Bosmina longirostris (O. F. Müller) 1745
Ceriodaphnia lacustris Birge 1893
Ceriodaphnia quadrangula (O. F. Müller) 1785
Camptocerus rectirostris (Schødler) 1862
Chydorus sphaericus (O. F. Müller) 1785
Leptodora kindtii (Focke) 1844

Copepoda

Diaptomus sicilis S. A. Forbes 1882
Diaptomus ashlandi Marsh 1893
Epischura nevadensis Lilljeborg 1889
Cyclops vernalis Fischer 1853
Cyclops bicuspidatus thomasi S. A. Forbes 1882
Cyclops agilis (Koch) 1838

the changes in zooplankton relative abundance observed in the upper 4 m were similar to those observed in the total water column (Figs. 4-16 to 4-18). In almost all cases the data indicate a higher concentration of zooplankton in the upper 4 m than throughout the water column.

At Station 1 a number of seasonal trends in the abundance of zooplankton were evident (Fig. 4-16). *Bosmina* occurred in low concentrations throughout the study period, except during August 1974. *Daphnia* populations were of some significance in September and November 1973 and demonstrated a marked peak in abundance in May 1974. The population then became substantially reduced and remained at very low levels for the remainder of 1974. Copepod nauplii showed a steady increase in abundance from September 1973 to March 1974, a sharp decrease in abundance in May 1974, an increase in July 1974, and then a steady decline in abundance until December 1974. *Cyclops* became significant only in March 1974 and remained at a similar concentration until October, when the abundance began to decrease. *Diaptomus* concentrations increased steadily from October 1973 until May 1974. The abundance had declined dramatically by June 1974 and remained low for the remainder of 1974.

At Station 2 the changes in *Bosmina* abundance were similar to those observed at Station 1 (Fig. 4-16). *Daphnia* abundance peaked three times during the study period, in December 1973, May 1974 and September 1974, but these peaks were less marked than the May 1974 peak at Station 1. Nauplii abundance fluctuated irregularly during the study period. *Cyclops* abundance was significant only during the period May to October 1974 with a small peak occurring in August 1974. The abundance of *Diaptomus* was variable, reaching a very low level in June 1974. The

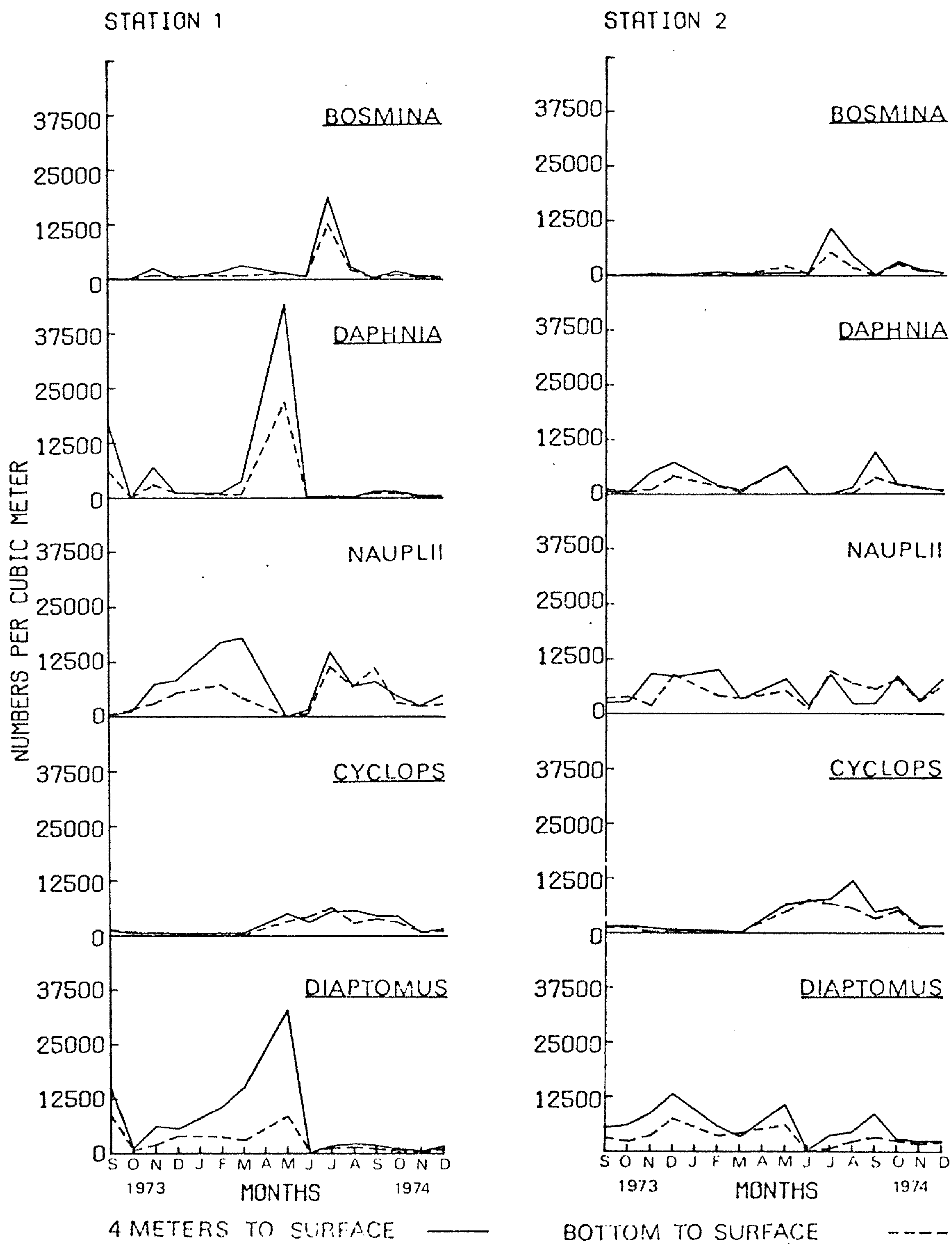

Fig. 4-16. Stations 1 and 2: Changes in Banks Lake zooplankton abundance by month.

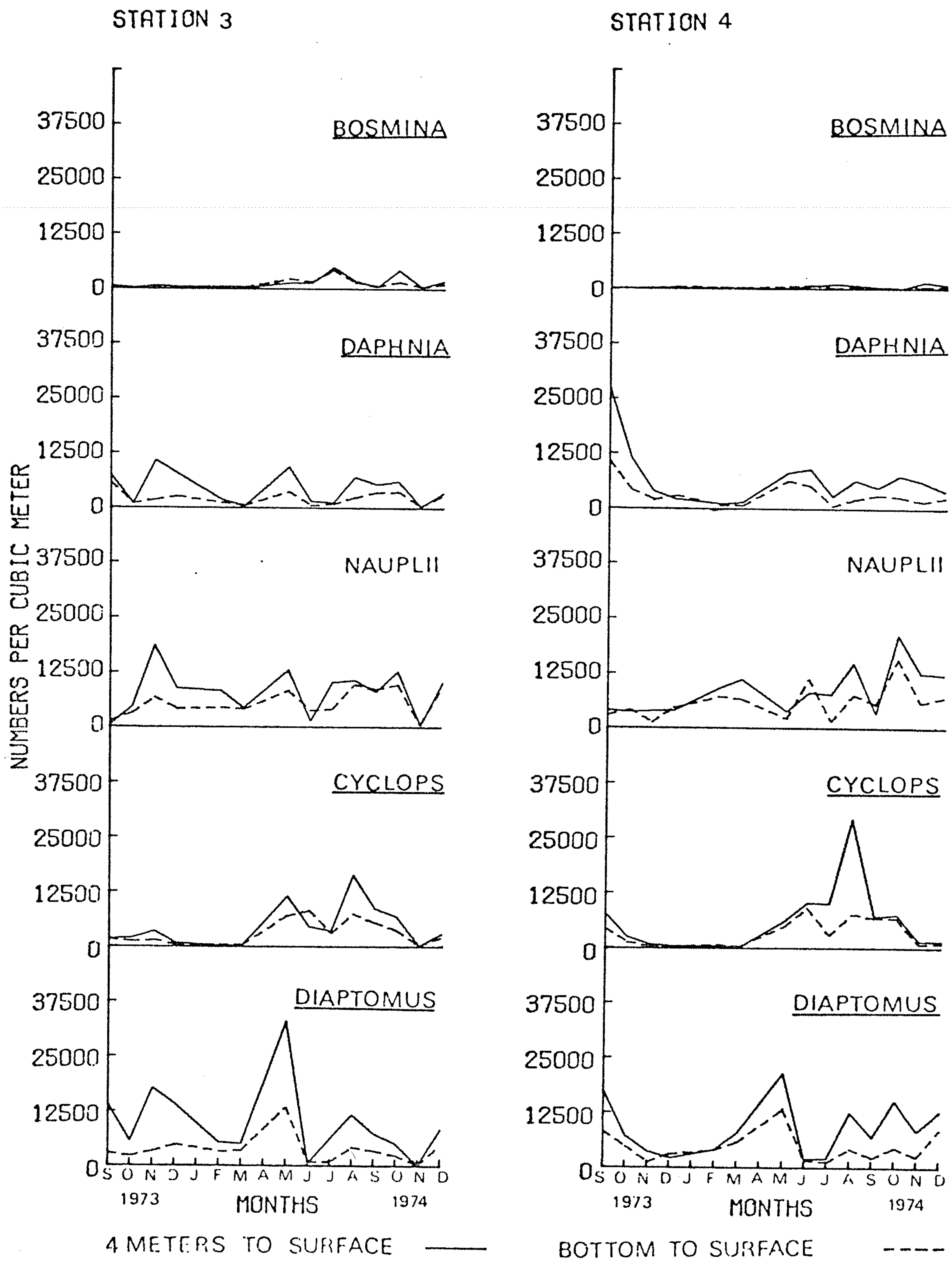

Fig. 4-17. Stations 3 and 4: Changes in Banks Lake zooplankton abundance by month.

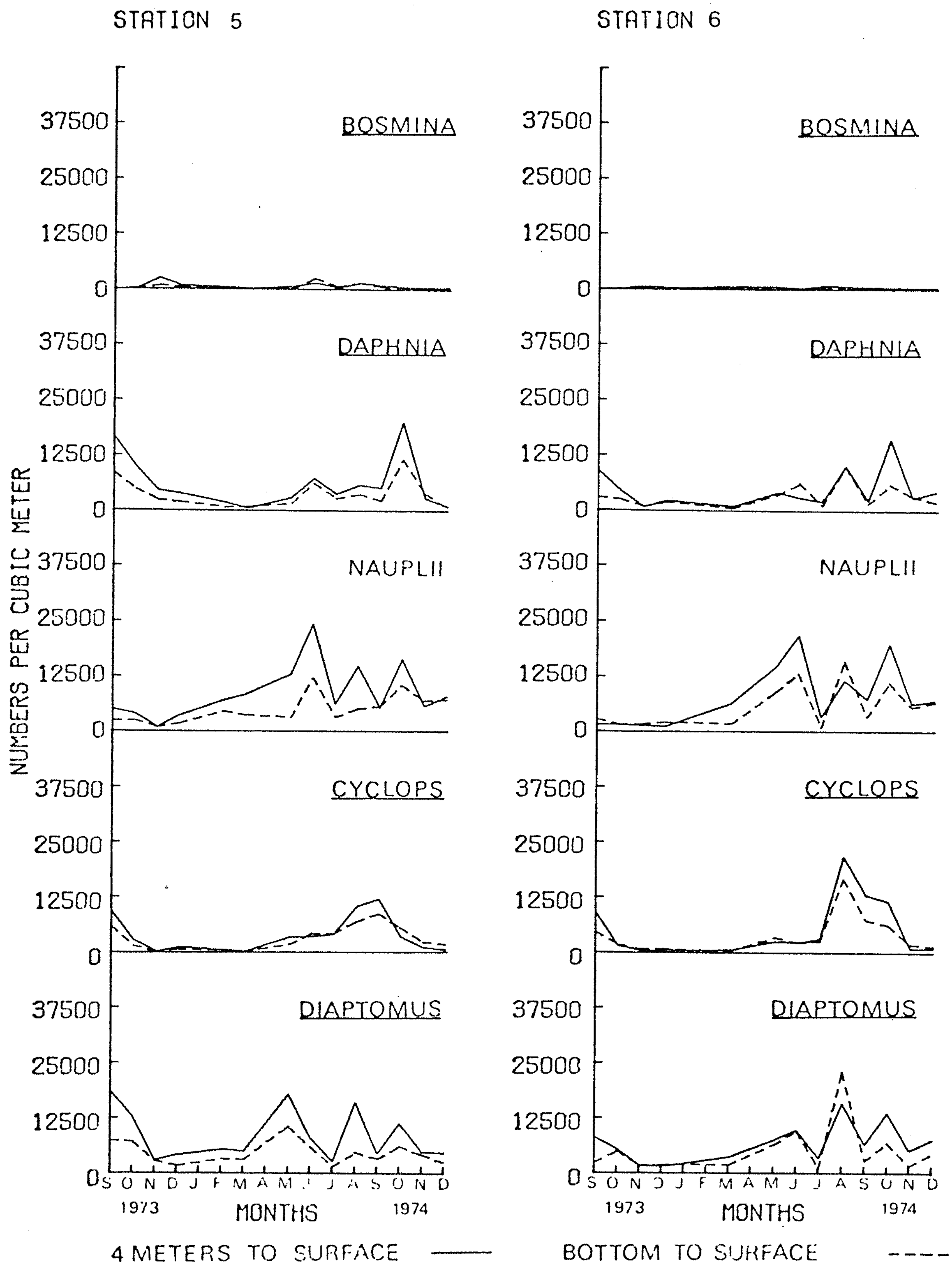

Fig. 4-18. Stations 5 and 6: Changes in Banks Lake zooplankton abundance by month.

changes in zooplankton abundance observed at Station 3 (Fig. 4-17) were similar to those discussed for Station 2. The peaks of *Bosmina* abundance were, however, less significant than those observed at Stations 1 and 2. The fluctuations in *Diaptomus* abundance were more marked than those observed at Station 2, with a peak in abundance in May 1974 similar to that observed at Station 1.

At Station 4 (Fig. 4-17) *Bosmina* abundance was low throughout the study period. *Daphnia* abundance declined from a significant peak in September 1973 and remained at low concentrations until May 1974. The abundance declined in June 1974 and remained at similar levels until December 1974. Although the abundance of copepod nauplii demonstrated marked fluctuations there was a trend of increasing concentration with time during the study period. *Cyclops* abundance was important only from May to October 1974. This abundance peaked in August 1974. *Diaptomus* abundance decreased from September to October 1973, remained at a low level during the winter, peaked in May 1974, declined in June 1974, and then demonstrated a trend of increasing concentration with time for the remainder of 1974.

Changes in abundance of zooplankton were similar at Stations 5 and 6 (Fig. 4-18). The trends were also similar to those observed at Station 4. *Bosmina* abundance was low throughout the study period. *Daphnia* abundance was relatively high in September 1973, declined to low concentrations during the winter, peaked in May 1974 and remained significant until November 1974. Copepod nauplii increased in abundance with time during the period November 1973 to May 1974 and then fluctuated from high to low concentrations during the remainder of 1974. *Cyclops* abundance was significant only during the period May to October 1974, peaking in September at Station 5 and August at Station 6. The abundance of *Diaptomus* fluctuated during the study period, with lower abundances occurring during winter 1973-74 than at other times during the period.

The changes in zooplankton abundance between stations varied with genus and time. *Bosmina* was generally more abundant at the northern stations although peak abundance in November 1973 was at Station 5. *Bosmina* abundance was always relatively low at Station 6. *Daphnia* abundance fluctuated markedly from station to station. Maximum abundance was at the southern stations in September and October 1973 and in June, July, August, October, November, and December 1974. Significant maximum abundance was observed at Station 1 in May 1974 prior to the pumped input of irrigation water and other abundance peaks occurred at the northern stations in November 1973 and September 1974 after the cessation or reduction of pumping. Nauplii were more abundant in North Banks Lake in November and December 1973 and July 1974, peaks also occurred at Station 1 in February and March 1974. Nauplii were more abundant at the southern stations in September 1973 and May, June, August, October, and November 1974.

Cyclops abundance was greater at the southern stations in September 1973 and in August and September 1974. Peak *Cyclops* abundance did not occur in North Banks Lake during the study. *Diaptomus* abundance at each station varied considerably. Peak abundance was in North Banks Lake from November 1973 to May 1974. From June to December 1974, however, there was a trend of increasing *Diaptomus* abundance with distance south, with peaks occurring at Station 4 in October, November, and December.

4.4.7 Zooplankton Input and Withdrawal

Estimates of the relative abundance of zooplankters pumped into and withdrawn from Banks Lake are presented in Table 4-8. Summation of the estimates of September and October 1973 suggest that larger numbers of *Diaptomus*, *Daphnia*, and *Bosmina* were imported into Banks Lake than were exported and the more nauplii and *Cyclops* were removed than contributed to the system. A different picture is seen, however, if data for one complete operational cycle is compiled (Table 4-8). During the 1974 operational cycle larger numbers of *Diaptomus*, *Cyclops*, nauplii, and *Daphnia* were withdrawn than were pumped in and only *Bosmina* numbers were greater in pumped in estimates than in withdrawal estimates.

4.5 Discussion

4.5.1 Physical Limnology

The temperature regime of Banks Lake is one of modified dimixis. The lake would be truly dimictic (Hutchinson 1957), however, the superimposition of controlled water supply and withdrawal upon a normal summer stratification pattern results in a system possessing properties characteristic of both a stratified lake and a river run reservoir.

The complexity of the flow characteristics in stratified reservoirs has been discussed by Wunderlich (1971) for TVA reservoirs and by Smith et al. (1960) for Lake Mead. In Banks Lake an underflow occurred because the incoming water was cooler and denser than the water in the vertically stratified body of the lake (Stations 4-6). The morphology of the lake emphasized this phenomenon. The convergence (Hoffman and Jonez 1973) was normally observed between Stations 2 and 3 in early summer. By late

Table 4-8. Estimated relative abundance of zooplankton pumped into Banks Lake through the feeder canal and withdrawn with the irrigation water during 1973 and 1974.

Period	Generic Group	Estimated Numbers Pumped in	Estimated Numbers Removed in Irrigation Water
Sept. and Oct. 1973	*Diaptomus*	6.274×10^{12}	1.310×10^{12}
	Cyclops	1.067×10^{12}	1.777×10^{12}
	nauplii	6.085×10^{11}	1.083×10^{12}
	Daphnia	4.327×10^{12}	1.319×10^{12}
	Bosmina	1.058×10^{11}	2.101×10^{10}
	Total	1.238×10^{13}	5.606×10^{12}
Irrigation Season 1974	*Diaptomus*	2.984×10^{12}	2.245×10^{13}
	Cyclops	1.202×10^{13}	2.141×10^{13}
	nauplii	1.903×10^{13}	2.112×10^{13}
	Daphnia	8.905×10^{11}	1.160×10^{13}
	Bosmina	1.301×10^{13}	1.384×10^{12}
	Total	4.771×10^{13}	7.824×10^{13}

summer, prior to the breakdown of stratification, the convergence occurred further north, between Stations 1 and 2. Convergence disappeared with seasonal cooling of the lake.

The horizontal temperature gradient observed during the summer was a function of this phenomenon since epilimnetic warming occurred south of the convergence. Surface temperatures increased to the south due to the effects of irrigation water flow. After the fall overturn had occurred in September during both years of the study, the horizontal gradient was reversed probably due to greater wind cooling in southern Banks Lake. The lake exhibited a reversal in horizontal surface temperatures due to the seasonal climatic cooling (increasing to the north) during fall, winter, and early spring.

Transparency was primarily influenced by phytoplankton standing stock, sediment due to wind action, and turbulence due to pumping. Much of the shoreline and lake bottom was easily disturbed fine glacial till. Stations 1 and 2 were particularly susceptible to current induced turbidity during pumping. During the summer Station 3, at the convergence point, was often the location of a buildup of detritus. Station 4, located in the widest section of the lake, was less subject to turbidity from littoral disturbance than the other stations. At Stations 5 and 6 the lake shores were steep and rocky with considerably less littoral area than elsewhere in the lake. Thus, during wind induced wave conditions, there was less sediment suspended in the water than at the northern stations.

During the two years of the study different trends were observed in the Secchi depth data. The decrease in transparency observed during the autumn of 1973 may have been due, in part, to phytoplankton blooms which were observed at the northern stations after pumping had ceased. The rate of pumping in 1974 was reduced gradually and did not cease until November when other factors may have been limiting primary production. The reduction in transparency observed in May and June 1974 correlates with the spring phytoplankton blooms. The transparency at Station 6 was consistently greater than at any other station. This indicated a reduction in the sediment induced turbidity and a lower phytoplankton standing stock.

Verduin (1956) developed the relationship

"euphotic zone depth = 5 x Secchi depth"

for Lake Erie and cited conversion factors used by different authors for a range of aquatic situations of between 2.5 and 5. Holmes (1970) noted that the depth of the euphotic zone (compensation point) is often estimated by multiplying Secchi depth by 3.

An experimental relationship between Secchi depth observations and light penetration for Banks Lake needs to be developed. However, the application of Holme's conversion factor (compensation point = 3 x Secchi depth) indicated the entire lake was often within the euphotic zone at maximum drawdown. Drawdown during the growing season may substantially reduce the area available for periphyton production as well as the volume of the lake available for limnetic phytoplankton production. Conversely, observations indicate that terrestrial plant production in the drawdown littoral area and aquatic macrophyte production at minimum lake level may be enhanced.

4.5.2 Chemical Limnology

The conductance of the water was low but consistent with other data reported for the Columbia Basin (U.S.G.S. 1973). The U.S.G.S. suggests a conversion for specific conductance to total dissolved solids (65% specific conductance = T.D.S.). This gives an approximate T.D.S. level of 59 mg/liter. Kiser (1965) reported T.D.S. values ranging from 88.6 to 118.8 mg/liter (mean 95.4) at Steamboat Rock during 1965-66. These values indicate below average levels of total dissolved solids for Banks Lake.

Observed values for total hardness and total alkalinity were relatively low but were consistent with data reported for the lake (Kiser 1965; Seattle Marine Laboratories 1974). Based on the most frequently observed pH conditions bicarbonate was the significant form of available carbon (Hutchinson 1967). pH is particularly difficult to measure in unbuffered water which may account for the wide range of observed values.

The dynamics of nutrient supply of Banks Lake are complex. The principal source of nutrients was the water supplied from Lake Roosevelt from the upper Columbia River Basin. Seasonal runoff from small streams and ground water in the basin adjacent to the lake may also have contributed small amounts. Some quantity of nutrients was continually removed by irrigation withdrawal. Intrinsic supplies of nutrients are most important when irrigation operations cease. During years of high drawdown the development and breakdown of littoral and terrestrial vegetation contributed to the lake nutrient budget, recycling both sedimented nutrients and nutrients removed from the water column.

The nutrient data suggest that the system may have been nitrate limited in July 1974 but that all available phosphates and nitrates were not utilized during the period August to December 1974. The available nitrogen appeared to be depleted as it flowed southward through the system during the irrigation season. Runoff and ground water sources may have been more significant in the northern section of the lake during this period. An overall increase in the concentration of nutrients in the lake occurred in the winter. During this period the lake was at maximum elevation and it is most likely that temperature, light, or other environmental factors limited primary production. Further data are required to substantiate the nutrient budget within the lake.

4.5.3 Biological Limnology

The levels of chlorophyll *a* abundance at Stations 1, 2, and 3 indicate a relationship between phytoplankton standing stock and operational conditions. An increase in chlorophyll *a* occurred in the fall of 1973 after pumping ceased. The decreased rate of flushing enabled phytoplankton to remain and utilize available nutrients more efficiently.

The peaks observed in February at Stations 2, 3, and 4 were probably due to the overturn associated with the end of ice cover when nutrients would have been recirculated through the water column. The very high chlorophyll *a* abundance observed at the three northern stations in June 1974 was a response to turbulent mixing and nutrients supplied in the water pumped from FDR Reservoir. Pumping had been initiated about 10 days before these observations were made. A seasonal interaction may have also been occurring. The sharp decrease in abundance in the two months following the June peak correlates with the maximum rate of pumping, indicating response to operational change. The late summer peak in abundance occurred during low rates of pumping. Chlorophyll *a* abundance decreased at the three northern stations during the autumn and early winter as the rate of water flow decreased and ceased in November; however, seasonal changes were also probably limiting. Chlorophyll *a* measurements were consistently lower at the three southern stations.

The clear distinction between the northern and southern regions of the lake, perpetuated by morphological and operational characteristics of the system, was further substantiated by the observed changes in the distribution and abundance of zooplankton.

Bosmina was important only at stations 1, 2, and 3 during the summer. This indicated that *Bosmina* may have been introduced from Lake Roosevelt or that conditions established by pumping favored limnetic survival. *Bosmina* only became important as the *Daphnia* population increased.

Bosmina longirostris is principally a littoral species (Brooks and Dodson 1965). However, Brooks (1968) reported a competitive interaction with *Daphnia* populations, suggesting importance limnetically when the *Daphnia* populations were low. *Bosmina* may also be an important constituent of the food of juvenile kokanee (Carlson 1974).

Fluctuations in *Daphnia* abundance followed similar patterns at Stations 4, 5, and 6 with high summer and low winter levels being observed. The observed *Daphnia* fluctuations at the three northern stations, however, were more erratic. Differences in food availability and temperature control of reproduction and growth rates may have influenced the observed spatial variations in distribution. The very high peak in abundance at Station 1 in May 1974 was succeeded by a marked reduction in June, after the initiation of pumping. This dramatic population decay was probably due to flushing. Lewis (1972) demonstrated that population size of *Daphnia* in Odell Lake, Oregon, was regulated primarily by kokanee predation; while this aspect of the zooplankton ecology has received little attention in this study it may be of some significance.

Distribution and abundance patterns for copepod nauplii were similar at Stations 4, 5, and 6. A trend of high summer and low winter abundance was observed. Superimposed upon this trend was a pattern of fluctuations which may have been associated with copepod life cycles, predation, or flushing. At Stations 1, 2, and 3 these fluctuations were more erratic and severe and seasonal trends were not observed.

The pattern of *Cyclops* abundance was clearly seasonal. Significant concentrations occurred at all stations only during the summer and autumn in 1974. At Station 1 the summer abundance was lower than elsewhere in the lake. The facultative ability of *Cyclops* to assume a benthic and littoral habit (Brooks 1968) may have influenced these fluctuations to a small extent.

Stations 4, 5, and 6 demonstrated similar patterns of change in the distribution and abundance of *Diaptomus*. There was a trend of high summer and low winter abundance but this was less marked than in other zooplankton groups. At Stations 1, 2, and 3 there was an overall pattern of rapid fluctuations. The *Diaptomus* population peaked in abundance at Station 1 in May 1974, then showed marked decrease and remained at a low level for the remainder of 1974. This was related to the flushing upon initiation of pumping. The fluctuations at Stations 2 and 3 were less severe.

The section of the lake represented by Stations 1, 2, and 3 appears to have provided a significantly different condition for limnetic zooplankton survival than that part of the lake represented by Stations 4, 5, and 6. Station 1 did, on occasion, demonstrate community changes not observed at other stations. These changes were probably a direct response to the inflow of water from Lake Roosevelt.

The significance of the biomass of zooplankton removed during the irrigation season is not clear. Further studies will be required to determine whether this loss influences limnetic fish production. It is possible that the removal of large numbers of *Daphnia* deprived such obligate carnivores as the kokanee and the lake whitefish of an important source of food.

The physical and biological studies clearly indicate that Banks Lake was characterized by two limnologically separate regions and that the influence of irrigation water input and withdrawal on the reservoir enhanced these differences. The temperature changes in Banks Lake were due to a complex seasonal-morphological-operational influence on the system. The operational influence was of greatest significance at the northern stations where direct responses were often apparent from the limnological observations. The effects of changes induced by operational conditions were born out by chlorophyll *a* abundance and zooplankton responses.

5.0 FISH POPULATION ECOLOGY

5.1 Introduction

A very diverse fish community exists in Banks Lake which supports an important sport fishery. The relative abundance, distribution, and life histories of the fish populations are being determined under the present water use regimes in order to develop predictive capabilities as to the potential effects from planned increases in irrigation and pumped storage operation. All species in the lake are being investigated, however, emphasis is being placed on yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), and kokanee (*Oncorhynchus nerka*) which are dominant. Baseline data are reported for the period between July 1973 and March 1975 during which the lake was primarily influenced by the input and withdrawal of irrigation water.

5.1.1 Origin of Stocks

The fish populations of Banks Lake comprise a large variety of species. The four major sources from which the fish species originated were (1) the small lakes which existed in the Grand Coulee prior to inundation; (2) stocking programs carried out by state agencies (Departments of Game and Fisheries); (3) irrigation water pumped in from Lake Roosevelt, and; (4) release by sport fishermen.

Devils Lake was the largest of several small lakes in the basin prior to the inundation of the Grand Coulee in 1951. Unfortunately, no records were made of the fish fauna of these small lakes. Information from local fishermen indicated that before inundation dense populations of largemouth bass, *Micropterus salmoides*, and pumpkinseed sunfish, *Lepomis gibbosus*, existed. Shortly after inundation the largemouth bass population increased rapidly and a kokanee salmon, *Oncorhynchus nerka*, fishery had begun to develop. Catch records from 1952, 1953, and 1954 indicate that largemouth bass and sunfish dominated the fisherman's creel. They amounted to 64 percent and 32 percent of the catch, respectively (Atley Nelson, WDG records, unpublished). Yellow perch, *Perca flavescens*; rainbow trout, *Salmo gairdneri*; and eastern brook trout, *Salvelinus fontinalis*, were identified in the 1953-54 catches while kokanee, crappie, *Pomoxis* spps.; burbot, *Lota lota*; and Dolly Varden, *Salvelinus malma*, were listed as "possible" species in the creel.

State agencies have introduced four species of salmonids: rainbow trout, kokanee, chinook, and coho salmon. The Washington Department of Game through continuous plants maintained substantial populations of rainbow trout and kokanee in Banks Lake (Appendix Table A-1). The program was initiated in 1953 when the Washington Department of Game planted 4,000 Kamloops rainbow trout. Subsequently, plants of 1,504,000 kokanee salmon fry, and 24,200 rainbow trout were made in 1956. Thereafter rainbow trout were planted annually and kokanee were planted every year except 1961-1962, 1967-1970, and 1972-1973. The Washington Department of Game introduced 101,750 coho salmon, *Oncorhynchus kisutch*, in 1971. The Washington Department of Fisheries introduced approximately 40,000 chinook salmon, *Oncorhynchus tshawytscha* in 1974.

The origin of the many other species of fish in Banks Lake must be deduced from indirect observations. Recruitment of fish into Banks Lake through the feeder canal is the likely origin of most species in Banks Lake. There were unconfirmed reports of a kokanee fishery that existed before the stocked kokanee were available. Gangmark and Fulton (1949) reported that kokanee were entrained through the Grand Coulee Dam generators, indicating a movement of kokanee out of Lake Roosevelt. The irrigation pump intakes leading from Lake Roosevelt to Banks Lake are in close proximity to the Grand Coulee Dam generator intakes. It is therefore logical to assume that kokanee and other species were also pumped into Banks Lake from Lake Roosevelt

A total of 29 species have been described in the surveys of the fish fauna of Lake Roosevelt, 25 species by Gangmark and Fulton (1949) and Earnest and Spence (1956 unpublished) and 4 species which have been observed incidentally by this study (Table 5-1). Sixteen of Lake Roosevelt's 30 species have been identified in Banks Lake. It is likely that many of these species were introduced into Banks Lake by entrainment in the water pumped from Lake Roosevelt.

Three species which found their way into Banks Lake which have not been described in Lake Roosevelt are brown trout, *Salmo trutta*, and the brown bullhead, *Ictalurus nebulosus*, and the black crappie, *Pomoxis nigromaculatus*. These species may have occurred in Lake Rosevelt and been missed by net sampling, however, since these species represent desirable sport fish their introduction may have been by local sportsfishermen. Large chinooks (5 to 11 lb) have recently been captured in Banks Lake by sportsfishermen. Chinooks this large were not from the 1974 plant into Banks Lake and were probably pumped up from Lake Roosevelt. Chinook salmon were planted in Lake Roosevelt in 1971-72.

Table 5-1. Fishes of Lake Roosevelt

	Common name	Scientific name	Gangmark and Fulton, 1949	Earnest and Spence, 1956	Incidental observation during present study
1	Rainbow trout	*Salmo gairdneri*	+	+	+
2	Brook trout	*Salvelinus fontinalis*	+	+	
3	Mountain whitefish	*Prosopium williamsoni*	+	+	
4	Pygmy whitefish	*Prosopium coulteri*	+	0	
5	Whitefish	*Prosopium oregonium*	+	0	
6	Kokanee	*Oncorhynchus nerka*	+	+	+
7	Cutthroat trout	*Salmo clarkii*	+	+	
8	Dolly Varden	*Salvelinus malma*	+	+	
9	Largemough bass	*Micropterus salmoides*	+	+	
10	Smallmouth bass	*Micropterus dolomen*	+	+	
11	Northern squawfish	*Ptychochelius oregonensis*	+	+	+
12	Peamouth	*Mylochelius caurinus*	+	+	+
13	Redsided shinner	*Richardsonius balteatus*	+	+	
14	Yellow perch	*Perca flavescens*	+	+	
15	Tench	*Tinca tinca*	+	0	
16	Carp	*Cyprinus carpio*	+	+	+
17	Pumpkinseed sunfish	*Lepomis gibbosis*	+	+	
18	Chub	*Achrochelius alutaceus*	0	+	
19	Lake whitefish	*Coregenus clupeaformis*	0	+	
20	Sculpin	*Cottus* species	+	+	+
	Suckers	*Catostomus* species	+	+	
21	Bridgelip sucker	*Catostomus columbianus*		+	+
22	Sucker	*Catostomus syncheilus*		+	
23	Lost River Sucker	*Catostomus lukatus*		+	
24	Largescaled sucker	*Catostomus macrochelius*		+	+
25	Longnose sucker	*Catostomus catostomus*		+	+
26	Walleye	*Stizostedion vitreum*	0	0	+
27	Burbot	*Lota lota*	0	0	+
28	Black crappie	*Pomoxis nigromaculatus*	0	0	+
29	Chinook salmon	*Oncorhynchus tshawytscha*	0	0	+

5.1.2 The Sportfishery

Duff (1973) estimated the 1971-72 fishing effort to be 92,236 fishermen days with a catch of 81.6 m tons (90 tons) worth $1.6 million to the angler.

The sportfishery was described as a multiple species fishery containing three salmoniformes (rainbow trout, kokanee, lake whitefish), five perciformes (yellow perch, largemouth bass, black crappie, walleye, sunfish), the brown bullhead, and the burbot. Largest catches were of yellow perch and kokanee. Since 1952-54 when the creel survey indicated predominantly bass and sunfish in the catch, the species composition shifted to predominantly yellow perch and kokanee as these fishes became established. Presently the populations of kokanee and yellow perch are stable having dominated the sport catch since 1965. However, other species such as burbot have virtually disappeared (Duff 1973). The recent introduction of the chinook salmon and plans to continue this experiment may cause further shifts in the species abundance. The 1971-72 creel survey contained the following species in order of abundance: yellow perch (56%), kokanee (30%), rainbow trout (5%), black crappie (4%), largemouth bass (2%), sunfish (2%), and lake whitefish, walleye, and burbot (1%).

5.2 Materials and Methods

5.2.1 Sampling Gear

Horizontal gill nets 30.5 m (100 ft) long by 1.8 m (6 ft) deep with nine panels of variable mesh monofilament nylon were used. The mesh sizes ranged from 2.5 cm to 12.7 cm stretched (1 inch to 5 inches) graduated in 1.3 cm (1/2 inch) intervals. Sets were made at the surface and bottom of the water column. The variable mesh horizontal gill nets effectively caught all sizes of yellow perch, lake whitefish, and kokanee except the age 0 fish.

The horizontal net could not be fished effectively at mid-depths and a vertical gill net was required to determine vertical distribution of fish. Vertical gill nets were constructed of 6.4 cm (2-1/2 inches) stretched monofilament nylon 24.4 m (80 ft) deep by 3.0 m (10 ft) wide. The 2.5 inch mesh was chosen since the largest catches of yellow perch, lake whitefish, and kokanee in the variable mesh net were made with this mesh size. Horizontal spreader bars of 6.4 mm (1/4 inch) aluminum rod were attached at the bottom, at 8 m (24 ft) intervals 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 inches) at each end to 6.4 mm (1/4 inch stretched) in the bunt. Rope leads 30.5 m long were attached to each end of the seine to facilitate hauling the net. The largest catches of age 0 fishes were made in the beach seine hauls.

Three tow nets were used to collect pelagic age 0 fishes: a 3 m x 3 m x 9 m mid-water trawl; a 0.5 m diameter 243 μ mesh plankton net; and a 2.0 m diameter 505 μ mesh bongo net. Largest catches of pelagic lake whitefish were made with the surface towed plankton and bongo nets.

Three traps were used to collect live species for mark and recapture experiments; a Lake Merwin trap; a 1/2 inch mesh (stretch) fyke net; and a 4 inch diameter, 5 inch (stretch) mesh hoop net. The largest catches were made with the Lake Merwin trap.

5.2.2 Sampling Design

The fish sampling was coordinated with the limnology and entrainment phases of the study to provide information on the effects of water input, withdrawal, and fluctuation on the fish populations.

A sampling plan was designed which entailed standardized, periodic sampling by nets at each of four transects across the lake (Fig. 4-1, Transects 1, 4, 5, and 6). The deployment of gear at each transect is shown in Fig. 5-1.

Gill-net sampling was conducted offshore at the four sampling transects at monthly intervals and along both shorelines of each transect at quarterly intervals.

The offshore gill-net sampling was designed to assess the changes in fish distribution along the length of the lake and throughout the water column and to provide sufficient specimens to estimate relative abundance, growth, maturation, and feeding of the dominant species in the lake. The offshore gill-net sets consisted of one vertical gill net, one surface horizontal gill net, and one bottom horizontal gill net. Sets made at the four transects were fished for two consecutive 24-hr periods monthly.

The shoreline gillnetting was designed to detect seasonal shifts of fish distribution inshore and to provide the necessary life history

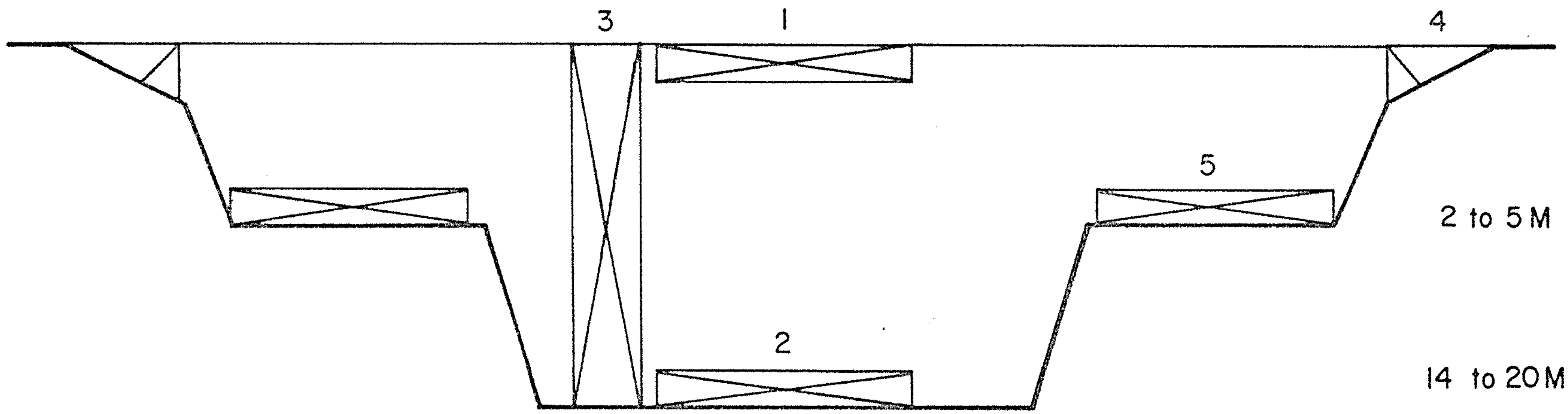

Fig. 5-1. Schematic section through one transect illustrating sampling site for each gear type. 1) surface set horizontal gill nets (monthly), 2) bottom set horizontal gill nets (monthly), 3) vertical gill nets (monthly), 4) beach seine hauls (monthly), 5) shoreline bottom set horizontal gill nets (quarterly).

information and to aid in explaining these observations. The shoreline gill-net sets were made with horizontal gill nets laid on the bottom in 6 to 10 ft of water, parallel to the shoreline. The shoreline sets were fished for two consecutive 24-hr periods quarterly. Two nets were fished along each shoreline, one net was placed on rock substrate and the other on mud substrate.

The gill-net catches were examined periodically during daylight, darkness, and crepuscular hours to determine diel behavior patterns of the fish. The selectivity of gill nets against small fish has been well documented. In order to obtain estimates of the relative abundance and distribution and life history of the age 0 fishes, beach seining was conducted at monthly intervals along the shorelines of the four sampling stations. The beach seining consisted of two hauls on both shorelines at each of the four transects and was repeated monthly, as long as the age 0 fish were inshore.

The bongo nets and surface-towed plankton nets were fished on a weekly basis in the spring when larval fish occurred in the pelagic zone. The hauls approximately 1,850 m long, were made along the shorelines and at mid-lake at each of the four transects. Tsurumi-Seiki Kosakusho (TSK) meters mounted in the opening of each net recorded the volume of water filtered.

Mark and recapture experiments were conducted to determine fish movement in Banks Lake. Live specimens for tagging were captured with lake traps and beach seines. Tagged specimens were helpful in interpreting the shifts in fish distribution suggested by the gill-net catch per unit effort (CPUE). Mark and recapture information was also used to calibrate the catchability of fish in the gill nets and evaluate the effectiveness of the sampling design.

5.2.3 Data Recording and Processing

The following data were recorded for each gill-net set or beach-seine haul: date, location, effort, time of day, gear type, water temperature, water transparency, bottom type, and catch information. 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 and/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 of lake whitefish and kokanee were taken consistently from the right side below the dorsal fin and above the lateral line. Scales of yellow perch were taken from below the lateral line. A Bausch and Lomb microprojector (5 x objective, 1.5 X power) was used to examine the scales after they had been impressed on plastic cards. Age was determined by scale readings and otoliths.

Stomach contents were examined visually and described by eight codes for food type and four codes for stomach fullness. Microscopic examination was conducted on a subsample of the fish stomachs for identification of organisms to genus, enumeration, and size estimation of food items.

Sex and maturity were recorded for each fish using an index modified from Nikolsky (Bagenal and Braum 1968). This maturity index was used to help establish time, interval, and location of spawning for the species examined. Direct observations from the shoreline, from boats and by SCUBA and skin diving was conducted in order to locate spawning fish, nests, depth of spawning, eggs, and spent or dying fish.

5.2.4 Data Analysis

The estimates of relative abundance and distribution are presented as catch per unit effort (CPUE). Since the sampling scheme employed a constant effort, the total catch was also 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-hr set.

Non parametric testing was employed in the analysis of fish distribution. Linear regression was used to describe length-weight relationships and analysis of covariance was used to compare the regressions.

5.3 Results

5.3.1 Species Composition

From July 1973 to March 1975 nineteen species were captured. In order of abundance in the catch they were: yellow perch, *Perca flavescens*; lake whitefish, *Coregonus clupeaformis*; longnose sucker, *Catostomus catostomus*; prickly sculpin, *Cottus asper*; black crappie, *Pomoxis nigromaculatus*; kokanee, *Oncorhynchus nerka*; largemouth bass, *Micropterus salmoides*; peamouth, *Mylocheilus caurinus*; carp, *Cyprinus carpio*; rainbow trout, *Salmo gairdneri*; mountain whitefish, *Prosopium williamsoni*; pumpkinseed sunfish, *Lepomis gibbosus*; brown bullhead, *Ictalurus nebulosus*; chinook salmon, *Oncorhynchus tshawytscha*; largescale sucker, *Catostomus macrocheilus*; walleye, *Stizostedion vitreum*; northern squawfish, *Ptychocheilus oregonensis*; burbot, *Lota lota*; and brown trout, *Salmo trutta* (Table 5-2).

Out of the 16 species reported by Duff (1973) only the bluegill sunfish, *Lepomis marochirus*, has not been taken. Coho salmon, *Oncorhynchus kisutch*, were planted in 1971 but no official record of capture exists. Eastern brook trout, *Salvelinus fontinalis*, were reported in the 1952 catch by Nelson (unpublished) but none have appeared in the 1965 and 1971-72 creel census or in the extensive fish sampling since July 1973.

5.3.2 Relative Abundance

Yellow perch, lake whitefish, kokanee, longnose sucker, and peamouth represented 96 percent of the total gill-net catch by number (Table 5-2). Yellow perch, lake whitefish, kokanee, longnose sucker, peamouth, carp, and rainbow trout represented 96 percent of the total gill-net catch by weight (Table 5-2). All 19 species found in the lake have been taken in gill nets. Yellow perch, lake whitefish, prickly sculpin, black crappie, largemouth bass represent nearly 100 percent of the beach seine catch (Table 5-2). All species except burbot and brown trout have been taken in beach seine hauls. The yellow perch, lake whitefish and kokanee were selected for detailed study because they dominated the catches of both gill nets and beach seines, amounting to 91 percent of the gill-net catch and 95 percent of the beach-seine catch. Most species were taken in gill nets in rough proportion to abundance but carp, largemouth bass, black crappie, brown bullhead are known to avoid capture in gill nets so their abundances are probably underestimated.

Table 5-2. Fishes of Banks Lake, 1973-1975 indicating percentage relative weight and abundance in catch

	Common name	Scientific name	Relative weight gill nets	Relative abundance gill nets	Relative abundance beach seine
1	Yellow perch	*Perca flavescens*	28.64	67.45	91.61
2	Lake whitefish	*Coregonus clupeaformis*	34.51	14.98	4.21
3	Kokanee salmon	*Oncorhynchus nerka*	13.29	8.02	<0.01
4	Longnose sucker	*Catostomus catostomus*	9.64	2.87	0.07
5	Peamouth	*Mylochelius caurinus*	2.30	2.31	0.10
6	Carp	*Cyprinus carpio*	4.31	0.67	0.06
7	Rainbow trout	*Salmo gairdneri*	3.11	1.25	0
8	Chinook salmon	*Oncorhynchus tshawytscha*	0.51	0.68	0
9	Black crappie	*Pomoxis nigromaculatus*	0.36	0.41	1.10
10	Largemouth bass	*Micropterus salmoides*	0.94	0.39	0.60
11	Mountain whitefish	*Prosopium williamsoni*	0.57	0.42	0.01
12	Pumpkinseed sunfish	*Lepomis gibbosis*	0.10	0.35	0.05
13	Brown bullhead	*Ictalurus nebulosus*	0.07	0.01	0.01
14	Walleye	*Stizostedion vitreum*	0.51	0.02	<0.01
15	Burbot	*Lota lota*	0.44	0.01	0
16	Brown trout	*Salmo trutta*	0.17	<0.01	0
17	Largescale sucker	*Catostomus macrochelius*	0.71	0.14	0
18	Northern squawfish	*Ptychochelius oregonensis*	0.08	0.01	0
19	Prickly sculpin	*Cottus asper*	0.01	<0.01	2.17

5.3.3 Yellow Perch, *Perca flavescens* (Mitchell)

5.3.3.1 Importance. The yellow perch is a small perciform (spiny ray), indigenous to the north central and eastern United States and south, central, and eastern Canada. Through introduction by man its range has extended to the Pacific Coast. The yellow perch successfully adapts to lentic waters and once established has a tendency to overpopulate. In waters where it maintains a reasonable size, rarely exceeding 11 inches, it represents a common and highly prized game fish since it is easily caught and has an excellent food quality.

The abundance of yellow perch was low during the first years of Banks Lake as indicated by the 1952-54 creel census by Atley Nelson. However, by the creel census in 1965 and 1971-72, yellow perch dominated numerically. Although the 1952-54 creel census indicated only small numbers of yellow perch were present in the early years of the reservoir they adapted well. Several species prey on yellow perch but their high reproductive potential coupled with flexibility in habitat and feeding requirements enabled it to become one of the most abundant species in Banks Lake.

5.3.3.2 Distribution. Inshore and offshore distributions of yellow perch were determined from the quarterly gill-net sampling during 1974. The relative abundance of yellow perch within and between each of the transects for each quarter (spring, summer, fall, winter) is illustrated in Fig. 5-2. Distribution within the water column was based on offshore gill-net catches.

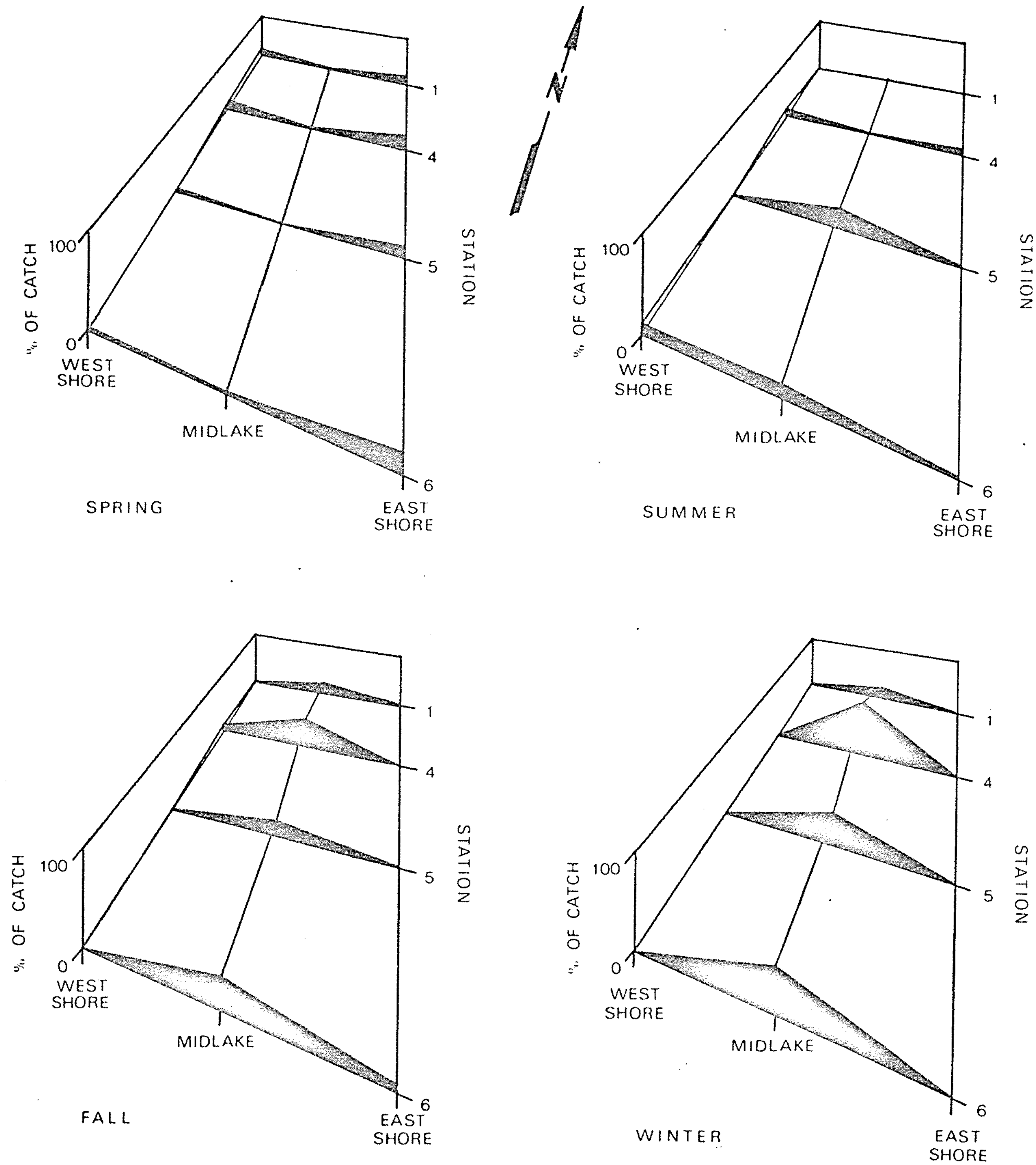

Fig. 5-2. The inshore/offshore distributions of yellow perch for the spring, summer, fall and winter seasons of 1974. The vertical axis represents the percent of the total catch for each season. The horizontal plane represents 12 sampling locations: an east shore, a midlake and a west shore site for 4 transects. The transects run from north to south and are: 1 (Electric City), 4 (Steamboat Rock), 5 (Million Dollar Mile), and 6 (Coulee City).

Yellow perch occurred predominantly inshore in the spring. In the summer they were more evenly distributed and by fall they had moved offshore. They remained offshore through the winter. The yellow perch were evenly distributed north and south except in the spring when they were more abundant in the northern half of the lake. The yellow perch were predominantly caught near the bottom. The only time yellow perch were in the upper water column was during the summer when large numbers were captured at the surface in the horizontal gill nets.

Age 0 yellow perch were most abundant at Transect 4. Insofar as the gill-net catch of yellow perch represents available spawners, the greatest abundance of spawners was at Transect 4. The Transect 4 shoreline had a large amount of shallow mud flats suitable for rearing the young fish. The beach-seine catch was highest at Transect 4 in 1973 and 1974 (Fig. 5-3). In 1973 and 1974 the age 0 yellow perch moved offshore in November.

5.3.3.3 Age and Growth. Length of the yellow perch at different ages were determined by examination of scales of 551 specimens representing the gill-net catches from all transects, by depth and time of year. The median lengths at ages 0 through 6 for the total sample are presented in Table 5-3. Annuli on the scales are formed from December through March. Although the lengths at each age overlapped, several differences between transects were apparent. Yellow perch of ages 1, 2, and 3 were largest at Transect 4. Ages 5 and 6 were largest at Transect 6. Fish at Transect 1 were smaller at all ages (except perhaps age 2) than perch at all the other transects (Fig. 5-4).

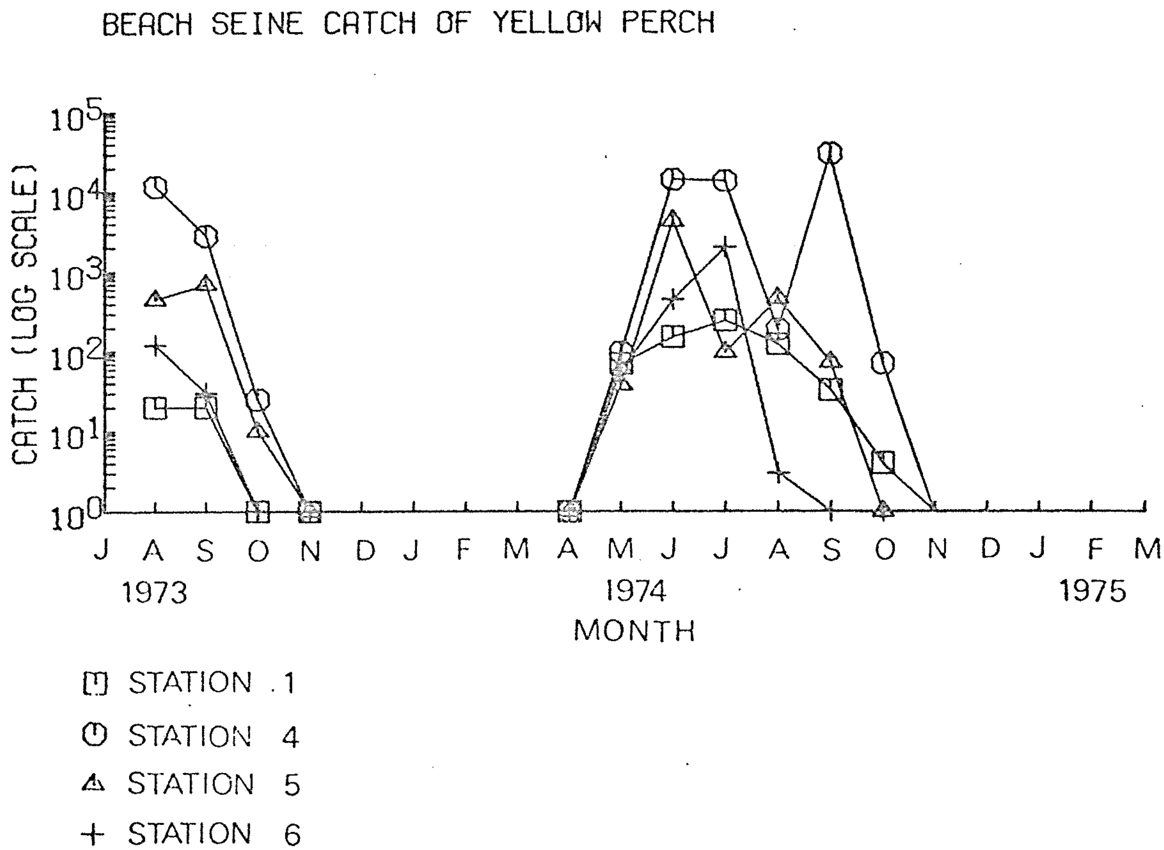

Fig. 5-3. Beach seine catch of yellow perch by station July 1973 - March 1975.

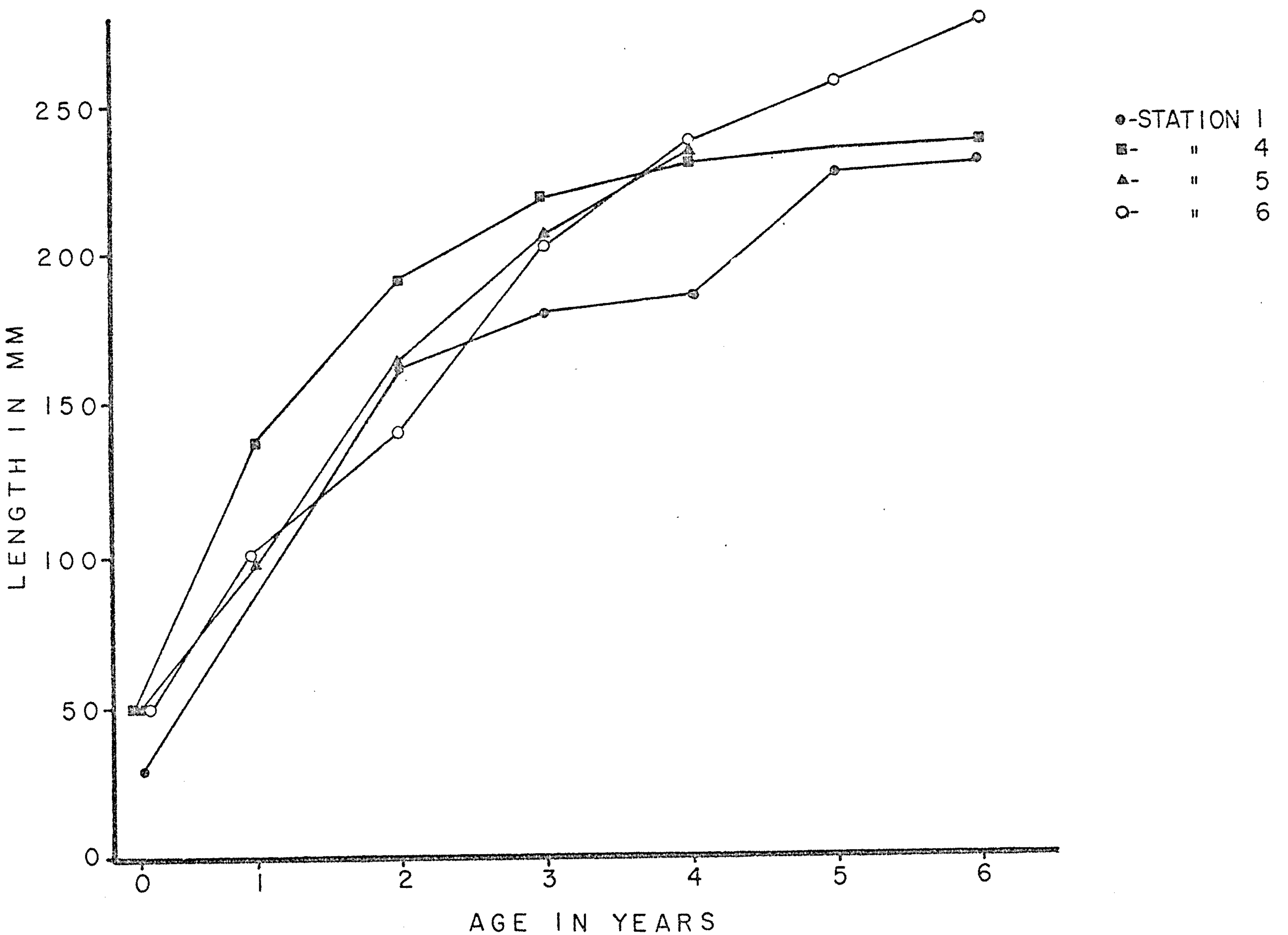

Fig. 5-4. Mean lengths at age for yellow perch caught at Stations 1, 4, 5 and 6, August-September, 1973.

Table 5-3. Median lengths of yellow perch, lake whitefish, and kokanee versus age

Species	Years 0	1	2	3	4	5	6
Yellow perch	101 mm (n=17)	142 mm (n=48)	203 mm (n=174)	230 mm (n=218)	242 mm (n=82)	253 mm (n=10)	288 mm (n=2)
Lake whitefish	242 mm (n=18)	342 mm (n=2)	454 mm (n=35)	457 mm (n=45)	458 mm (n=18)	456 mm (n=2)	
Kokanee	263 mm (n=15)	282 mm (n=84)	320 mm (n=18)	363 mm (n=2)			

The beach-seine catches of age 0 yellow perch confirmed that the growth rate of yellow perch was slowest at Transect 1. The mean length of the age 0 yellow perch was less than the mean lengths at Transects 4, 5, and 6 (Table 5-4).

Table 5-4. Median lengths of age 0 yellow perch by transect for 1973, in millimeters

	Transect 1	4	5	6
July 26, 1973	26 mm	40 mm	34 mm	29 mm
August 8, 1973	33 mm	45 mm	45 mm	45 mm
August 26, 1973	44 mm	54 mm	63 mm	--
September 19, 1973	39 mm	56 mm	64 mm	--

Yellow perch were fatter at Transects 4, 5, and 6 than they were at Transect 1. This supports the observation that growth was reduced at Transect 1 as was previously indicated by age and growth of the gill-net and beach-seine catches of yellow perch.

5.3.4.4 Food Habits. Stomachs of yellow perch captured in the gill nets (one year old and older) were inspected for type of food consumed, fullness and presence/ absence of food (Fig. 5-5). Five types of food were found: zooplankton, fish, insects, benthos, and animal debris. The average fullness of the stomachs was underestimated because some yellow perch were observed to regurgitate their stomach contents when removed from the gill net.

The stomach contents of yellow perch were found to vary greatly in composition and fullness with season. Zooplankton was the most frequent food observed in the yellow perch stomachs. Approximately 100 percent of the zooplankton was identified as *Daphnia*. Fish was the second most frequent food found in the perch stomachs. Eighty-nine percent of the identifiable fish were sculpins and the remaining 11 percent yellow perch. Some insects (primarily damsel flies and chironomids), benthos (primarily snails), and detritus were observed incidentally in the stomach.

The proportion of zooplankton to fish in the stomachs of yellow perch was higher in 1973 than in 1974. Insofar as the stomach contents demonstrate the availability of food, fish prey was more available in 1974 than 1973. The large 1974 catch of sculpins and age 0 yellow perch in the beach seine supports the contention that fish prey was more available for yellow perch in 1974 than in 1973.

5.3.3.5 Reproduction. Yellow perch spawn along the shoreline of Banks Lake over rocky and mud substrate in the early spring (March-April) when water temperatures ranged from 7° to 10°C. After spawning,

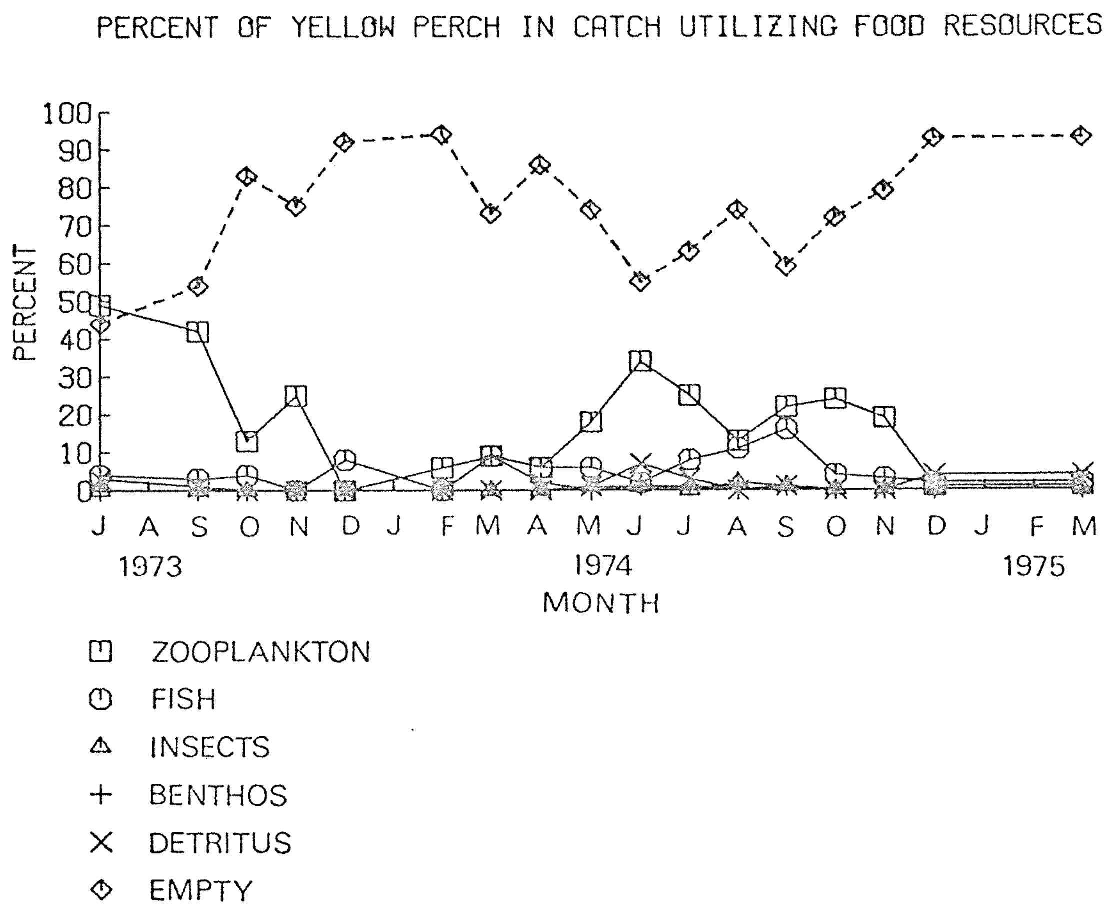

Fig. 5-5. The stomach contents of yellow perch. The vertical axis represents the percent of the yellow perch stomachs containing a specific food category. Dashed line represents percent of stomachs which were empty. The yellow perch were caught in gill nets between July 1973 and March 1975.

feeding activity increased and by mid-summer their gonads had begun to develop in preparation for the next spawning season. The percentage of mature and spawning fish in the offshore and inshore gill-net catch was determined for each sampling period (Figs. 5-6 and 5-7).

Maturity is reached in the first year of life by a large proportion of males which are captured along the shoreline in spring. Most fish of both sexes have reached maturity by their second year. Yellow perch are unique among the freshwater fish and spawn their eggs on a variety of substrates (rock and mud) in long gelatinous strands which are translucent, semibuoyant, and nonadhesive. Egg masses are common inshore but have been recovered in gill nets in over 20 m of water. Larval yellow perch are first taken in large numbers in the beach seine in June, one month after peak spawning was observed. This indicates an incubation of less than four weeks. From May through September large schools of juvenile yellow perch were observed along shallow beaches.

5.3.3.6 Mark and Recapture. An attempt was made to estimate the population of yellow perch at Transect 1 in 1974. Floy anchor tags were used. A Lake Merwin trap and beach seines were used to capture, tag, and release 548 live specimens. However, the experiment was discontinued when it was determined that a minimum of 2,500 fish needed to make the population estimate could not be obtained.

From this tagging a total of 19 yellow perch were recaptured: 5 in the Lake Merwin trap within two days after tagging, 11 from fishermen, and 3 from the monthly gillnetting. Eighteen of the fish were recovered at Transect 1 and three fish were recaptured in the feeder canal.

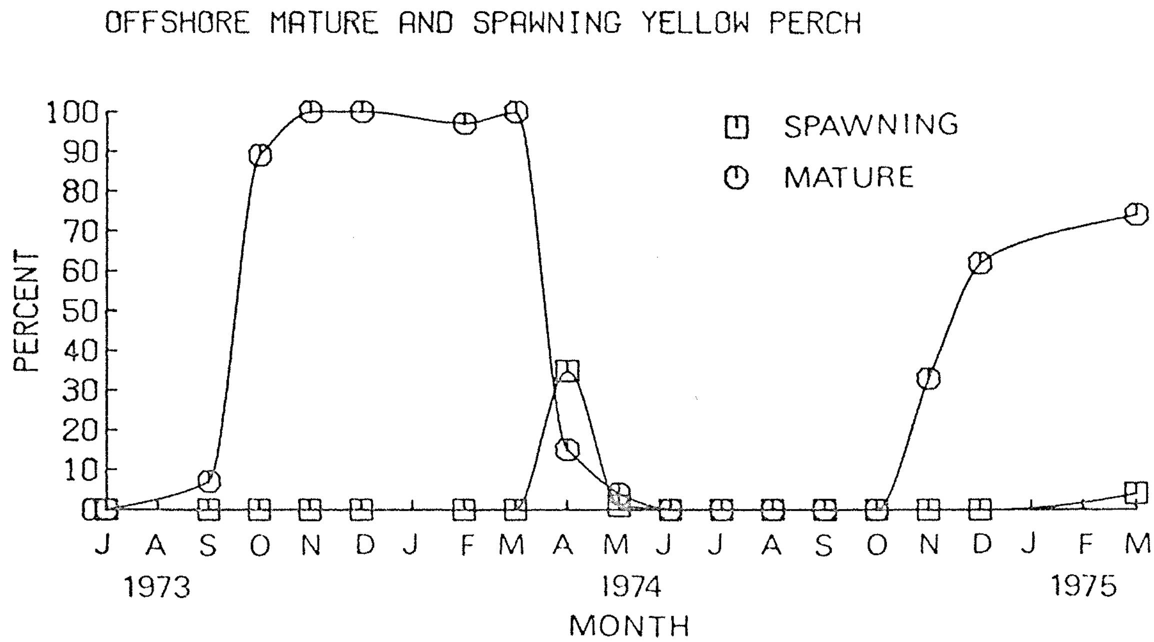

Fig. 5-6. The percent of mature and spawning yellow perch caught offshore in gill nets, July 1973 - March 1975.

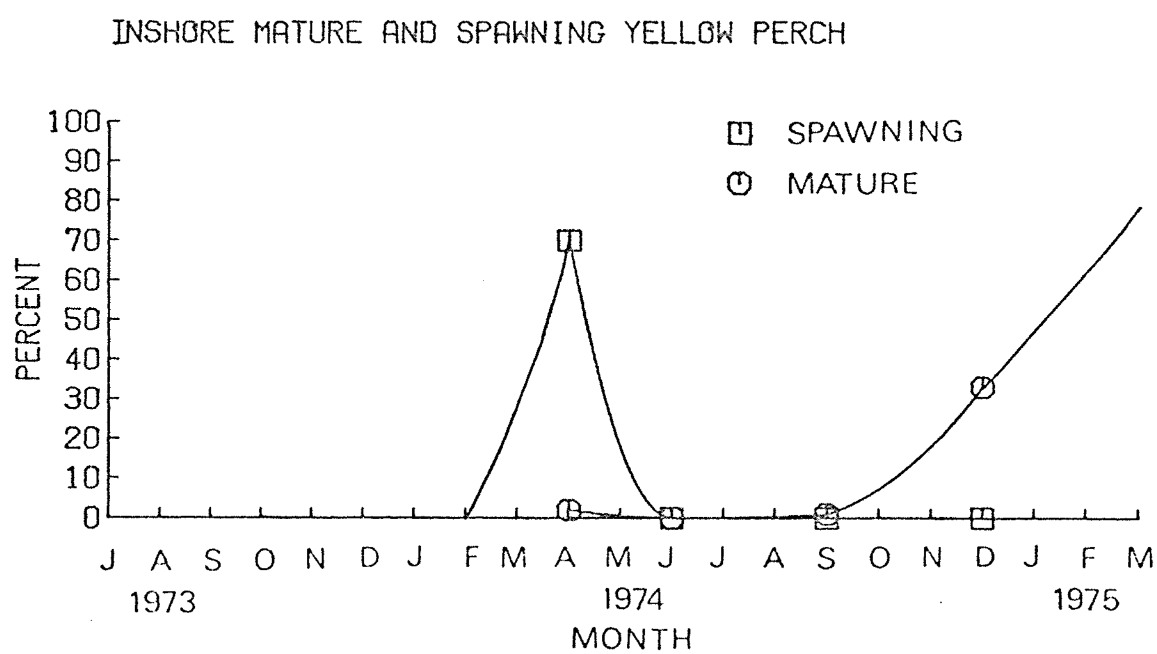

Fig. 5-7. The percent of mature and spawning yellow perch caught inshore in gill nets, April, July, September and October 1974.

5.3.4 The Lake Whitefish

5.3.4.1 Importance. The coregonids (whitefish) belong to the order Salmoniformes which is distinguished by soft-rayed fins. The coregonids are similar to the salmonids, having an adipose fin and inhabiting cold water systems, but are different morphologically in having smaller mouths and larger scales. The lake whitefish is the largest coregonid indigenous to Washington State. Its desirability among commercial fisheries led to its introduction into many southern Canadian and northern U.S. waters. However, these attempts were highly unsuccessful. The lake whitefish even when abundant does not support a sport fishery due to its unwillingness to take a hook.

Lake whitefish were not introduced to Banks Lake in any known stocking program, nor is there any reason to believe they would have been stocked since they are abundant elsewhere but unexploited. Lake whitefish were recorded by Earnest and Spence (1965 unpublished) in Lake Roosevelt and were probably introduced to Banks Lake through the feeder canal. The first record of lake whitefish from Banks Lake was in a 1965 creel survey by Merrill Spence (cited from Duff 1973). From 1968-1970 the lake whitefish population suffered large winter dieoffs (Duff, personal communication), and their recovery as a dominant species in the lake was in question. However, the lake whitefish has successfully adapted to these large and "apparent" natural mortalities and today appears to be the second most numerous gamefish.

The lake whitefish is unique among freshwater fish since it has a pelagic larval stage. With the exception of this early life history stage, the lake whitefish of Banks Lake appears to have few predators. There is an abundance of suitable shoreline and reproduction appears to be quite successful.

5.3.4.2 Distribution. Inshore and offshore distributions of lake whitefish were determined from the 1974 quarterly gill-net catches. The relative abundance of lake whitefish within and between each transect for each quarter (spring, summer, fall, winter) is illustrated in Fig. 5-8. Distribution within the water column was based upon the monthly offshore gill-net catches.

In the spring the lake whitefish were evenly distributed between the inshore and offshore areas. In the summer they moved offshore where they remained through the fall. In the winter the lake whitefish spawners moved inshore leaving only immature fish offshore. The lake whitefish were evenly distributed north and south except in the fall when the catch was larger at Transects 4, 5, and 6. Lake whitefish were found throughout the water column except in the summer when they were taken predominantly on the bottom.

Larval lake whitefish in early yolk sac stage were taken in largest numbers in March and April 1973 in the south half of the lake. Highest densities were recorded along the shoreline directly in front of the irrigation canal (Table 5-5). In May 1973 when the whitefish moved inshore the highest beach-seine catches were made in the north end of the lake (Fig. 5-9). Since larval lake whitefish are weak swimmers they are particularly vulnerable to the currents created by water withdrawal. It is logical to assume that larval lake whitefish were entrained through

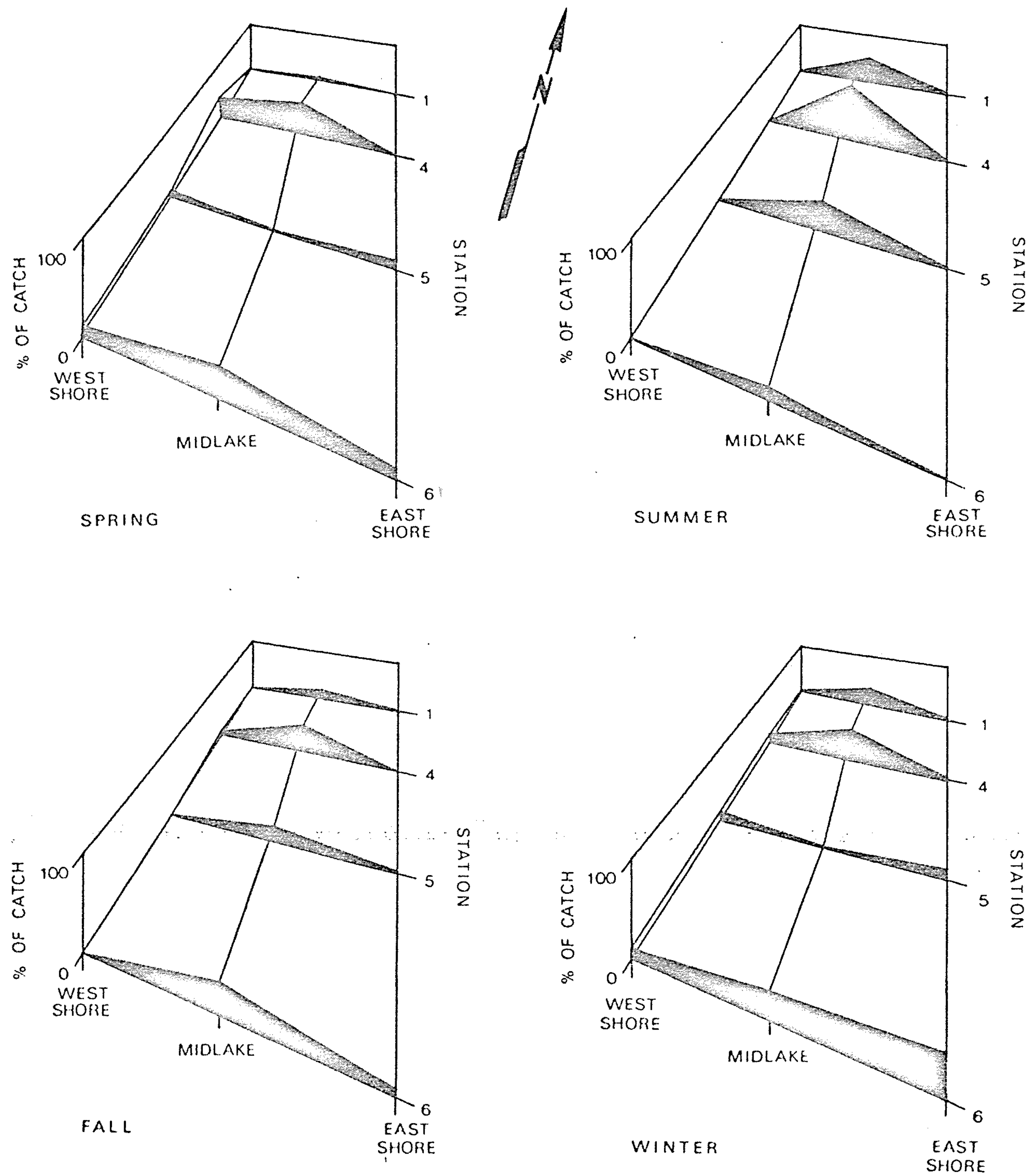

Fig. 5-8. The inshore/offshore distributions of lake whitefish for the spring, summer, fall and winter seasons of 1974. The vertical axis represents the percent of the total catch for each season. The horizontal plane represents 12 sampling locations: an east shore, a midlake and a west shore site for 4 transects. The transects run from north to south and are: 1 (Electric City), 4 (Steamboat Rock), 5 (Million Dollar Mile), and 6 (Coulee City).

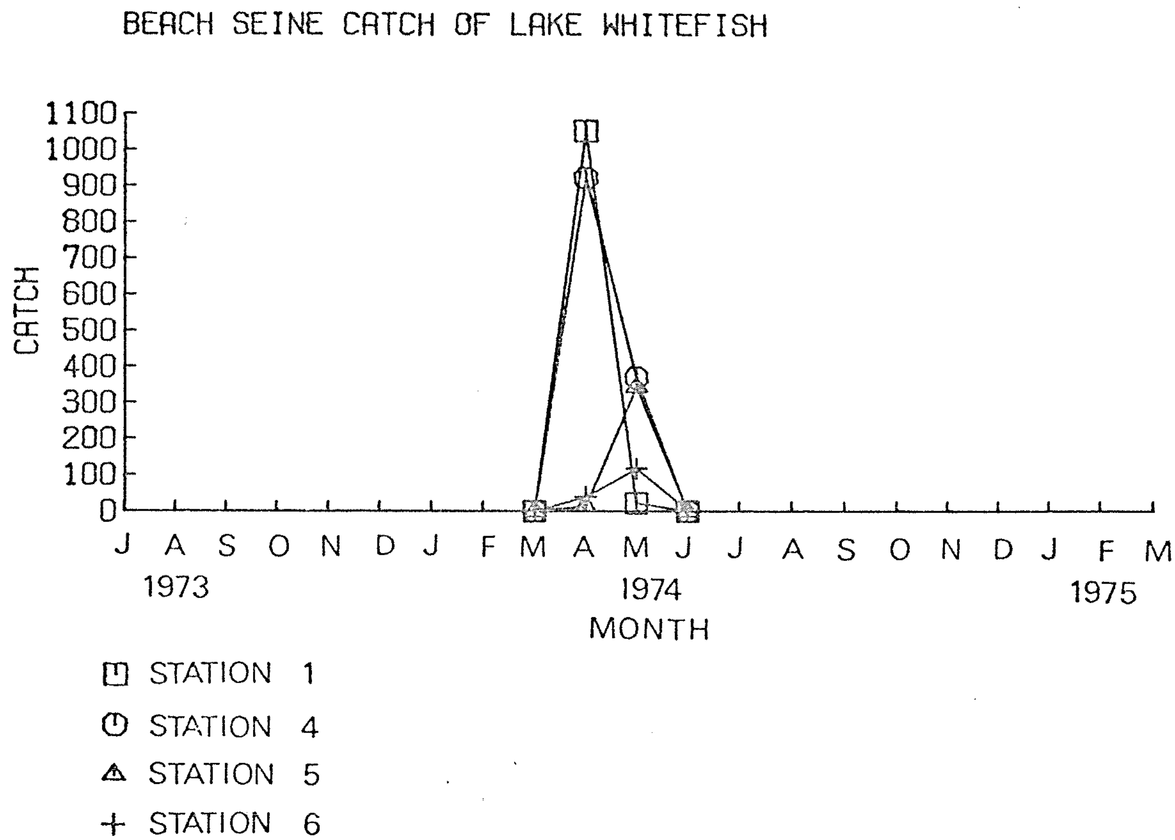

Fig. 5-9. Beach seine catch of lake whitefish by station July 1973 - March 1975.

the irrigation canal. The decrease in catch of age 0 lake whitefish from March to May 1973 in the south end of the lake may have been due to entrainment. Tow-net results for 1974 show similar trends except in March when samples could not be taken due to the presence of ice cover.

Table 5-5. Larval whitefish densities (number/m^3)

	Transect				Irrigation outlet
	1	4	5	6	
March 1973	0.01888	0.00472	0.04246	0.08954	1.3447
April 1973	0.01416	0.00472	0.07336	0.01888	0
May 1973	0	0	0	0	0
March 1974	*	*	*	*	*
April 1974	0.02518	0.02624	0.20740	0.09346	0
May 1974	0	0	0.04246	0.00472	0

*Ice cover, no sample.

5.3.4.3 Age and Growth. Length of the lake whitefish at different ages was determined by examination of scales from 121 specimens representing the gill-net catches from all transects, by depth and time of year. Annuli on the scales are formed between January and February but false checks may confound age determination. The preliminary aging of the oldest lake whitefish indicated fish to be between 11 and 19 years old. This estimate seemed suspiciously high and was re-evaluated with the aid of otoliths and recent outside literature (Peters 1964; Healey 1975). The recent age determinations indicate lake whitefish reach a maxiumum age of five years. The length frequency of the age 0 lake whitefish by month over the 1974 season supports this much faster growth rate. The median length increased with age but appears to approach a limit of about 457 mm (Table 5-3). Since there was no indication of different growth rates between transects and the seasonal distribution suggested extensive movement between stations, the catch for the four stations was combined.

5.3.4.4 Food Habits. Stomachs of the lake whitefish captured in the gill nets were visually inspected for food type, fullness, and the presence/absence of food (Fig. 5-10). Five types of food were found: zooplankton, insects, benthos, plant debris, and animal debris. Regurgitation of stomach contents while not observed, however, may occur during capture. Therefore the average fullness of the stomachs may be underestimated.

The stomach contents of lake whitefish were found to vary greatly in composition and fullness with season. Zooplankton was the most frequent food observed in the lake whitefish stomachs.

The zooplankton was identified to be composed of approximately 100 percent *Daphnia*. Insects (predominantly chironomids) were the second most frequent food found. Plant debris, animal debris, and benthos were observed incidentally in the lake whitefish stomachs.

The amount of zooplankton observed in the whitefish stomachs during the summer and fall of 1973 was greater than the summer and fall of 1974. The amount of zooplankton in the lake whitefish stomachs during the winter of 1973 was less than the winter of 1974. (Fig. 5-10). Insofar as the stomach contents demonstrated the availability of food zooplankton was more available in the summer and fall of 1973 than in 1974. This observation correlates with the results found for the yellow

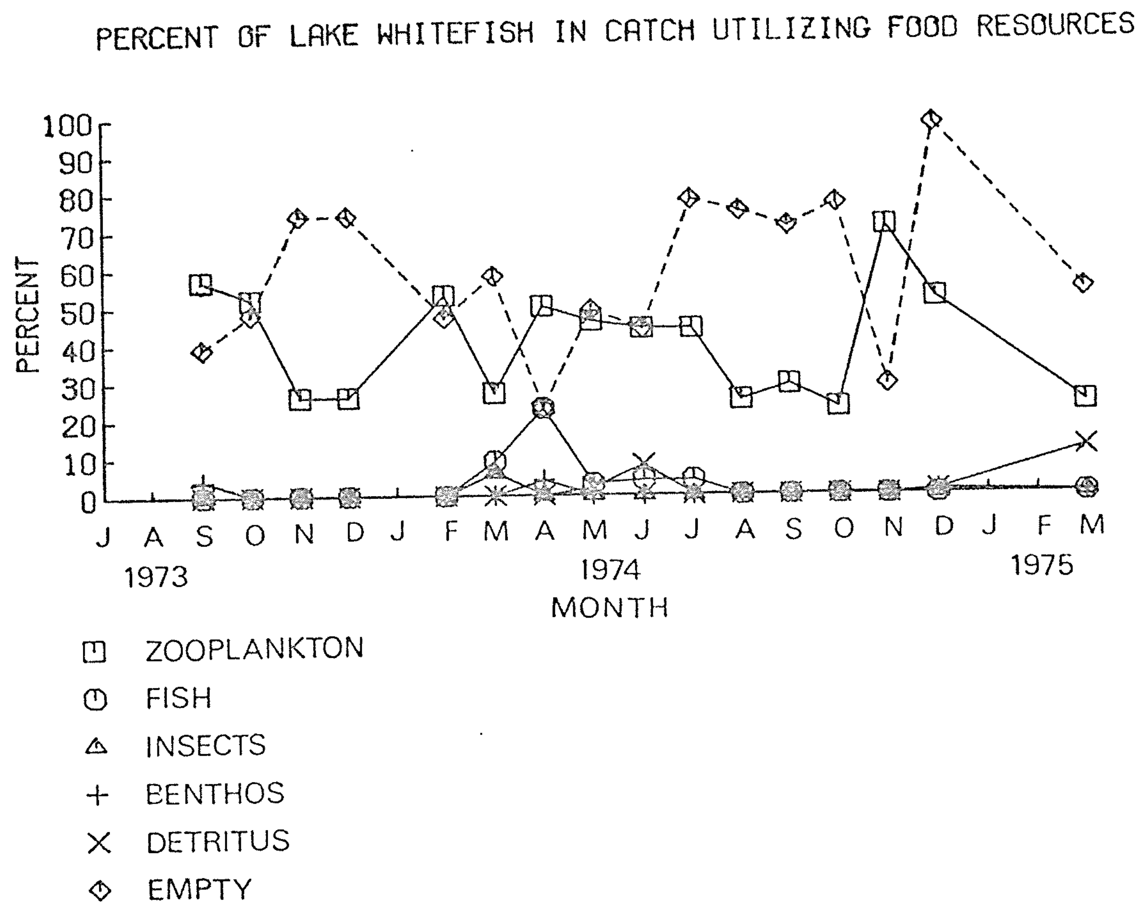

Fig. 5-10. The stomach contents of lake whitefish. The vertical axis represents the percent of the lake whitefish stomachs containing a specific food category. Dashed line represents percent of stomachs which were empty. The lake whitefish were caught in gill nets between July 1973 and March 1975.

perch stomachs. The large proportion of zooplankton in the lake whitefish stomachs during the winter of 1974 was due to a large year class of age 0 fish which were actively feeding offshore. A strong year class of age 0 fish were not present in winter of 1973 and the catch was predominantly of spawning fish which were not actively feeding. Judging from the occurrence of insects and benthos in the stomachs, these food sources were most available in the spring. This conclusion is reasonable since emergence of many species occurs in the spring and it has been well documented that water level fluctuation is a major factor controlling the densities of benthos and aquatic insects (Fraser 1974).

5.3.4.5 Reproduction. Lake whitefish spawn along the shoreline in November and January (Figs. 5-11 and 5-12). Spawning occurred primarily over rock substrate along the steep talus shoreline of Transects 5 and 6 when the water temperature ranged from 4° to 6°C. However, a few spawning fish were captured along the shoreline at all transects and on mud substrate. The percentage of large fish which did not mature in 1974 suggests that Banks Lake whitefish may not spawn annually. The fecundity is large, estimated at 40,000 for a 454 mm female. The lake whitefish broadcast its eggs over the bottom and there is no parental care. The eggs average less than a centimeter in diameter. Spawning fish were taken only in the shallow shoreline sets. Spawning and emergence were estimated to occur between early December and early April, following an incubation period of approximately four months. Most of this incubation was spent under the ice cover in 1974 and was quite successful as indicated by the densities of age 0 fish taken in the bongo-net, beach-seine, and gill-net catches.

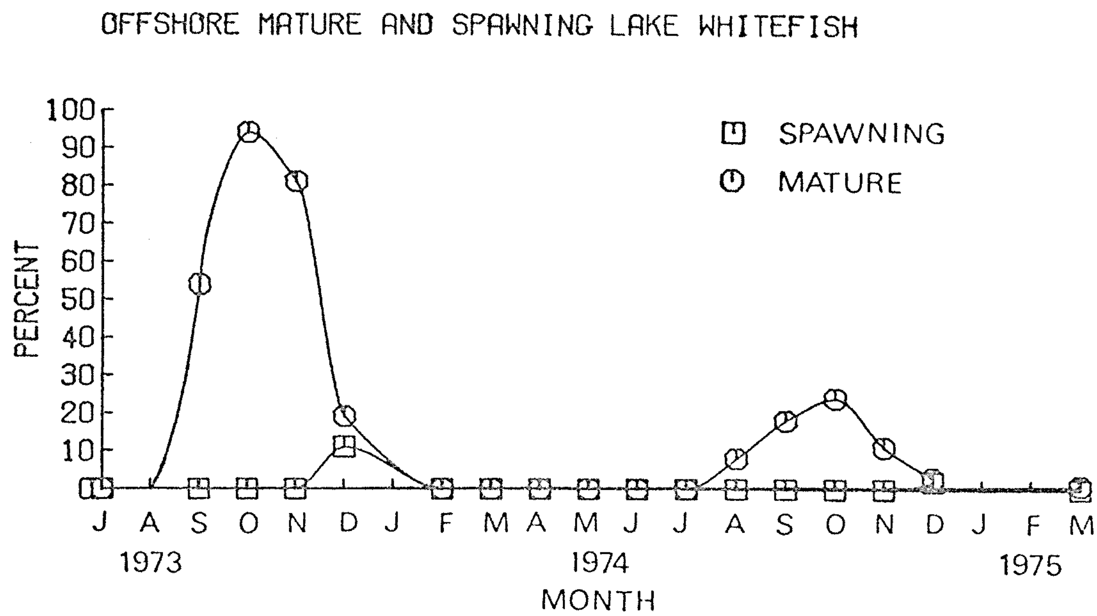

Fig. 5-11. The percent of mature and spawning lake whitefish caught offshore in gill nets, July 1973 - March 1975.

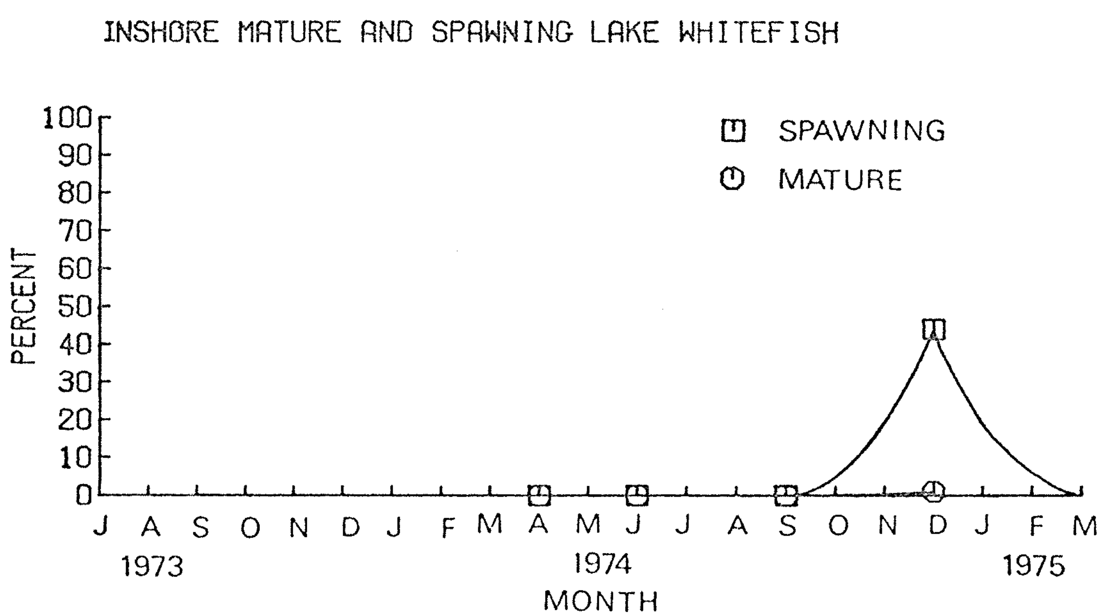

Fig. 5-12. The percent of mature and spawning lake whitefish caught inshore in gill nets, April, July, September and October 1974.

5.3.5 Kokanee, *Oncorhynchus nerka* (Walbaum)

5.3.5.1 Importance. The kokanee is the nonanadromous form of the sockeye salmon (*O. nerka*) which is indigenous to the Columbia River system. A self-sustaining population has existed in Lake Roosevelt since the construction of Grand Coulee Dam, which is believed to be, in part, the source of the original stocks in Banks Lake. Kokanee from the Leavenworth Hatchery have been planted irregularly since 1956, with the origin of the parent stocks Lake Whatcom (Duff, personal communication). The kokanee has been extensively introduced to inland waters throughout the U.S. in hopes of creating sport fisheries and as a forage fish for large gamefish (Calhoun 1966). Despite its difficulty to capture with standard sports fishing gear, the kokanee's fine fight and excellent food quality make it a highly desirable sport fish.

The kokanee of Banks Lake appear to be self-sustaining since the 1972 creel survey indicated the presence of large numbers of 2-, 3-, and 4-year-old fish which could not have originated from the last plant by the Washington Department of Game in 1966. The question of annual contribution from Lake Roosevelt stocks is being investigated under the entrainment phase of this study. The success of kokanee appears to be due to a sufficient food supply (plankton) and its pelagic habitat which offers it "spatial isolation" from the primary predators in the lake (except diving birds). However, the recent introduction of the chinook salmon by the Washington StateDepartment of Fisheries represents the addition of a new pelagic predator. The feeding behavior of the chinook salmon will be monitored through 1975 when the age 0 kokanee will first be available to them.

5.3.5.2 Distribution. A comparison of inshore and offshore distributions of kokanee was based upon the 1974 quarterly gill-net catches. The relative abundance of kokanee within and between each transect for each quarter (spring, summer, fall, winter) is illustrated in Fig. 5-13. The kokanee were predominantly offshore during spring, summer, and winter seasons. In the fall the kokanee spawners moved inshore leaving the immature fish offshore. The kokanee were more abundant at the north end of the lake in the spring. In the summer the greatest abundance was recorded in the center (Transects 4 and 5) of the lake and in the fall and winter the kokanee abundance increased from the north end to the south end of the lake. Kokanee were found throughout the water column except during the summer months when they were primarily taken along the bottom. High surface water temperatures best explain these vertical distributions.

Beach seine, lake trap, and trawl sampling have failed to capture sufficient numbers of age 0 kokanee for analysis of distribution, abundance, and life history. A few age 0 kokanee have been taken at the north end of the lake after the initial irrigation pumping.

5.3.5.3 Age and Growth. Length of the kokanee at each age was determined by examination of 119 specimens representing the gill-net catches from all transects, by depth and time of year. Annuli on the scales are formed between January and February. The median length increased with age (Table 5-3). Since there was no indication of different growth rates between transects and the seasonal distribution suggested extensive movement between stations, the catch of the four stations was combined.

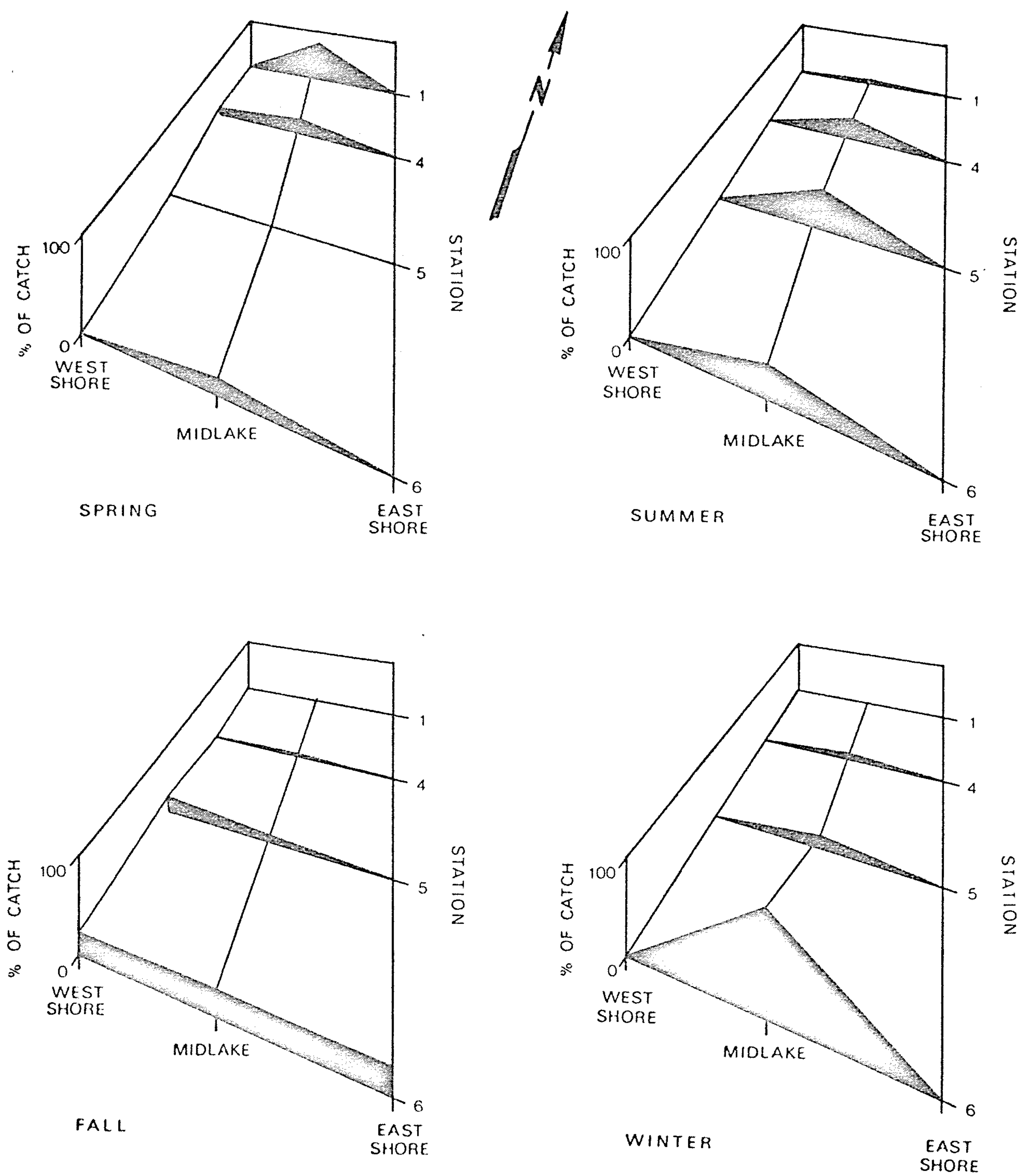

Fig. 5-13. The inshore/offshore distributions of kokanee for the spring, summer, fall and winter seasons of 1974. The vertical axis represents the percent of the total catch for each season. The horizontal plane represents 12 sampling locations: an east shore, a midlake and a west shore site for 4 transects. The transects run from north to south and are: 1 (Electric City, 4 (Steamboat Rock), 5 (Million Dollar Mile), and 6 (Coulee City).

5.3.5.4 Food Habits. The stomachs of the kokanee were inspected for food type, fullness, and presence/absence of food (Fig. 5-14). Zooplankton was the only food found in the kokanee stomachs. The zooplankton was identified to be approximately 100 percent *Daphnia* spps. Regurgitation of stomach contents while not observed may occur during capture, therefore, average fullness of the stomachs was probably underestimated.

5.3.5.5 Reproduction. Maturity of kokanee was estimated for the gill-net catch and the percent of inshore and offshore mature and spawning fish was determined by month (Figs. 5-15 and 5-16). The kokanee spawning occurred in October and November when the water temperature ranged from 6° to 13°C. The last spent individual was observed in December.

In October and November diving surveys were conducted along the shorelines of each transect and in other areas of suspected spawning. Mature and spawning individuals were observed in largest numbers along the steep talus cliffs of the west shoreline at Transects 5 and 6. As many as 250-300 spawners were observed in a 30 m stretch of shoreline. The fish were spawning on shelves which were 1 to 3 m wide and from 1 to 6 m deep. The shelf substrate was composed of basalt rubble ranging from less than 1 cm to 15 cm in diameter. The spawning areas were easily recognized because they were comparatively free of the dense periphyton which covered the surrounding area. Aggressive behavior between kokanee (chasing) and unsuccessful attempts at redd digging were observed. The eggs appeared to be broadcast over the rubble. Several single and a few aggregations of eggs were observed.

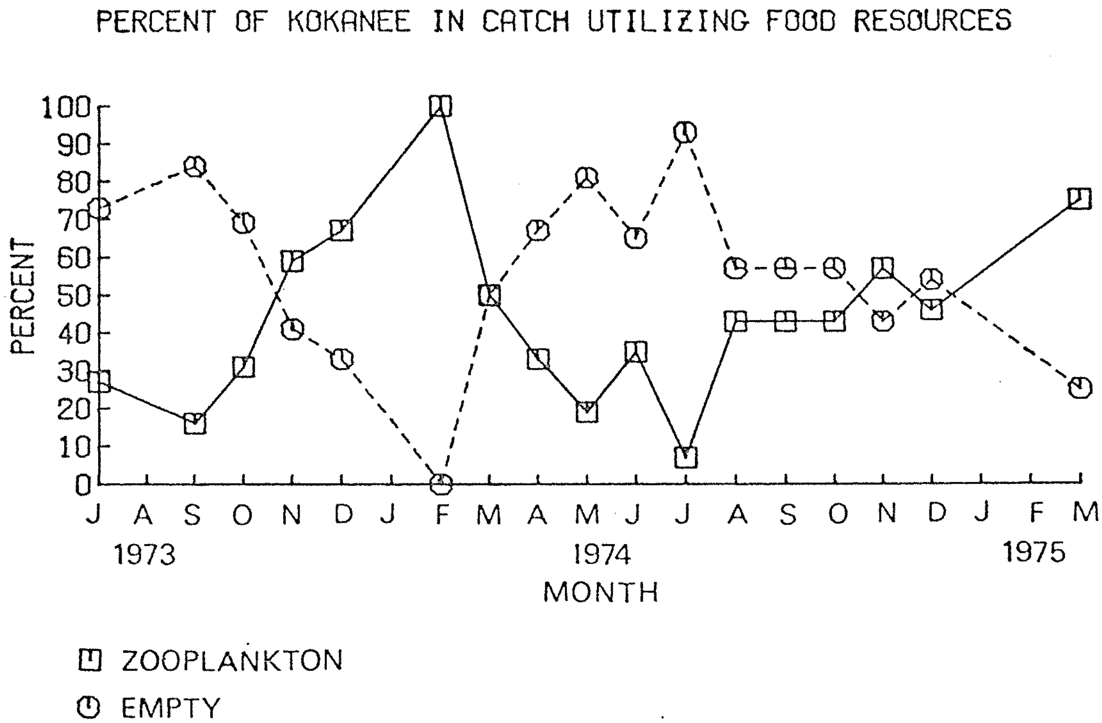

Fig. 5-14. The stomach contents of kokanee. The vertical axis represents the percent of kokanee stomachs containing a specific food category. Dashed line represents percent of stomachs which were empty. The kokanee were caught in gill nets between July 1973 and March 1975.

OFFSHORE MATURE AND SPAWNING KOKANEE

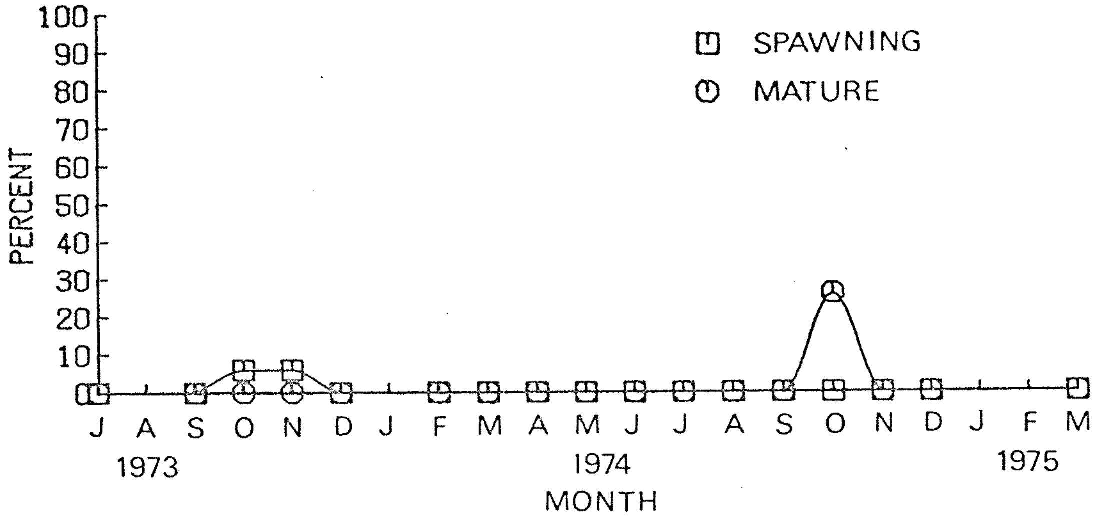

Fig. 5-15. The percent of mature and spawning kokanee caught offshore in gill nets, July 1973 - March 1975.

INSHORE MATURE AND SPAWNING KOKANEE

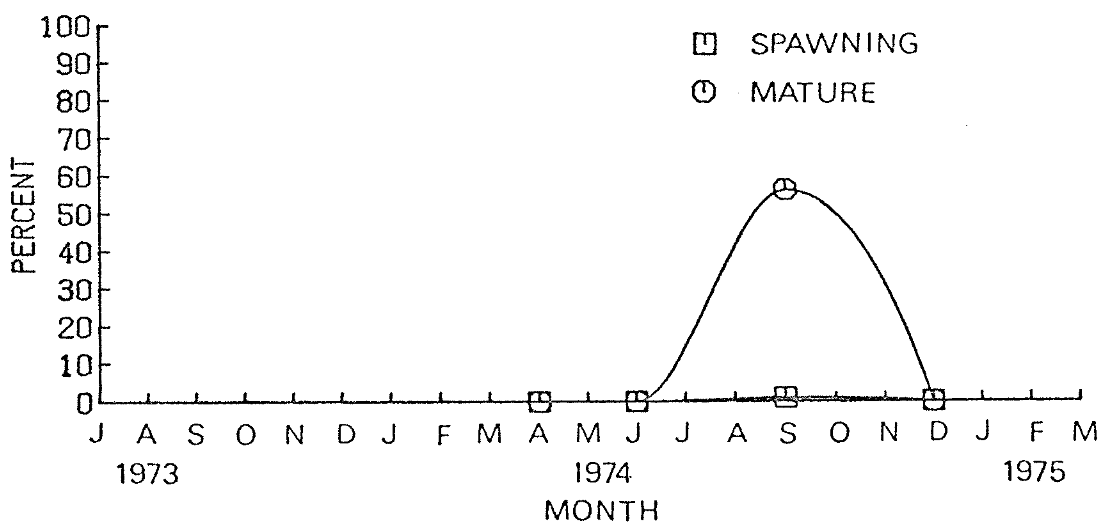

Fig. 5-16. The percent of mature and spawning kokanee caught inshore in gill nets, April, July, September and October 1974.

Kokanee in spawning condition were also observed at the feeder canal (≈500), the irrigation canal (≈300), the new Coulee City Marina (≈50), Northrup Creek (≈6), and Million Dollar Mile (≈20). Approximately 8 km of shoreline was covered by diving, 24 km visually from a boat, and 24 km visually from shore.

Egg deposition was estimated to be 1,222 eggs/female. Eight spawned out females were found to retain an average of 50 eggs. The average fecundity for Banks Lake kokanee was determined to be 1,272 (N = 67).

5.3.5.6 Mark Recapture. In October, 1974, 120,000 marked kokanee averaging 55 mm were stocked in Banks Lake. They were marked with dietary tetracycline. This summer a tow-netting program for age 0 kokanee will be carried out in order to estimate the ratio of natural to stocked kokanee.

Fourteen mature kokanee were tagged in mid-July 1974 at Transect 1 with floy anchor tags. Six of these fish were recaptured in the feeder canal in late July and August 1974 by sports fishermen. Visual observations of several more tagged kokanee at the feeder canal entrance were made in August 1974.

5.3.6 Other Game Species

5.3.6.1 Black Crappie. The introduction of the black crappie in Banks Lake was probably from Lake Roosevelt, however, the wide introduction of black crappie to lakes throughout Washington by local fishermen suggests this may also account for its occurrence. The black crappie is well established in Banks Lake and supports a substantial sport fishery.

The total gill-net catch of black crappie was only 34 fish, of which 30 were taken in the summer shoreline sampling. The beach seine captured 801 age 0 black crappie in September, 760 of these at Station 4. The stomach contents of black crappie caught in the gill nets consisted of 67 percent fish, 10 percent insects, and 8 percent zooplankton with 20 percent of the fish empty. Spawning fish have been taken in June 1973. The largest fish was a 316 mm, 563-g mature female which was four years old. The median lengths for each age were determined from scale reading to be: 145 mm for age 1 (n = 4), 218 mm for age 2 (n = 46), 234 mm for age 3 (n = 63), and 267 mm for age 4 (n = 4).

5.3.6.2 Pumpkinseed sunfish. The pumpkinseed sunfish was present in the small lakes prior to the inundation of the Grand Coulee. It was a dominant species in the 1952-54 sport catch. The present sport fishery for pumpkinseed is limited to incidental catches made by shoreline fishermen pursuing other species and is seldom kept owing to its small size. Fifteen fish have been captured in gill nets and 14 of these were taken in the summer shoreline catch. Few age 0 pumpkinseed sunfish have been taken in the beach-seine sampling. The stomach contents of pumpkinseed sunfish in the gill-net catch consisted of 7 percent zooplankton, 7 percent fish, and 7 percent insects with 79 percent of the fish empty. Spawning fish were taken in June 1974. The largest fish captured was a 184 mm, 103-g mature female taken in the June 1974 gillnetting.

5.3.6.3 Brown Bullhead. The brown bullhead is the only ictalurid found in Banks Lake. Its introduction was most likely by local fishermen since it has not been described in Lake Roosevelt. It supports a minor sport fishery in Osborne Bay at the north end of the lake. The total gill-net catch of brown bullhead consisted of five fish captured along the shoreline. Small numbers of age 0 fish have been captured in the beach-seine hauls at Transects 4 and 6. The stomach of a 230 mm fish was full of eggs. The largest fish was a 279 mm, 411-g female.

5.3.6.4 Walleye. The walleye is a native spiny ray which was probably introduced to Banks Lake in the irrigation water pumped in from Lake Roosevelt. It was not very abundant and was taken most frequently by fishermen trolling for kokanee. Only 10 fish were taken in the gill-net sampling and 1 age 0 fish in the beach-seine sampling. Half of the gill-net caught fish were taken at Transect 1. Three fish contained yellow perch in their stomachs. The largest fish was a 595 mm, 2,610-g male which was captured at the surface in a June offshore gill-net set.

5.3.6.5 Burbot. The burbot is a native Gadidae (codfish) which was probably introduced to Banks Lake in the irrigation storage water pumped in from Lake Roosevelt. The burbot supported a substantial winter fishery in 1965 but since that time has almost disappeared from the lake. Four fish have been taken in the offshore gill-net catch. Spawning normally occurs during the winter under ice cover. Spawning or mature fish have not been observed. Age 0 fish have not been captured. All four burbot were taken on the bottom and had empty stomachs. The largest fish was a 730 mm, 3,980-g male which was seven years old.

5.3.6.6 Rainbow Trout. The rainbow trout has been stocked in Banks Lake on an annual basis since 1953. Despite the continued stocking program, the salmonid fishery has always been dominated by the kokanee. The gill-net catch of rainbows appears to consist primarily of stocked hatchery fish and their distribution between transects is strongly influenced by the location of the most recent stocking. Seven percent of the spring shoreline catch of rainbow trout was spawning fish. Native age 0 fish have not been taken in the beach seining. The stomach contents consisted of 15 percent zooplankton, 16 percent fish, 17 percent insects, 10 percent eggs, and 18 percent detritus. The largest rainbow captured was a 515 mm, 2,105-g, four-year-old mature male captured in the winter shoreline gill-net samples at Transect 6.

5.3.6.7 Largemouth Bass. The largemouth bass is centrarchid which was present in the small lakes of the Grand Coulee prior to inundation. It was the dominant sport fish (along with the pumpkinseed sunfish) in the 1952-54 creel census. Although the present sport fishery catch per unit effort is lower, the annual catch of bass is approximately the same as in 1952-54. On a comparative basis, Banks Lake is considered to support one of the finest bass fisheries in the State of Washington. Largemouth bass are taken exclusively inshore with highest gill-net catches in June at Station 4. Substantial numbers of age 0 largemouth bass were taken in the September beach seine catch. Twenty-three percent of the bass contained fish in their stomachs, primarily yellow perch. Spawning fish have been taken in June 1974. The mean length at age was calculated from scale readings to be: 122 mm for age 0 (n = 7), 290 mm for age 1 (n = 2), 310 mm for age 3 (n = 10), 400 mm for age 3 (n = 3), 440 mm for age 4 (n = 2), and 550 mm for age 6 (n = 2). The largest bass taken was a 558 mm, 3,980-g spawning male taken in the summer shoreline sampling at Transect 4.

5.3.6.8 Brown Trout. The brown trout occurs in the Colville River which enters Lake Roosevelt but has not been observed in Lake Roosevelt. Nevertheless, it may occur in Lake Roosevelt and have been introduced through the feeder canal or planted by local sport fishermen. Only two individuals have been observed, both taken along the shoreline at Transect 1. The largest fish was a 710 mm, 4,100-g male which was aged at seven years.

5.3.6.9 Mountain Whitefish. The mountain whitefish is native to the Columbia River and was described in Lake Roosevelt by Gilbert and Evermann (1894). It appears incidentally in the creel and is seldom separated from the lake whitefish. Highest catches were made in the winter gill-net sampling. Twenty-five age 0 fish have been taken in the beachseine catch. Stomach contents consisted of 16 percent zooplankton, 4 percent insects, 7 percent eggs, and 12 percent detritus with 67 percent of the fish empty (n = 41). The largest fish was a 798 mm, 508-g mature male taken in the winter gill-net sampling.

5.3.6.10 Chinook Salmon. The chinook salmon was introduced to Banks Lake in the fall of 1974 by the Washington State Department of Fisheries. Sixty-two chinook salmon were captured by gill nets in the fall of 1974; 36 in offshore sets and 26 in inshore sets. The offshore catch was made predominantly at the surface. The catch decreased in numbers from Transect 1 (the release site) to Transect 6. In the fall, 4 percent of the chinook salmon caught in the gill nets contained zooplankton and 12 percent contained fish and 84 percent were empty. The total length-weight relationships and mean length versus time relationship have been computed. The largest chinook caught to date was a

318 mm, 508-g fish taken in December 1974. Fifty-seven of the 62 chinook salmon captured in September 1974 gill nets were precocious males.

5.3.7 Nongame Species

5.3.7.1 Peamouth. The peamouth is a native cypriniform which occurs incidentally in the fisherman's creel. Its introduction is assumed to be from Lake Roosevelt through the feeder canal. They appear well established in Banks Lake and were common in Transect 1 gill-net catch. The shoreline gill-net catch was largest in spring when mature and spawning fish dominated the catch. The offshore gill-net catch was largest in the spring and fall, the majority of the catch being taken from surface to 10 m depth. Stomachs contained primarily zooplankton with an occasional terrestrial or aquatic insect. Age 0 fish with a mean length of 15 mm were first taken in July by beach seining. The largest peamouth taken were a 352 mm, 497-g female and a 338 mm, 534-g female which were both four years of age.

5.3.7.2 Longnose Sucker. The longnose sucker is a native cypriniform which was assumed to have been introduced from Lake Roosevelt through the feeder canal. It appears well established and represents the second most abundant nongame species taken in the gill-net sampling (4% of the total gill-net catch). The largest gill-net catches of longnose sucker were made in the spring at Transect 1. Both the offshore and the onshore spring gill-net catches consisted of mature and spawning fish. The longnose sucker was taken almost exclusively in the bottom 2 m of the water column. Age 0 fish averaging 17 mm in length were first taken in July by beach seining. The largest longnose sucker was a 542 mm, 2,130-g mature female.

5.3.7.3 Carp. The carp is a cypriniform which was assumed to have been introduced from Lake Roosevelt through the feeder canal. It appears to be well established, the largest catches being made at Transects 1 and 6. The gill-net catch was almost exclusively restricted to the shoreline and was largest in the summer. Age 0 fish averaging 19 mm in length were first taken in August. The largest carp taken was a 798 mm, 8,400-g female which was estimated to be seven years old.

5.3.7.4 Prickly Sculpin. The prickly sculpin, *Cottus asper*, was the only cottid identified in the catch. This species is indigenous to the Pacific Northwest and was probably introduced from Lake Roosevelt by the feeder canal. The prickly sculpin was the most abundant nongame species in the catch and was taken almost exclusively by beach seine. The largest beach-seine catches were made at Transect 1 in June when the age 0 fish were first captured. The largest fish was a 160 mm, 92-g female taken in a shoreline gill-net set. A 155 mm specimen taken in the winter shoreline sampling was full of whitefish eggs.

5.3.7.5 Largescale Sucker. The largescale sucker is a native cypriniform which was assumed to have been introduced from Lake Roosevelt through the feeder canal. Only 12 individuals of this species have been captured in the gill nets with 10 of these taken along the shoreline at Transect 1. The largest fish was a 528 mm, 2,000-g spawning female taken in the spring.

5.3.7.6 Northern Squawfish. The northern squawfish is a native cypriniform which was assumed to have been introduced from Lake Roosevelt by the feeder canal. Three squawfish have been taken at Transect 1, two in the gill nets, and one age 0 fish in the beach seine. The largest fish was a 528 mm, 2,570-g mature female taken in the spring.

5.4 Discussion

The slower growth rate of yellow perch at Transect 1 suggests a sedentary population. A small amount of mark and recapture information and the high CPUE indicates stable populations of yellow perch at all four transects.

Yellow perch move inshore for the spring spawning and offshore with the fall decline in water temperature. The distribution of spawning yellow perch suggest they utilize the entire lake and an extensive range of substrate and depth. The age 0 fish appear in June and are present in the littoral zone until the fall decrease in water temperature occurs.

The whitefish move out of the north end of Banks Lake in the late summer and early fall and move back into the north end during the winter spawning period. Growth characteristics were similar among stations. These results suggest that the lake whitefish are one population which moves in and out of the north end of the lake.

Lake whitefish move onshore for the winter spawning season and offshore during the summer and fall when water temperatures are highest. They prefer the steep talus slopes along the southwest shoreline and the feeder canal for spawning. The density of age 0 lake whitefish was largest at Station 6 March, Station 5 in April, and Station 1 in May. Since growth characteristics were similar among stations, this reduction in density at the south end of the lake was believed to be due to entrainment of the pelagic larvae into the irrigation canal.

The growth characteristics for kokanee were similar among stations. These results suggest the kokanee are one population which maintains itself in the main body of the lake (Transects 4, 5, and 6) with migrations of spawning fish onshore at Stations 5 and 6 during the fall. Movements into the north end of the lake occur during the spring and later into the feeder canal during the summer and fall.

The kokanee move inshore at Stations 5 and 6 for spawning in the fall and offshore in the summer when water temperatures are high. Mature fish move into the north end of the lake in the spring and enter the feeder canal in the summer.

Spawning kokanee prefer the steep talus slopes of the southwest shoreline of the lake and are attracted to the currents of the irrigation and feeder canals. Although successful spawning has been observed, only a few age 0 fish have been captured at Station 1 after the irrigation pumping had begun. Therefore, these fish may have been introduced from Lake Roosevelt.

As a result of the present water use regimes, there are five major phenomena which affect the fishes of Banks Lake. First is the pumped input of cold water into Banks Lake from the hypolimnion of Lake Roosevelt. Second is the water level fluctuation (spring through fall) which results from unequal volumes of irrigation water being pumped in and withdrawn. Third is the initiation by irrigation pumping which directly affects the distribution of fishes and undoubtedly has a strong influence on the food chain. Fourth is the entrainment of fishes from the south end of Banks Lake due to irrigation withdrawal. Fifth is the operation of pump storage which will entrain fishes out of the north end of Banks Lake and cause fluctuations in water level and hydrological disturbances at the north end of the lake.

The colder temperatures of the water pumped from Lake Roosevelt have an inhibiting effect on the growth rate and behavior of the fishes at the north end of the lake. The growth of species not sedentary to the north end would be slowed in proportion to time spent there. The kokanee and lake whitefish were found to move freely from north to south and exhibited marked changes in distribution probably due to temperature and water velocity. The yellow perch population was believed to be sedentary. The growth rate of yellow perch was slowest at the north end, and probably reflects the effect of the pumped input of cold Lake Roosevelt water.

The effect of water level fluctuation on the fishes is dependent upon the magnitude, rate, and direction of the fluctuation and the timing of drawdown with the life history and distribution of each fish species. The most pronounced effects are the interference with reproduction resulting in the loss or gain of available spawning habitat and the stranding of eggs and/or young-of-the-year fishes. The fish and their food resources would be directly affected by the change in volume and the crowding or stranding which would increase the rate of predation or mortality, respectively.

The successful salmonid species in Banks Lake are the fall spawning kokanee and lake whitefish. During the fall to spring period Banks Lake is normally held at full pool representing the period of water level stabilization. The rainbow trout is a spring spawner and despite the assistance of annual introductions, has not become established under the spring-summer water level reductions.

The spiny ray spawning is similarly affected by water level fluctuation. The two early spring spawners are yellow perch and walleye. Spawning yellow perch utilize the entire lake over an extensive range of substrates and depths. This flexibility in spawning requirements may explain the success of the adaptation of yellow perch to the Banks Lake system. However, walleye are shallow water, nest building spawners which have not become abundant in Banks Lake despite the existence of adequate supplies of its preferred food, the yellow perch. Spring drawdown may be the factor limiting walleye reproductive success. The black crappie and largemouth bass are nest-building spiny rays which have been quite successful in spawning under the existing water level fluctuations. These species spawn from May through July when water levels have usually ceased dropping and are beginning to increase.

The effect of water level fluctuation on food supplies may also be significant. Drawdown has the effect of reducing or eliminating benthic production in the littoral zone. This may cause fish to seek new food sources (Frazer 1974). In Banks Lake there exists a large population of lake whitefish, a species which normally is a benthic feeder. Preliminary observations indicate that benthic organisms are not abundant in the lake. The exploitation of zooplankton by lake whitefish probably represents utilization of a secondary food resource. Interspecific competition for food between lake whitefish and kokanee, obligate plankton-feeders, may increase. Population size and growth rates between these species may be influenced. Yellow perch have the greatest flexibility among the dominant species in feeding requirements and when food resources, primarily fish, are in low supply, it appears to be competing with the lake whitefish and kokanee for zooplankton.

The vulnerability of fish populations to irrigation water input and withdrawal and pump/storage operation is presently being assessed through analysis of temporal and spatial characteristics of each species abundance and distribution. Considerations for specific behaviors of each species are being taken into account. Changes in the inshore-offshore and north-south distributions of fish have been observed upon initiation of irrigation pumping and irrigation withdrawal. The temporal characteristics of irrigation withdrawal may play a major role in determining year class strength of lake whitefish as well as other species.

6.0 FISH ENTRAINMENT STUDIES

6.1 Gear Development

Considerable effort was expended to develop a method of fixed-net quantitative sampling in the feeder canal to determine entrainment of fishes during pumping and generating phases of operation. Several obstacles complicated the development of fixed-net sampling: (1) flow occurred in both directions over a wide range of velocities (from 1 to 8 fps), (2) the size and swimming capabilities of Banks Lake fish species varied widely requiring multiple net and mesh sizes to adequately sample the entire range, and (3) the behavioral responses of Banks Lake fish species to water currents varied widely in response to inflowing and outflowing water velocities. Feeding individuals (trout and walleye) were observed to actively seek out both in- and out-flowing water. Sexually mature individuals of trout, salmon, and whitefish actively seek out in-flowing waters. Perch and whitefish larvae passively drift with currents in the irrigation withdrawal waters, particularly at night. The variety of responses to current required sampling capabilities in upstream as well as downstream directions. The combined factors of varied response to current, varied size and avoidance capability, varied direction and velocity of flow prevented the development of a quantitative net-sampling program through the first 18 months of study.

An attempt to sample with fixed gear was made with a Sacramento River trap on which tests were conducted in the feeder canal 75 yd west of the headworks. The trap measured 8 ft in diameter by 16 ft long and was covered with 1-inch-mesh chicken wire. During one week of continuous fishing from November 15 to 22, 1974 the trap caught one walleye, one longnose sucker, one sunfish, and one lake whitefish. It was apparent that these catches were not representative of the actual abundance or species composition of fishes present from the large concentration of lake whitefish and rainbow trout visible in the trap vicinity. The inefficiency of the trap was partly attributed to a high degree of water clarity which made the trap easily visible.

Two alternate sampling methods were planned but were thwarted before their installation by winter weather factors. The first method entailed the use of a drift seine designed to sweep the fish from a 300-yd section of the feeder canal just west of the headworks. Power for handling the net and for maintaining the net in fishing configuration was to be provided by towing vehicles positioned on either side of the canal. However, the technique was abandoned when preliminary tests with a towed-trawl net proved the road surfaces unsuitable for hauling during winter weather. The second method entailed positioning a fixed net diagonally across the feeder canal to act as a lead. The net was designed to operate during current flow in both directions and to capture fish in downstream-oriented traps attached to the lead on both sides of the canal. The method was abandoned when ice formed in the canal and prevented the further use of fixed nets.

Due to the difficulties of developing a satisfactory method of net sampling to determine the entrainment of fishes in the feeder canal, we elected to use the closed-circuit television camera offered for use by the engineering and maintenance division of the Grand Coulee Dam. The U.S.B.R. installed and operated the camera on the trash racks of P/G

Units 7 and 8 and scheduled three periods of P/G in January and February 1975 which enabled us to observe the passage of entrained fishes.

The camera was mounted to a vertical bar on the outer edge of the trash rack by means of a specially constructed bracket which held both the television camera (Edo Western) and flood lamp (150 w thalium iodide) (Fig. 6-1). A team of divers from the U.S.B.R. installed the bracket with the camera and flood lamp aimed horizontally across the opening of the P/G unit. The power supply-video cable was led to a video unit and tape recorder (Sony AV3650) housed in the siphon-breaker house 150 ft away from the trash racks. During the first test the camera was mounted one-third the distance down from the top of the trash rack (15 ft subsurface) and aimed approximately 15 degrees below horizontal. In succeeding tests the camera was mounted halfway down the trash rack (18 ft subsurface) and aimed horizontally. The camera angle was 48 degrees which enabled viewing of approximately one-fourth of the entire area of the trash rack, or 54 ft^2.

6.2 Observation of Entrained Fishes

The high current velocity through the trash rack (12 fps) made positive identification of most fish difficult even during stop-action and slow-motion play back of the video tape. Despite this, several species including rainbow trout, lake whitefish, and chinook salmon were identified. Several other fish were tentatively identified as yellow perch. In all, 30 fish were recorded during 35.5 hr observation during generation flow. No fish were recorded during 5 hr observation during pumpback (Table 6-1).

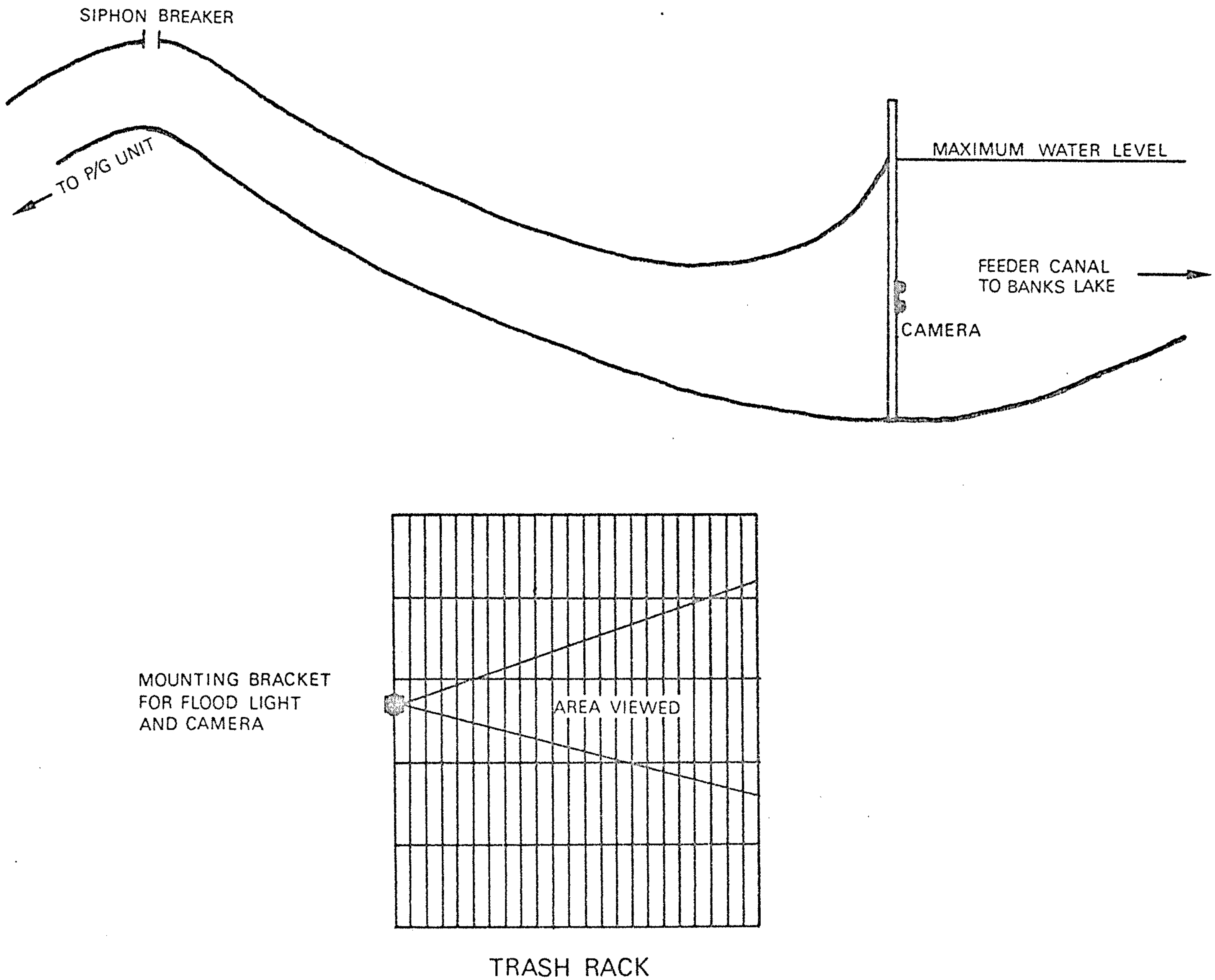

Fig. 6-1. Installation of television camera on P/G trash rack for observing the entrainment of fishes.

Table 6-1. Summary of observations of entrained fishes at the feeder canal headworks, January to March, 1975.

Date	Time	Hours	Mode	Number of Fish
1/30	0800-1130	3.5	G	6
	1600-2000	4.0	G	8
1/31	0800-1200	4.0	G	5
	1600-2000	4.0	G	1
2/1	0800-1200	4.0	G	2
	1600-2000	4.0	G	1
2/10	1030-1330	3.0	G	2
	1600-2000	4.0	G	2
3/2	1500-2000	5.0	P	0
3/3	0800-1200	4.0	G	1
	1600-2000	4.0	G	2
		40.5		30

The tests were designed to approximate the routine operation of the P/G units under two power-demand situations: (1) under low power demand in which water for morning and evening generation periods was replaced daily by post-midnight pumping; and (2) under moderate power demand in which water for generation was incompletely replaced by daily pumping, but would be replaced ultimately during week-end pumping. Observations of generation flow were preceeded by from one to two days of pumping which simulated week-end pumpback during moderate power demand. The second and third day observations of generation flow simulated mid-week operation.

Fish passed through the trash-rack slots equally in headfirst and tailfirst positions and some were observed to strike the vertical bars of the rack. Some, which entered the viewing field headfirst, quickly reversed direction in attempts to avoid being drawn through the trash rack. These struck the bars with greater frequency because of an inability to complete a turn before being drawn crosswise through the slots.

The highest rate of fish passage (1.02 fish/hr) occurred during the first test period in the generation mode as compared with 0.57 and 0.38 fish/hr in succeeding tests. No significance was attached to these preliminary differences.

The rate of fish passage during the January 30 to February 1 period of generation was highest during the first day (1.86 fish/hr), decreased by half the second day (0.75 fish/hr), and by half again on the third day (0.38 fish/hr). These differences indicated a possible decreasing rate of entrainment with time. A decreasing rate of entrainment was expected in view of ice and snow cover which completely blanketed Banks Lake during the test, and probably inhibited the movements of fish. During this period, fish which were in the vicinity of the feeder canal at the onset of generation were entrained through the canal and not readily replaced by others.

An effect of P/G operation became evident in early March 1975 when the feeder canal was drained for annual maintenance. In past years, draining had always stranded many thousands of yellow perch and lesser numbers of other species in the lowest part of the canal. This year, however, the numbers stranded were greatly reduced. Actual count produced 27 Rocky Mountain whitefish, 3 lake whitefish, 30 rainbow trout, 6 perch, 1 ling, 1 walleye, 2 chinook salmon and 5 longnose sucker. The smaller numbers of fishes stranded in the canal can be attributed to the flow created by P/G, particularly regarding yellow perch which tend to avoid flowing water.

6.3 P/G Effects on Ice Cover

The effects of P/G on the ice cover of Banks Lake were observed during the January 30 to February 1 tests in order to determine whether the water flow caused significant melting. A prolonged period of moderately cold weather during January had resulted in the formation of an unbroken ice cover which was overlain by snow in amounts ranging from 3 inches at the south end to 5 inches at the north end. The thickness of the ice in Banks Lake was not determined but was measured at 8 inches in the feeder canal. Generation on January 30 was preceeded by 10 hr of pumping which completely removed ice cover from the feeder canal and melted the ice immediately offshore from the mouth of the feeder canal.

The melted area extended along the north shoreline for 100 yd and offshore for about 20 yd. No effects were visible at the Narrows near Station 2.

Upon completion of the test on February 2 the area of open water off the mouth of the feeder canal appeared unchanged, but in the Narrows several small patches of open water were observed and several cracks in the ice were apparent from lines of water-soaked snow. The ice fishery on Banks Lake was probably unaffected by this test because nearly all fishing at the time occurred in the side bays at the Punch Bowl, near the causeway, and along the west shore of the south dam (Fig. 4-1). Water volume exchange during these tests did not approach the maximum possible therefore no changes in the ice cover were observed due to water level fluctuations.

6.4 Feeder Canal Entrainment During Irrigation

Efforts to determine the entrainment of fishes from Roosevelt Lake into Banks Lake by irrigation pumping were largely unsuccessful because no suitable sampling gear was developed. However, information was obtained on the species composition of fishes in the feeder canal during low flows in the fall and during slack flow in the winter. These data were obtained from the catches of variable-mesh gill nets fished horizontally on the bottom at three locations: 100 yd west of the headworks, 100 yd west of the cut-and-cover section, and 100 yd west of the radial gates. Whether the fish in these catches originated from Roosevelt Lake or from Banks Lake was not definitely known but the kokanee and whitefish which were sexually mature, quite likely responded to the flow into Banks Lake by swimming upstream into the feeder canal.

The sampling was divided into three distinct periods relative to irrigation pumping: (1) pre-pumping in mid-March, (2) during pumped input in August and September, (3) post-pumping in early December (Table 6-2). Before pumping began the catches comprised small numbers of six species. In August and September 1974 kokanee were predominate in the catch (17.8/net-day) and contained small numbers of five other species. In December, after pumping had ceased lake whitefish (8.3/net-day) along with small numbers of two other species. Rainbow trout and lake whitefish were caught during all three sampling periods.

The concentrations of kokanee and lake whitefish in the feeder canal also were readily apparent in the sport catch and from visual observations at the headworks. The buildup of kokanee actually began in June and continued until mid-October before diminishing. The buildup of lake whitefish at the headworks began early in November, increased through November, and then rapidly diminished after the pumping stopped.

The noteworthy features of these data are the in-migration and subsequent out-migration of kokanee from the feeder canal before the normal P/G period (December through February) and the in-migration of lake whitefish to the feeder canal near the end of irrigation pumping.

6.5 Discussion

Delay in the routine operation of P/G units 7 and 8 has greatly limited the available information on entrainment of fishes through the feeder canal. Operation of the P/G units, originally scheduled for the winter of 1973-74, was delayed by technical difficulties until February 1974 and then occurred as three intermittent tests of two or three days duration each. The entrainment data obtained must be considered preliminary.

Table 6-2. Comparison of gill net catches in the feeder canal from pre-, during- and post-irrigation pumping.

Stage of Pumping	Date	Location	Net No.	Days Fished	Kokanee	Rainbow	Chinook	Lake Whitefish	Walleye	Longnose Sucker	Peamouth	Crappie	Total
Pre-	3/15/74	Radial gates	A	1		1		3		2	2	1	9
	3/15/74	Radial gates	B	1				1			3		4
			Total	2		1		4		2	5	1	
		Catch per net day			0.0	0.5	0.0	2.0	0.0	1.0	2.5	0.5	
During-	8/27/74	Cut and cover	A	1		2							4
	8/27/74	Headworks	A	1	14								16
	8/28/74	Cut and cover	A	1	16			2	1	1			20
	8/28/74	Headworks	A	1	28	1		2	2				33
	8/29/74	Cut and cover	A	1	27	1							28
	9/15/74	Headworks	A	1	22	1	3						27
			Total	6	107	5	3	4	4	5			
		Catch per net day			17.8	0.8	0.5	0.7	0.7	0.8	0.0	0.0	
Post-	12/01/74	Headworks	A	1	1			10					11
	12/01/74	Headworks	B	1		1		8					9
	12/01/74	Headworks	C	1	1	1		16					18
	12/02/74	Headworks	A	1	1	1		7					9
	12/02/74	Headworks	B	1				6					6
	12/02/74	Headworks	C	1		2		3					5
			Total	6	3	5		50					
		Catch per net day			0.5	0.8	0.0	8.3	0.0	0.0	0.0	0.0	

The observations of entrainment by means of closed-circuit television indicated that roughly 4.7 fish per hr per P/G unit were entrained from Banks Lake to Roosevelt Lake during late January, February, and early March and that most of these fish were rainbow trout.

There are at least two factors, however, which complicate the use of these data to determine the rate of entrainment: (1) Because the first test indicated a decreasing rate of entrainment with time, the actual rate under prolonged P/G may be less than 4.7 fish/hr with other factors constant. (2) The ice and snow cover which blanketed Banks Lake continuously during the tests probably inhibited the movements of fish thereby minimizing the observed rate of entrainment. The entrainment rate of fishes particularly during the early (October-November) and late (March) P/G season may be substantially greater since the fish are more active especially during the former. It is imperative that sampling be conducted over the entire P/G season in order to adequately assess fish loss due to entrainment.

7.0 GLOSSARY

Compensation level (point)	Corresponds to the light intensity at which the photosynthetic activities of plant cells are exactly balanced by their respiratory needs.
Dimictic	Referring to a lake which experiences spring and autumn overturns.
Dimixis	Describes a dimictic lake.
Epilimnion	The upper region of more or less uniformally warm, circulating, and fairly turbulent water which occurs during thermal stratification.
Euphotic zone	The lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur due to ineffective light penetration.
Hypolimnion	The deep, cold, and relatively undisturbed region which lies beneath the epilimnion during thermal stratification.
Lentic	Standing water.
Limnetic	The open water region of a lake.
Littoral	The shoreward region of the lake.
Metalimnion	The region in which the temperature gradient is steep. Occurs between the epilimnion and the hypolimnion during stratification.
Thermocline	The plane of maximum rate of increase in temperature.
Total Alkalinity	The capacity of water to accept protons; usually imparted by bicarbonate, carbonate, and hydroxide components of natural waters.
Total Hardness	The characteristic of water which represents the total concentration of calcium and magnesium ions expressed as calcium carbonate.

8.0 REFERENCES

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Appendix Table A-1. Known fish introductions to Banks Lake.

Date	Number	Species	Common Name	Size	Origin
2/53	4,000	*Salmo gairdneri*	rainbow trout (Kamloops)	30/lb	
4/56	10,010	*Salmo gairdneri*	rainbow trout	11/lb	
5/56	1,504,000	*Oncorhynchus nerka*	kokanee salmon	fry	Leavenworth
10/56	14,190	*Salmo gairdneri*	rainbow trout	11/lb	
6/57	1,533,000	*Oncorhynchus nerka*	kokanee salmon	fry	Leavenworth
9/57	12,250	*Salmo gairdneri*	rainbow trout	12.5/lb	
10/4-8/57	28,000	*Salmo gairdneri*	rainbow trout	14/lb	
4/4/58	10,035	*Salmo gairdneri*	rainbow trout	9/lb	
6/5/58	29,500	*Salmo gairdneri*	rainbow trout	59/lb	
6/13/58	39,600	*Salmo gairdneri*	rainbow trout	66/lb	
7/2/58	63,000	*Salmo gairdneri*	rainbow trout	45/lb	
8/5/58	18,000	*Salmo gairdneri*	rainbow trout	30/lb	
9/3-16/58	97,300	*Salmo gairdneri*	rainbow trout	20/lb	
5/23/58	1,298,800	*Oncorhynchus nerka*	kokanee salmon	1,640 lb	Leavenworth
6/10/59	89,060	*Salmo gairdneri*	rainbow trout	20-22/lb	
6/3-9/59	59,980	*Salmo gairdneri*	rainbow trout	9-18/lb	
7/14/59	28,270	*Salmo gairdneri*	rainbow trout	22/lb	
7/23/59	24,988	*Salmo gairdneri*	rainbow trout	30-45/lb	Tucannon
3/23/59	949,560	*Oncorhynchus nerka*	kokanee salmon	5,790 lb	Leavenworth
4/27/60	946,400	*Oncorhynchus nerka*	kokanee salmon	5,200 lb	Leavenworth
6/28/60	14,400	*Salmo gairdneri*	rainbow trout	18/lb	
7/1-17/60	72,000	*Salmo gairdneri*	rainbow trout	17-20/lb	
8/16/60	50,100	*Salmo gairdneri*	rainbow trout	14-19/lb	
9/28/60	12,000	*Salmo gairdneri*	rainbow trout	15/lb	
1961 NO RECORDS					
6/13/62	31,430	*Salmo gairdneri*	rainbow trout	14/lb	Columbia Basin
6/15/62	14,300	*Salmo gairdneri*	rainbow trout	13/lb	Columbia Basin
7/13/62	14,980	*Salmo gairdneri*	rainbow trout	14/lb	Columbia Basin
9/20/63	65,680	*Salmo gairdneri*	rainbow trout	8.5-12/lb	Columbia Basin
8/20/63	10,000	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin

Appendix Table 1. Known fish introductions to Banks Lake (cont.)

Date	Number	Species	Common Name	Size	Origin
7/1-2/63	47,340	*Salmo gairdneri*	rainbow trout	10-12/lb	Columbia Basin
6/17-24/63	44,040	*Salmo gairdneri*	rainbow trout	11-12/lb	Columbia Basin
4/25/63	506,000	*Oncorhynchus nerka*	kokanee salmon	6,175/lb	Leavenworth
5/8/64	954,000	*Oncorhynchus nerka*	kokanee salmon	5,600/lb	Leavenworth
5/6/64	56,000			125/lb	Spokane
5/20-26/65	1,000,000	*Oncorhynchus nerka*	kokanee salmon	fry	Leavenworth
9/65	25,000	*Oncorhynchus nerka*	kokanee salmon	9/lb	Leavenworth
10/65	85,000	*Oncorhynchus nerka*	kokanee salmon	7-12/lb	Leavenworth
9/22/65	24,000	*Oncorhynchus nerka*	kokanee salmon	25/lb	
	26,300			20/lb	
5/13/66	1,000,000	*Oncorhynchus nerka*	kokanee salmon	fry	Leavenworth
4/27-29/66	50,400			9/lb	Columbia Basin
5/6/66	9,000			9/lb	Columbia Basin
7/7/66	8,500			12/lb	Columbia Basin
7/21/66	17,550	*Salmo gairdneri*	rainbow trout (Kamloops)	15/lb	Columbia Basin
8/25-31/66	39,120	*Salmo gairdneri*	rainbow trout	10-12/lb	Columbia Basin
6/13/67	46,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
7/19/67	32,300	*Salmo gairdneri*	rainbow trout	9-10/lb	Columbia Basin
8/8/67	11,600	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
	5,400	*Salmo gairdneri*	rainbow trout (Kamloops)		
10/31/67	6,500	*Salmo gairdneri*	rainbow trout	19/lb	Chelan
11/21/67	15,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/3/68	20,000	*Salmo gairdneri*	rainbow trout	20/lb	Columbia Basin
10/3/68	21,150	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
10/30/68	11,250	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
11/6/68	32,600	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
11/7/68	28,525	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
11/8/68	16,500	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
6/11/69	8,500	*Salmo gairdneri*	rainbow trout	5/lb	Columbia Basin
5/23/69	12,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
9/25/69	12,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin

Appendix Table 1. Known fish introductions to Banks Lake (cont.)

Date	Number	Species	Common Name	Size	Origin
9/30/69	26,100	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/1/69	24,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/6/69	11,500	*Salmo gairdneri*	rainbow trout	9-10/lb	Columbia Basin
10/15/69	12,300	*Salmo gairdneri*	rainbow trout (Kamloops)	12/lb	Chelan
10/8/69	11,160	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
11/20/69	19,575	*Salmo gairdneri*	rainbow trout	13/lb	Tucannon
9/2/70	50,883	*Salmo gairdneri*	rainbow trout	21/lb	Chelan
9/4/70	20,265	*Salmo gairdneri*	rainbow trout	21/lb	Columbia Basin
10/8/70	20,230	*Salmo gairdneri*	rainbow trout	7/lb	Columbia Basin
10/13/70	12,500	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/21/70	26,200	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/22/70	13,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/29/70	10,350	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
11/10/70	10,950	*Salmo gairdneri*	rainbow trout	4/lb	Columbia Basin
11/18/70	7,600	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
11/18/70	11,825	*Salmo gairdneri*	rainbow trout	11/lb	Columbia Basin
3/30/71	20,000	*Salmo gairdneri*	rainbow trout	16/lb	Columbia Basin
3/30/71	9,000	*Salmo gairdneri*	rainbow trout	18/lb	Columbia Basin
3/30/71	42,000	*Salmo gairdneri*	rainbow trout	25/lb	Columbia Basin
4/5/71	21,750	*Salmo gairdneri*	rainbow trout	25/lb	Columbia Basin
4/19/71	20,116	*Salmo gairdneri*	rainbow trout	18/lb	Columbia Basin
5/10/71	150,000	*Oncorhynchus nerka*	kokanee salmon		Leavenworth
5/12/71	12,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
4/27/71	8,850	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
4/30/71	32,000	*Oncorhynchus kisutch*	coho salmon	160/lb	Columbia Basin
4/30/71	69,750	*Oncorhynchus kisutch*	coho salmon	150/lb	Columbia Basin
10/29/71	18,000	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
11/1/71	16,515	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
11/2/71	8,820	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
11/2/71	7,850	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
5/5/72	11,475	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin

Appendix Table 1. Known fish introductions to Banks Lake (cont.).

Date	Number	Species	Common Name	Size	Origin
5/5/72	8,550	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
5/30/72	15,000	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
5/31/72	11,280	*Salmo gairdneri*	rainbow trout	19/lb	Columbia Basin
6/6/72	1,800	*Salmo gairdneri*	rainbow trout	9/lb	Columbia Basin
6/6/72	10,400	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
6/28/72	11,050	*Salmo gairdneri*	rainbow trout	13/lb	Columbia Basin
6/28/72	3,600	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
6/28/72	10,800	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
6/29/72	7,600	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
6/29/72	4,950	*Salmo gairdneri*	rainbow trout	11/lb	Columbia Basin
10/2/72	16,335	*Salmo gairdneri*	rainbow trout	11/lb	Columbia Basin
10/3/72	15,500	*Salmo gairdneri*	rainbow trout	10/lb	Columbia Basin
10/3/72	6,215	*Salmo gairdneri*	rainbow trout	11/lb	Columbia Basin
10/26/72	25,542	*Salmo gairdneri*	rainbow trout	8.5/lb	Columbia Basin
11/8/72	3,120	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
11/8/72	3,300	*Salmo gairdneri*	rainbow trout	8/lb	Columbia Basin
5/1/73	37,290	*Salmo gairdneri*	rainbow trout	12/lb	
8/73	110,660	*Salmo gairdneri*	rainbow trout	22/lb	Winthrop
5/28/74	16,445	*Salmo gairdneri*	rainbow trout	13/lb	Columbia Basin
8/11/74	40,000	*Oncorhynchus tshawytscha*	chinook salmon	3/lb	
10/23/74	23,202	*Salmo gairdneri*	rainbow trout	9/lb	
10/24/74	12,615	*Salmo gairdneri*	rainbow trout	10.7/lb	
10/24/74	110,000	*Oncorhynchus nerka*	kokanee	50/lb	Leavenworth
10/24/74	11,748	*Salmo gairdneri*	rainbow trout	11/lb	
10/31/74	21,004	*Salmo gairdneri*	rainbow trout	8/lb	
10/31/74	22,375	*Salmo gairdneri*	rainbow trout	12.5/lb	
11/6/74	15,750	*Salmo gairdneri*	rainbow trout	12.5/lb	
11/13/74	1,350	*Salmo gairdneri*	rainbow trout	13.5/lb	
11/13/74	11,024	*Salmo gairdneri*	rainbow trout	10.6/lb	