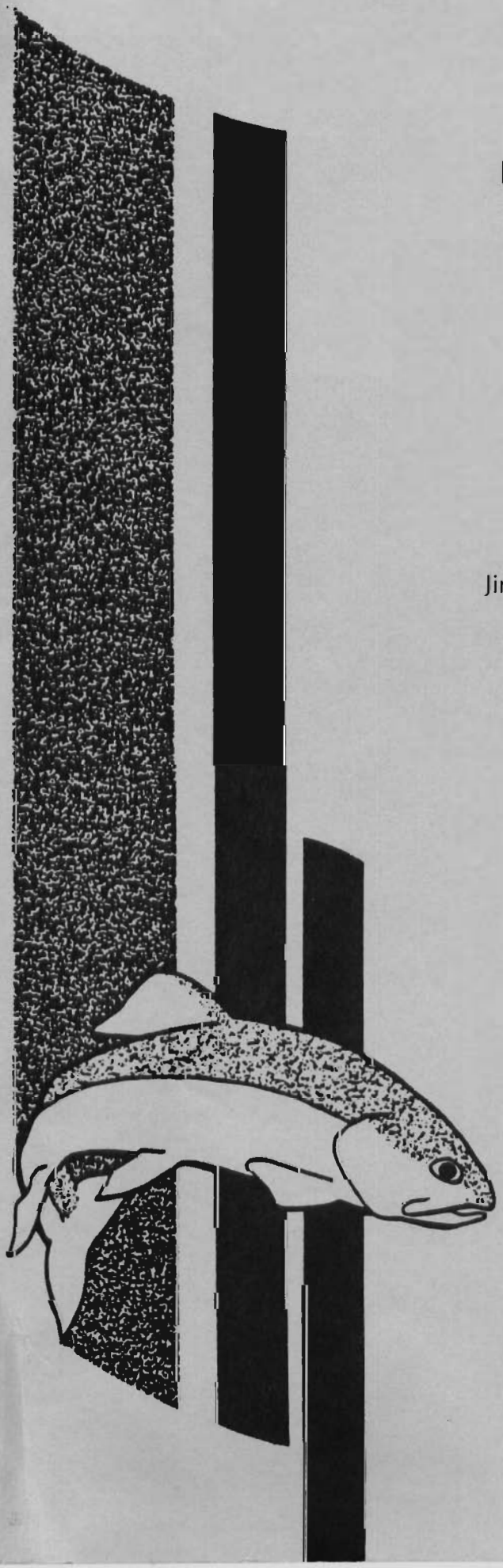

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Fisheries Project Report No. RD 49

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Ministry of Environment, Lands and Parks
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Fisheries Project Reports frequently contain preliminary data, and conclusions based on these may be subject to change. Reports may be cited in publications but their manuscript status (M.S.) must be noted.

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Kootenay Lake Fertilization Experiment: Year 3 (1994-1995) Report

Introduction

This report reviews the third year (1994) of a planned five year project (i.e., 1992-1996) involving the experimental fertilization of the North Arm of Kootenay Lake. This experiment remains one of the largest and most ambitious projects ever undertaken by the Ministry of Environment, Lands and Parks (MoELP), and next to Chilko Lake, B.C. (20,032 ha), the North Arm of Kootenay Lake (17,363 ha) is the second largest lake to have undergone experimental fertilization world-wide. Previous progress reports (Ashley and Thompson, 1993 and Ashley et al., 1994) had reported the North Arm surface area as 13,000 ha, however, a recent digitization (Compugrid Version 7 program) of the Canadian Hydrographic Service map of Kootenay Lake (CHS chart 3050, 1986 edition) indicates the revised North Arm surface area is 17,363 ha, the South Arm surface area is 22,174 ha and the whole lake is 39,537 ha. The purpose of this progress report is to provide a preliminary analysis of the various field and laboratory data collected at Kootenay Lake in 1994.

The philosophy of the Kootenay Lake fertilization experiment is that it is clearly an experiment, and there is a potential risk of failure or non-achievement of the desired goal(s). The adaptive environmental assessment (AEA) workshop process was used initially to define the extent and magnitude of the problem(s) and develop alternative management policy options that were amenable to experimentation (Walters et al., 1991). Following funding approval and public acceptance of the experimental fertilization proposal, the adaptive management approach was adopted (Walters, 1986) in which the management policy selected (i.e., fertilization) is monitored in sufficient detail such that appropriate modifications can be taken if necessary.

1994 Public Participation Program

There were no formal public presentations on the fertilization experiment in the spring of 1994 as most area residents had not expressed any significant concerns about the results to date from the fist two years (i.e., 1992 and 1993) of the planned five year experiment. Information bulletins were prepared by the Nelson MoELP office and mailed out to interested participants in March/April, 1994. The majority of individuals in attendance in previous years presentations were supportive of the fertilization experiment and they encouraged the MoELP and B.C. Hydro to continue with the planned five year experiment. It was also stated that the public participation program was useful and informative, and that annual information updates would be appreciated by the public. On the basis of the successful Year 1 (1992) and Year 2 (1993) field seasons and a favourable public response to previous information meetings, the MoELP and B.C. Hydro decided to proceed with Year 3 (1994) of the experimental fertilization program on the North Arm of Kootenay Lake.

List of Personnel, Affiliation and Responsibilities

An interdisciplinary team of scientists, fisheries biologists and technicians participated in the 1994 field program at Kootenay Lake. The 1994 activities were weighted towards limnological and fisheries monitoring, as was the case in 1993, since the majority of the physical limnology tasks were completed in the 1992 field season. A listing of the 1994 project focus, personnel, and affiliation are as follows (Table 1):

Table 1. Listing of 1994 Kootenay Lake project focus, personnel and affiliation.

Project Focus	**Personnel**	**Affiliation**
Senior Scientist	Dr. Carl Walters	Fisheries Centre, UBC
Fertilizer application	George Veale	G. Veale Holdings Ltd.
Bi-weekly physical, chemical, phyto and zooplankton sampling	Mark Young Albert Chirico Don Miller	Kootenay Wildlife Services Ltd.
Ecosystem dynamics study (zooplankton and kokanee analysis)	Lisa Thompson Leanne Haywood-Farmer Candy Thomson	Fisheries Centre, UBC
Kokanee and mysid acoustic sampling	Dale Sebastian George Scholten	Fisheries Branch, MoELP, Victoria
Mysid net sampling	George Scholten Mark Young Don Miller	Fisheries Branch, MoELP, Victoria; Kootenay Wildlife Services Ltd.
Kokanee trawling	Don Miller Bill Bing	Kootenay Wildlife Services Ltd.
Meadow Creek kokanee adult enumeration	Les Fleck John Bell Murray Pearson	Fish and Wildlife, MoELP, Nelson; Kootenay Wildlife Services Ltd.
Meadow Creek kokanee fry enumeration	John Bell Murray Pearson	Fish and Wildlife, MoELP, Nelson; Kootenay Wildlife Services Ltd.
Mysid biology	Dr. Dave Lasenby Karen Smokorowski Laurie McEachern	Biology Dept., Trent University, Ontario

Phytoplankton ecology	Dr. Frances Pick Dr. Jing-Rong Yang Paul Hamilton	Biology Department, University of Ottawa; Canadian Museum of Nature
Regional support and logistics	John Bell Les Fleck Bob Lindsay Jay Hammond	Fish and Wildlife, MoELP, Nelson
Steering committee	Harvey Andrusak Ken Ashley Jay Hammond Al Martin Gary Birch	Fisheries Branch, MoELP, Victoria; Fish and Wildlife, MoELP, Nelson; B.C. Hydro, Castlegar
Project co-ordination and scientific liaison	Ken Ashley Bob Lindsay	Fisheries Branch, MoELP, UBC; Fish and Wildlife, MoELP, Nelson

1994/95 Kootenay Lake Budget Expenditures

Funding for the Kootenay Lake Fertilization project was supplied by the Columbia Basin Fish and Wildlife Compensation Program (CBFWCP) and the Ministry of Environment, Lands and Parks (MoELP). The overall Kootenay Lake budget expenditures for the 1994/95 fiscal year were $475,500. This does not include project management time allocated by the MoELP staff in Nelson and Vancouver. The CBFWCP contributed $450,000 and MoELP contributed $25,500. The budget breakdown was as follows (Table 2):

Table 2. Kootenay Lake fertilization budget for 1994-1995.

Task	**Expenditure ($)**	**Agency/Supplier**
Liquid fertilizer	237,866	Cascade Fertilizer Ltd.
Distribution of fertilizer (tug and barge)	36,840	George Veale Holdings
Fertilizer sub-total	**274,706**	
Water, plankton and mysid sampling	30,000	Kootenay Wildlife Services
Water chemistry analyses	25,500	Zenon Laboratories
Phytoplankton analysis	10,000	Dr. F. Pick, U. Ottawa
Zooplankton and kokanee analysis	49,000	Dr. C. Walters, UBC

Mysid analysis	25,000	Dr. D. Lasenby, Trent University
Field hydroacoustics	7,400	Fisheries HQ staff
Office hydroacoustic analysis	6,000	Fisheries HQ staff
Trawl contract	27,000	Kootenay Wildlife Services
Sampling/monitoring sub-total	**179,900**	
Data entry, open house meetings and reporting	3,500	MoELP
Equipment	2,000	MoELP
Travel	3,600	MoELP and BC Hydro
Boat operation and maintenance	10,000	MoELP
Rentals	0	MoELP
Misc.	1,794	MoELP
Operations/travel sub-total	**20,894**	
GRAND TOTAL	**$475,500**	

Materials and Methods

Fertilizer Type

Liquid fertilizer was again used in 1994. The formulation was a seasonally varied blend of liquid ammonium polyphosphate, 10-34-0 (N-P_2O_5-K_20; % by weight), and liquid urea-ammonium nitrate, 28-0-0 (N-P_2O_5-K_20; % by weight) (Appendix 1). This formulation was identical to that used since July 1993 when the original principal nitrogen source (i.e., 32-0-0) was replaced by 28-0-0 due to problems with 32-0-0 precipitation and crystallization in the barge application tanks.

Application System

A pusher tug/barge unit was fitted with two 40,000 L liquid fertilizer tanks supplied by Cascade Fertilizers Ltd. The tanks were connected together via plastic tubing and were filled via gravity feed from a fertilizer delivery transport truck at the Lardeau moorage site. Each tank was fitted with a metered visual sight gauge to ensure balanced loading for barge stability. The fertilizer was pumped from the tanks by a 3.7 kW gasoline powered fertilizer pump and metered through a flow meter (accurate to 0.1 L) located at the bow of the tug before discharging at the stern (through a 5 m manifold drilled with approximately 20 orifices, each with 0.6 cm diameter) into the propwash from the tug's 2 m diameter propeller.

The fertilizer release zone was designated as the middle section of Kootenay Lake from 3.2 km south of Lardeau to 3.2 km south of Schroeder Creek, a distance of 10 km (Fig. 1). An application schedule for the 10-34-0/28-0-0 blend (Appendix 2) was supplied to the tug's skipper (Mr. George Veale). The radar equipped tug was steered in an accurate zig-zag course down the centre of Kootenay Lake from Lardeau to Schroeder Creek. The skipper was able to view the flow meter from the wheelhouse and make any necessary adjustments to the flow rate en route. One half of the total weekly fertilizer load was delivered on the 10 km trip down lake, and the remaining load delivered on the return leg. The tug/barge speed was approximately 5 $km \cdot h^{-1}$ therefore, each leg of the trip required approximately 2 hours. An additional hour was required to prepare the pump system and berth the tug. Given the operators' extensive local knowledge of Kootenay Lake, the accurate flow meter, and the radar guided navigational capabilities of the tug, the fertilizer was released in the designated treatment zone in a consistent fashion throughout the duration of the fertilizer application period. On the few occasions where storm activity on the lake created unsafe application conditions, the fertilizer was released the following day or when the storm subsided.

Seasonal Loading and Timing

The seasonal loading and timing of fertilizer application was intended to approximate pre-impoundment (i.e., Duncan and Libby reservoirs) spring freshet conditions for phosphorus loading to Kootenay Lake (i.e., natural hydrograph discharge shaping) and to compensate for biological uptake of dissolved inorganic nitrogen (DIN) as the summer progressed. This resulted in a late spring-early summer peak of weekly P loading, which then declined to a constant summer and eventually reduced late summer loading in terms of weekly phosphorus additions (Fig. 2).

Fertilizer treatment started on 23 April 1994 and continued to 8 September 1994. Weekly nitrogen loading started at low rates in the spring, increased throughout the summer and decreased in late summer (Fig. 2) in an attempt to prevent the occurrence of cyanobacteria (blue-green algae) which are often associated with low N:P ratios (Smith, 1983; Pick and Lean, 1987). The fertilizer N:P ratio (weight to weight basis) changed approximately every 3-4 weeks and increased from 0.67:1 (i.e., 10-34-0 only) in the initial spring applications to 7.5:1 in the late summer applications. The total weekly weight of the fertilizer additions ranged from 8.8 Mg (1 Mg = 1 metric tonne = 1,000 kg = 0.984 ton) in late April to 81.15 Mg on 6 August 1994. The 1994 treatment year fertilizer application is shown in Table 3.

The historical data indicates the estimated annual pre-impoundment P loading (as soluble reactive phosphorus, SRP) to Kootenay Lake was 140 Mg in 1949 (Table 4). Phosphorus loading peaked in 1966 at 2350 Mg while the Cominco fertilizer plant was in full operation and prior to pollution abatement measures and dam construction. Phosphorus loading then declined to 51 Mg in 1977 following completion of the Duncan and Libby dams and implementation of pollution abatement measures by Cominco (Daley et al., 1981), and is currently estimated at 98.1 Mg due to the addition of 47.1 Mg from the experimental fertilization. The fertilizer plant eventually closed in 1987.

Table 3. Fertilizer applications to the North Arm (17,363 ha) of Kootenay Lake for the 1994 application period: 23 April - 8 September 1994.

10-34-0 (Mg)	**as P (Mg)**	**as mg · m^{-2} P**	**as µg · L^{-1} P** (0-20 m epilimnion)
317.1	47.1	271.3	13.6
28-0-0 (Mg)	**as N (Mg)**	**as mg · m^{-2} N**	**as µg · L^{-1} N** (0-20 m epilimnion)
624.8	206.7 (includes N from 10-34-0)	1,190.5	59.5
Total 941.9 Mg			

The total experimental P loading to the North Arm in 1994 was 47.1 Mg. Based on the 1977 post-impoundment loadings (Daley et al., 1981), the estimated total annual P loading (natural and experimental) to the North Arm of Kootenay Lake in 1994 was approximately 69.5 Mg (i.e., 47.1 Mg fertilizer P + 22.4 Mg natural P) (Table 4). This is an increase of approximately 13% above 1949 P loadings.

Table 4. Historical and 1994 experimental P loadings to Kootenay Lake.

Year and nutrient status	**Whole Lake (Mg P · yr^{-1}) area = 395.37 km^2**	**North Arm (Mg P · yr^{-1}) area = 173.63 km^2**	**North Arm (g P · m^{-2} · yr^{-1}) area = 173.63 km^2**
1949 (natural loading)	140.0	61.5	0.354
1966 (fertilizer plant peaks)	2,350.0	1,032.0	5.943
1977 (post-impoundment)	51.0	22.4	0.129
1994 (experimental P loading)	N/A	47.1	0.271
1994 (estimated natural and experimental P loading)	98.1	69.5	0.400

Theoretically, the experimental P loadings could be reduced by 8.0 Mg to more closely match the 1949 loadings, however, Kootenay Lake did not contain any mysids prior to 1949, and the current 13% additional phosphorus loading is likely required to compensate for the additional presence of a large population of mysids in the Kootenay Lake ecosystem. On a whole lake basis, 1994 P loadings were approximately 70% of pre-impoundment (i.e., 1949) loading levels.

Physical Limnology

A Hydrolab (Surveyor II) probe was used to profile the water column from 0 to 50 m at 1 m intervals at each of the seven permanent sampling stations (Fig. 1). Parameters measured included temperature, dissolved oxygen, pH, ORP (oxidation-reduction potential), specific conductance and salinity. Vertical profiles were conducted biweekly from 11 April to 9 November 1994. Secchi disk transparency was also measured bi-weekly from 19 April to 9 November at each of the seven sampling stations.

Water Chemistry

A 2.54 cm (inside diameter) tube sampler was used to obtain an integrated water column sample from 0 to 30 m at each of the seven sampling stations. Parameters measured included major nutrients, general ions and total metals. Water chemistry samples were collected biweekly from 19 April to 9 November 1994. Water samples were placed on ice immediately and shipped to Zenon Environmental Laboratories (Burnaby, B.C.) for analysis within 24 h of sample collection.

Phytoplankton

A 2.54 cm (inside diameter) tube sampler was used to obtain an integrated water column chlorophyll *a* and phytoplankton composition sample from 0 to 20 m at each of the seven sampling stations. Phytoplankton samples were collected biweekly from 19 April to 18 October 1994. Phytoplankton samples were preserved with Lugol's solution and shipped to Dr. Frances Pick's laboratory (University of Ottawa) throughout the sampling period.

Dates of sampling of the 63 samples enumerated from 1994 are given in Appendix 3. Samples were enumerated from each of the seven stations at one month intervals. Additional samples were enumerated from Stations 2 and 6 to provide an analysis every two weeks of seasonal trends between the fertilized zone and the nonfertilized area of the lake.

Subsamples were preserved for phytoplankton analysis using Lugol's iodine solution. Enumerations were made using the Utermöhl method on a Wild M40 inverted microscope (Utermöhl, 1938: Lund et al., 1958). Aliquots of 8-15 ml were settled overnight (16 hours) in 26 mm diameter sedimentation chambers. For each sample, a minimum of 300-350 phytoplankton cells was counted along randomly selected transects to ensure an 85-90% counting accuracy (Lund et al., 1958). The length of each transect equaled the diameter of the chamber. Cell counts and dimensions were recorded on a computerized counter (Hamilton, 1990) to facilitate the calculations of the parameters describing phytoplankton community

structure. For counting purposes cells were assigned to one of three magnifications: 400X, 200X and 100X, depending on their size and nature. The cells were consistently identified and enumerated at the assigned magnification.

Estimates of total algal biomass, and size and division distribution were derived from the enumerations. Algal biomass was determined from estimations of the volume of each algal taxon. One of seven preselected shapes (sphere, cone, double cone, ellipsoid, parallelepiped, half parallelepiped and rod) was assigned to each species (Hamilton, 1990). The dimensions were measured on 3-10 individuals per species. The summation of the individual cell volumes: the biovolume ($m^3 \cdot m^{-3}$), was converted to biomass ($mg \cdot m^{-3}$) assuming a density of 1 (Utermöhl, 1958).

Taxa were assigned to specific size classes based on the mean of their longest dimension. Accordingly, total biomass was partitioned into six size classes: the picoplankton (0.2-2 mm), the m-ultraplankton (2.1-5 mm), the ultraplankton (5.1-10 mm), the nanoplankton (10.1-22 mm), the microplankton (22.1-64 mm) and the net plankton (> 64 mm). Total biomass was further separated into seven main divisions: Cyanobacteria, Chlorophyta, Euglenophyta, Chrysophyta, Cryptophyta, Pyrrophyta and diatoms. A species list for all phytoplankton enumerated is given in Appendix 4 along with the codes used for these species. The count sheets of the raw data are given in Yang et al., 1994.

To ensure consistent counting techniques, Rowena Rae, who counted the first two years of the Kootenay Lake fertilization experiment phytoplankton data (i.e., 1992 and 1993), spent two full weeks with the phytoplankton authors, comparing enumerations and identifications conducted by each on the same samples. We used the same settling, enumeration, and identification techniques with the same microscope and computer program and these techniques are well established for all work done with the Canadian Museum of Nature.

Zooplankton

Macrozooplankton

Macrozooplankton (length >150 μm) were sampled biweekly from 20 April to 10 November 1994 using a Clarke-Bumpus sampler. At each of the seven stations three replicate oblique tows were made from a depth of 40 to 0 m at a boat speed of 1 $m \cdot s^{-1}$ with a 150 μm mesh net. Tow duration was usually 3 min, with approximately 2,500 L of water filtered per tow. From 26 July to 2 September tow times were reduced to 1.5 minutes because of problems with algae clogging the mesh. The volume sampled was estimated from the revolutions counted by the Clarke-Bumpus flowmeter. The net and flowmeter were calibrated in April 1993 and 1994 and February 1995 in a flume at the Civil Engineering Department at the University of British Columbia. Zooplankton samples were preserved in 70% ethanol and analyzed for species density, biomass (to be estimated from empirical length-weight regressions) and fecundity.

Samples were re-suspended in tap water filtered through a 74 μm mesh and sub-sampled using a four chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope. For each replicate, organisms were identified to species and counted until up to 200 organisms of the predominant species were recorded (if 150 organisms were counted by the end of a split, a new split was not started). The lengths of 30 organisms of each species were measured, for use in biomass calculations, using a mouse cursor on a live television image of each organism. The copepod species *Diaptomus ashlandi* and *Cyclops bicuspidatus* were analyzed to copepodite stage for one replicate at each station, to allow the tracking of cohorts through the season and the observation of any changes in development time. The number of eggs carried by gravid females and the length of these individuals were recorded for use in fecundity calculations.

Microzooplankton

Microzooplankton (rotifers, 35 - 150 μm) were added to the sampling program in 1994 to check whether they were responding to fertilizer additions, potentially at the expense of macrozooplankton such as *Daphnia*. Should rotifer abundance increase, mysid abundance could increase, since mysids feed on rotifers as well as macrozooplankton. However, since kokanee do not appear to feed on rotifers, they would not be able to profit from this response of the system to fertilization.

Rotifers were sampled with a 35 μm mesh Birge closing net with a 35 μm mesh on the bucket. (A Birge closing net is a Wisconsin-style net with a conical mesh and a nylon reducing cone at the front to increase efficiency. The long reducing cone allows the net to be closed at a desired depth underwater so that a sample can be collected from a specific depth interval e.g., 40 to 20 m). Vertical haul samples from 40 to 0 m were collected monthly from June to October 1994 at the seven sampling stations. Triplicate samples were collected in June and September; in other months one sample was collected per station. Samples were preserved in Lugol's solution.

Samples will be analyzed for total rotifer density and biomass (to be estimated from empirical length-weight regressions) by placing sub-samples in a Sedgewick-Rafter cell and examining them with a compound microscope at 100 X magnification. Enough sub-samples will be examined that a minimum of 200 organisms will be counted. The length of the first thirty rotifers observed will be measured to give an estimate of the average length for biomass calculations.

A summary of the biweekly Kootenay Lake sampling program is shown in Table 5.

Table 5. Biweekly physical, chemical and plankton sampling program.

Parameter sampled	Sampling frequency	Sampling technique
Temperature, dissolved oxygen, pH, ORP, specific conductance, salinity	Bi-weekly	Hydrolab at 1 m intervals at 7 sampling stations from 0 to 50 m
Transparency	Bi-weekly	Secchi disk (without viewing chamber) at 7 sampling stations
Water chemistry: general ions, nutrients and metals	Bi-weekly	Integrated sampling tube at 0 - 30 m at 7 sampling stations
Chlorophyll *a*	Bi-weekly	Integrated sampling tube at 0 - 20 m at 7 sampling stations
Phytoplankton	Bi-weekly	Integrated sampling tube at 0 - 20 m at 7 sampling stations
Macrozooplankton	Bi-weekly	3 replicate 3 minute oblique Clarke-Bumpus hauls from 40 to 0 m at 7 sampling stations (150 µm net)
Rotifers (microzooplankton)	Monthly	1-3 vertical Birge net hauls from 40 to 0 m at 7 sampling stations (35 µm net)

Zooplankton Productivity Experiment

An enclosure experiment was conducted from July to September 1994 to obtain estimates of *Daphnia* and *Diaphanosoma* productivity in the absence of predation. Nine enclosures were placed near the boathouses at the Kaslo Marina in Kaslo Bay (between Stations 2 and 3) in the North Arm. Three sets of three enclosures were stocked with natural zooplankton assemblages. The second and third sets of enclosures were installed and stocked about one and two weeks, respectively, after the first, to control for potential effects of seasonal and lunar changes. Each enclosure was cylindrical, with 1 m diameter and 4 m depth, and constructed of 200 µm mesh. This mesh size was chosen to keep the majority of macrozooplankton inside, and to exclude *Mysis* and fish, yet allow phytoplankton to drift in to maintain food supplies for the zooplankton. Zooplankton from the main lake (between Stations 2 and 3) were collected with a 100 µm mesh Birge closing net with a 35 µm mesh on the bucket. Thirteen vertical hauls from 20 to 0 m were made to collect organisms from a volume equal to the volume of each enclosure. Zooplankton were held in a large plastic container until transfer to the enclosure. Water temperature was monitored to ensure the transfer occurred without overheating. During collection of zooplankton for the second and third set of enclosures, three extra vertical hauls were made and the zooplankton were preserved in 70%

ethanol to provide an estimate of the zooplankton species present and the concentrations which were stocked.

Each set of enclosures was run for at least four weeks, but data from only the first two weeks of each run is presented because algal growth on the sides of the enclosures could have affected the type of phytoplankton available to the zooplankton. The enclosures were sampled every third day using the same net as was used for stocking. One vertical haul was made from 3 to 0 m. The zooplankton were rinsed out of the net using an aqueous solution of 4% sodium bicarbonate (to help prevent them from releasing their eggs) and were preserved in 70% ethanol. Samples were analyzed using the same microscope system and counting protocol as for the routine lake zooplankton samples.

Mysids

Distribution and Abundance

Mysids were collected on moonless nights at the same time as the monthly kokanee hydroacoustic sampling was conducted. Three vertical hauls were collected (with the boat stationary) along each of the seven hydroacoustic transects (Fig. 1), using a 1 m^2 square-mouthed net with 1,000 mm primary mesh net, 210 mm terminal mesh and 100 mm bucket mesh. Two hauls were made from the deepest part each transect (i.e., > 100 m), and one haul was collected from a shallow (i.e., < 60 m) near-shore zone (Appendix 4). The net was raised with a hydraulic winch at 0.3 $m \cdot s^{-1}$. The samples were stored in 95% ethanol and shipped to Dr. Lasenby's lab (Trent University) for analysis. Mysid abundance estimates are for the 1994 sampling year, January to December inclusive.

Mysids were counted, measured and sexed using a low power dissecting scope. Results are expressed as numbers of mysids captured (equivalent to number per m^2). Abundance estimates for the 1993 sampling season are presented in Appendix 5. The results are expressed as number captured (equivalent to number per m^2), and have been compared to results from 1992 and 1993. All among-year comparisons are based on May to October averages for deep hauls only, as there were no samples taken through the winter of 1992, and the 1993 samples did not include November.

Mysid Gut Content Analysis

For gut content analysis, the stomach was removed and placed in a drop of glycerine on a microscope slide. Fine forceps and probes were used to tease apart the stomach walls, break up lumps of material and distribute the stomach contents on the slide. A cover slip was placed on the slide and a compound microscope used to scan the slide at 100X magnification. All rotifers, zooplankton mandibles and postabdominal claws were identified and counted. For each date the average number of zooplankton food items per mysid was determined. Although items were

identified to species level, the results are summarized as cladocerans, copepods and rotifers (Smokorowski et al., 1995).

Ten mysid stomachs were examined from each station for each date sampled (usually from the deepest site at each station). Therefore, if seven stations were sampled, the contents for that date are based on a sample size of seventy. Gut contents have been analyzed for all samples received for 1992 and 1993, and to July of 1994. Due to problems with sample labels, only two stations were examined in both July and August of 1993. Beginning in April 1994 (time of release of the young) the contents of 3 juvenile mysid stomachs were analyzed from each site in order to ascertain the time at which the juvenile mysids are able to consume macrozooplankton.

Clearance Rate Experiment

To determine the *in situ* clearance rate (in $mL \cdot h^{-1}$) of adult *Mysis relicta* in Kootenay Lake a small-enclosure feeding experiment was developed following the methods of Nero and Sprules (1986). The experiment was pre-run in Crystal Lake, Ontario, so that the procedure could be performed efficiently in Kootenay Lake. The experiment was successfully run twice, using adult mysids only, in Queen's Bay, Kootenay Lake in August 1994.

To determine the volume of water one mysid could clear of zooplankton in one night, twenty feeding chambers (20 L) were filled with metalimnetic water at approximately 10 °C. A 10 L Schindler trap was modified by closing off the net opening with heavy plastic to avoid concentrating the zooplankton. Water contained in the trap was drained into a bucket for transfer to the feeding chambers. Approximately three Schindler hauls were required to fill one feeding chamber.

Just after dusk, ten mysids were added to each of ten chambers. All chambers were then suspended at the metalimnion (20 m) for approximately eight hours, after which time the contents were filtered and macrozooplankton were counted. The difference between the mean number of zooplankton in the chambers "with" and "without" mysids was assumed to be the number consumed by the mysids.

These results were then incorporated into the following formula (Gauld, 1951 modified by Vanderploeg et al., 1982) to determine clearance rates:

$$F = 1000\ V\ \ln(C/Z) / tn$$

where: F is the clearance rate ($mL \cdot h^{-1}$)
V is the volume of the experimental chamber (L)
C is the number of prey in the control chamber at the end of the experiment
Z is the number of prey in the experimental chamber at the end of the experiment
t is the duration of the experiment (h)
n is the number of predators in the experimental chamber.

This experiment was run four times in Kootenay Lake, however, only two runs were considered successful as the first and second runs encountered a number of problems which led to some method modifications. For example, moderate wave action during the Schindler hauls resulted in the opening of the trap as it travelled up the water column, which could have resulted in epilimnetic zooplankton combining with metalimnetic zooplankton.

Subsequent trials were conducted on much calmer days, and the trap was raised at a greater rate to avoid opening. Strict attention was paid to the temperature of the water retrieved from the trap. If the temperature was not approximately 11 °C (the temperature at the depth from where water was supposed to come from) the water was discarded. An additional problem was discovered when filtering the chambers; mysid mortality ranged from a minimum of 30% up to 90% mortality. For the third and fourth runs of the experiment, mysids were collected at least one day in advance to ensure that only healthy mysids were placed in the carboys. Mysids used in these experiments had a 100% survival rate.

Length-Weight Relationship and Caloric Content

In August 1994, mysids were collected from Kootenay Lake for the purposes of determining a length-weight relationship and caloric content. For the length-weight relationship, 85 mysids of varying size were starved in filtered lake water for 24 hours, removed from the water and measured. Each mysid was placed in a small petri dish on a pre-weighed piece of aluminum foil. The mysids were air dried in a "sun-powered" drying oven for two days, transported to the Trent University lab, and placed in a drying oven set at 16 °C for over a week. The mysids were transferred from the oven to a desiccator where they remained for over a week. The mysids were weighed using a Fisher Scientific Micro Gram-Atic Balance No. 1-912.

Growth and Life History

Samples taken for the abundance estimates were also used for growth and life history analyses. When necessary, each sample was split using a Folsom plankton splitter to obtain a subsample of approximately 100 mysids. If the sample contained less than 160 mysids, the entire sample was analyzed. Mysids were measured from the tip of the rostrum to the base of the telson using a dissecting microscope with an ocular micrometer and up to 4X magnification. Some of the samples were poorly preserved and total body length could not be measured. In these cases, a regression relationship between total body length and antennal scale length was used to predict total body length from antennal scale length.

The stages of maturity and sex were determined. Mature males were recognized as having the fourth pleopod extending beyond the base of the telson and a well developed antennular peduncle. Mature females were identified by the presence of fully developed oostegites without eggs. Brooding females contained eggs or embryos, and spent females had no eggs. Immature animals were recognized as having distinguishing sex characteristics, while juveniles exhibited no sex characteristics (Reynolds and DeGraeve, 1972).

Hydroacoustic Sampling

Mysid hydroacoustic data were collected directly over the net haul sites during the vertical mysid net hauls. The hydroacoustic information is imbedded in the monthly kokanee echosounding data sets and cannot be retrieved at the present time as the mysid signal is masked by background noise and kokanee targets in the acoustic signal. Dean Addison (U. Victoria/IOS) attempted to develop pattern recognition software that would allow separation of background noise and kokanee signals from the mysid signal, however, this procedure has not been successful and is on indefinite hold.

Kokanee

Hydroacoustic Sampling

Hydroacoustic surveys consisted of monthly surveys (on or about the new moon) conducted from May to October 1994 concurrent with mysid netting at six stations in 1992 and seven stations in 1993 and 1994. In addition, one complete survey of the lake was conducted each year during the fall. The fall survey consisted of continuous hydroacoustic monitoring along 18 transects evenly spaced from the north to south end of the lake (Fig. 3). These data were then compared to data collected in previous years to estimate annual variation in kokanee density. Data collection consisted of continuous recording of acoustic signals along radar navigated transects at a boat speed of 2 $m \cdot sec^{-1}$ (Sebastian and Scholten, 1995).

Hydroacoustic sampling of kokanee used two types of echosounding equipment simultaneously. The dual beam system (BioSonics Model 105 @ 420 kHz, 6 degree beam angle) recorded kokanee echo data on Digital Audio Tape (DAT) for later analysis. At present, kokanee data are obtained by manual interpretation of the echo chart traces, although an electronic (and very expensive) echointegration technique is available that can automatically process the data. Boat speed and transducer stability are critical to the quality of the data gathered with the BioSonics system.

The second data set was collected using a Simrad sounder (EY200P @ 70 kHz, 11.6 degree beam angle) coupled with HADAS software (Version 3.98; Lindem, 1991) for data analysis. This unit produces a colour chart enabling limited real time visual estimates of fish size as well as abundance and size distribution. The BioSonics and Simrad systems both provide data on kokanee density, the main differences being that HADAS uses a single, wider beam of lower frequency and applies a statistical deconvolution procedure to estimate the size frequency distribution of fish targets. Kokanee density estimates and age proportions were produced using the Simrad/HADAS system. Adjustments in the size cut-off between age 0 and age 1-3 fish were made as fish grew over the summer period. The cut-offs were verified using size-frequency distributions from monthly trawl surveys converted to equivalent acoustic units (decibels) using Love's (1977) empirical relation.

Growth

Kokanee were sampled monthly from May to October 1994 during the new moon, when the fish are found nearest to the surface and are least able to see and avoid the sampling gear. Trawling for kokanee began at dusk using a 5 m by 5 m beam trawl net attached to a bridle and single tow line cable. The net was towed at a speed of 0.9 $m \cdot s^{-1}$ and had mesh small enough to ensure the capture of fry. A depth sounder was used to determine efficient trawling depths. Up to six hauls were made at each station in order to capture at least fifty fry. These hauls were of varying duration, oblique or straight, and made at depths chosen to maximize the capture of fry for diet samples. At each station, twenty fry caught within two hours of dusk were preserved in 70% ethanol for diet analysis (ethanol was replaced within three days for long term storage). A further thirty fry were preserved temporarily on ice and their fresh lengths and weights measured. These fish were then frozen for subsequent otolith analysis and back-calculation of growth histories of surviving fish. Any older fish caught within two hours of dusk were also preserved for diet analysis, and those caught later were measured, weighed and had scales removed for ageing.

In early October the standard annual trawl series was done to monitor annual variation in kokanee density, and length and weight-at-age. Six 40-min hauls were made at each of Stations 3 to 6. Oblique hauls were made by towing the net for 8 min at each 5 m depth stratum from 40 m to the surface. A sample area of 0.216 ha was covered by each haul. Trawls at Stations 1, 2, and 7 were done as in other months.

Diet

Stomach samples were analyzed for zooplankton counts and biomass by species (weights estimated from published empirical length-weight regressions, McCauley, 1984), mysid counts and biomass (weights estimated from empirical length-weight regression, Lasenby, 1977, unpublished data), and total dry weight of other organisms such as terrestrial insects. Samples were examined with the same apparatus as the zooplankton samples. Zooplankton were identified to species where possible, and were otherwise identified as either cladocerans or copepods. For small fry the entire stomach contents were analyzed; for larger fish one quarter of the petri dish was counted so that at least two hundred organisms were recorded. In either case up to thirty organisms of each zooplankton species were measured. Mysids were usually fragmented so total length was calculated from regressions relating total length to length of the antennal scale, carapace, exopod or endopod.

Spawner Escapement, Size and Fecundity

Adult kokanee returning to spawn in the Meadow Creek spawning channel were observed from 28 August to early October 1994. The channel was full by 3 September; after that time new fish were allowed to enter the channel only after some fish within the channel were moved upstream into John Creek and upper Meadow Creek, above the spawning channel. The number of adults entering the spawning channel was counted at the lower fence, and visual shoreline counts were made of

kokanee spawning in Meadow Creek between the channel and Kootenay Lake. A standardized visual estimate of the number of adults returning to the Lardeau River and Wilkie Creek was made by helicopter. Kokanee in Meadow Creek were sampled for length, sex ratio, fecundity and egg retention. Otoliths and scales were taken for ageing.

Fry Outmigration

Juvenile kokanee migrating out of the Meadow Creek spawning channel were monitored from 14 April to 16 June 1994. Stop nets were used at the lower end of the channel to estimate numbers of kokanee fry emigrating from the channel. Sampling was conducted every few days, and daily during the peak of the migration (28 April to 14 May). Samples were collected hourly from 2100 h until 0300 h, for 10 min each hour but for as short a time as 1 min during the peak hours of migration, which usually occurred between 2100 and 0200 h. Appropriate expansion factors were used to estimate total emigration from the spawning channel.

Kokanee Stock Origin Study

Kokanee were introduced to Koocanusa (Libby) Reservoir in about 1977 (Skaar et al., 1995 in prep.), and the entrainment of kokanee through the dam has occurred since at least 1981 (Huston et al., 1984, in Skaar et al., 1995 in prep.). If these fish survive and move downstream to Kootenay Lake, they could confound estimates of Kootenay Lake kokanee abundance, and could potentially interbreed with the native Kootenay stocks. The Montana Department of Fish, Wildlife and Parks studied fish entrainment through the Libby Dam from 4 December, 1990 to 30 June, 1994 (Skaar et al., 1995 in prep.). Fyke nets were used to capture fish in the draft-tubes of the dam, from January, 1992 to June, 1994. Kokanee composed 97.5% of the catch. Skaar et al. (1995 in prep.) estimated that between 1.15 million and 4.47 million fish could have been entrained in the year from January 1992 to January 1993. About 81% of the large kokanee (>124 mm total length) captured in the draft-tubes had suffered injuries assumed to have been caused by the turbines. However, 32% of the kokanee had sustained only minor, non-lethal injuries (another 19% of the total had injuries that could have been caused by the netting procedure). Thus, between 368,000 and 1.43 million fish, mainly kokanee, could have survived entrainment and made their way into Kootenay Lake.

Since 1993 a snag fishery for kokanee has taken place below Kootenai Falls (Mr. Steve Dalbey, pers. comm., Montana Department of Fish, Wildlife and Parks, Libby, Montana). The fishery occurs from about 15 September to 15 October each year. About 25,000 to 40,000 fish were estimated to be present in both 1993 and 1994, but fewer fish returned in 1995. Approximately 50 to 100 anglers were present per day, which resulted in an estimated annual fishing effort of 1,500 to 3,000 angler-days.

In the fall of 1993 a kokanee spawner run was observed in Lake Creek, a tributary of the Kootenai River below Kootenai Falls (S. Dalbey, pers. comm.). Electrophoretic analysis indicated that these fish were Libby stock (pers. comm., Dr. George K. Sage, Division of Biological Sciences, The University of Montana, Missoula, Montana). Since it is not possible for fish to make their way

above the Kootenai Falls, it is likely that fish that have passed over the Libby Dam are living in Kootenay Lake prior to spawning below Kootenai Falls, and in tributaries of the Kootenai River, and that these fish could be caught in trawls in the main lake. The presence of these fish could confound estimates of Kootenay Lake kokanee growth and survival.

In 1993/94 a genetic analysis of kokanee from Kootenay Lake was conducted to determine if some of the fish caught in trawls in Kootenay Lake could have originated in Koocanusa Reservoir, and the relative contribution of Koocanusa fish to the Kootenay Lake kokanee populations. Fish from the North, South and West Arms, and the central part of Kootenay Lake were compared with one another and with fish analyzed in a previous study of Koocanusa kokanee collected from Lake Creek and the Kootenai River. In September 1993 spawning kokanee were collected from the Meadow Creek (North Arm), Kokanee Creek and Redfish Creek (West Arm) spawning channels. These fish were supplemented with fish caught over the summer in trawls at Stations 1 (North Arm), 5 (central) and 7 (South Arm). The fish were frozen and transported to the University of Montana, where electrophoretic analyses were performed. "Horizontal starch gel electrophoresis was used to determine the genotype of each fish at 45 genes that code for proteins present in eye, liver, or muscle tissue. The data from these loci were used to determine if genetic differences exist between age classes within samples, and between samples." (pers. comm., G.K. Sage).

Kokanee Fry Vertical Migration

In July/August 1994 a hydroacoustic study was conducted to examine the feeding behaviour of kokanee fry at two points along the nutrient gradient, and to see if the time spent feeding by fry was lower nearer the point of nutrient additions. Kokanee fry are known to migrate vertically to feed near the surface at dawn and dusk (Levy, 1991). Juvenile sockeye make a trade-off between time spent feeding, and hence vulnerable to predation, versus time spent in deeper, darker water where there is less food but less chance of predation (Clark and Levy, 1988). If there is an increased abundance of macrozooplankton, fry may "choose" to spend more time feeding, thereby increasing their growth rate, but also their mortality rate. Alternatively, fry may opt to feed so as to grow to a minimum threshold size for over-wintering. Since they would spend less time doing so if food were abundant, their mortality rate should decline if food is plentiful.

Hydroacoustic data were collected using a dual beam echosounder (BioSonics Model 105 @ 420 kHz, 6 degree beam angle) and recorded on Digital Audio Tape (DAT). The transducer was mounted on a fin and towed at a depth of 40 m so that upward-looking data could be collected. This technique allows a clear "view" of fish targets near the surface, unlike downward-looking methods. The transducer cannot receive signals from targets less than 1 m away, and the cone of sound is very narrow near the transducer, so placing the transducer well below the fish allows the collection of data on their vertical positions near the surface.

Hydroacoustic transects were made at Stations 1 and 4, over a period of 12 days, from 21 July to 2 August. Data were collected for three consecutive days at Station 4, then three days at Station 1, and again for three days each at Station 4 and Station 1, to control for the effects of the lunar cycle

and weather on fish behaviour. Transects were made across the lake for 1.5 h on either side of dawn and dusk; a total of 72 h of target strength and depth data were collected.
Incident light intensities were monitored at 1 m above the water surface (on the boat) using a LiCor lightmeter (Lambda Instruments LI-185 Quantum/Radiometer) at 10 minute intervals. The vision of salmonids is sensitive to ultraviolet light (Beaudet et al., 1993) and some fishes may feed more effectively at dusk and dawn, when the proportion of ultraviolet light is greatest (pers. comm., Dr. Craig W. Hawryshyn, Dept. of Biology, University of Victoria, Victoria, BC). In order to correct for possible differences in ultraviolet light absorbance at the two stations, we collected triplicate 50 ml water samples each dawn, and filtered them through a 0.45 μm Sartorius 11103 cellulose acetate filter. Later the samples were analyzed for ultraviolet absorbance at 310 nm using an LKB Biochrom Ultrospec II 4050 UV/Visible spectrophotometer. These absorbances can be converted into attenuation coefficients to predict the depth of penetration of ultraviolet light (Scully and Lean, 1994) at the two stations. This may help in explaining any differences in time spent feeding at the two stations that is not attributable to differences in zooplankton and/or fish abundance.

Data are currently being analyzed with echosignal processing and size frequency distribution software to determine the times at which fish were observed at different depths. These depth-time frequencies will be compared for the two stations to see if there are differences which could be attributed to differences in food densities.

Gerrard Rainbow Trout

Escapement and Size

Visual counts of Gerrard rainbow trout spawners have been made each spring in April and May at the spawning ground in the Lardeau River near Gerrard from 1957 to 1994. Annual peak counts are recorded, and total escapement is estimated to be three times the peak count (pers. comm., Les Fleck, BC Ministry of Environment, Lands and Parks, Nelson, BC). Samples of fish were trapped over the period from 1982 to 1992. Fish weight and length were measured, and fish were examined for fecundity.

Results and Discussion

Fertilizer Application

The first tanker shipment of fertilizer (i.e., 10-34-0) arrived on 23 April 1994, and the 1994 distribution schedule began the same day. All of the 1994 applications were completed on schedule without any complications (see Appendix 2). The 1994 application schedule specified a total combined annual application of 712,228 litres of 10-34-0 and 28-0-0. According to the log book records submitted by the contractor, the actual application volume was also 712,228 litres, which is 100% of the target application volume. Given the accuracy of the fertilizer delivery system, this result was not surprising and was accepted without audit as being factual.

Physical Limnology

Temperature

Kootenay Lake was isothermal at the start of the spring sampling period (11 April 1994) in the North Arm (Stations 1-4), while thermal stratification had already developed in the South Arm (Stations 5-7) (Fig. 4a-g). Stratification was not delayed at Station 7 in 1994, presumably due to the variable influence of the Kootenai River inflows, as was the case in 1993. A thermocline gradually developed at Stations 1 and 2 over the summer between 10 and 35 m as the lake warmed, however, the thermocline extended almost to the surface at Stations 3-7 with peak summer surface temperatures exceeding 20 °C at Stations 4-7. Temperatures at 50 m remained near 4-5 °C throughout the year. The lake began to cool in late August-early September and deep mixing was well underway by October, however, complete mixing had not occurred prior to the termination of the data collection on 9 November 1994. Clearly, 1994 was a warmer year than 1993, and anecdotal information from lake area residents confirmed our observations as swimmers were observed in the usually cold main lake (pers. comm., B. Lindsay, Ministry of Environment, Lands and Parks, Nelson, BC).

Dissolved Oxygen

Dissolved oxygen concentrations were relatively constant throughout 1994, with minimal variation at all depths (Fig. 5a-g). The minimum concentration recorded at 50 m was 11 $mg \cdot L^{-1}$, indicating the increased organic production from the fertilizer treatments was not causing any detectable decline in hypolimnetic oxygen concentrations.

pH

Kootenay Lake pH values showed minimal variation throughout 1994 with respect to season, sample location and depth, hence only Stations 2 and 6 are shown (Fig. 6a and b). At Station 2, pH values were fairly constant at 8.0-8.5 with a minor peak of 9.0 near the surface in August to mid October, which may be a result of increased epilimnetic phytoplankton activity. At Station 6, pH values were similar, ranging from 8.0 to 9.0.

Redox Potential

The redox potential is proportional to the equivalent free energy change per mole of electrons associated with a given reduction (Wetzel, 1975). In simpler terms, it is the net sum of the half-cell electrochemical reactions in the lake, and values which are positive are associated with oxidizing conditions, and negative values are associated with reducing (i.e., zero oxygen conditions). All of the 1994 values were highly positive, including the 50 m values, indicating oxidizing conditions were present at all depths (Fig. 7a and b). This is supported by the dissolved oxygen data (Fig. 5a-g). Redox values were similar at both stations (i.e., 300-400 mV), in contrast to 1993 when redox values tended to be higher at Station 6.

Specific Conductance

Specific conductance is a measure of a water's capacity to conduct an electrical current and is related to the total concentration of dissolved ionic matter in the water (Lind, 1979). Kootenay Lake conductivity values showed a slight seasonal and vertical trend throughout 1994. Values ranged vertically from 0.15 to 0.20 at Station 2 and 0.13 to 0.21 $mS \cdot cm^{-1}$ at Station 6 (Fig. 8a and b). At both stations, conductivity tended to decrease slightly in the epilimnion during the period of thermal stratification, with minimum values of 0.15 and 0.13 $mS \cdot cm^{-1}$ observed in Stations 2 and 6 respectively.

Secchi Depth

Secchi depths started out in the spring of 1994 at approximately 8-12 m for all stations, with Station 1 having the lowest initial value due to the influence of the Duncan and Lardeau Rivers (Fig. 9). Secchi depths quickly declined to 4-6 m for all stations during the spring bloom, after which Stations 1 and 2 generally recorded the lowest values for the remainder of the summer. Secchi depths began to increase in early September, and exhibited very similar values throughout the fall months.

Water Chemistry

Phosphorus

The concentration of dissolved inorganic phosphate ion (PO_4^{-3}) (measured as soluble reactive phosphorus, i.e., SRP) was below low level detection limits (i.e., $< 1\ \mu g \cdot L^{-1}$) on most occasions in 1994 (Fig. 10). This result was not surprising, as inorganic P is quickly taken up by plankton and bacteria in nutrient limited lakes (Wetzel, 1975). Three small SRP spikes were recorded in the North Arm on 28 June (Station 2), August 7 (Station 4) and 3 September (Station 2), and four small SRP spikes were recorded in the South Arm (17 May at Station 5, 28 June at Stations 5, 6 and 7, 27 July at Stations 5 and 6, and 7 August at Stations 5 and 6). Due to the unreplicated sampling design, it is not known if these were true readings or collection/laboratory errors. However, the fact that 8 of 11 small spikes occurred in the South Arm indicates that the added nutrients were quickly utilized in the North Arm and that the fertilization treatment was not creating an excess of available SRP.

Total phosphorus exhibited a weak north-south gradient in concentration, mainly during the period of highest weekly P additions (8 May to 6 August) (Fig. 11). The concentration of total phosphorus in the North Arm generally ranged between 4-10 $\mu g \cdot L^{-1}$, which indicates an oligotrophic to mesotrophic range (Wetzel, 1975).

Lekstrum et al. (1994) used the Kootenay Lake Fertilization Response Model (KLFRM, Walters et al., 1991) in combination with historical hydrological and phosphorus loading data to examine the potential impact of the Duncan and Libby Dams on mid-lake total phosphorus concentrations and

productivity in Kootenay Lake. The scenario simulating a restored hydrograph from Duncan and Libby dams, and historical P loading from the Kootenay, Lardeau and Duncan Rivers resulted in a 209% increase in surface total P concentrations from baseline conditions (3 $\mu g \cdot L^{-1}$) to an average July mid-lake concentration of 8 $\mu g \cdot L^{-1}$, which is within the observed range of 4-10 $\mu g \cdot L^{-1}$ recorded at mid-lake during July 1994. This result is encouraging as it suggests the experimental fertilizer loadings have increased the North Arm total phosphorus concentration to the range of the pre-impoundment era, which is the target for the fertilization experiment.

Nitrogen

Dissolved inorganic nitrogen (DIN, NO_2-N + NO_3-N + NH_3-N) exhibited a weak north-south gradient in concentration, with Station 1 usually showing the highest concentrations throughout the fertilizer application period (Fig. 12). An overall seasonal decline in DIN was recorded throughout the lake, despite the addition of approximately 206.7 Mg of inorganic nitrogen (624.8 Mg of 28-0-0 urea-ammonium nitrate). This confirms previous observations of a seasonal decline in DIN due to biological uptake, and supports the principle of gradually increasing the nitrogen loading and N:P ratio throughout the fertilizer application period. However, the concentration of DIN remained in the oligotrophic range (i.e., < 200 $\mu g \cdot L^{-1}$, Wetzel, 1975) throughout the year.

Kjeldahl nitrogen (KJN, i.e., organic nitrogen + NH_3-N) exhibited a slight north-south gradient from late May to late July. However, from August on there was no clear trend and two of the South Arm stations (5 and 7) recorded elevated concentrations of KJN on a few occasions in August and October (Fig. 13). Presumably this reflects the natural loading of KJN from the Kootenay River. The general seasonal trend of KJN was fairly constant, around 100 $\mu g \cdot L^{-1}$ throughout the sampling period and KJN concentrations generally remained in the oligotrophic range (i.e., < 200 $\mu g \cdot L^{-1}$, Wetzel, 1975) throughout the year.

Silica

The concentration of dissolved reactive silica showed a distinct north-south gradient, with the South Arm stations remaining higher throughout the period from April to October (Fig. 14). This gradient reflects the natural differences in loading from the Lardeau, Duncan and Kootenay Rivers as silica was not identified in the fertilizer mixture. Diatoms use silica to form their skeletal cell walls, and may become silica limited if concentrations decline below 0.5 $mg \cdot L^{-1}$ (Wetzel, 1975). The purpose of the fertilization program was to fertilize the lake at a sufficient level to stimulate primary production but not drive the diatoms into silica limitation which could alter the seasonal succession of phytoplankton in Kootenay Lake. The increase in silica in late October and early November is due to remineralization of dissolved reactive silica during lake overturn.

Carbon

Total inorganic carbon (TIC) data is available from 19 April to 31 May only, due to an error in the laboratory procedures (Fig. 15). Total organic carbon data was not collected.

Fluoride

A weak north-south gradient in dissolved fluoride was observed on two occasions from July to August 1994, with Stations 1 and 4 generally exhibiting slightly higher concentrations, although the second highest concentration on 13 July was recorded at Station 5 (Fig. 16). Most of the dissolved fluoride concentrations were at or below the minimum detection concentration (MDC) of 100 $\mu g \cdot L^{-1}$. A mass balance calculation indicates that the expected concentration of fluorine in the North Arm due to fertilizer application would be approximately 0.2 $\mu g \cdot L^{-1}$, assuming the fertilizer was evenly mixed throughout the top 20 m of the North Arm of Kootenay Lake. Since the MDC for dissolved fluoride wa 100 $\mu g \cdot L^{-1}$, it is likely that this gradient was due to natural dissolved fluoride loading from the Duncan and Lardeau Rivers, rather than via fluoride additions from the fertilizer, of which the 10-34-0 formulation contains 0.2 % by weight of fluorine. The maximum acceptable concentration of fluoride in Canadian drinking water is 1,500 $\mu g \cdot L^{-1}$ (CCREM, 1987) which is an order of magnitude greater than the concentrations observed in Kootenay Lake.

Turbidity

A weak north-south gradient in turbidity was observed in 1994, with Stations 1 and 2 generally showing the highest values, and Stations 5, 6 and 7 the lowest (Fig. 17), except during spring freshet when Stations 5 and 6 exhibited the highest turbidity values. This reflects the natural differences between the glacially coloured Lardeau and Duncan Rivers, and the less turbid Kootenai River, which has also been impounded by the Libby Dam (Koocanusa Reservoir) prior to entering Kootenay Lake.

Total alkalinity

Total alkalinity represents the buffering capacity of water and it is the quantity and kinds of compounds present that collectively shift the pH to the alkaline side of neutrality (i.e., pH > 7) (Lind, 1979). The concentration of total alkalinity showed a distinct north-south gradient, with the South Arm stations remaining higher throughout the period from April to September (Fig. 18). This gradient reflects the natural differences in loading from the Lardeau, Duncan and Kootenay Rivers.

Chlorophyll *a*

Chlorophyll *a* (not corrected for phaeophytin) exhibited a north-south gradient, with Stations 1, 2 and 3 generally showing the higher concentrations during the growing season (Fig. 19). Peak concentrations of chlorophyll *a* generally followed the period of highest weekly P loadings (i.e., >

13 Mg 10-34-0/week), which occurred from 8 May to 6 August 1994. The range of observed chlorophyll *a* concentrations are indicative of oligo-mesotrophic conditions (Wetzel, 1975). The low overall concentrations of chlorophyll *a* in the North Arm suggests that the nutrient application procedure allowed most of the increased phytoplankton biomass to pass on to higher trophic levels in the food web rather than accumulating as non-grazable algae in the epilimnion or diversion into the microbial food web.

Phytoplankton

Monthly transects and total biomass

The overall trend seen throughout the 1994 sampling season was one of decreasing algal biomass from the North Arm stations (Stations 1, 2, 3, 4) towards those in the South arm (Stations 5, 6 and 7) (Fig. 20). This was particularly striking in July and August, but was not evident in September and October. The following discussion examines each month in turn.

Total algal biomass in both April and May was low relative to the rest of the sampling season, however, biomass at the fertilized stations was about two times higher than for the same period in 1993. The North Arm stations had higher biomass (as high as 750 $mg \cdot m^{-3}$) than the South Arm stations (high of 380 $mg \cdot m^{-3}$). The majority of the biomass was comprised of centric diatoms (*Cyclotella* spp. and *Stephanodiscus* spp.) and flagellated cryptophytes and chrysophytes. Dinoflagellates also contributed to the total algal biomass at higher levels than in 1993.

In early June the biomass levels increased at Stations 2 and 3 with an increase in the pennate diatom *Asterionella formosa* and in the scaled chrysophte *Mallomonas*. *A. formosa* did not reach the bloom proportions observed in 1993. In 1994 as in 1993, total biomass was lower at Stations 5, 6 and 7 but only Station 7 remained at the low levels seen in April and May.

During June and July, *A. formosa* was replaced by *Fragilaria crotonensis* and algal biomass continued to increase at Stations 2, 3 and 4. In July, *Tabellaria*, *F. crotonensis*, and centric diatoms, such as *Cyclotella bodanica* and *Stephanodiscus niagare*, dominated the algal biomass. Phytoplankton in the division Chrysophyta, particularly *Mallomonas* sp., also contributed significantly to the total biomass.

Algal biomass reached a peak for the 1994 field season in August at Station 2 primarily due to a bloom of *Tabellaria* and *F. crotonensis*. Biomass was significantly lower at Station 1 and was similar to the levels observed in the South Arm.

In September, algal biomass declined to spring levels at Stations 1-5 resulting in similar concentrations at all stations. However, the biomass at Stations 6 and 7 remained at approximately 500 $mg \cdot m^{-3}$, which was higher than the spring biomass. This slight increase was caused by a higher abundance of cryptophytes, particularly *Cryptomonas erosa* and *C. ovata*.

Total biomass in October was highest at Stations 4 and 6 (750 $mg \cdot m^{-3}$). This increase in biomass was due to a bloom of centric diatoms.

Average biomass

Total algal biomass, averaged over the months of June, July and August, was significantly higher at North Arm stations relative to South Arm stations (Fig. 21). The trend shows decreasing algal biomass with increasing distance from the zone of fertilizer application and is remarkably similar to the trend observed during 1993 (Ashley et al., 1994).

The hypothesis that algal biomass would be higher at the fertilized stations relative to the unfertilized ones is now clearly supported by the 3 years of data. Average annual total biomass as well as the summer average has increased since the beginning of fertilization in 1992 (Table 6). Station 2 has exhibited progressively higher annual summer biomass although the summer average in 1994 was similar to that observed the previous year. Station 2 has now reached algal biomass levels typical of a mesotrophic lake while Station 6 remains at oligotrophic levels.

Table 6. Biomass averages ($mg \cdot m^{-3}$) at the fertilized station (Stn. 2) in the North Arm and the "control" station (Stn. 6) in the South Arm during the first 3 years (1992-94) of fertilization.

Year	Annual (April-October) (n=7-14)		Summer (June - August) (n= 3)	
	Station 2	Station 6	Station 2	Station 6
1992	445	359	534	473
1993	658	364	1091	455
1994	900	477	1183	557

Composition

Kootenay Lake continues to be a diatom dominated lake and diatoms responded positively to the fertilization treatment (Fig. 22). At Station 2, in contrast to 1993, *Asterionella formosa* did not form as large a bloom in the spring of 1994. This may have been due to differences in water column stability and onset of stratification, as 1994 was considerably warmer than 1993. *Asterionella* is typical of the vernal period in temperate lakes and dominates under conditions of strong vertical mixing (Reynolds, 1984). The large increase in diatoms in late summer of 1994 (Fig. 22) is due mainly to a large bloom of *Tabellaria*, a taxon that was less dominant in 1993. This taxon typically succeeds *Asterionella* seasonally and is dominant under conditions of moderate nutrient availability and intermediate water column stability (Reynolds, 1984).
The Cryptophyta and Chrysophyta were also generally stimulated by the fertilization. The Chlorophyta represented a very small proportion of the overall biomass. As in previous years,

cyanobacteria were never common in the phytoplankton samples and were often not seen at all. The largest biomass of cyanobacteria enumerated was only 20 $mg \cdot m^{-3}$ (4.3% of total algal biomass) of *Anabaena* spp. at Station 6 in mid-September. The total algal biomass is still sufficiently low that cyanobacteria should not be a significant component of the algal community (Pick and Lean, 1987).

Size Distribution

As in 1993, the increase in biomass at Station 2 relative to Station 6 was due to an increase in all size fractions of phytoplankton (Fig. 23). In late summer there was a slight relative increase in the microplankton (22-64 μm), still within the range of zooplankton edibility. The edible fraction of taxa below 20 μm represented on average half of the biomass at both stations. However, because of the higher biomass at Station 2, the nanoplankton biomass was significantly higher at Station 2 (Fig. 24) during the first part of the season when it would be critical for zooplankton development.

Preliminary Conclusions

As in 1993, the fertilization of the North Arm in 1994 resulted in higher algal biomass than in the South Arm. Since the size distribution of the algal biomass was similar in both arms, the higher biomass in the North Arm meant a higher biomass of algae in the nanoplankton size range (2-22 μm), considered the most edible size fraction for zooplankton. In both arms, the non-edible size fraction of the netplankton (> 64 μm) remained low. The fertilization regime would appear to be beneficial for enhancing zooplankton production.

Zooplankton

Macrozooplankton

The seasonal mean zooplankton density observed in 1994 was higher than in 1992 and 1993, and was similar to the highest densities observed from 1972 to 1984 (Fig. 25). For comparison with historical data the average at the mid-lake Station 5 (near Crawford Bay) was used. The proportion of cladoceran zooplankton, a preferred food source of kokanee and *Mysis*, continued to be higher than at any previously observed period of time (Fig. 26). Cladocerans comprised about 7.5% of the zooplankton in the North Arm in 1994, 12% in 1993, and 7.5% in 1992, compared with values less than 5% observed between 1949 and 1991. It appears that the density of preferred food for kokanee and mysids continues to be higher than in the past.

Zooplankton densities peaked in June and September (Figs. 27 - 30). The first cladocerans appeared in early May (3 May sample at Station 2), but the first *Daphnia* were observed in mid-June (15 June sample at Station 7) (Fig. 27, 30). Cladoceran densities peaked in August, with the highest density observed at Station 6. Few cladocerans were observed in November. Zooplankton densities did not follow the nutrient gradient (i.e., higher at the north end of the lake, and lower in the south). This may indicate that kokanee and/or mysids responded to increased zooplankton

productivity in the fertilized part of the lake by moving to that area to feed, thus cropping down the zooplankton.

Zooplankton Productivity Experiment

The zooplankton observed in the nine enclosures did not exhibit densities or fecundities higher than zooplankton in the main lake, despite the lack of predation from *Mysis* and kokanee. There does not appear to have been a bias against the Birge net used to capture and sample the enclosure zooplankton, versus the Clarke-Bumpus net used in the routine main lake sampling. Main lake zooplankton densities estimated from samples caught with the Birge net on the same days as the second and third sets of enclosure zooplankton ("Lake-Wisc") were higher than densities calculated from the Clarke-Bumpus net; i.e., the Birge net is more efficient than the Clarke-Bumpus net (Fig. 31, 34).

Daphnia densities in the enclosures were consistently lower than densities observed in the main lake (Fig. 31). Densities in the enclosures were always less than 1.5 individuals·L^{-1}, versus densities as high as 3.2 individuals·L^{-1} in the main lake. There are several possible explanations for the low densities observed in the enclosures. Temperatures in Kaslo Bay may have been higher than optimal, the zooplankton may not have been able to migrate vertically as much as necessary because the enclosures were only 4 m deep, or chemicals (e.g., anti-fouling paint) in the waters near the marina may have adversely affected the zooplankton.

Daphnia fecundities, expressed as number of eggs per unit volume, were also lower in the enclosures than in the main lake (Fig. 32). To examine the effect of different densities, fecundity was plotted against density (Fig. 33). The fecundity per individual was higher in the main lake samples. The number of eggs per litre increased as density increased for main lake samples, but no increase was apparent for enclosure samples, perhaps because of the small range of densities observed. Individuals carried an average of less than 0.5 eggs. In the main lake the average was about 0.38 eggs, and about 0.1 eggs in the enclosures.

Similar results were obtained for *Diaphanosoma* (Fig. 34). Densities observed in the enclosures were as high as 1 individual·L^{-1}, but as high as 2.7 individuals·L^{-1} in the main lake. During the time period of the first set of enclosures, fecundities in the main lake tended to exceed those observed in the enclosures (Fig. 35), but by Julian day 210 (29 July), fecundities in the enclosures and the main lake were similar, and very close to zero. With the exception of three observations in the main lake, the number of eggs·L^{-1} did not increase as densities increased (Fig. 36). Fecundities ranged from 0.04 eggs per individual to 1 egg per individual.

We do not plan to repeat this experiment in 1995, because there is no viable alternative site to locate the enclosures which would be deeper and/or away from boat engine and anti-fouling paint pollution. Zooplankton productivity will be estimated from main lake density and fecundity data, and estimated natural mortality rates, as well as data on feeding rates of *Mysis* and kokanee.

Mysids

Distribution and Abundance

Mysid densities ranged from 0 to 923 no·m^{-2}. In 1994, average densities were similar across all seven stations, shallow and deep (Fig. 37). Mysid densities were consistently greater at the deep sites than the shallow sites. Mysid numbers were highest in the lake in August at the deep sites and from May to August inclusive at the shallow sites (Fig. 38), probably as a result of the release of the young in spring.

Seasonal, whole-lake average densities in 1994 were slightly lower than in 1993, and were less than 50% of the 1992 densities (Fig. 39). Although mysid abundance has declined, numbers are not lower than those found historically (e.g., less than 100 no·m^{-2} in 1972 across the lake; Crozier and Duncan, 1984), and it is not uncommon for mysid abundance to fluctuate greatly from year to year in Kootenay Lake (Fig. 40).

When the lake is divided into three regions (South Arm, Mid-lake, and North Arm) distributional differences and seasonal patterns of mysid densities are observed (Figs. 41a-c; 42a-c). In 1992 abundances were highest in the North Arm; in 1993 abundances were lowest in the North Arm. In 1994, overall abundances were similar across all three regions (Fig. 41c). Abundances were highest seasonally from May to October in all regions and for all years (Figs. 41a-c; 42a-c). Long-term monitoring is therefore required before any conclusions can be drawn from yearly abundance estimates.

Mysid Gut Content Analysis

Gut content analysis for 1993 samples indicate that mysids feed primarily on cladocerans, copepods, and rotifers. Occasionally items such as pollen grains, mysid mandibles, sediment and diatoms are also observed in the gut contents. The range of food items (mandibles, rotifers) counted was highly variable between mysids in a single sample (e.g., from 1 to 44 *Daphnia galeata mendotae* mandibles). Fig. 43 (a to h) illustrates the seasonal variation in the average number of food items in the mysid guts at the seven sampling sites. The highest numbers of cladocerans were found in the stomach contents from August through October (Fig. 44a); this corresponds with the relatively higher cladoceran abundance in the lake during this period (Ashley et al., 1994). Copepod mandibles are found in the stomach contents throughout the year (Fig. 44b), varying from an average of ten mandibles per mysid in June (the lowest number observed), to an average of twenty-six mandibles per mysid in July (the highest number observed). One area of particular interest is the presence of cladocerans in the mysid guts in spring and early summer (Fig. 45) when none were found in the zooplankton samples (Fig. 27), indicating the efficiency of mysid predation on cladocerans.

In both 1992 and 1993, *Diaptomus* mandibles were found in greater abundance than *Cyclops* mandibles in the mysid guts (Fig. 46 a-b). *Keratella cochlearis* and *Kellicottia longispina* were

present in the gut contents throughout 1992 and 1993; *Keratella hiemalis* was found infrequently over this period (Fig. 47 a-b).

From May to July 1992 and from December through June 1993, the prevalent cladoceran mandibles found in the gut contents were *Bosmina longirostris* (Fig. 48 a-b), a relatively small zooplankter. The absence of cladocerans in the early spring zooplankton samples may indicate that mysids are more proficient than our sample nets at capturing this type of zooplankter. Gut contents for 1994 samples are currently being analyzed.

Clearance Rate Experiments

Clearance rates represent the volume of water an individual mysid can clear of a specific prey item per unit time. This experiment provides an *in situ* estimate of the potential feeding rates of mysids on zooplankton in Kootenay Lake. Feeding rates estimated by the clearance rate experiment will provide an independent check of the caloric requirements predicted by bioenergetics models (Stewart et al., 1983; Rudstam, 1989). Extrapolating these results to the entire mysid population, and comparing predicted consumption to estimates of zooplankton production (determined by Lisa Thompson), will give an indication of the number of prey remaining for other zooplankton predators, including kokanee fry.

A significant difference was found in zooplankton density between the experimental and the control chambers (Table 7a-b; Fig. 49a-b). Mysid clearance rates ranged from 241.7 $mL \cdot h^{-1}$ for *Diaphanosoma*, to 47.26 $mL \cdot h^{-1}$ for calanoid copepods (Table 8; Fig. 50). Generally, clearance rates for cladocerans were higher than for copepods. Overall, these rates are low when compared with the average values of mysid clearance rates determined by Nero and Sprules (1986) which ranged from 748 $mL \cdot h^{-1}$ for *Diaphanosoma* to 237 $mL \cdot h^{-1}$ for adult copepods. However, their results also indicate that clearance rates differ significantly between lakes, experimental dates and mysid age.

Table 7a. Zooplankton density in the control and experimental chambers following the clearance rate experiment in Kootenay Lake, 9 August 1994. SD equals 1 standard deviation.

Organism	**Average Density ($no \cdot L^{-1}$) Control**	**SD**	**Average Density ($no \cdot L^{-1}$) Experimental**	**SD**
Calanoid	3.11	0.53	2.37	0.29**
Cyclopoid	13.19	2.24	9.18	0.99**
Daphnia	1.17	0.47	1.24	0.3*
Diaphanosoma	1.47	1.58	0.41	0.15n.s.
Bosmina	0.33	0.15	0.16	0.11*
Total	19.81	2.7	13.36	1.18**

n.s. = not significant; * = significant at the 5% level; ** = significant at the 1% level

Table 7b. Zooplankton density in the control and experimental chambers following the clearance rate experiment in Kootenay Lake, 12 August 1994. SD equals 1 standard deviation.

Organism	Average Density ($no \cdot L^{-1}$) Control	SD	Average Density ($no \cdot L^{-1}$) Experimental	SD
Calanoid	3.03	0.5	2.21	0.34**
Cyclopoid	11.19	2.28	8.98	2.31*
Daphnia	1.59	0.58	0.82	0.53**
Diaphanosoma	0.91	0.45	0.22	0.14**
Bosmina	0.57	0.3	0.16	0.1**
Total	18.02	3.25	12.42	2.91**

n.s. = not significant; * = significant at the 5% level; ** = significant at the 1% level

Table 8. Clearance rates of Kootenay Lake mysids on 9 August and 12 August 1994.

Organism	Clearance rates ($mL \cdot h^{-1}$) 9 August 1994	Clearance rates ($mL \cdot h^{-1}$) 12 August 1994
Calanoid	47.26	53.71
Cyclopoid	63.03	48.06
Daphnia	55.89	112.71
Diaphanosoma	222.06	241.67
Bosmina	125.90	186.10
Total	68.51	63.35

Length-Weight Relationship and Caloric Content

The bioenergetics model is used to predict consumption given the observed growth of an animal (Rudstam, 1989). Growth, determined from the life history analysis, is measured as a change in length. The model requires that growth is measured in terms of a change in weight. Therefore it was necessary to develop a length-weight relationship for mysids in Kootenay Lake, using unpreserved specimens. Determination of the caloric content of mysids in Kootenay Lake is also required for use of the bioenergetics model.

Plotting mysid dry weight (mg) against length (mm) resulted in a power curve, $y = 0.00256x^{3.025}$, where y = dry weight and x = length (Fig. 51a). The natural log of each variable was calculated, yielding the linear relationship $\ln(y) = 3.025 \ln(x) - 5.9669$ ($r^2 = 0.97$) (Fig. 51b). Raw data are presented in Appendix 4. The caloric content of juvenile, adult male and adult female mysids, collected from Kootenay Lake in August 1994, will be determined by microbomb calorimetry in 1996.

Growth and Life History

Growth and life history studies are being done to test the hypothesis that food is a factor regulating mysid life history. Life history characteristics include life span, age and size at which reproduction begins (i.e., time to maturity), fecundity, and frequency of reproduction (Stearns, 1976). Life history theory predicts that when individuals in a population are presented with abundant resources, those individuals should be able to grow more rapidly, reproduce at an earlier age, and produce more progeny than when in a population presented with limited resources (Stearns 1976). Life history theory, coupled with empirical observations from field populations (Morgan, 1981; Beeton and Gannon, 1991) predicts that growth rates of mysids in Kootenay Lake should increase to the point where a change in time to maturity could be observed.

If increased food levels in Kootenay Lake result in increased mysid growth rates, some individuals should be able to mature in one year, instead of the previously observed two year period. Also, a reduction in time to maturity should not result in a reduction in brood development time and therefore should not significantly affect quality of offspring. Therefore, in theory, the *Mysis* population should increase in overall productivity by maturing earlier under more fertile conditions.

To date all 1992 and 1993 deep haul samples for all seven stations have been measured, sexed, and analyzed, representing over 12,000 mysids. Samples through to the end of June 1994 have been measured and sexed.

When mysid density is plotted against mysid length, the population in Kootenay Lake exhibits a bimodal size distribution. Stations 2, 4 and 6 have been plotted adjacent to one another to facilitate comparison of population structure among stations along the length of the lake (Fig. 52 a - o). For some dates samples were not available for analysis and therefore could not be used in the comparison. No differences were apparent among these three stations.

In May the smaller cohort consisted of juveniles while the larger cohort consisted of immature males and females. This cohort also contained large two-year-old females which recently released the juvenile cohort. Mature females were also present throughout the year. Mature males first appeared in samples in late August 1992 and in late July in 1993, which indicated the commencement of the breeding season. Brooding females first appeared in October in 1992 and were present in samples through to the end of May 1993.

Plotting the mean length of the monthly cohorts against time illustrates the life history of mysids in Kootenay Lake. Figure 53 (a to g) illustrates the life history (i.e., life span) of mysids captured at all 7 stations along the lake. Juvenile mysids were released in the spring at a length of between 3.5 and 4.0 mm, and did not reach maturity by the end of the summer. By the end of July they became recognizable as male and female. They overwintered between lengths of 10 to 11 mm, showing little growth. By the end of their second summer they reached full maturity at a

length of 13.0 to 14.0 mm. Eggs were released into the brood pouch as early as October. Six to seven months later, when females were approximately 15.0 mm long, the juvenile mysids were released from the brood pouch. No significant difference in growth rates was found among sites or between years (ANCOVA, $p < 0.05$).

Shallow haul samples (hauls taken close to either the east or west shores) have been analyzed for Station 4 (Fig. 54). Analysis of shallow hauls from other stations are currently being conducted. Preliminary results indicate that the population structure in the shallow regions of Kootenay Lake is composed of a greater proportion of year-1 mysids than the deep regions of the lake (Fig. 55 a-l). A greater proportion of juvenile mysids in shallow waters, due to horizontal migration, have been documented for three California and Nevada mountain lakes (Morgan and Threlkeld, 1982). Furthermore, shallow haul sample abundances were always lower than deep haul sample abundances. Such differences could have significant implications when estimating the impact of *Mysis* on grazing zooplankton populations.

Consistently fewer animals would indicate lower levels of consumption. Smaller mysids consume a different size spectrum of zooplankters than larger mysids (Wetzel, 1983). It is also possible that mysid feeding rates would vary with age and level of sexual development. If the shallower portions of Kootenay Lake are viewed as being distinct from the deep basin, then a different population distribution could theoretically result in different levels of food consumption. Ignoring any potential differences, by not analyzing these samples, could yield greatly skewed results when analyses of *Mysis* predation impacts on zooplankton prey are extrapolated to the entire lake.

Preliminary Conclusions

In Kootenay Lake, mysid abundance estimates vary considerably from year to year and along the lake. Thus far, fertilization does not appear to have enhanced mysid numbers. Long-term monitoring may reveal trends in mysid abundance within the lake and therefore should be extended beyond the five year span of the initial fertilization experiment.

Mysids feed on cladocerans, copepods and rotifers, which indicates a potential for competition with the kokanee fry. No changes in diet have been observed from 1992 to 1993. The feeding habits of immature and juvenile mysids will be included in the Year 4 (1995) Kootenay Lake Fertilization Experiment report.

The extent of the impact of mysid feeding on zooplankton has yet to be accurately determined. However, preliminary calculations using 1994 clearance rates (this report) and 1993 zooplankton data (Ashley et al. 1994) indicate that mysids at an average density of 321.2 per m^2 (August 1993 whole lake density, deep hauls only) can consume 42% of cladocerans and 5% of copepods in fifteen days in Kootenay Lake. Fifteen days is a conservative estimate of the generation time of these zooplankters (Barnes, 1980).

The clearance rate experiment will be repeated during a second field season in Kootenay Lake (August-September 1995) with both adult and young-of-the-year mysids. In general, at any given time in the season, density of young-of-the-year mysids is greater than adult mysid density. Knowledge of consumption rates for this proportion of the population is essential for estimating the overall predator impact on zooplankton in Kootenay Lake. Consumption rates for mysids at various stages in their life history would then be available for comparison to rates as estimated by the bioenergetics model.

There has been no change in growth rate or time to maturity of mysids in Kootenay Lake over the two years analyzed to date. No differences were observed among the seven sites along the lake. It appears that the shallow regions of the lake support a greater proportion of year-1 mysids than the deep portions of the lake. Analysis of additional shallow haul samples should clarify this observation.

Kokanee

Hydroacoustics

Trawl surveys verified the majority of pelagic fish observed with the hydroacoustic equipment were kokanee. The fall hydroacoustic surveys suggested average kokanee densities of approximately 225 fish·ha^{-1} in 1992, 300 fish·ha^{-1} in 1993 and 900 fish·ha^{-1} in 1994 (Fig. 56). Since 1992, fish densities have increased and their distributions are less uniform, with higher concentrations of fish in the North Arm near the fertilization zone. Fish densities during July and August have increased by up to seven times since 1992, based on monthly monitoring at seven stations (Fig. 57). Although there is no background data (e.g., pre-1992) on kokanee distributions at this time of year for comparison, the extremely high densities of fish (up to 3,500 fish·ha^{-1}) observed in the North Arm are likely a result of the fertilizer treatment.

Monthly estimates of kokanee abundance based on only seven sites varied by up to 25% from August to October (Fig. 58). Although these estimates were not considered sufficiently accurate to show mortality rates over the summer, they indicated a four fold increase in the lake population between 1992 and 1994, which was supported by the more comprehensive fall surveys. The fall surveys estimated total kokanee abundance in Kootenay Lake at 9 million in 1992, 12 million in 1993 and 36 million in 1994. The North Arm fry populations peaked in July 1994 and gradually decreased by October (Fig. 59). During the same period, the South Arm fry population increased steadily, suggesting the fish move southward over the summer period and become more uniformly distributed in the lake by fall. Except for 1992, the age 1-3 fish appeared to reach highest densities in both the North and South Arms early in the summer, and decreased over the remainder of the summer period (Fig. 60). The patterns of movement in age 1-3 kokanee were less obvious and may result from opportunistic feeding migrations within the lake.

The low densities during June surveys suggest that fry may not have completed their offshore migration into pelagic habitats. The vertical distribution of fish in June indicated that some fish may have been too near the surface to be enumerated reliably with a downward facing transducer. Kokanee in July to October surveys were not found near the surface at night, once the lake became thermally stratified.

Growth

Spawner data from the Meadow Creek spawning channel were combined with trawl data to compare the length-at-age of cohorts from 1985 to 1994 (Fig. 61). Fall fry size, and fall age 1+ sizes do not appear to have changed significantly since 1985. Age 2+ fish have shown increased size from 1991 to 1994. Age 3+ fish have been larger from 1992 to 1994. These larger sizes have occurred despite a trend of increased densities (of spawning-aged fish) from 1992 to 1994.

Within-year growth in 1994 is plotted from May to October (Fig. 62-69). Fry length increased from about 28 mm in May to about 60 mm in October. Weights increased from about 0.15 g to 2.2 g over this period (Fig. 66). There were no consistent trends in length along the lake from May to August, but fry at Stations 6 and 7 were significantly larger than those at Station 1 in October, and there appears to be a trend toward increased fry length from north to south along the lake in August, September and October.

Comparison of hydroacoustically-estimated fish densities at different points along the gradient indicate that fry densities were higher in the North Arm than in the South Arm for most of the summer (Fig. 59). Fry densities became fairly even along the length of the lake by October, after fertilization had stopped for the year, and near the end of the algal and zooplankton growing season. This distribution pattern suggests that most fry are opting to stay in the North Arm during the summer (where zooplankton productivity may be higher as a result of fertilization) despite facing greater intra-specific competition for food. Algal biomass (particularly the grazeable nanoplankton size class) was higher in the North Arm throughout the growing season (Table 6). However, zooplankton densities did not show a comparable trend along the length of the lake during the 8 months sampled (Fig. 27).

This suggests that the high densities of kokanee in the North Arm caused enough predation on zooplankton that the zooplankton density was kept at about the same level as in the South Arm, despite increased zooplankton productivity in the North Arm. Since the feeding opportunity for an individual fish on a given day depends on the density of zooplankton, not on their productivity, fish should have done equally well in either arm of the lake, despite the difference in fish density (i.e., if fish were following an "ideal free distribution" of fish relative to their prey's productivity and density). The larger size of fry at Stations 6 and 7 versus Station 1, and the trend toward larger fry in the South Arm, may result from fry in the South Arm simply being older. They would have emerged earlier from the Meadow Creek spawning channel and would have had more time to travel to the South Arm, and more days in the lake to grow. Otolith analyses of daily growth rings will be done to determine the age of fry from different stations, and to clarify the fishes' growth histories and distribution behaviour.

The average length of 1+ fish increased from about 80 mm to 140 mm, with no consistent differences in size along the lake (Fig. 63). Weights of 1+ fish increased from 5 g to about 30 g over the season (Fig. 67). Age 2+ fish grew from about 170 mm to 215 mm (Fig. 64), while their weights increased from about 50 g to 120 g (Fig. 68). Age 3+ fish showed little change in length over the season (Fig. 65), with lengths ranging from about 210 mm to 250 mm, but sample sizes for this age class were very small. Weights of 3+ fish caught in trawls ranged from 100 g to 175 g (Fig. 69).

Spawner Escapement, Size and Fecundity

Kokanee escapement at the Meadow Creek channel and in the Lardeau River was 1.25 million fish in 1994 (Fig. 70). Escapements at both sites were the highest observed since 1986, but lower than some escapements observed in the 1970's. However, scale and otolith analyses, which will indicate the proportion of spawners which are 2+ (young spawners) and 4+ (older spawners), have yet to be taken into account.

Adult sizes at the Meadow Creek channel in 1994 were lower than those observed in 1992 and 1993, but still higher than any year prior to 1992 (Fig. 71). Fecundities were lower than in 1993, but higher than 1992, and similar to peak values observed between 1971 and 1978. As in the case of the abundance data, accurate ageing of the spawners will be necessary before the increases in average size and fecundity can be linked to beneficial fertilization effects rather than the effect of fish which have had to remain in the lake an extra year in order to achieve spawning size (i.e., fish that wait until age 4+ to spawn).

Egg Deposition and Fry Outmigration

Kokanee fecundity, egg deposition and fry outmigration data are compared for the period 1969 to 1994 (Fig. 72). Egg deposition in 1994 was over 120 million eggs, just below that of 1993. Deposition was higher than 1992, despite similar fecundities in 1992 and 1994, because of the increased number of spawners. Because the increasing trend in fecundity began before the onset of fertilization, it is not possible to tell at this time whether the continued increases are linked to nutrient additions or to density dependent effects on fish growth and fecundity.

Kokanee Stock Origin Study

The genetic analyses performed on fish caught in Kootenay Lake trawls and at the three spawning channels produced results that are somewhat ambiguous, but will allow us to monitor possible future mixing of the Koocanusa Reservoir and Kootenay Lake stocks. The kokanee in Koocanusa Reservoir originated from fry that were released from the Kootenay Trout Hatchery. Some moribund fry that were flushed out along with dead fry (morts) appear to have revived when they encountered natural food supplies in the reservoir. (pers.comm., Peter Brown, Kootenay Trout Hatchery, Fort Steele, BC). These fish could have been from the following stocks:

Lamb Creek (Moyie Lake)

Paleface Creek (Chilliwack Lake)
Okanagan River
Meadow Creek (Kootenay Lake)

Given the different times that these stocks were present at the hatchery, and the times that kokanee were first observed in Koocanusa Reservoir (around 1982), it is unlikely that the Koocanusa fish originated from Meadow Creek stock (pers. comm., Peter Brown, Kootenay Trout Hatchery, BC Ministry of Environment, Lands and Parks, Ft. Steele, BC). Thus, it would be possible that Koocanusa and Kootenay Lake kokanee would show genetic differences.

The kokanee native to Kootenay Lake were supplemented with hatchery fry from 1990 to 1993 (i.e., 1989 to 1992 year classes). These fish were of Hill Creek (i.e., Arrow Lake) and Meadow Creek stock, and were reared at the Loon Lake hatchery (near Clinton, B.C.), then in net pens in Kaslo Bay, prior to being released into the lake (pers. comm., Bob Lindsay, BC Ministry of Environment, Lands and Parks, Nelson, BC). This stocking should not have caused any mixing of genes between Kootenay Lake and Koocanusa kokanee.

The electrophoretic analyses performed at the University of Montana produced the following conclusions about the Kootenay Lake kokanee, based on allele frequency comparisons:

- fish caught in the North Arm (including fish from the Meadow Creek spawning channel) were different from fish caught in the central part of the lake, and the West Arm, but were similar to fish from the South Arm;
- fish from the central part of the lake were different from fish from the North, West and South Arms;
- fish from the West Arm were different from fish from the North Arm, central lake and South Arm;
- fish from the South Arm were different from West Arm and central fish, but similar to North Arm fish.

In summary, North and South Arm fish could not be distinguished genetically, and could be treated as one spawning population (pers. comm., George K. Sage). It is not surprising that the West Arm fish were genetically different from fish from other parts of the lake, since they spawn in unique areas in the West Arm. However, it is not clear why the fish from the central part of the lake differed from fish from all other areas.

Comparisons were also made between the four groups of Kootenay Lake fish and fish caught in the Kootenai River, Montana and Lake Creek, Montana (pers. comm., George K. Sage, Division of Biological Sciences, The University of Montana, Missoula, Montana). The Kootenai River and Lake Creek locations are upstream of Kootenay Lake, but below Kootenai Falls, so fish caught there could have originated in Koocanusa Reservoir, but would have been unable to migrate above the falls to spawn. No significant differences were observed between North and South Arm fish and those caught in Montana, but significant differences did exist between the Montana fish and those from the West Arm and central lake. Because there are no data available on the genetic

population structure of the Kootenay Lake kokanee prior to the time when Koocanusa kokanee could have begun moving into Kootenay Lake, it is not possible to say whether or not the North and South arm fish may have mixed with Koocanusa fish. However, because differences exist between the Montana fish and the West Arm and central lake fish, it will be possible to tell whether Koocanusa kokanee contribute to the Kootenay Lake kokanee population in the future.

Gerrard Rainbow Trout

Escapement and Size

Rainbow trout escapement (measured as the peak count observed at the Gerrard spawning ground on the Lardeau River) has ranged from 150 to 1,800 fish with the maximum occurring in 1979 (Fig. 73). This corresponded with rising kokanee abundances from 1973 to 1978 (Fig. 70). The peak count increased slightly in 1994 to about 900 fish, which is close to the long term average.

Size data is available from 1982 to 1992 (Fig. 73). Both males and females appeared to be slightly larger from 1984 to 1987, but small sample sizes make comparisons difficult. Physical size measurements were not made in 1993 or 1994, but observations during visual counting suggest that fish observed in 1993 were smaller than in 1992 (pers. comm., Les Fleck, BC Ministry of Environment, Lands and Parks, Nelson, BC).

Additional Publications

Much of the physical limnology data collected during the 1992 field season at Kootenay Lake was presented at international conferences in Grenoble, France (29 June - 2 July 1994) and Spokane, Washington (15-16 November 1994) and has been published in the respective conference proceedings (i.e., Stevens et al., 1994a; Stevens et al., 1994b; Hamblin et al., 1994a; Hamblin et al., 1994b). An additional report from the 1992 field season documenting river induced transport in Kootenay Lake (Stevens et al., 1995) is included in Appendix 6 with permission of the authors.

The laboratory component of the Resonant Enhanced Mysis Export study is completed in which physical (Allan, 1993) and numerical modeling (Gu, 1993) was conducted to determine the feasibility of increasing mysid transport over the West Arm sill by enhancing the internal seiche amplitude of Kootenay Lake via controlled discharges at the Corra Linn Dam. Publications from this study are currently in preparation and hopefully will be included in the 1995 annual report. The study of physical and behavioural factors influencing the export of mysids from Kootenay Lake (Dean Addison) experienced technical difficulties during the 1992 field season, and an attempt to salvage the data has been unsuccessful, therefore this component of the Kootenay Lake fertilization experiment has been terminated.

Recommendations for 1995

Project Management

Minor delays remain with regard to the timely forwarding of samples to the various laboratories once they have been collected. This problem can be resolved by outlining a shipping schedule so that the individuals collecting the samples are responsible for prompt forwarding to the various laboratories for analysis. In addition, a field sampling log must be provided with the shipped samples to facilitate accurate inventory and processing. Otherwise, the Kootenay Lake fertilization experiment is proceeding satisfactorily, and all participants should be congratulated for their performance.

Bull Trout

Bull trout have received minimal attention in the Kootenay Lake fertilization experiment, both in the original modelling workshop, and in the ongoing field studies. Given the increasing public and agency attention being directed at bull trout as a potential rare and endangered species, increased emphasis should be placed on their life history in Kootenay Lake, and how they may be influenced by the fertilization experiment. Inclusion of bull trout as an additional parameter in the Kootenay Lake Fertilization Response Model should be a relatively straightforward task for experienced modellers. Collection of field data is also required, and may be facilitated by the current operating orders for the Duncan Dam, which may allow direct enumeration of the number and size of bull trout migrating upstream to Duncan Reservoir. Additional tagging studies should also be undertaken to obtain more detailed life history information on Kootenay Lake bull trout.

Acknowledgements

This experiment would not have been possible without the dedication and enthusiasm of many individuals and organizations. Thanks to the Columbia Basin Fish and Wildlife Compensation Program (Gary Birch and Colin Spence) for kindly providing funding support. Thanks to the staff of Kootenay Wildlife Services Ltd. (Don Miller, Mark Young, Albert Chirico and Bill Bing) for sample collection under often inclement and difficult conditions. Region 4 staff of the Ministry of Environment, Lands, and Parks in Nelson (John Bell, Les Fleck, Jay Hammond and Bob Lindsay) were helpful as usual. Cascade Fertilizers Ltd. (Ray Reichel) and GVH Construction (George Veale) ensured the fertilizer was delivered on time and distributed in the correct location. Special thanks to Drs. Paul Hamblin, Greg Lawrence, Craig Stevens and Carl Walters for their continuing interest, support and scientific guidance. Special thanks to Les McDonald (Ministry of Environment, Lands, and Parks - Cranbrook) and Rick Crozier (Ministry of Environment, Lands, and Parks - Nelson) for providing valuable historical data on Kootenay Lake. Special thanks to Harvey Andrusak and Al Martin for ensuring Year 3 of the experiment proceeded as originally envisioned in the 5 year experimental program.

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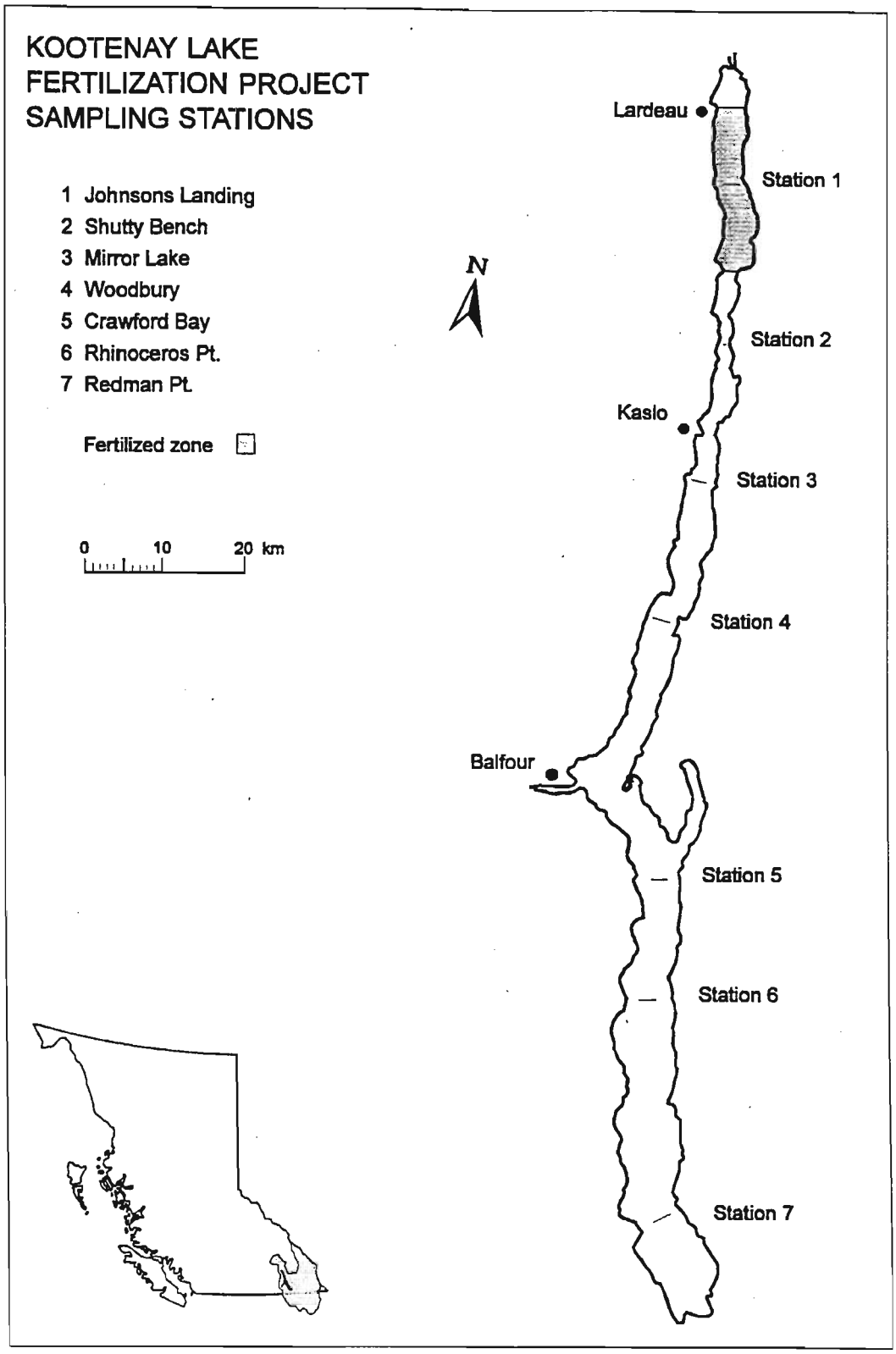


Fig. 1. Map of Kootenay Lake showing the seven sampling stations, kokanee trawl sites and the fertilizer application zone.

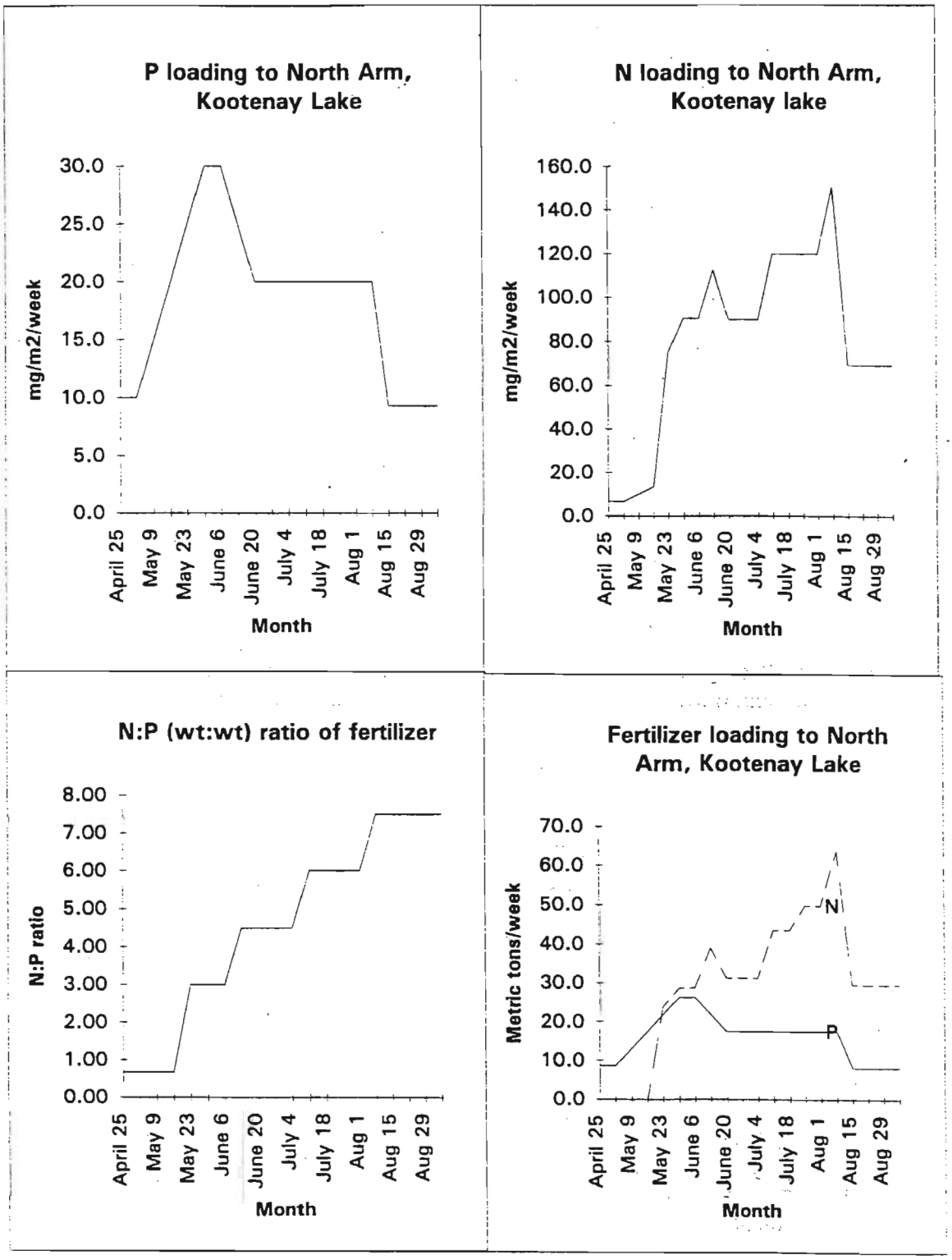


Fig. 2. Phosphorus and nitrogen loading, N:P ratio and total weight of fertilizer applied to the North Arm of Kootenay Lake in 1994.

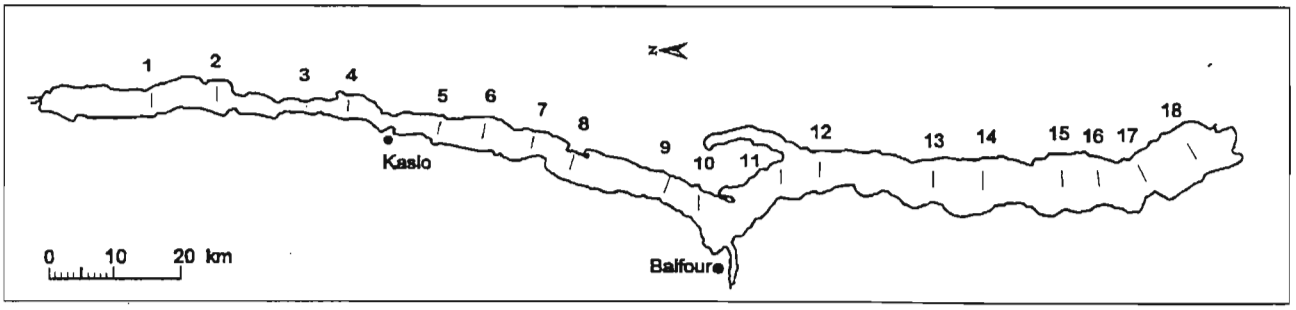


Fig. 3. Map of Kootenay Lake showing the location of the eighteen transects used during the fall hydroacoustic kokanee sampling.

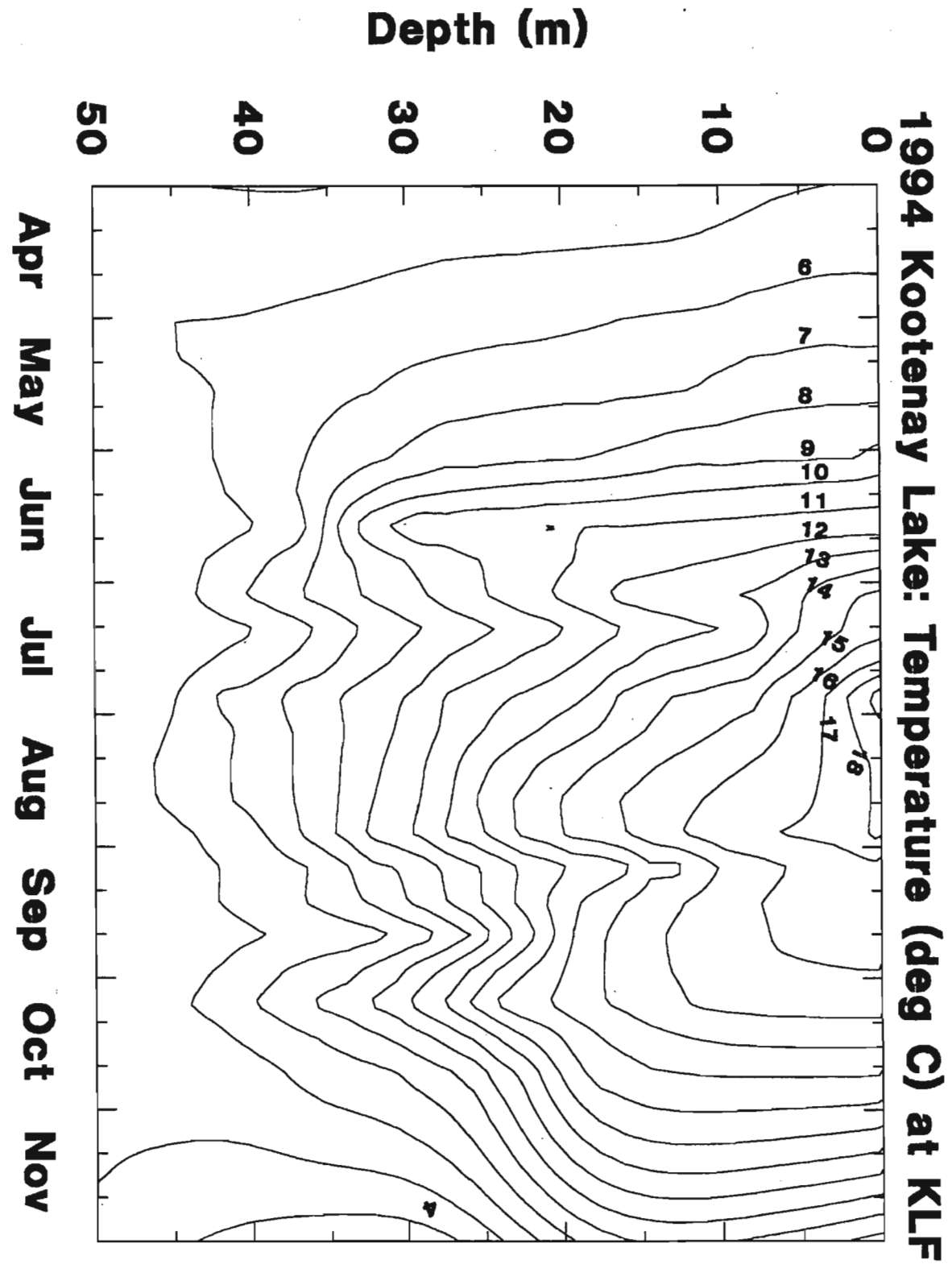


Fig. 4a. Temperature isopleths at Station 1 in 1994.

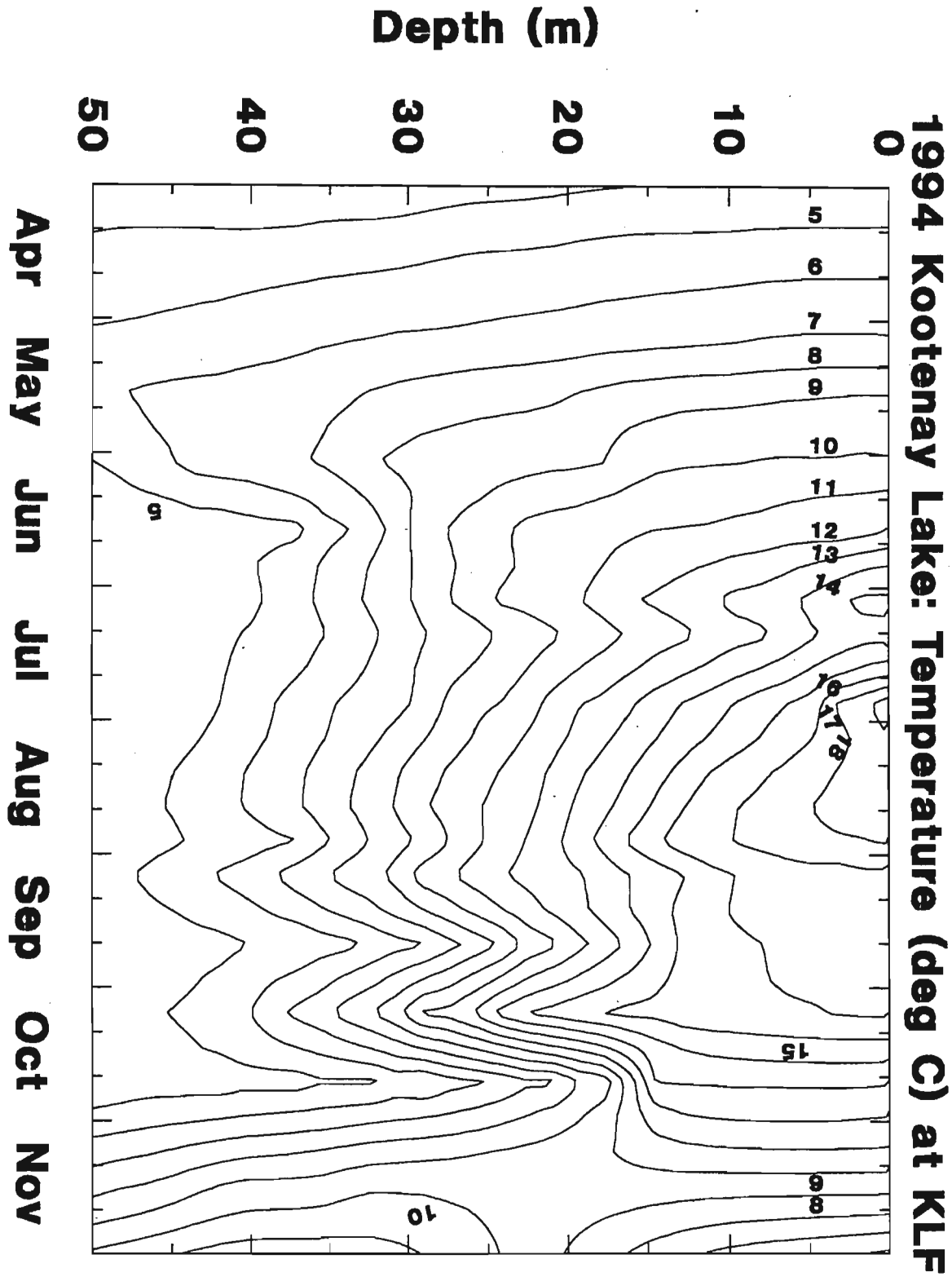


Fig. 4b. Temperature isopleths at Station 2 in 1994.

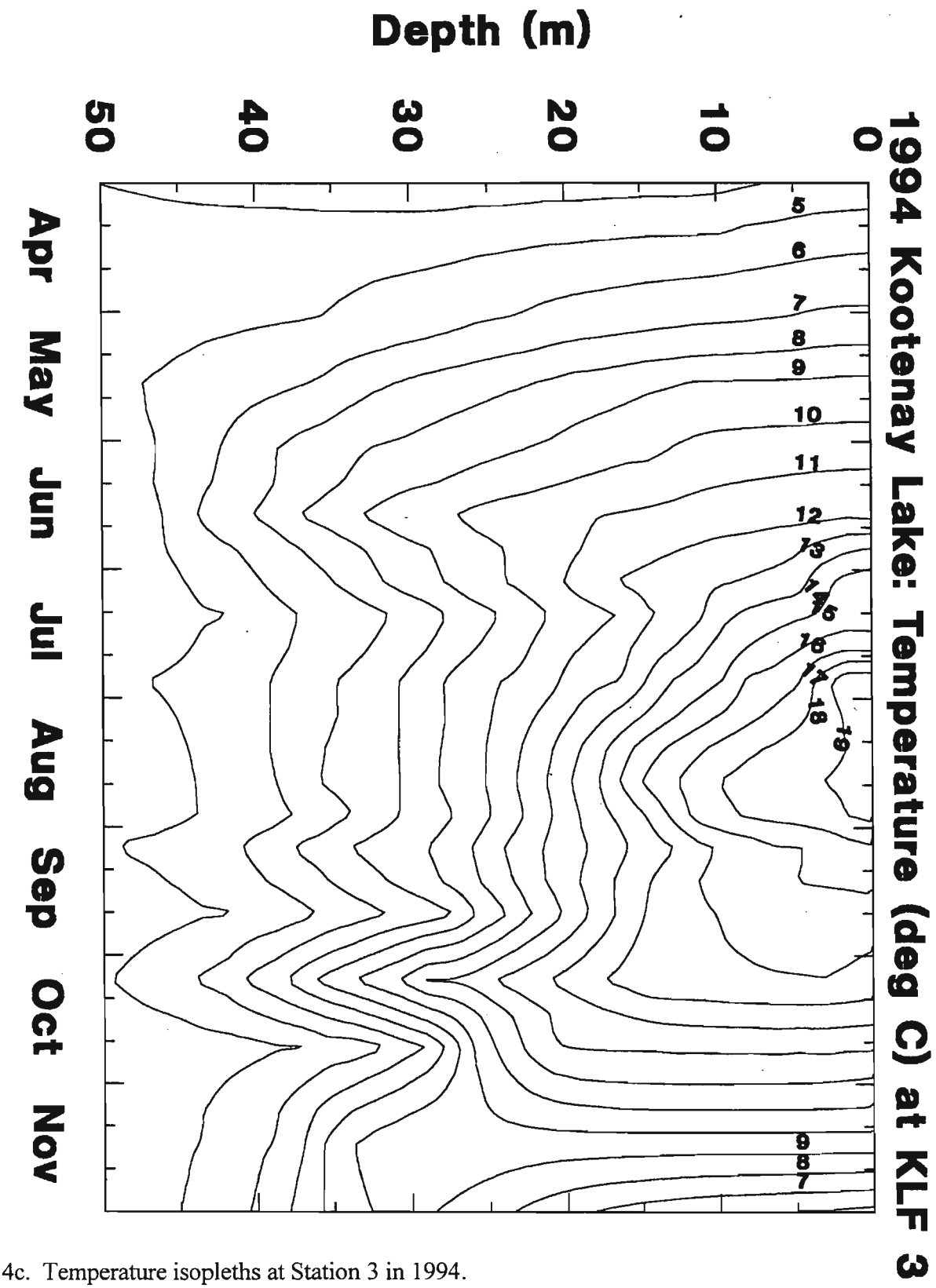


Fig. 4c. Temperature isopleths at Station 3 in 1994.

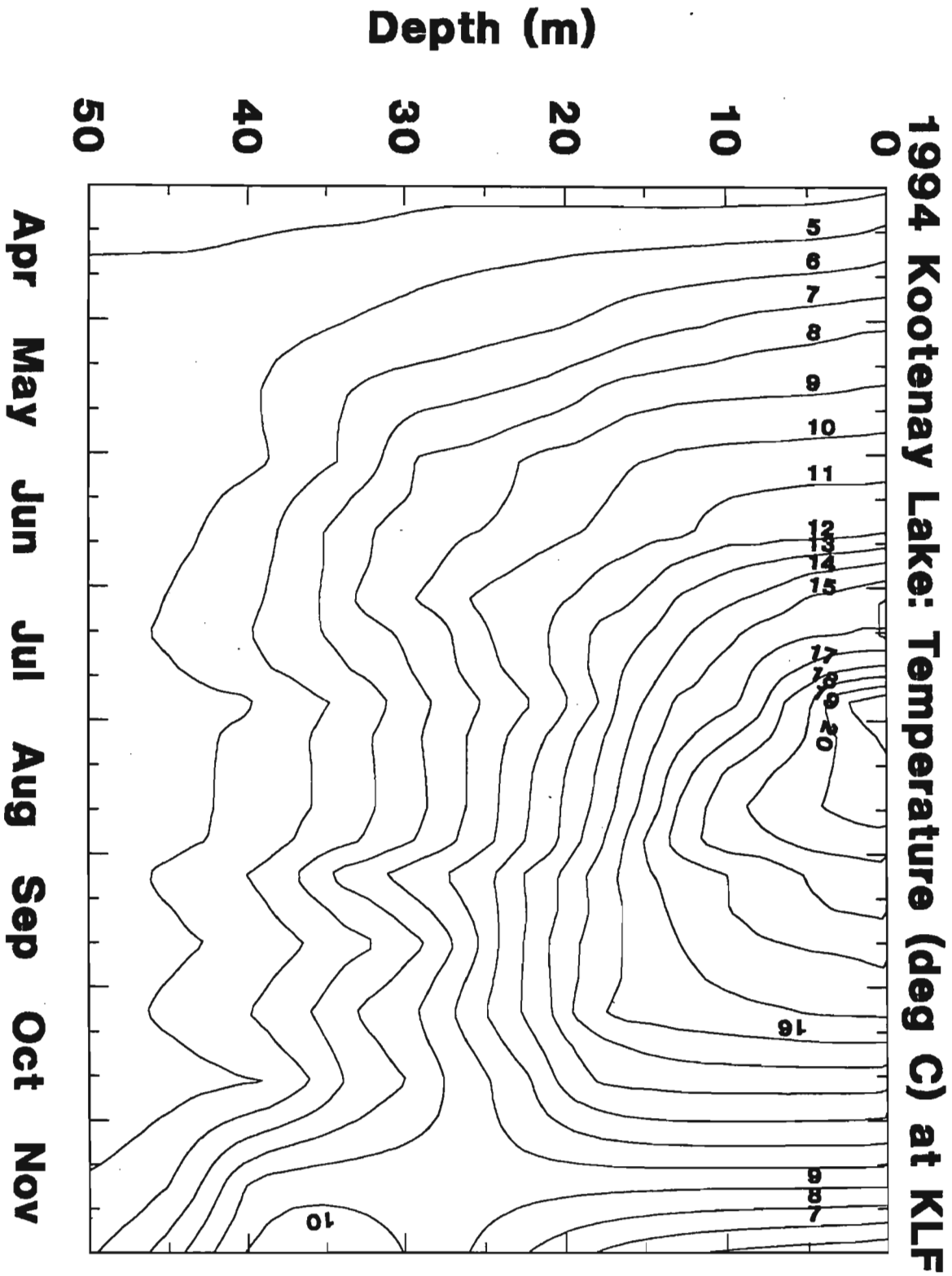


Fig. 4d. Temperature isopleths at Station 4 in 1994.

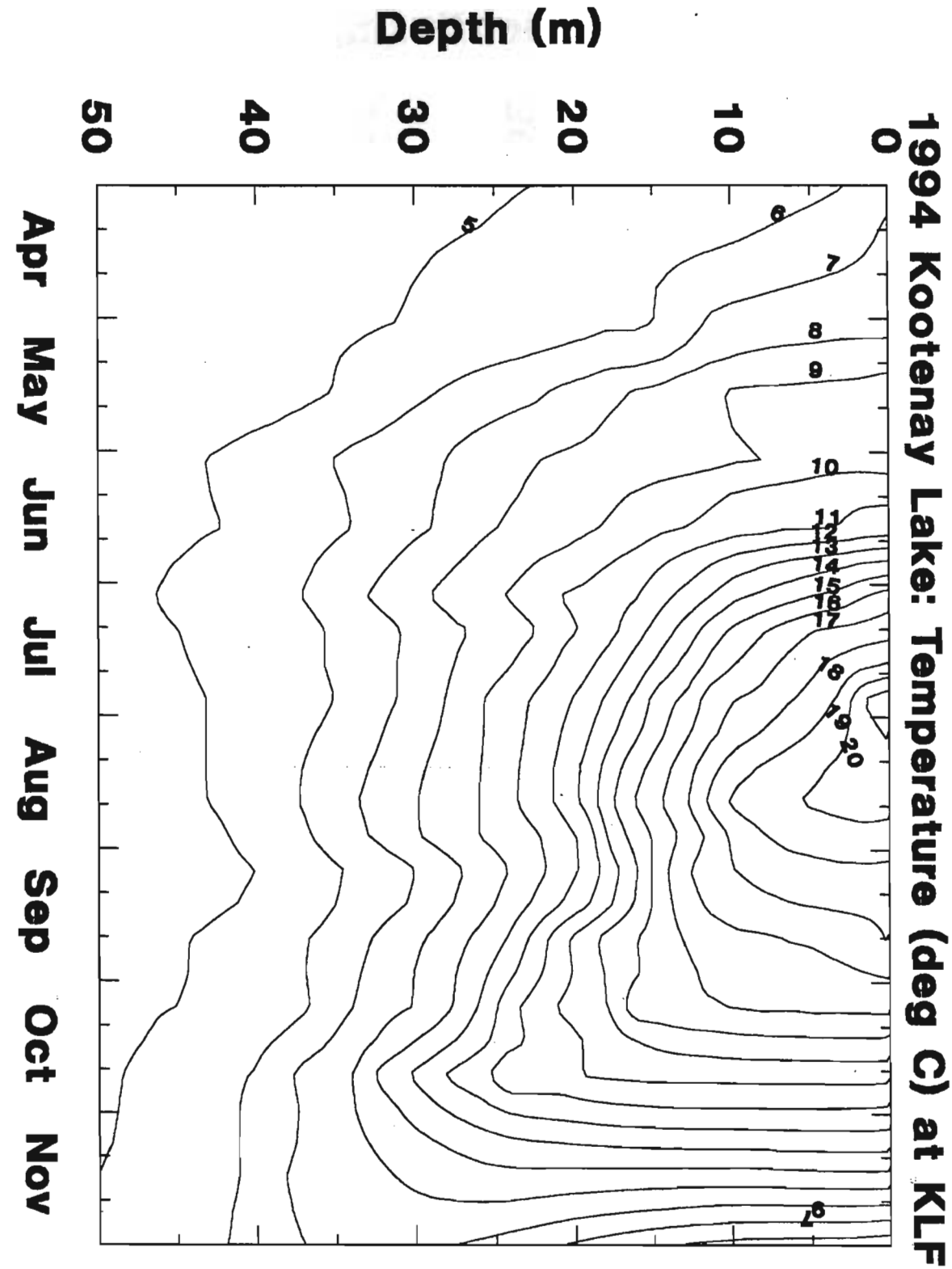


Fig. 4e. Temperature isopleths at Station 5 in 1994.

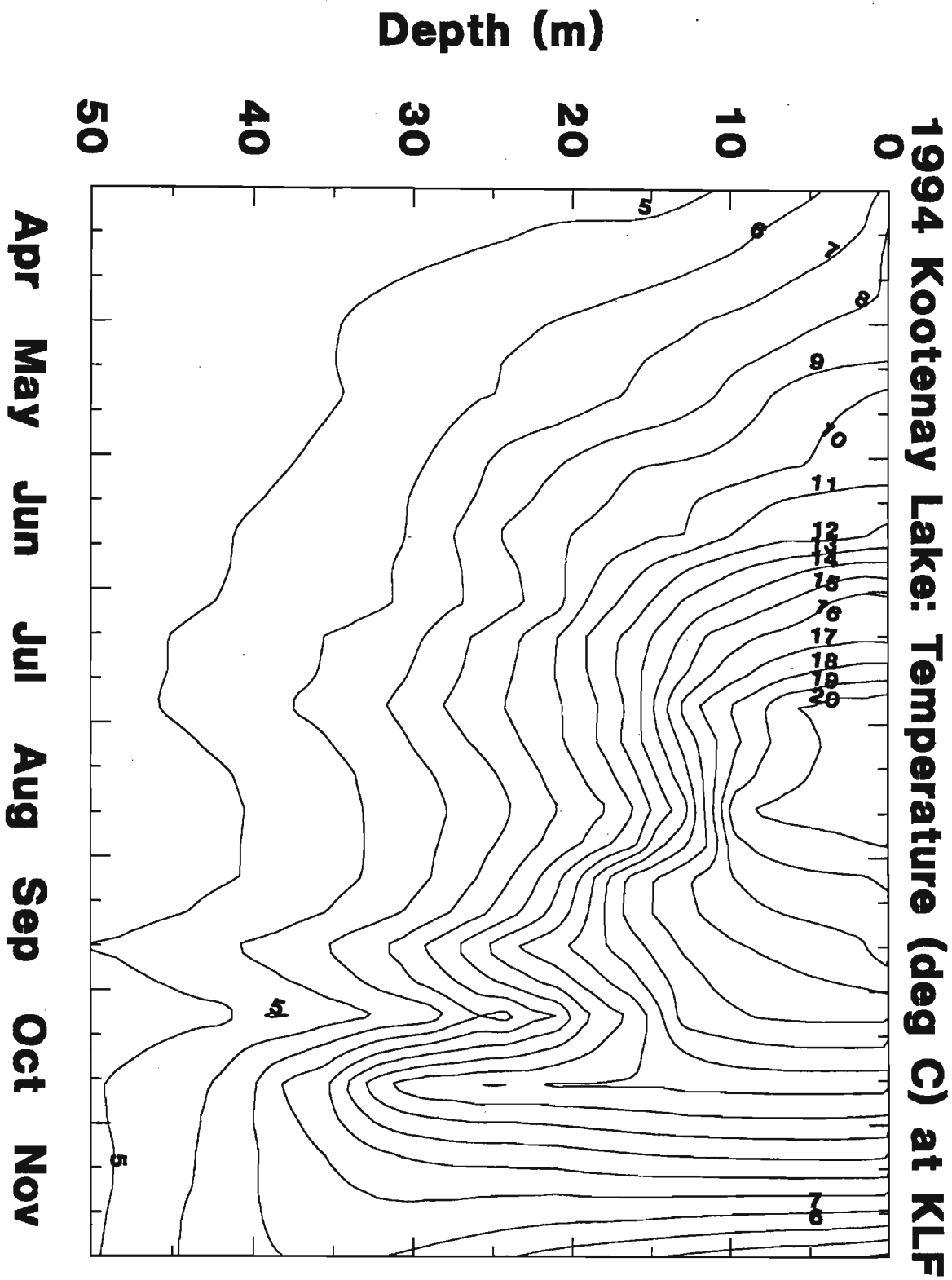


Fig. 4f. Temperature isopleths at Station 6 in 1994.

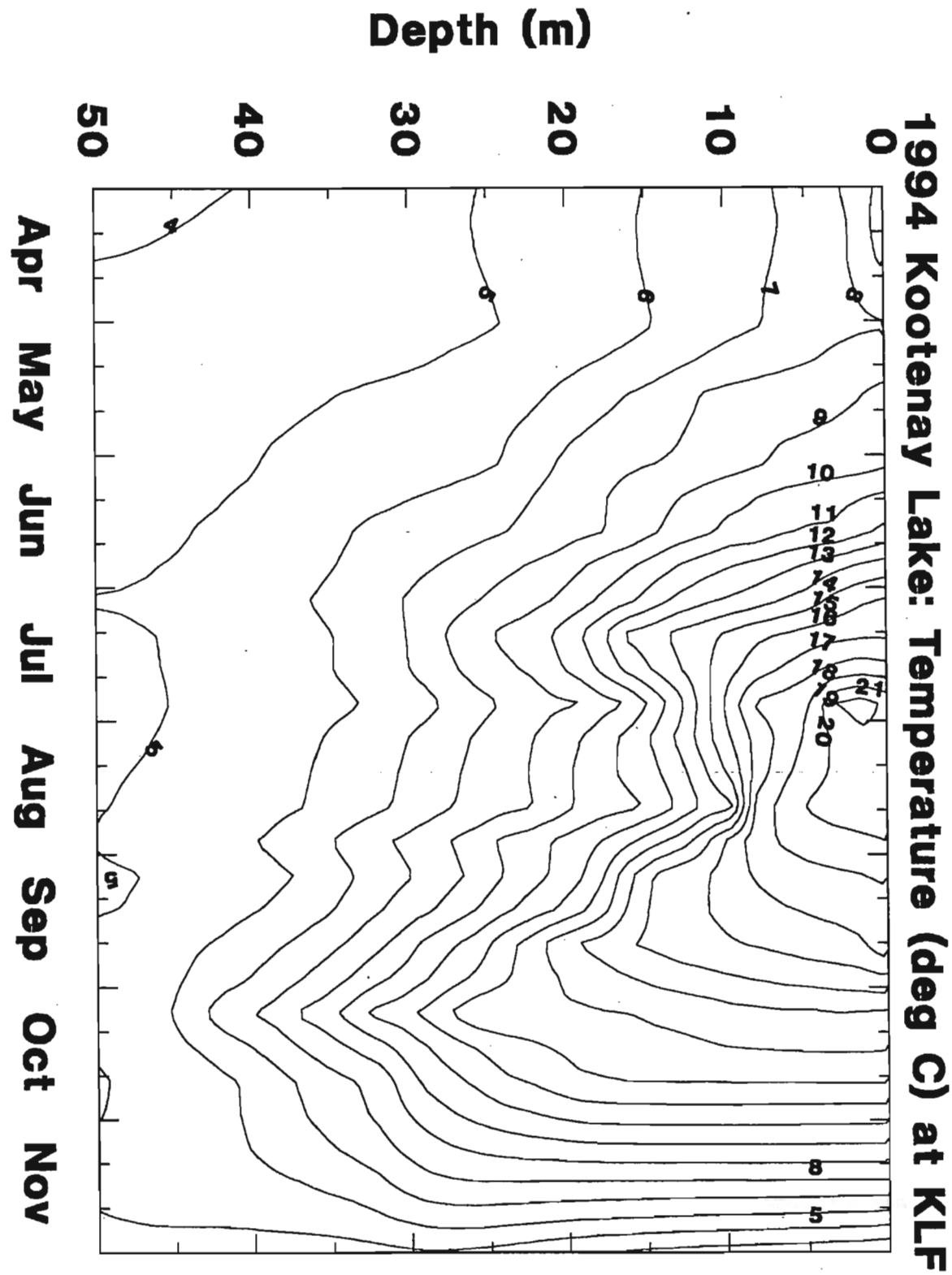


Fig. 4g. Temperature isopleths at Station 7 in 1994.

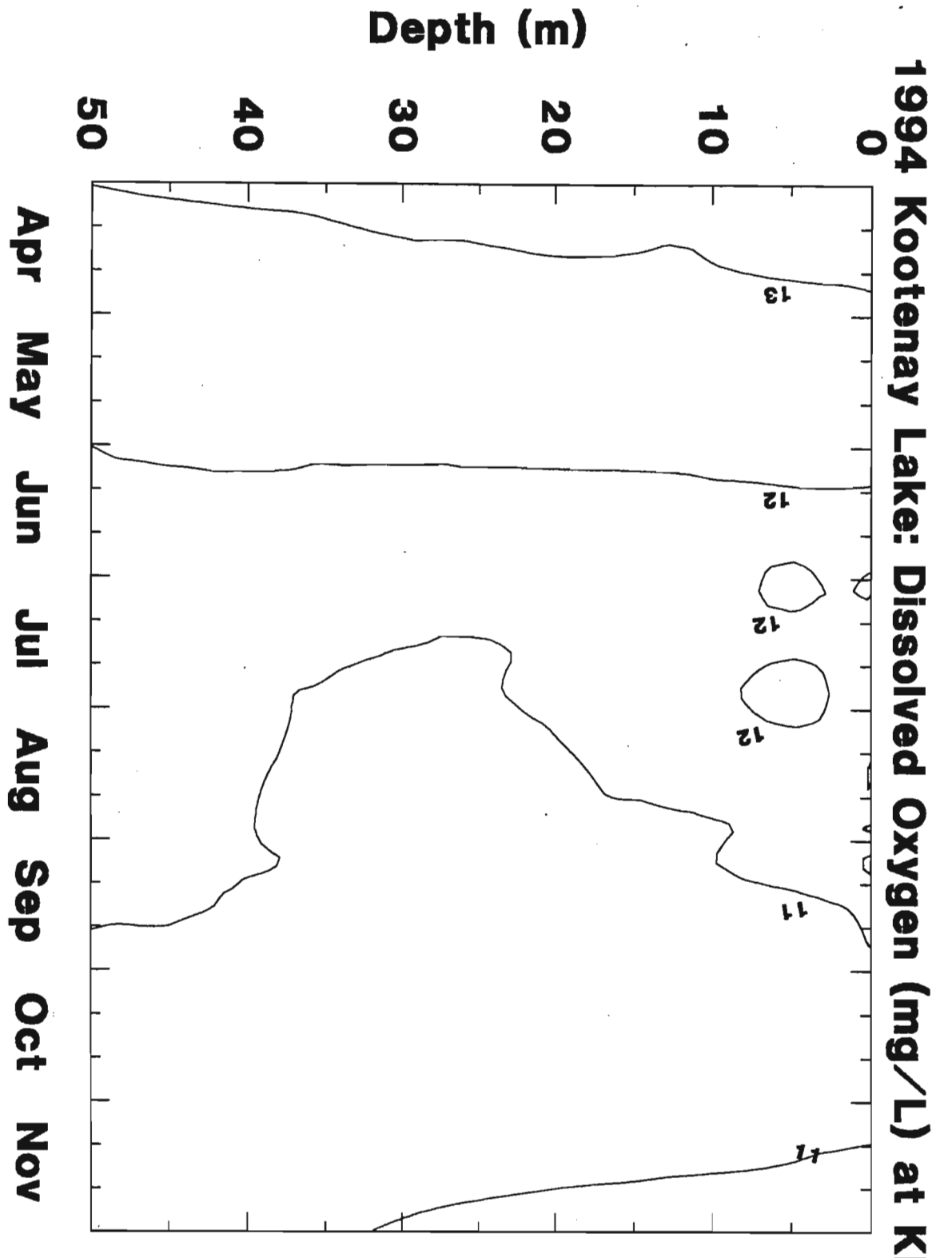


Fig. 5a. Oxygen isopleths at Station 1 in 1994.

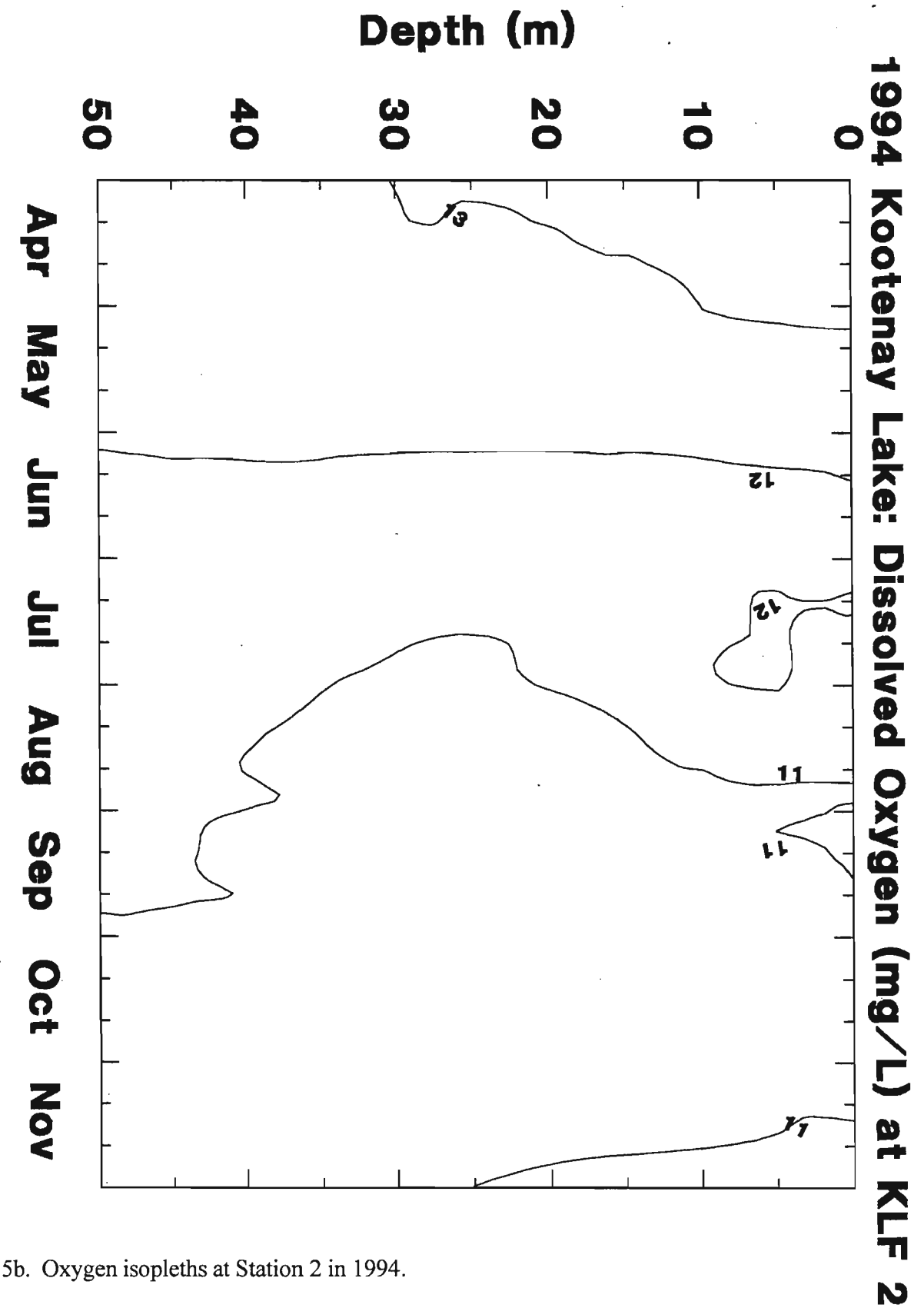


Fig. 5b. Oxygen isopleths at Station 2 in 1994.

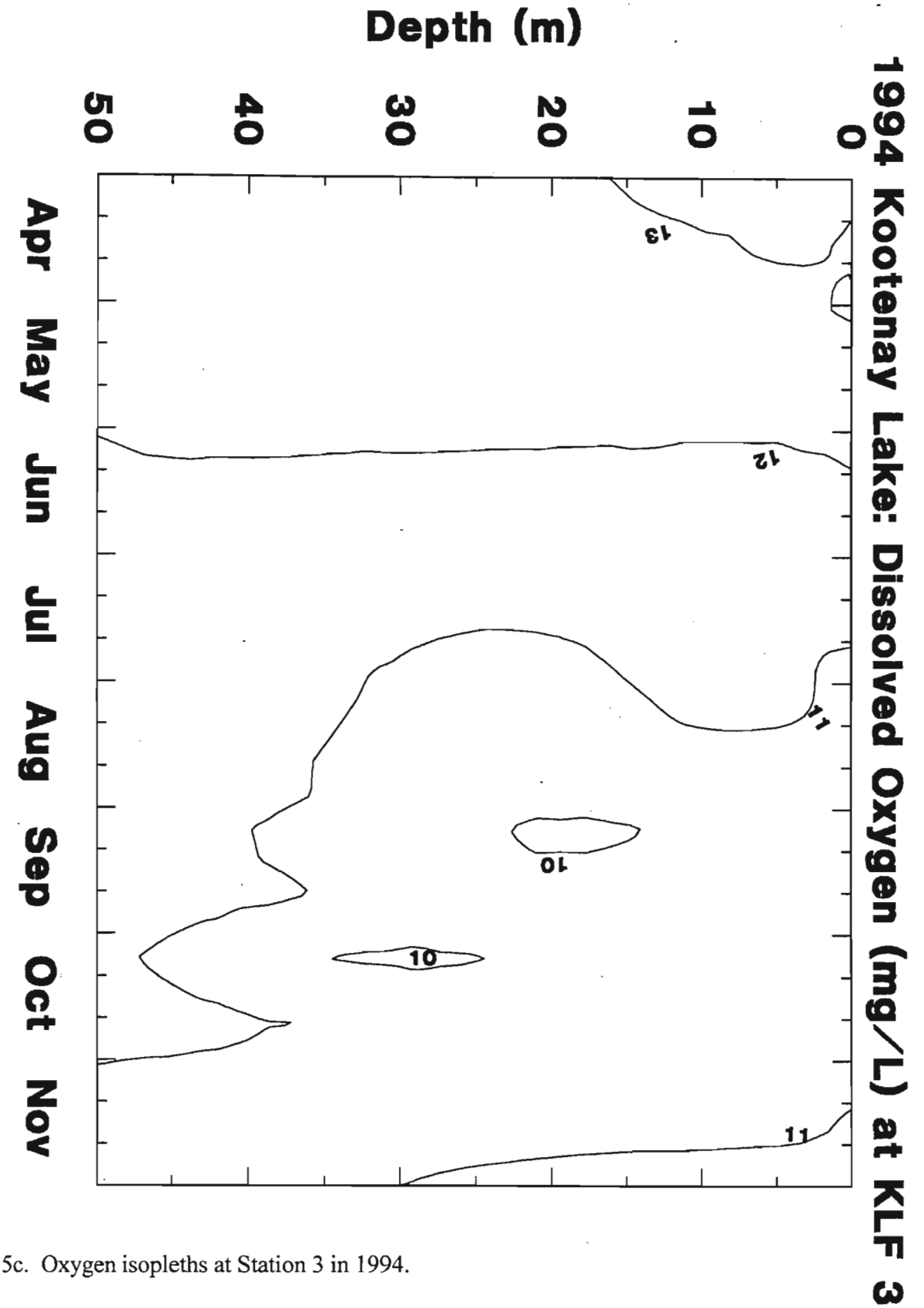


Fig. 5c. Oxygen isopleths at Station 3 in 1994.

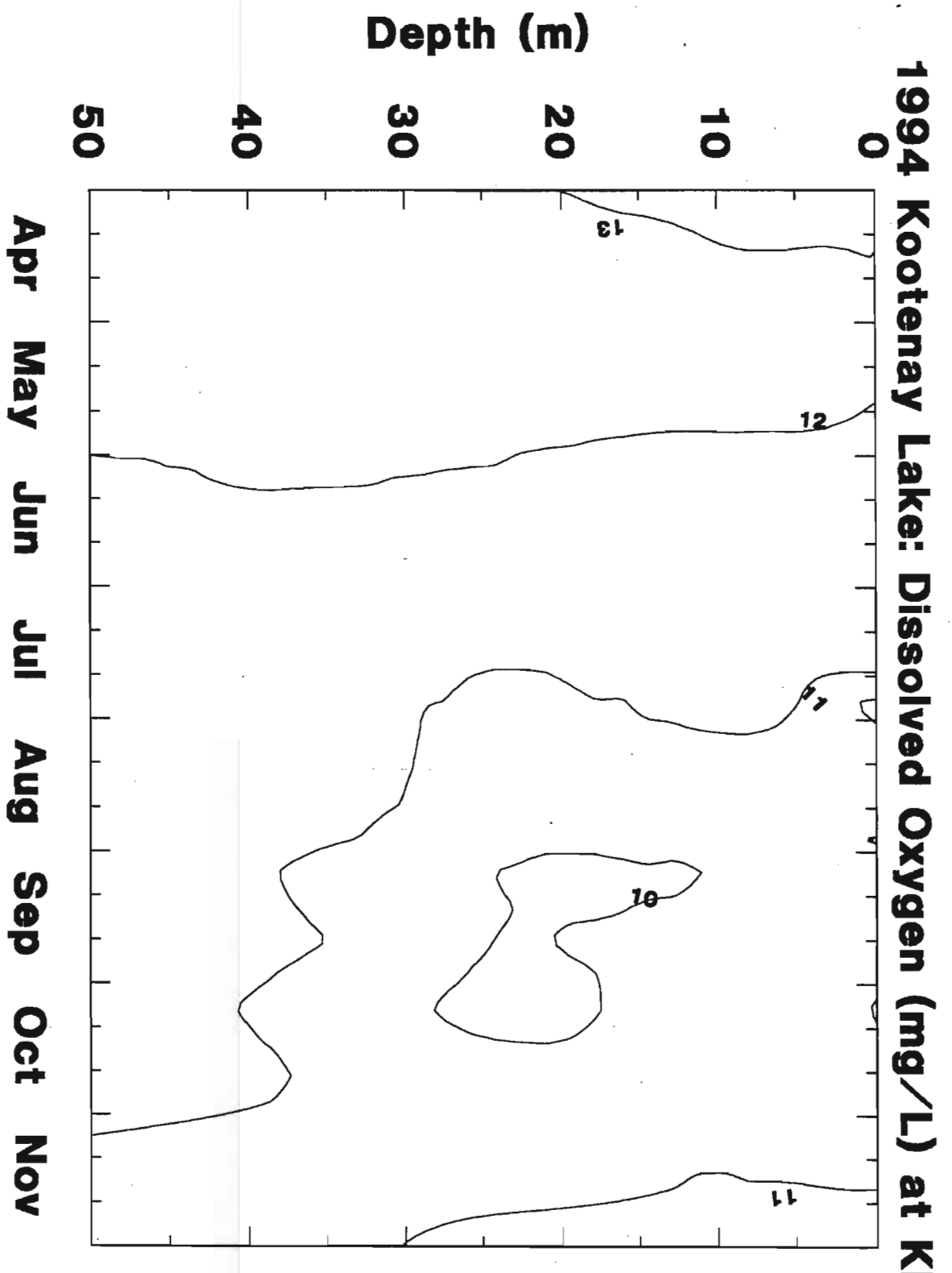


Fig. 5d. Oxygen isopleths at Station 4 in 1994.

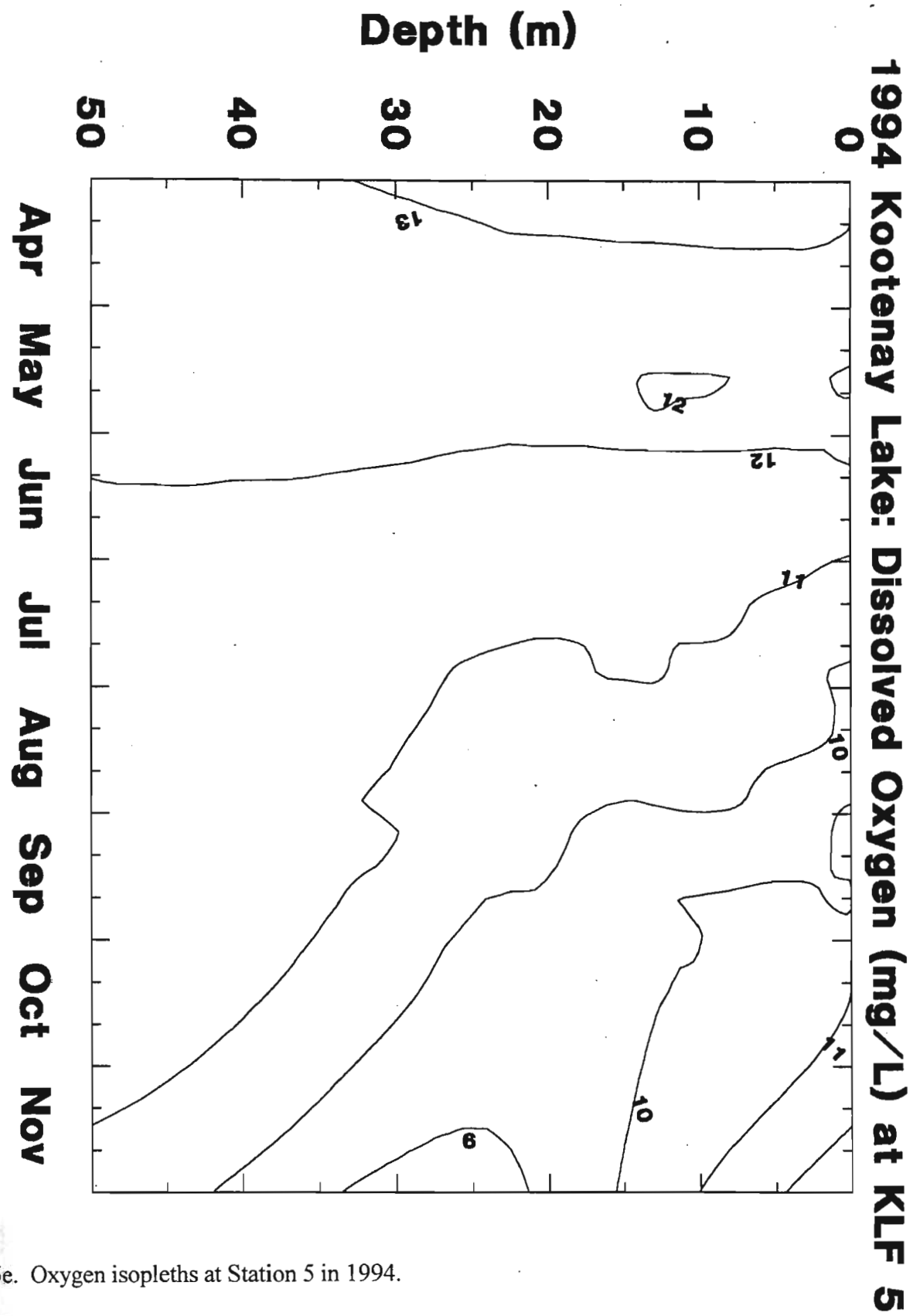


Fig. 5e. Oxygen isopleths at Station 5 in 1994.

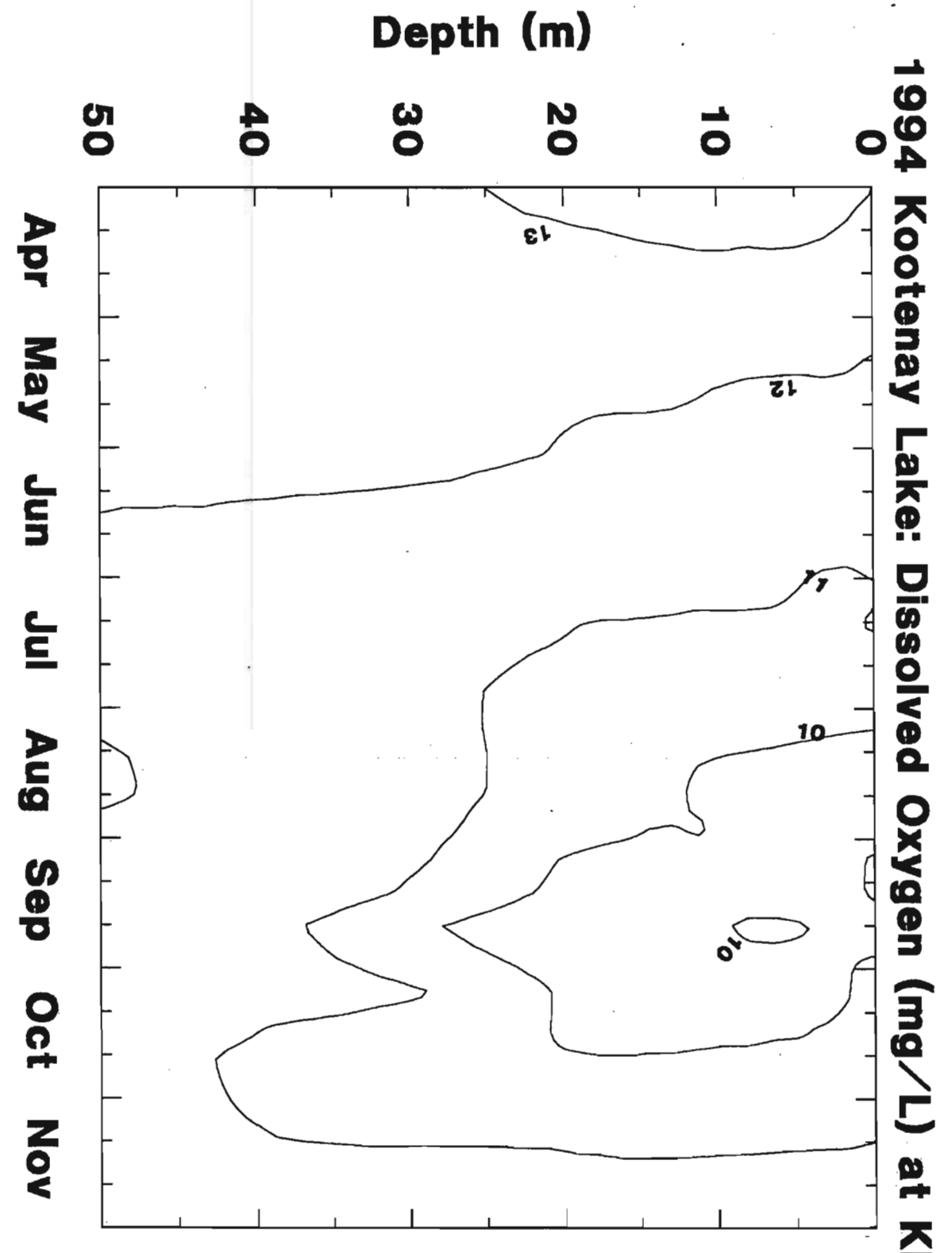


Fig. 5f. Oxygen isopleths at Station 6 in 1994.

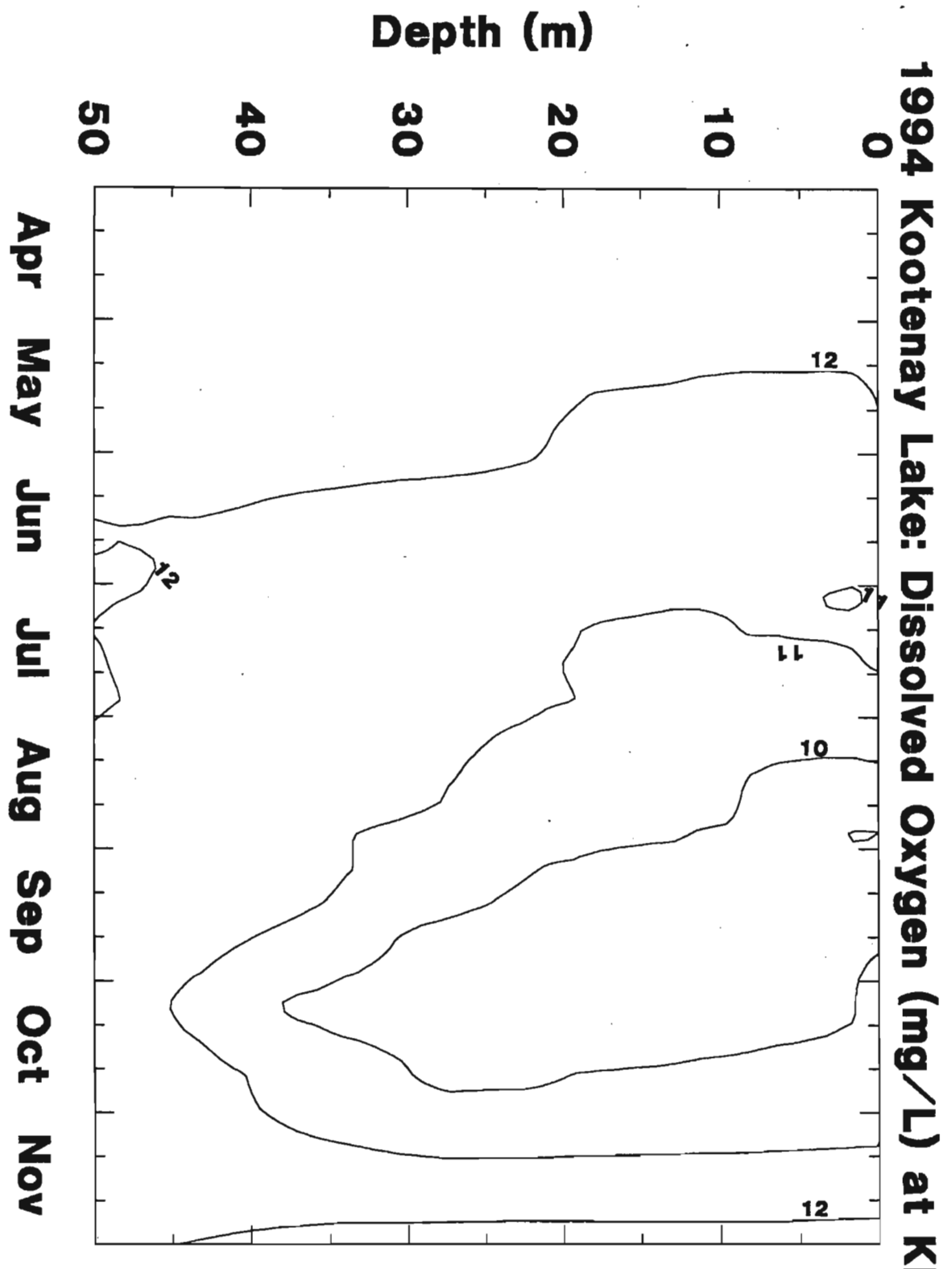


Fig. 5g. Oxygen isopleths at Station 7 in 1994.

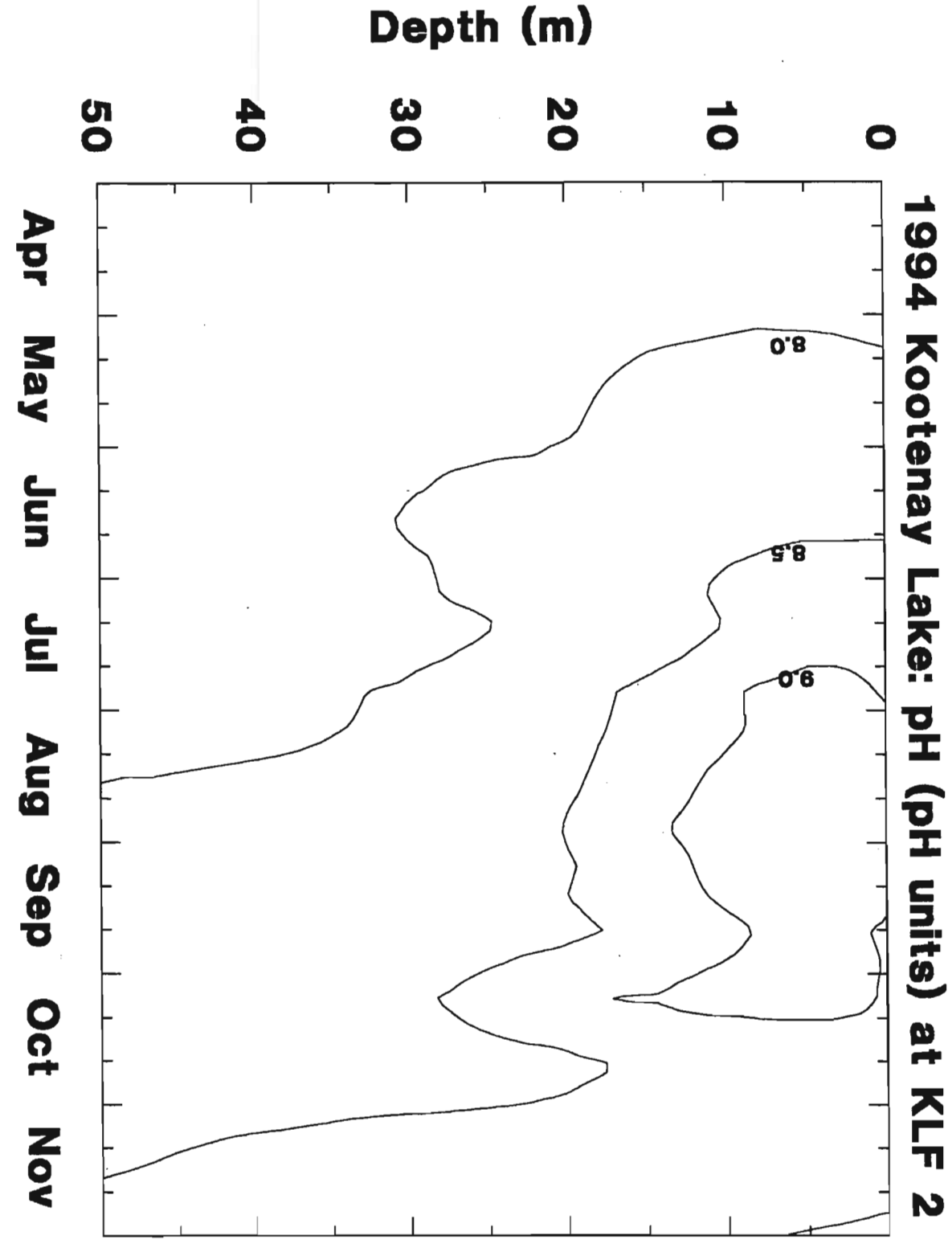


Fig. 6a. pH isopleths at Station 2 in 1994.

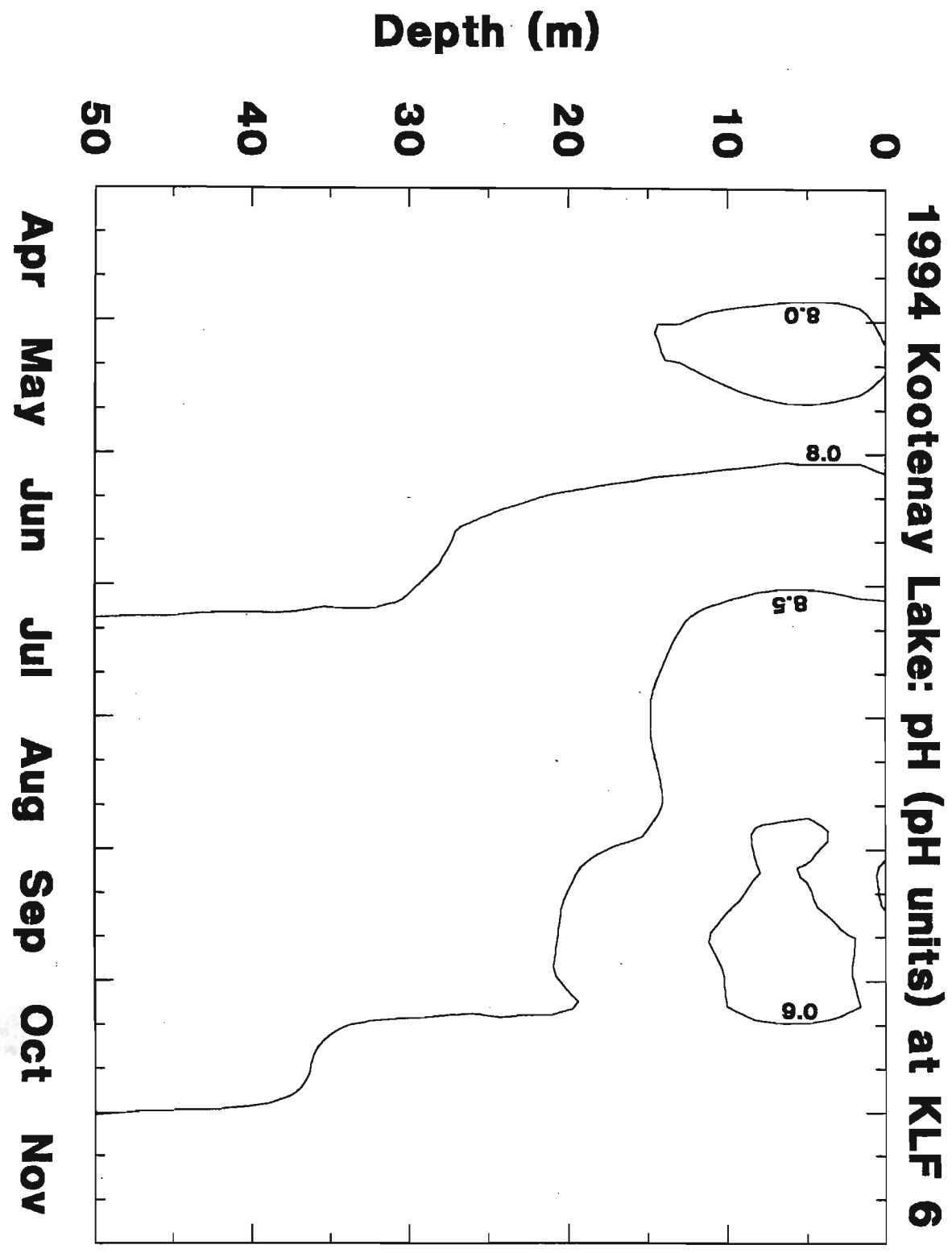


Fig. 6b. pH isopleths at Station 6 in 1994.

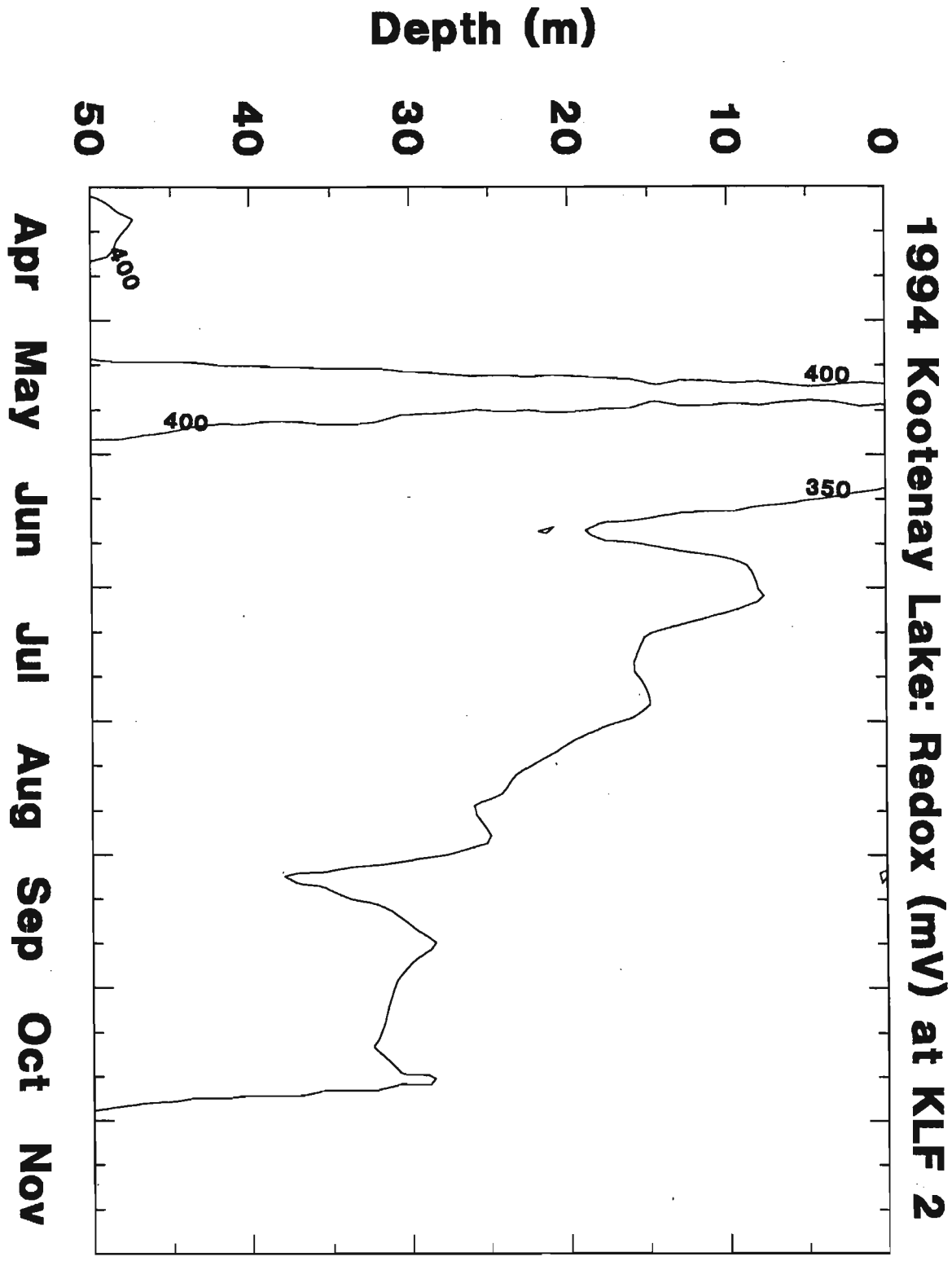


Fig. 7a. Redox potential isopleths at Station 2 in 1994.

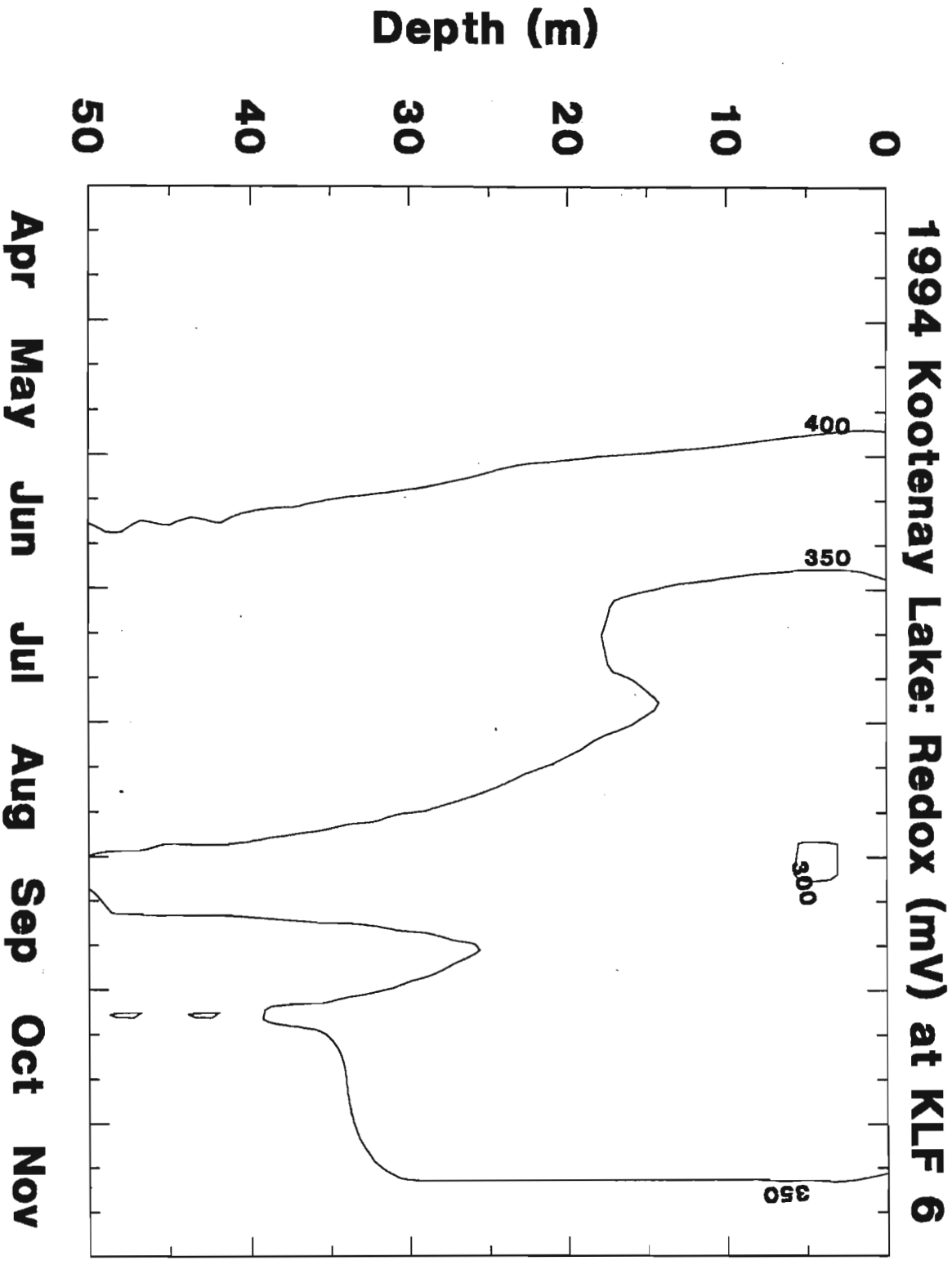


Fig. 7b. Redox potential isopleths at Station 6 in 1994.

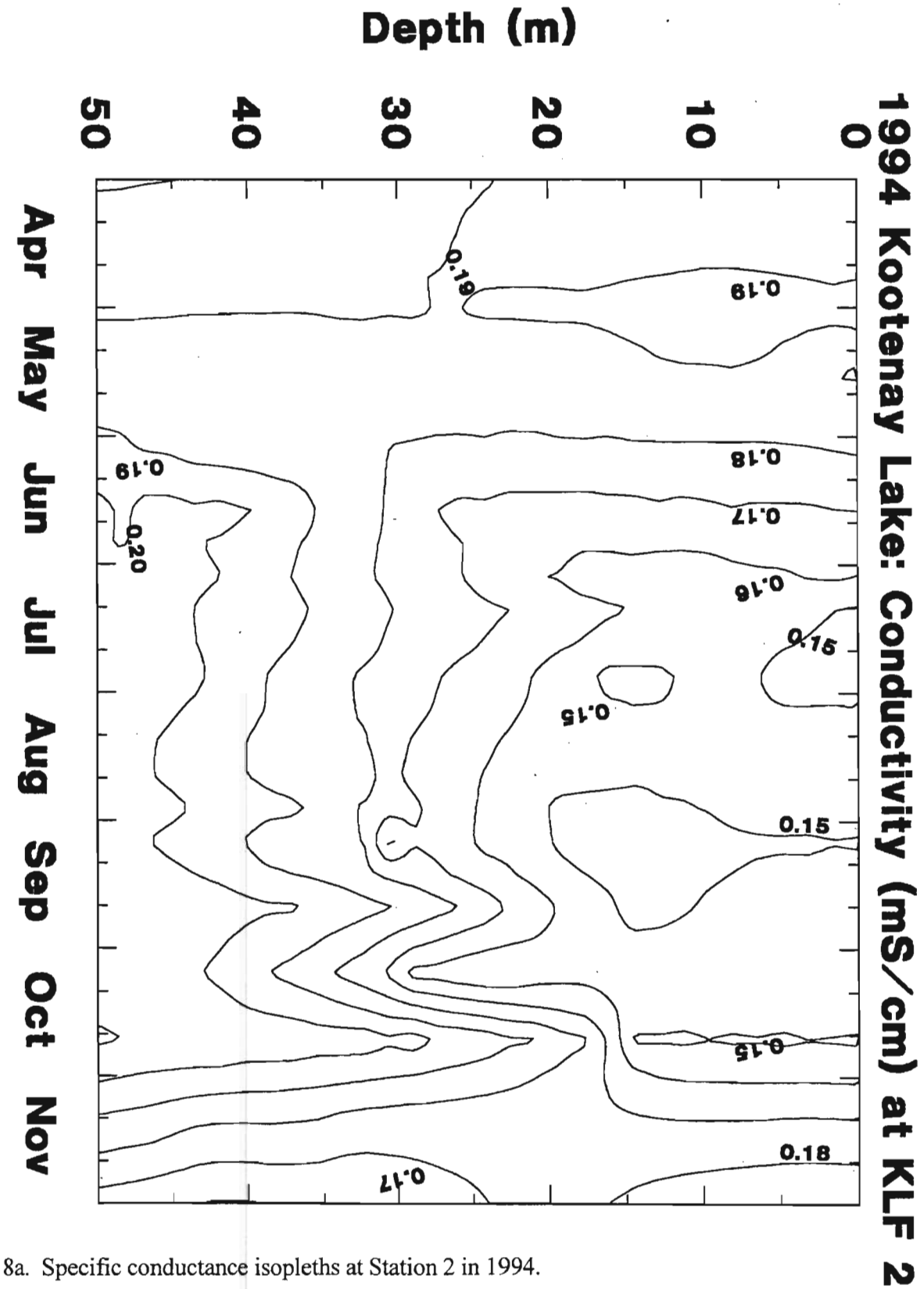


Fig. 8a. Specific conductance isopleths at Station 2 in 1994.

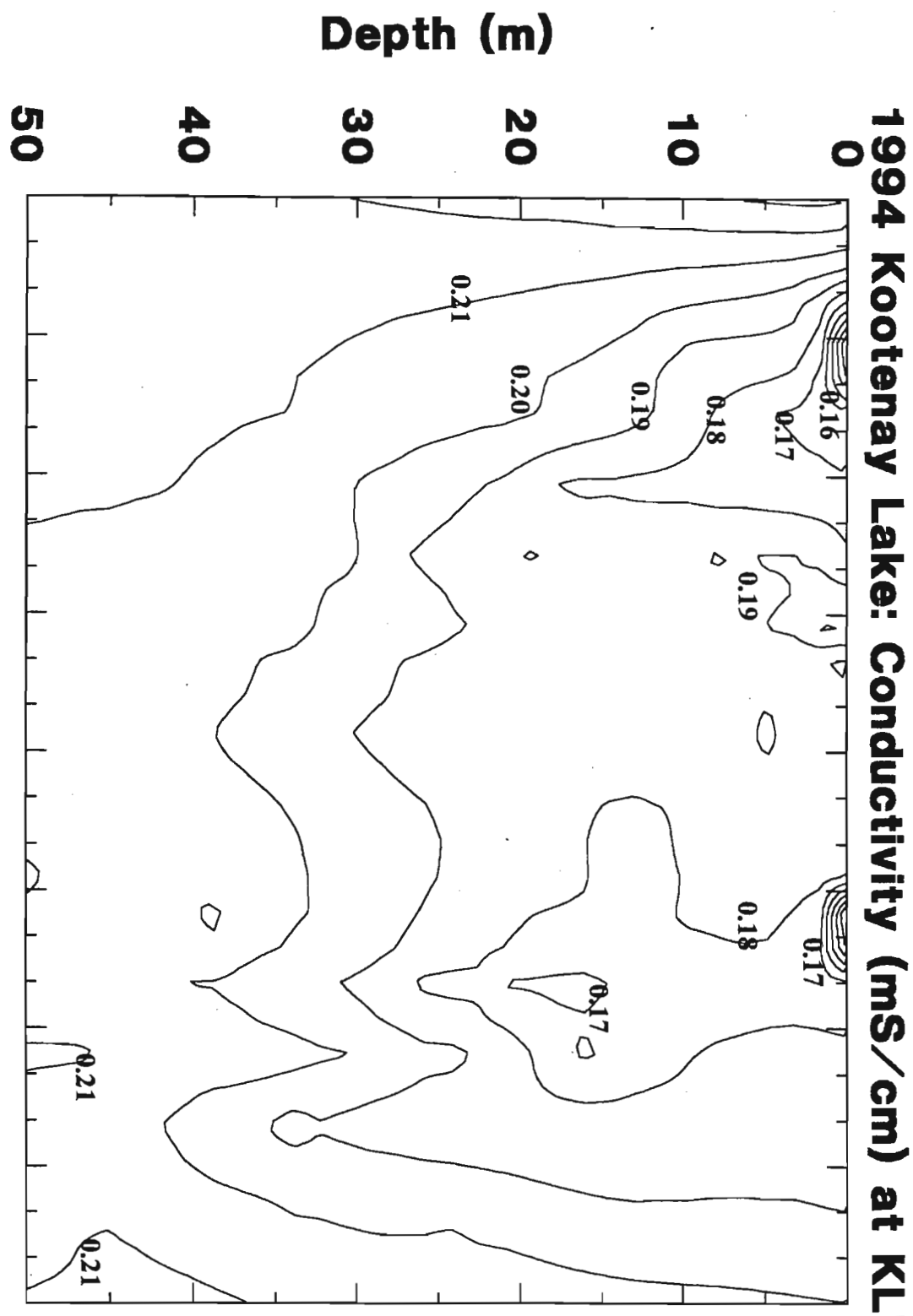


Fig. 8b. Specific conductance isopleths at Station 6 in 1994.

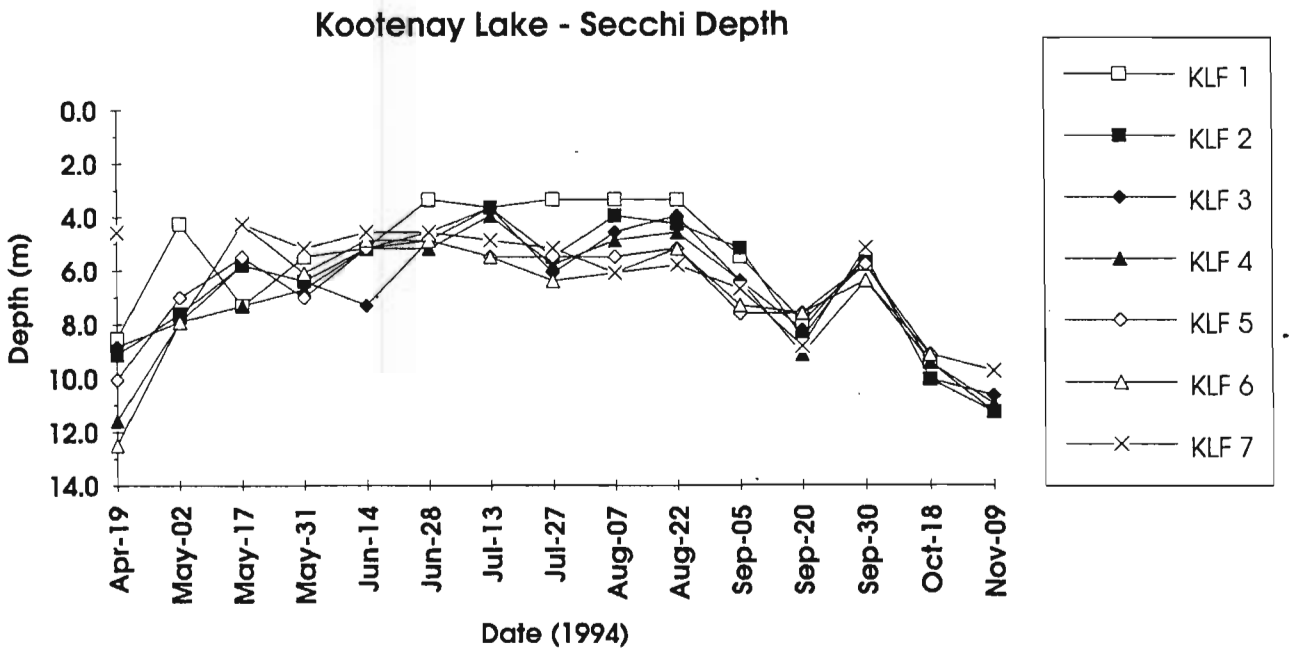


Fig. 9. Secchi depths in 1994.

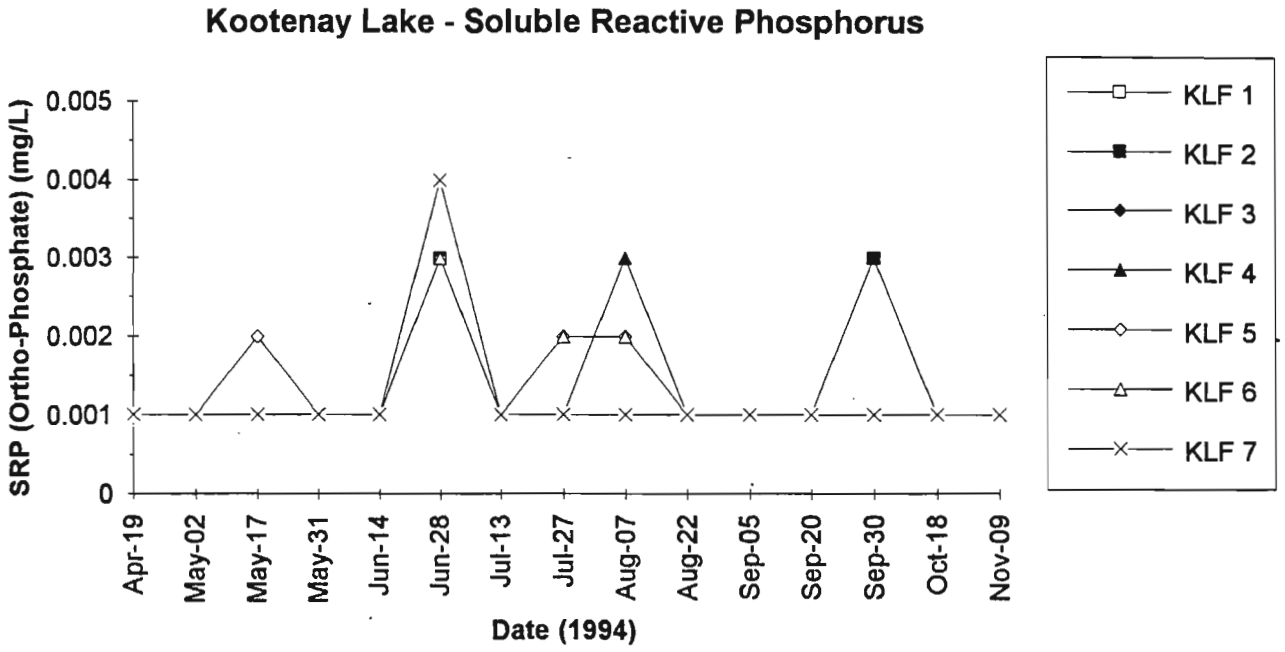


Fig. 10. Soluble reactive phosphorus concentrations in 1994.

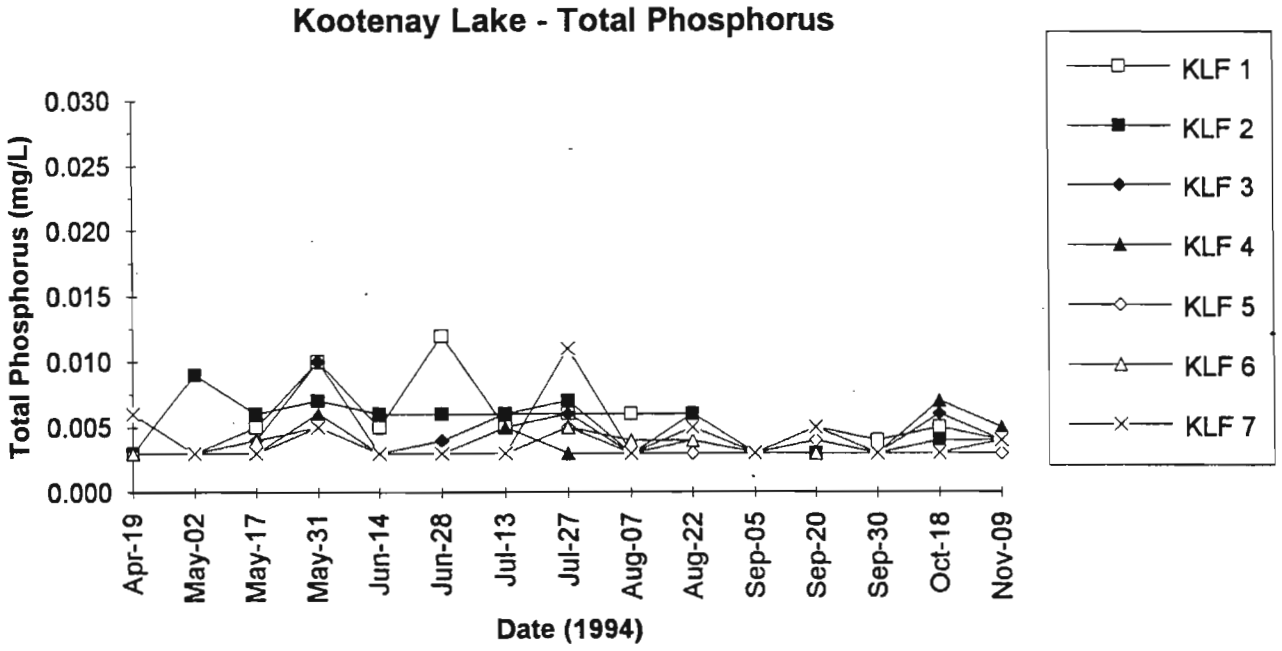


Fig. 11. Total phosphorus concentrations in 1994.

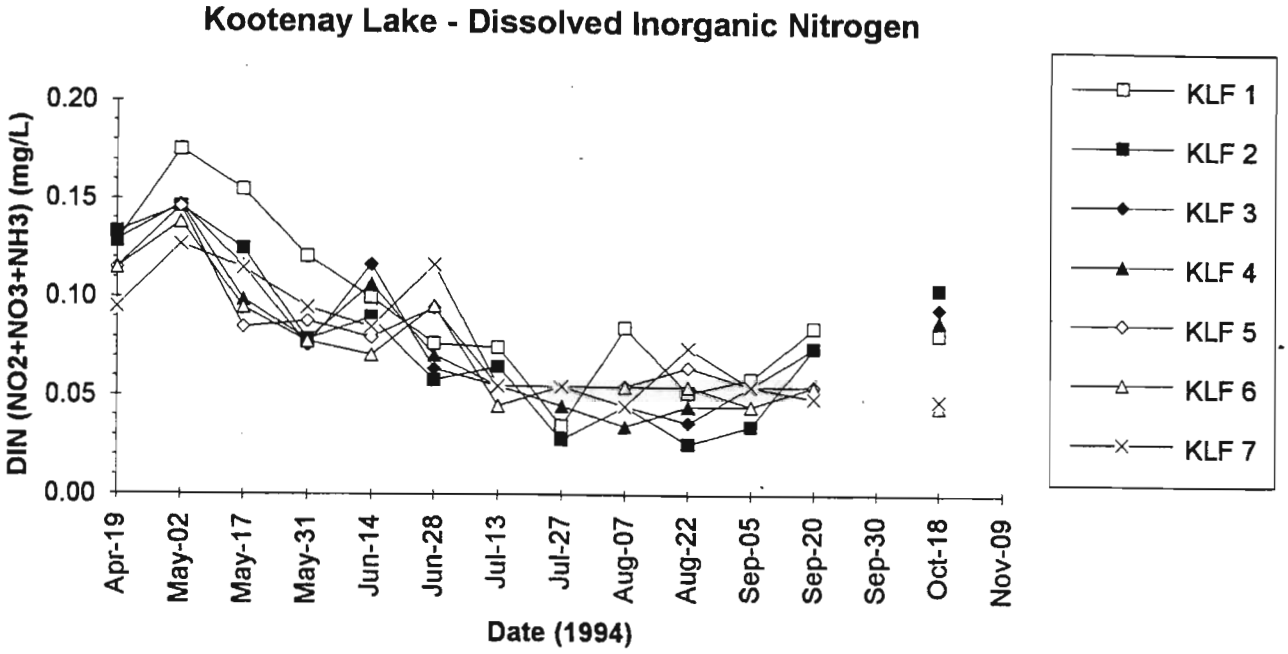


Fig. 12. Dissolved inorganic nitrogen concentrations in 1994.

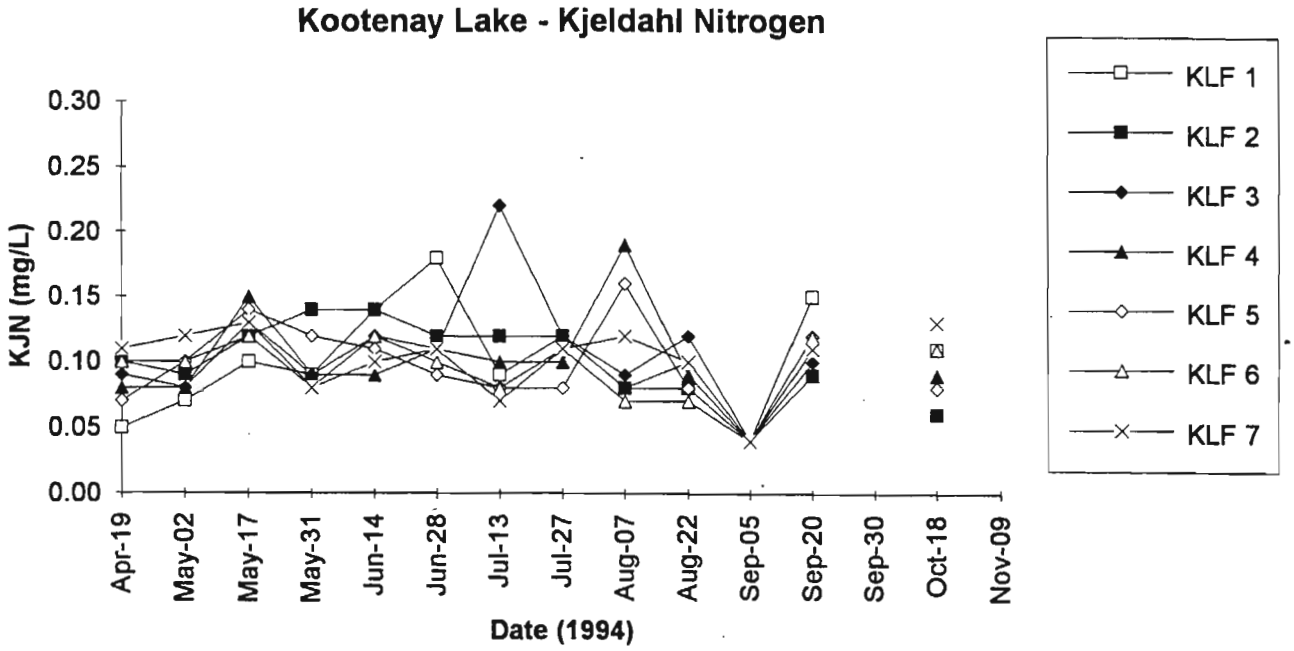


Fig. 13. Kjeldahl nitrogen concentrations in 1994.

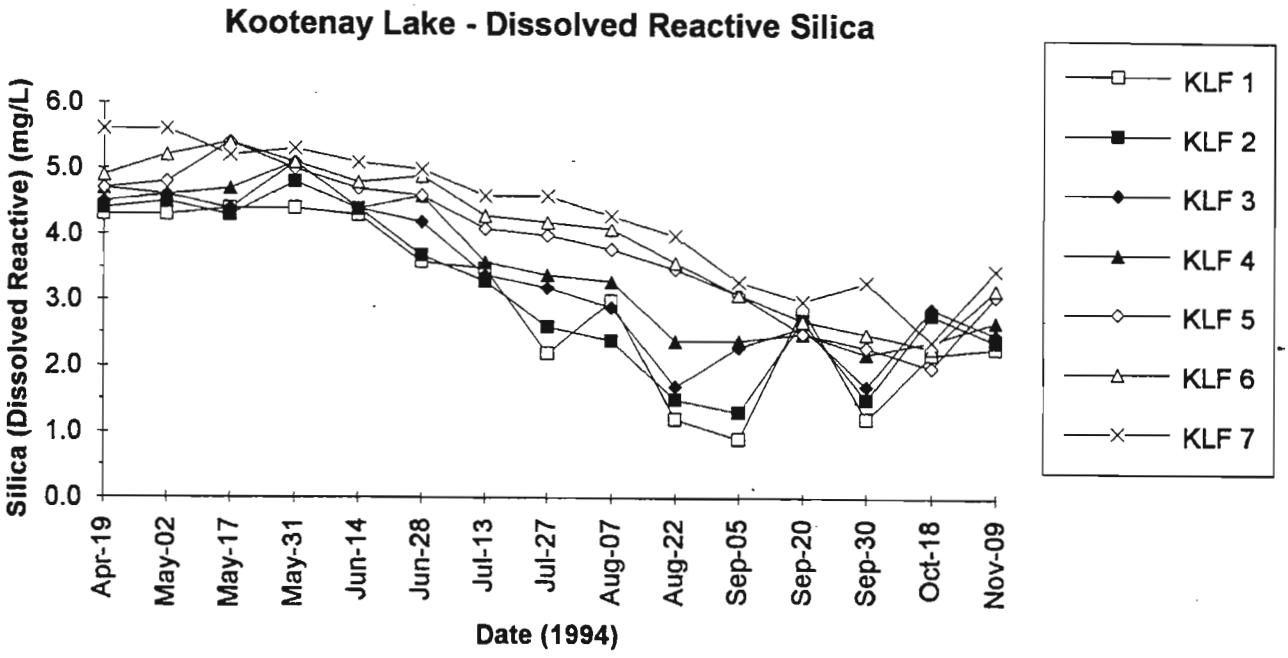


Fig. 14. Dissolved reactive silica concentrations in 1994.

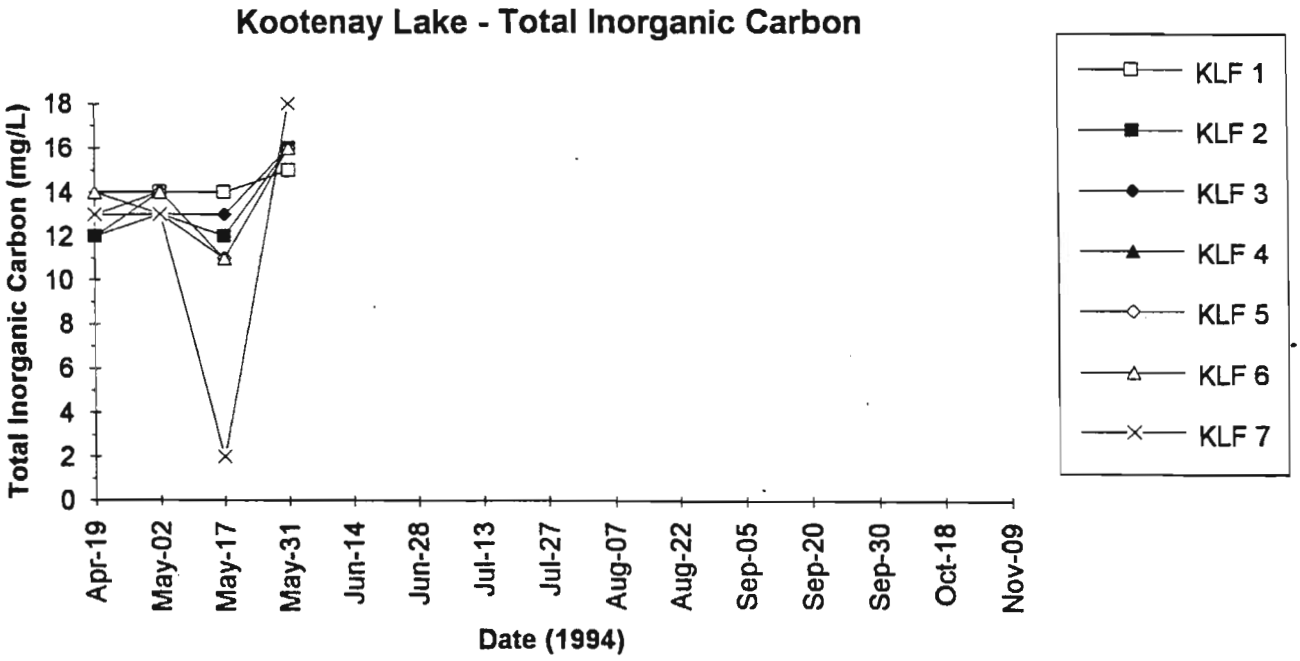


Fig. 15. Total inorganic carbon concentrations in 1994.

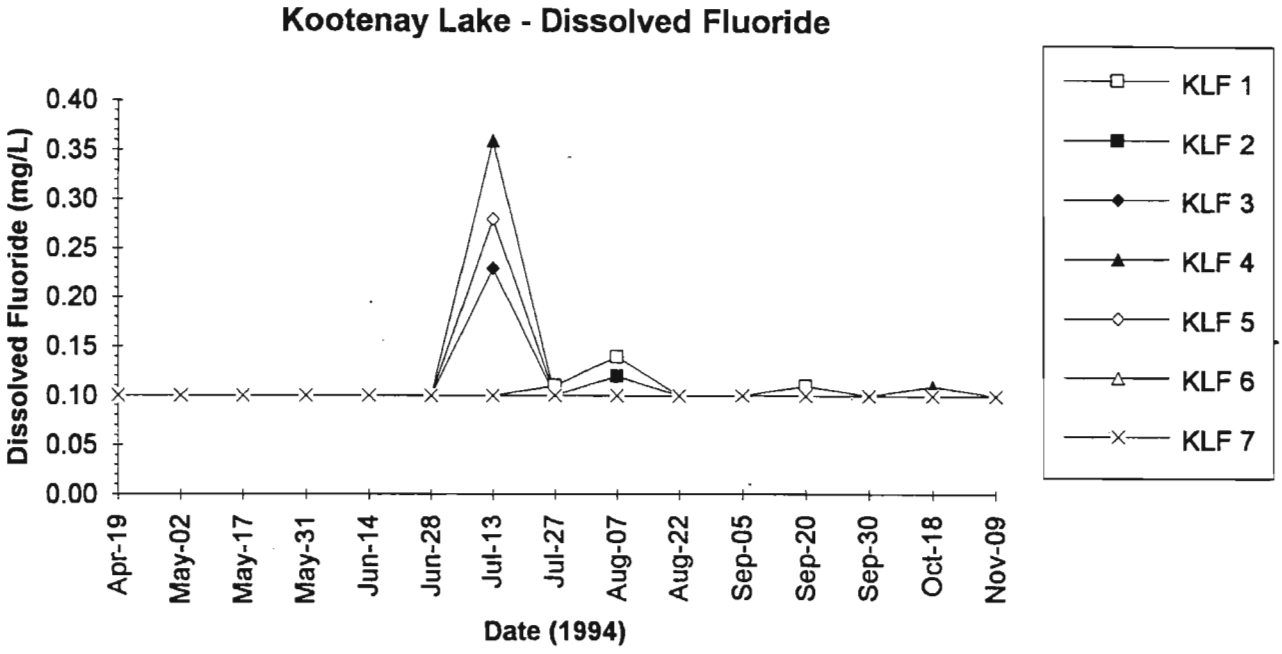


Fig. 16. Dissolved fluoride concentrations in 1994.

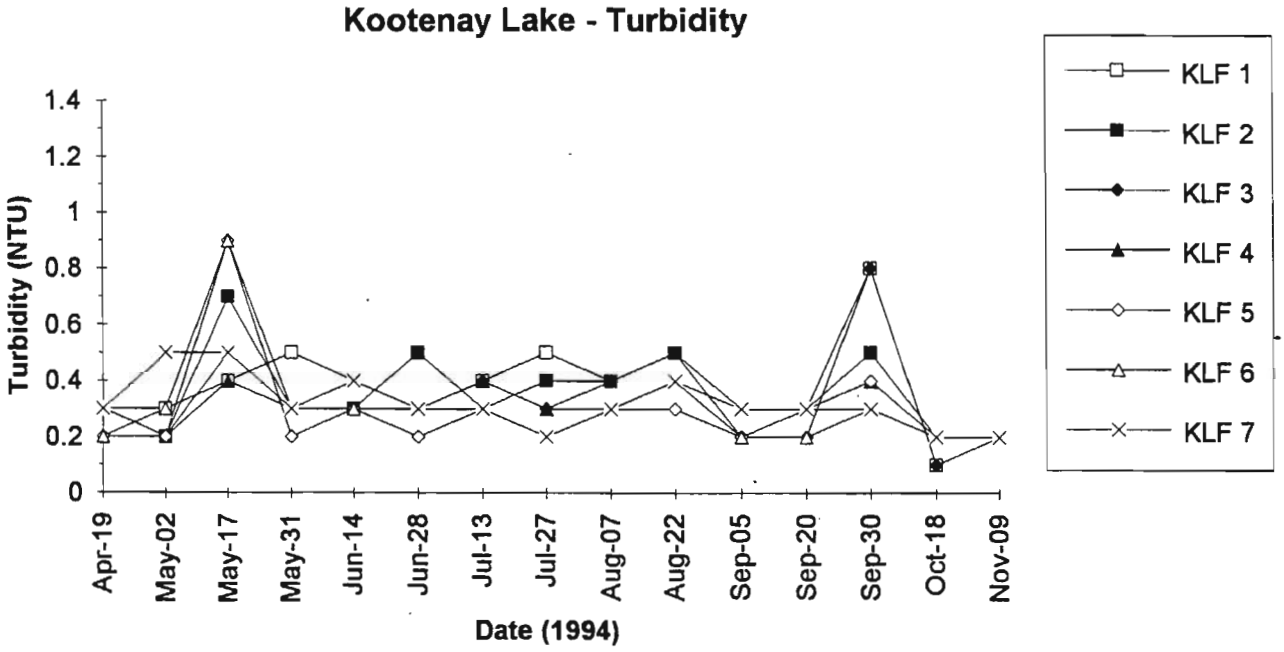


Fig. 17. Turbidity concentrations in 1994.

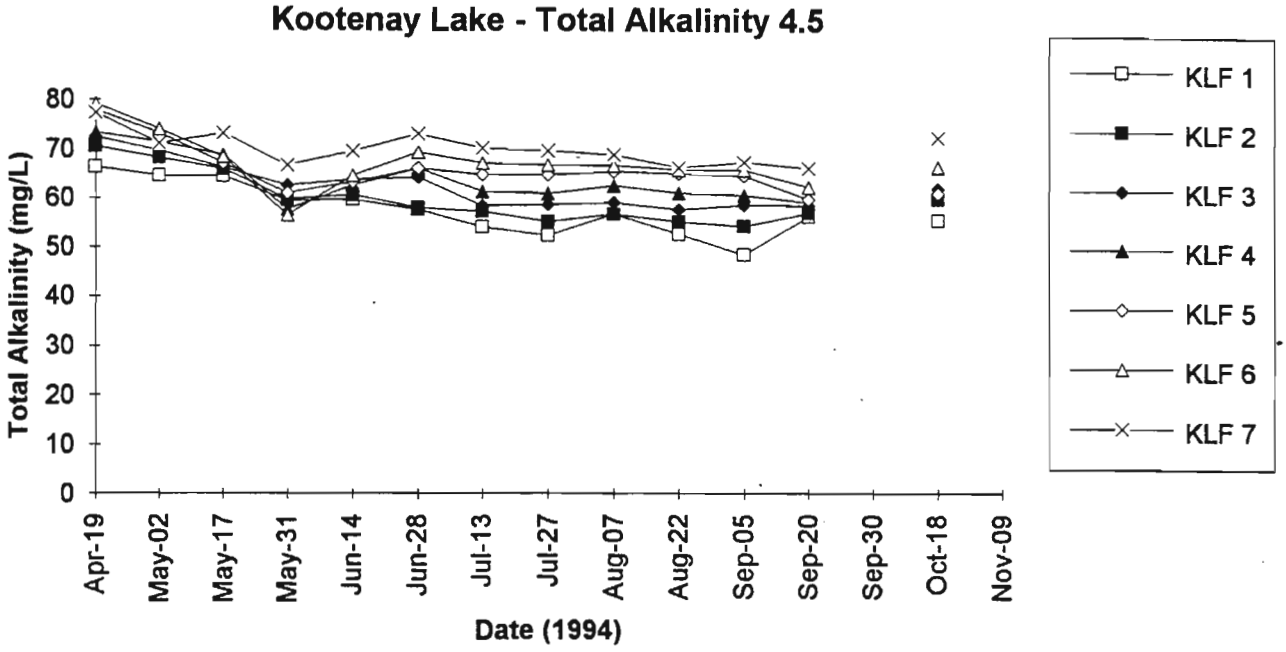


Fig. 18. Total alkalinity concentrations in 1994.

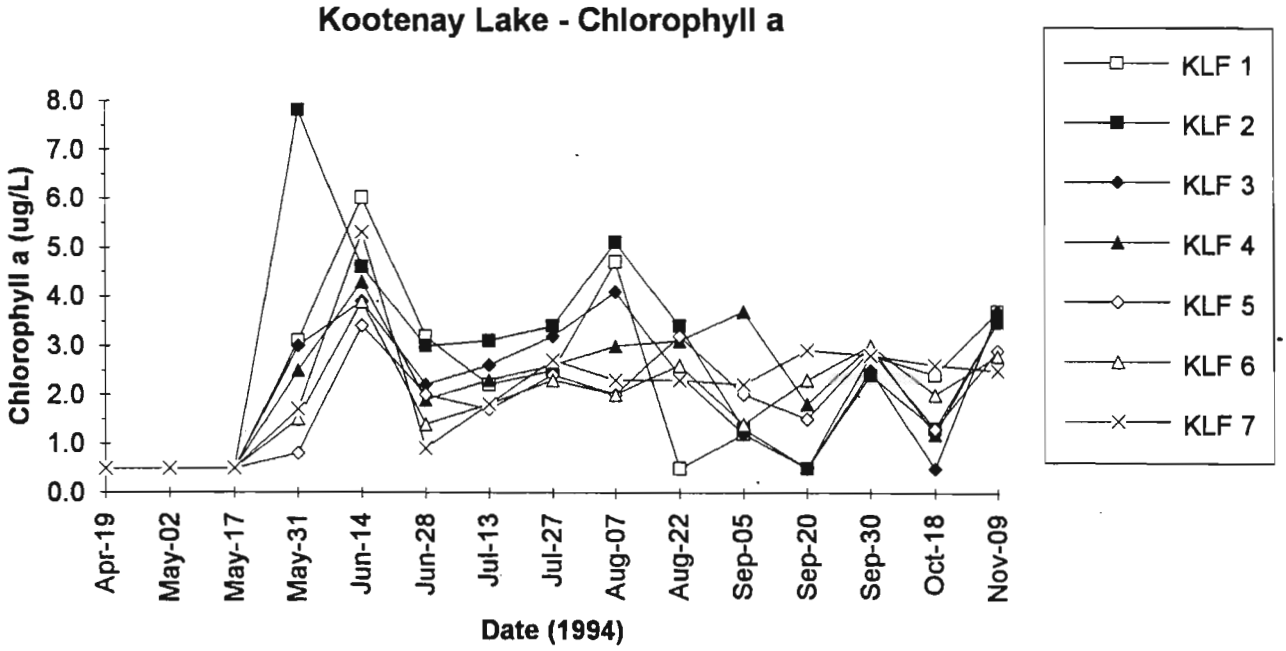


Fig. 19. Chlorophyll *a* concentrations in 1994.

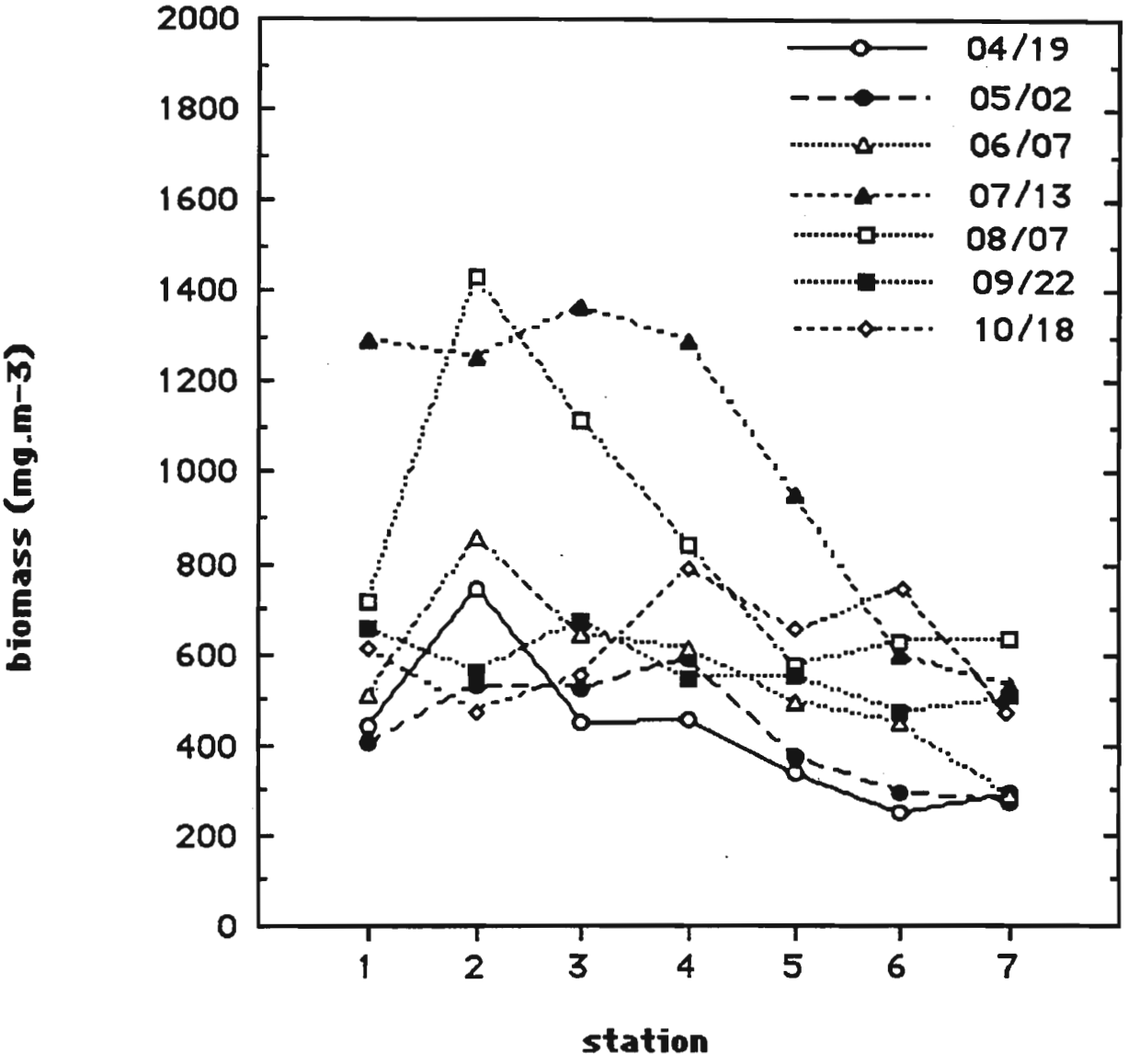


Fig. 20. Total algal biomass, along the entire lake transect of Kootenay Lake, at one month intervals from April through October of 1994.

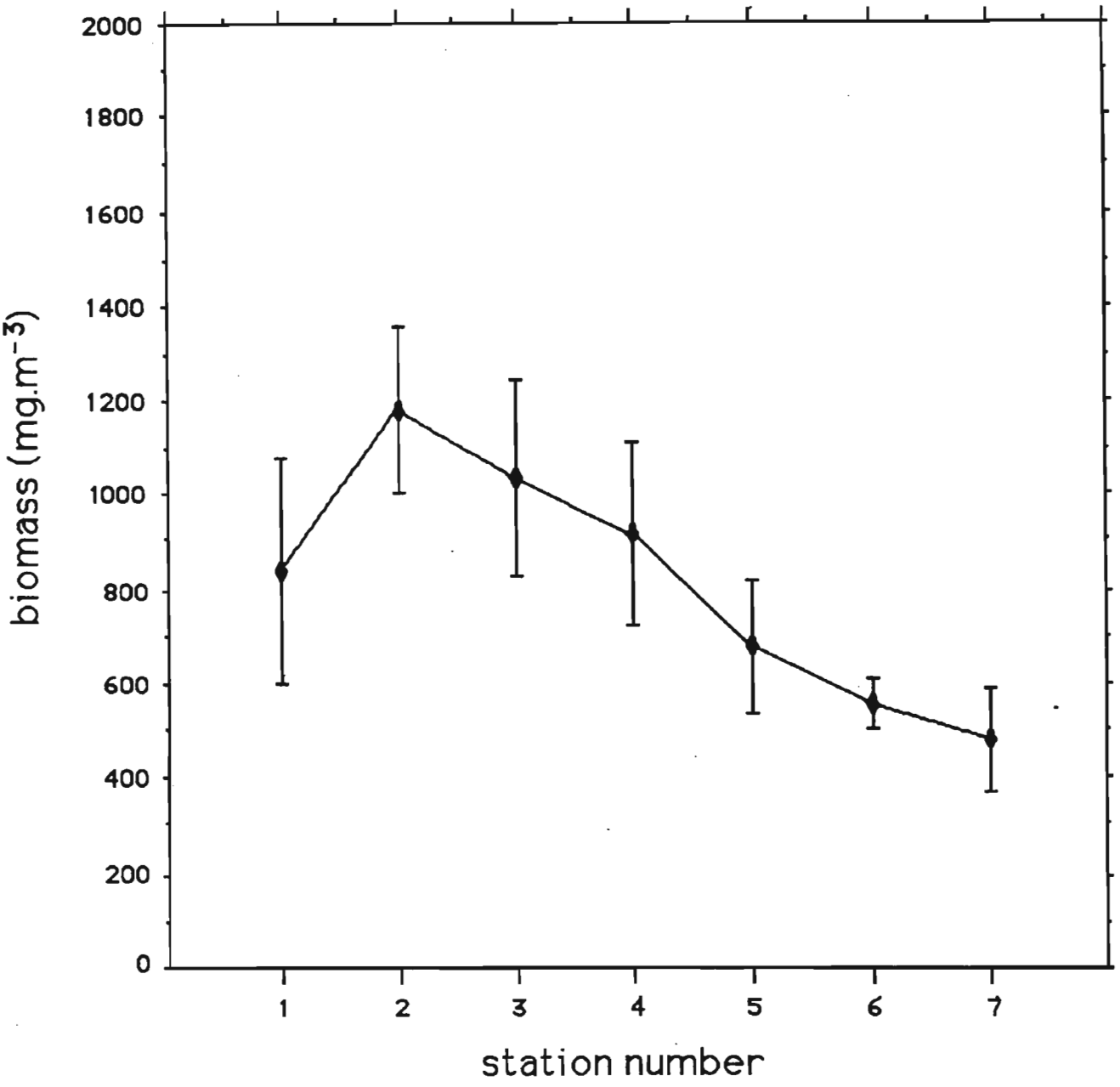


Fig. 21. Average summer algal biomass along the lake. Means are ± 1 standard error.

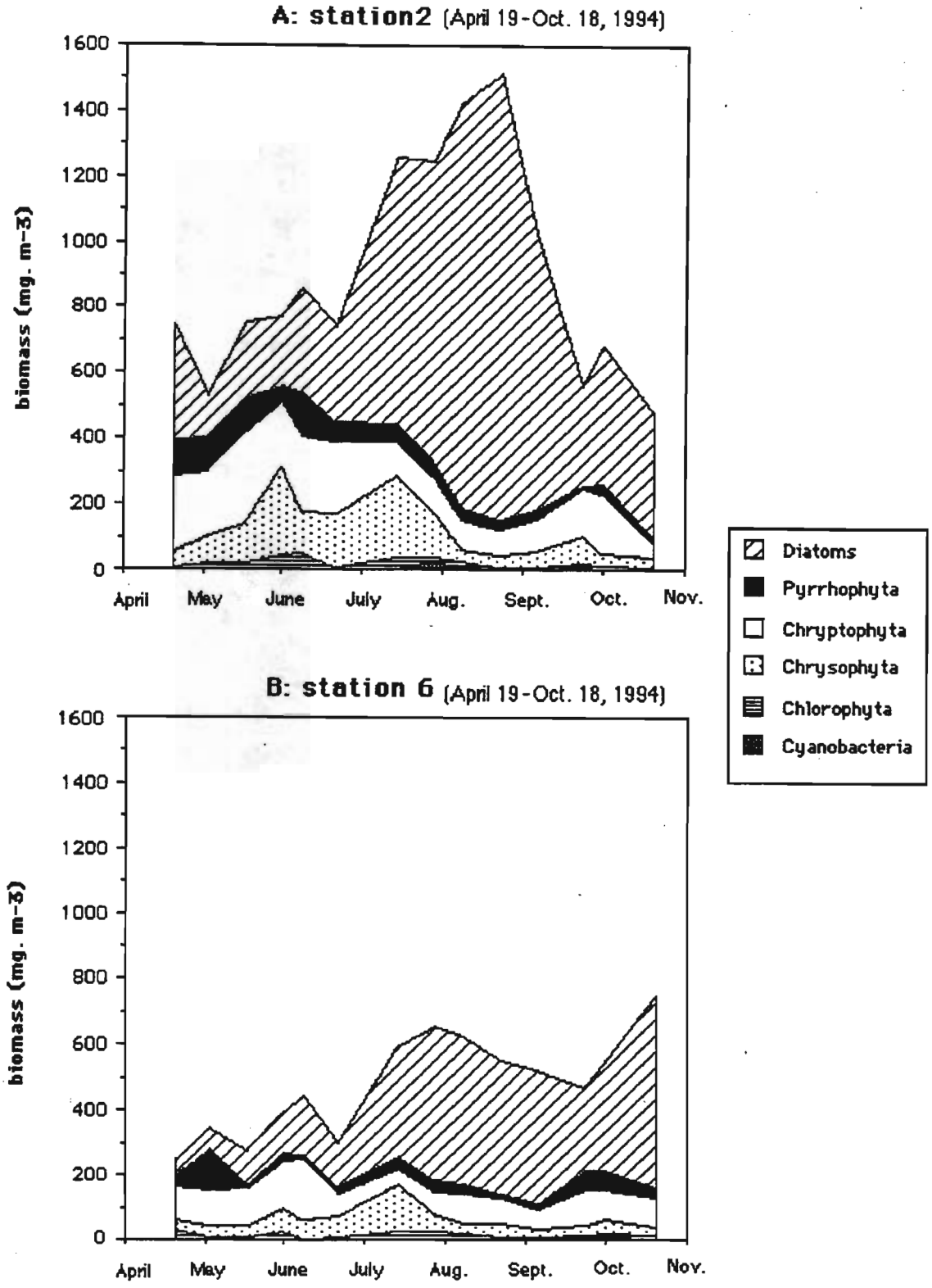


Fig. 22. Seasonal algal biomass, by division, for Station 2 (fertilized) and Station 6 (unfertilized) in 1994. A: Station 2, B: Station 6.

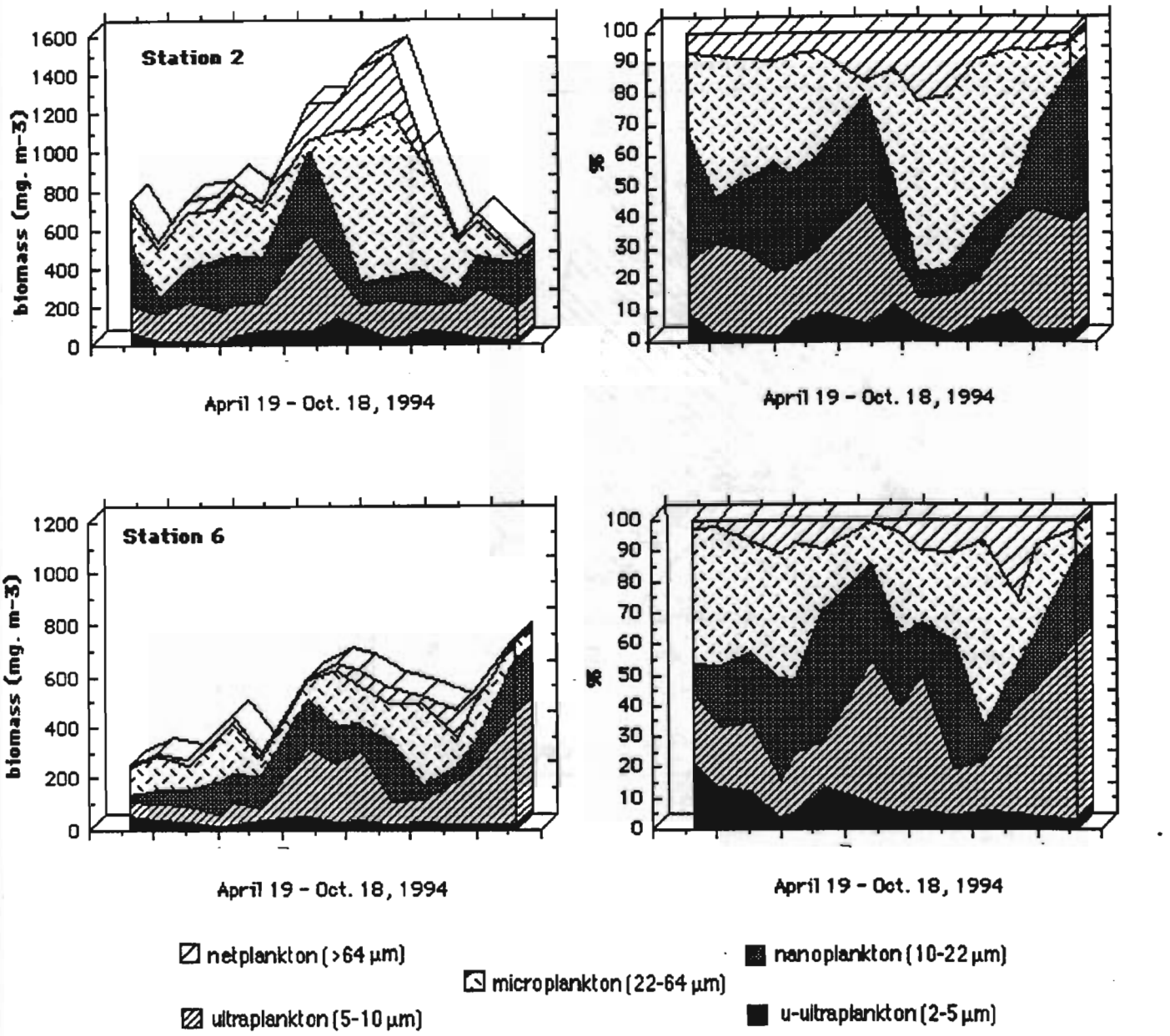


Fig. 23. Seasonal algal biomass, by size fraction, for Station 2 (fertilized) and Station 6 (unfertilized) in 1994. Panels on the right present the size fraction data as percentages of the total biomass.

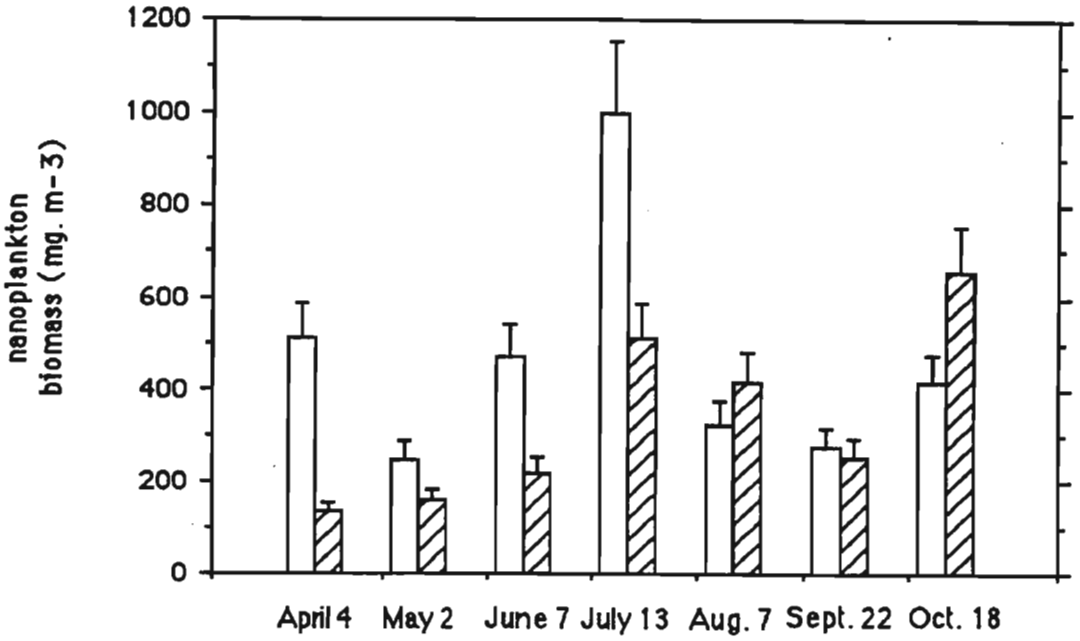


Fig. 24. Seasonal biomass of edible size class of phytoplankton (nanoplankton 2-22 μm) at Stations 2 (open histogram) and 6 (hatched histogram). Error bars represent error due to counting (approximately 15%, see Lund et al., 1958).

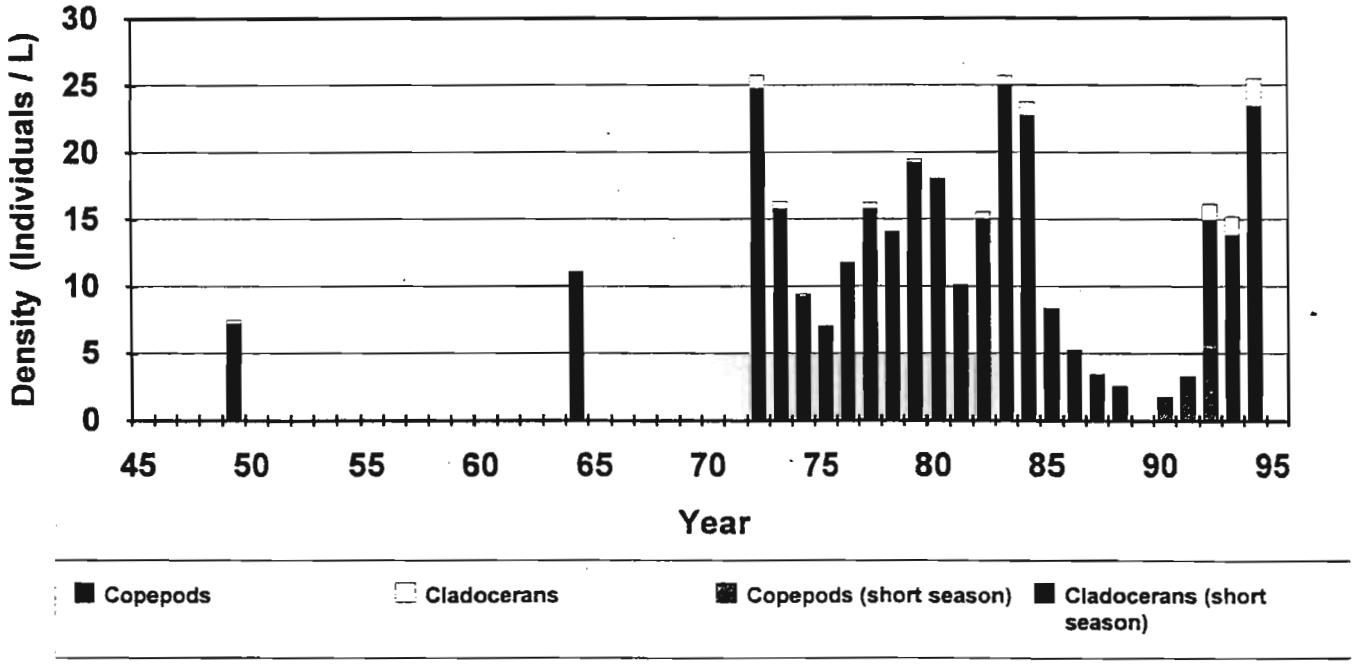


Fig. 25. Cladoceran and copepod zooplankton density from 1949 to 1994 for mid-lake station (at or near current Station 5, Crawford Bay).

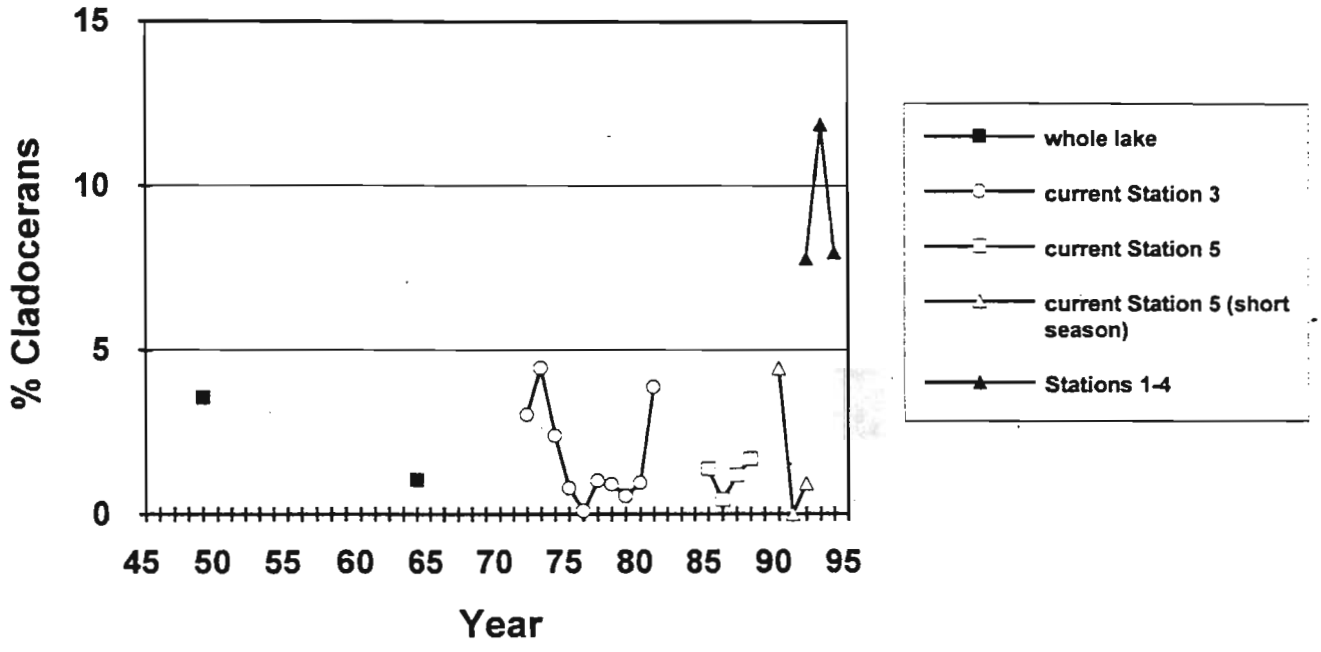


Fig. 26. Proportion of cladocerans, relative to annual average total macrozooplankton density, in Kootenay Lake, from 1949 to 1994.

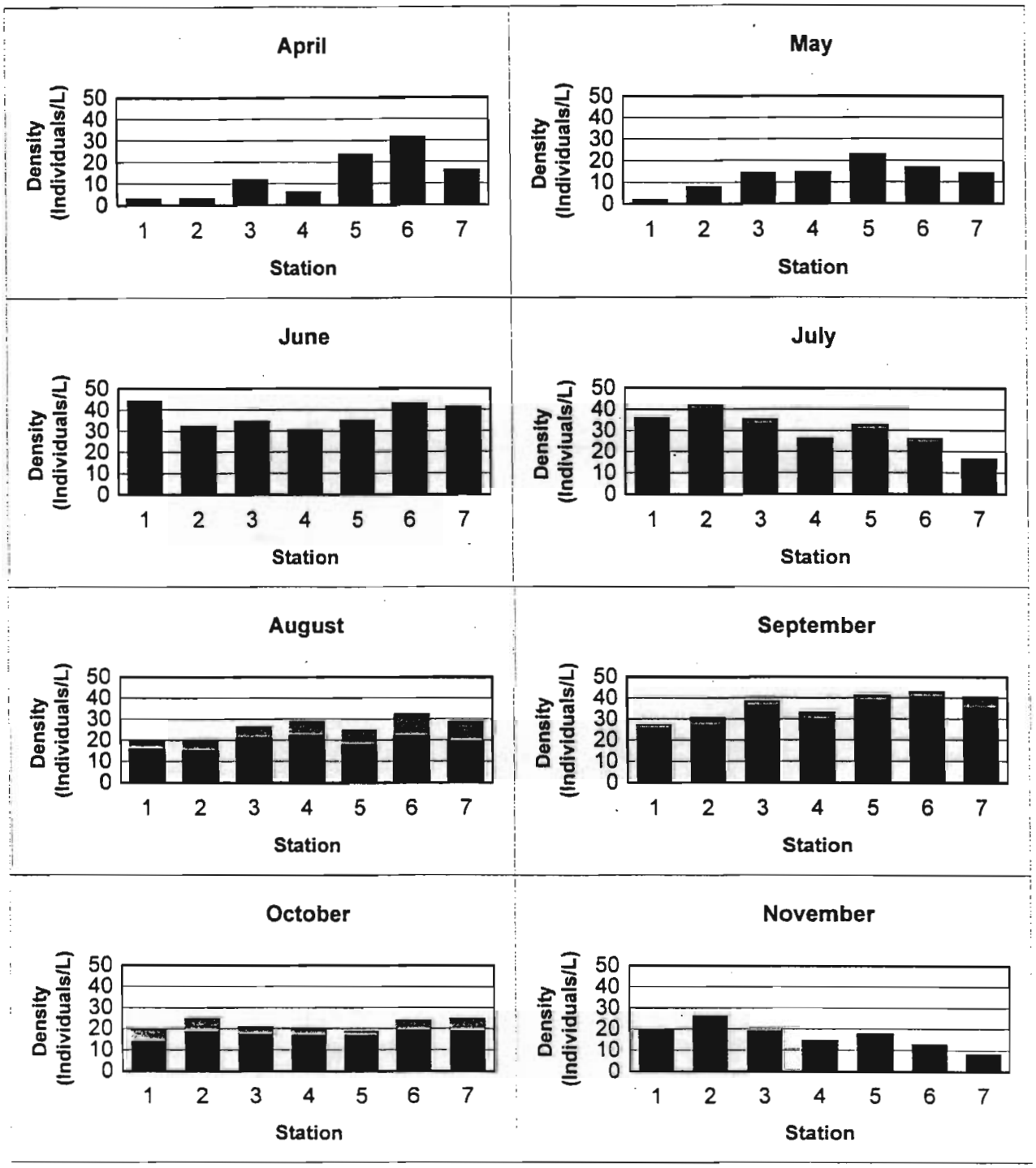


Fig. 27. Total zooplankton density plotted by station and month for 1994. Copepod density in black; cladoceran density in grey.

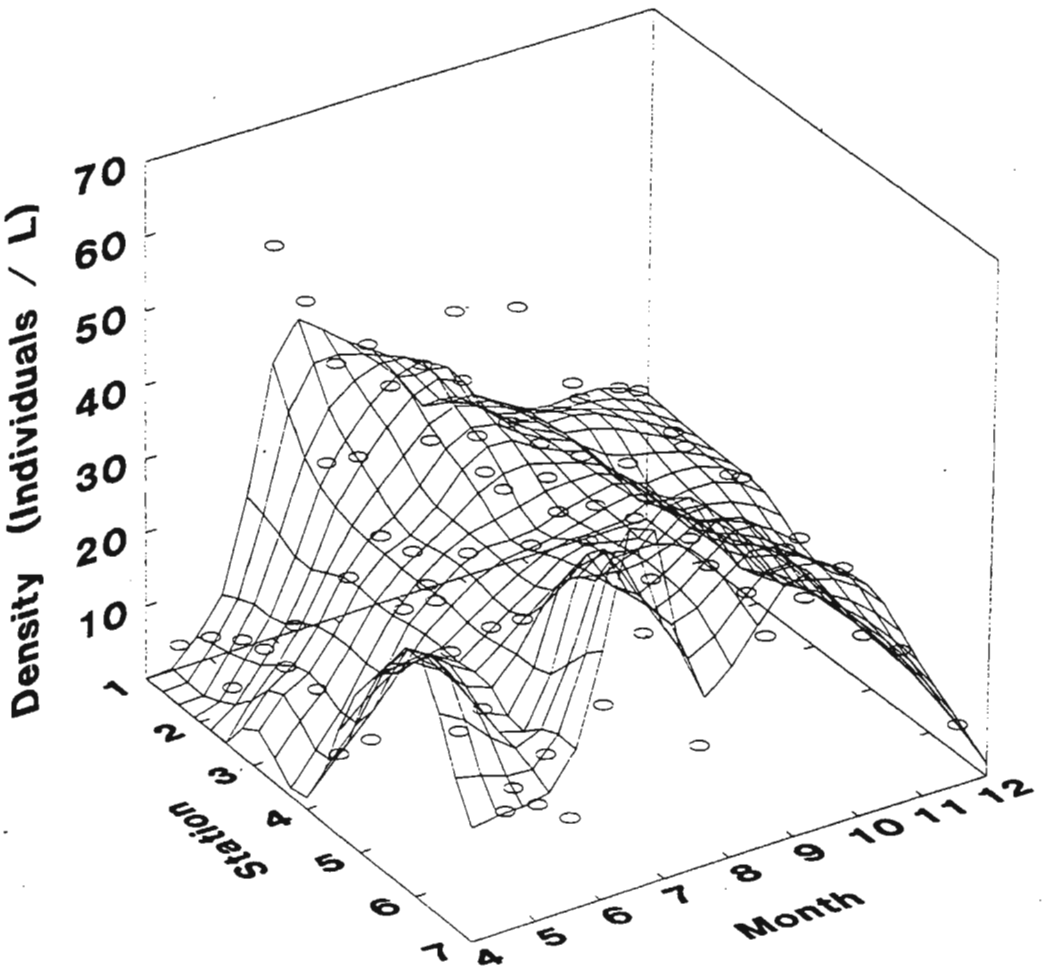


Fig. 28. Total zooplankton density plotted by station and month for 1994.

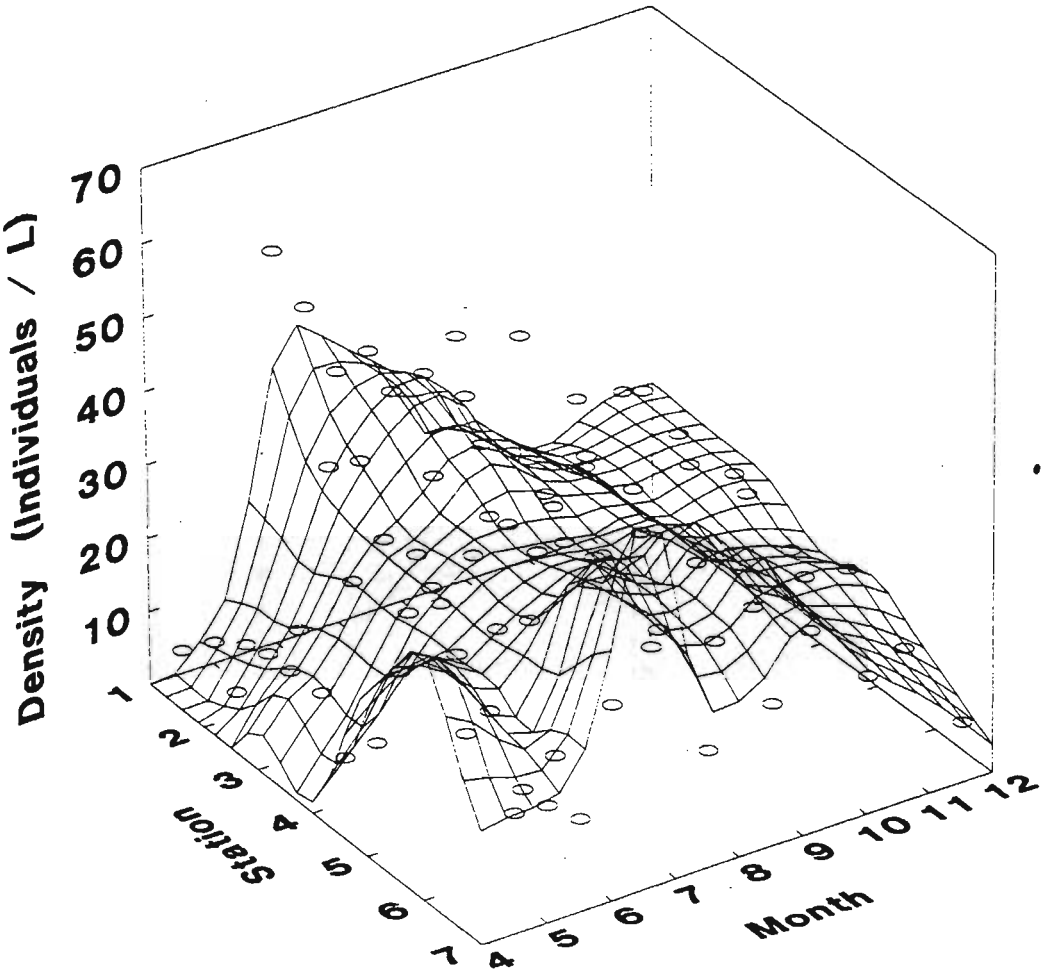


Fig. 29. Copepod zooplankton density plotted by station and month for 1994.

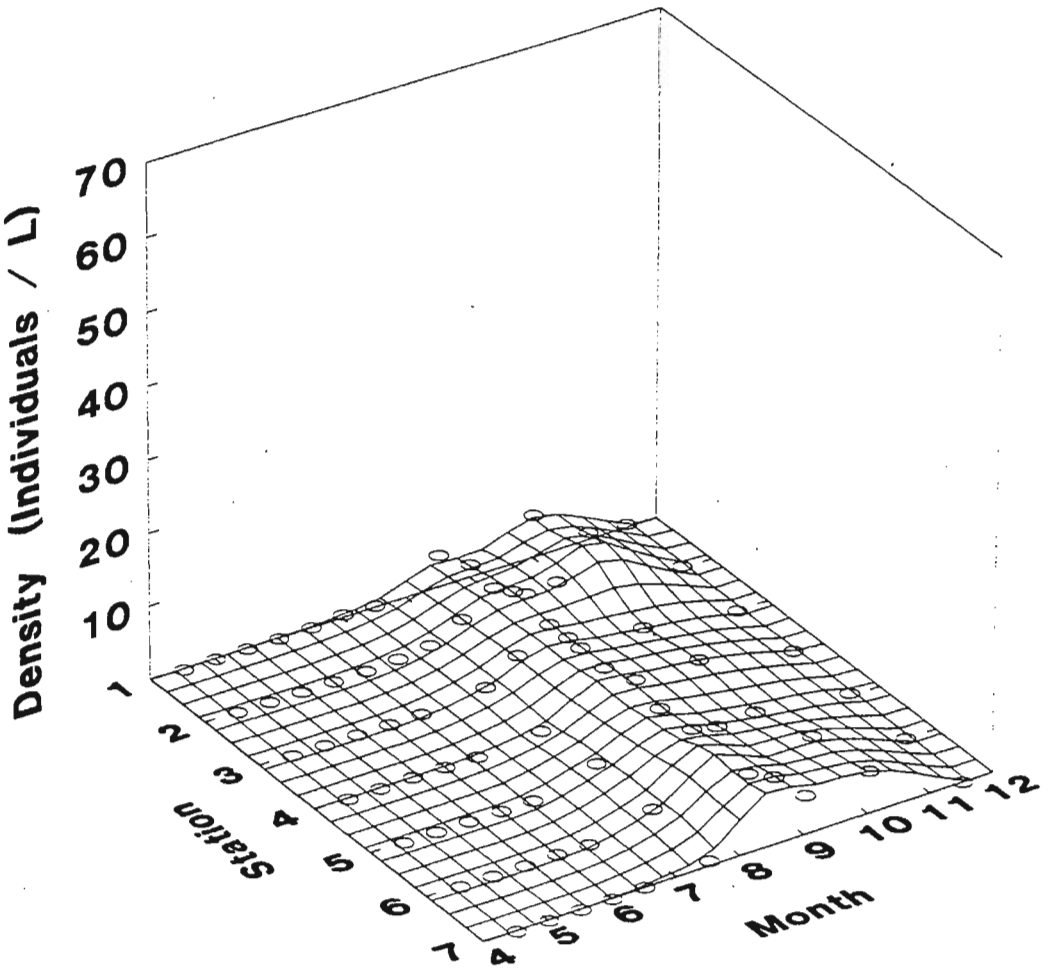


Fig. 30. Cladoceran zooplankton density plotted by station and month for 1994.

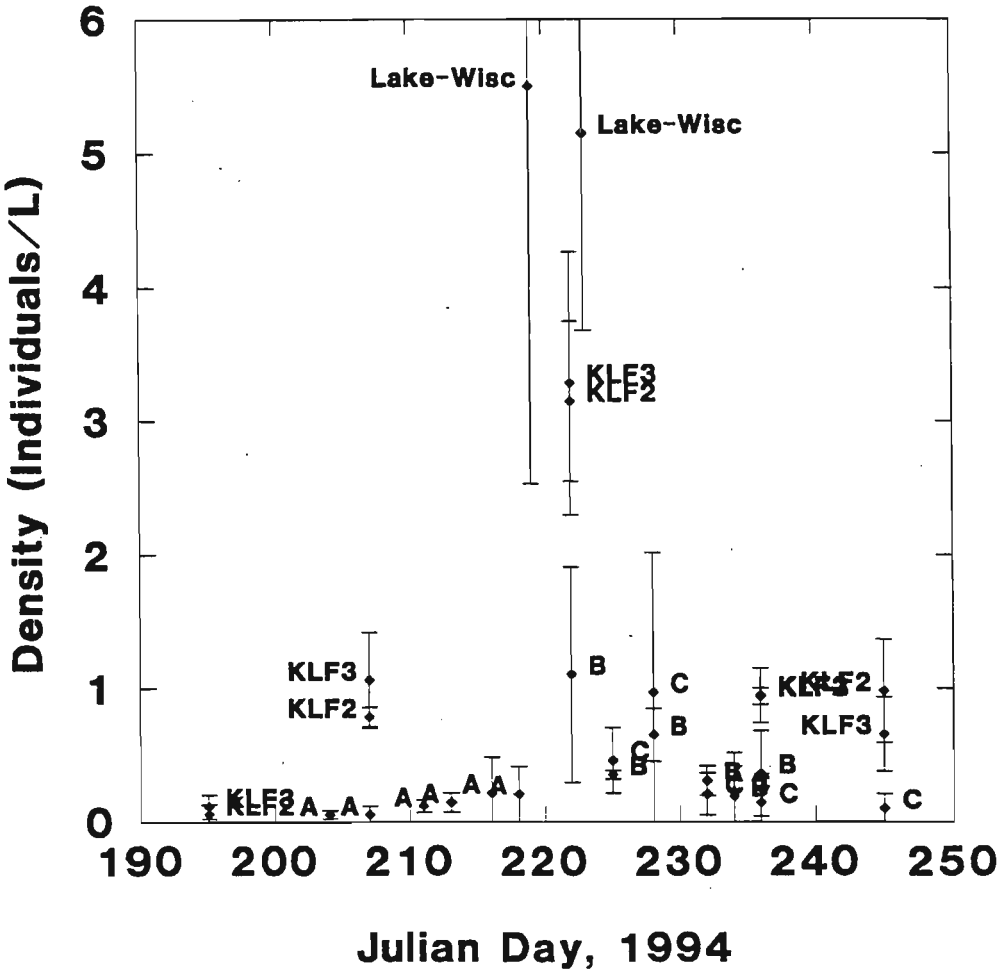


Fig. 31. Density of *Daphnia* plotted against Julian date in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate densities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

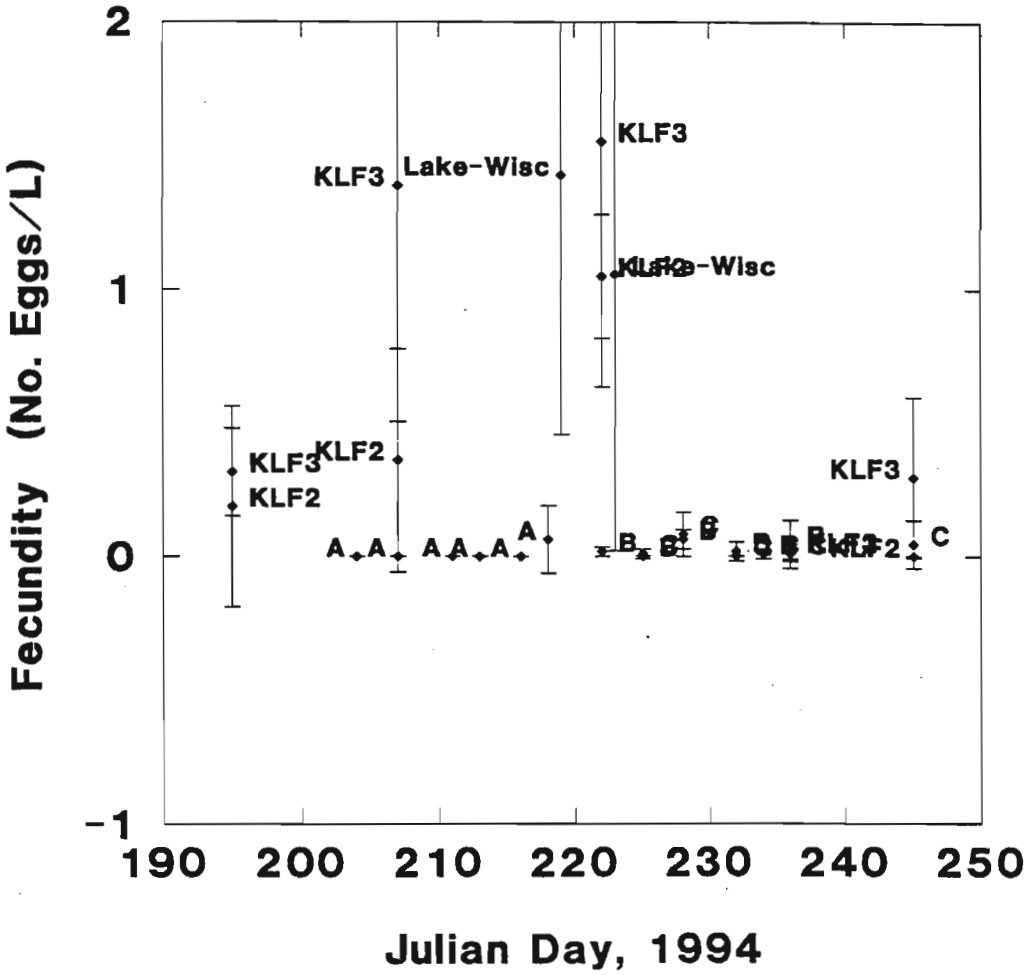


Fig. 32. Fecundity of *Daphnia* (total number of eggs per unit volume) plotted against Julian date in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate fecundities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

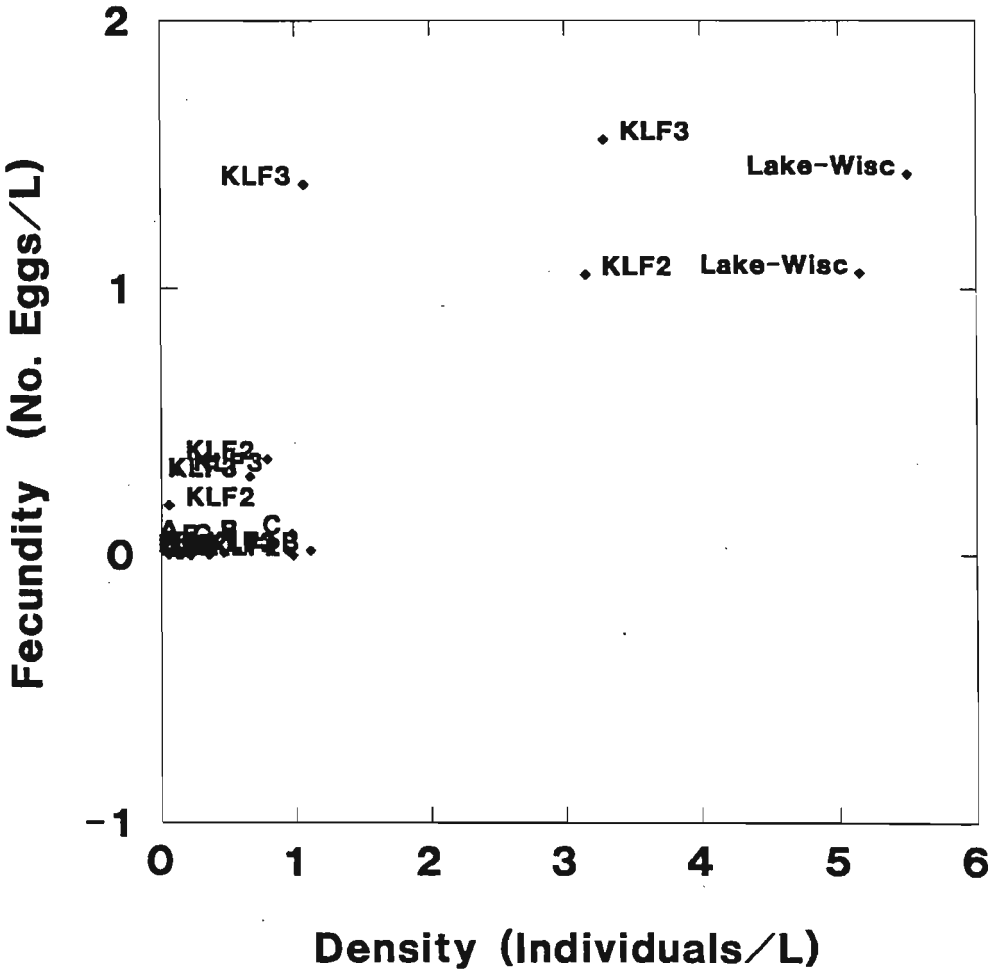


Fig. 33. Fecundity of *Daphnia* plotted against *Daphnia* density in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate fecundities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

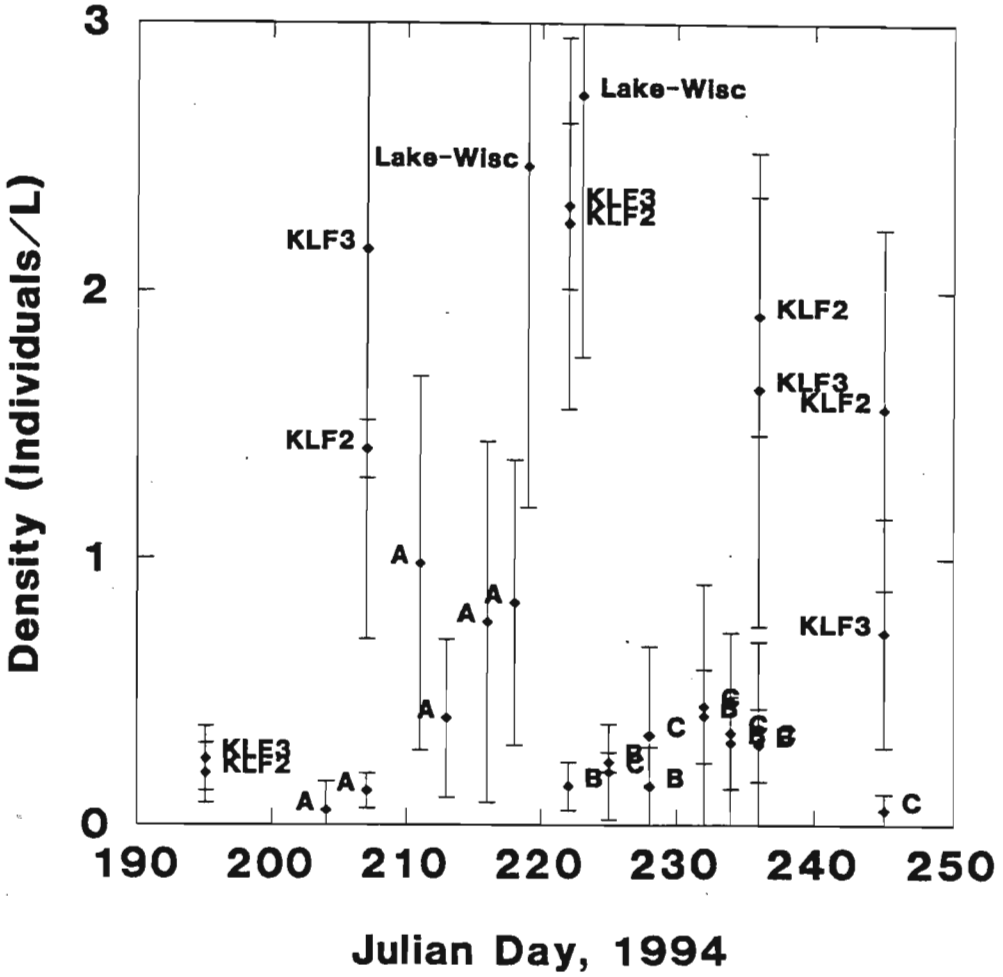


Fig. 34. Density of *Diaphanosoma* plotted against Julian date in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate densities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

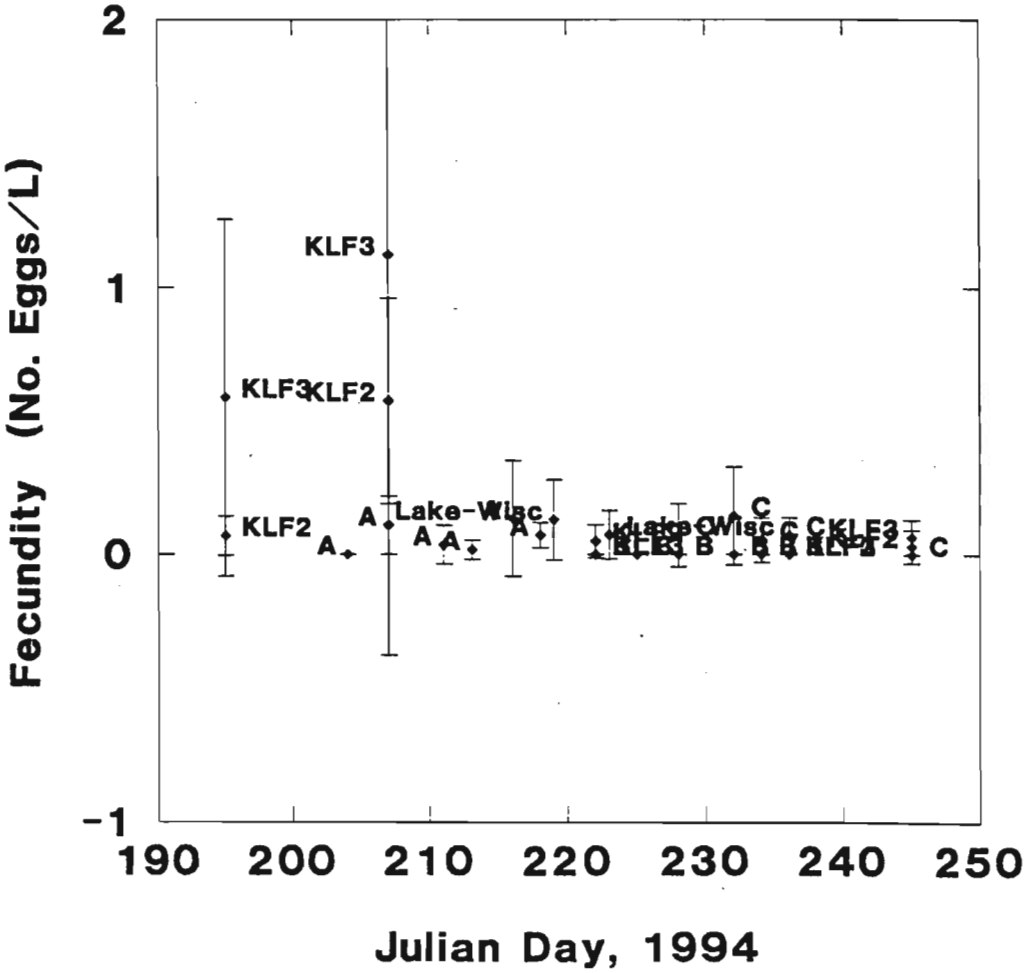


Fig. 35. Fecundity of *Diaphanosoma* (total number of eggs per unit volume) plotted against Julian date in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate fecundities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

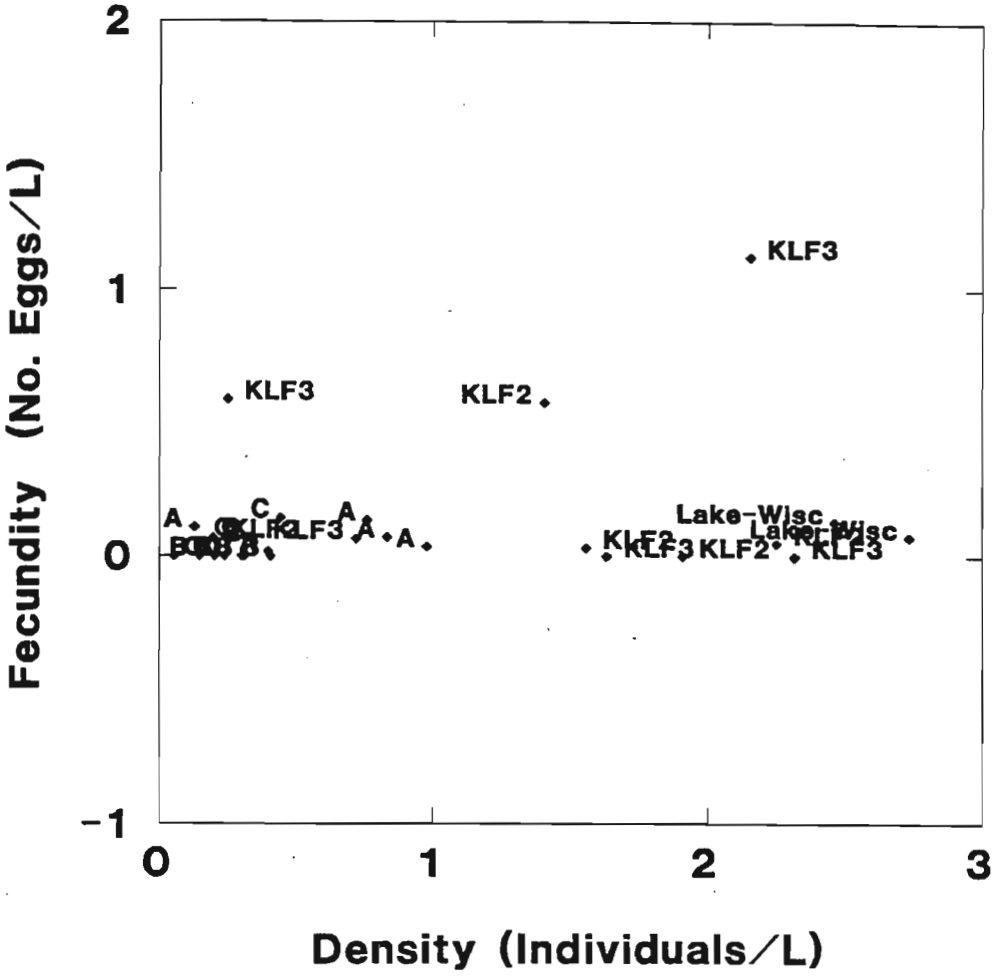


Fig. 36. Fecundity of *Diaphanosoma* plotted against *Diaphanosoma* density in enclosures and in the main lake. A, B, and C indicate the three series of three enclosures each; samples were caught with the Wisconsin net. "Lake-Wisc" indicates samples caught using the Wisconsin net in the main lake. KLF 2 and KLF3 indicate fecundities observed in Clarke-Bumpus net hauls in the main lake at Stations 1 and 2. Error bars are two times the standard error of the mean.

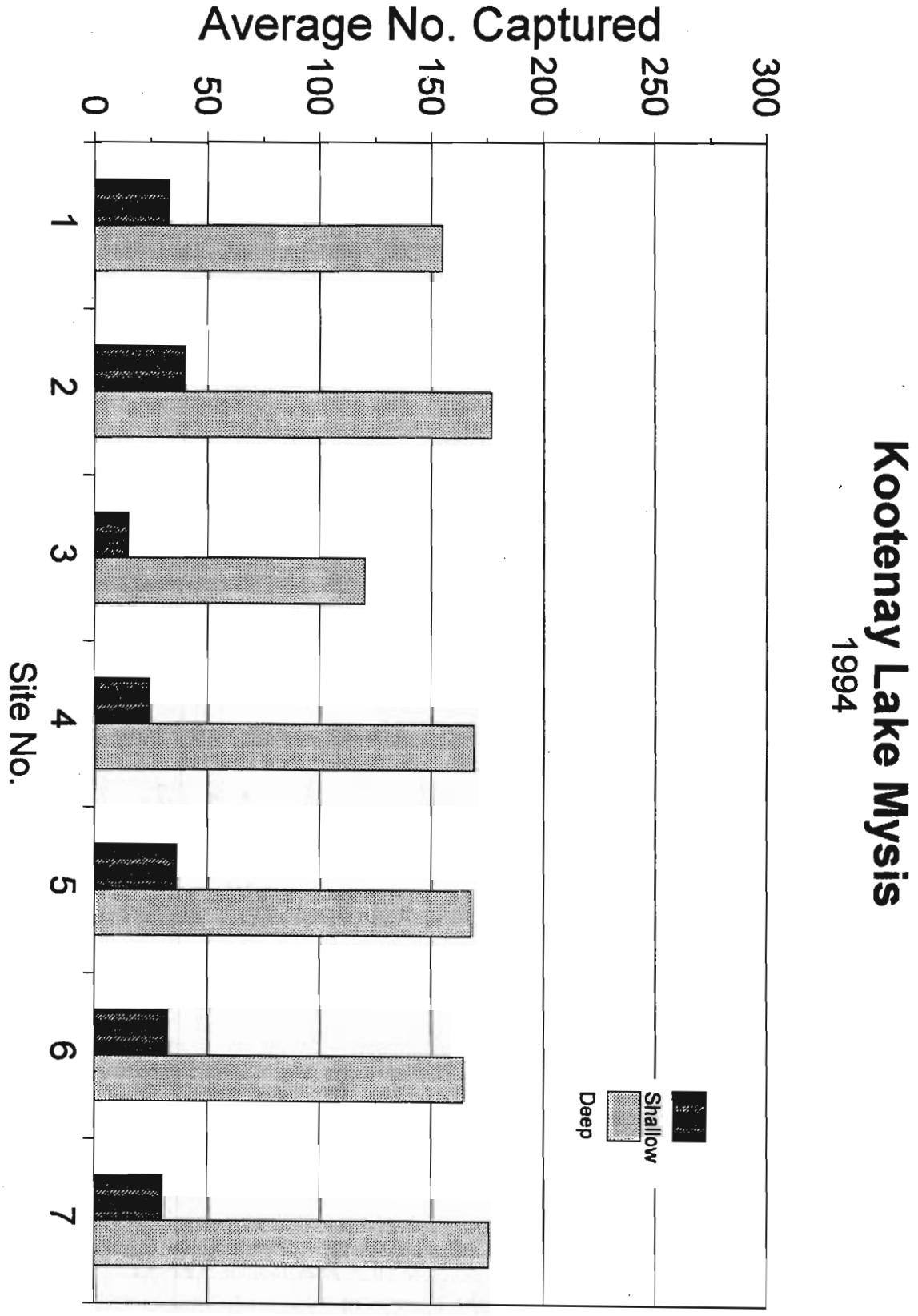


Fig. 37. Average number of mysids captured at Stations 1 to 7 in 1994.

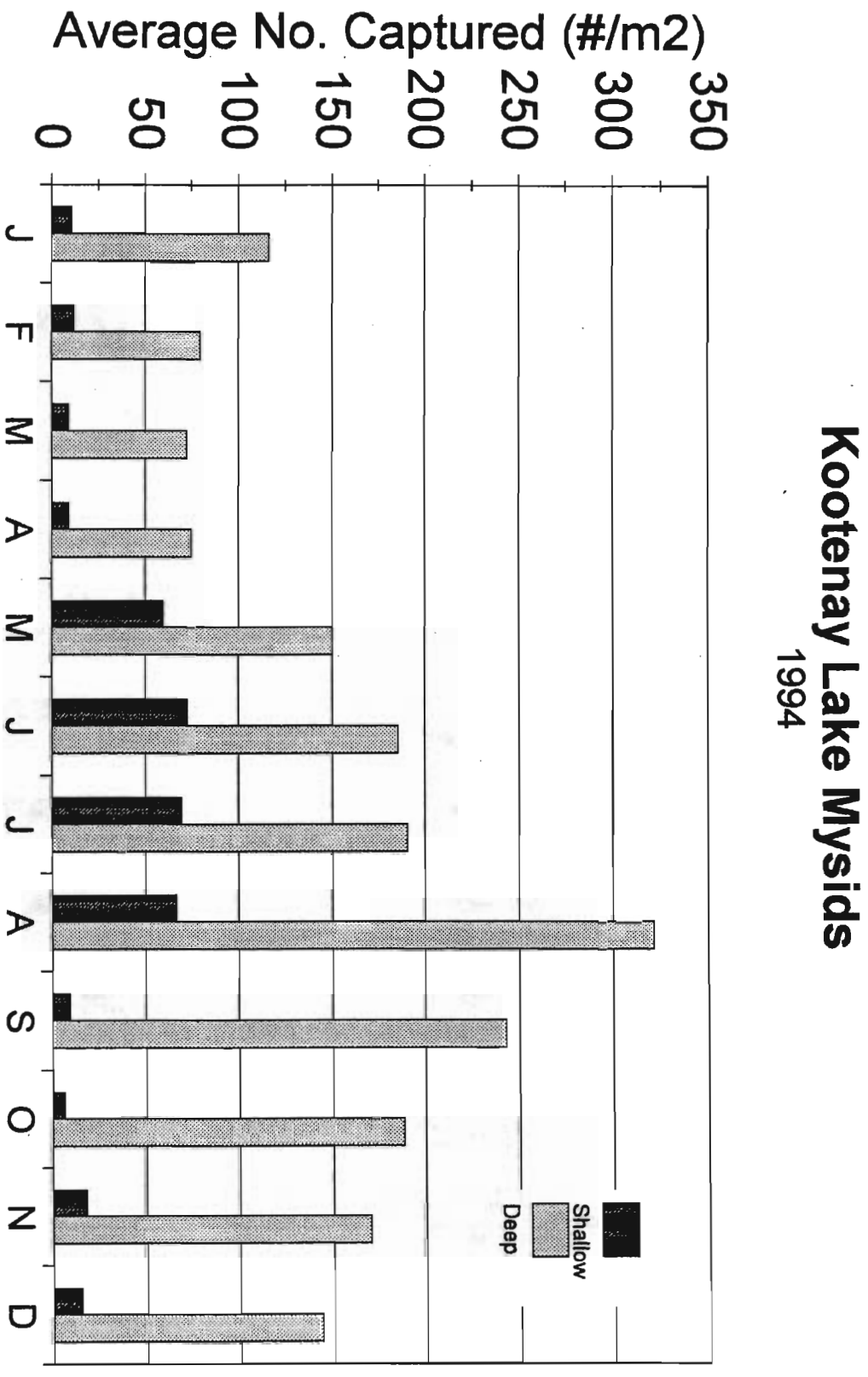


Fig. 38. Average number of mysids at all seven stations January to December, 1994.

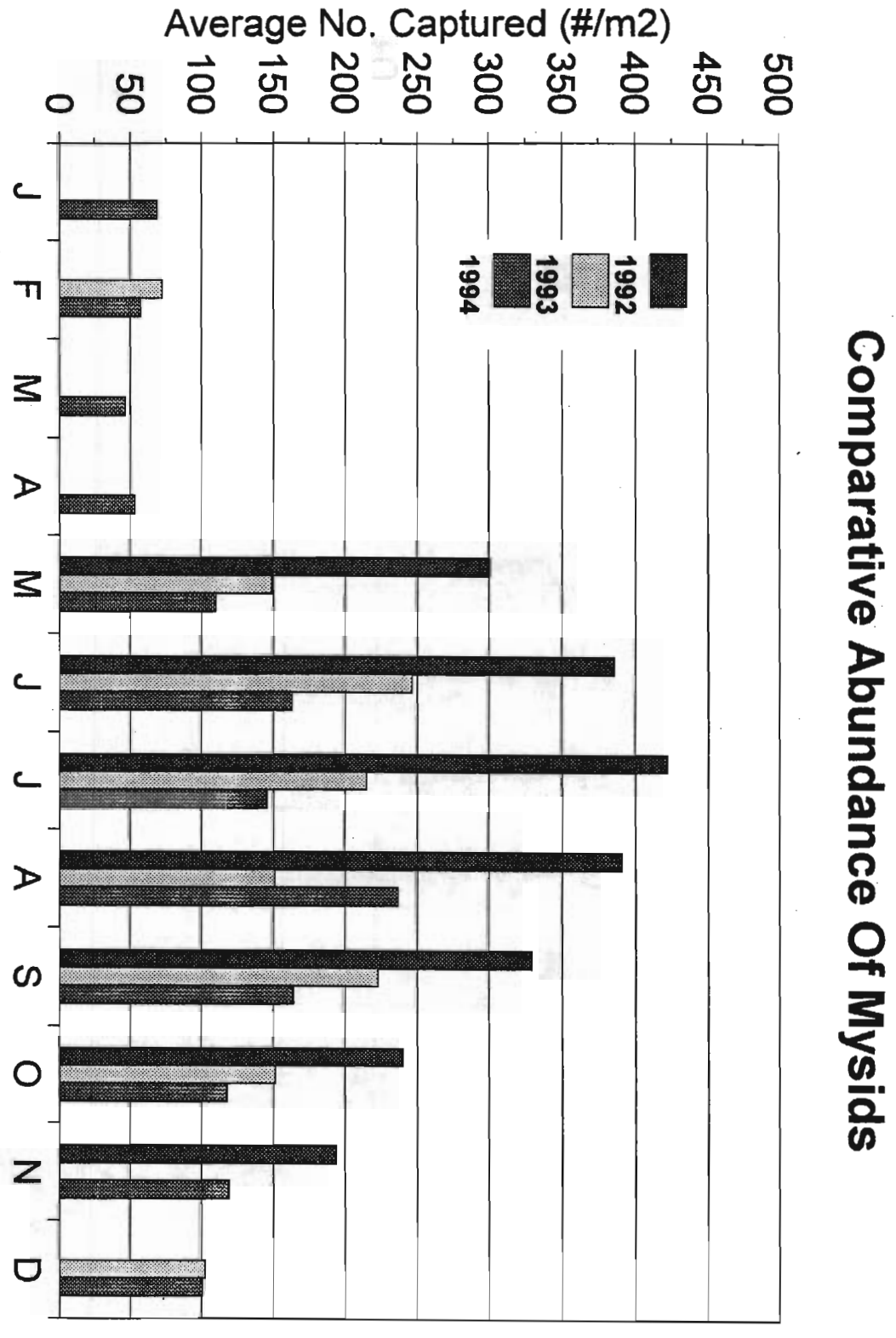


Fig. 39. Comparative seasonal abundance of mysids from 1992 to 1994.

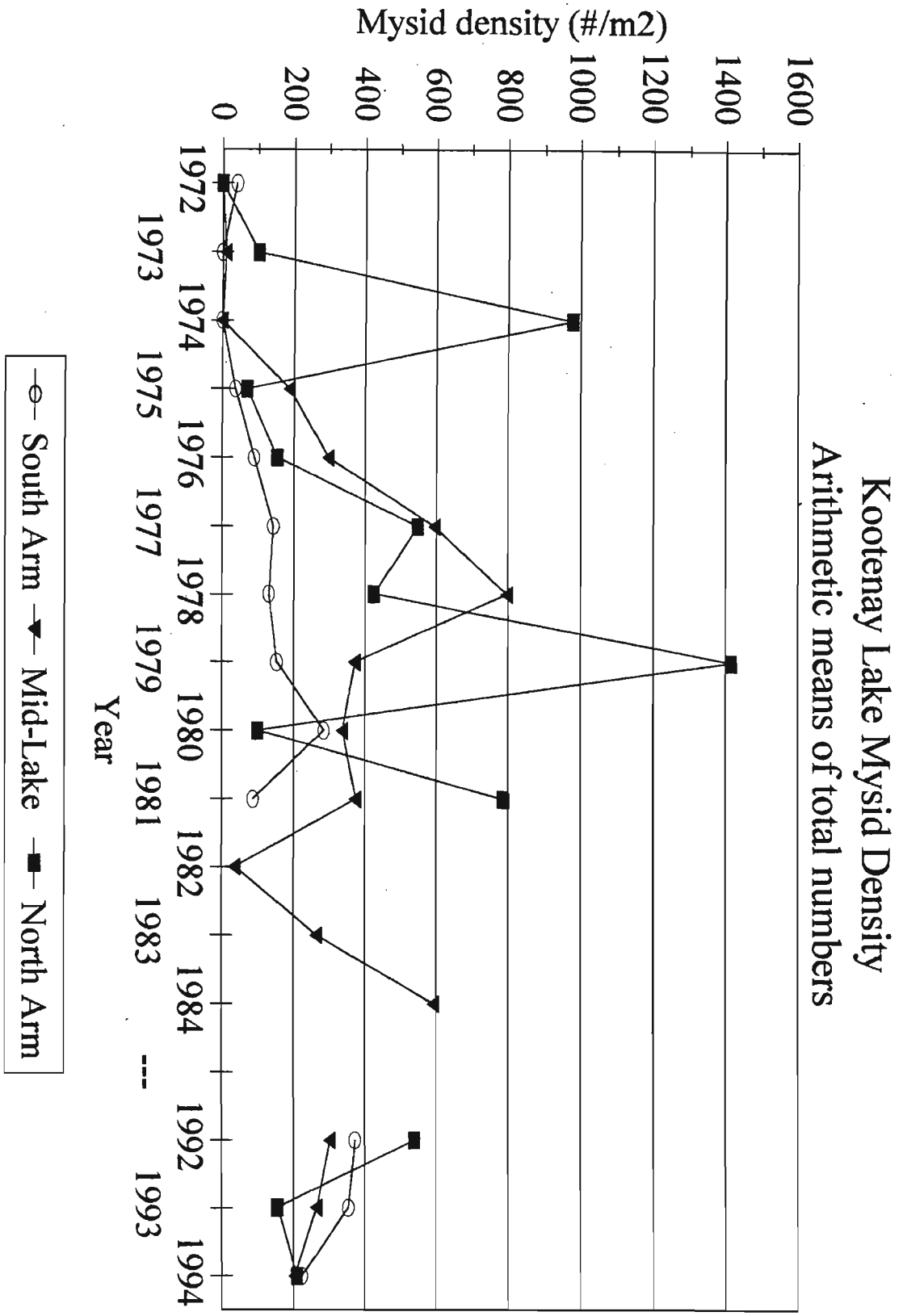
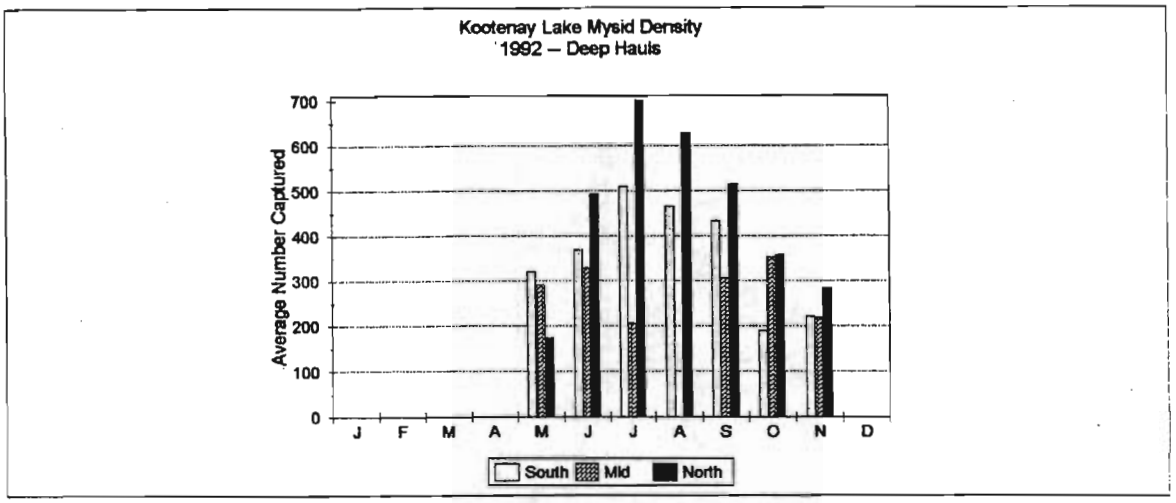
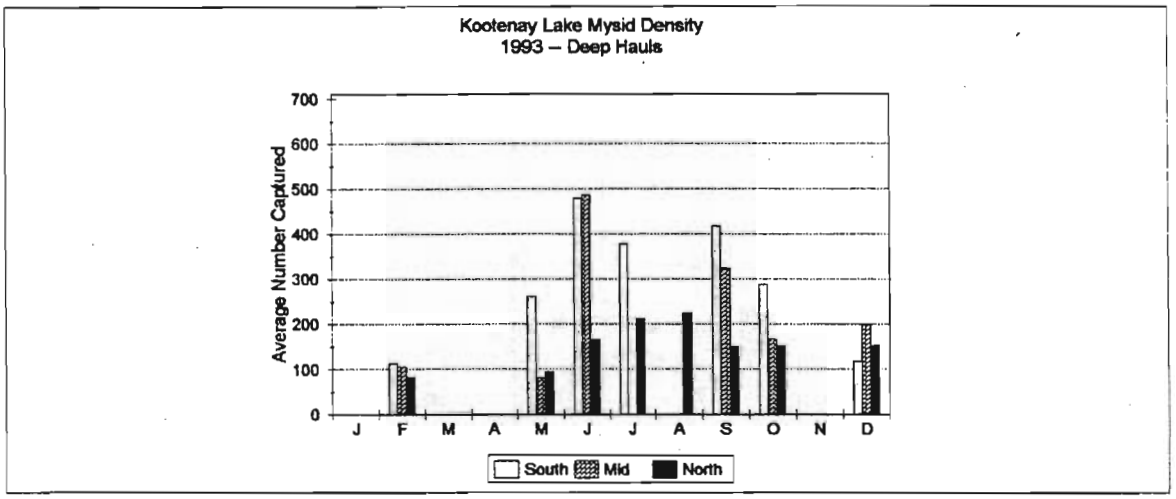


Fig. 40. Change in mysid density (no·m^{-2}) through time in Kootenay Lake.





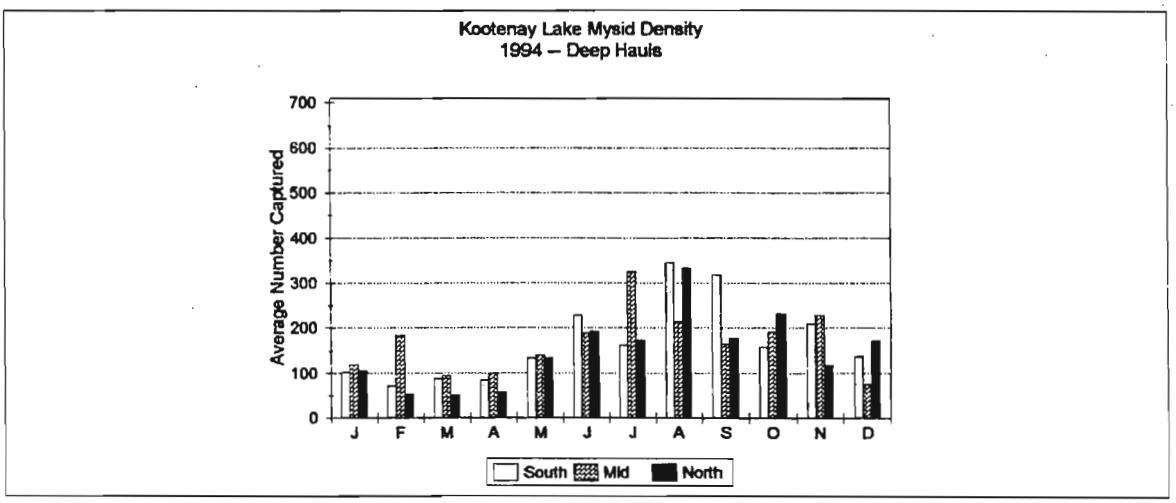
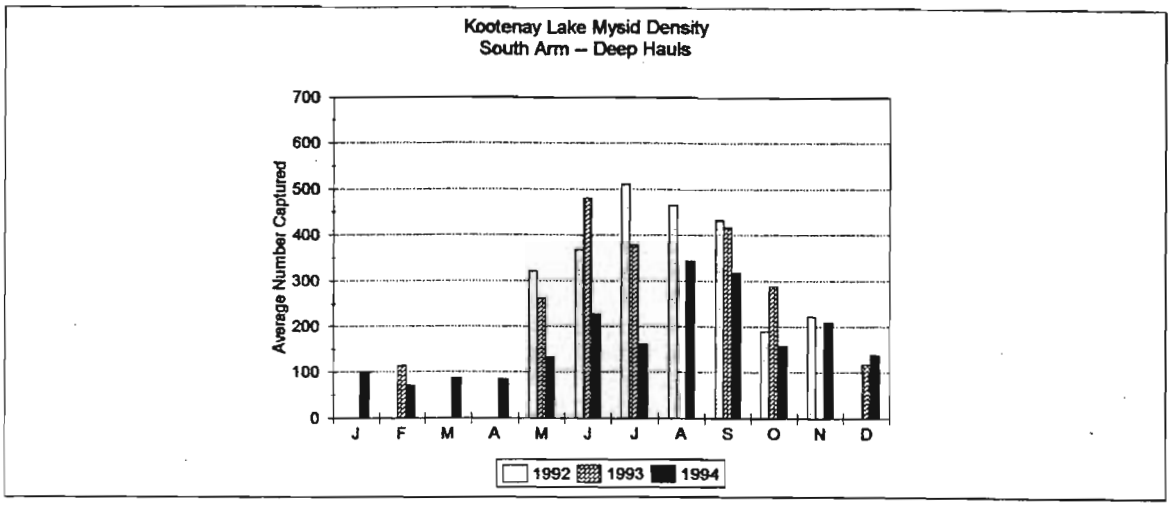
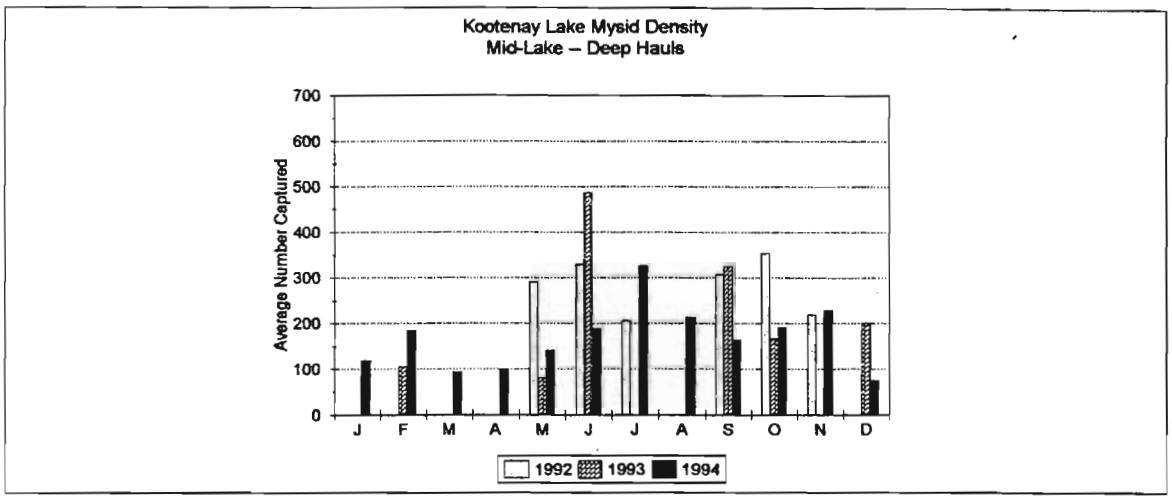


Fig. 41. Seasonal comparison of South Arm, Mid Lake and North Arm mysid abundances for deep hauls. a) 1992; b) 1993; c) 1994.





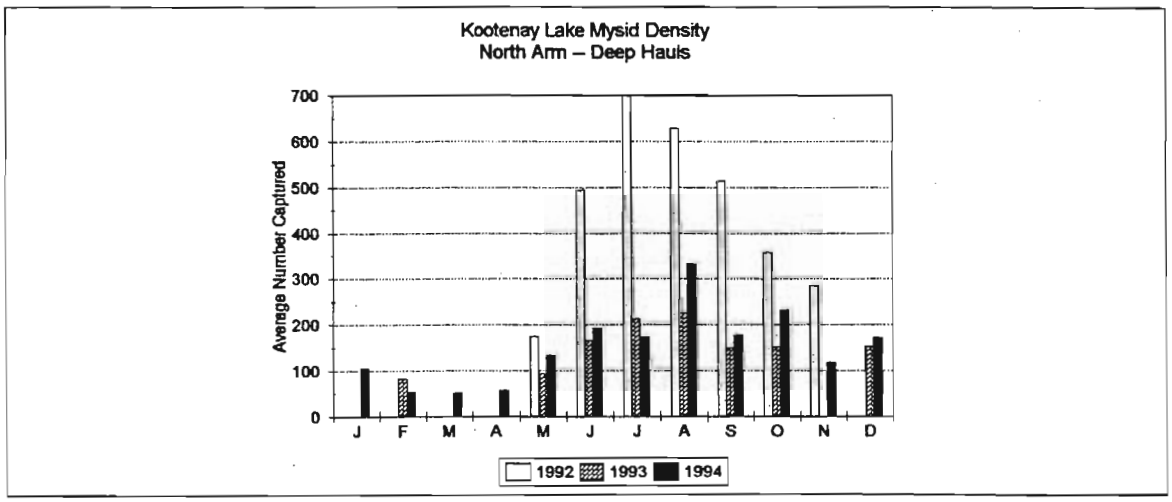


Fig. 42. Between year comparison of mysid abundances for deep hauls. a) South Arm; b) Mid Lake; c) North Arm.

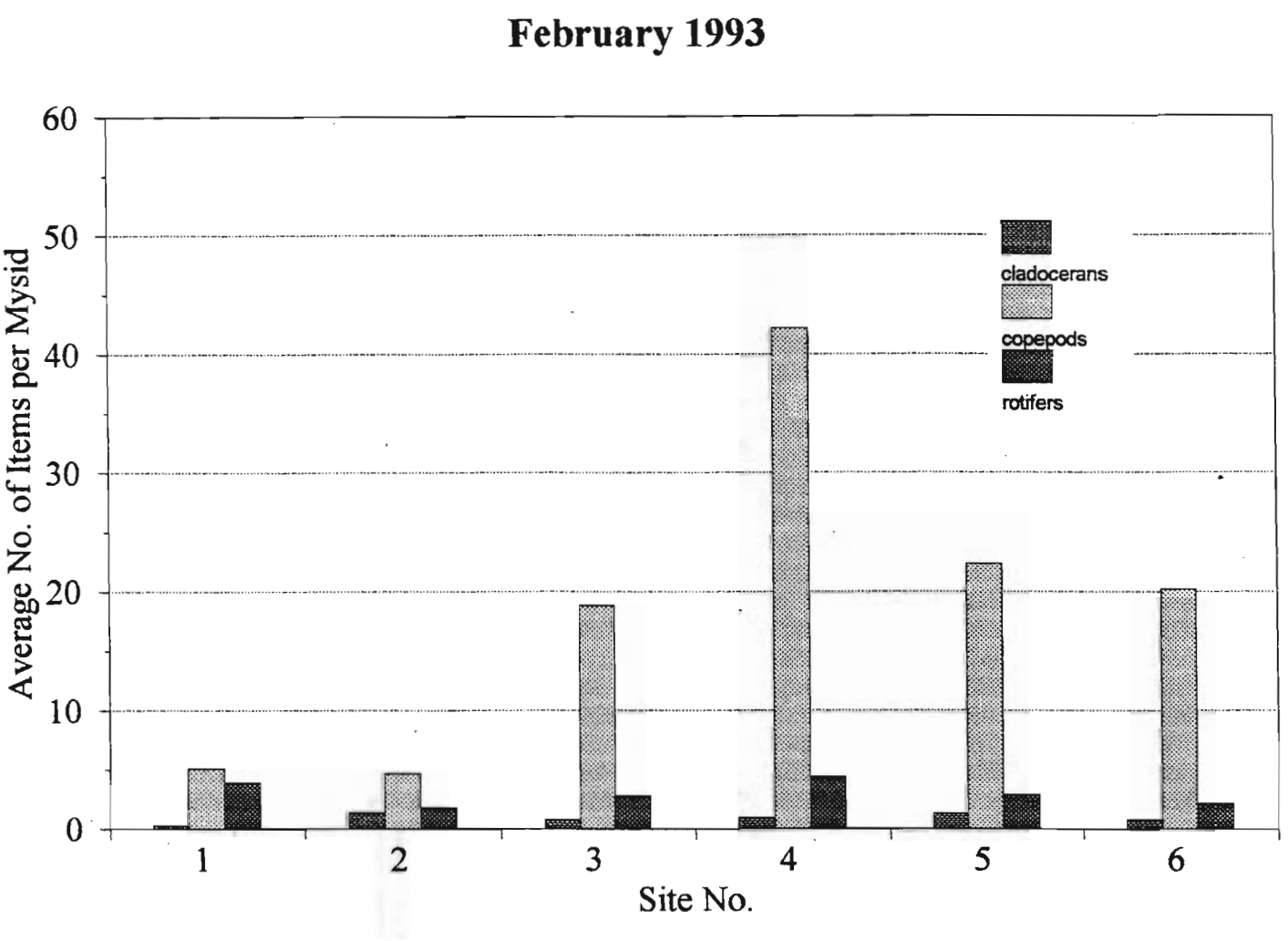


Fig. 43a. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, February, 1993. Bars represent standard error.

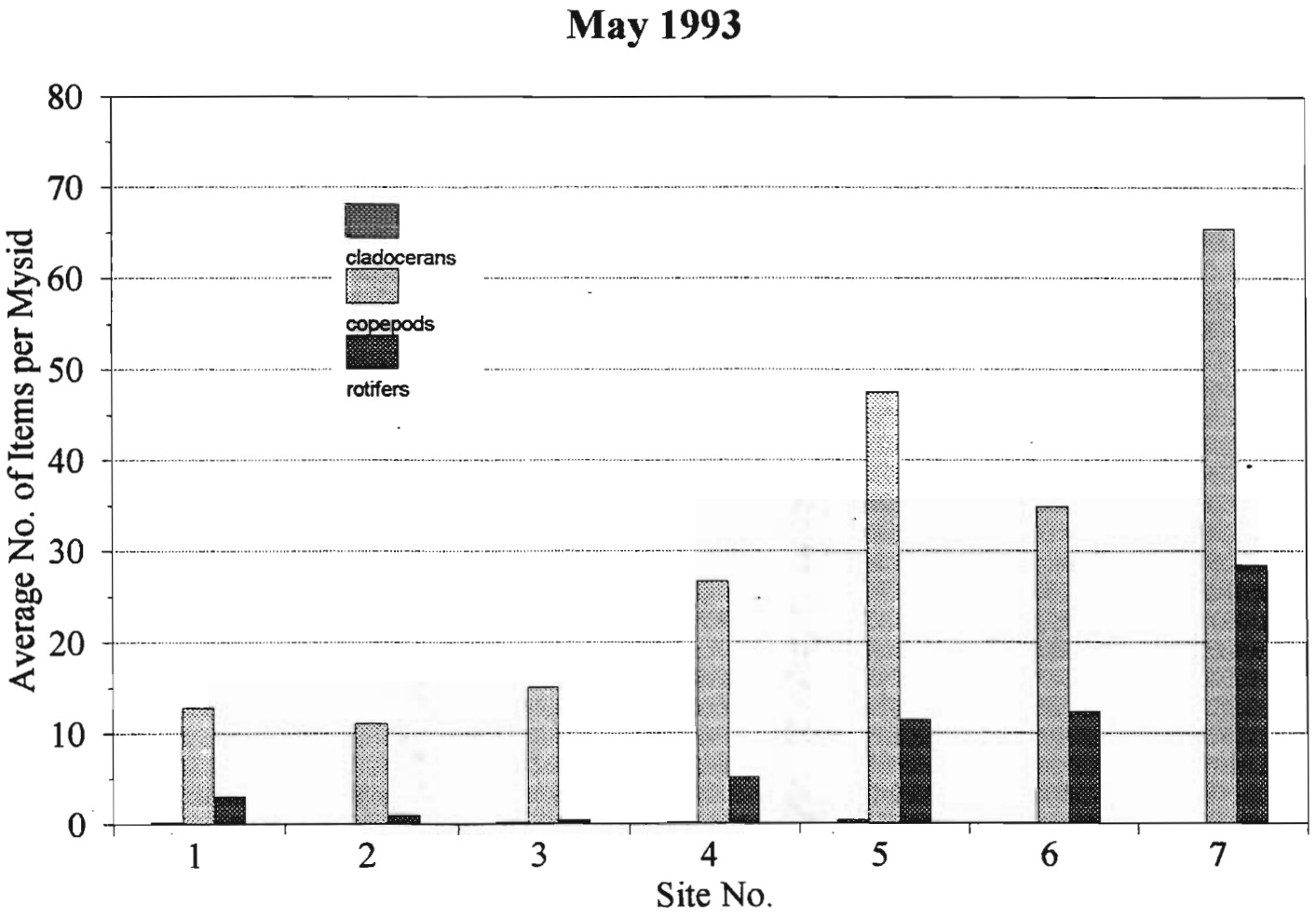


Fig. 43b. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, May, 1993. Bars represent standard error.

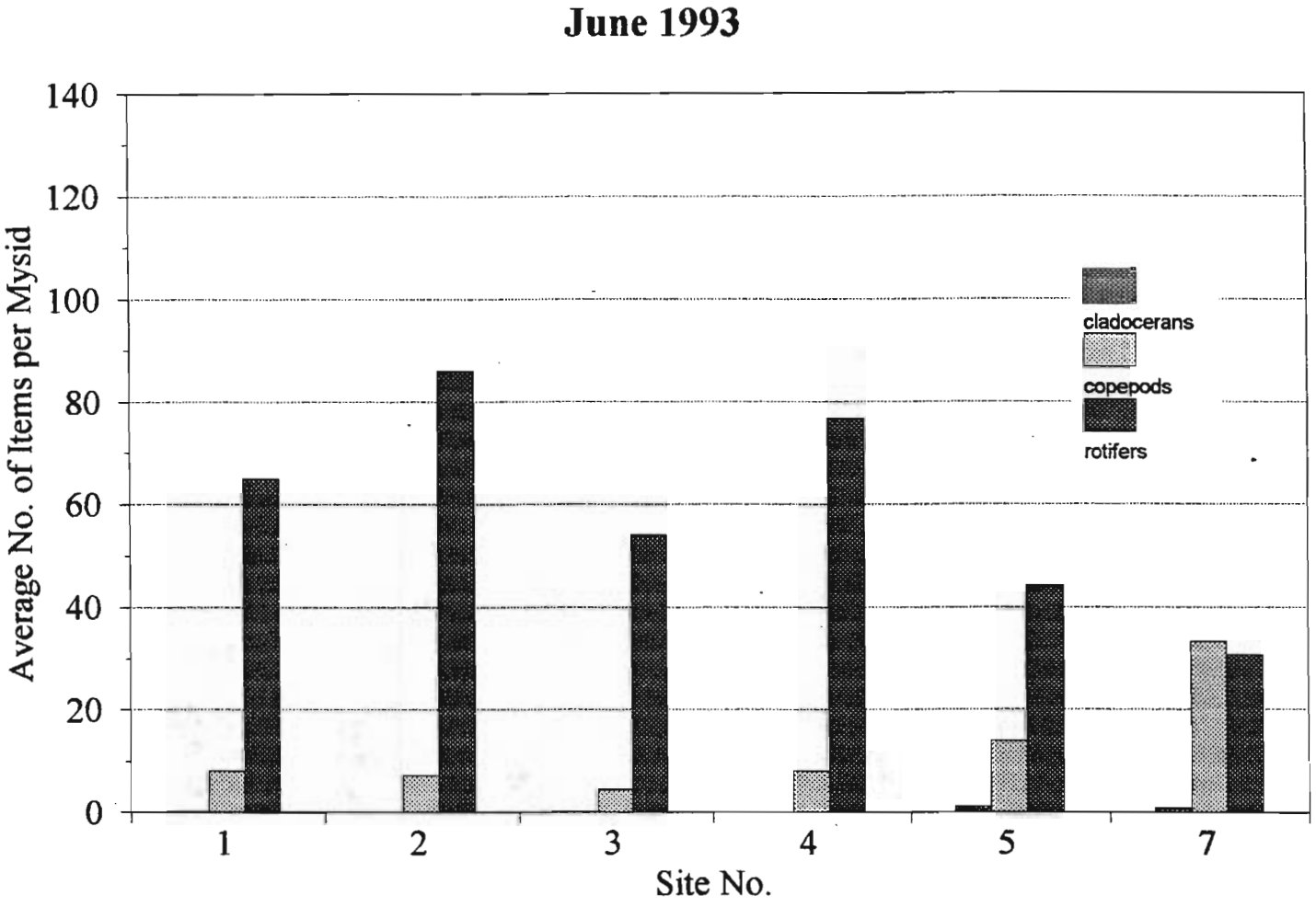


Fig. 43c. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, June,1993. Bars represent standard error.

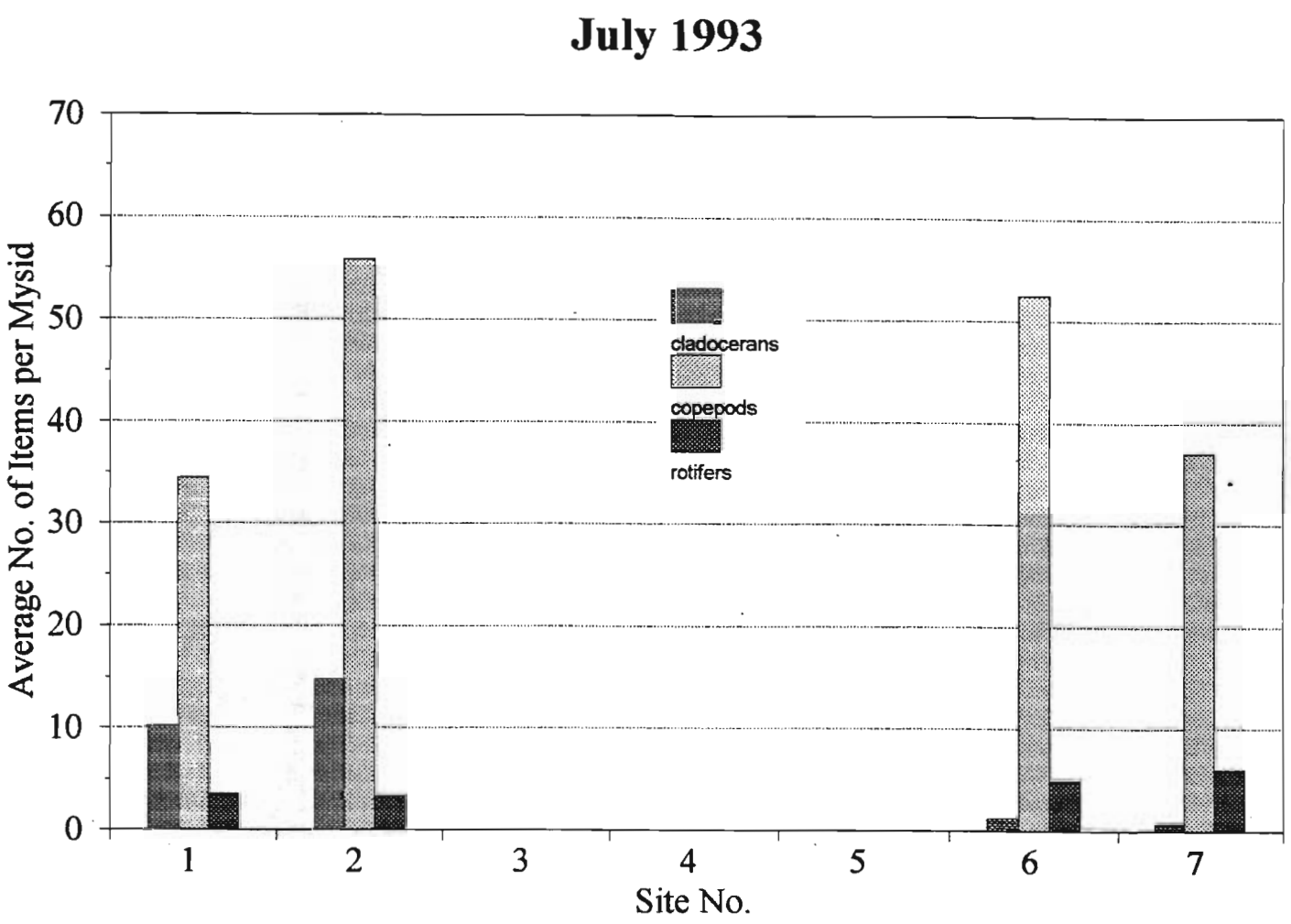


Fig. 43d. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, July, 1993. Bars represent standard error.

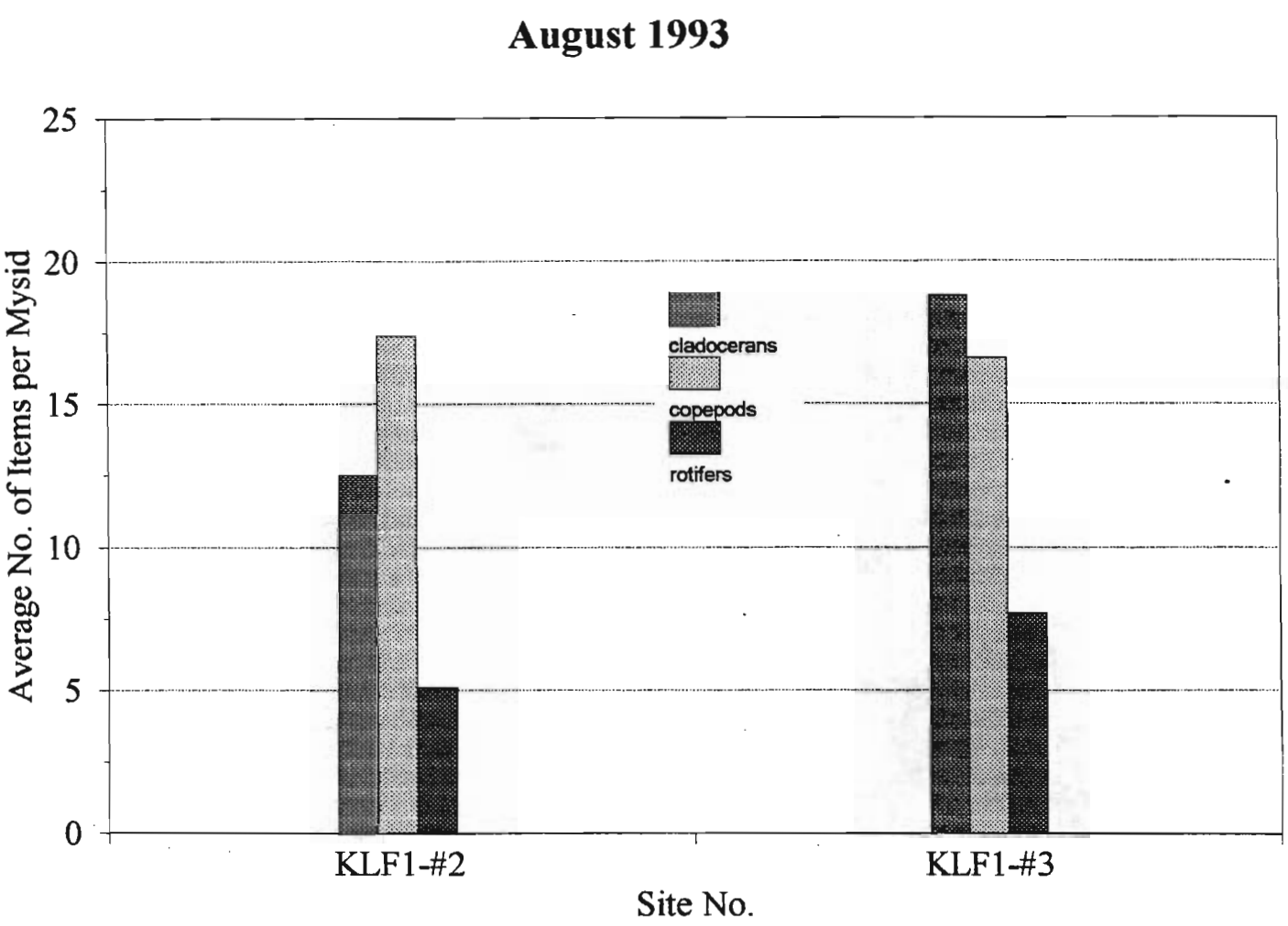


Fig. 43e. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, August, 1993. Bars represent standard error.

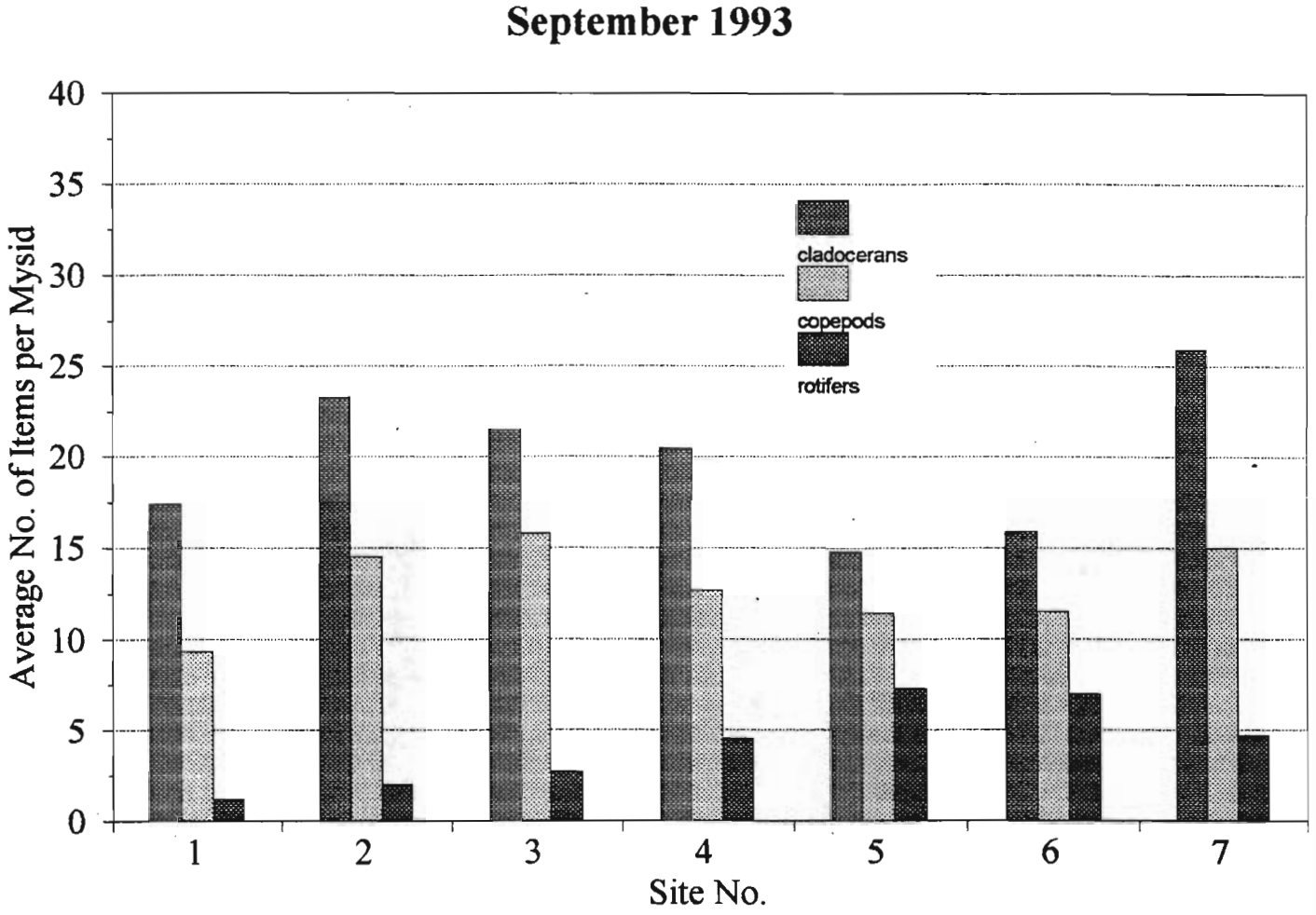


Fig. 43f. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, September, 1993. Bars represent standard error.

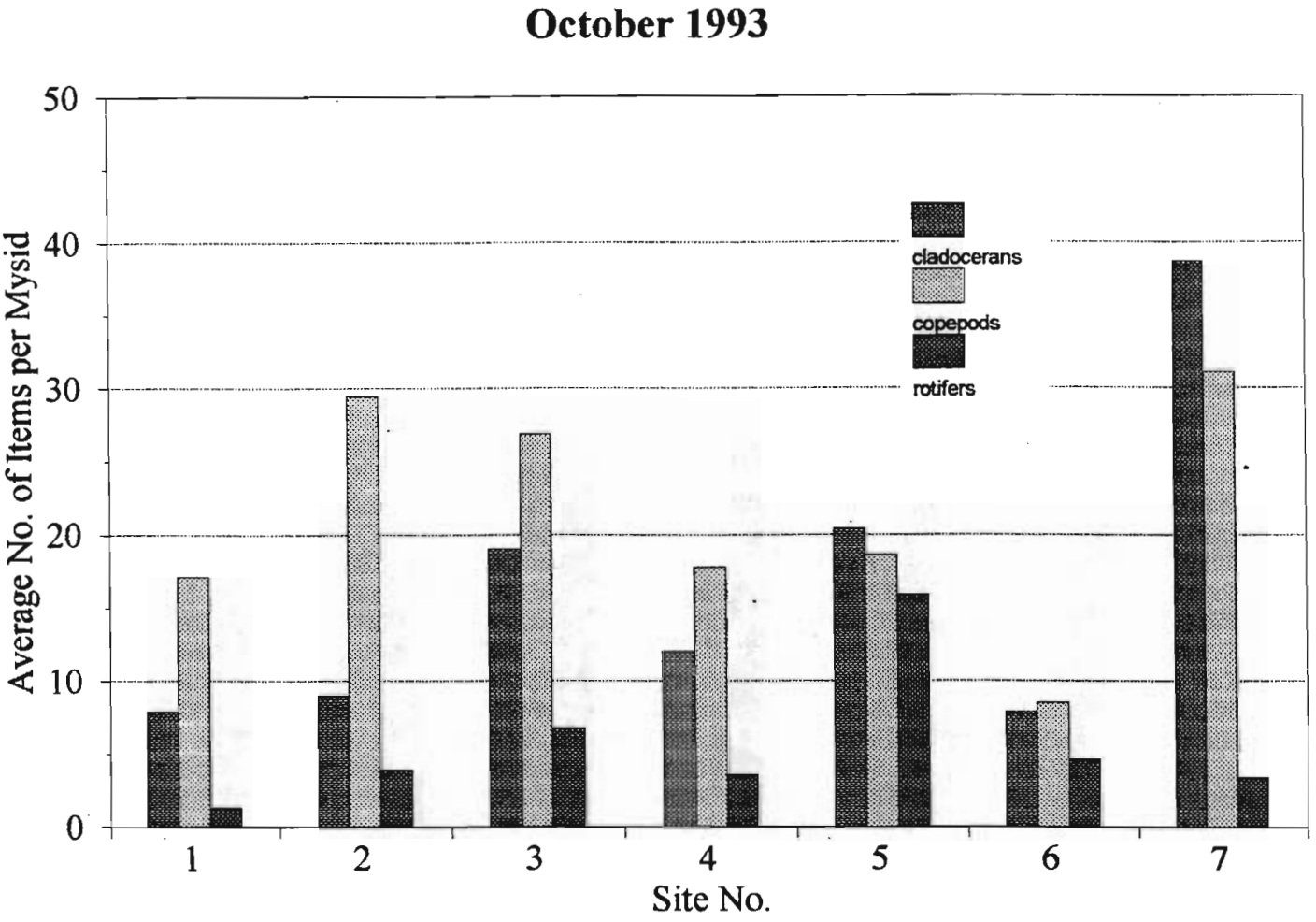


Fig. 43g. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, October, 1993. Bars represent standard error.

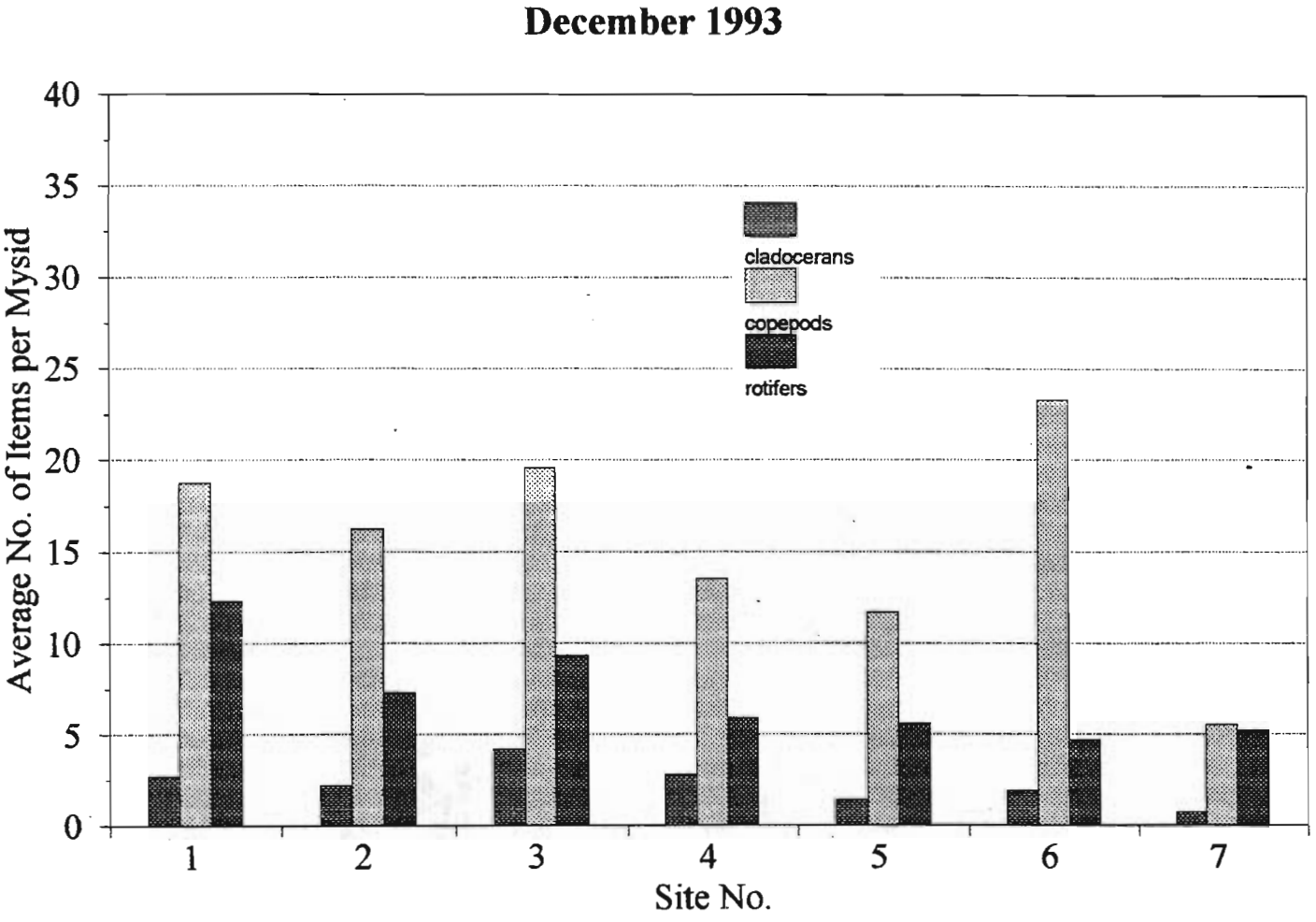


Fig. 43h. Monthly average number of cladoceran and copepod mandibles and rotifers found in mysid stomach contents, December, 1993. Bars represent standard error.

Comparison of Gut Contents

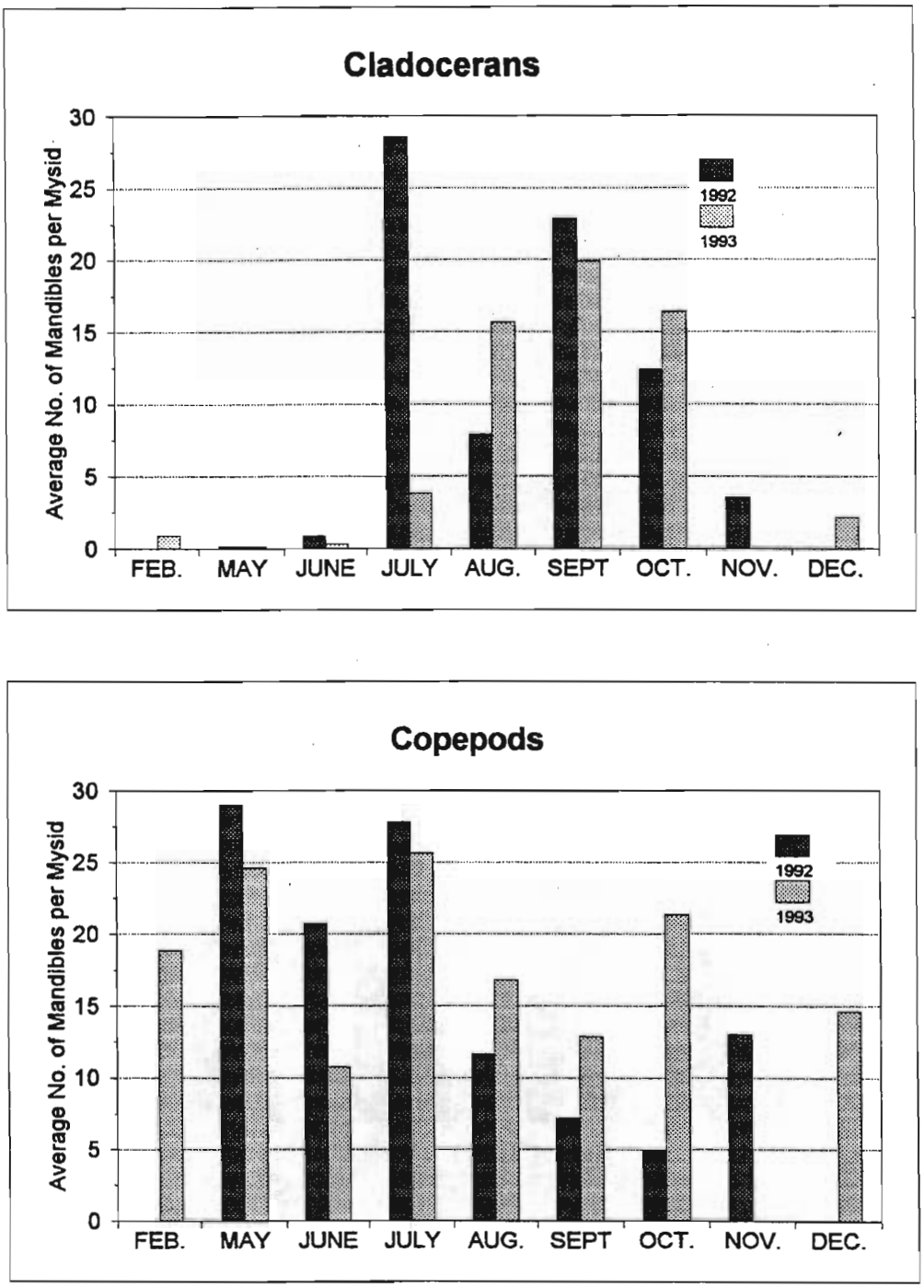


Fig. 44. Seasonal variation in average number of a) cladoceran mandibles and b) copepod mandibles in the mysid guts for 1992 and 1993.

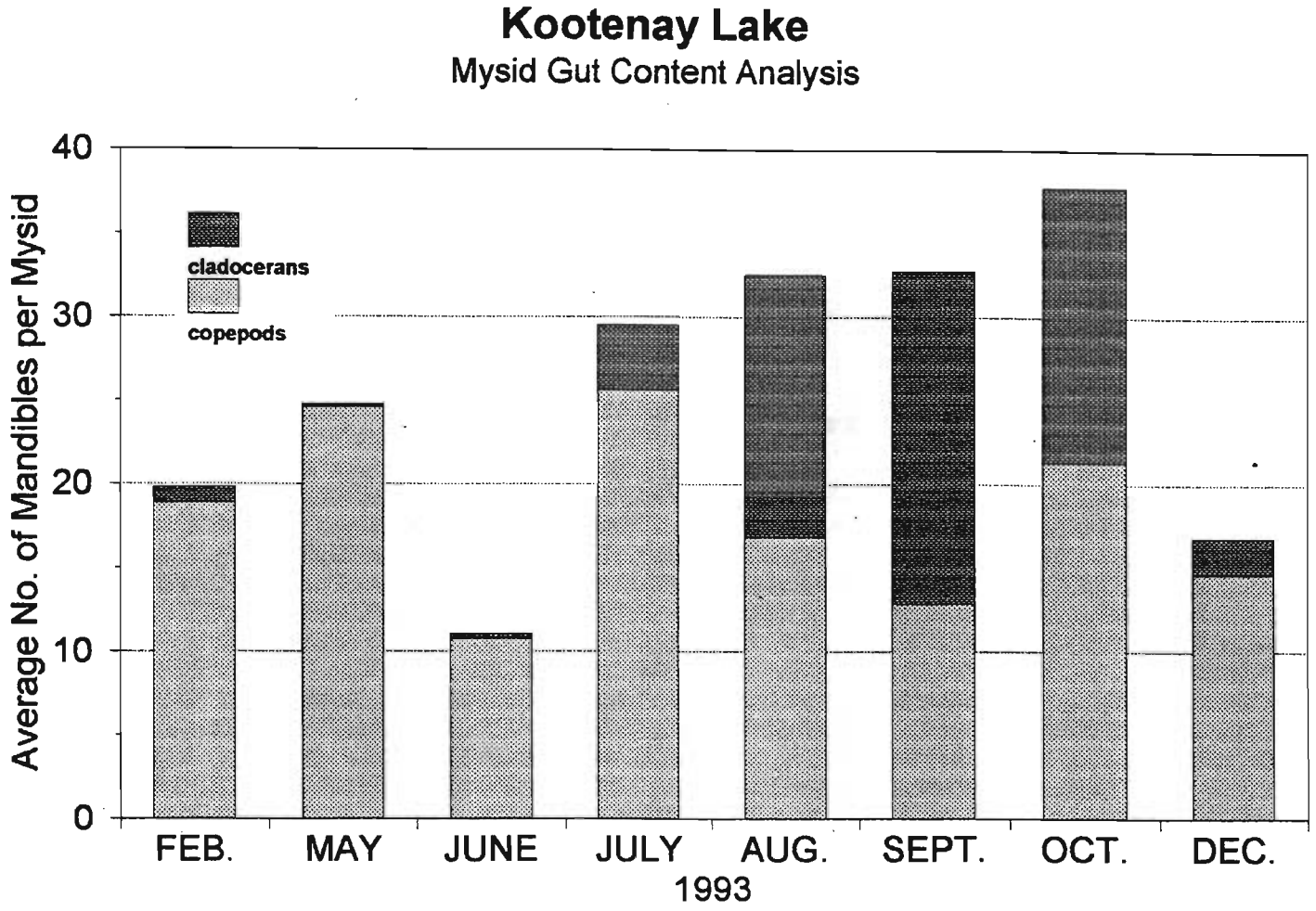


Fig. 45. Relative abundance of cladoceran and copepod mandibles in the mysid guts in 1993.

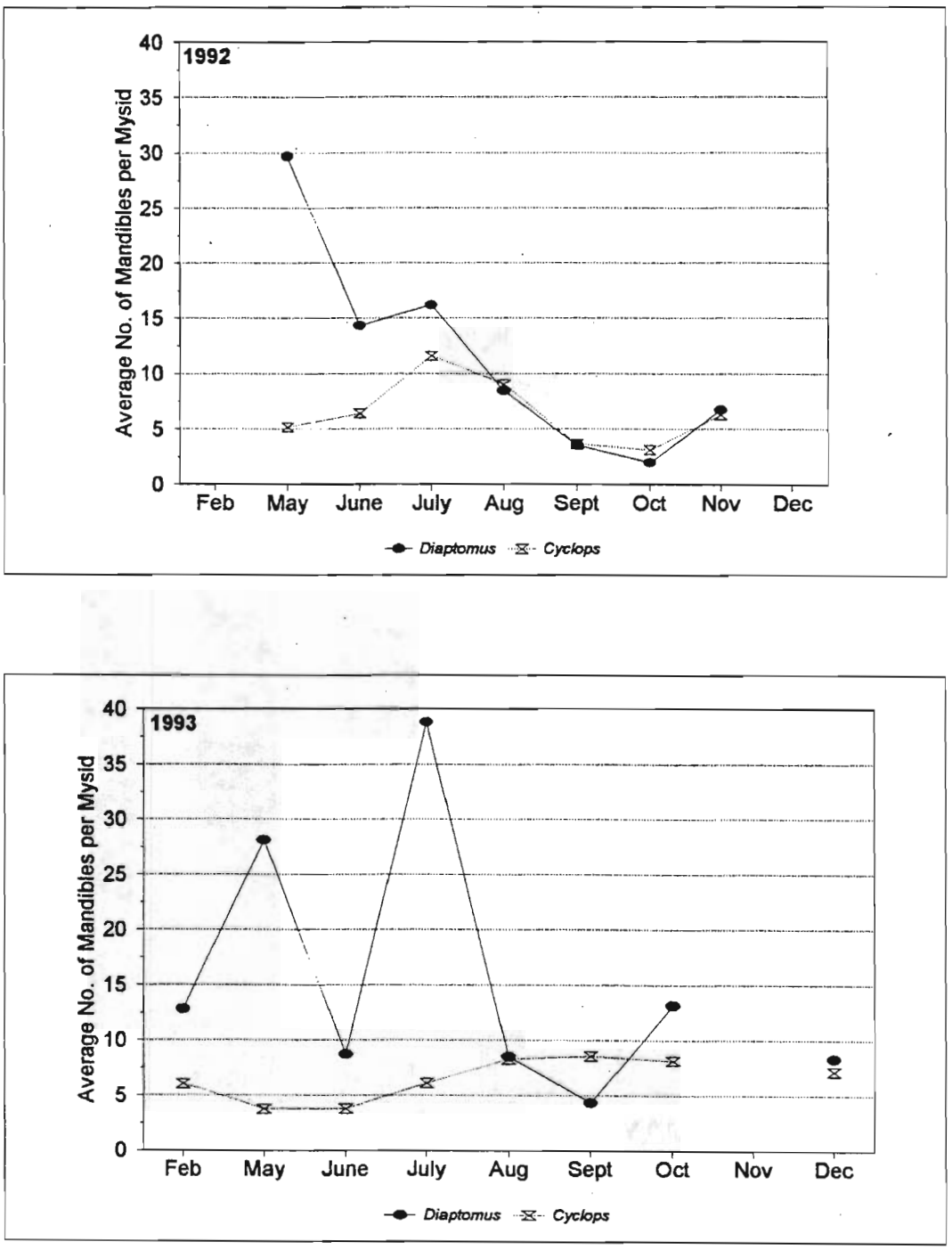
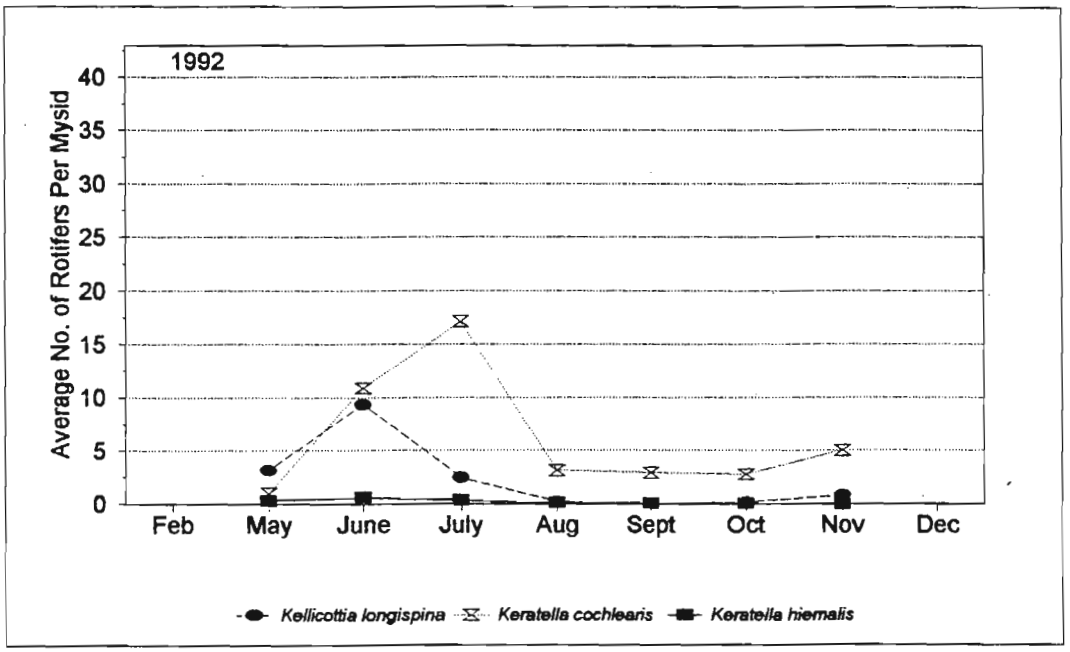


Fig. 46. Comparative abundance of *Diaptomus* and *Cyclops* mandibles in the mysid guts for a) 1992 and b) 1993.



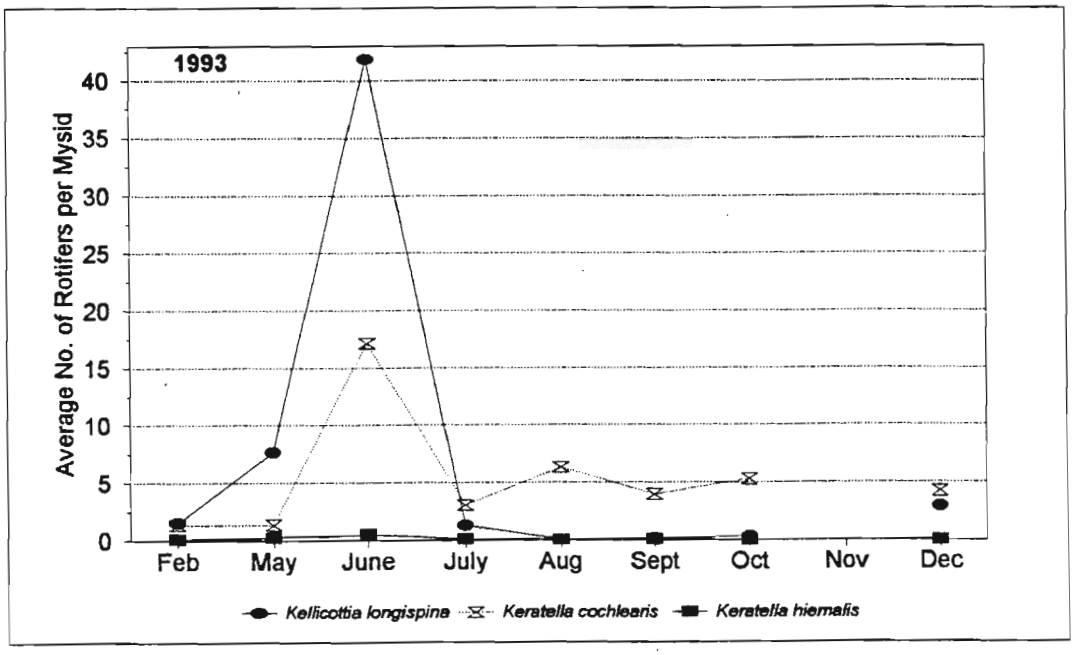


Fig. 47. Comparative abundance of *Kellicottia longispina*, *Keratella cochlearis* and *Keratella hiemalis* in the mysid guts for a) 1992 and b) 1993.

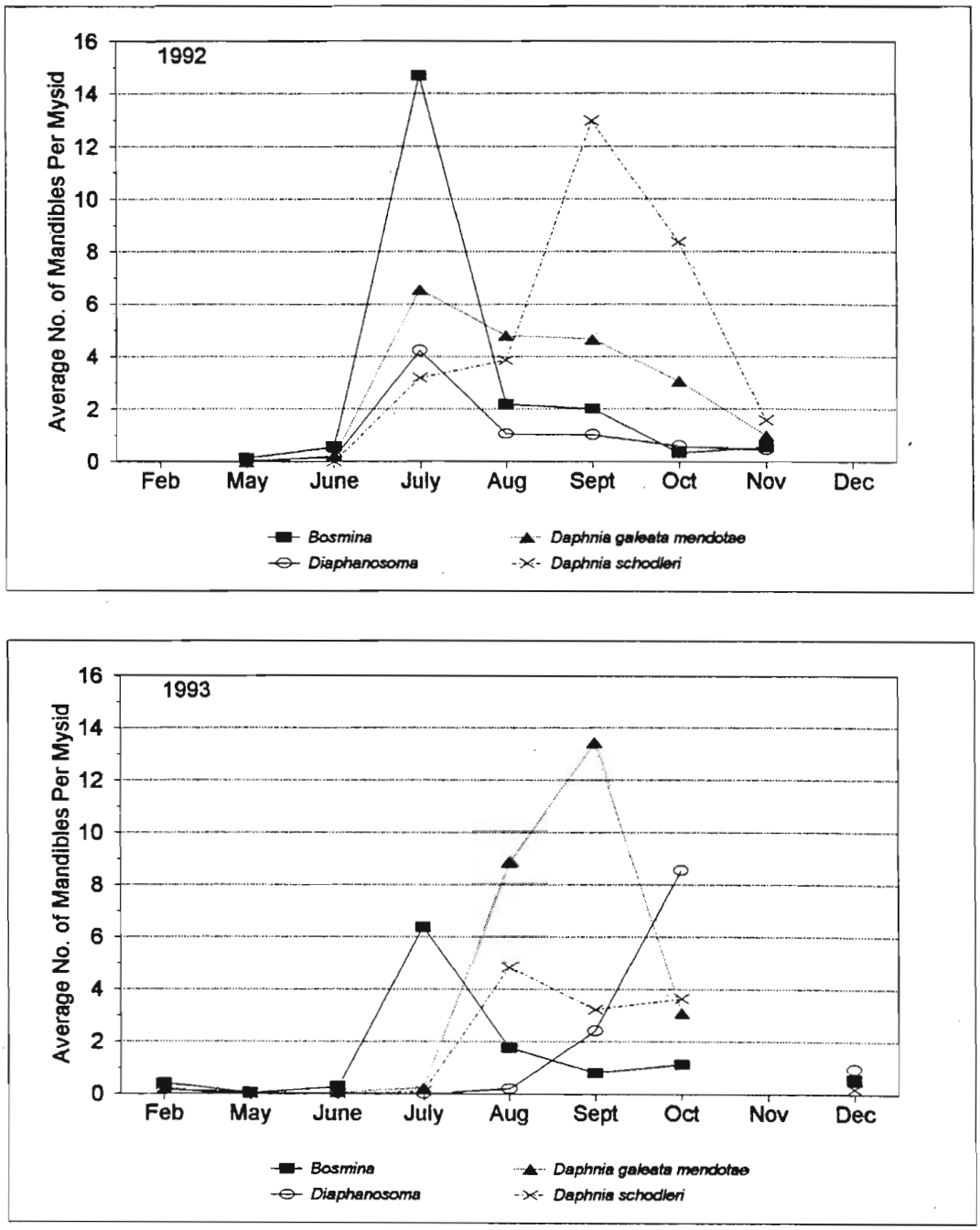
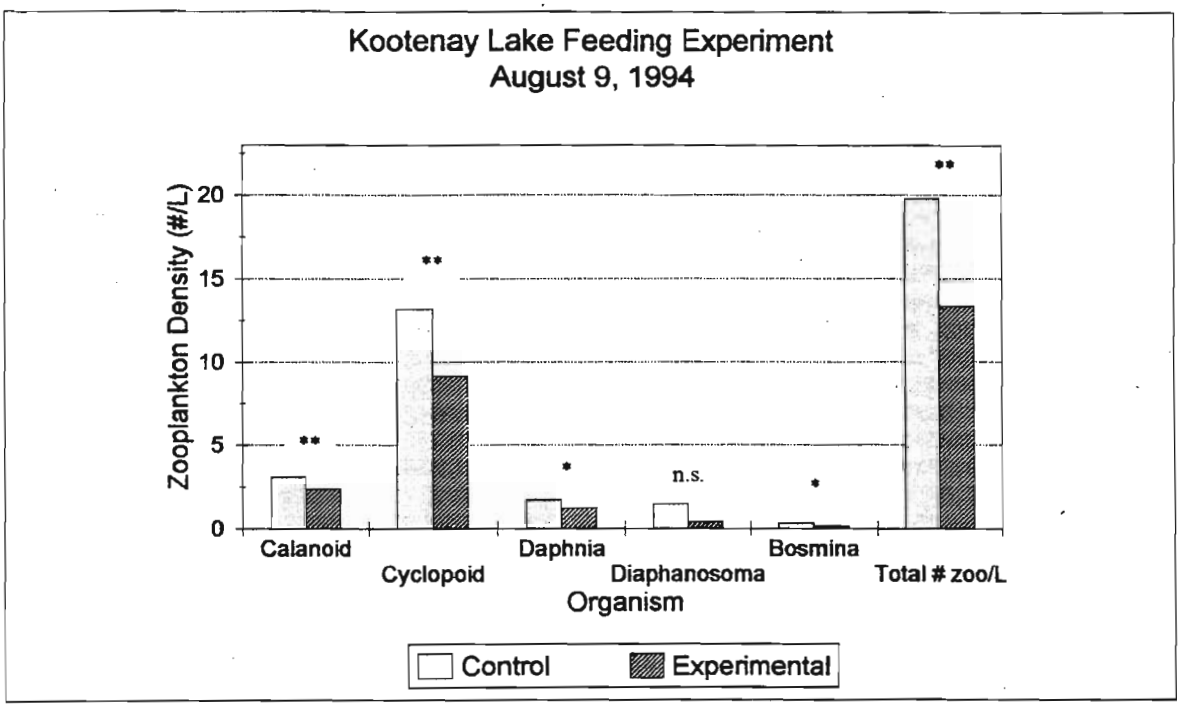


Fig. 48. Comparative abundance of *Bosmina coregoni*, *Diaphanosoma leuchtenbergianum*, *Daphnia galeata mendotae* and *Daphnia schodleri* in the mysid guts for a) 1992 and b) 1993.



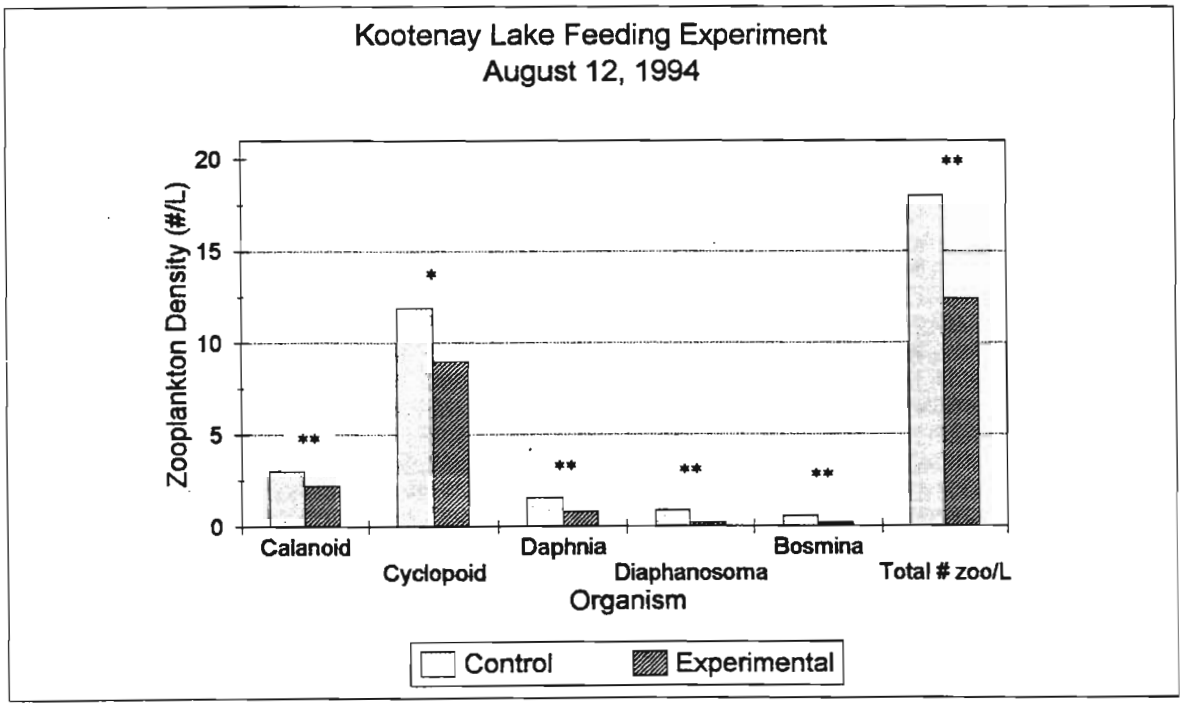


Fig. 49. Comparative densities of zooplankton in control and experimental chambers for experiments carried out on a) 9 August 1994 and b) 12 August 1994.

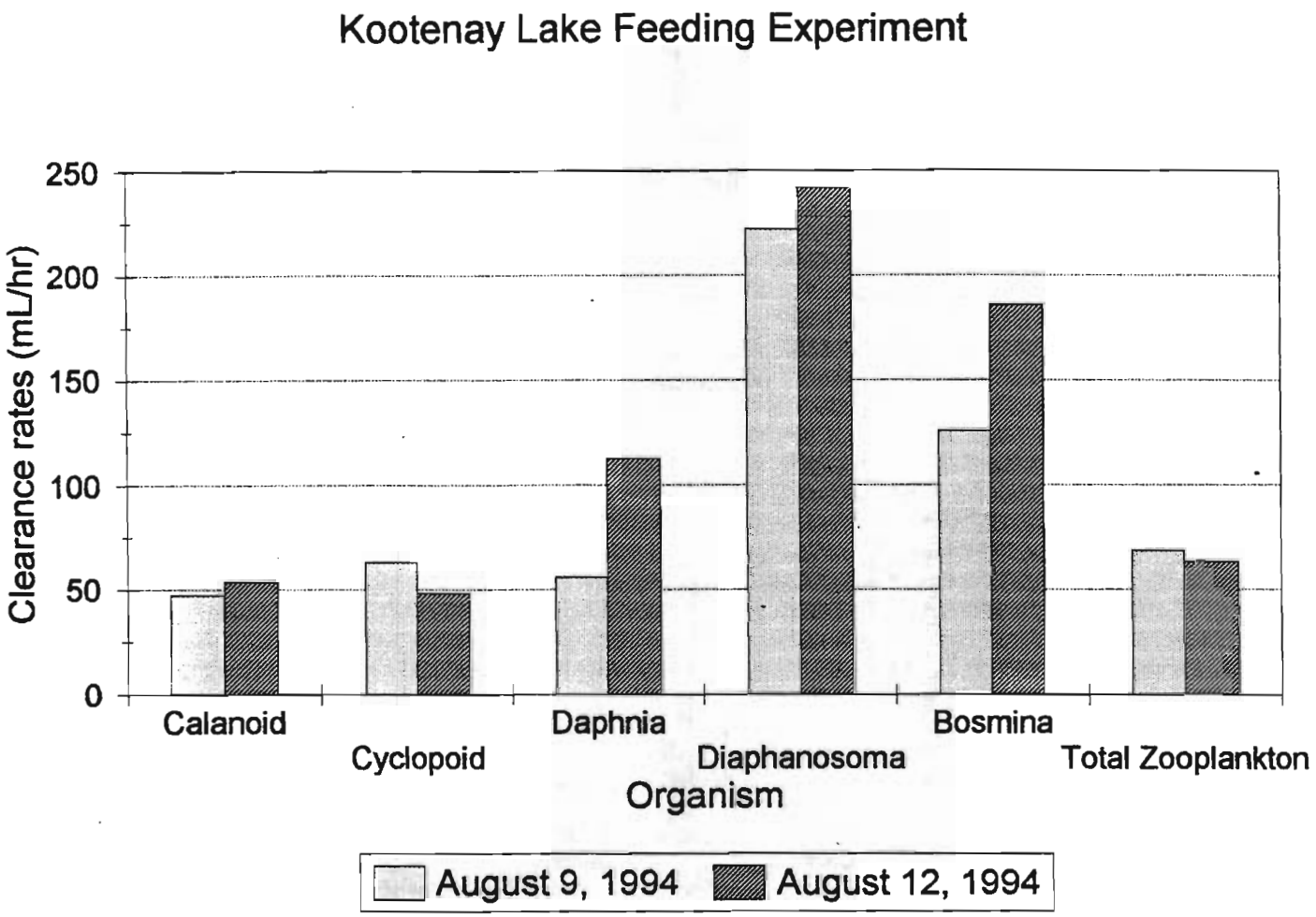
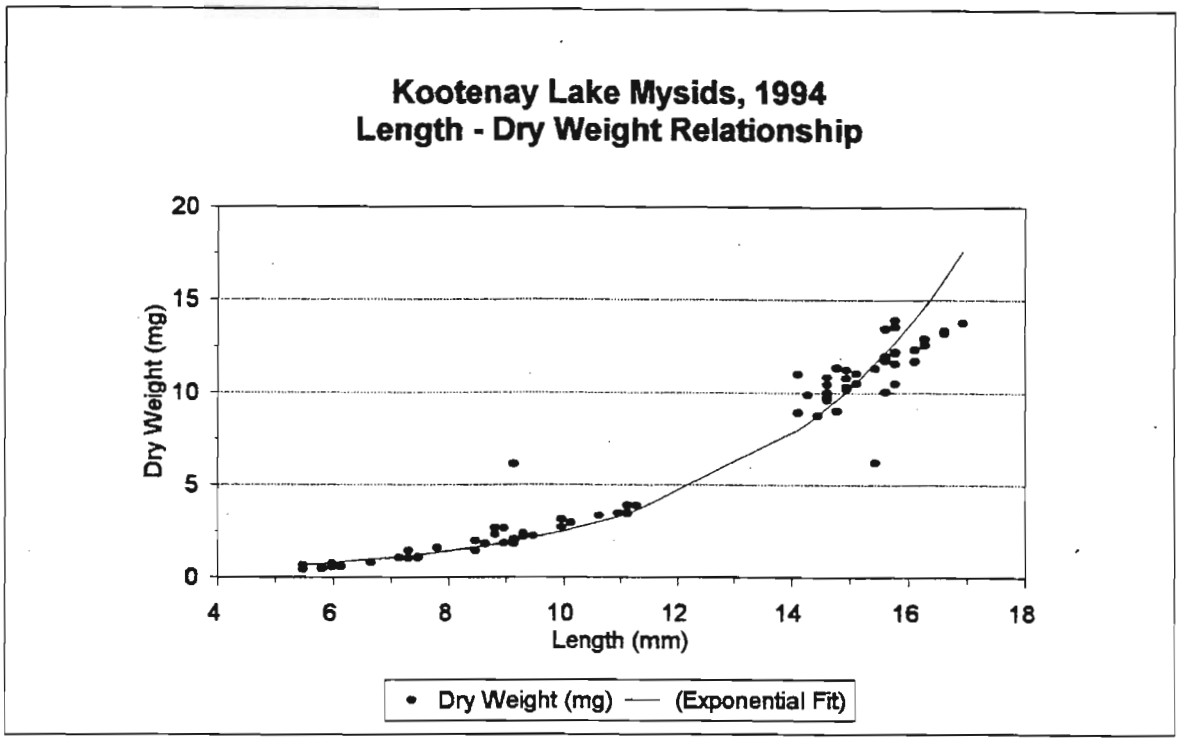


Fig. 50. Comparative clearance rates for zooplankton as determined by experiments carried out on 9 August and 12 August, 1994.



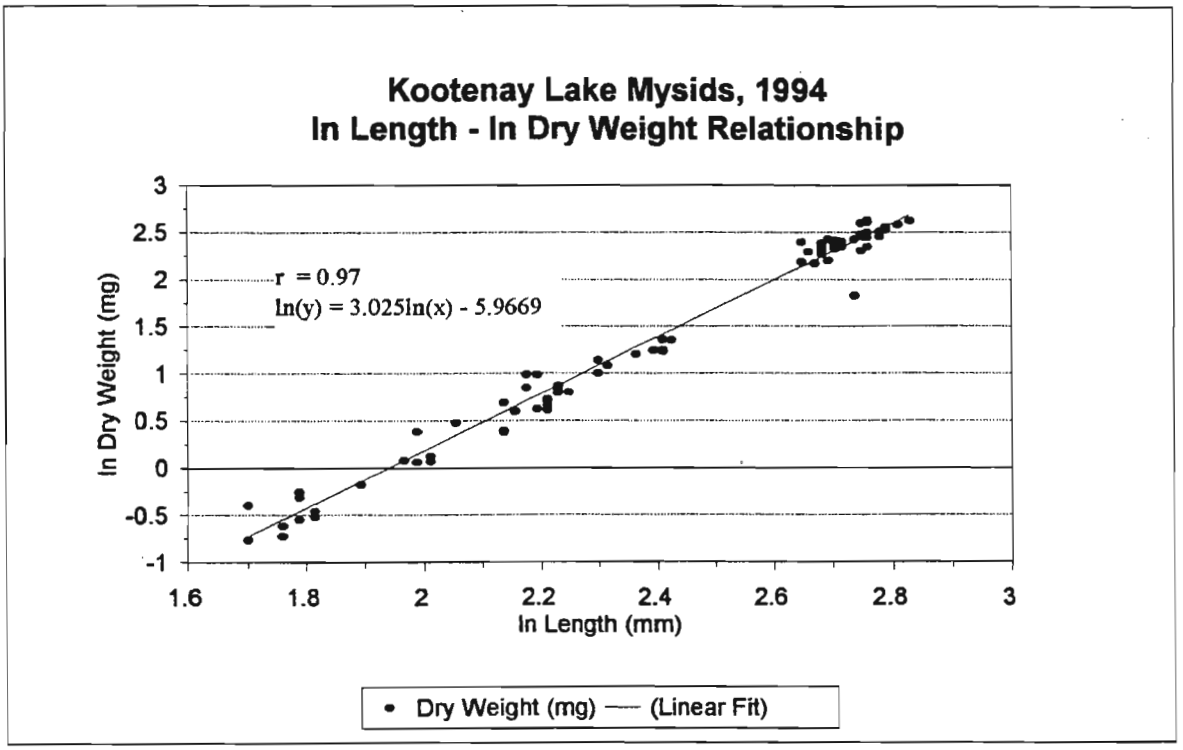
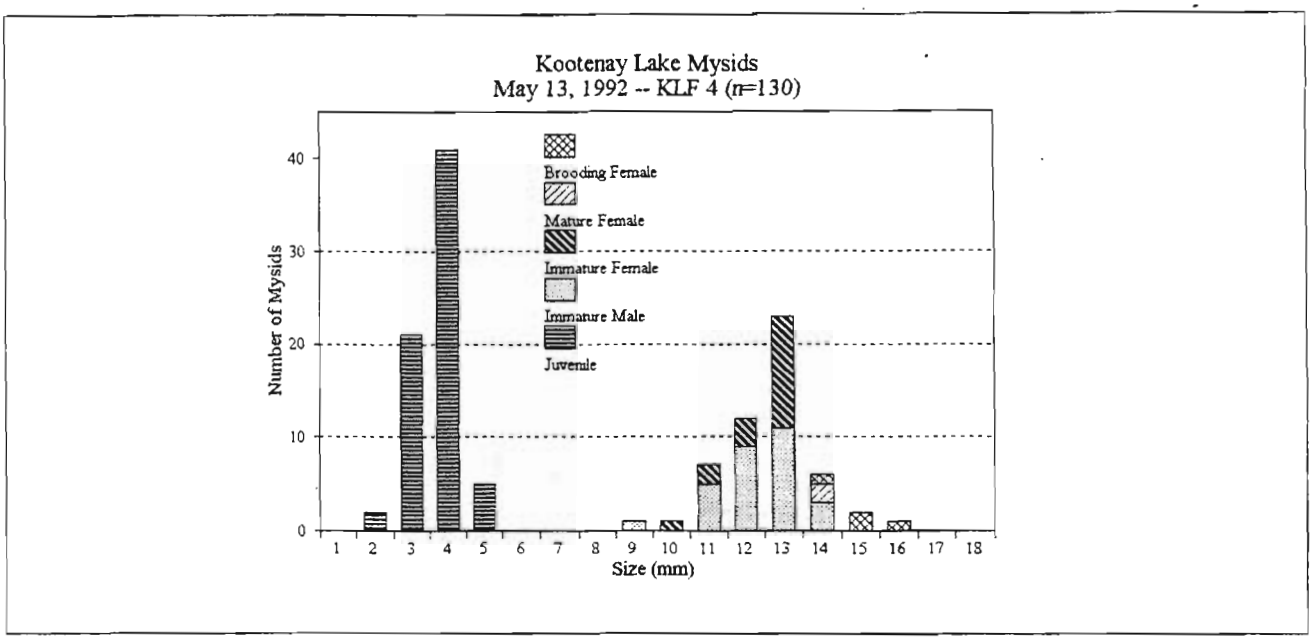


Fig. 51. Length-dry weight relationship for Kootenay Lake mysids, August 1994, showing a) linear scale and b) ln scale.



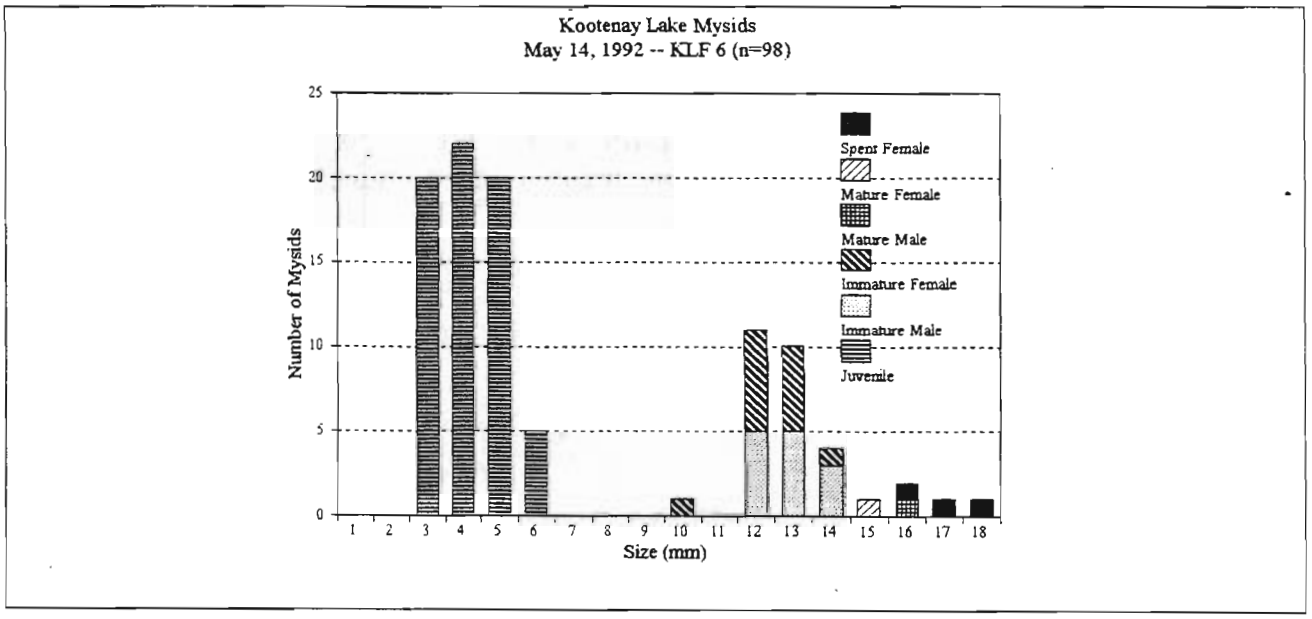


Fig. 52a. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

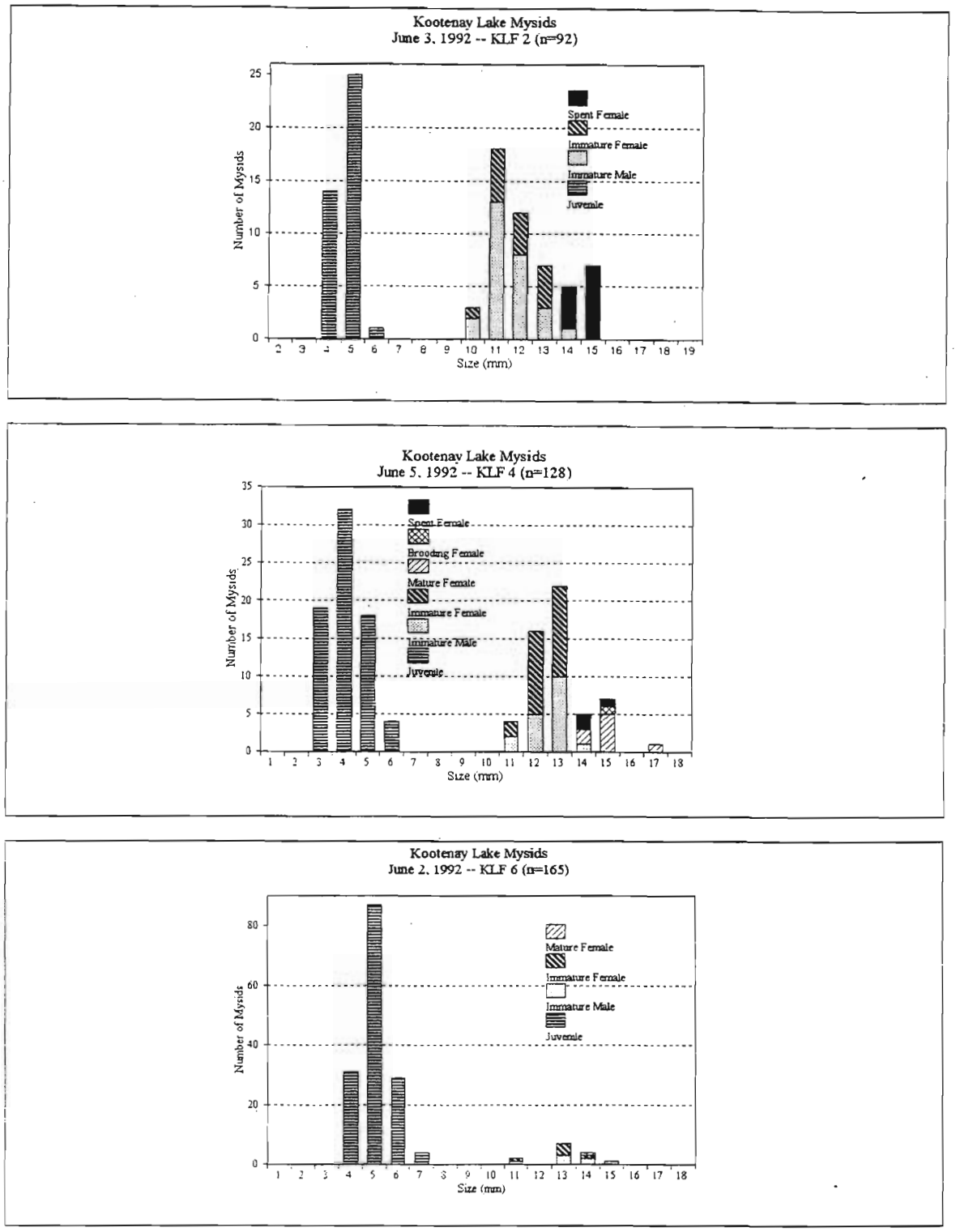
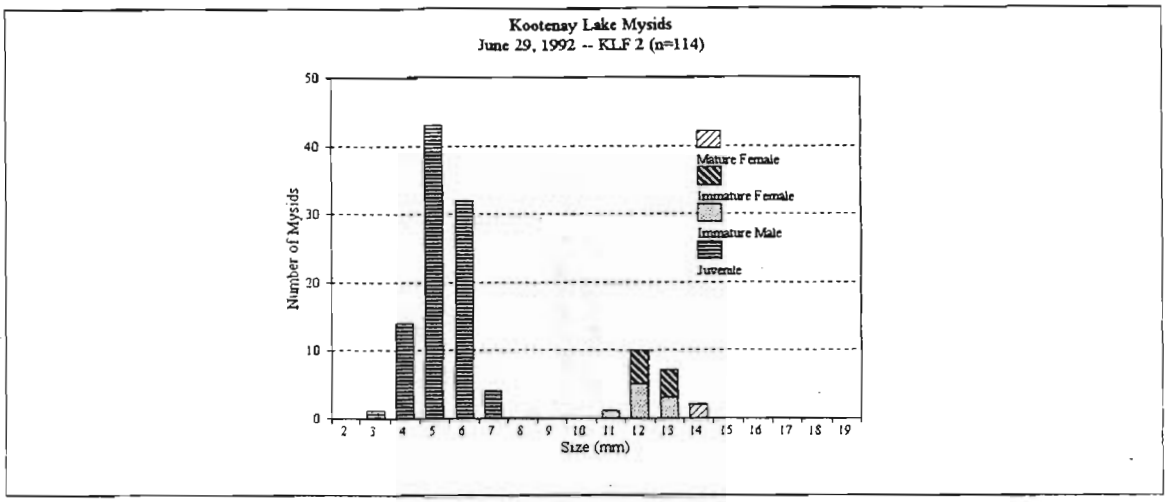
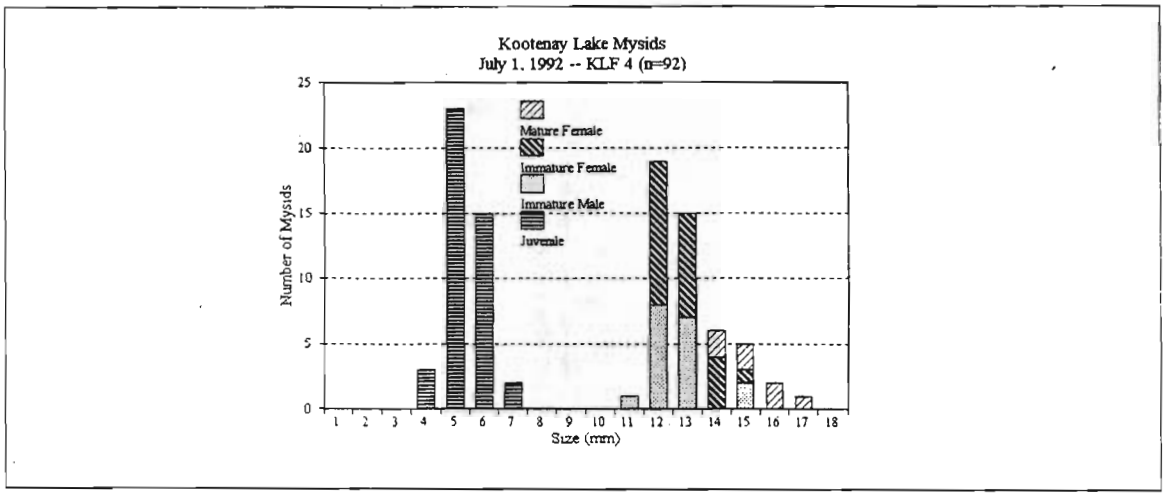


Fig. 52b. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).





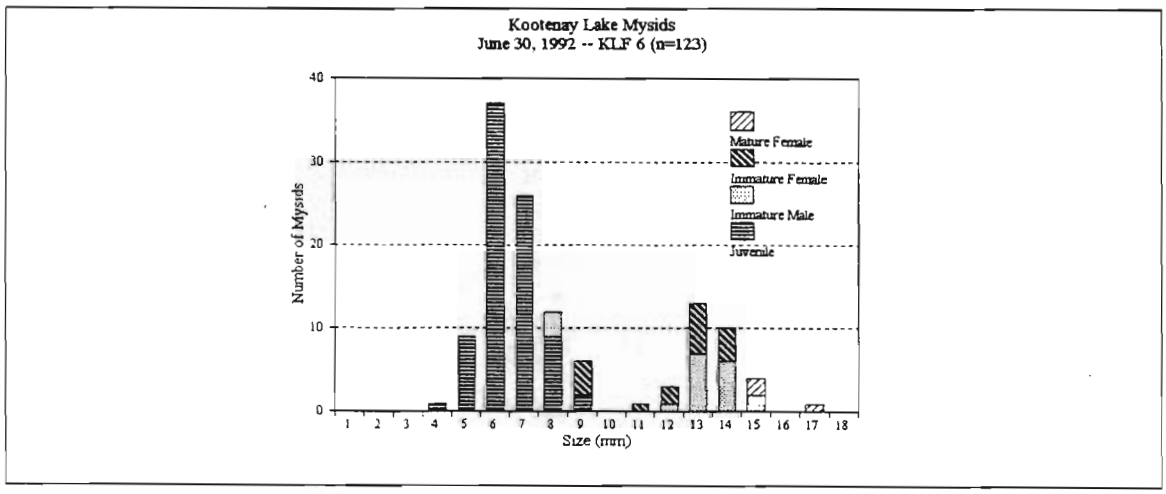


Fig. 52c. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

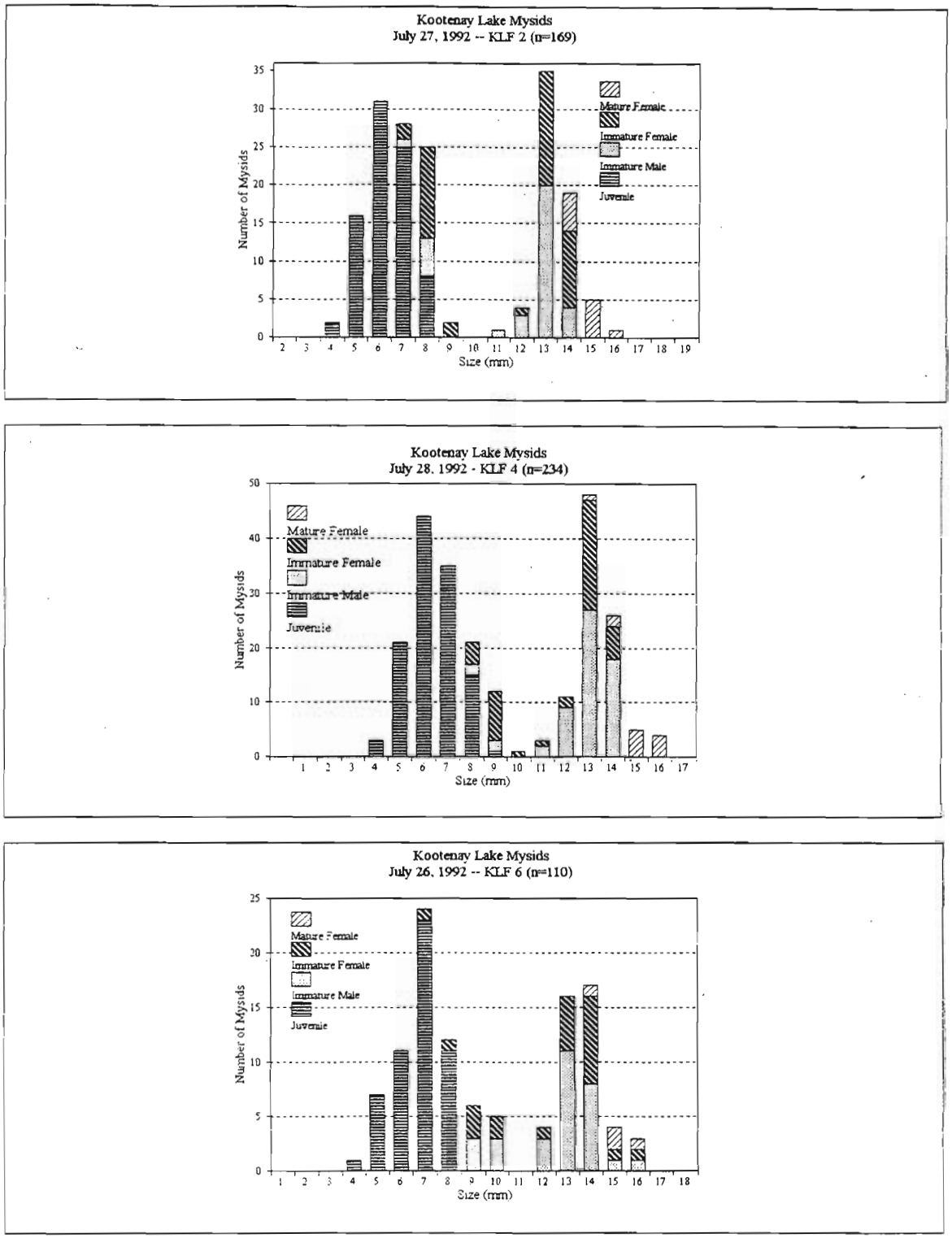
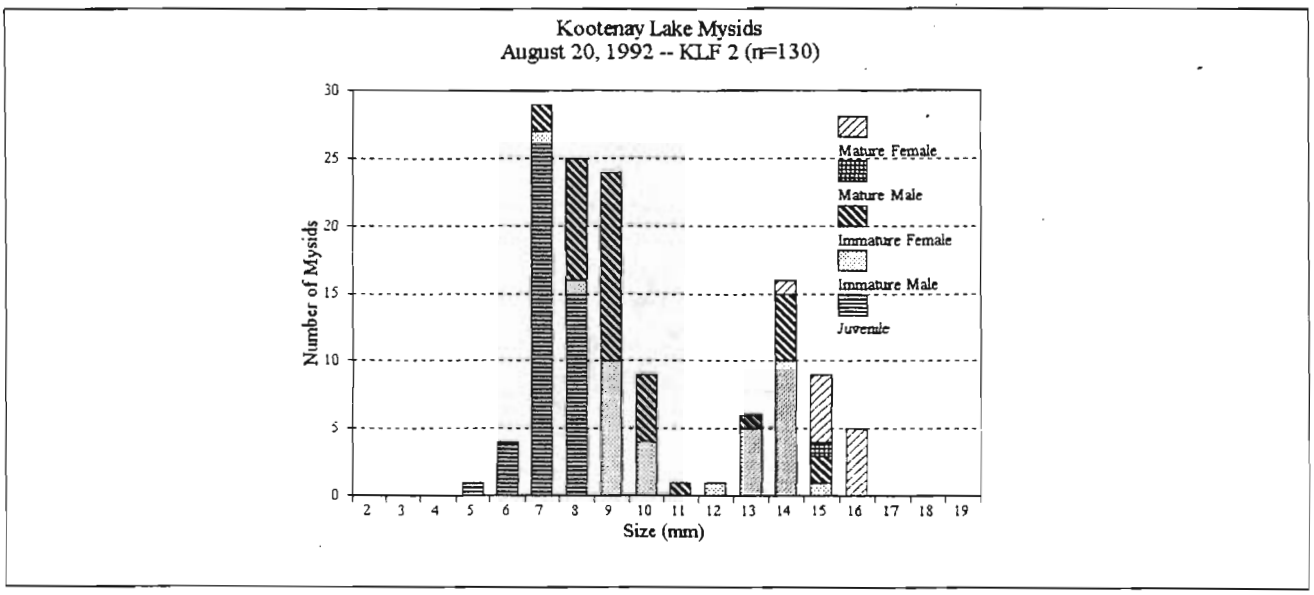


Fig. 52d. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).



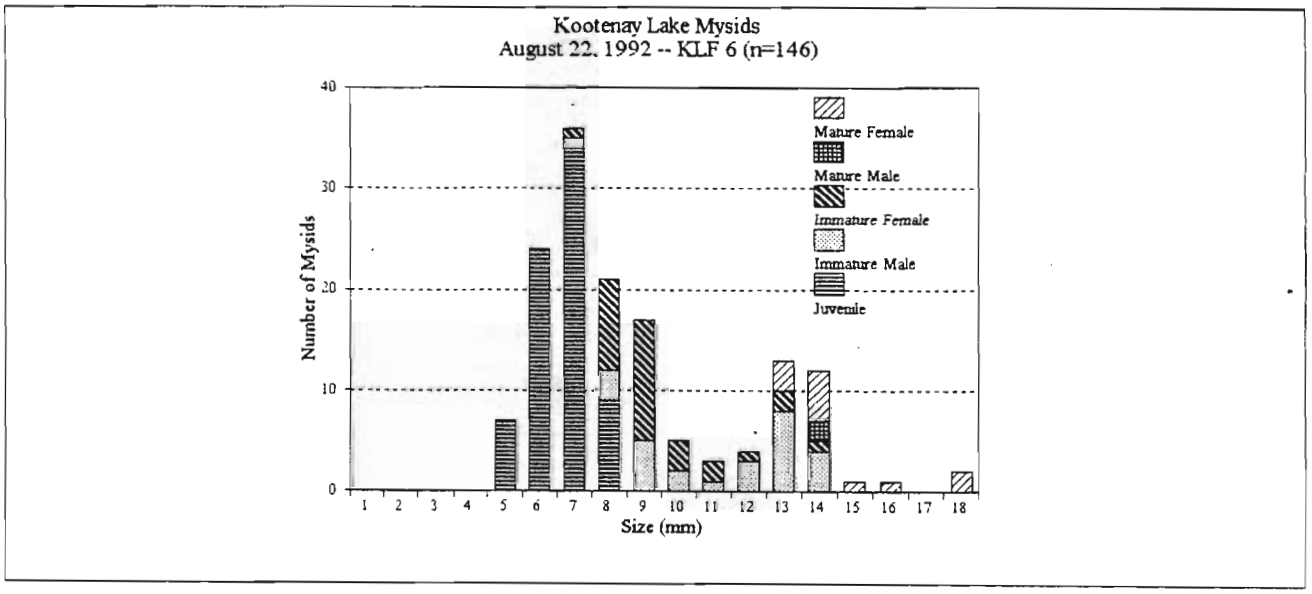


Fig. 52e. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

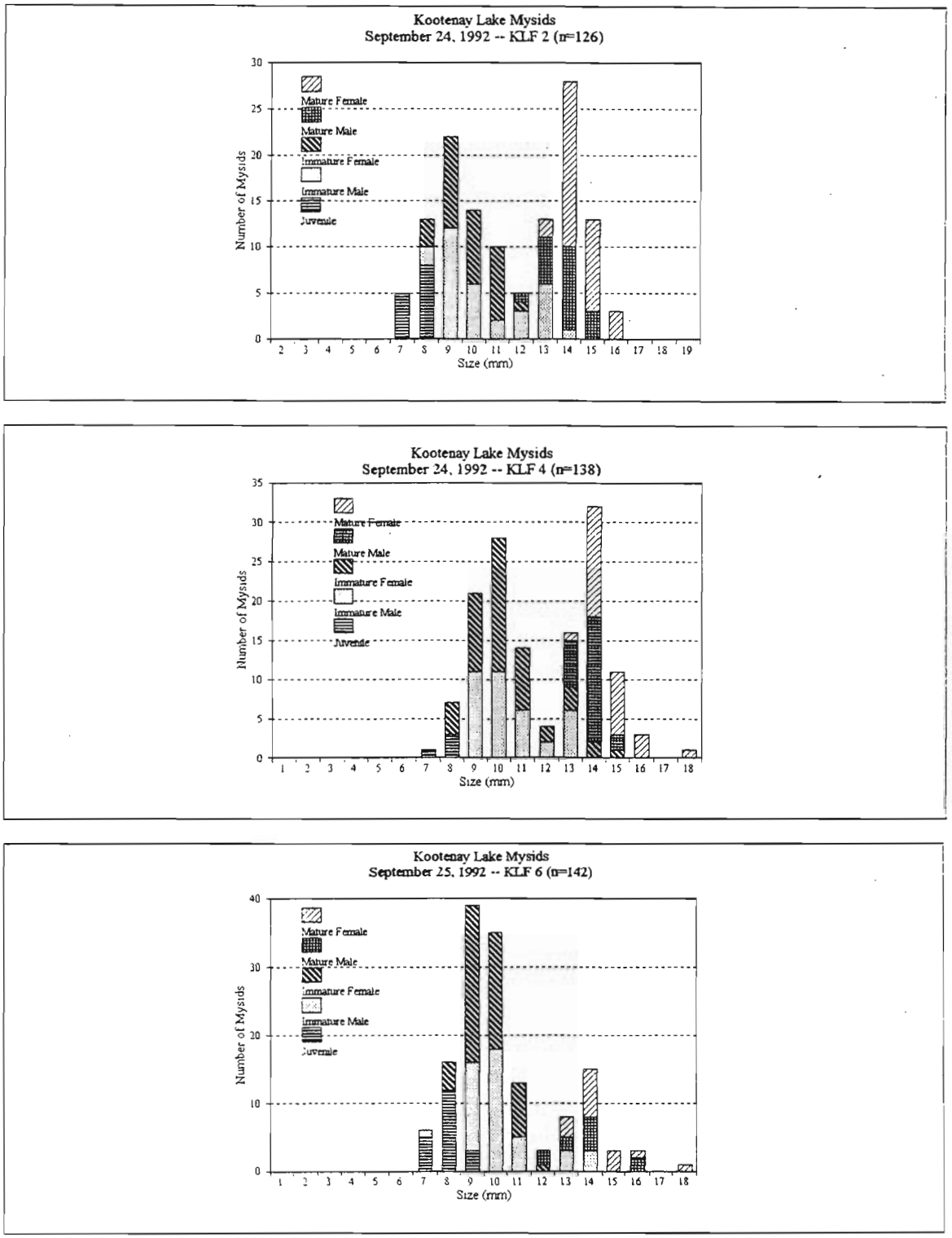


Fig. 52f. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

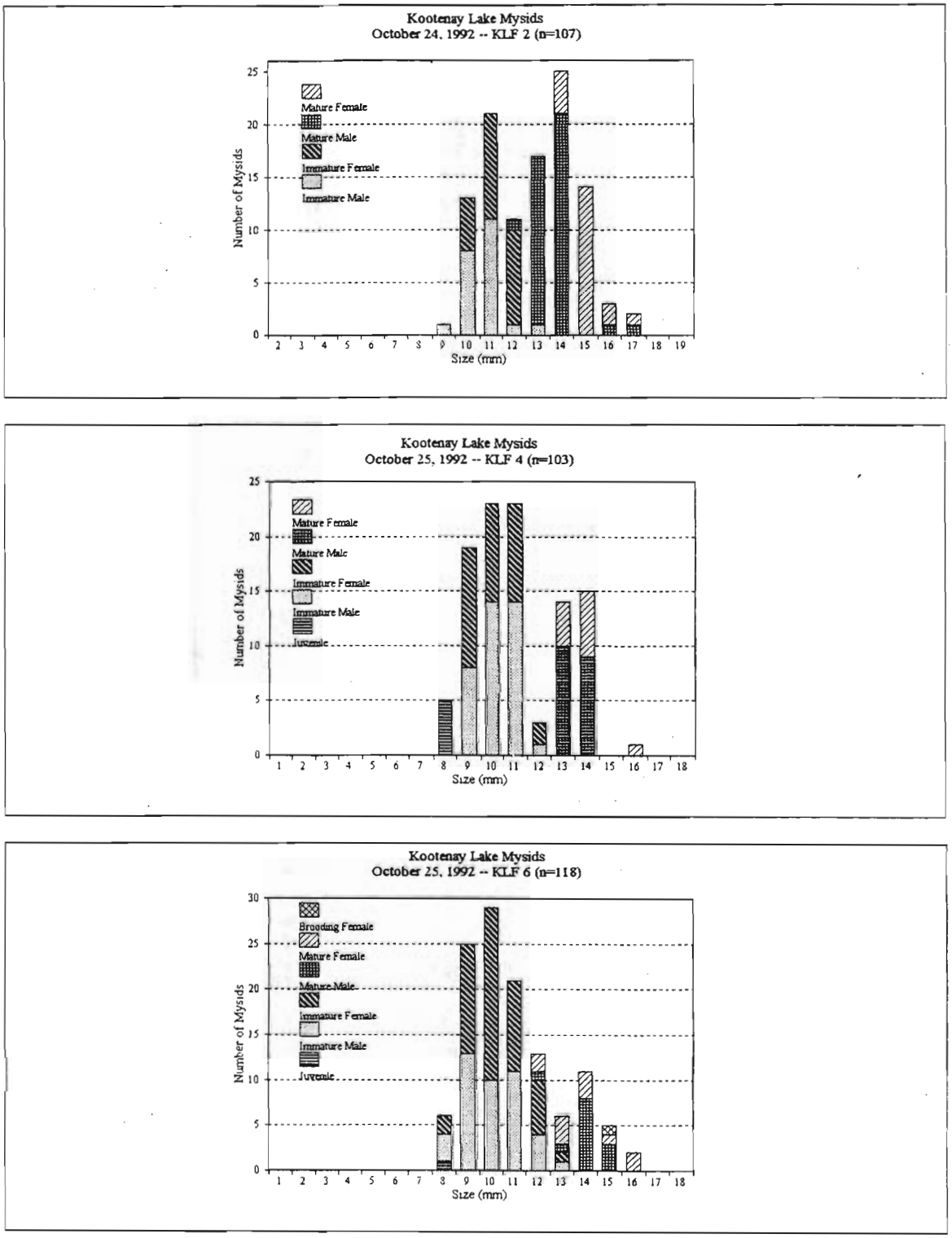


Fig. 52g. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

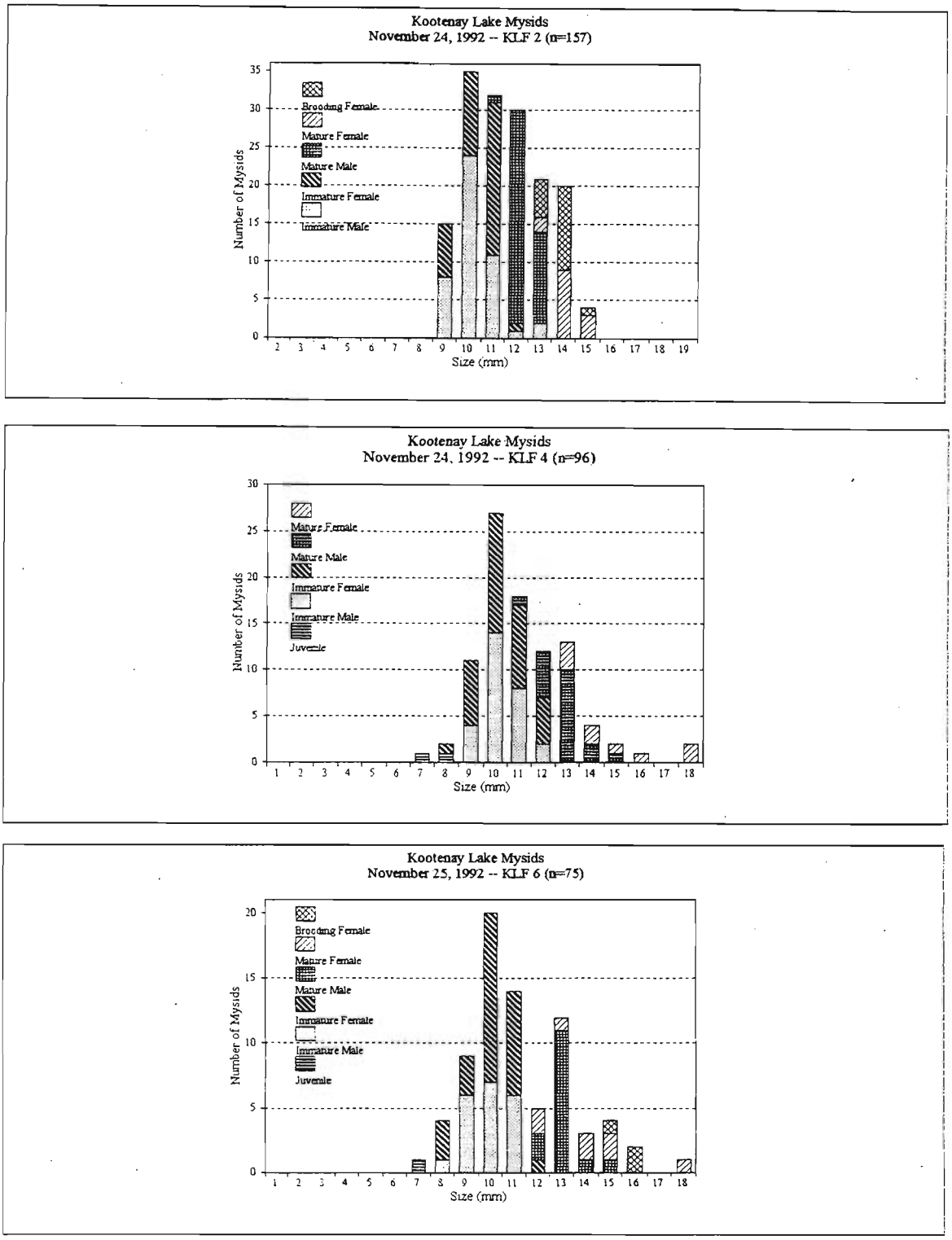


Fig. 52h. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

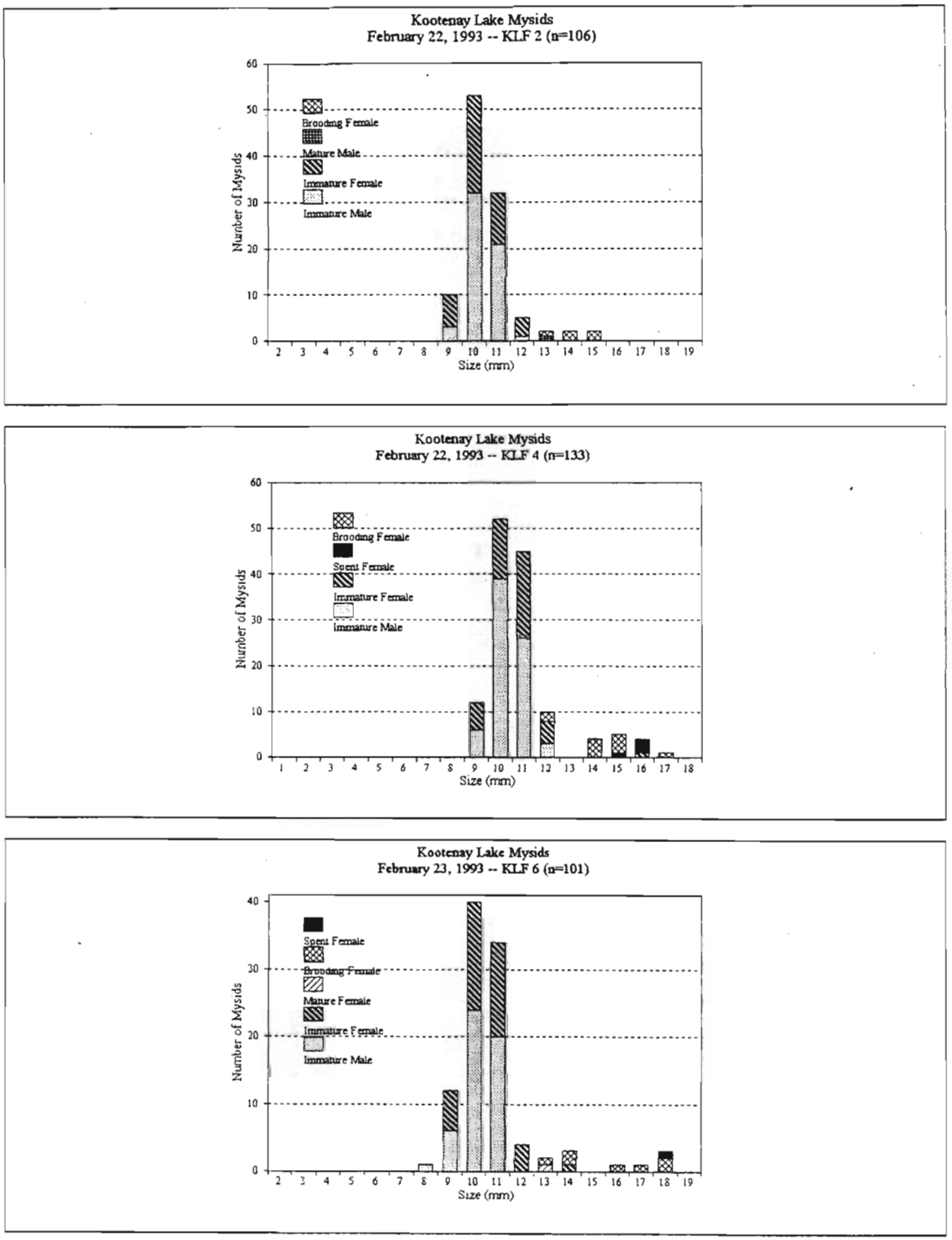
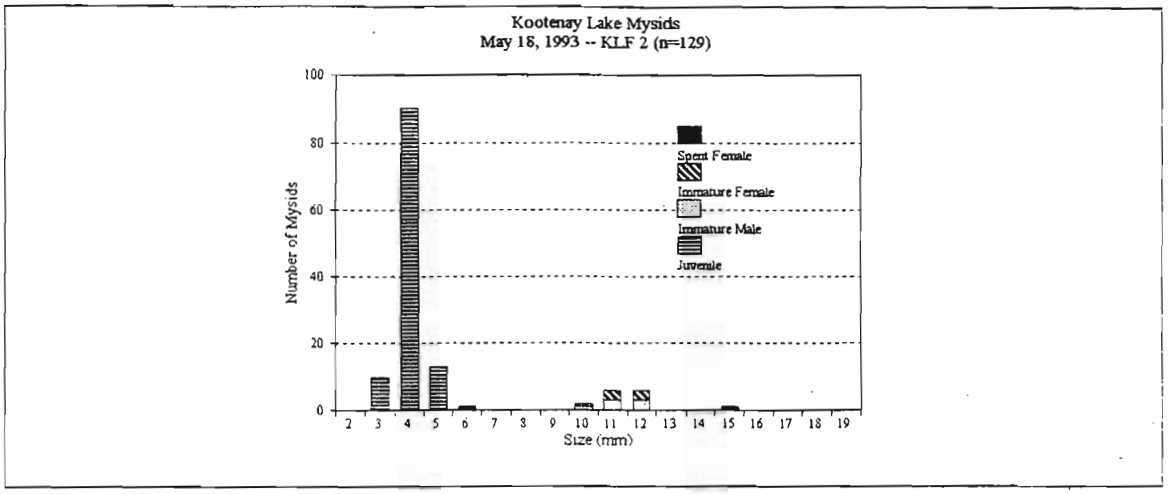
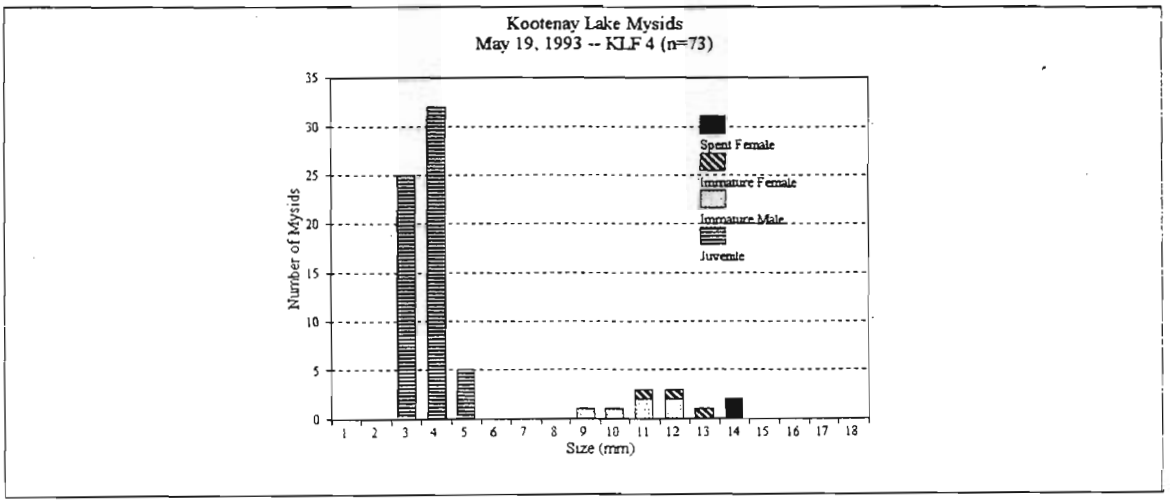


Fig. 52i. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).





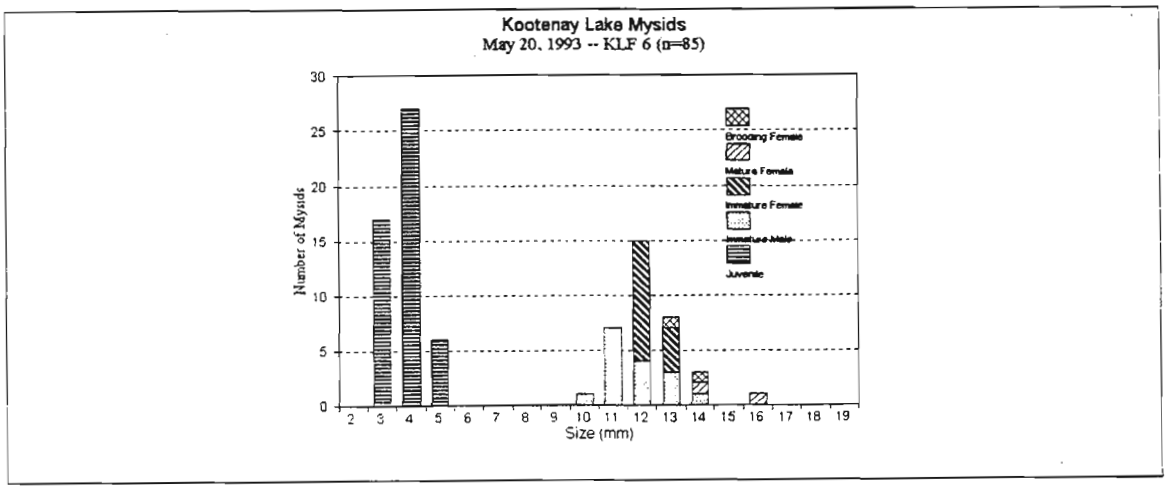
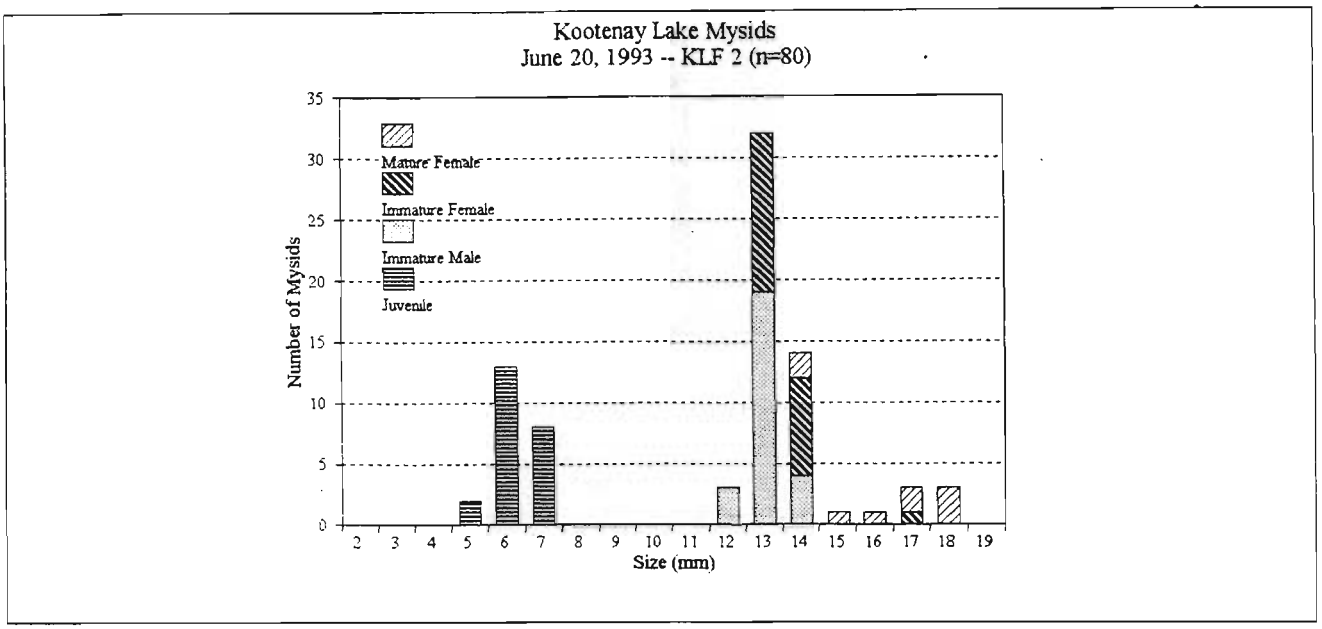


Fig. 52j. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).



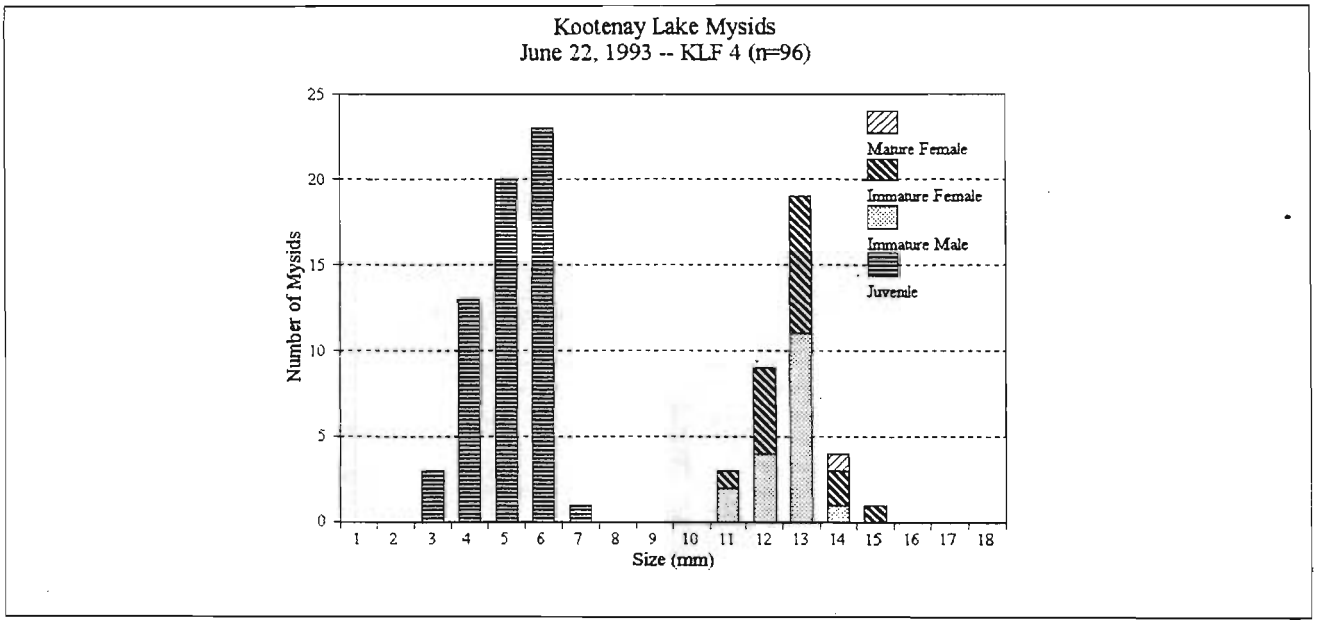
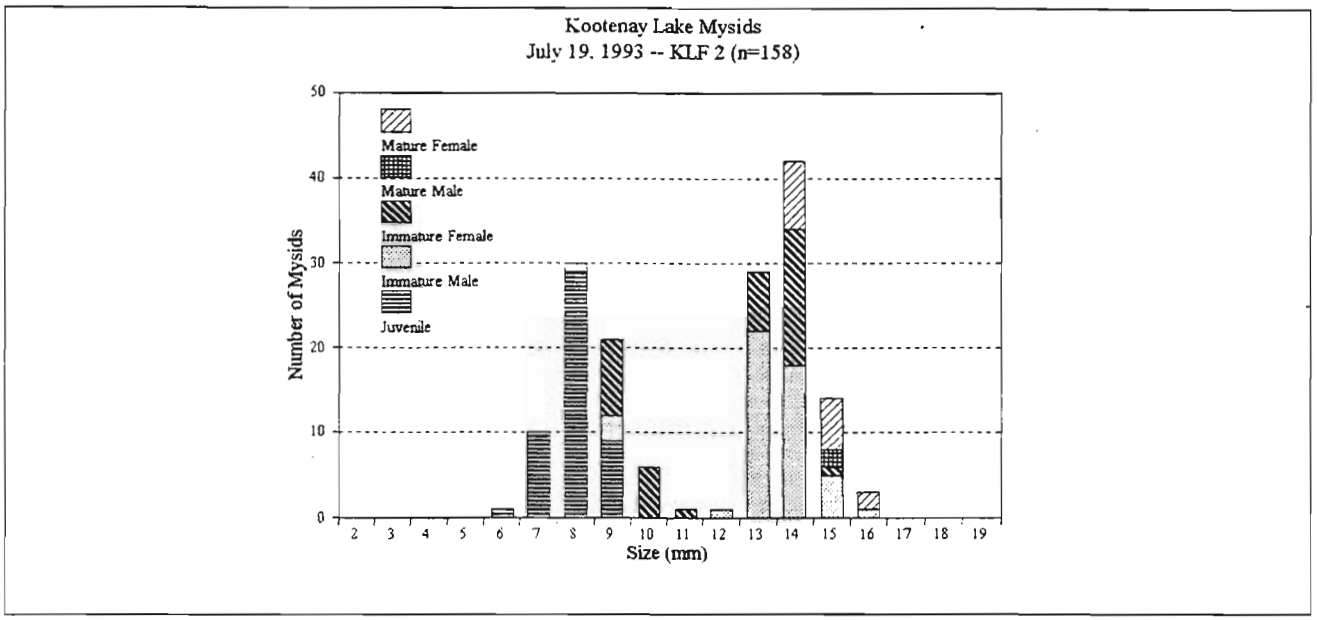


Fig. 52k. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).



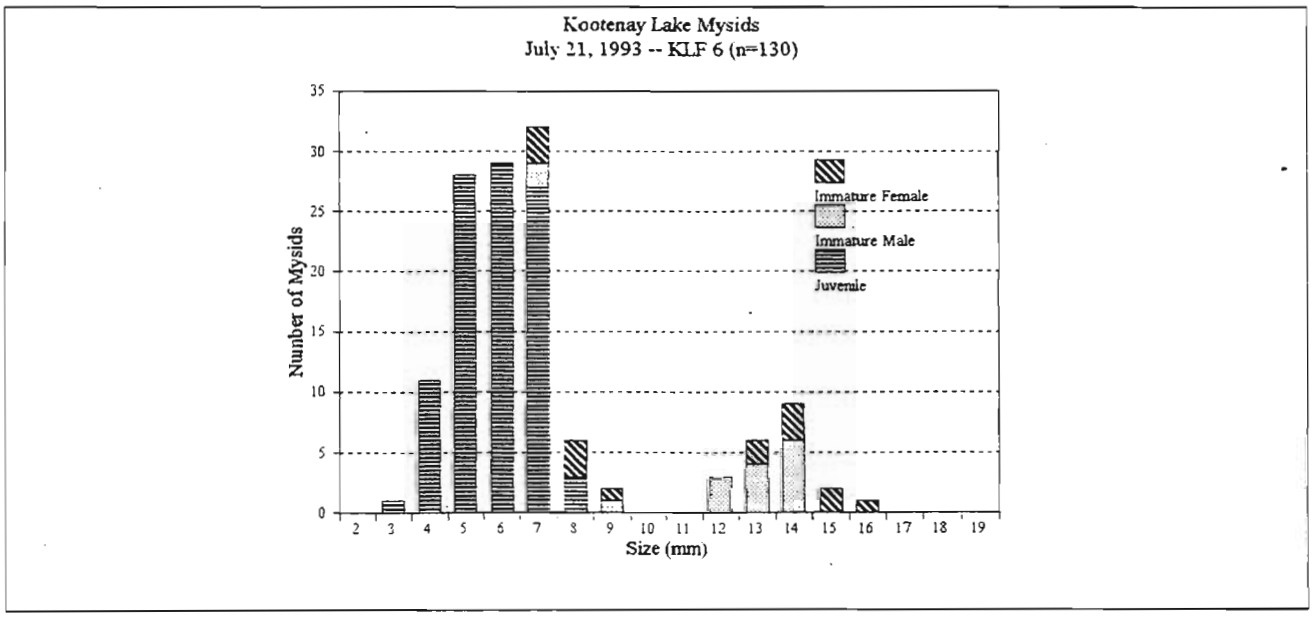
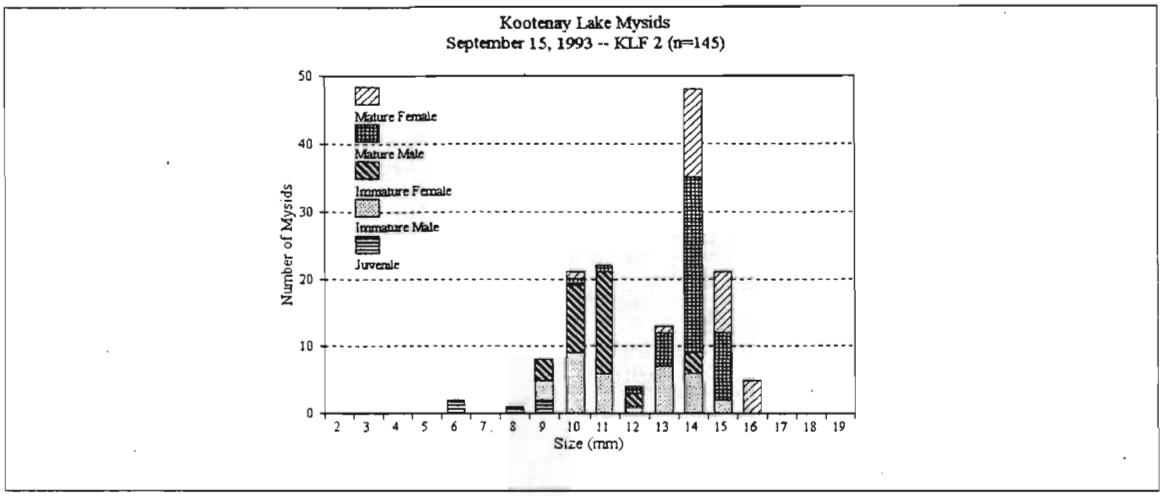
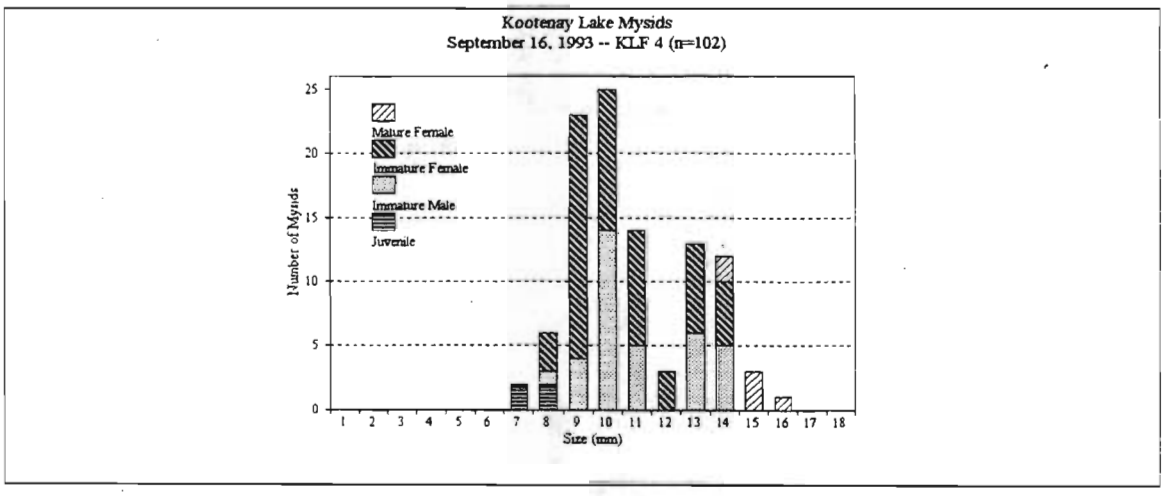


Fig. 52l. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).





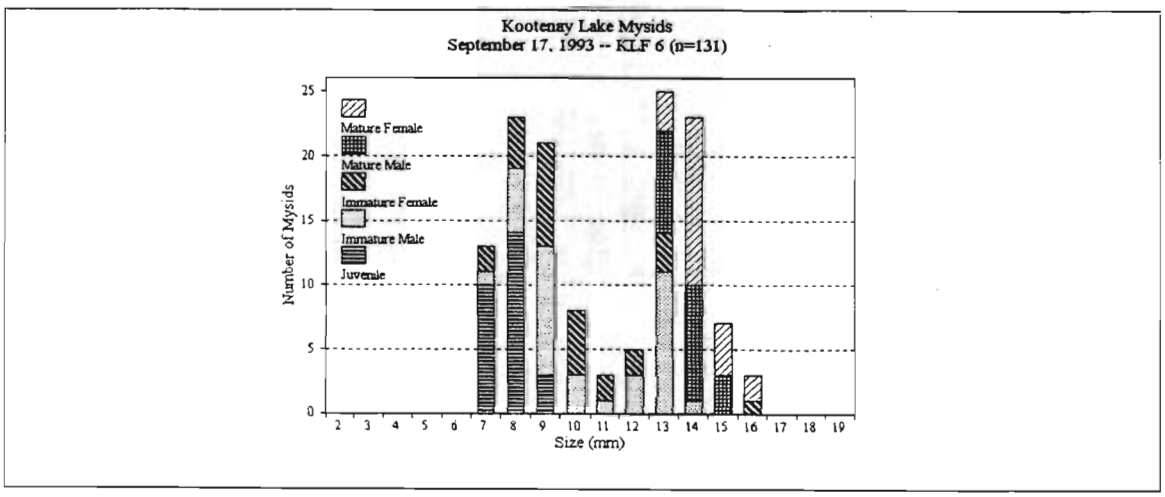


Fig. 52m. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

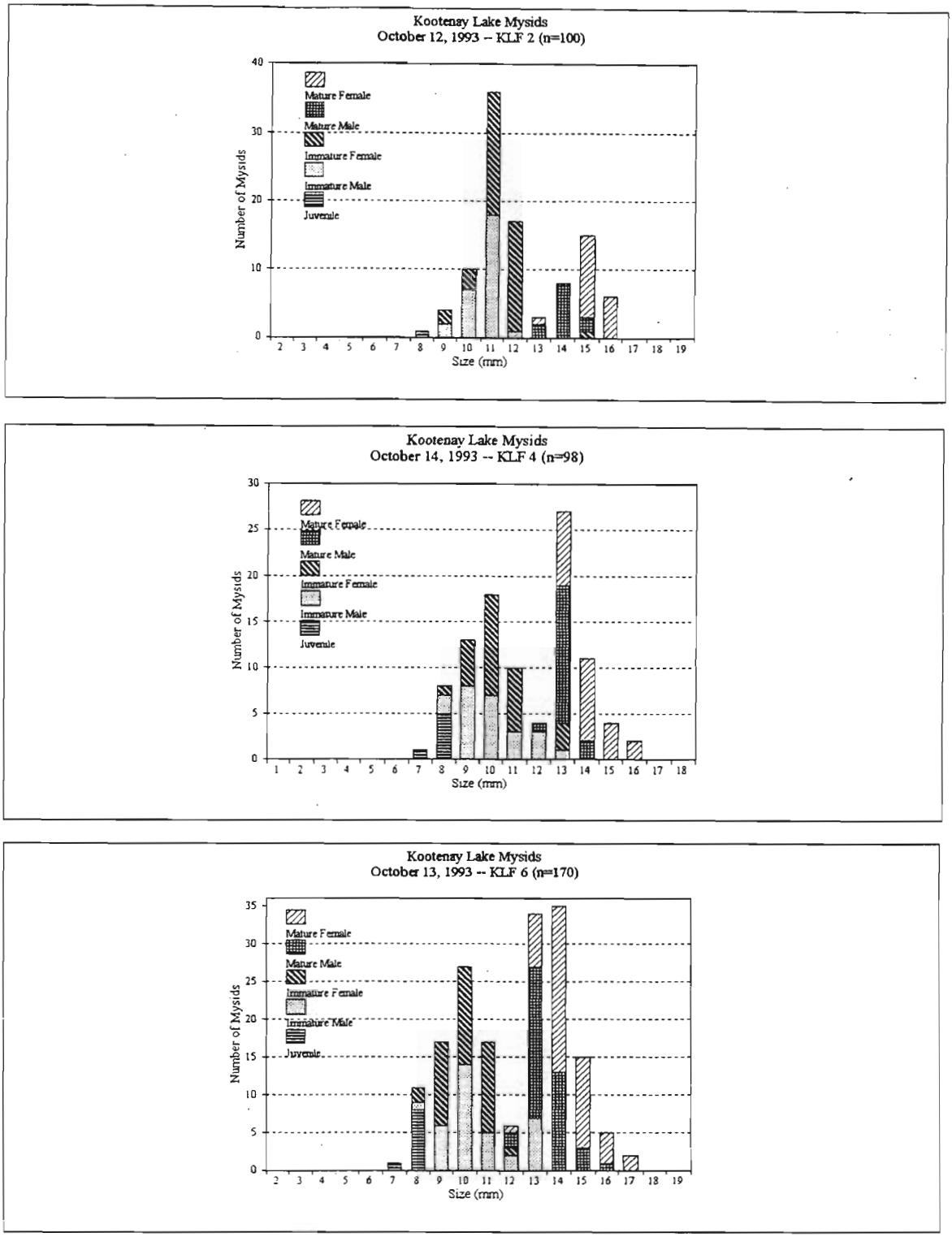
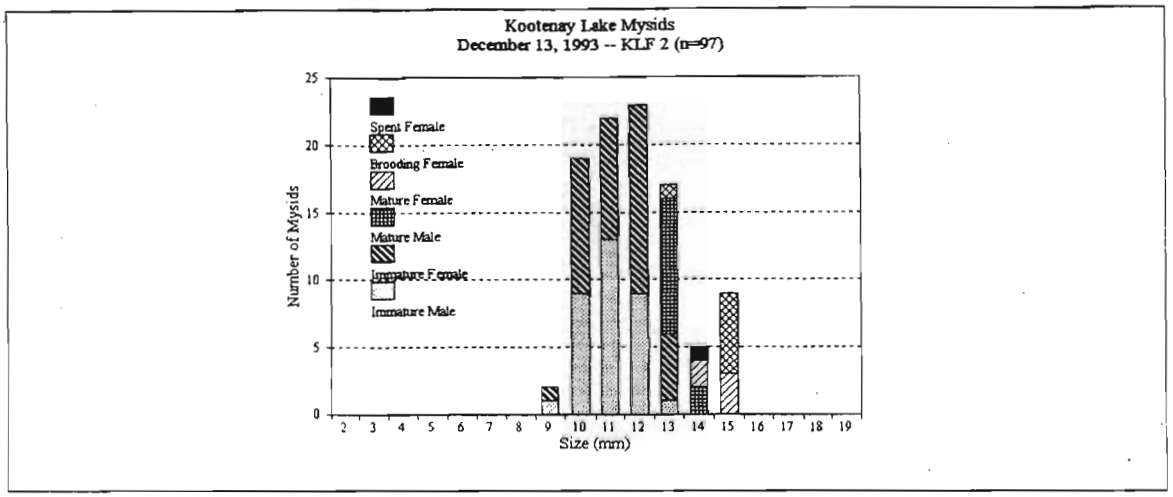
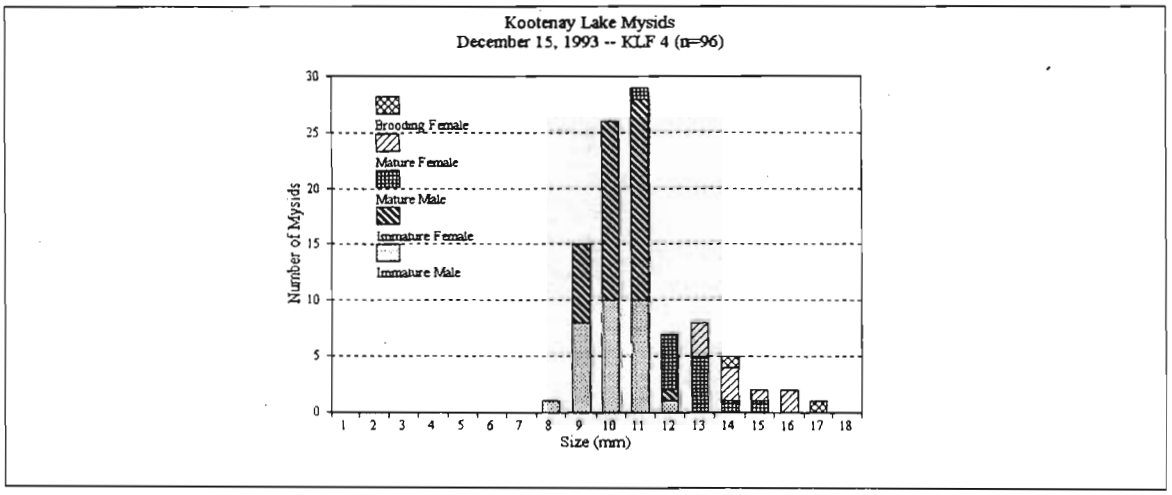


Fig. 52n. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).





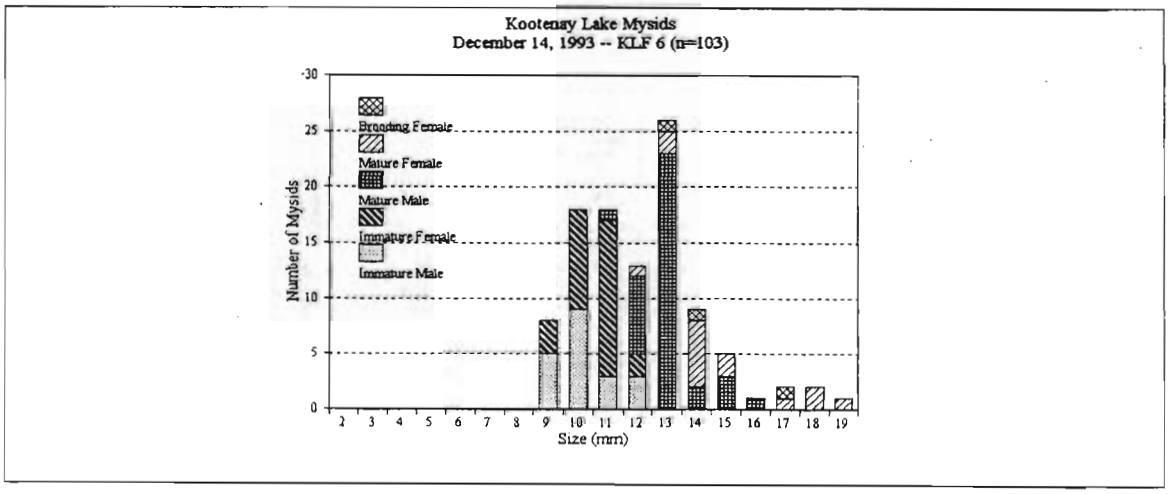


Fig. 52o. Comparison of population structure of mysids at Stations 2, 4 and 6, May 1992 through December 1993 (when available).

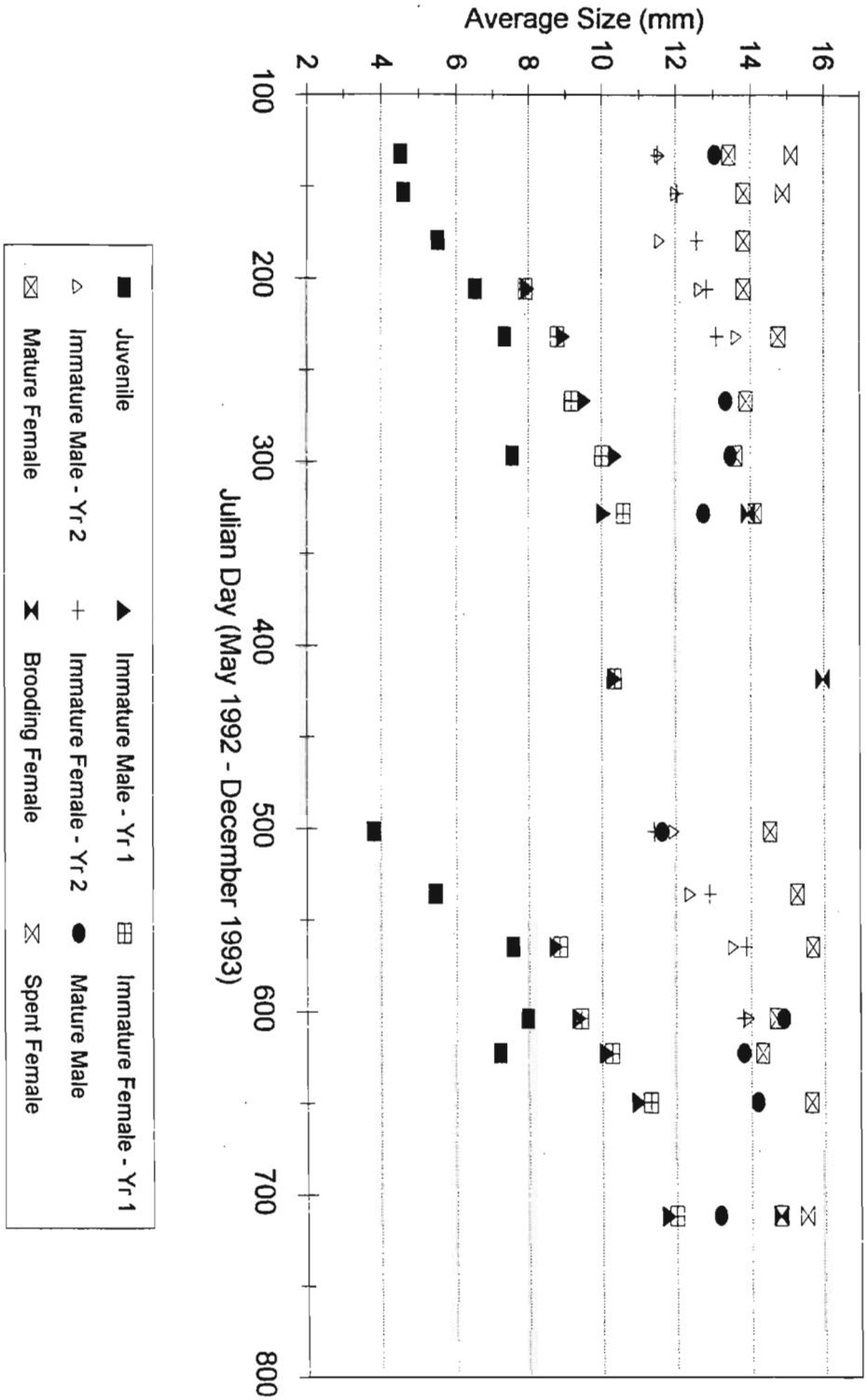


Fig. 53a. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

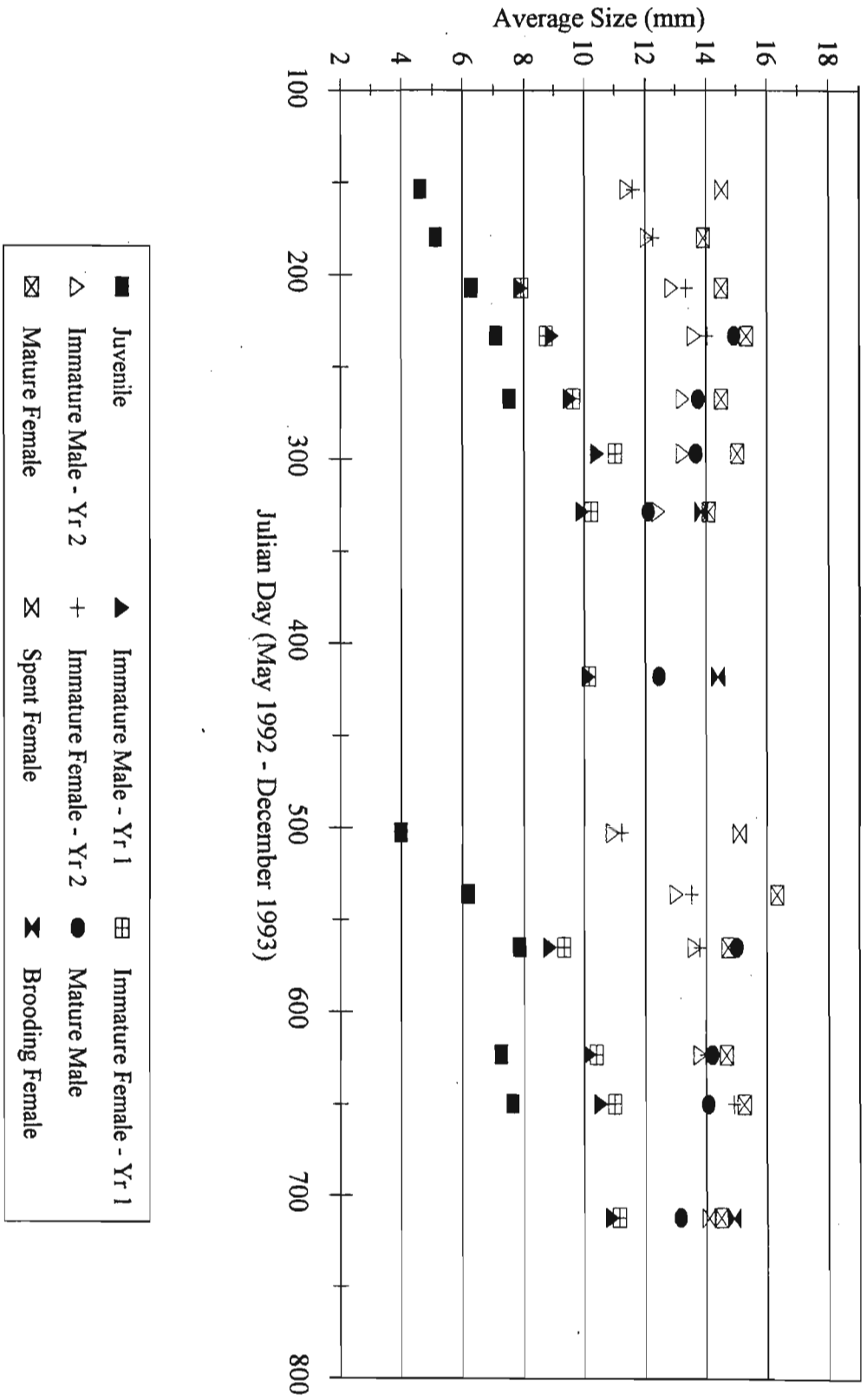


Fig. 53b. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

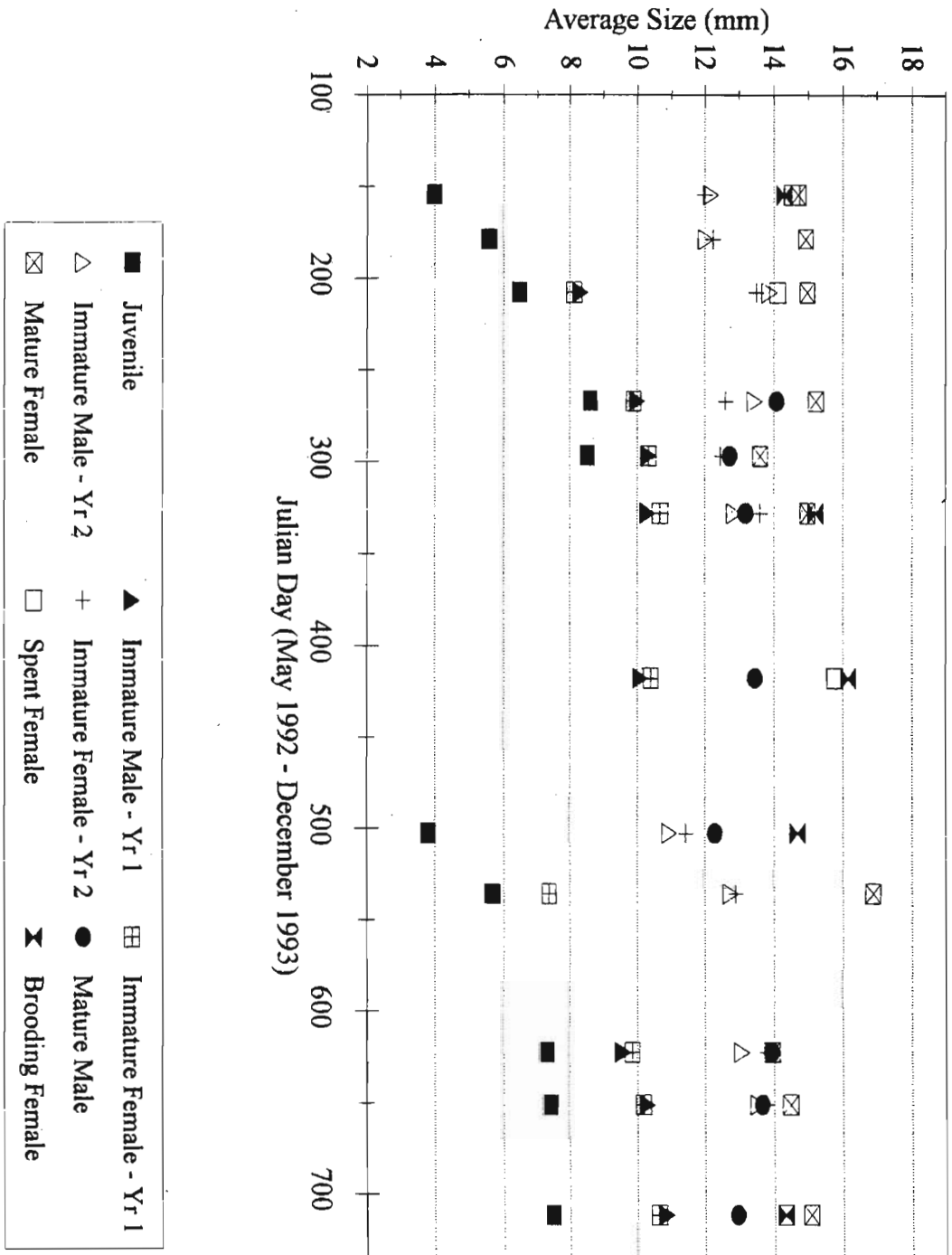


Fig. 53c. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

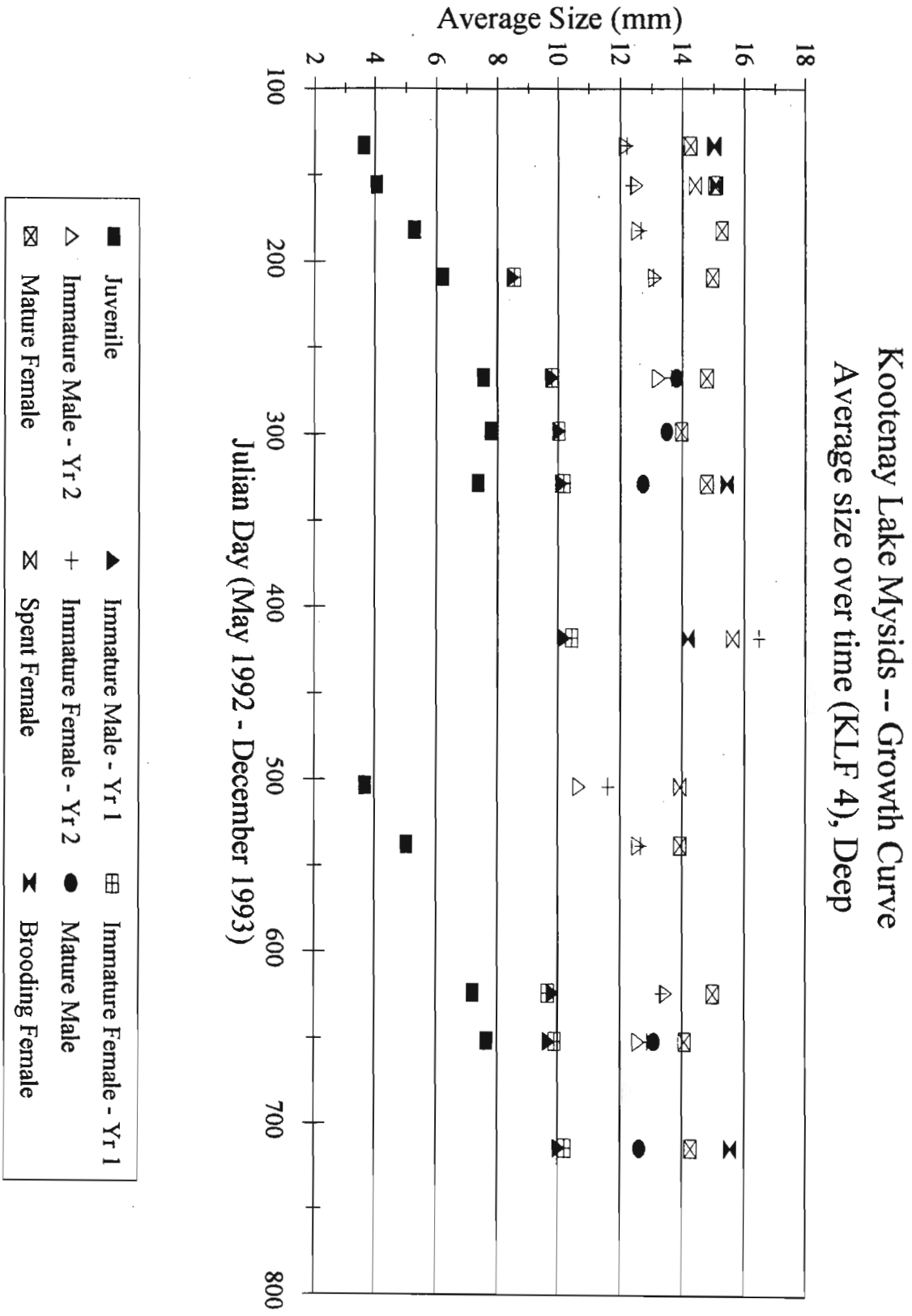


Fig. 53d. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

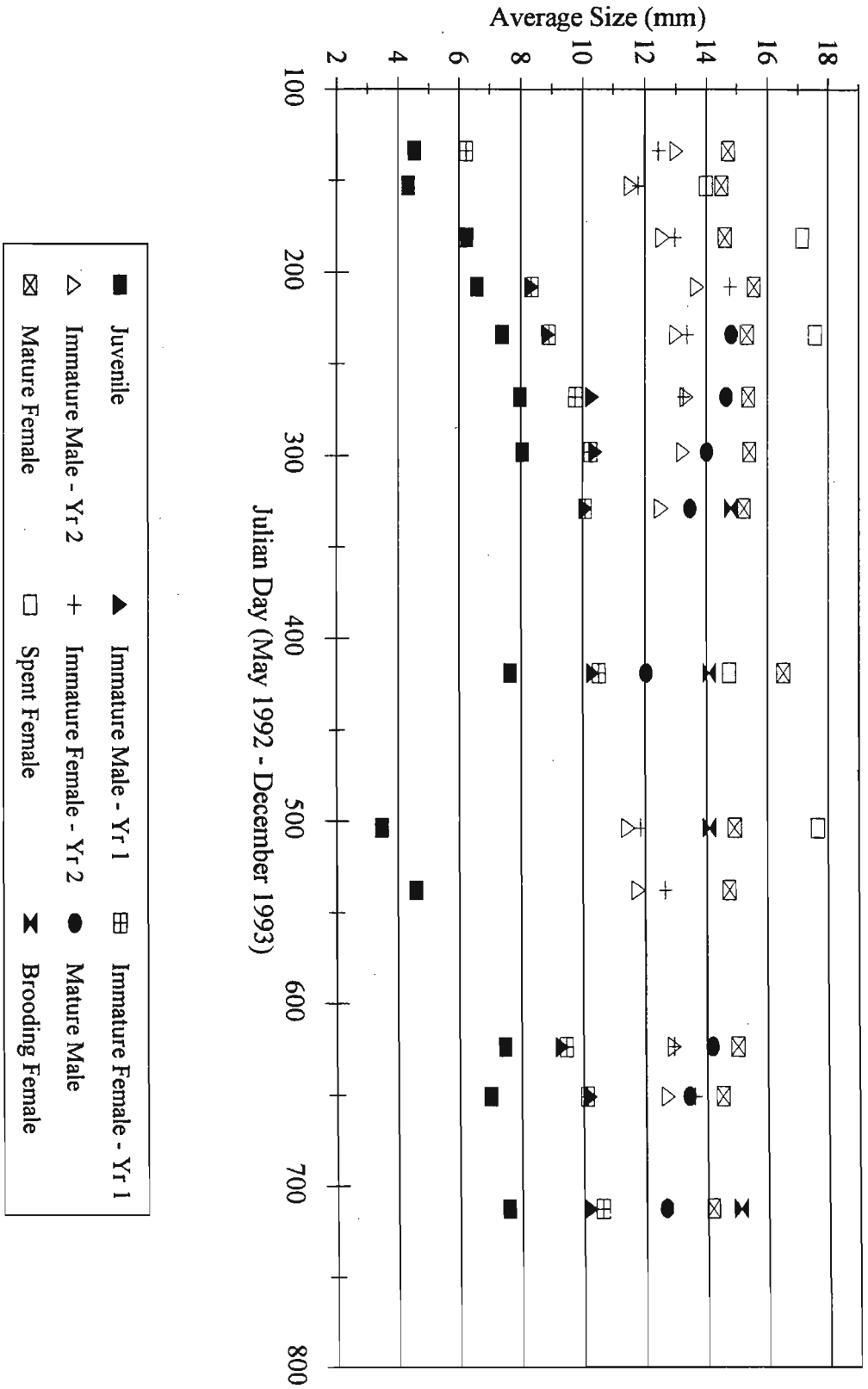


Fig. 53e. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

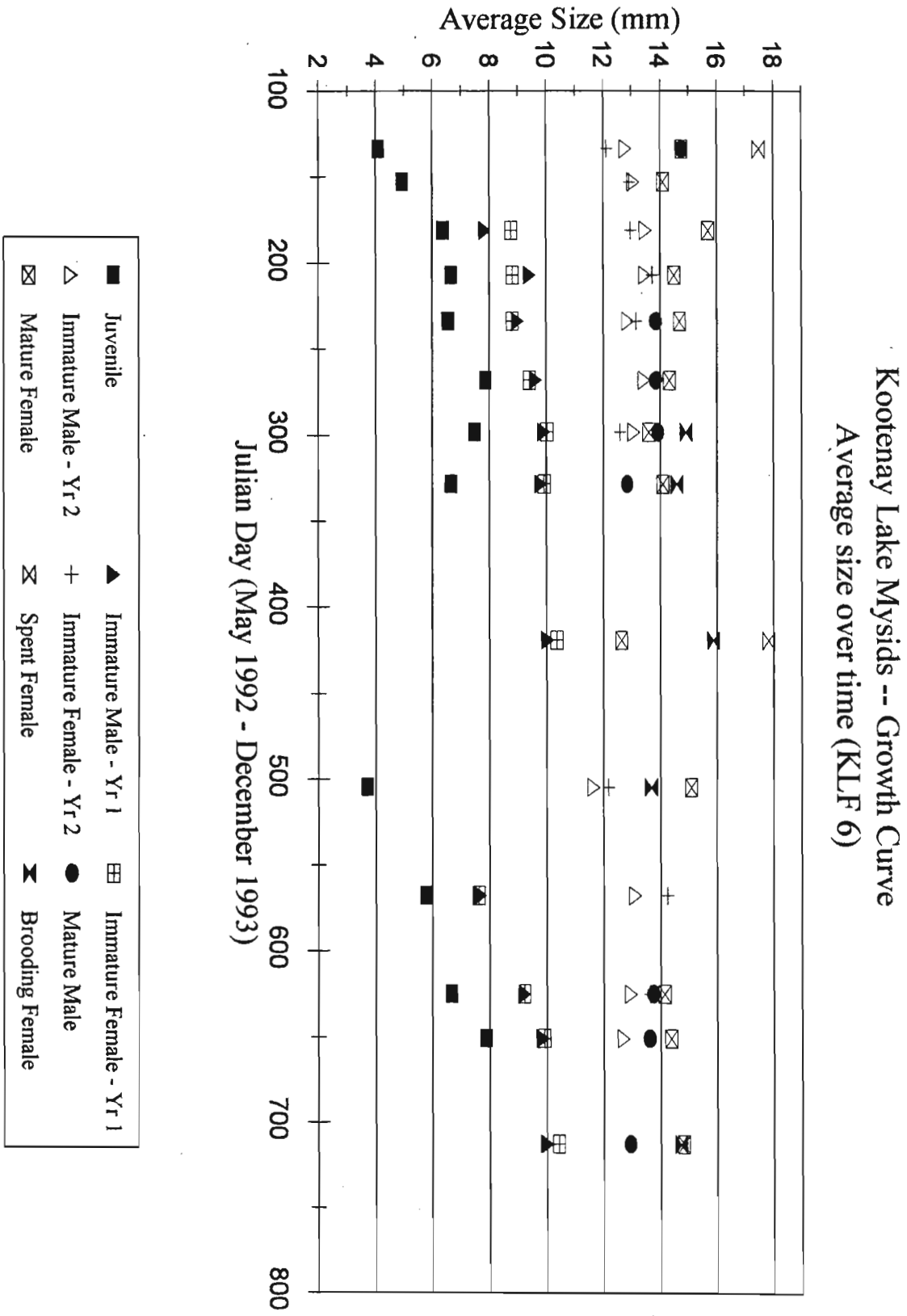


Fig. 53f. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

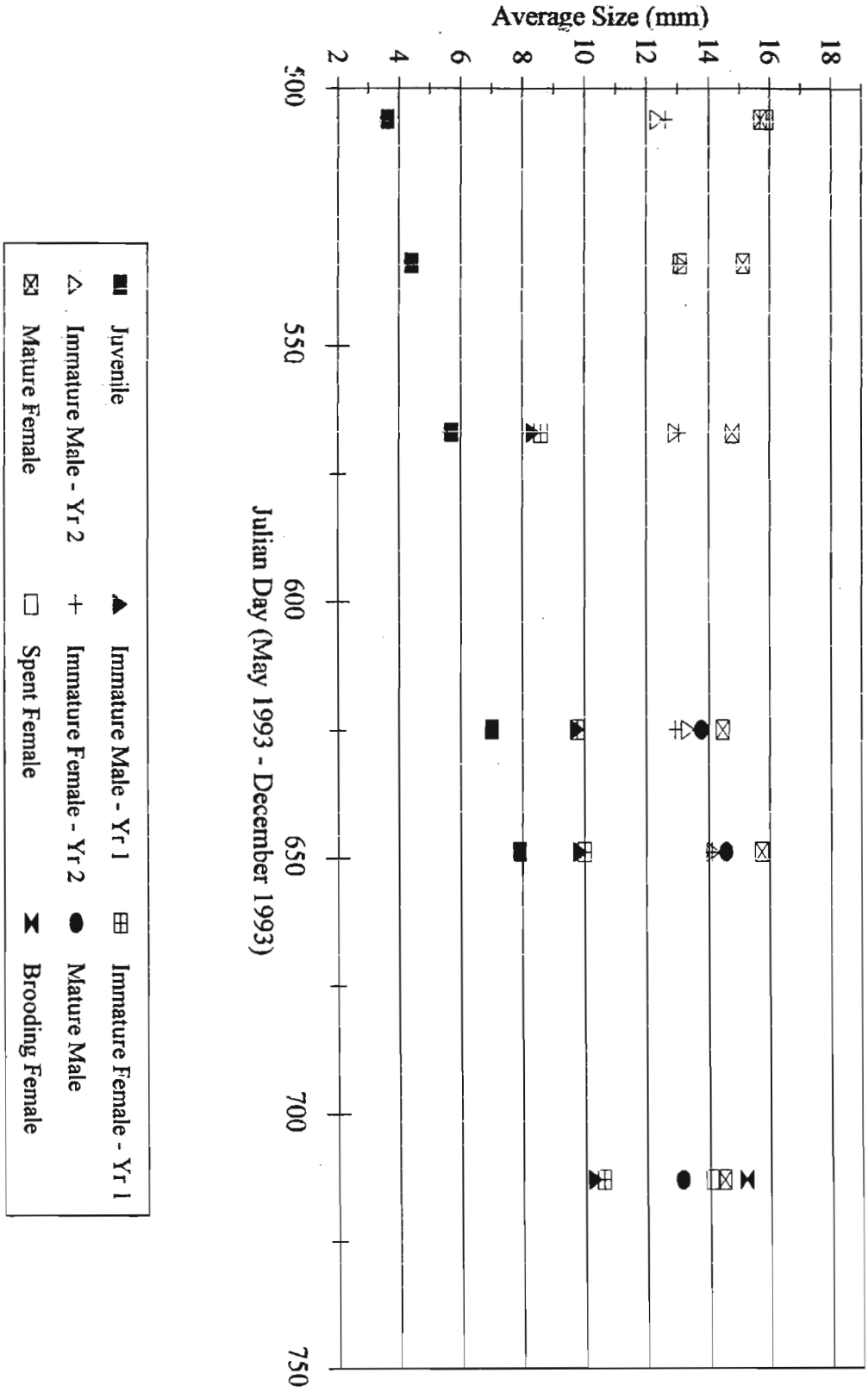


Fig. 53g. Average size of mysid cohorts at Stations 1 through 7, from May 1992 through December 1993.

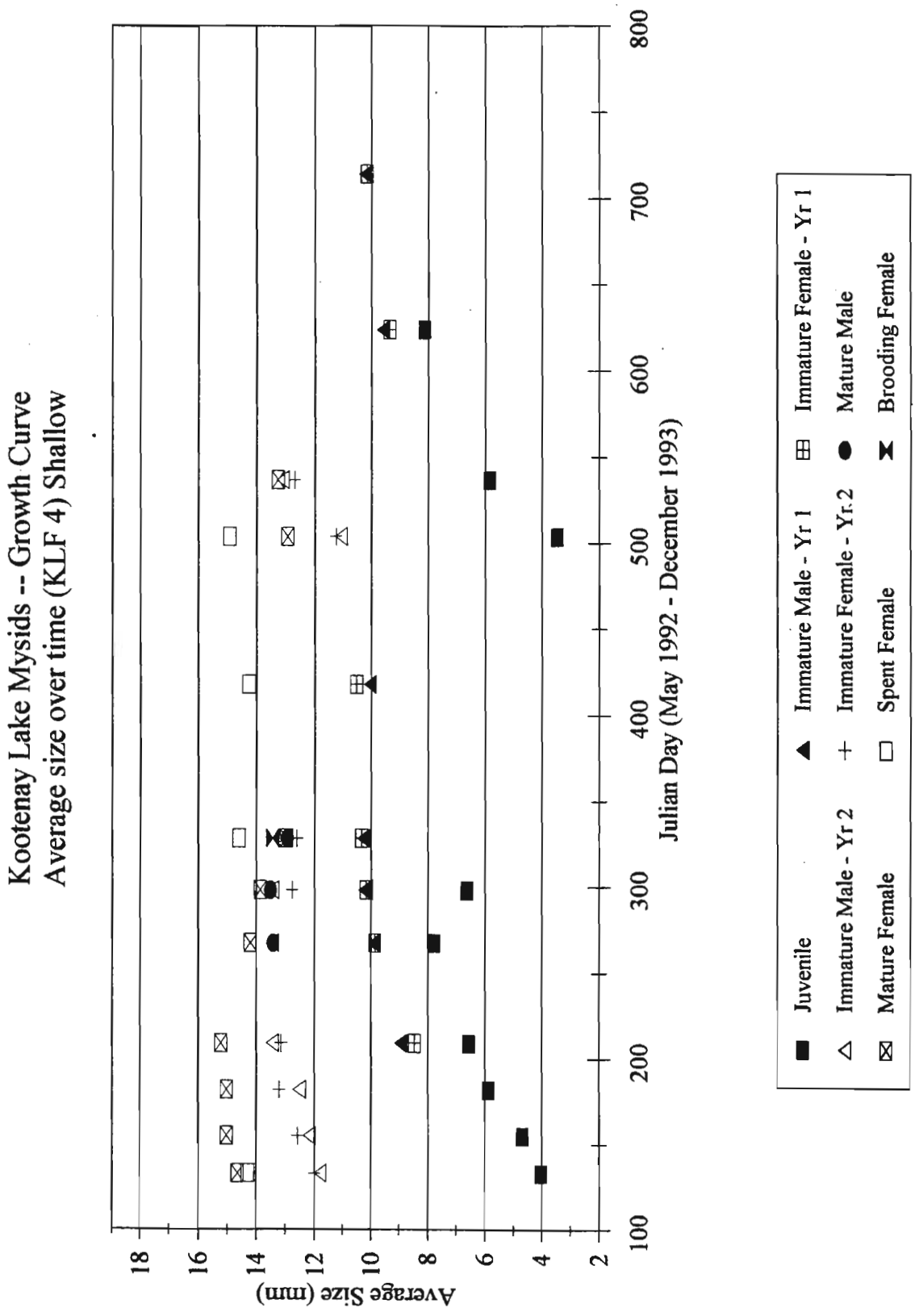
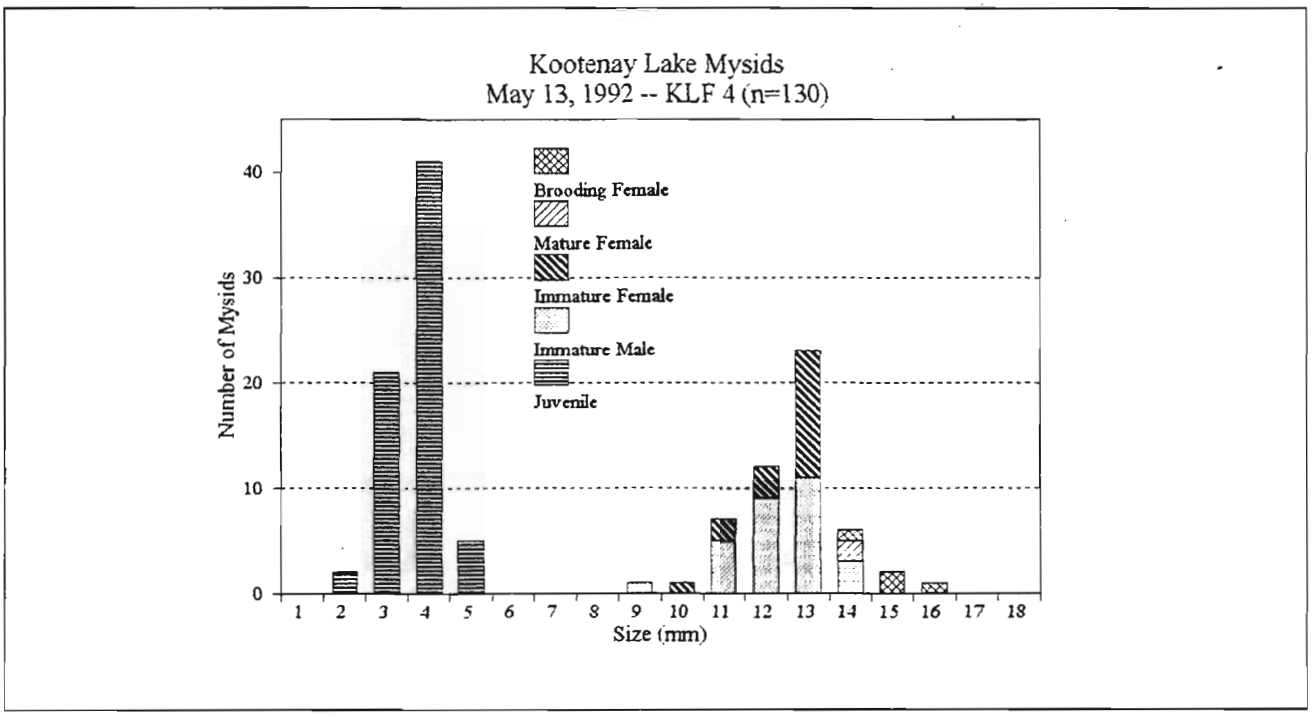


Fig. 54. Average size of mysid cohorts at Station 4, shallow hauls, from May 1992 through December 1993.



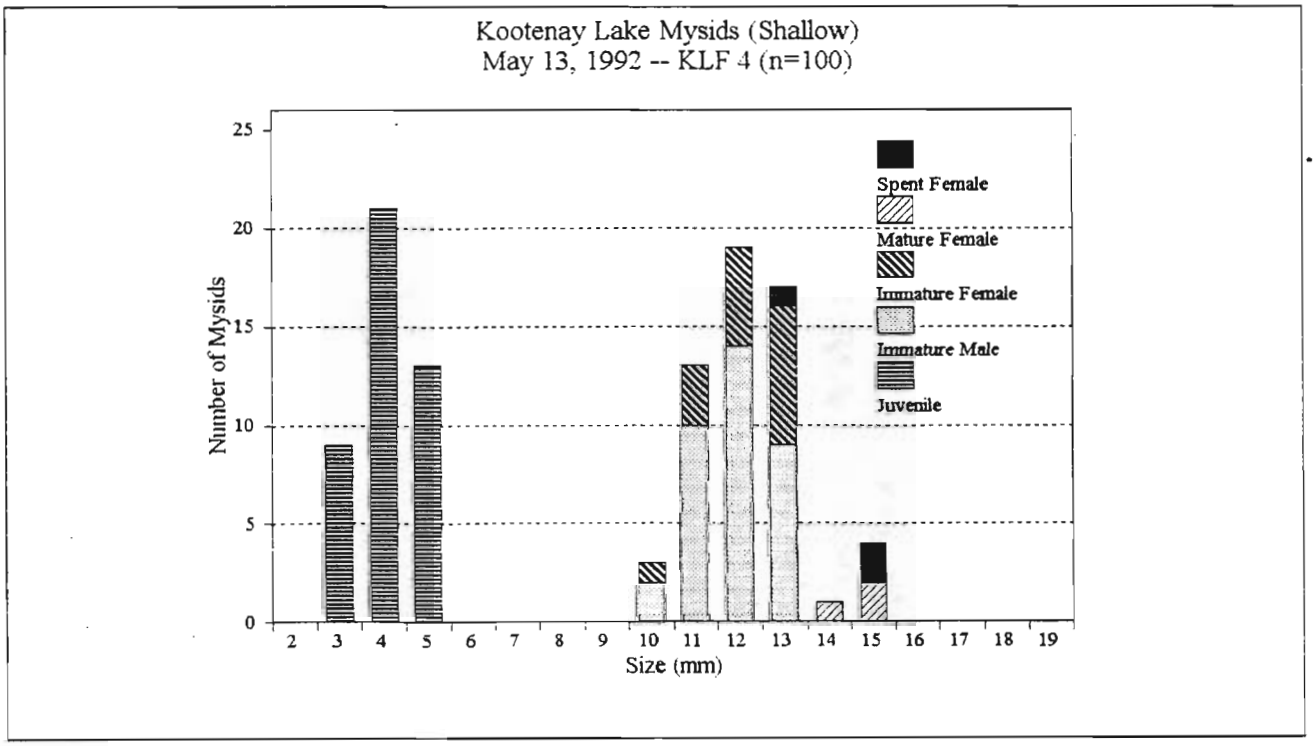
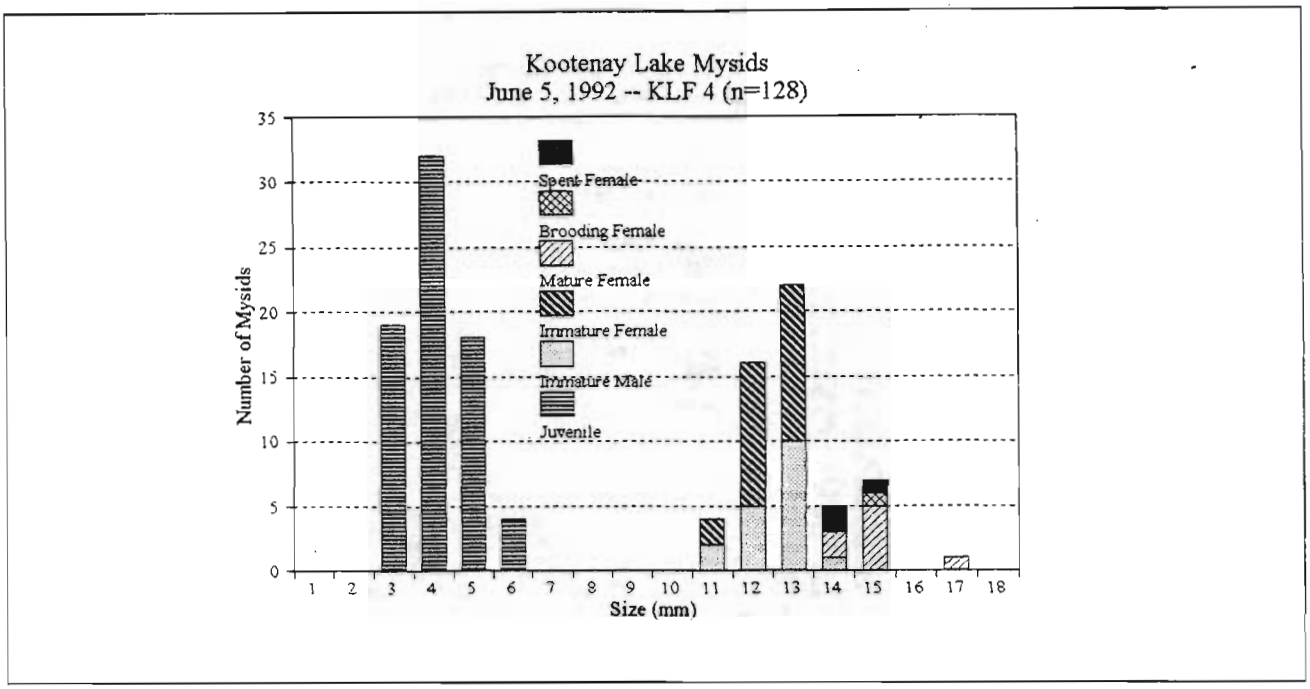


Fig. 55a. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



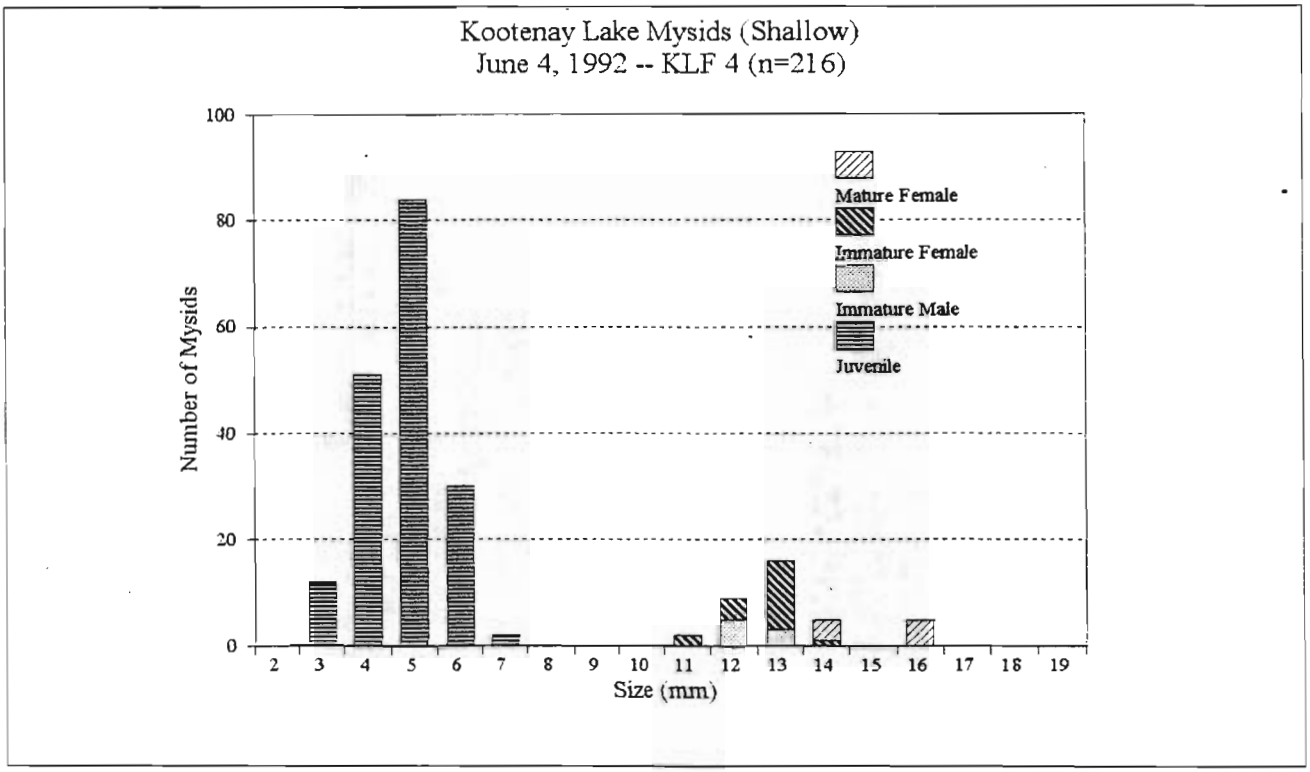
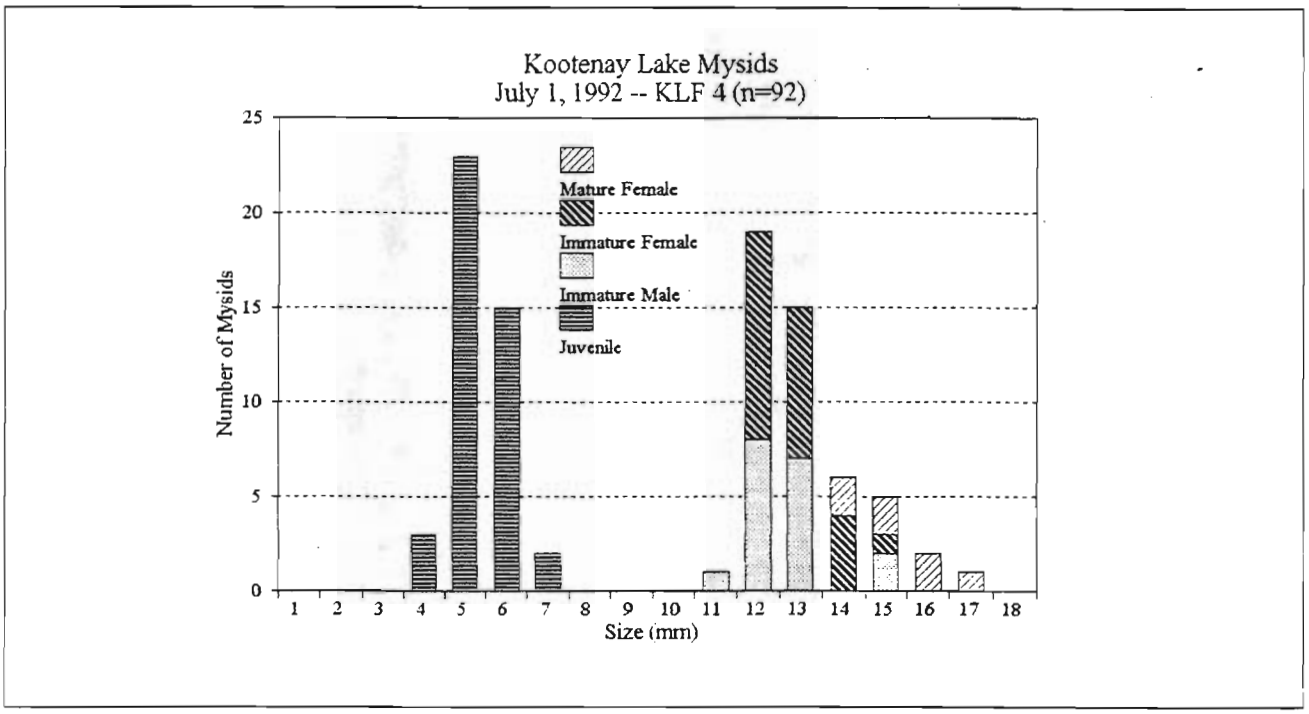


Fig. 55b. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



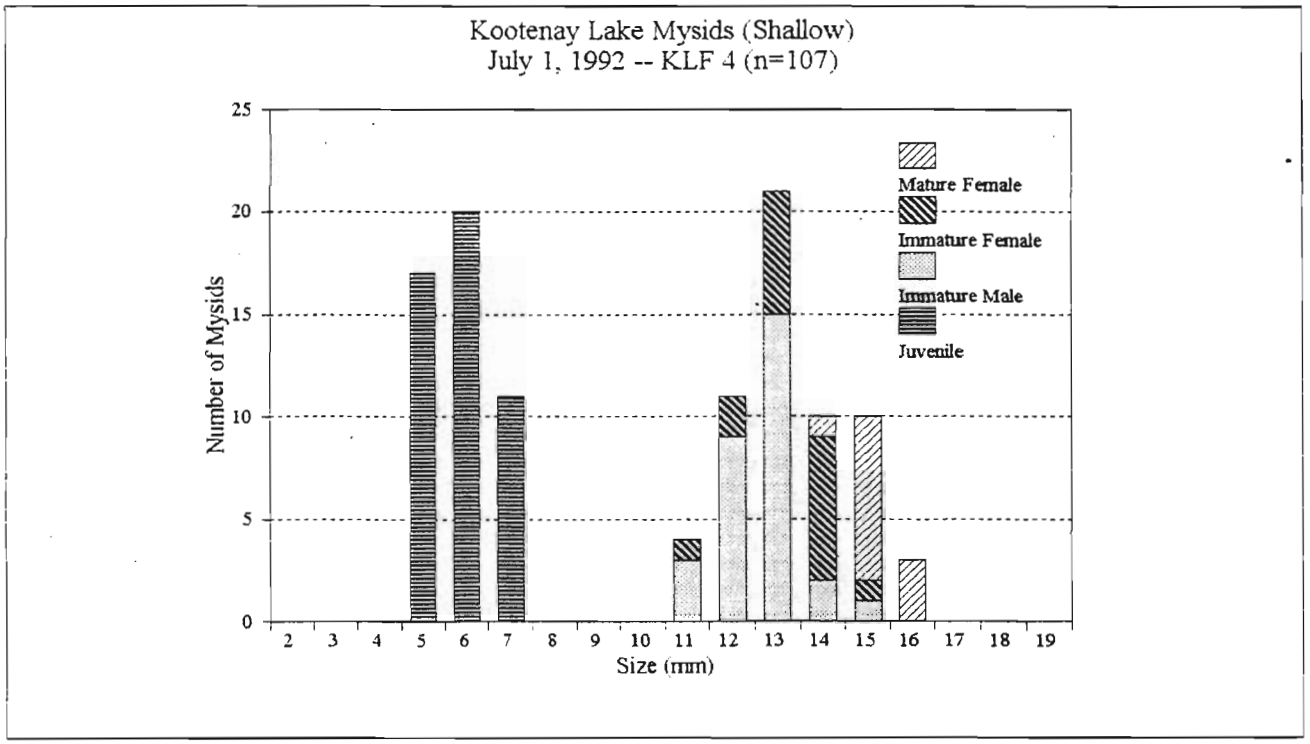
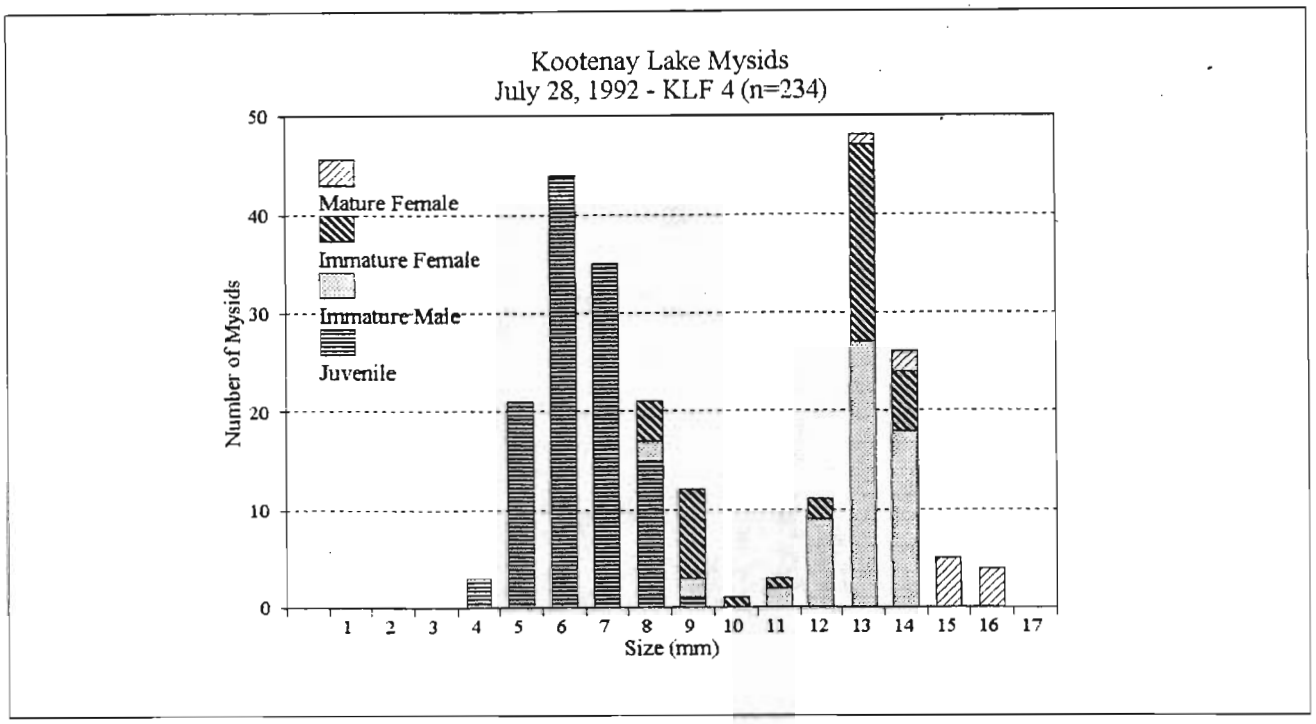


Fig. 55c. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



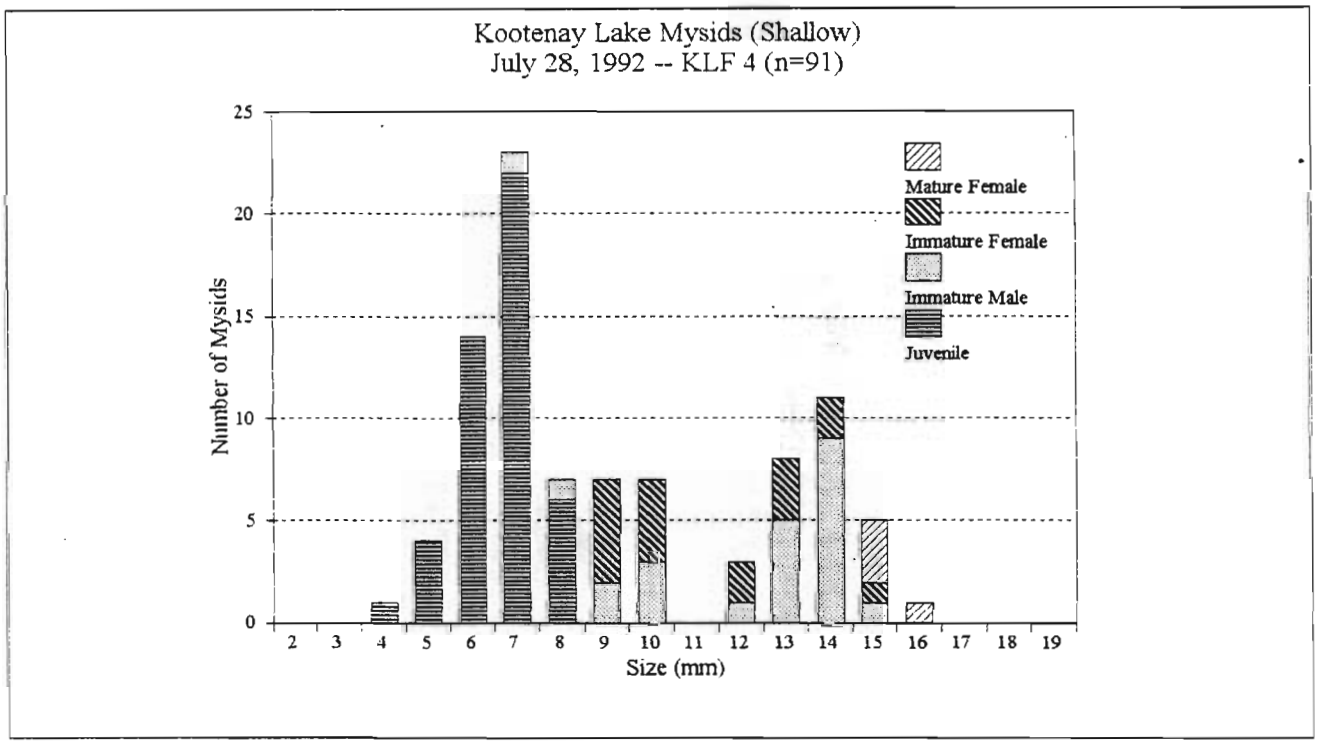
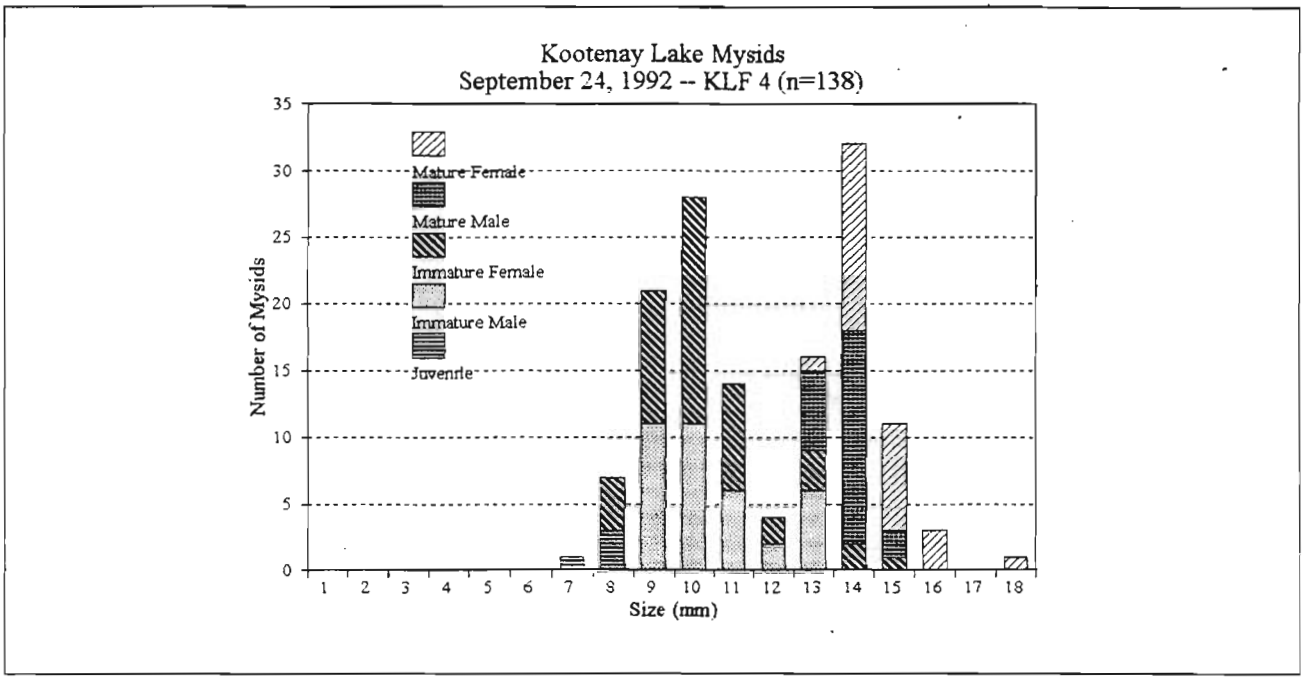


Fig. 55d. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



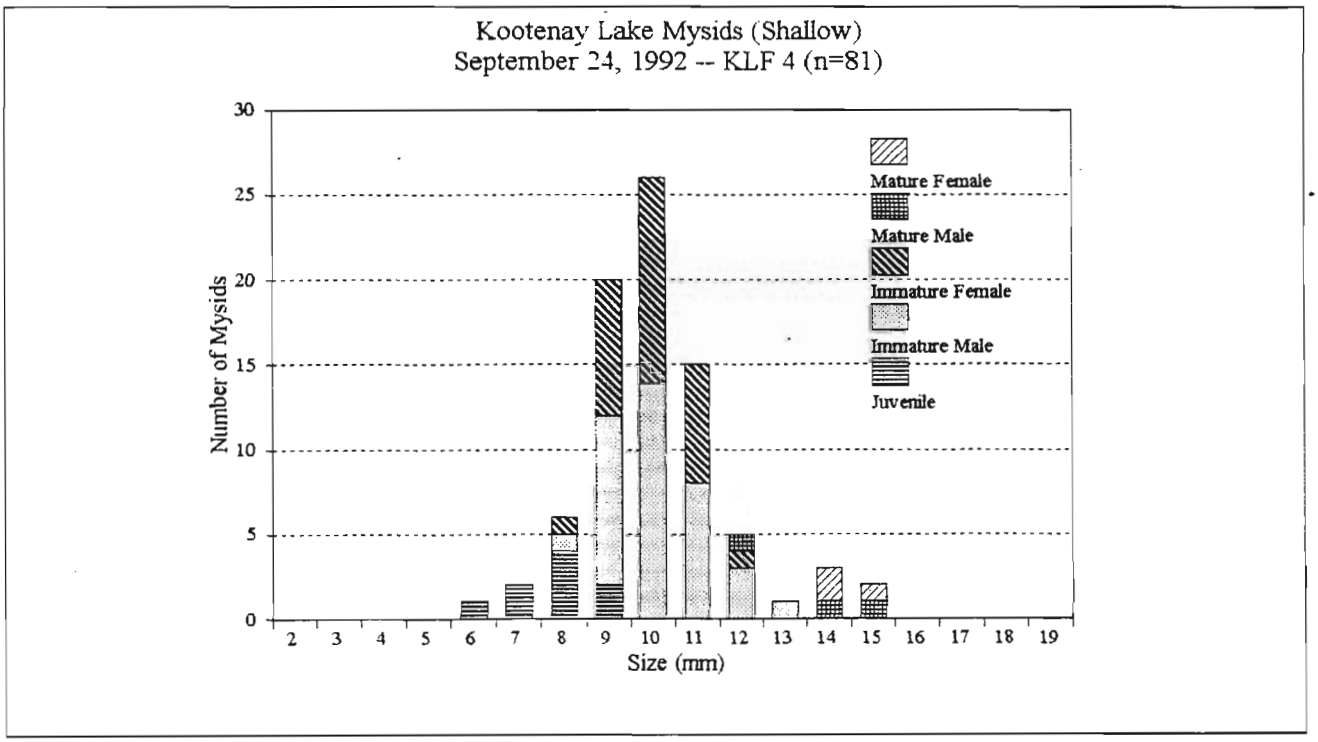
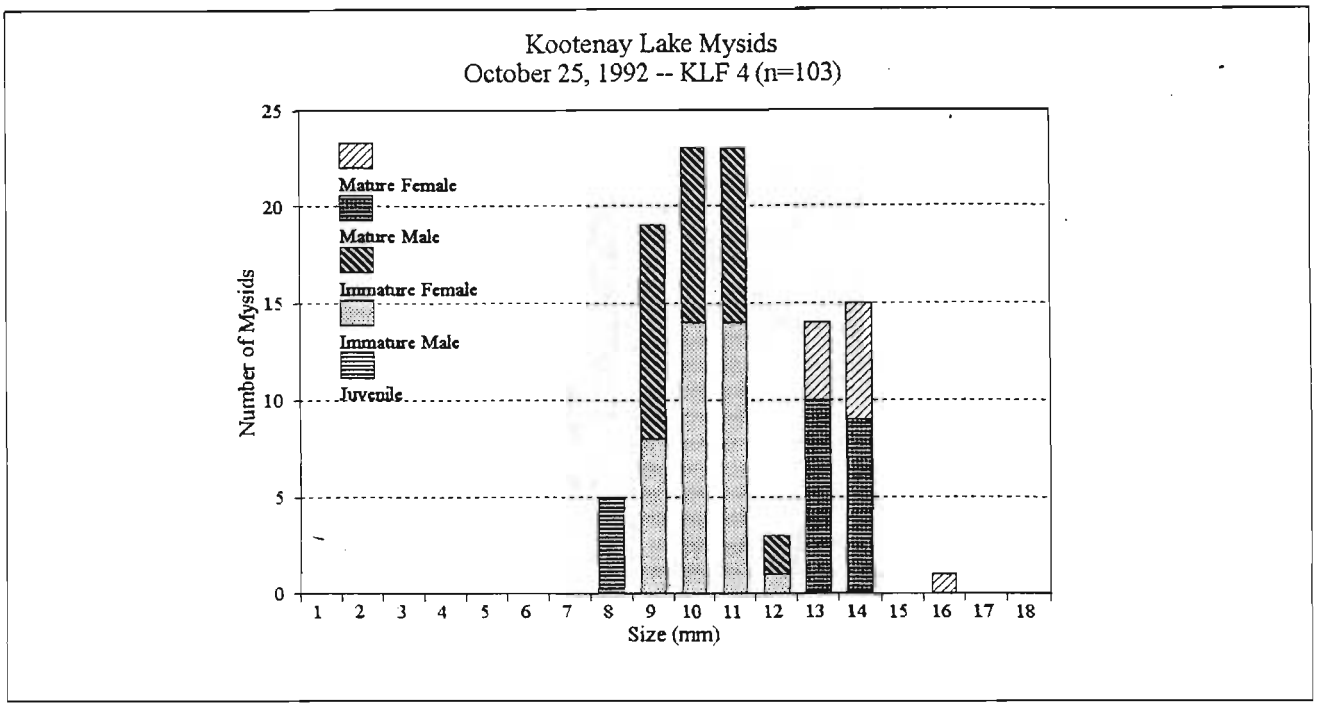


Fig. 55e. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



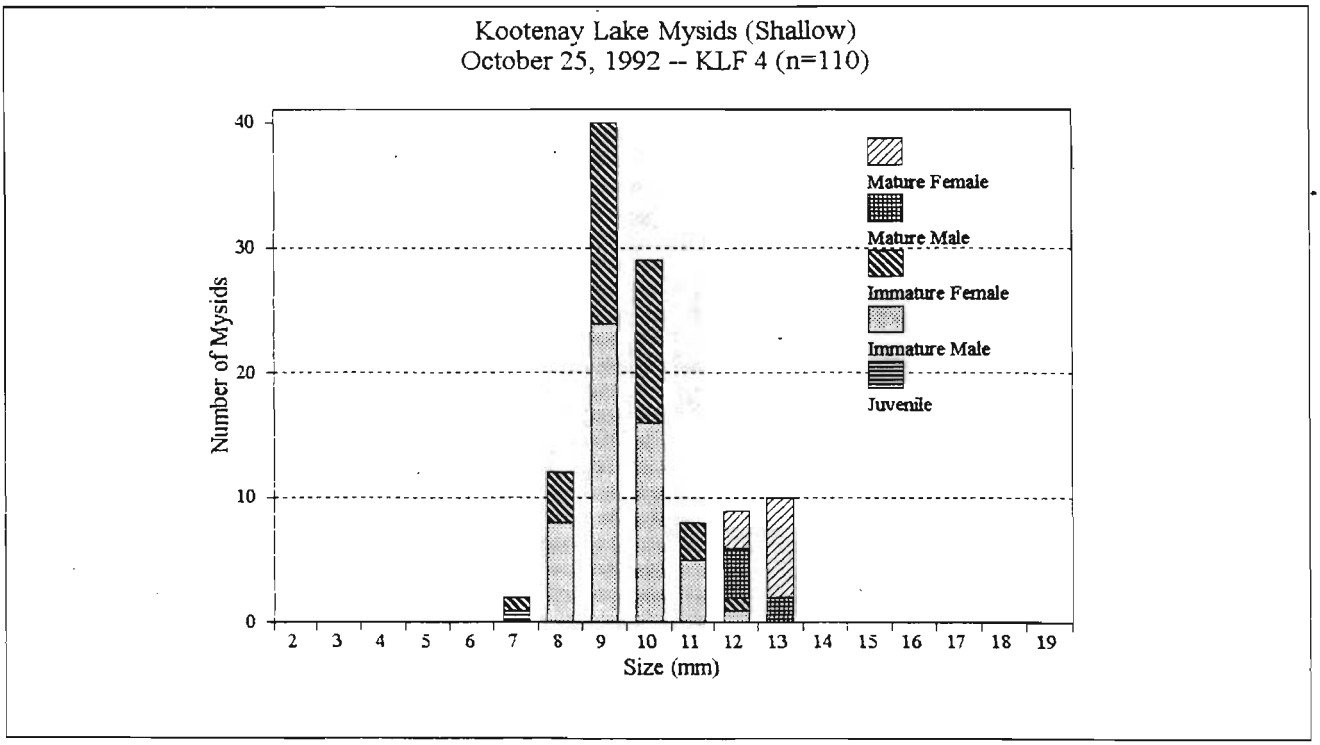
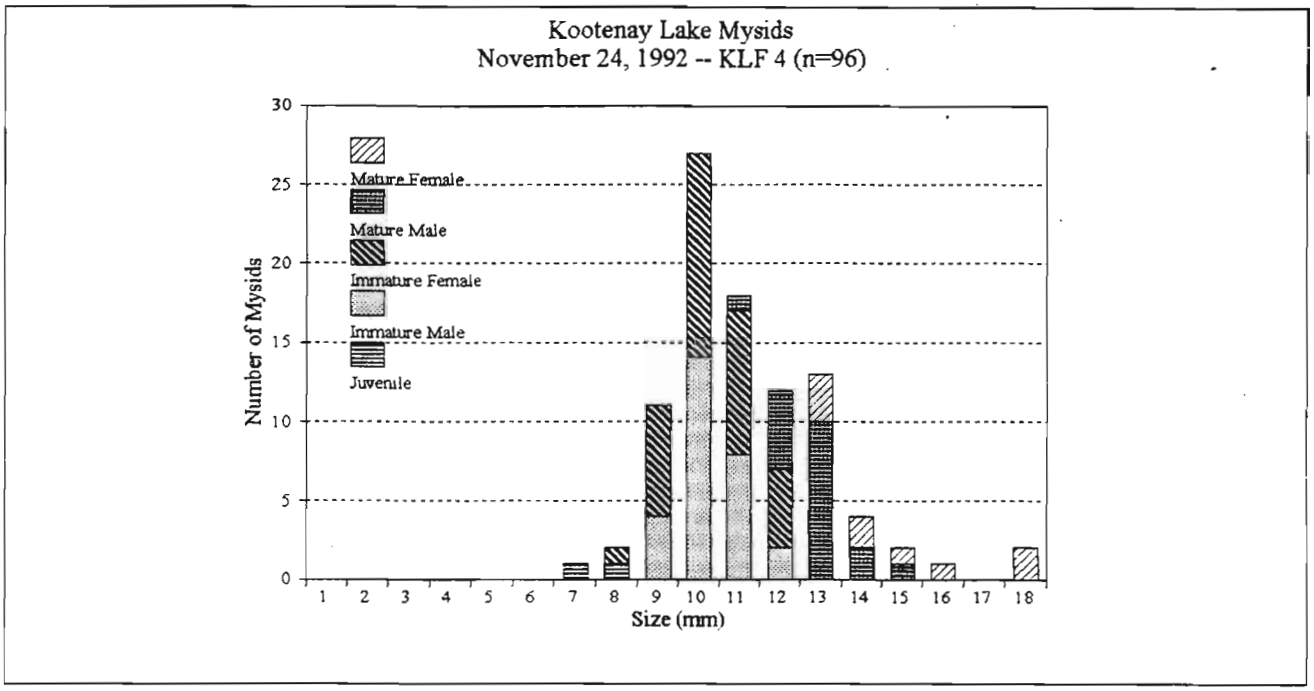


Fig. 55f. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



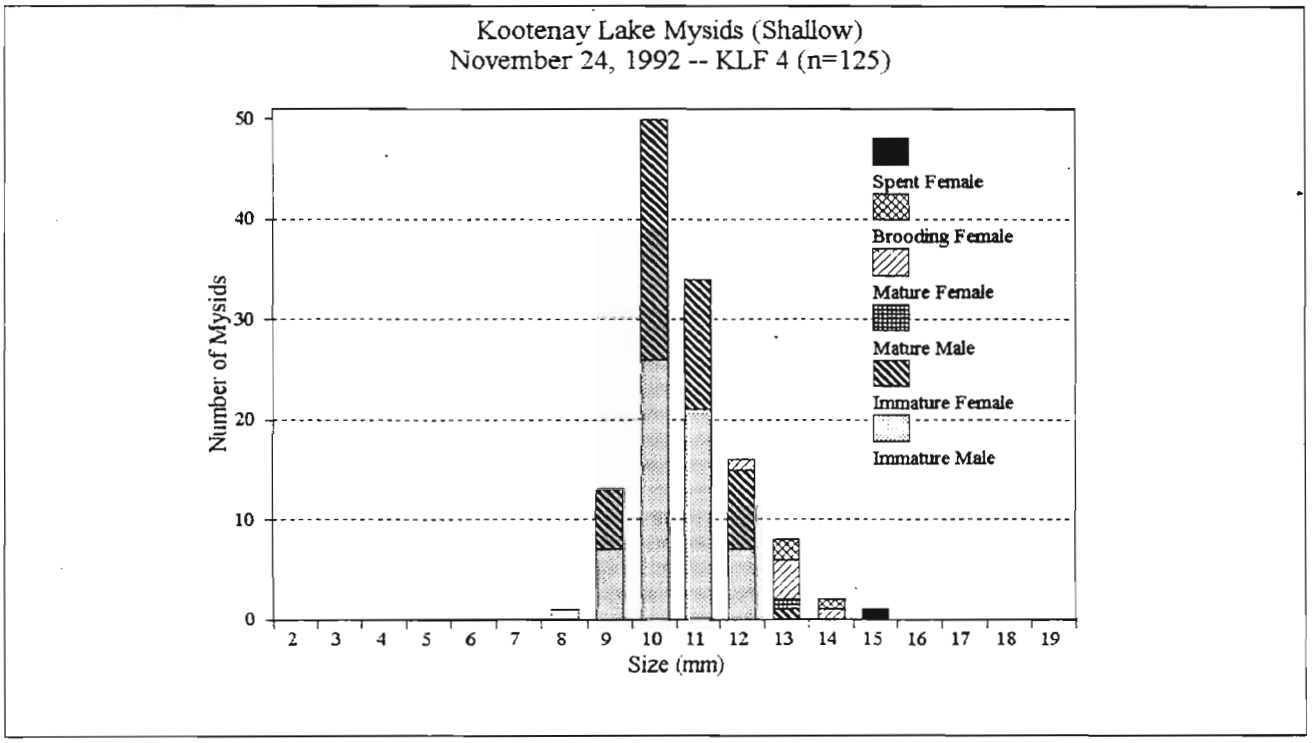
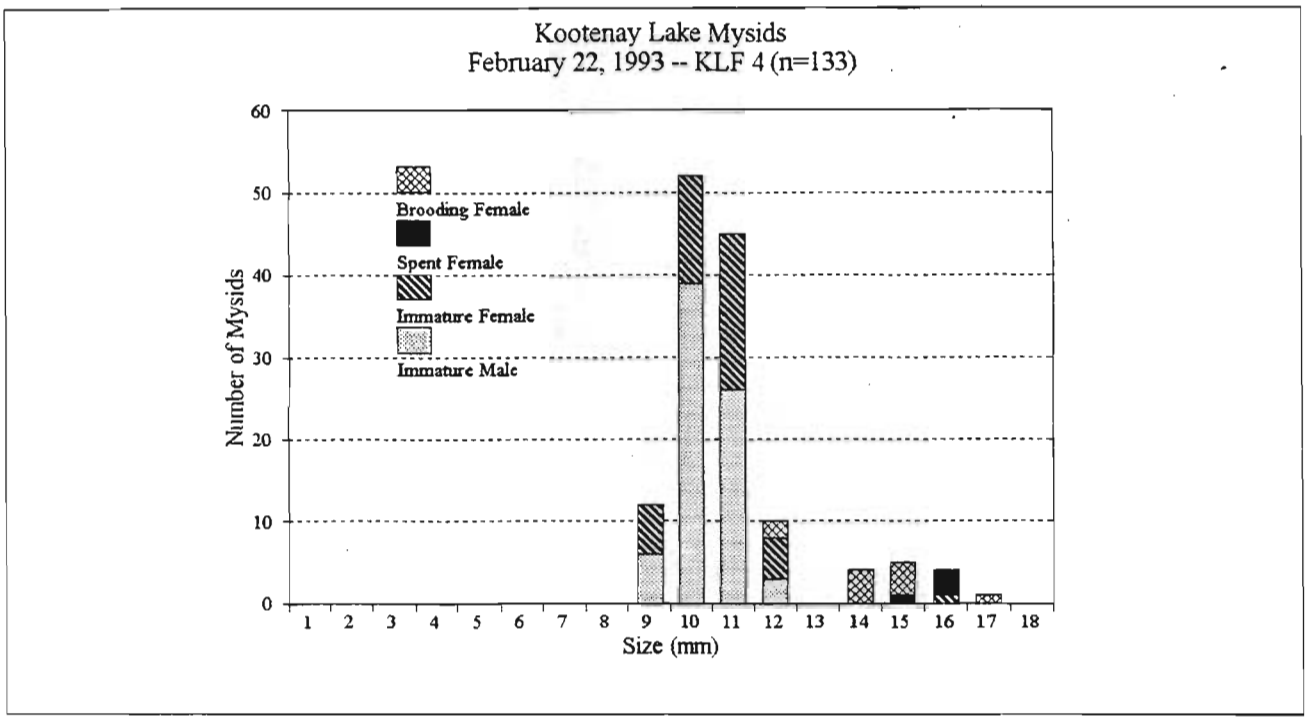


Fig. 55g. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



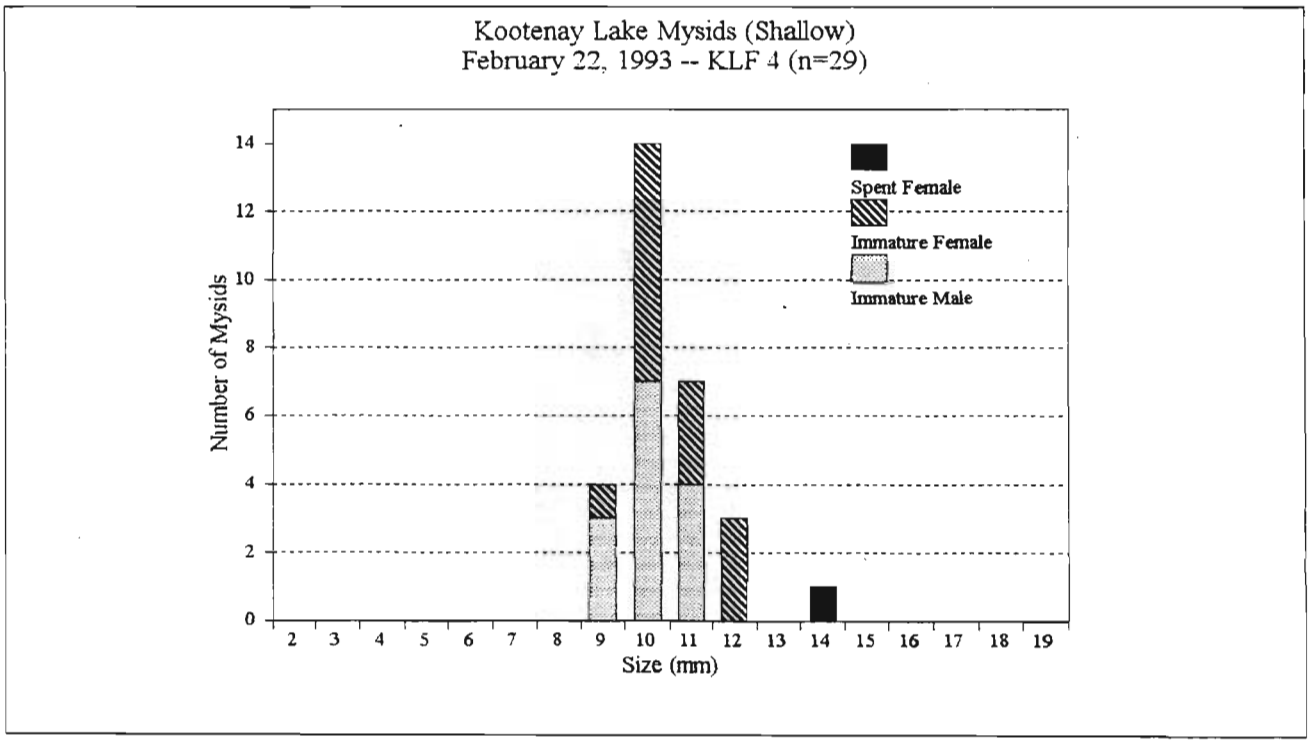
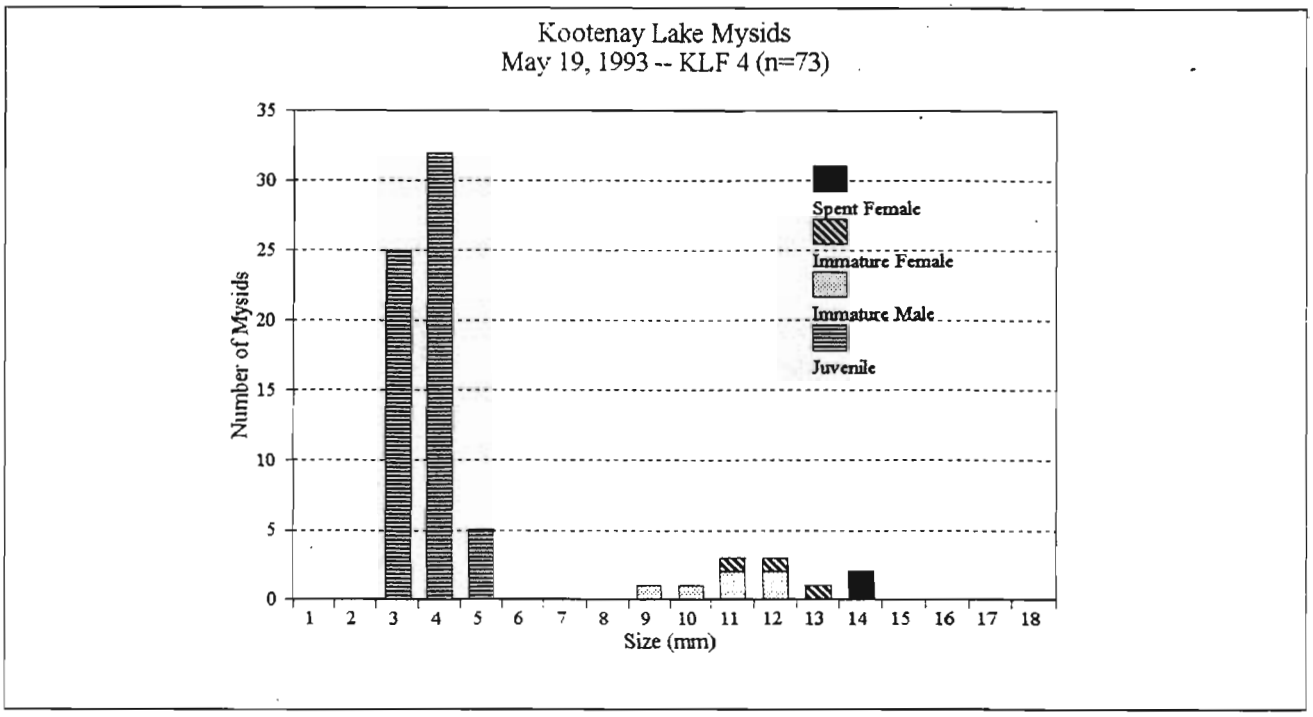


Fig. 55h. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



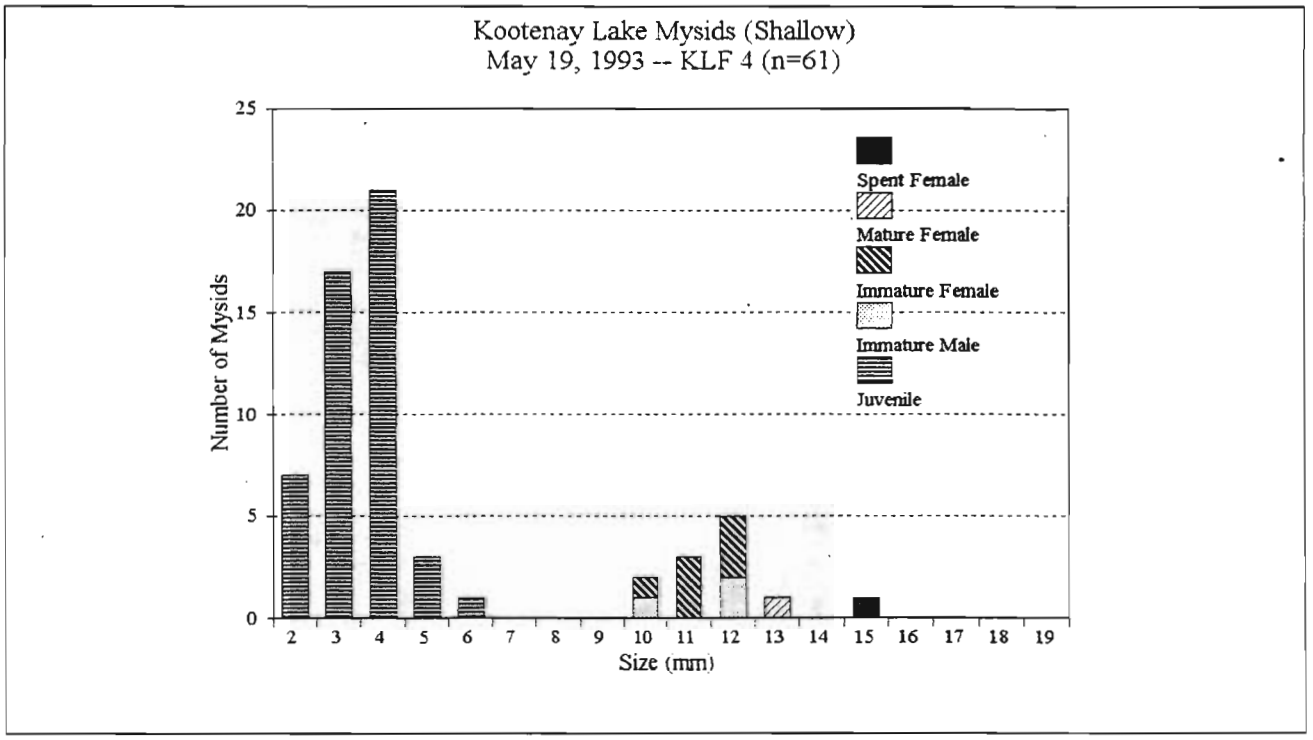
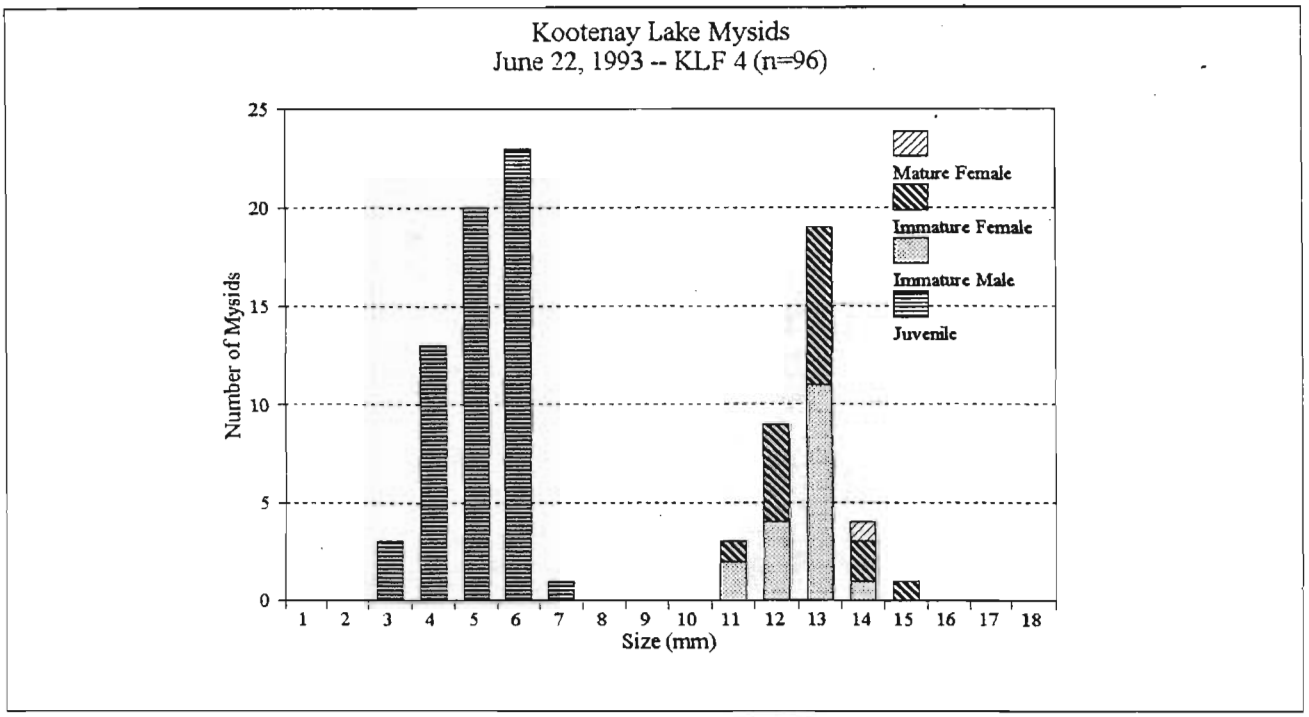


Fig. 55i. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



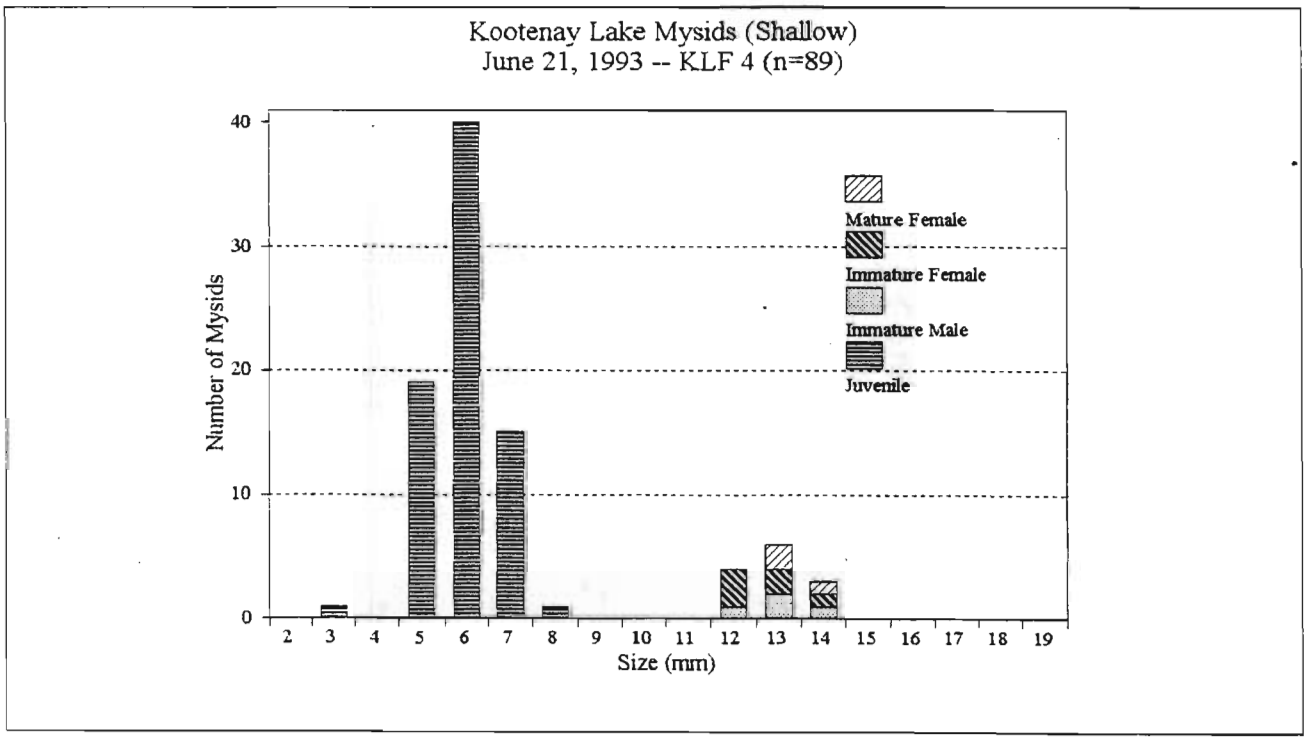
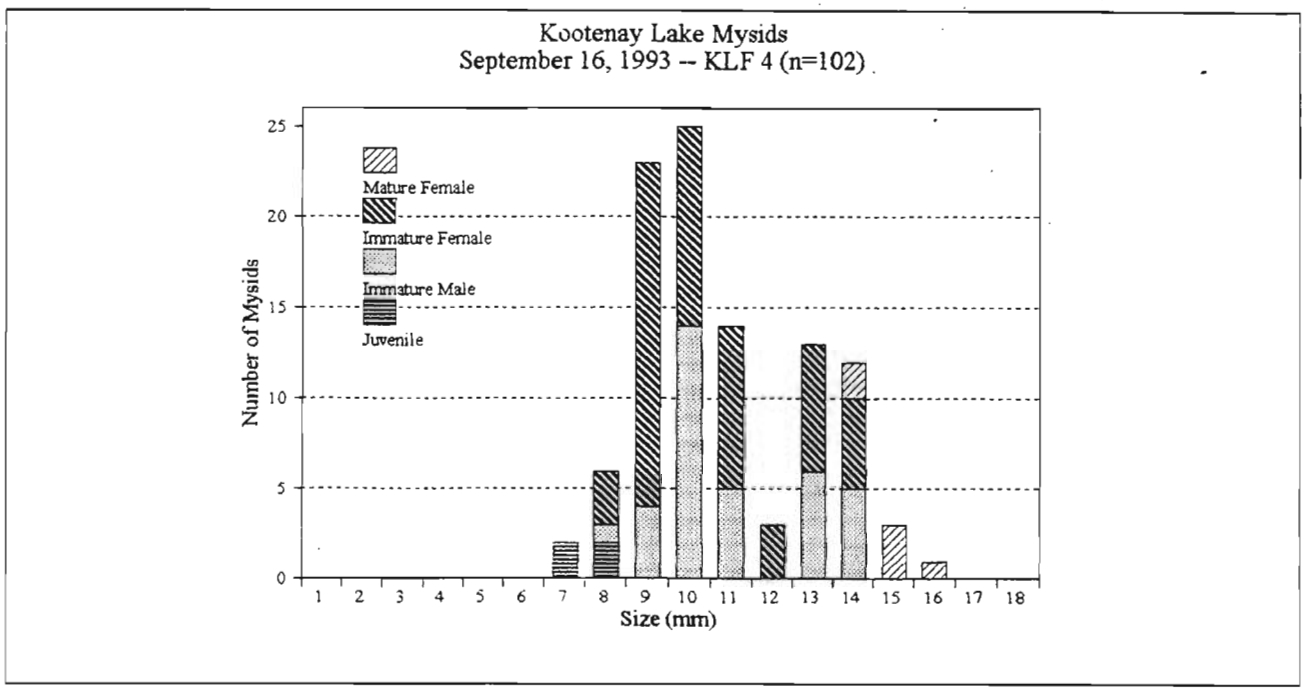


Fig. 55j. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



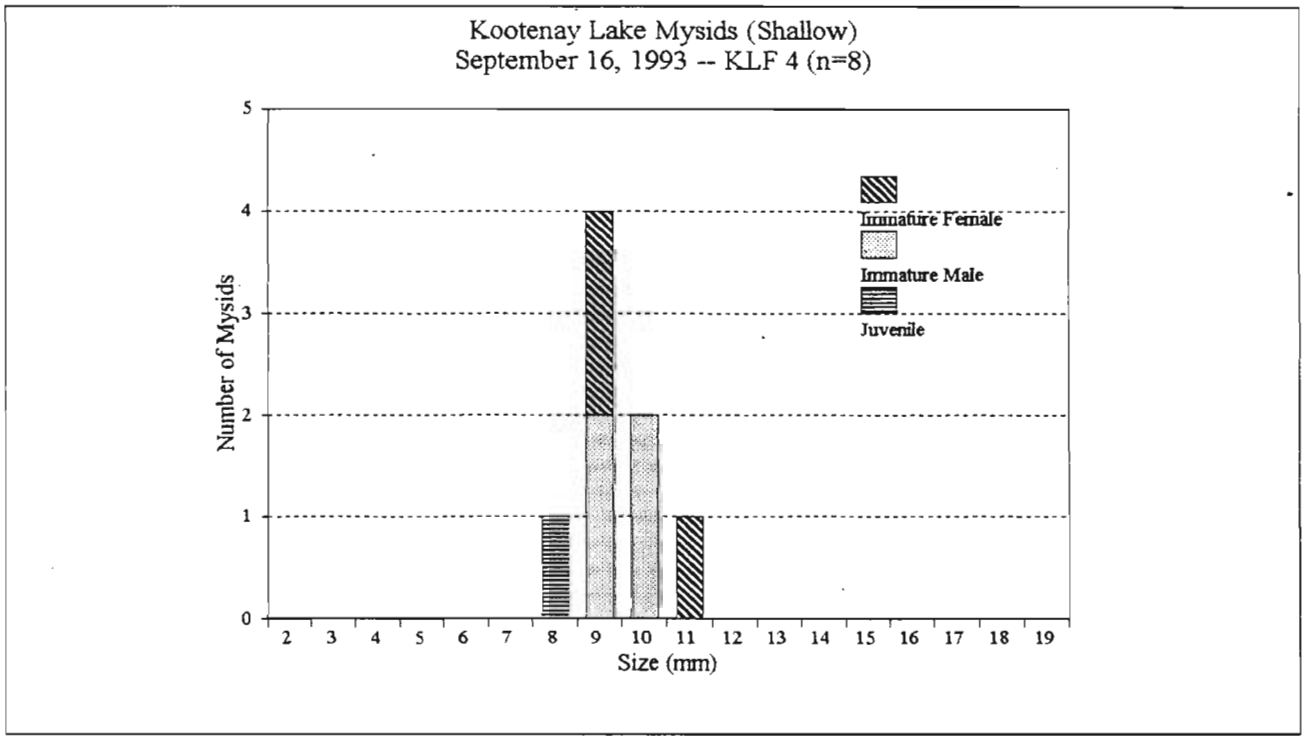
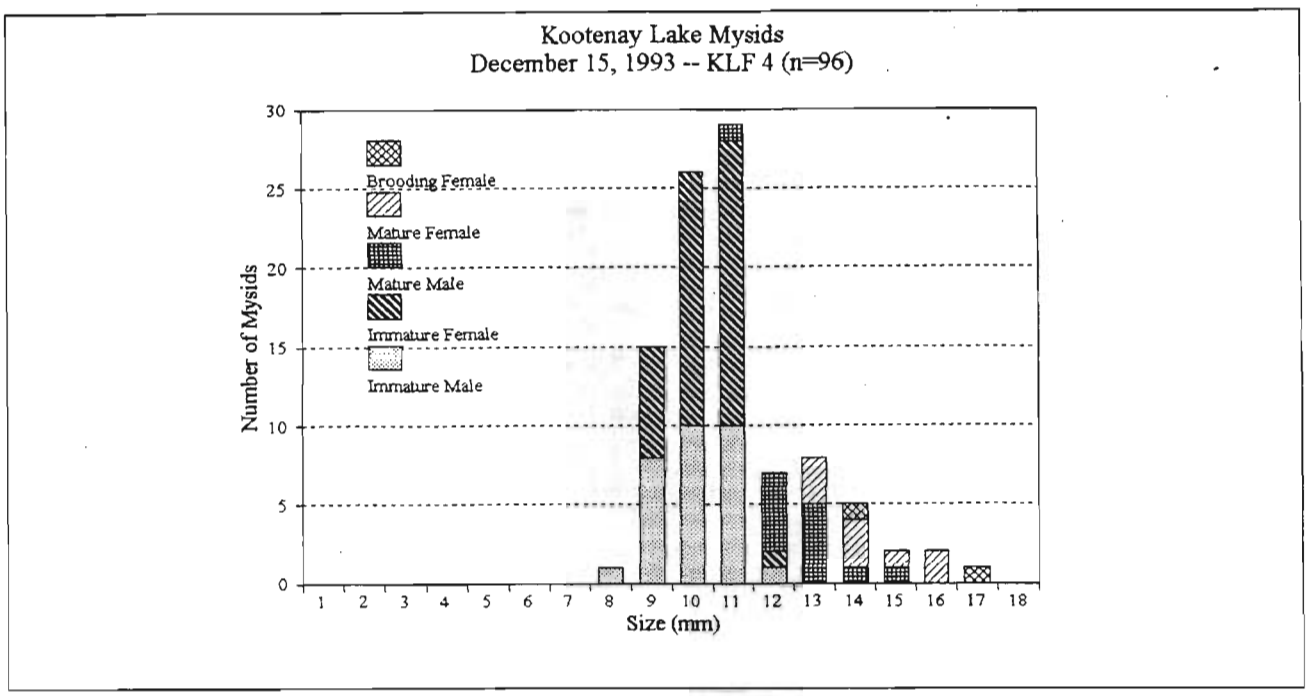


Fig. 55k. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).



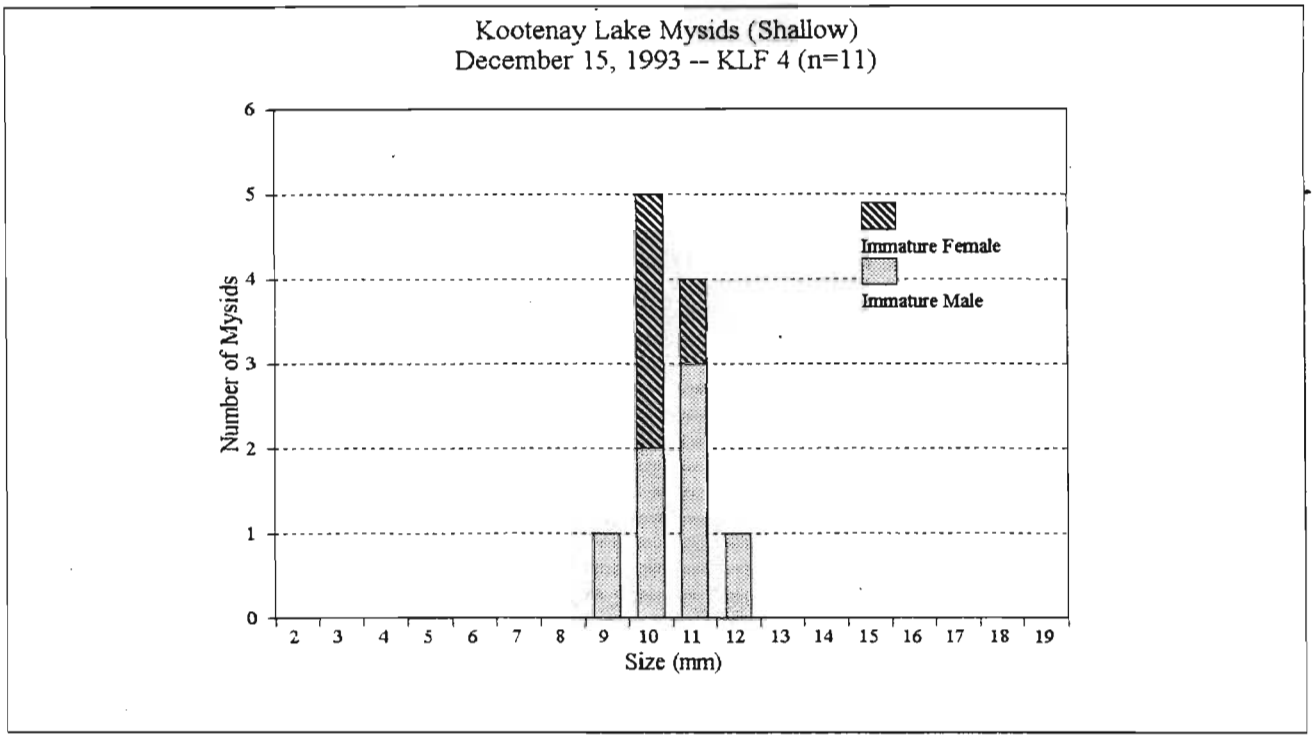


Fig. 55l. Comparison of population structure of mysids for deep vs. shallow sites, May 1992 though December 1993 (when available).

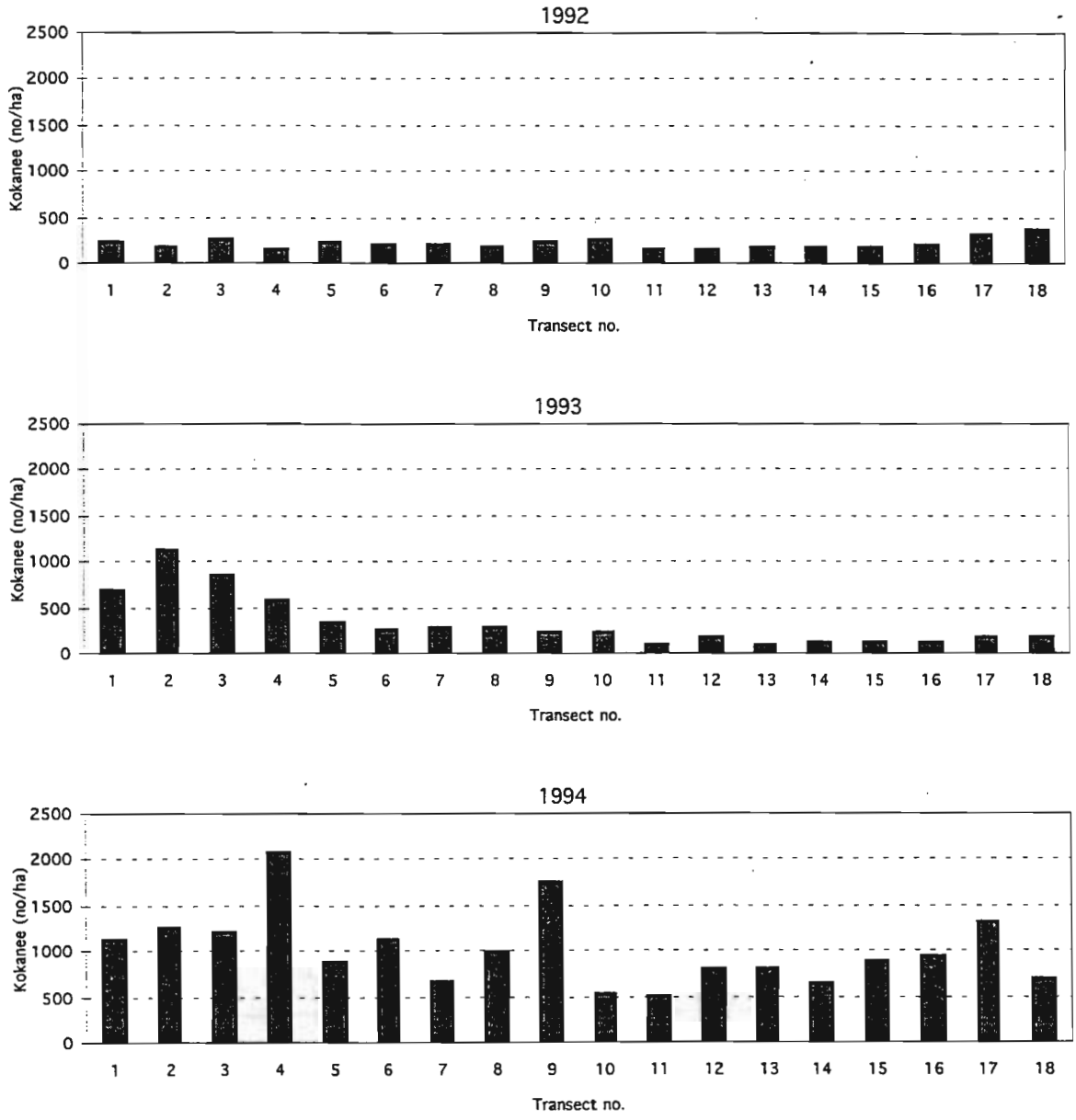


Fig. 56. Kokanee distribution from fall hydroacoustic surveys; 1992-1994. The map shows sampling locations.

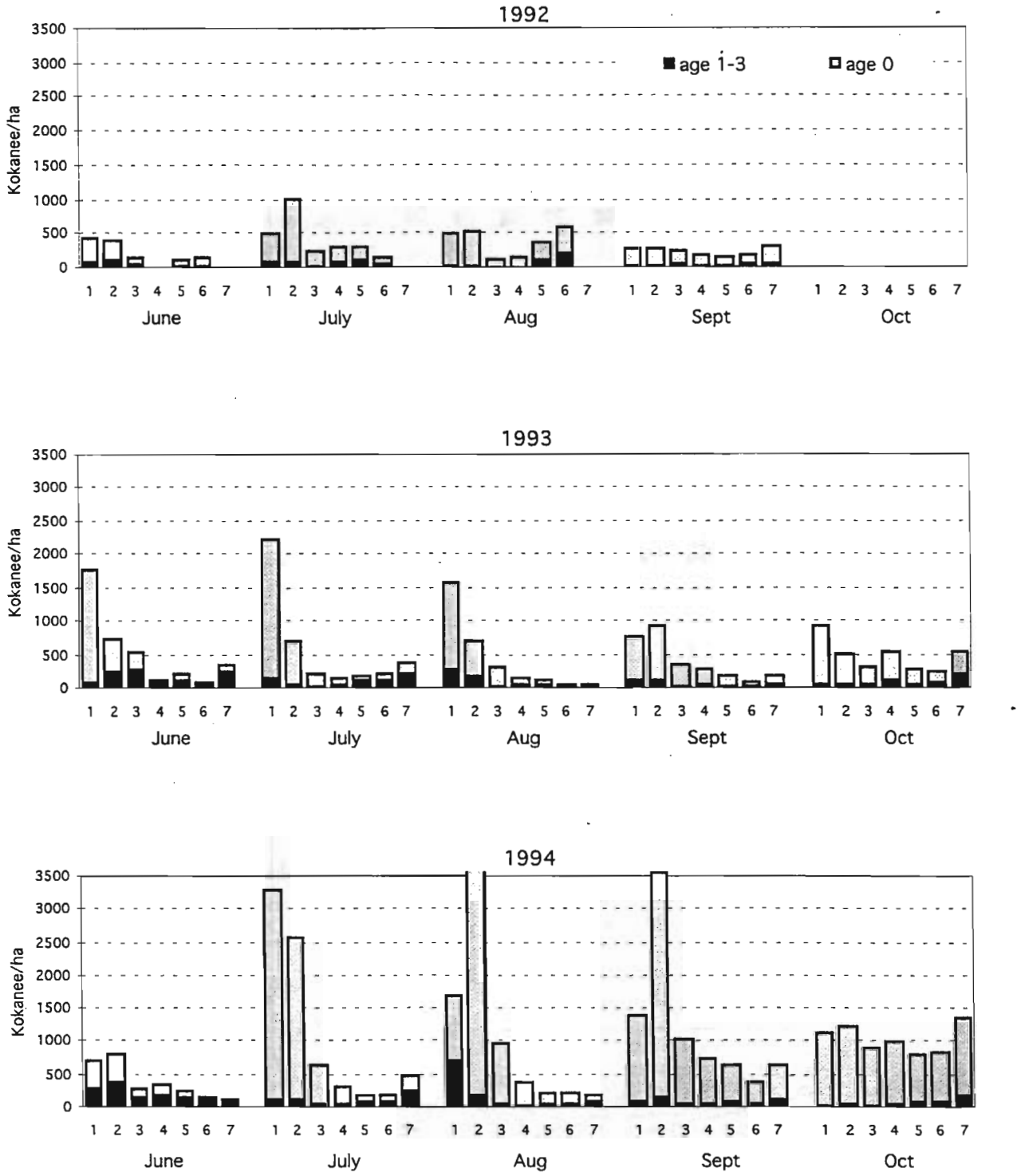


Fig. 57. Kokanee density (no·ha^{-1}) by age class for seven stations based on monthly hydroacoustic surveys, 1992-94. Note that sites with zero densities in 1992 were not sampled.

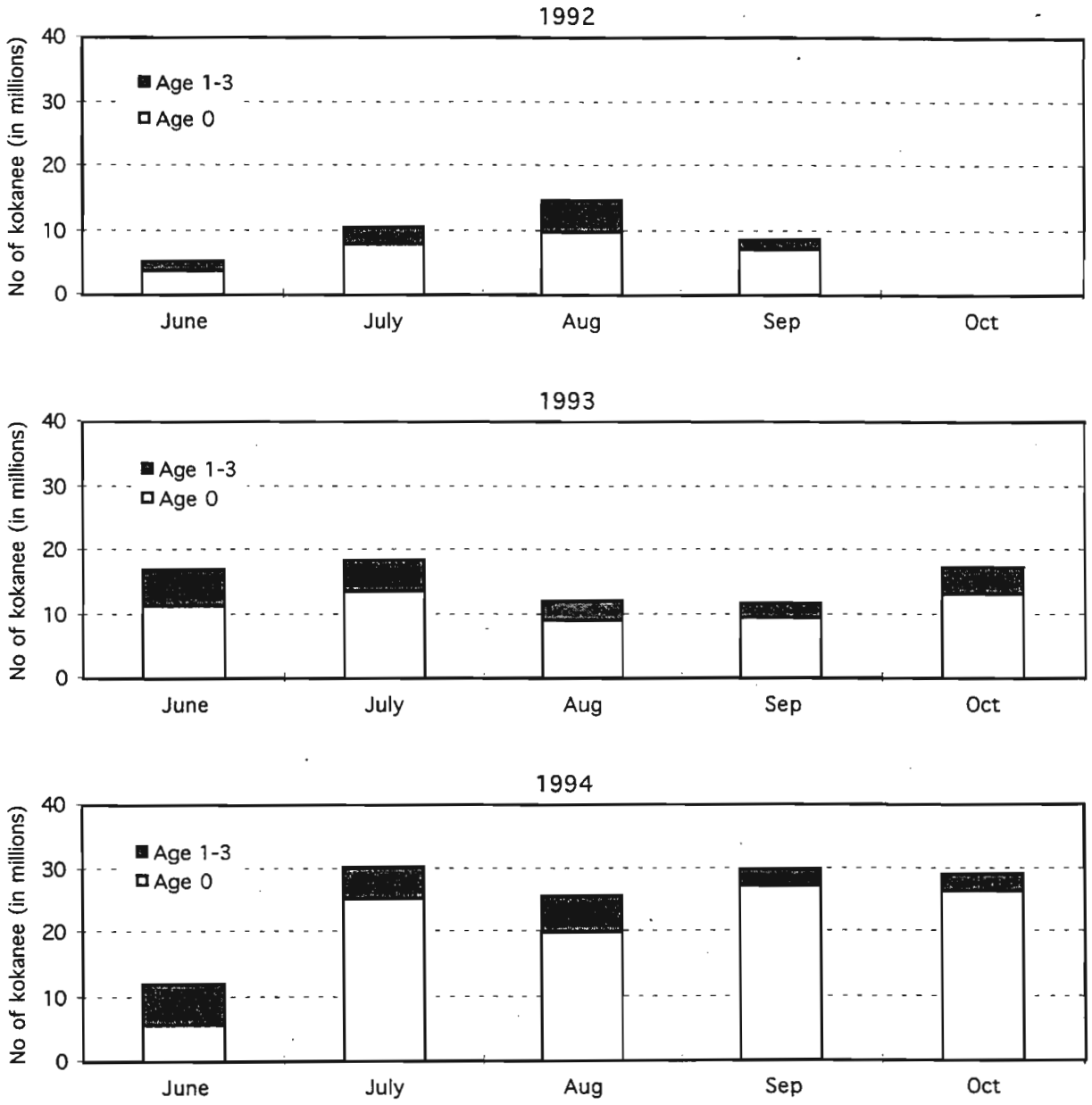


Fig. 58. Relative abundance estimates for kokanee by age group based on limited monthly hydroacoustic sampling (i.e., 7 stations).

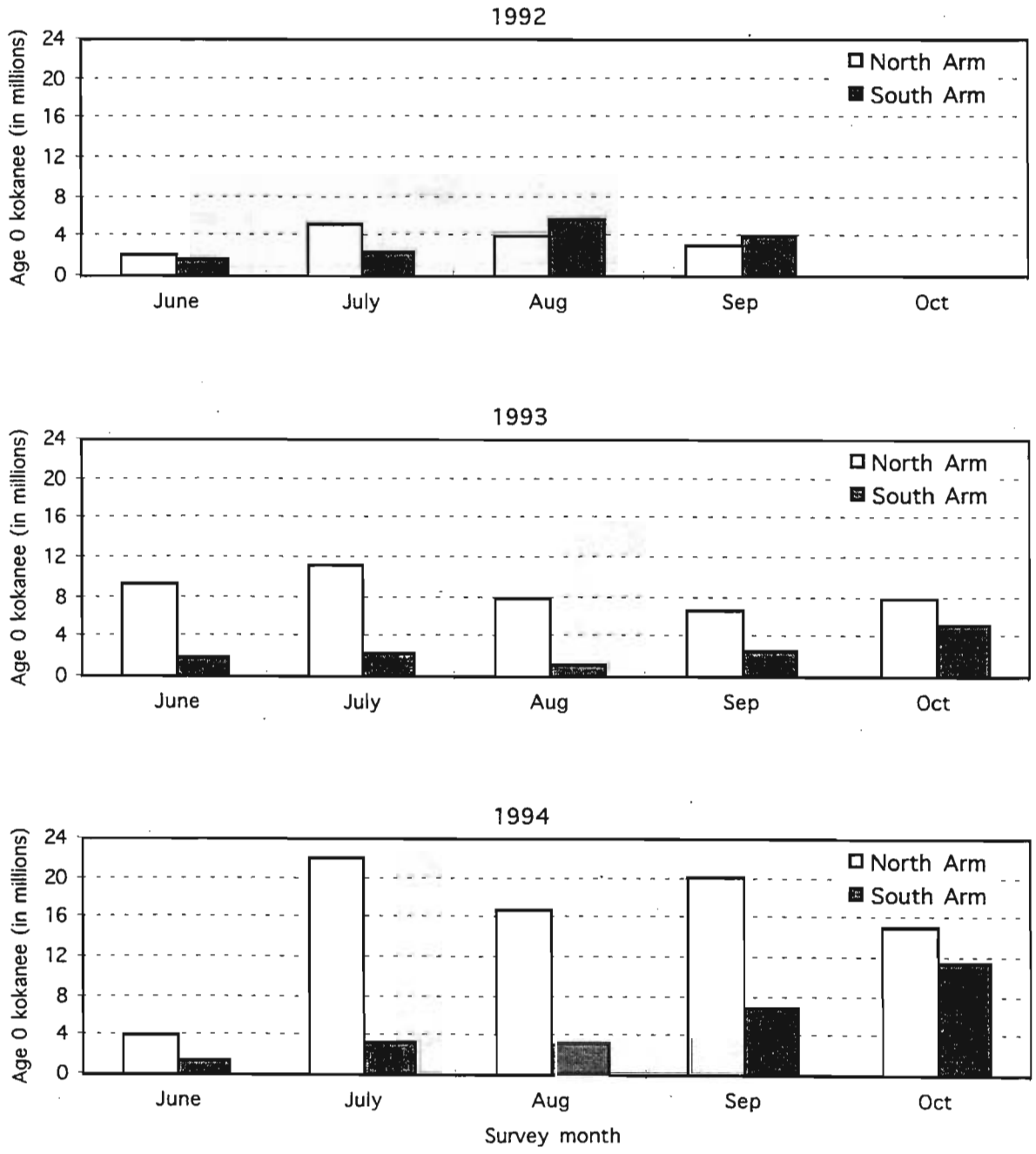


Fig. 59. Kokanee age 0+ abundance in North and South arms based on monthly hydroacoustic surveys, 1992-94. Note: there was no survey done in October 1992.

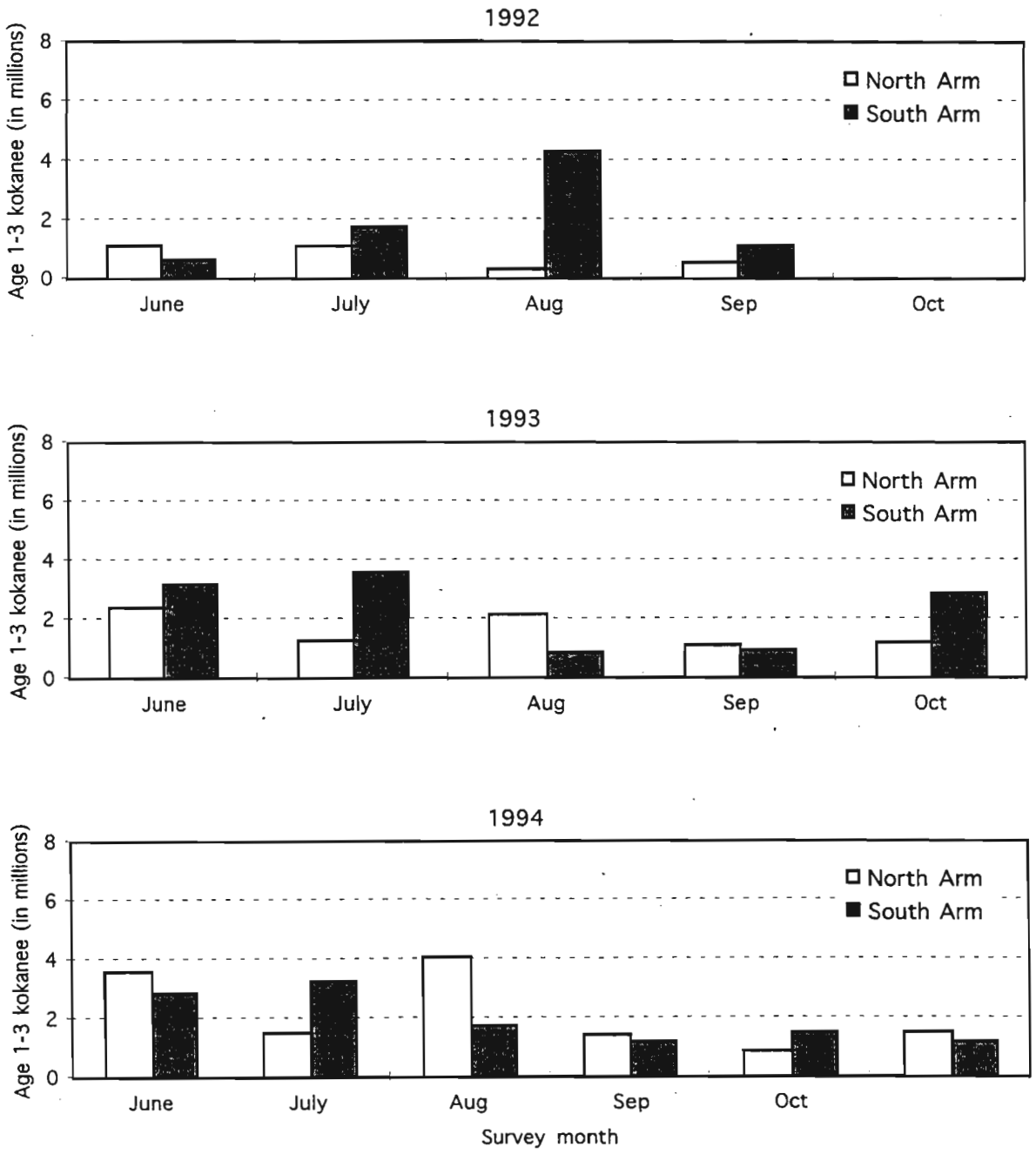


Fig. 60. Kokanee age 1-3+ abundance in North and South arms based on monthly hydroacoustic surveys, 1992-94. Note: there was no survey done in October 1992.

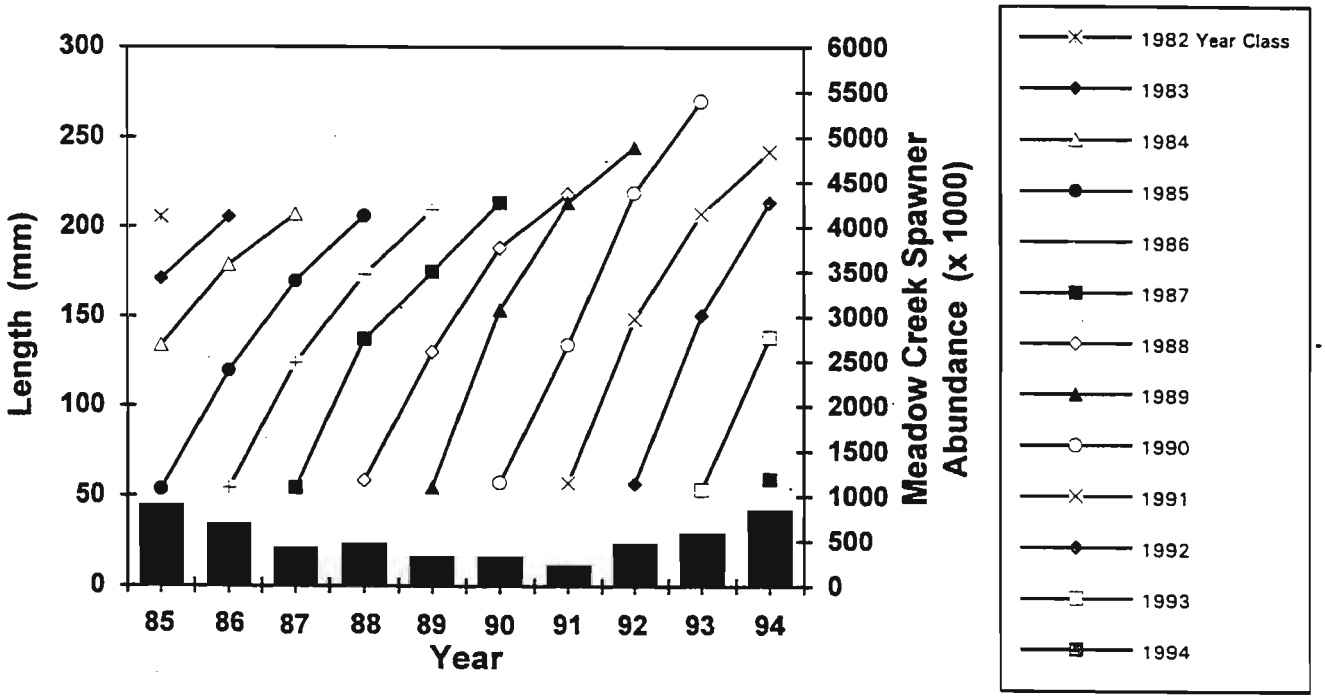


Fig. 61. Kokanee length-at-age observed during major autumn trawls (1985 - 1994) plotted with Meadow Creek spawner abundance.

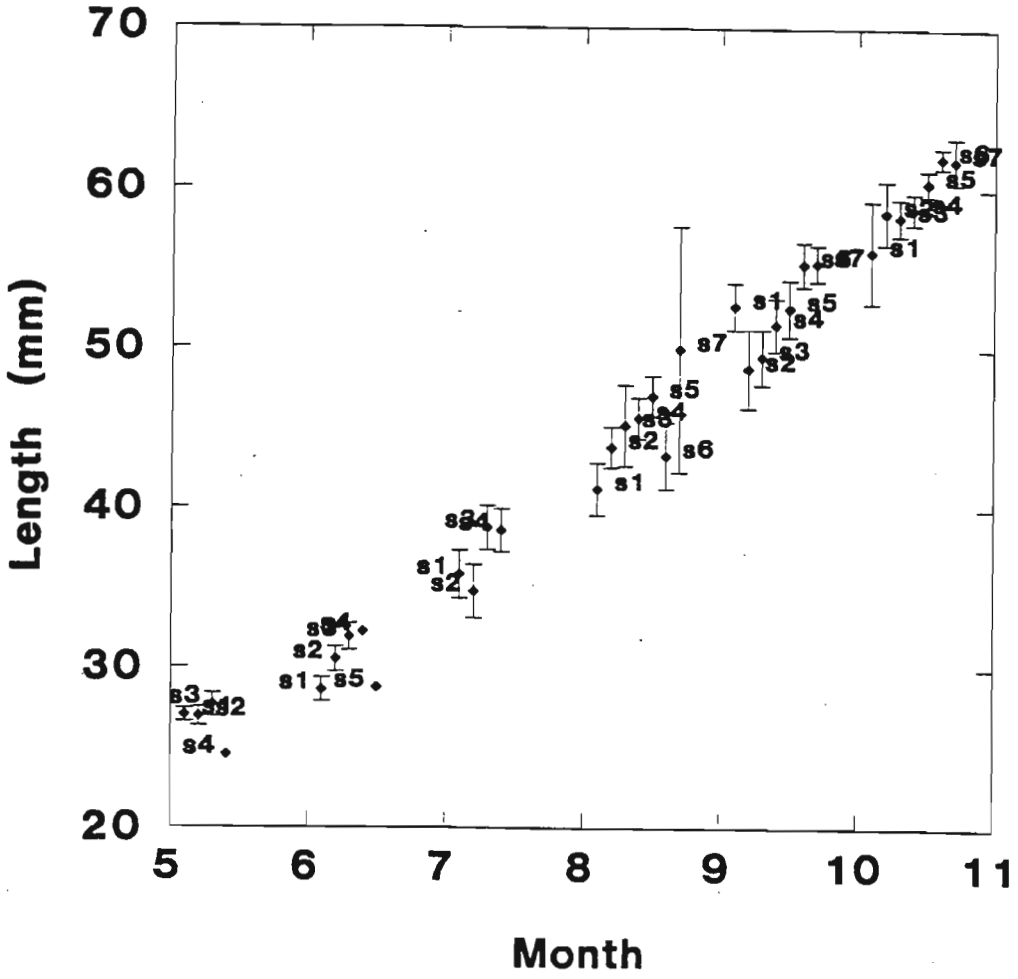


Fig. 62. Length of age 0+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

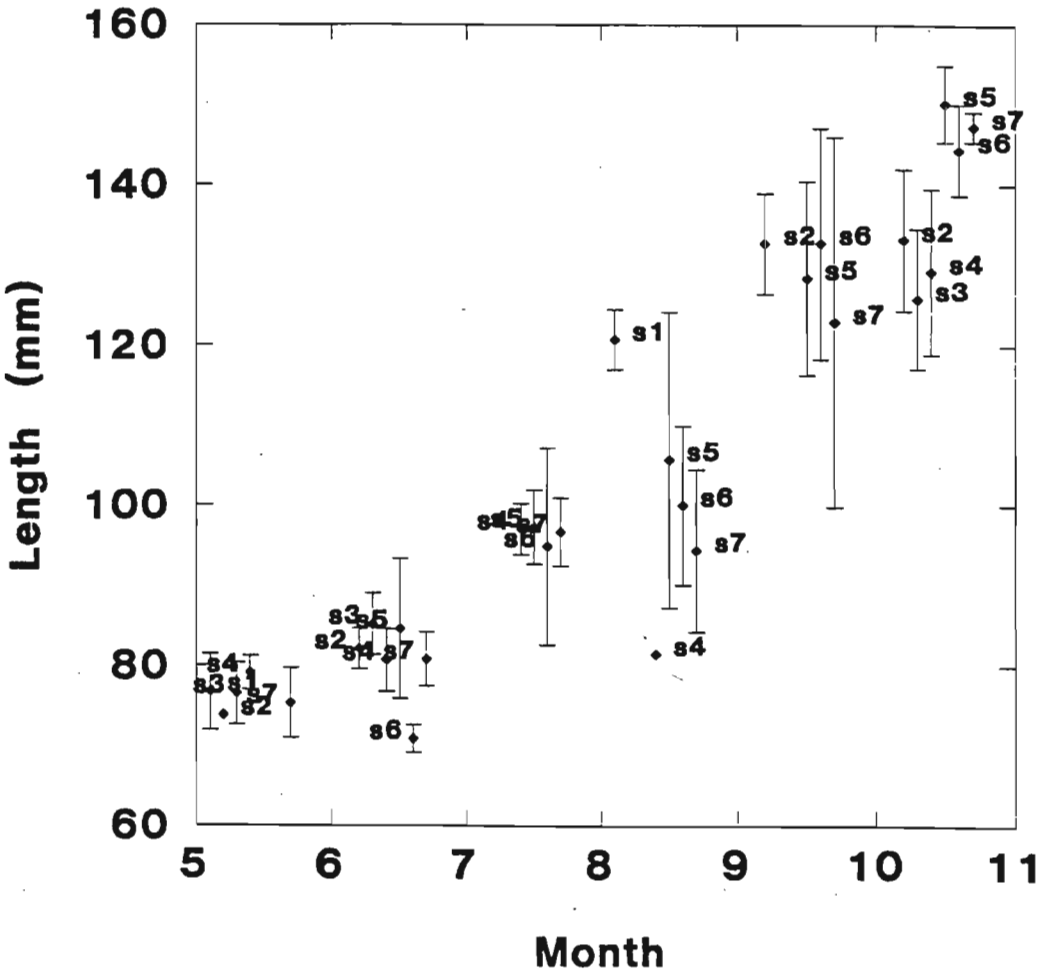


Fig. 63. Length of age 1+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

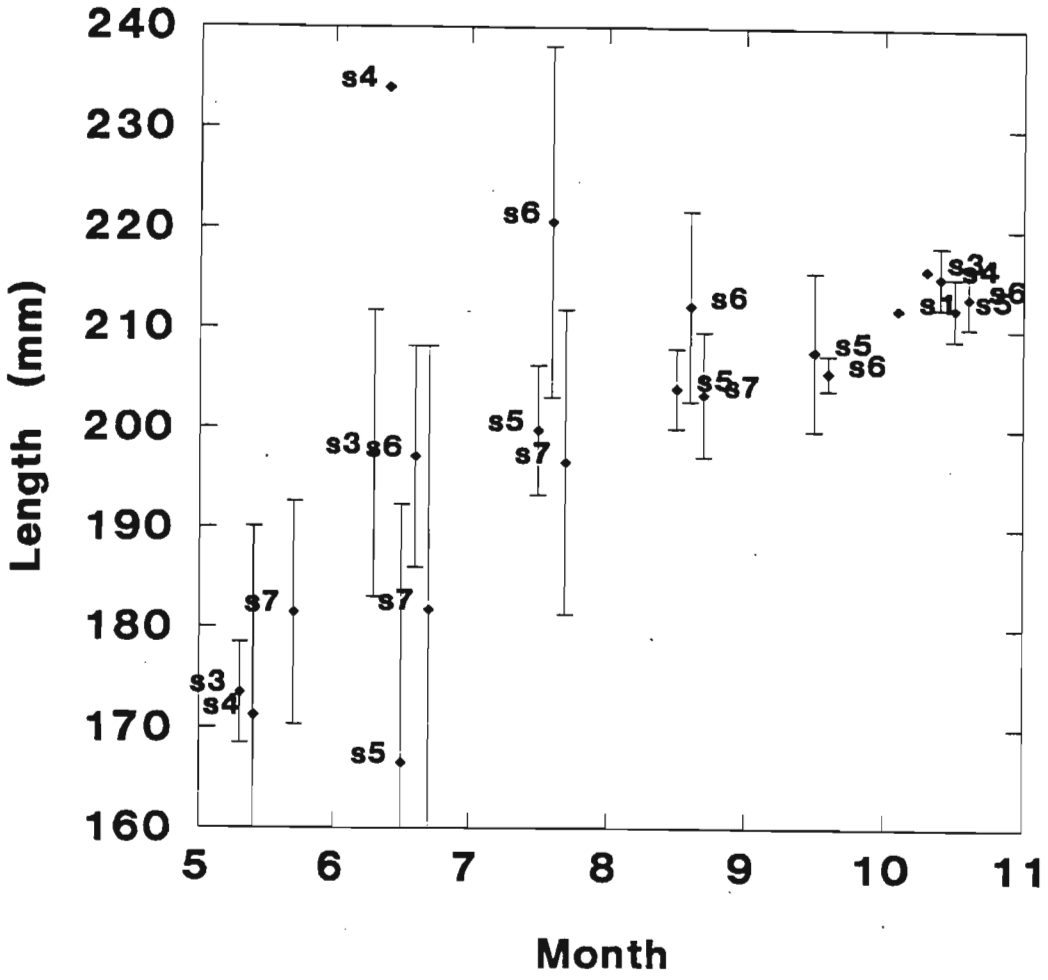


Fig. 64. Length of age 2+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

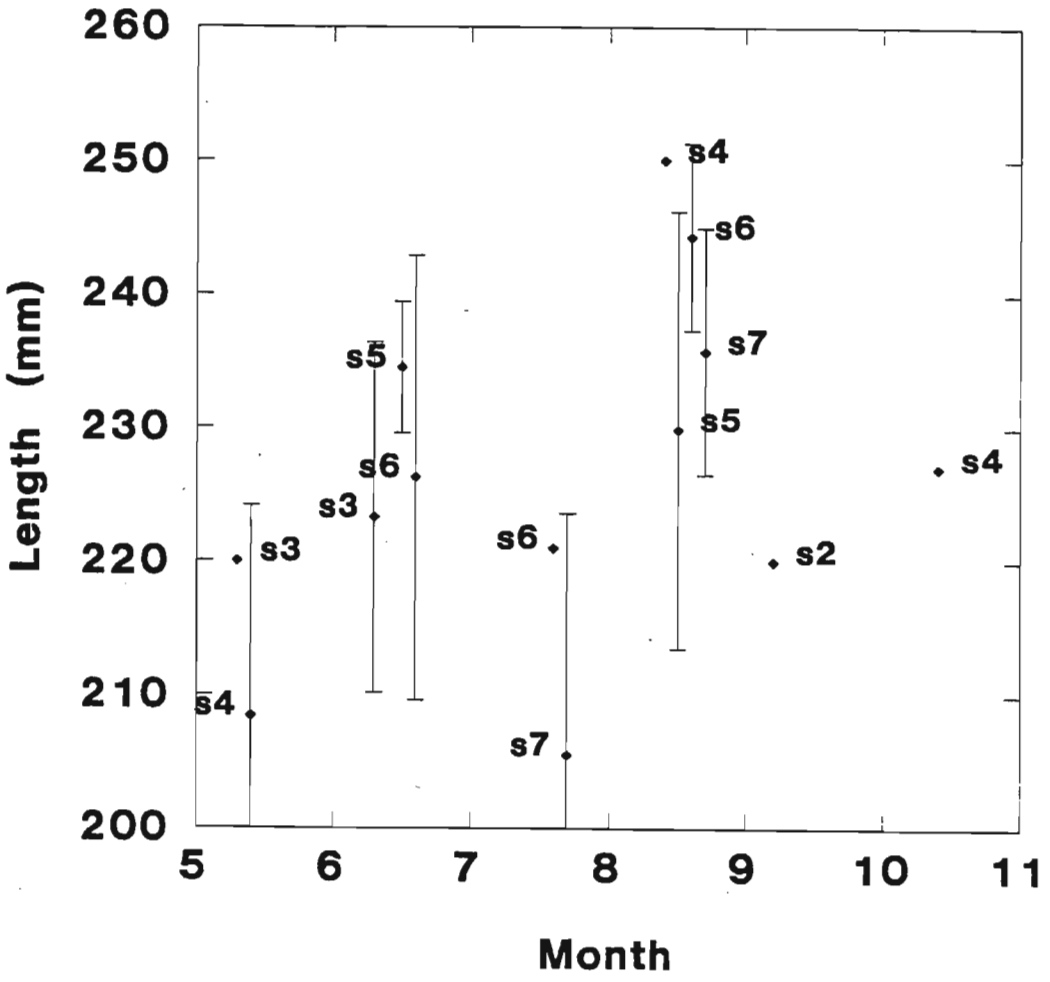


Fig. 65. Length of age 3+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

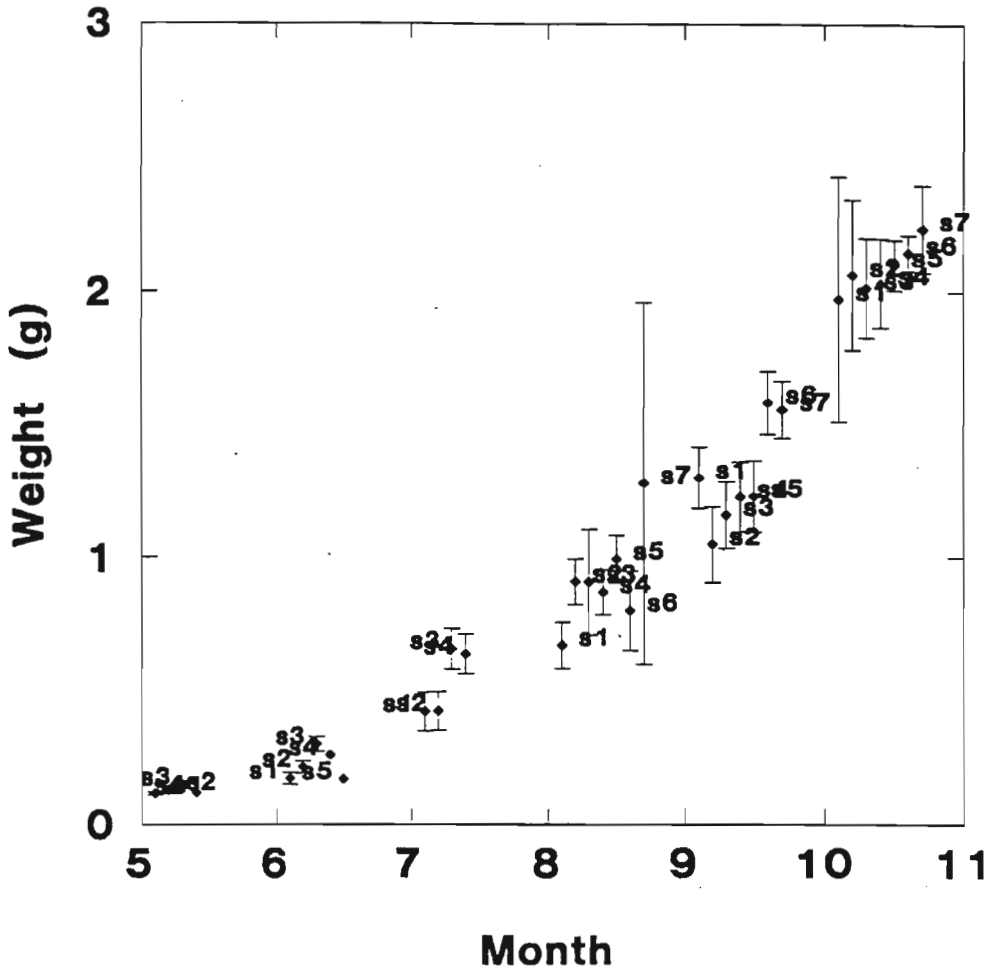


Fig. 66. Weight of age 0+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

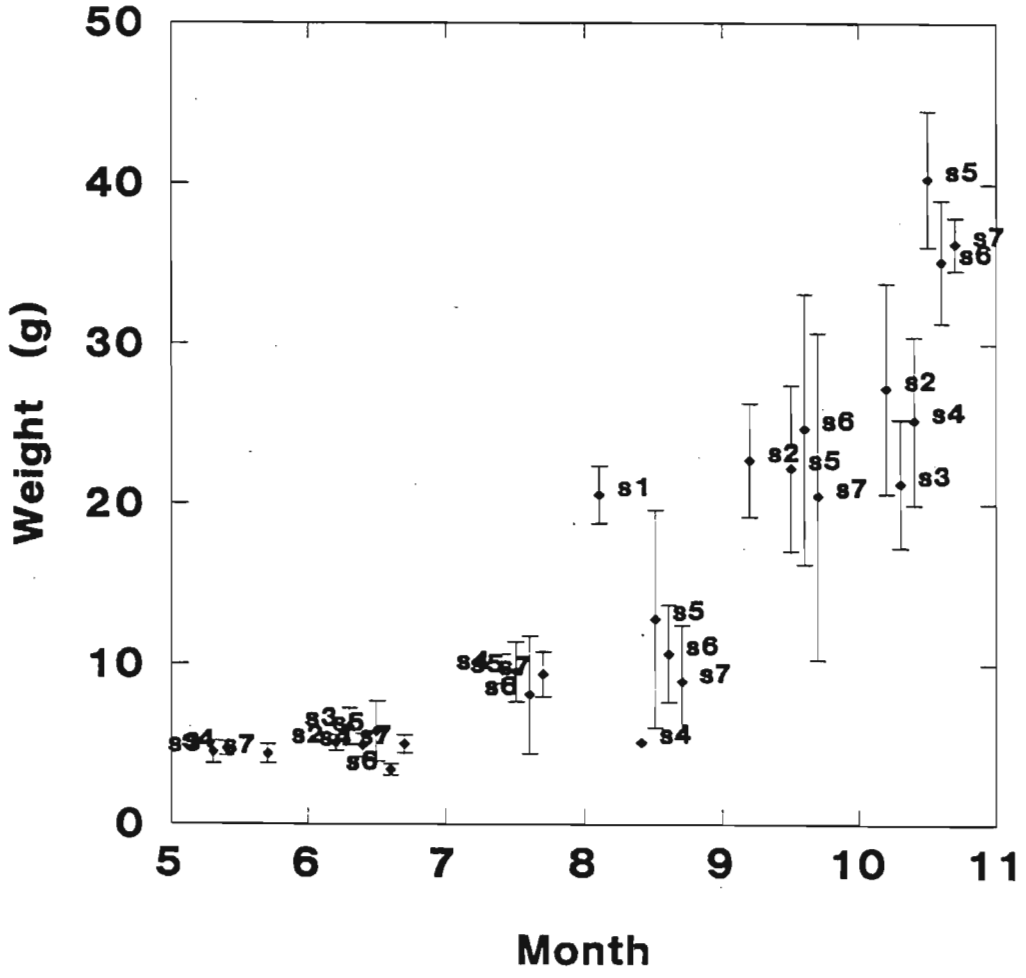


Fig. 67. Weight of age 1+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

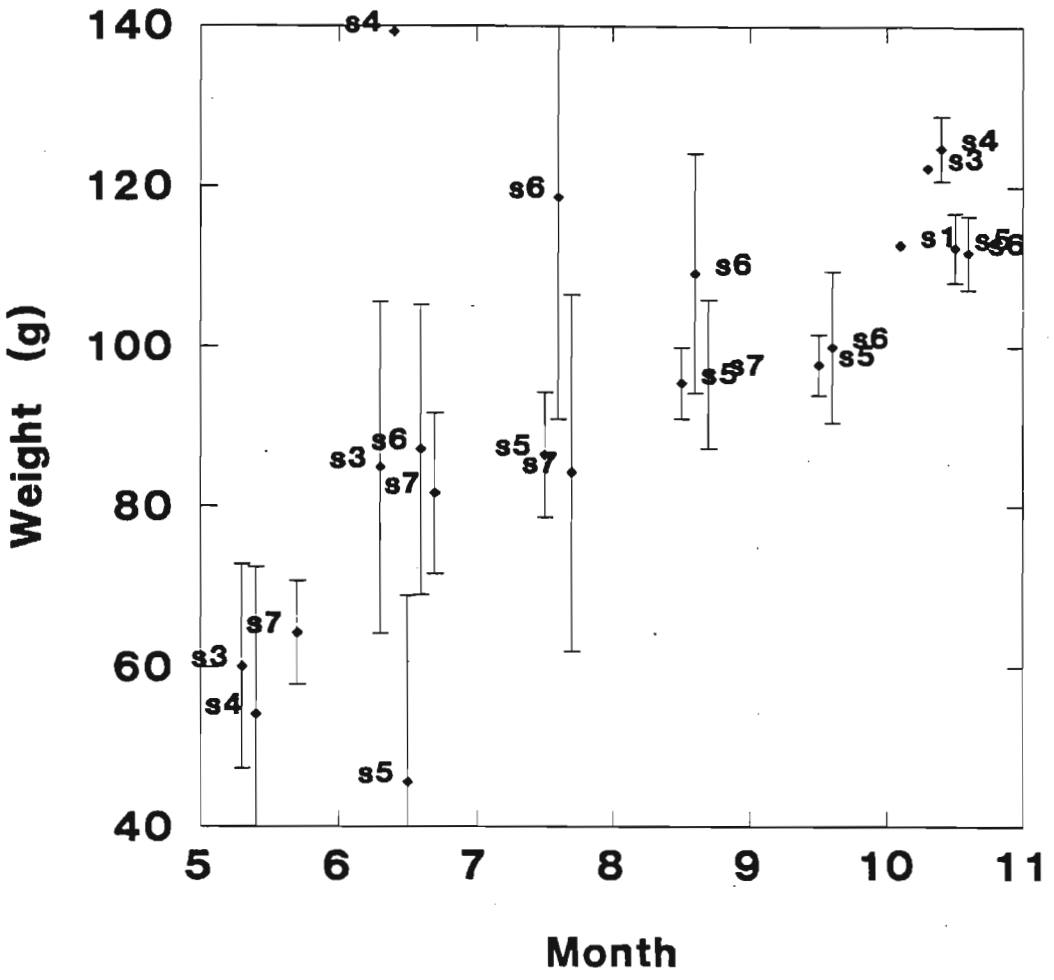


Fig. 68. Weight of age 2+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

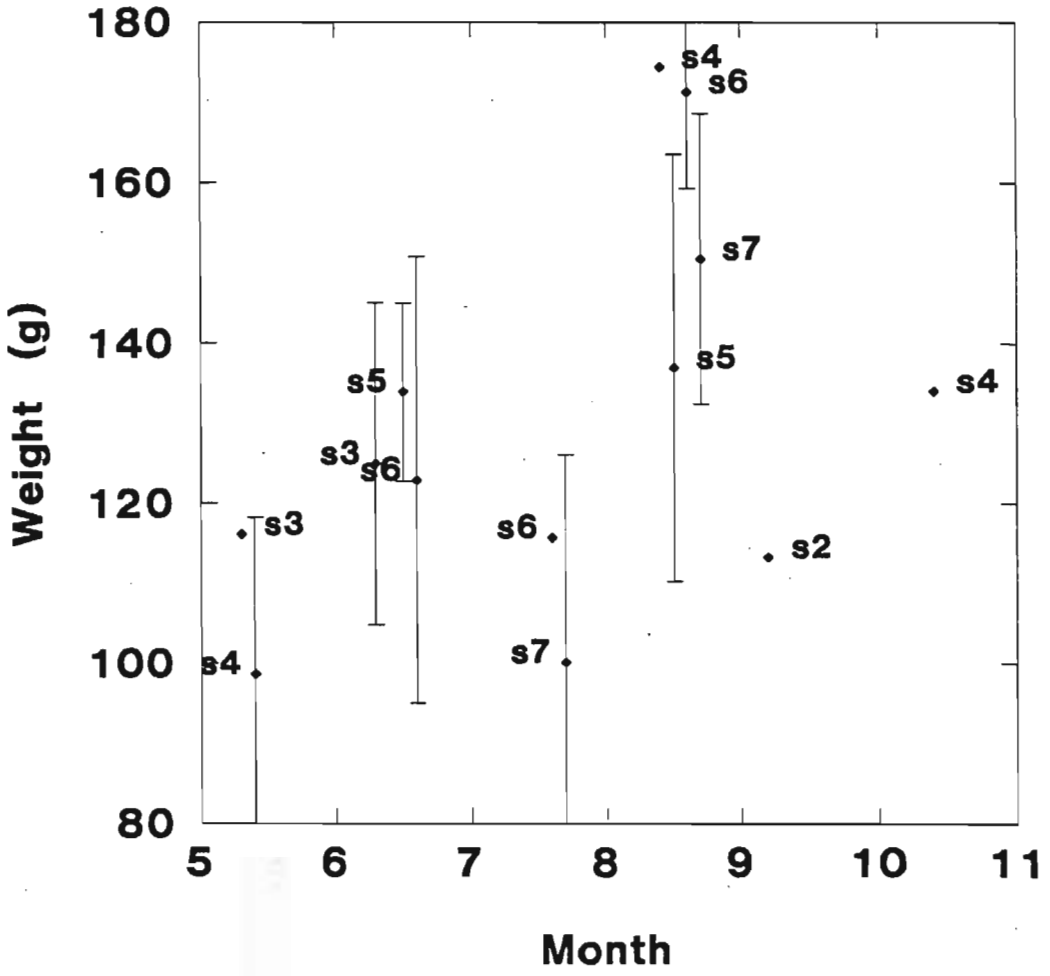


Fig. 69. Weight of age 3+ kokanee in 1994. Error bars are two times the standard error of the mean. Labels s1 to s7 indicate sampling station.

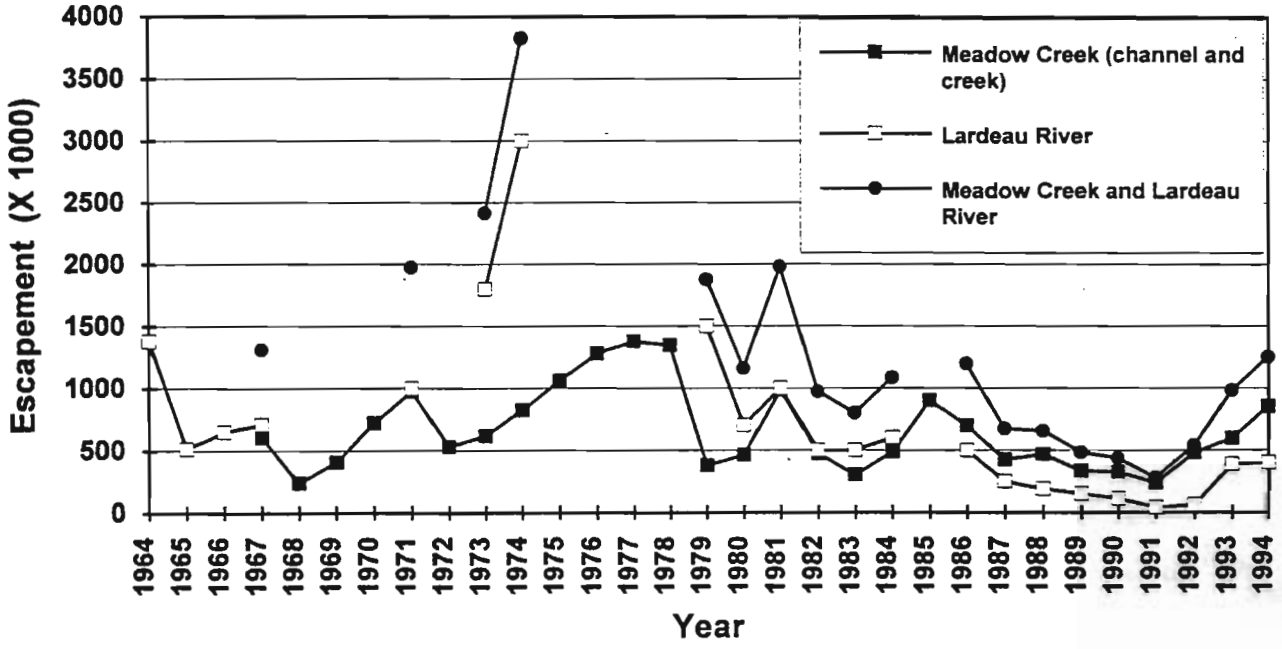


Fig. 70. Kokanee spawner escapement to Meadow Creek and the Lardeau River from 1964 to 1994.

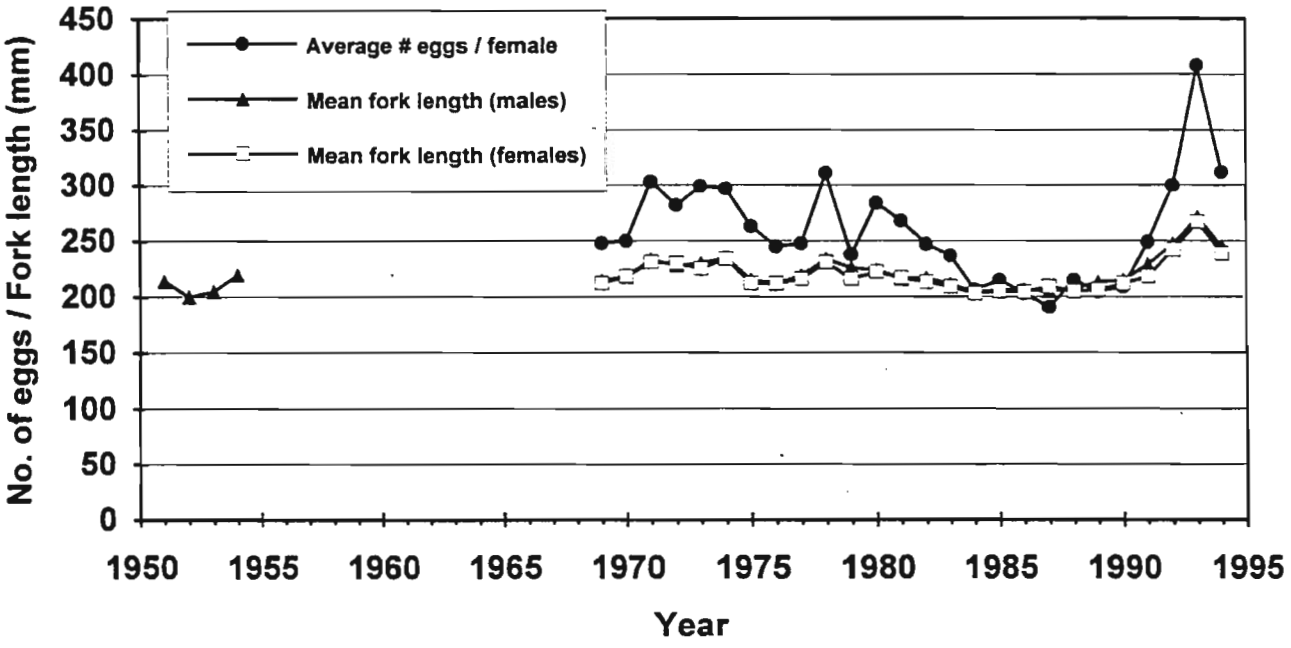


Fig. 71. Average size and fecundity of kokanee spawners at the Meadow Creek channel from 1951 to 1994.

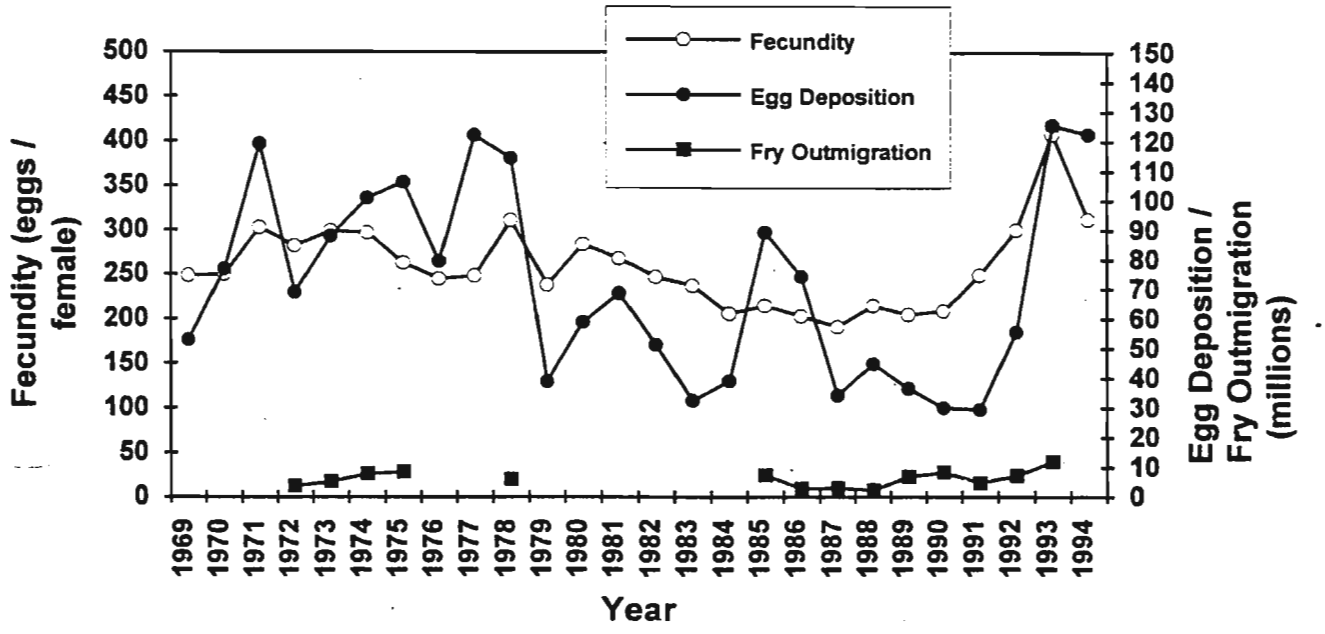


Fig. 72. Meadow Creek kokanee spawner fecundity, egg deposition and fry outmigration, 1969 to 1994.

Appendices

Appendix 1. Fertilizer specifications for 1994 treatment year.

Appendix 2. Fertilizer application schedule for 1994 treatment year.

Appendix 3. Samples for phytoplankton analyses of 1994 from Kootenay Lake

Appendix 4. Mysid sampling dates for 1994 from Kootenay Lake.

Appendix 5. Mysid sampling dates for 1993 from Kootenay Lake.

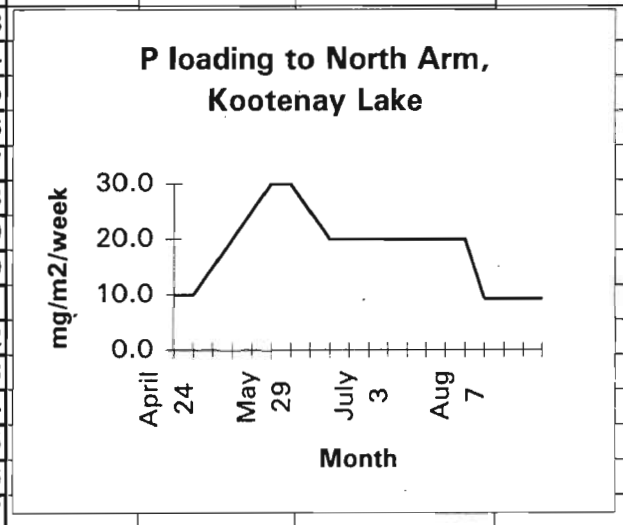
Appendix 6. Stevens, C.L., P.F. Hamblin, G.A. Lawrence and F.M. Boyce. 1995. River-induced transport in Kootenay Lake. Journ Environ. Eng. 121:830-837.

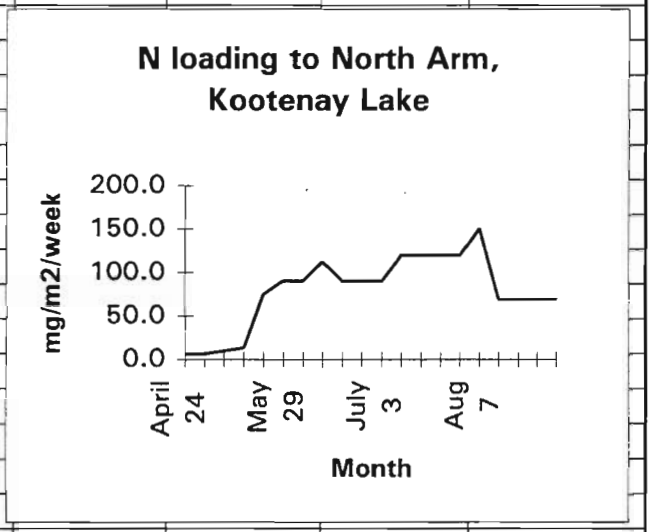
Appendix 1. Fertilizer specifications for 1994 treatment year.

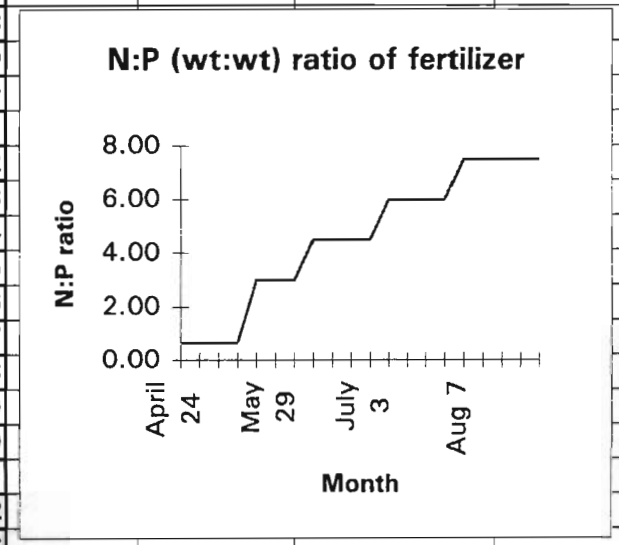
	A	B	C	D	E	F	G	H
1	Timing, fertilizer load and N:P ratios for Kootenay Lake - K. Ashley, February 11/94							
2	Fertilizer: blend of 10-34-0 (ammonium polyphosphate) and 28-0-0 (urea-ammonium nitrate)							
3	Density of 10-34-0 is 1.415 kg/L, and 28-0-0 is 1.28 kg/L @ 15 C							
4	N:P ratios are increased during application period					Year 3 - 1994		
5								
6	Week	Nutrient	N / P Loading	Amount	Amount	Form	N:P ratio	Expected
7	Dates	P or N	mg/m2/wk	N or P kg	Fert (mt)	fertilizer	wt:wt	P (ug/L)
8	April 24	P	10.0	1,300	8.8	10-34-0	0.67	1.2
9		N	6.7	876		10-34-0		
10		N	0.0	0		**28-0-0**		
11	May 1	P	10.0	1,300	8.8	10-34-0	0.67	1.4
12		N	6.7	876		10-34-0		
13		N	0.0	0		**28-0-0**		
14	May 8	P	15.0	1,950	13.1	10-34-0	0.67	1.7
15		N	10.1	1,313		10-34-0		
16		N	0.0	0		**28-0-0**		
17	May 15	P	20.0	2,600	17.5	10-34-0	0.67	2.1
18		N	13.5	1,751		10-34-0		
19		N	0.0	0		**28-0-0**		
20	May 22	P	25.0	3,250	21.9	10-34-0	3.00	2.6
21		N	16.8	2,189		10-34-0		
22		N	58.5	7,601	27.1	**28-0-0**		
23	May 29	P	30.0	3,900	26.3	10-34-0	3.00	3.2
24		N	20.2	2,627		10-34-0		
25		N	70.6	9,174	32.8	**28-0-0**		
26	June 5	P	30.0	3,900	26.3	10-34-0	3.00	3.8
27		N	20.2	2,627		10-34-0		
28		N	70.6	9,174	32.8	**28-0-0**		
29	June 12	P	25.0	3,250	21.9	10-34-0	4.50	4.3
30		N	16.8	2,189		10-34-0		
31		N	96.1	12,488	44.6	**28-0-0**		
32	June 19	P	20.0	2,600	17.5	10-34-0	4.50	4.7
33		N	13.5	1,751		10-34-0		
34		N	76.9	9,991	35.7	**28-0-0**		
35	June 26	P	20.0	2,600	17.5	10-34-0	4.50	5.1
36		N	13.5	1,751		10-34-0		
37		N	76.9	9,991	35.7	**28-0-0**		
38	July 3	P	20.0	2,600	17.5	10-34-0	4.50	5.5
39		N	13.5	1,751		10-34-0		
40		N	76.9	9,991	35.7	**28-0-0**		
41	July 10	P	20.0	2,600	17.5	10-34-0	6.00	5.9
42		N	13.5	1,751		10-34-0		
43		N	106.9	13,901	49.6	**28-0-0**		
44	July 17	P	20.0	2,600	17.5	10-34-0	6.00	6.3
45		N	13.5	1,751		10-34-0		
46		N	106.9	13,901	49.6	**28-0-0**		
47	July 24	P	20.0	2,600	17.5	10-34-0	6.00	6.7
48		N	13.5	1,751		10-34-0		

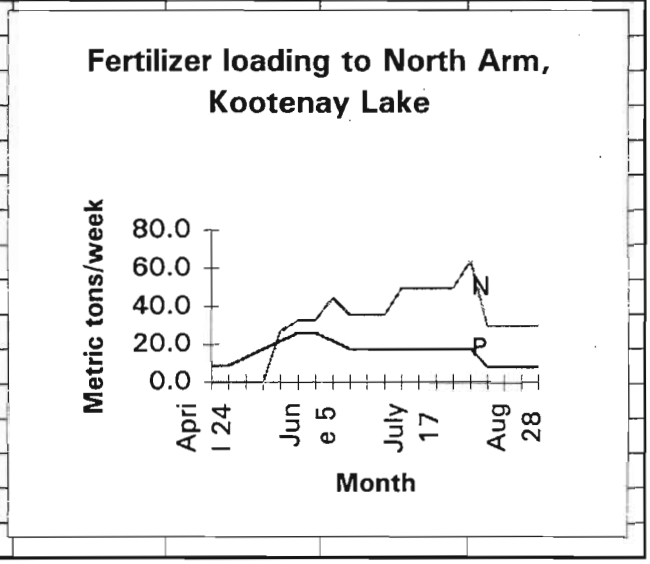
	A	B	C	D	E	F	G	H
49		N	106.9	13,901	49.6	**28-0-0**		
50	July 31	P	20.0	2,600	17.5	10-34-0	6.00	7.1
51		N	13.5	1,751		10-34-0		
52		N	106.9	13,901	49.6	**28-0-0**		
53	Aug 7	P	20.0	2,600	17.5	10-34-0	7.50	7.5
54		N	13.5	1,751		10-34-0		
55		N	137.1	17,822	63.7	**28-0-0**		
56	Aug 14	P	9.3	1,208	8.1	10-34-0	7.50	7.7
57		N	6.3	814		10-34-0		
58		N	63.7	8,277	29.6	**28-0-0**		
59	Aug 21	P	9.3	1,208	8.1	10-34-0	7.50	7.9
60		N	6.3	814		10-34-0		
61		N	63.7	8,277	29.6	**28-0-0**		
62	Aug 28	P	9.3	1,208	8.1	10-34-0	7.50	8.0
63		N	6.3	814		10-34-0		
64		N	63.7	8,277	29.6	**28-0-0**		
65	Sept 4	P	9.3	1,208	8.1	10-34-0	7.50	8.2
66		N	6.3	814		10-34-0		
67		N	63.7	8,277	29.6	**28-0-0**		
68								
69								
70		**Total P**	362.2	47.1	317.1	$95,135		
71		**load**	mg/m2	metric ton	metric ton	Cost of P		
72			in 20 weeks	of P	of 10-34-0	@$300/mt		
73								
74								
75		**Total N**	1603.1	206.7	624.8	$124,960		
76		**load**	mg/m2	metric ton	metric ton	Cost of N		
77			in 20 weeks	of N	of 28-0-0	@$200/mt		
78								
79								
80	Total	weight	941.9		Total cost	$220,095		
81		of N and P	metric tons		of fertilizer			
82		fertilizer						
83								
84			**Phosphorus**			**Nitrogen**		
85		**Load**	**Amount**	**10-34-0**	**Load**	**Amount**	**28-0-0**	**N:P Ratio**
86		**mg/m2**	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**	
87	April 24	10.0	1,300	8.8	6.7	876	0.00	0.67
88	May 1	10.0	1,300	8.8	6.7	876	0.00	0.67
89	May 8	15.0	1,950	13.1	10.1	1,313	0.00	0.67
90	May 15	20.0	2,600	17.5	13.5	1,751	0.00	0.67
91	May 22	25.0	3,250	21.9	75.3	9,790	27.15	3.0
92	May 29	30.0	3,900	26.3	90.8	11,801	32.76	3.0
93	June 5	30.0	3,900	26.3	90.8	11,801	32.76	3.0
94	June 12	25.0	3,250	21.9	112.9	14,677	44.60	4.5
95	June 19	20.0	2,600	17.5	90.3	11,742	35.68	4.5
96	June 26	20.0	2,600	17.5	90.3	11,742	35.68	4.5

	A	B	C	D	E	F	G	H
97	July 3	20.0	2,600	17.5	90.3	11,742	35.68	4.5
98	July 10	20.0	2,600	17.5	120.4	15,652	49.65	6.0
99	July 17	20.0	2,600	17.5	120.4	15,652	49.65	6.0
100	July 24	20.0	2,600	17.5	120.4	15,652	49.65	6.0
101	July 31	20.0	2,600	17.5	120.4	15,652	49.65	6.0
102	Aug 7	20.0	2,600	17.5	150.6	19,573	63.65	7.5
103	Aug 14	9.3	1,208	8.1	69.9	9,091	29.56	7.5
104	Aug 21	9.3	1,208	8.1	69.9	9,091	29.56	7.5
105	Aug 28	9.3	1,208	8.1	69.9	9,091	29.56	7.5
106	Sept 4	9.3	1,208	8.1	69.9	9,091	29.56	7.5
107								
108								
109		362.2	47.1	317.1	1589.7	206.7	624.80	
110		mg/m2	P	10-34-0	mg/m2	N	28-0-0	
111		in 20 week	metric ton	metric ton	in 20 week	metric ton	metric ton	
112								









Appendix 2. Fertilizer application schedule for 1994 treatment year.

Kootenay Lake Fertilization Schedule - April 24 to Sept 4/94. K. Ashley, February 12/94

1994 Schedule - Applications on Sundays (or Saturday)

Week	Date	M. tons 10-34-0	litres 10-34-0	M. Tons 28-0-0	litres 28-0-0	Total litres	Blend (%) N-P2O5-K2O	Total M. Tons	Application rate litres/min
1	24-Apr	8.8	6,219	0.0	0	6,219	10-34-0	8.8	26
2	1-May	8.8	6,219	0.0	0	6,219	10-34-0	8.8	26
3	8-May	13.1	9,258	0.0	0	9,258	10-34-0	13.1	39
4	15-May	17.5	12,367	0.0	0	12,367	10-34-0	17.5	52
5	22-May	21.9	15,477	27.1	21,172	36,649	20.4-14.4-0	49.0	153
6	29-May	26.3	18,587	32.8	25,625	44,212	20.4-14.3-0	59.1	184
7	5-Jun	26.3	18,587	32.8	25,625	44,212	20.4-14.3-0	59.1	184
8	12-Jun	21.9	15,477	44.6	34,844	50,321	22.5-10.5-0	66.5	210
9	19-Jun	17.5	12,367	35.7	27,891	40,258	22.5-10.4-0	53.2	168
10	26-Jun	17.5	12,367	35.7	27,891	40,258	22.5-10.4-0	53.2	168
11	3-Jul	17.5	12,367	35.7	27,891	40,258	22.5-10.4-0	53.2	168
12	10-Jul	17.5	12,367	49.6	38,750	51,117	23.6-8.2-0	67.1	213
13	17-Jul	17.5	12,367	49.6	38,750	51,117	23.6-8.2-0	67.1	213
14	24-Jul	17.5	12,367	49.6	38,750	51,117	23.6-8.2-0	67.1	213

15	31-Jul	17.5	12,367	49.6	38,750	51,117	23.6-8.2-0	67.1	213
16	7-Aug	17.5	12,367	63.7	49,766	62,133	24.4-6.8-0	81.2	259
17	14-Aug	8.1	5,724	29.6	23,125	28,849	24.4-6.7-0	37.7	120
18	21-Aug	8.1	5,724	29.6	23,125	28,849	24.4-6.7-0	37.7	120
19	28-Aug	8.1	5,724	29.6	23,125	28,849	24.4-6.7-0	37.7	120
20	4-Sep	8.1	5,724	29.6	23,125	28,849	24.4-6.7-0	37.7	120
MT of	**10-34-0**	**317.0**	**MT**	**624.9**	**Total**	712,231	**Total MT of**	**941.9**	
			28-0-0		**litres**		**10-34-0 and**		
							28-0-0		
	MT of P	47.1	MT of N	175.0					
			in 28-0-0						
			MT of N	31.7					
			in 34-0-0						
			Total						
			MT of N	206.7					
Litres	**10-34-0**	*******	**Litres**	488203.1					
			28-0-0						
George: The aplication rate is based on 4 hours of travelling time between a point									
2 miles south of Lardeau to a point 2 mile south of Schroder Creek.									
The travel time for the tug and barge are 2 hours each way, for a total of 4 hours, or 240 minutes.									
Note: Density of 10-34-0 is 1.415 kg/L, 28-0-0 is 1.28 kg/L at 15 deg. C									

Appendix 3: Samples for phytoplankton analyses of 1994 from Kootenay Lake

Date of sampling	Station
94/04/19	KLF 1-7
94/05/02	KLF 1-7
94/05/17	KLF 2 & 6
94/05/31	KLF 2 & 6
94/06/07	KLF 1-7
94/06/20	KLF 2 & 6
94/07/13	KLF 1-7
94/07/27	KLF 2 & 6
94/08/07	KLF 1-7
94/08/22	KLF 2 & 6
94/09/05	KLF 2 & 6
94/09/22	KLF 1-7
94/09/30	KLF 2 & 6
94/10/18	KLF 1-7

Appendix 4. Mysid sampling dates for 1994 from Kootenay Lake.

KOOTENAY LAKE MYSIS COUNTS – 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
01/11/94	KLF 1	17:06	E. SHORE	0-20M	1	0
01/11/94	KLF 1	17:23	.5 NM OFF E.S.	0-107M	2	106
01/11/94	KLF 1	17:42	.5NM OF W.S.	0-105M	3	174
01/11/94	KLF 2	18:16	.5 NM OFF E.S.	0-125M	1	104
01/11/94	KLF 2	18:26	.5 NM OFF W.S.	0-122M	2	103
01/11/94	KLF 2		BROKEN			
01/11/94	KLF 3	19:13	.5NM OFF E.S.	0-128M	1	67
01/11/94	KLF 3	19:26	.5 NM OFF W.S.	0-127M	2	83
01/11/94	KLF 3	19:47	W.SHORE	0-22M	3	16
01/13/94	KLF 4	17:10	.5NM OFF E.S.	0-150M	1	141
01/13/94	KLF 4	17:35	.5 NM OFF W.S.	0-147M	2	98
01/13/94	KLF 4	17:43	W.SHORE	0-23M	3	6
01/12/94	KLF 5	19:35	E. SHORE	0-23M	1	21
01/12/94	KLF 5	19:48	.5NM OFF E.S.	0-140M	2	131
01/12/94	KLF 5	20:10	.5NM OFF W.S.	0-144M	3	193
01/12/94	KLF 6	18:30	.5NM OFF W.S.	0-157M	1	89
01/12/94	KLF 6	18:48	.5 NM OFF E.S.	0-152M	2	70
01/12/94	KLF 6	19:09	E. SHORE	0-23M	3	15
01/12/94	KLF 7	17:25	E.SHORE	0-22M	1	7
01/12/94	KLF 7	17:34	.5NM OFF E.S.	0-135M	2	72
01/12/94	KLF 7	17:48	.5NM OFF W.S.	0-137M	3	55
02/15/94	KLF 1	18:10	E. SHORE	0-33M	1	1
02/15/94	KLF 1	18:20	.5NM OFF E.S.	0-101M	2	50
02/15/94	KLF 1	18:36	.5NM OFF W.S.	0-101M	3	32
02/15/94	KLF 2	19:30	.5NM OFF E.S.	0-119M	1	36
02/15/94	KLF 2	19:55	.5NM OFF W.S.	0-119M	2	43
02/15/94	KLF 2	20:15	W. SHORE	0-25M	3	23
02/15/94	KLF 3	20:50	.5 NM OFF E.S.	0-119M	1	80
02/15/94	KLF 3	21:05	.5 NM OFF W.S.	0-118M	2	79
02/15/94	KLF 3	21:27	W. SHORE	0-24M	3	4
02/16/94	KLF 4	18:45	.5NMN OFF E.S.	0-133M	1	133
02/16/94	KLF 4	18:30	.5NM OFF W.S.	0-134M	2	236
02/16/94	KLF 4	18:45	W. SHORE	0-23M	3	29
02/16/94	KLF 5	20:39	E. SHORE	0-29M	1	14
02/16/94	KLF 5	21:00	.5NM OFF E.S.	0-129M	2	82
02/16/94	KLF 5	21:20	.5NM OFF W.S.	0-131M	3	95
02/16/94	KLF 6	19:37	E. SHORE	0-20M	1	3
02/16/94	KLF 6	19:50	.5NM OFF E.S.	0-144M	2	55
02/16/94	KLF 6	20:15	.5NM OFF W.S.	0-146M	3	43
02/16/94	KLF 7	18:05	.5NM OFF W.S	0-121M	1	85
02/16/94	KLF 7	18:19	.5NM OFF E.S.	0-123M	2	70
02/16/94	KLF 7	18:45	E. SHORE	0-21M	3	12

KOOTENAY LAKE MYSIS COUNTS – 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
03/23/94	KLF 1	19:15	E. SHORE	0-60M	1	14
03/23/94	KLF 1	19:25	.5 NM OFF E.S.	0-105M	2	35
03/23/94	KLF 1	19:45	.5 NM OFF W.S.	0-109M	3	43
03/23/94	KLF 2	20:20	W. SHORE	0-22M	1	0
03/23/94	KLF 2	20:40	.5NM OFF W.S.	0-119M	2	62
03/23/94	KLF 2	21:00	.5NM OFF E.S.	0-121M	3	69
03/23/94	KLF 3	21:20	.5NM OFF E.S.	0-126M	1	50
03/23/94	KLF 3	21:40	.5 NM OFF W.S.	0-129M	2	44
03/23/94	KLF 3	21:55	W. SHORE	0-20M	3	1
03/24/94	KLF 4	19:00	.5NM OFF E.S.	0-135M	1	98
03/24/94	KLF 4	19:20	.5NM OFF W.S.	0-132M	2	90
03/24/94	KLF 4	19:40	W. SHORE	0-26M	3	2
03/22/94	KLF 5	21:10	E. SHORE	0-18M	1	2
03/22/94	KLF 5	21:30	.5NM OFF E.S.	0-123M	2	126
03/22/94	KLF 5	21:50	.5NM OFF W.S.	0-126M	3	165
03/22/94	KLF 6	20:05	.5NM OFF W.S.	0-135M	1	40
03/22/94	KLF 6	20:25	.5NM OFF E.S.	0-138M	2	73
03/22/94	KLF 6	20:45	E.SHORE	0-33M	3	4
03/22/94	KLF 7	19:00	.5NM OFF W.S.	0-121M	1	88
03/22/94	KLF 7	19:20	.5NM OFF E.S.	0-120M	2	35
03/22/94	KLF 7	19:40	E. SHORE	0-35M	3	42
04/12/94	KLF 1	20:20	.5NM W.S.	0-100M	1	69
04/12/94	KLF 1	20:35	.5NM E.S.	0-102M	2	77
04/12/94	KLF 1	20:50	E.S.	0-29M	3	16
04/12/94	KLF 2	21:20	W.S.	0-27M	1	6
04/12/94	KLF 2	21:35	.5NM W.S.	0-115M	2	74
04/12/94	KLF 2	21:50	.5NM E.S.	0-116M	3	68
04/12/94	KLF 3	22:15	.5NM E.S.	0-113M	1	27
04/12/94	KLF 3	22:30	.5NM W.S.	0-114M	2	26
04/12/94	KLF 3	22:45	W.S.	0-20M	3	4
04/14/94	KLF 4	20:30	.5NM E.S.	0-133M	1	97
04/14/94	KLF 4	20:45	.5NM W.S.	0-132M	2	103
04/14/94	KLF 4	21:00	W.S.	0-26M	3	5
04/13/94	KLF 5	22:55	E.S.	0-29M	1	14
04/13/94	KLF 5	22:40	.5NM E.S.	0-124M	2	89
04/13/94	KLF 5	22:55	.5NM W.S.	0-125M	3	71
04/13/94	KLF 6	21:25	E.S.	0-27M	1	12
04/13/94	KLF 6	21:40	.5NM E.S.	0-142M	2	91
04/13/94	KLF 6	21:55	.5NM W.S.	0-143M	3	88
04/13/94	KLF 7	20:15	.5NM W.S.	0-119M	1	102
04/13/94	KLF 7	20:30	.5NM E.S.	0-120M	2	70
04/13/94	KLF 7	20:45	E.S.	0-24M	3	8

KOOTENAY LAKE MYSIS COUNTS – 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
05/09/94	KLF 1	22:40	E. SHORE	0-45M	1	127
05/09/94	KLF 1	23:08	.5 NM OFF E.S.	0-103M	2	95
05/09/94	KLF 1	23:33	.5NM OFF W.S.	0-103M	3	70
05/09/94	KLF 2	00:30	.25NM OFF E.S.	0-120M	1	107
05/09/94	KLF 2	00:59	.25NM OFF W.S.	0-108M	2	321
05/09/94	KLF 2	01:13	W.S.	0-34M	3	107
05/10/94	KLF 3	22:45	.5NM E.S.	0-123M	1	88
05/10/94	KLF 3	23:04	.5NM W.S.	0-119M	2	124
05/10/94	KLF 3	23:21	W.S.	0-23M	3	43
05/10/94	KLF 4	00:43	.5NM E.S.	0-135M	1	193
05/10/94	KLF 4	01:10	.5NM W.S.	0-130M	2	89
05/10/94	KLF 4	01:30	W.S.	0-25M	3	2
05/18/94	KLF 5	22:25	E.S.	0-26M	1	96
05/18/94	KLF 5	22:06	.5NM E.S.	0-139M	2	88
05/18/94	KLF 5	21:50	.5NM W.S.	0-138M	3	121
05/11/94	KLF 6	00:10	E.S.	0-32M	1	13
05/11/94	KLF 6	00:30	.5NM E.S.	0-143M	2	197
05/11/94	KLF 6	00:50	.5NM W.S.	0-149M	3	146
05/11/94	KLF 7	22:45	E.S.	0-33M	1	30
05/11/94	KLF 7	21:50	.5NM E.S.	0-114M	2	118
05/11/94	KLF 7	21:25	.5NM W.S.	0-125M	3	133
06/07/94	KLF 1	22:55	E.S.	0-58M	1	106
06/07/94	KLF 1	23:15	.5NM E.S.	0-103M	2	165
06/07/94	KLF 1	23:40	.5NM W.S.	0-105M	3	228
06/08/94	KLF 2	01:00	.5NM E.S.	0-118M	1	166
06/08/94	KLF 2	01:20	.5NM W.S.	0-115M	2	242
06/08/94	KLF 2	01:40	W.S.	0-32M	3	24
06/09/94	KLF 3	22:00	.5NM E.S.	0-125M	1	184
06/09/94	KLF 3	21:45	.5NM W.S.	0-118M	2	172
06/09/94	KLF 3	22:15	W.S.	0-23M	3	44
06/09/94	KLF 4	23:17	.5NM E.S.	0-133M	1	218
06/09/94	KLF 4	23:40	.5NM W.S.	0-131M	2	161
06/09/94	KLF 4	23:50	W.S.	0-20M	3	87
06/10/94	KLF 5	21:50	E.S.	0-40M	1	61
06/10/94	KLF 5	21:40	.5NM E.S.	0-127M	2	82
06/10/94	KLF 5	22:15	.5NM W.S.	0-136M	3	245
06/09/94	KLF 6	00:30	E.S.	0-28M	1	60
06/09/94	KLF 6	00:50	.5NM E.S.	0-133M	2	131
06/09/94	KLF 6	01:10	.5NM W.S.	0-152M	3	335
06/08/94	KLF 7	23:00	E.S.	0-21M	1	128
06/08/94	KLF 7	22:10	.5NM E.S.	0-115M	2	197
06/08/94	KLF 7	21:47	.5NM W.S.	0-125M	3	384

KOOTENAY LAKE MYSIS COUNTS – 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
07/05/94	KLF 1	23:37	E.S.	0-20M	1	103
07/05/94	KLF 1	23:20	.5NM E.S.	0-99M	2	133
07/05/94	KLF 1	22:40	.5NM W.S.	0-99M	3	553
07/06/94	KLF 2	00:41	.5NM E.S.	0-120M	1	67
07/06/94	KLF 2	01:00	.5NM W.S.	0-115M	2	74
07/06/94	KLF 2	01:26	W.S.	0-28M	3	42
07/07/94	KLF 3	22:25	.5NM E.S.	0-123M	1	144
07/07/94	KLF 3	23:00	.5NM W.S.	0-103M	2	69
07/07/94	KLF 3	23:18	W.S.	0-25M	3	26
07/08/94	KLF 4	00:45	.5NM E.S.	0-122M	1	344
07/08/94	KLF 4	01:00	.5NM W.S.	0-119M	2	308
07/08/94	KLF 4	01:12	W.S.	0-16M	3	95
07/08/94	KLF 5	23:18	E.S.	0-20M	1	91
07/08/94	KLF 5	22:55	.5NM E.S.	0-130M	2	332
07/08/94	KLF 5	22:10	.5NM W.S.	0-137M	3	69
07/07/94	KLF 6	00:45	E.S.	0-30M	1	93
07/07/94	KLF 6	01:10	.5NM E.S.	0-132M	2	93
07/07/94	KLF 6	01:30	.5NM W.S.	0-151M	3	131
07/06/94	KLF 7	23:18	E.S.	0-33M	1	39
07/06/94	KLF 7	23:00	.5NM E.S.	0-115M	2	160
07/06/94	KLF 7	22:15	.5NM W.S.	0-125M	3	189
08/03/94	KLF 1	21:30	E.S.	0-30M	1	9
08/03/94	KLF 1	21:50	.5NM E.S.	0-102M	2	130
08/03/94	KLF 1	22:10	.5NM W.S.	0-103M	3	203
08/04/94	KLF 2	21:30	.5 NM E.S.	0-119M	1	923
08/04/94	KLF 2	21:55	.5NM W.S.	0-114M	2	365
08/04/94	KLF 2	22:05	W.S.	0-25M	3	235
08/04/94	KLF 3	23:29	.5NM E.S.	0-122M	1	182
08/04/94	KLF 3	23:50	.5NM W.S.	0-118M	2	198
08/04/94	KLF 3	00:00	W.S.	0-18M	3	3
08/04/94	KLF 4	01:15	.5NM E.S.	0-130M	1	208
08/04/94	KLF 4	01:26	.5NM W.S.	0-131M	2	220
08/04/94	KLF 4	01:41	W.S.	0-24M	3	24
08/06/94	KLF 5	23:41	E.S.	0-26M	1	51
08/06/94	KLF 5	21:30	.5NM E.S.	0-137M	2	137
08/06/94	KLF 5	00:05	.5NM W.S.	0-131M	3	289
08/05/94	KLF 6	23:00	.5NM W.S.	0-148M	1	578
08/05/94	KLF 6	23:18	.5NM W.S.	0-146M	2	541
08/05/94	KLF 6	00:06	E.S.	0-32M	3	120
08/05/94	KLF 7	21:20	.5NM W.S.	0-112M	1	240
08/05/94	KLF 7	21:35	.5NM E.S.	0-109M	2	283
08/05/94	KLF 7	22:20	E.S.	0-25M	3	28

KOOTENAY LAKE MYSIS COUNTS – 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
09/07/94	KLF 1	21:30	E.S.	0-31M	1	12
09/07/94	KLF 1	20:27	.5NM E.S.	0-103M	2	46
09/07/94	KLF 1	20:45	.5NM W.S.	0-103M	3	286
09/07/94	KLF 2	22:30	.5NM E.S.	0-118M	1	263
09/07/94	KLF 2	22:46	.5NM W.S.	0-114M	2	163
09/07/94	KLF 2	21:59	W.S.	0-22M	3	1
09/08/94	KLF 3	20:30	.5NM E.S.	0-123M	1	286
09/08/94	KLF 3	20:42	.5NM W.S.	0-113M	2	120
09/08/94	KLF 3	21:00	W.S.	0-15M	3	0
09/08/94	KLF 4	21:50	.5NM E.S.	0-133M	1	213
09/08/94	KLF 4	22:10	.5NM W.S.	0-132M	2	116
09/08/94	KLF 4	22:27	W.S.	0-22M	3	0
09/09/94	KLF 5	21:18	E.S.	0-20M	1	2
09/09/94	KLF 5	20:33	.5NM E.S.	0-131M	2	255
09/09/94	KLF 5	20:53	.5NM W.S.	0-132M	3	223
09/06/94	KLF 6	22:58	E.S.	0-29M	1	22
09/06/94	KLF 6	23:09	.5NM E.S.	0-132M	2	506
09/06/94	KLF 6	23:28	.5NM W.S.	0-151M	3	177
09/06/94	KLF 7	21:29	E.S.	0-29M	1	30
09/06/94	KLF 7	20:35	.5NM W.S.	0-124M	2	617
09/06/94	KLF 7	20:20	.5NM E.S.	0-114M	3	133
10/01/94	KLF 1	19:27	E.S.	0-30	1	1
10/01/94	KLF 1	19:35	.5NM E.S.	0-102	2	209
10/01/94	KLF 1	19:45	.5NM W.S.	0-102	3	255
10/01/94	KLF 2	20:12	.5NM E.S.	0-118	1	211
10/01/94	KLF 2	20:24	.5NM W.S.	0-118	2	246
10/01/94	KLF 2	20:37	W.S.	0-19	3	1
10/01/94	KLF 3	20:56	.5NM E.S.	0-118	1	216
10/01/94	KLF 3	21:07	.5NM W.S.	0-118	2	260
10/01/94	KLF 3	21:22	W.S.	0-22	3	10
10/01/94	KLF 4	21:41	.5NM E.S.	0-130	1	193
10/01/94	KLF 4	21:53	.5NM W.S.	0-130	2	190
10/01/94	KLF 4	22:08	W.S.	0-21	3	4
10/01/94	KLF 5	23:10	E.S.	0-23	1	11
10/01/94	KLF 5	23:53	.5NM E.S.	0-130	2	257
10/01/94	KLF 5	22:38	.5NM W.S.	0-130	3	152
10/02/94	KLF 6	20:05	E.S.	0-31	1	19
10/02/94	KLF 6	22:25	.5NM E.S.	0-118	2	104
10/02/94	KLF 6	22:35	.5NM W.S.	0-117	3	154
10/02/94	KLF 7	19:25	E.S.	0-22	1	1
10/02/94	KLF 7	19:00	.5NM E.S.	0-112	2	173
10/02/94	KLF 7	18:50	.5NM W.S.	0-110	3	115

KOOTENAY LAKE MYSIS COUNTS -- 1994 SAMPLING SEASON

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER
11/02/94	KLF 1	18:40	E.S.	0-21	1	1
11/02/94	KLF 1	18:30	.5NM E.S.	0-101	2	125
11/02/94	KLF 1	18:10	.5NM W.S.	0-102	3	95
11/05/94	KLF 2	16:55	.5NM E.S.	0-118	1	87
11/05/94	KLF 2	17:12	.5NM W.S.	0-117	2	74
11/05/94	KLF 2	17:20	W.S.	0-32	3	2
11/05/94	KLF 3	17:35	.5NM E.S.	0-114	1	172
11/05/94	KLF 3	17:53	.5NM W.S.	0-114	2	114
11/05/94	KLF 3	17:58	W.S.	0-20	3	12
11/05/94	KLF 4	18:17	.5NM E.S.	0-132	1	257
11/05/94	KLF 4	18:34	.5NM W.S.	0-133	2	201
11/05/94	KLF 4	18:45	W.S.	0-27	3	31
11/05/94	KLF 5	20:50	E.S.	0-29	1	32
11/05/94	KLF 5	20:38	.5NM E.S.	0-125	2	263
11/05/94	KLF 5	20:21	.5NM W.S.	0-126	3	287
11/05/94	KLF 6	20:01	E.S.	0-25	1	23
11/05/94	KLF 6	19:58	.5NM E.S.	0-139	2	107
11/05/94	KLF 6	19:31	.5NM W.S.	0-139	3	126
11/03/94	KLF 7	17:47	E.S.	0-37	1	26
11/03/94	KLF 7	17:30	.5NM E.S.	0-102	2	278
11/03/94	KLF 7	17:15	.5NM W.S.	0-103	3	198
12/20/94	KLF 1	17:25	E.S.	0-25	1	7
12/20/94	KLF 1	17:10	.5NM E.S.	0-99	2	253
12/20/94	KLF 1	16:45	.5NM W.S.	0-95	3	290
12/20/94	KLF 2	18:10	W.S.	0-25	1	1
12/20/94	KLF 2	17:55	.5NM W.S.	0-119	2	212
12/20/94	KLF 2	17:40	.5NM E.S.	0-119	3	178
12/20/94	KLF 3	19:05	.5NM E.S.	0-118	1	64
12/20/94	KLF 3	19:20	.5NM W.S.	0-119	2	36
12/20/94	KLF 3	19:40	W.S.	0-25	3	19
12/19/94	KLF 4	20:33	.5NM E.S.	0-134	1	88
12/19/94	KLF 4	21:00	.5NM W.S.	0-130	2	63
12/19/94	KLF 4	21:20	W.S.	0-25	3	11
12/19/94	KLF 5	19:00	E.S.	0-54	1	45
12/19/94	KLF 5	19:30	.5NM E.S.	0-127	2	266
12/19/94	KLF 5	19:55	.5NM W.S.	0-131	3	212
12/19/94	KLF 6	17:50	E.S.	0-25	1	8
12/19/94	KLF 6	18:05	.5NM E.S.	0-136	2	46
12/19/94	KLF 6	18:28	.5NM W.S.	0-141	3	24
12/19/94	KLF 7	17:50	E.S.	0-25	1	14
12/19/94	KLF 7	16:55	.5NM E.S.	0-111	2	146
12/19/94	KLF 7	16:43	.5NM W.S.	0-113	3	135

Appendix 5. Mysid sampling dates for 1993 from Kootenay Lake.

KOOTENAY LAKE MYSIS COUNTS **1993 SAMPLING SEASON**

DATE	SITE	TIME	LOCATION	DEPTH	SAMPLE NO.	TOTAL NUMBER	
93/02/22	KLF 1	18:13	MID	0-110M	1	76	
93/02/22	KLF 1	18:32	MID	0-120M	2	99	
93/02/22	KLF 1	18:54	OFF E.S.	0-35M	3	13	
93/02/22	KLF 2	19:19	W.S.	0-21M	1	54	
93/02/22	KLF 2	19:30	MID	0-115M	2	110	
93/02/22	KLF 2	19:50	MID	0-134M	3	91	
93/02/22	KLF 3	20:21	W.S.	0-27M	1	21	
93/02/22	KLF 3	20:30	MID	0-120M	2	58	
93/02/22	KLF 3	20:50	MID	0-123M	3	60	
93/02/22	KLF 4	21:16	MID	0-115M	1	81	
93/02/22	KLF 4	21:40	MID	0-121M	2	131	
93/02/22	KLF 4	21:55	W.S.	0-28M	3	29	
93/02/23	KLF 5	19:43	E.S.	0-24M	1	17	
93/02/23	KLF 5	19:56	MID	0-95M	2	124	
93/02/23	KLF 5	20:15	MID	0-99M	3	148	
93/02/23	KLF 6	18:25	MID	0-130M	1	102	
93/02/23	KLF 6	18:45	MID	0-119M	2	82	
93/02/23	KLF 6	19:00	E.S.	0-24M	3	9	
93/05/17	KLF 1	2247	JOHN. LANDING	0-26M	1	14	
93/05/17	KLF 1	2320	JOHNSONS	0-105M	2	89	
93/05/17	KLF 1	2350	JOHN. LANDING	0-106M	3	89	
93/05/18	KLF 2	0100		0-28M	1	52	
93/05/18	KLF 2	0125	.5 OFF W.S.	0-130M	2	64	
93/05/18	KLF 2	0200		0-116M	3	125	
93/05/18	KLF 3	2315	.5 OFF E.S.	0-125M	1	97	
93/05/18	KLF 3	2345	.5 OFF W.S.	0-124M	2	100	
93/05/19	KLF 3	0013	OFF W.S.	0-24M	3	27	
93/05/19	KLF 4	0152	.5 OFF E.S.	0-138M	1	91	
93/05/19	KLF 4	0230	.5 OFF W.S.	0-136M	2	73	
93/05/19	KLF 4	0245	WEST SHORE	0-38M	3	72	
93/05/19-20	KLF 5	0137	OFF EAST SIDE	0-30M	1	303	
93/05/19-20	KLF 5	0216	.75NM OFF E.S.	0-139M	2	209	
93/05/19-20	KLF 5	0245	.75NM OFF W.S.	0-140M	3	212	
93/05/19-20	KLF 6	2308	EAST SHORE	0-43M	1	211	
93/05/19-20	KLF 6	2345	.75NM OFF E.S.	0-148M	2	226	
93/05/19-20	KLF 6	0030	.75NM OFF W.S.	0-157M	3	276	
93/05/20-21	KLF 7	2237	.36 OFF E.S.	0-40M	1	144	
93/05/20-21	KLF 7	2303	.75 OFF E.S.	0-121M	2	349	
93/05/20-21	KLF 7	2329	.75 OFF W.S.	0-126M	3	299	
93/06/19	KLF 1	23:15	OFF E. SIDE	0-26M	1	19	
93/06/19-20	KLF 1	00:04	.5 M OFF E.S.	0-102M	2	176	
93/06/20	KLF 1	00:32	0.5M OFF W.S.	0-103M	3	178	+fish
93/06/20	KLF 2	01:42	.5M OFF E.S.	0-122M	1	191	
93/06/20	KLF 2	02:13	.5 OFF W.S.	0-112M	2	82	
93/05/20	KLF 2	02:32	OFF W.S.	0-35M	3	17	
93/06/20-21	KLF 3	23:09	EAST SHORE	0-36M	1	74	
93/06/20-21	KLF 3	23:43	.5 NM OFF E.S.	0-126M	2	184	
93/06/20-21	KLF 3	00:13	.5 NM OFF W.S.	0-124M	3	182	

93/06/21-22	KLF 4	01:24	OFF E.S.	0-23M	1	88	
93/06/21-22	KLF 4	01:54	.5 NM OFF E.S.	0-137M	2	364	
93/06/21-22	KLF 4	02:22	.5 OFF W.S.	0-132M	3	611	
93/06/22-23	KLF 5	23:27	EAST SHORE	0-40M	1	74	
93/06/22-23	KLF 5	23:55	.5 OFF E.S.	0-135M	2	730	
93/06/22-23	KLF 5	00:17	.5 OFF W.S.	0-135M	3	364	
93/06/18	KLF 7	23:36	WEST SHORE	0-35M	1	270	
93/06/18	KLF 7	00:06	.5 MI OFF W.S.	0-126M	2	248	
93/06/18	KLF 7	00:34	.5 MI OFF E.S.	0-116M	3	580	

93/07/19	KLF 1	22:35	EAST SHORE	0-40M	1	23	
93/07/19	KLF 1	23:05	.5 MI OFF E.S.	0-103M	2	334	+fish
93/07/19	KLF 1	23:33	.5 NM OFF W.S.	0-106M	3	267	+fish
93/07/19-20	KLF 2	00:50	.25 MI OFF E.S.	0-118M	1	158	
93/07/19-20	KLF 2	01:20	.25 OFF W.S.	0-112M	2	91	
93/07/19-20	KLF 2	01:45	OFF W.S.	0-23M	3	40	
93/07/19	KLF 3	00:24	EAST SHORE	0-35M	1*		
93/07/19	KLF 3	00:50	.5 OFF E.S.	0-135M	2*		
93/07	KLF 3	01:10	.5 MI OFF W.S.	0-	2*		
93/07/19	KLF 4	21:56	EAST SHORE	0-24M	1*		
93/07/	KLF 4	22:25	.5 OFF E.S.	0-134M	2*		
93/07/	KLF 4	22:46	.5 MI OFF W.S.	0-130M	3*		
93/07/19-20	KLF 5	00:19	EAST SHORE	0-38M	1*		
93/07/19-20	KLF 5	00:49	.5 NM OFF E.S.	0-136M	2*		
93/07/21-22	KLF 6	00:40	EAST SHORE	0-27M	1	125	
93-07/21-22	KLF 6	01:00	.5 NM OFF E.S.	0-56M	2	325	
93-07/21-22	KLF 6	01:17	.5 NM OFF W.S.	0-56M	3	820	
93/07/21	KLF 7	22:29	EAST SHORE	0-30M	1	26	
93/07/21	KLF 7	22:55	.5 NM OFF E.S.	0-56M	2	206	
93/07/	KLF 7	23:15	.5 NM OFF W.S.	0-56M	3	163	

Note: * label unclear

93/08/17	KLF 1	22:00	EAST SHORE	0-22M	1	2
93/08/17	KLF 1	22:50	.5 OFF W.S.	0-105M	2	218
93/08/17	KLF 1	22:42	.75 OFF E.S.	0-106M	3	233

93/09/15	KLF 1	20:37	.5 NM OFF W.S.	0-109M	1	146
93/09/15	KLF 1	21:14	.5 NM OFF E.S.	0-110M	2	162
93/09/15	KLF 1	21:38	EAST SHORE	0-24M	3	9
93/09/15	KLF 2	22:08	WEST SHORE	0-26M	1	2
93/09/15	KLF 2	22:17	.5 NM OFF W.S.	0-121M	2	126
93/09/15	KLF 2	22:35	.5 NM OFF E.S.	0-123M	3	146
93/09/15	KLF 3	23:11	.5 NM OFF W.S.	0-122M	1	133
93/09/15	KLF 3	23:30	.5 NM OFF E.S.	0-131M	2	192
93/09/15	KLF 3	23:52	EAST SHORE	0-22M	3	27
93/09/16	KLF 4	20:27	WEST SHORE	0-30M	1	10
93/09/16	KLF 4	20:38	.5 NM OFF W.S.	0-138M	2	254
93/09/16	KLF 4	20:55	.5 NM OFF E.S.	0-140M	3	396
93/09/16	KLF 5	21:46	.5 NM OFF W.S.	0-143M	1	704
93/09/16	KLF 5	22:09	.5 NM E.S.	0-138M	2	588
93/09/16	KLF 5	22:33	EAST SHORE	0-24M	3	60
93/09/17	KLF 6	21:51	.5 NM OFF W.S.	0-159M	1	288
93/09/17	KLF 6	22:16	.5 NM OFF E.S.	0-136M	2	350

93/09/17	KLF 6	22:37	EAST SHORE	0-24M	3	108	
93/09/17	KLF 7	20:38	.5 NM OFF W.S.	0-128M	1	347	
93/09/17	KLF 7	20:59	.5 NM OFF E.S.	0-118M	2	234	
93/09/17	KLF 7	21:16	EAST SHORE	0-21M	3	391	
93/10/12	KLF 1	20:36	EAST SHORE	0-33M	1	8	
93/10/12	KLF 1	21:06	.5 NM OFF E.S.	0-102M	2	95	
93/10/12	KLF 1	21:29	.5 NM OFF W.S.	0-103M	3	154	
93/10/12	KLF 2	22:26	.25 NM OFF E.S.	0-120M	1	184	rotten
93/10/12	KLF 2	23:00	.25 NM OFF W.S.	0-108M	2	99	
93/10/12	KLF 2	23:06	WEST SHORE	0-26M	3	20	rotten
93/10/14	KLF 3	19:30	EAST SHORE	0-27M	1	10	
93/10/14	KLF 3	19:58	.5 NM OFF E.S.	0-123M	2	171	
93/10/14	KLF 3	20:18	.5 NM OFF W.S.	0-118M	3	206	
93/10/14	KLF 3	20:30	.5 NM OFF W.S.	0-60M	EXTRA	108	
93/10/14	KLF 3		.5 NM OFF W.S.	0-30M	EXTRA	49	
93/10/14	KLF 4	22:01	.5NM OFF E.S.	0-134M	1	238	
93/10/14	KLF 4	22:30	.5 NM OFF W.S.	0-132M	2	97	+1 v. rott.
93/10/13	KLF 5	22:15	EAST SHORE	0-27M	1	14	
93/10/13	KLF 5	22:45	.5 NM OFF E.S.	0-128M	2	310	
93/10/13	KLF 5	23:11	.5 NM OFF W.S.	0-129M	3	401	
93/10/13	KLF 6	19:49	EAST SHORE	0-25M	1	6	
93/10/13	KLF 6	20:23	.5 NM OFF E.S.	0-139M	2	348	
93/10/13	KLF 6	20:57	.5 NM OFF W.S.	0-150M	3	170	
93/10/11	KLF 7	20:57	OFF E.S.	0-35M	1	38	
93/10/11	KLF 7	21:32	.5 NM OFF E.S.	0-120M	2	273	rotten
93/10/11	KLF 7	22:00	.5 OFF W.S.	0-125M	3	219	rotten
93/12/13	KLF 1	17:10	E. SHORE	0-21M	1	0	
93/12/13	KLF 1	17:30	.5NM OFF E.S.	1-112M	2	98	
93/12/13	KLF 1	17:40	.5 NM OFF W.S.	0-113M	3	53	
93/12/13	KLF 2	18:16	W. SHORE	0-20M	1	5	
93/12/13	KLF 2	18:40	.25NM OFF W.S.	0-124M	2	191	
93/12/13	KLF 2	18:56	.25 NM OFF E.S.	0-124M	3	271	
93/12/13	KLF 3	19:43	.5 NM OFF E.S.	0-130M	1	185	
93/12/13	KLF 3	20:05	.5 NM OFF W.S.	0-124M	2	118	
93/12/13	KLF 3	20:10	W. SHORE	0-25M	3	23	
93/12/15	KLF 4	17:15	W. SHORE	0-27M	1	11	
93/12/15	KLF 4	17:40	.5 NM OFF W.S.	0-147M	2	198	
93/12/15	KLF 4	17:59	.5 NM OFF E.S.	0-144M	3	204	
93/12/14	KLF 5	19:16	E. SHORE	0-20M	1	20	
93/12/14	KLF 5	19:26	.5 NM OFF E. S.	0-143M	2	145	
93/12/14	KLF 5	19:55	.5 NM OFF W.S.	0-141M	3	94	
93/12/14	KLF 6	18:21	E. SHORE	0-32M	1	30	
93/12/14	KLF 6	18:40	.5 NM OFF E.S.	0-155M	2	105	
93/12/14	KLF 6	19:04	.5 NM OFF W.S.	0-156M	3	104	
93/12/14	KLF 7	17:04	E. SHORE	0-21M	1	7	
93/12/14	KLF 7	17:17	.5 NM OFF E.S.	0-129M	2	124	
93/12/14	KLF 7	17:45	.5 NM OFF W.S.	0-127M	3	142	

Appendix 6. Stevens, C.L., P.F. Hamblin, G.A. Lawrence and F.M. Boyce. 1995. River-induced transport in Kootenay Lake. Journ. Environ. Eng. 121:830-837.

River-Induced Transport in Kootenay Lake

By Craig L. Stevens,[1] Paul F. Hamblin,[2] Gregory A. Lawrence,[3] Member, ASCE, and Farrell M. Boyce[4]

Abstract: A series of dye-tracer experiments was performed in and around a river plume in Kootenay Lake, British Columbia. River and stream inflows are often considered to be a method of nutrient or waste introduction and dispersal; in this paper we show that they can be unpredictable and highly variable in their behavior over short time scales. Consequently, diffusivities observed over small length scales and short time scales are likely to differ greatly from those that might be attributed to average flow conditions in the absence of detailed observations. The observed presence of velocity shears associated with wind stress, river inflow, and basin geometry suggests that the phenomenon of shear dispersion augments the stirring action of local turbulence. The densimetric Froude number indicates that the river behaves as a mixing layer and values of the apparent horizontal diffusion coefficient in and near the river plume are of the order of 2–5 m^2s^{-1} and the dispersion in the direction of the river inflow is separated from the transverse turbulent diffusion.

INTRODUCTION

Kootenay Lake is the largest natural lake in British Columbia [Fig. 1(a)]. Its resident populations of Kokanee salmon (*Onchorynchus nerka*) and Gerrard rainbow trout (*Oncho-rynchus mykiss*) have provided a valuable fishery since aboriginal times. Numbers and condition of spawning Kokanee salmon have declined alarmingly from 1974 to 1991, raising fears that the fishery for both the Kokanees and the Gerrard rainbows (which feed on immature Kokanee) could be wiped out. Biological modeling (Walters et al. 1991) suggests that increasing the primary productivity of the lake through artificial fertilization may help reverse the decline, although it should be pointed out that the decline can be attributed to other factors as well (Daley et al. 1981). Artificial fertilization of lakes has been proposed as a solution to a range of limnological problems. Thus, in the spring of 1992, the British Columbia Ministry of the Environment began a fertilization program in Kootenay Lake (Ashley and Thompson 1993). The sensitivity of the natural environment, the substantial cost of introducing the nutrients (liquid ammonium polyphosphate and liquid urea–ammonium nitrate), and the possibility that nutrients might not be effectively delivered to where they are needed calls for an examination of the physical transport mechanisms active in the surface waters of Kootenay Lake, particularly at the northern end of the lake where the nutrients are injected. Thus, physical field experiments were carried out in late spring of 1992 in conjunction with a biological sampling program; both were to provide data for further whole-lake biological modeling (Walters et al. 1991). Much of the available field data of similar nature to that described here were collected from more energetic coastal or Great Lakes regions.

The objective of this paper is to illustrate the variability of riverine inflows into long lakes in steep valley regions with a field experiment, then estimate probable rates of dispersion based on the available environmental parameters.

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TRANSPORT OF INJECTED TRACER BY WATER MOVEMENTS

The behavior of a river entering a lake and its subsequent development under similar circumstances has been modeled in detail by Hamblin and Carmack (1978, 1980). However, these authors considered only the steady-state behavior, which effectively represents a seasonally averaged description of the riverine distribution. These models may be a reasonable description of the average distribution of conservative tracers but they are ill-suited to situations where the time scales of both biological uptake and flow variability range from a few minutes to a few hours (Lean et al. 1987).

The concentration of dissolved nutrients at a fixed point in the lake changes with time as waters of differing nutrient concentrations move past the point and as nutrient concentrations are changed by the biological and chemical processes of uptake and/or regeneration (Boyce 1974). The usual mathematical form of the above statement, the equation of conservation of species, is a differential equation that balances advection, sources, sinks, and diffusion so that

$$\frac{\partial C}{\partial t} = S - (\mathbf{U}\cdot\nabla)C + \nabla(\boldsymbol{\kappa}\nabla C) \qquad (1)$$

where $\mathbf{U}$ = the fluid velocity vector; $\boldsymbol{\kappa}$ = the apparent diffusivity of a tracer of concentration C in different directions, i.e., $\boldsymbol{\kappa} = (\kappa_x, \kappa_y, \kappa_z)$; $\partial/\partial t$ = the partial derivative with respect to time; S = a source or loss term; and ∇ = the gradient operator. Here we label the apparent diffusivity in the principal (i.e., longitudinal) flow direction as κ_x, that in the normal (i.e., transverse) direction as κ_y and κ_z is the vertical component.

The left-hand side of (1), $\partial C/\partial t$, is the time rate of change of nutrient (or tracer) concentration observed at the control point. Of the three terms on the right-hand side, the first represents the local rate of regeneration or removal. For the purposes of this paper, sources include the fertilizer or dye injection, and losses include decay due to the action of ultraviolet radiation for Rhodamine WT, and uptake by the local biomass for the fertilizer. With respect to conservation of species within the photic zone, adsorption to settling particles acts as a loss for both fertilizer and Rhodamine. Our paper is not directly concerned with this source/sink term, but we cannot interpret the meaning of local changes in nutrient or tracer concentrations without knowledge of it. The second term on the right-hand side of (1) describes advected changes in species concentration. The third term in (1) expresses the global effect of turbulence as a diffusion process where the flux of nutrient mass is proportional to the large-scale average concentration gradient.

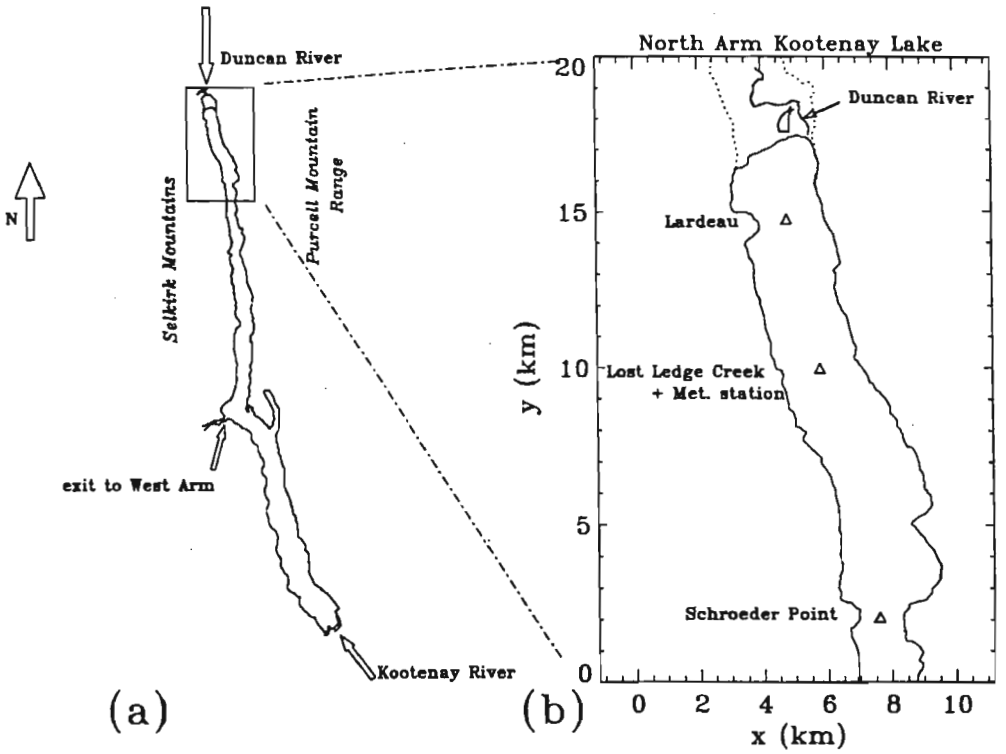

FIG. 1. Shoreline Data for: (a) Entire Main Lake; (b) Study Site at Northern End of North Arm (Triangles Indicate Positions of Main Thermograph Arrays, and Meteorological Data Was Recorded at Array Location Adjacent to Lost Ledge Creek)

Our experiments are largely concerned with linking observations to the second and third terms. The coefficient κ in front of the gradient term ∇C has the dimensions of diffusivity; consequently, it is called the eddy diffusivity. A virtue of this formulation is that its mathematical expression is identical to that of the flux of heat in a material of spatially varying thermal conductivity, a widely explored problem of mathematical physics with results that are directly transferable. Often κ is assumed spatially invariant. However, as the magnitude of the eddy diffusivity is a function of the flow and not the fluid, this assumption is not made immediately here. The flow behavior in the 20-m-deep surface layer of a 100-km-long lake is not the same everywhere (Hamblin et al. 1994). An additional complicating feature is that of shear dispersion whereby the interaction of velocity shear and background turbulence leads to enhanced transport rates. Shear dispersion is ably described by Csanady (1973) and Fischer et al. (1979). Briefly, elements of an identifiable cloud of diffusing substance are drawn apart by velocity differences, due perhaps to the wind-driven surface layer or a river inflow, across the diffusing patch or cloud. In our case we will consider vertical variations of horizontal velocity as the dominant component of velocity shear in the context of observations described here. This stretching enhances the ∇C term in (1). Fischer et al. (1979) show how a known velocity profile can be used to generate a new coefficient that encompasses the effect of the shear and of the turbulent diffusion. Generally this coefficient is called the coefficient of shear dispersion. As the observations described here involve a complex and time varying velocity field the term "apparent diffusivity" is appropriate.

The interaction of turbulence, stratification and velocity shear mean that it is almost impossible to prescribe a universal relationship for the apparent diffusivity κ in (1). In addition, larger definable clouds of species encounter a greater range of velocity variations and thus grow at a greater rate. Csanady (1973) summarizes a quasi-empirical method developed by Okubo (1971) whereby the apparent horizontal diffusivity is related to the size of some definable cloud of fluid (in their case, Rhodamine B) so that a radially symmetric diffusion coefficient is described by

$$\kappa_r = \alpha l^{\beta} \tag{2}$$

where α and β = empirically determined; and l = the characteristic scale of the cloud. For three-dimensional isotropic turbulence $\beta = 4/3$, however, the directionality and shear generated by the riverine flow mean that the expansion of the dye patch is uneven. Okubo (1971) emphasized caveats in applying this result, especially near boundaries and inflows as well as small scales. Nevertheless, Lawrence et al. (1995) show that it does appear to remain valid under some of these conditions even in very small lakes and observe general values for the coefficients to be (l is in meters) $\alpha \approx 3.2 \times 10^{-4}$ and $\beta = 1.1$. The α constant is dimensional and has units of $m^{(2-\beta)}s^{-1}$. Here κ_r is used to describe diffusion levels in the open lake and may be considered to be an average value for κ against which observations in the river plume may be compared.

Molecular rates of diffusion for the tracer are a lower bound for κ. An upper value for κ might be taken from the engineering literature for apparent diffusion in a bounded turbulent flow with vertical shear (Fischer et al. 1979). However, as stratification provides some resistance to transport in the vertical direction, the appropriate values here lie somewhere in between. The first step in improving on the quasi-empirical model is to explicitly include the effects of shear dispersion. Observations allow identification of the important terms and parametrization in (1), an essential step toward modeling the flow in an efficient and accurate manner.

EXPERIMENTS: LOCATION AND METHODS

Location

Kootenay Lake is a long (110 km), narrow (average width, 3 km), deep (100 m), steep-sided fjordlike lake. It forms part of the Columbia River system, and its major inflows and

outflow are regulated by hydroelectric dams. The study examined only the northernmost region of the lake from Schroeder Point [Fig. 1(b)]. The seasonal circulation pattern identified by Carmack et al. (1986) describes the lake structure as a deep, stagnant, hypolimnion topped by an active surface layer that forms after the winter overturn and increases to between 40 and 60 m thick by the end of summer. The Kootenay and Duncan rivers, in the south and north respectively, generate the bulk of the inflow to the lake. Water leaves the main lake via the shallow and narrow connection to the West Arm and from there, via the Kootenay River, to the Columbia River. The two major inflows and the outflow are dammed. The Duncan River inflow is modeled by Carmack et al. (1986) as entering the lake at the surface early in spring and the flowing out along the base of the thermocline later in the summer.

The Duncan River delta that forms the northern boundary of the lake is a complex and changing pattern of streams. Fig. 2 shows sections from a SPOT satellite scene illustrating the convoluted flow paths taken by the Duncan River before entering the lake. The main river path in the delta is clearly visible, initially coming down the central axis of the lake, then sharply moving to the east, and finally entering the lake more or less running directly south. The dynamics of the river change dramatically due to upstream flow regulation over time scales as short as a week.

The ongoing British Columbia Ministry of the Environment's fertilization program injects nutrients into the water column from a barge traveling down the center of the lake between Lardeau and Schroeder Point [Fig. 1(b)]. In addition, the agency considered the feasibility of using the Duncan River as an injection vehicle. Thus we selected experiment sites at Lardeau, in the river plume near the village of Argenta, and at various sites south of Lardeau, away from direct influence of the river. The fertilizer injection lasts from April through to early September.

Moored, Self-Recording Instruments

Vertical arrays of self-recording thermistors (Brancker, 2.5-min response time) were installed midlake at Lardeau, Lost Ledge Creek, Schroeder Point, and further south at the entrance to the West Arm. The arrays were sampled at 1-min intervals and yielded a set of time series approximating the vertical temperature profile at each station throughout the experimental period. A meteorological recording system was deployed on a raft at the Lost Ledge midlake site, recording air temperature, humidity, vapor pressure, wind speed, wind direction, and incoming solar radiation every 10 min.

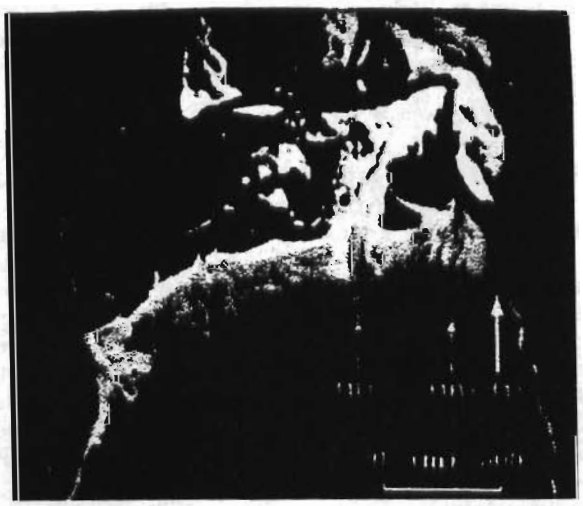

FIG. 2. SPOT Satellite Data with Resolution of 5 by 5 m Pixels, Showing Duncan River Delta (Main Flow Path Is Obvious, but Indicators of Several Secondary Flow Paths Are also Apparent)

Measurements of Water Movements and Tracer Concentration

Rhodamine WT dye was used as a tracer to delineate transport and mixing processes in the surface layer. Two vessels were required for these measurements. The first carried a dye injection apparatus (pump and diffuser) and Rhodamine WT dye (specific gravity of 1.15 as supplied) premixed with methanol to near neutral density. This fluorescing dye is specifically designed for water/tracer experiments [no significant photochemical corrections required for experiments less than 7 days in duration (Smart and Laidlaw 1977)]. The larger second vessel towed an instrument package that included a SeaBird conductivity-temperature-depth (CTD) device and a Variosens fluorometer adjusted specifically for the Rhodamine WT. The instrument package could be made to undulate vertically through the top 50 m of the water column as the launch moved slowly ahead. A microwave positioning system provided location information. All signals were sampled (0.67 Hz) and recorded digitally under the control of a microcomputer, and the track of the vessel was displayed graphically on the screen of a laptop computer. The spatial resolution of the measurements was typically 1 m.

An acoustic Doppler current profiler (ADCP) was mounted on a third vessel through a well in the bottom of the hull. Its ultrasound signals beamed downwards and yielded estimates every 15 s of water velocity relative to the boat at 1-m intervals from 2 to 25 m. In water less than 30 m deep, the absolute velocity of the boat could be inferred from the bottom-reflected signal. At greater depths data from a satellite navigation system (Global Positioning System [GPS]) were recorded with the ADCP data, with a view to converting the relative ADCP information to absolute water velocities. The ADCP launch ran numerous "velocity" transects in the vicinity of the dye experiments. Unfortunately, a second GPS receiver intended to provide postfield differentially corrected GPS coordinates failed to operate. Consequently, only relative velocities can be inferred from the deep-water measurements (greater than 30 m). Nonetheless, the ADCP data are useful in providing vertical shear information in the vicinity of the dye to a resolution of 2–3 $cm \cdot s^{-1}$. This is crucial for estimates of shear dispersion rates.

Typical Experiment

First the dye injection vessel deployed drogues in the area of the experiment for visual orientation and reference. Next, the dye (typically 40 L of a methanol/Rhodamine WT mixture) was injected into the lake by pumping it through a flexible hose that terminated in a multiport diffuser. The dye entered the water as a ring of small-scale turbulent jets, thus ensuring significant initial dilution. The diffuser was lowered and raised repeatedly through the top 20 m of the water column (approximately the photic zone) until the required amount was injected, a procedure that typically took 30 min. In the Duncan River, dye was poured in at the surface because we could rely on river turbulence for initial dilution. The injections were made relatively quickly to reveal the short term flow variations that would have been obscured by a long slow release (e.g., Blanton and Ng 1971).

Before, during, and after the actual dye injection, the two other vessels criss-crossed the study site with the ADCP and the CTD package. Thus, spatial and temporal observations of the dye were made while the background physical properties of the water column were recorded.

OBSERVATIONS

Because Kootenay Lake lies in a steep-sided valley between the Purcell and Selkirk mountains, the winds blow mainly up and down the lake, approximately north and south. Southerly winds in this study period usually occurred during the afternoon, reversing late in the evening to generally weaker northerly winds. Figs. 3(a)–3(d) shows some of the meteorological data recorded at the Lost Ledge Creek site. The wind-direction data illustrate a daily cycle that is broken only by the large wind event commencing on the evening of June 12. The other data follow similar daily and synoptic trends.

The combined effect of the surface heating and cooling and the wind stirring resulted in a weakly but uniformly stratified water column, with changes of a few degrees over the top 20 m. The stratification varied with the passing of internal waves and the storm of June 12–13 fully mixed the top 25 m of the water column and created internal waves of amplitudes exceeding 5 m (Hamblin et al. 1994).

Experiment of June 12

On June 12, 1992, after dye was injected into the river several hundred meters upstream from the lake, the CTD and fluorometer package was held just beneath the surface at the main entrance to the lake. In this experiment, unlike the usual rapid injections, the first 20 L of tracer were introduced initially over 12 min and the last 20 L over a period of over 1 h with a brief gap between the two injections. The fluorometer was positioned in the river mouth region long enough to capture the passage of the first injection. The initial injection manifests itself as a gaussian concentration curve followed by a substantial tail region as depicted in Fig. 4(a). The lower panel of Fig. 4(b) shows the injection regime and illustrates how the peak in the resulting concentration-versus-time plot of Fig. 4(a) is related to the initial injection and occurs 25 min after the middle of the first dye-injection period. The tail region in Fig. 4(a) is interesting and suggests

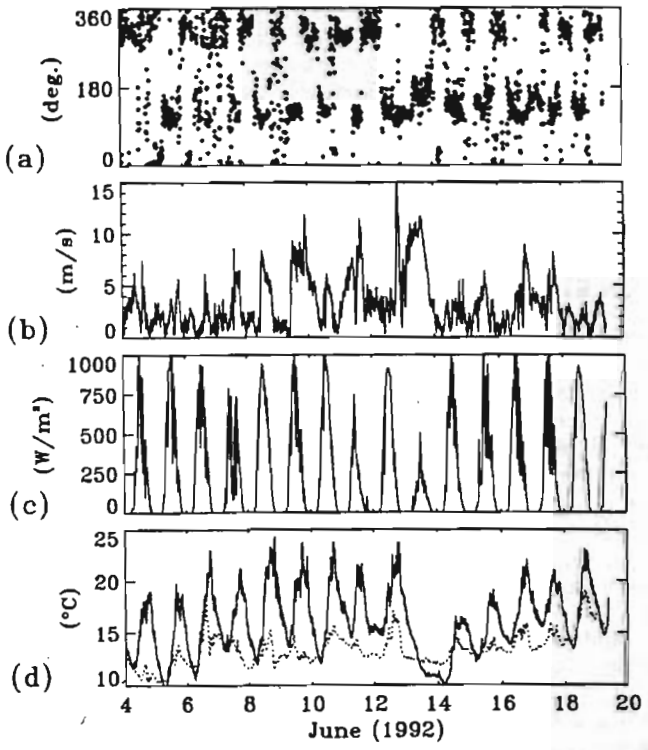

FIG. 3. Meteorological Data: (a) Wind Direction Where 0° Represents Wind from North; (b) Wind Speed; (c) Solar Radiation; and (d) Air (Solid Line) and Surface Water (Dotted Line) Temperatures

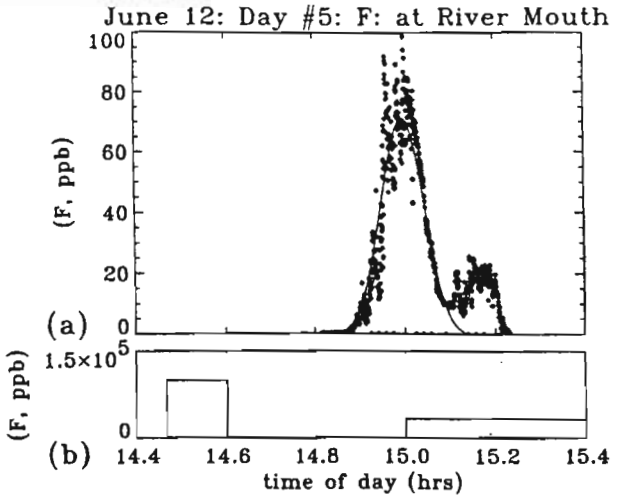

FIG. 4. (a) Data (◇) Recorded on June 12, 1992 at Duncan River Main Entrance into Lake (Best-Fit Gaussian Distribution to Initial Portion of Curve is Included); (b) Idealized Injection Strategy for June 12 Experiment (Concentrations Are After Initial Mixing in River)

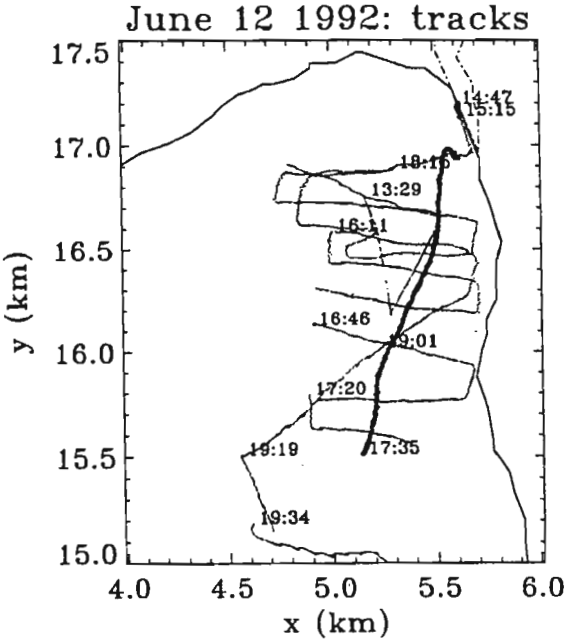

FIG. 5. Shiptracks for June 12, 1992

that, even with a rapid dye injection, the river flow is affected by back eddies and stagnation zones near the banks where some dye could accumulate and slowly leak back into the main flow.

A real-time CRT display of the vessel path that also indicated whether the fluorometer was detecting dye at concentrations greater than a preset background level enabled us to track the dye plume directly rather than be obliged to swathe the area blindly. For example, the vessel tracks shown in Fig. 5 approximate the dye plume itself, and the area crisscrossed in Fig. 5 shows where the dye spread over the afternoon. In the late afternoon the highlighted transect of Fig. 5, running north-northeast, yielded contours of dye and temperature [Figs. 6(a) and 6(b)] that show the structure of the river plume. The transect is on a line running up the middle of the dye cloud from the south from the experiment on June 12, 1992. The actual locations that data were recorded is shown as dots on the plot. The units of the contours in Fig. 6(a) are the natural logarithms of dye concentration (F) normalized to a background concentration (F_o) representative

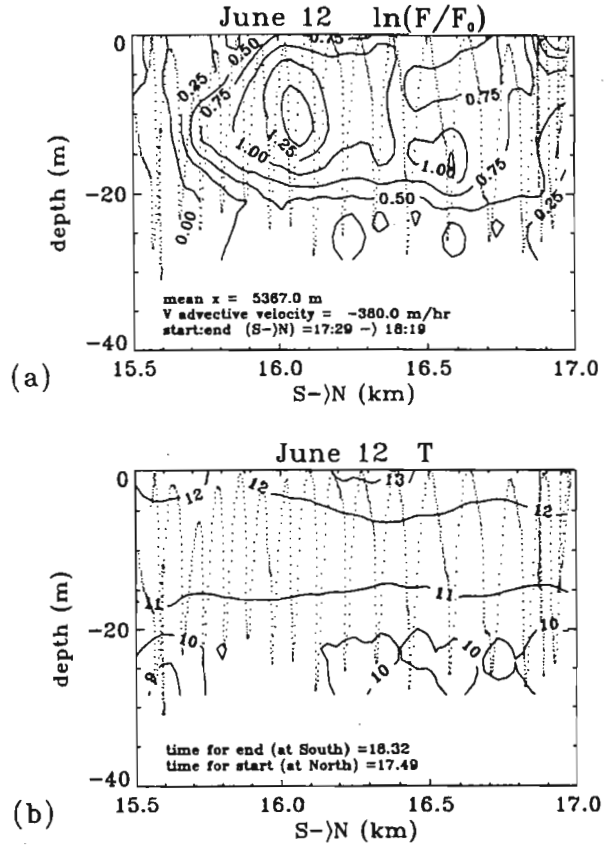

FIG. 6. Contour Plots of Data from June 12, 1992, Showing: (a) $\ln(F/F_0)$ Where F Is Observed Dye Concentration and F_0 Is Background Reading in Lake Surface Water; (b) Temperature

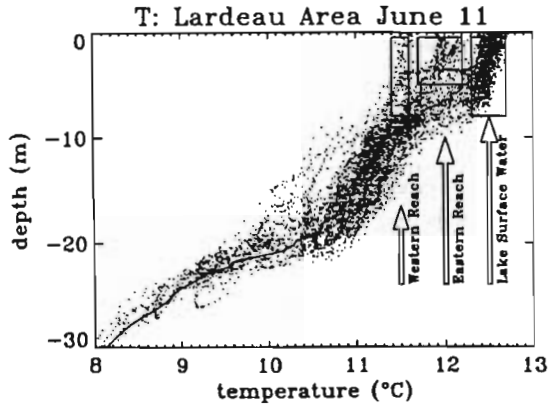

FIG. 7. Temperature Plotted against Depth for June 11 (Three Surface Waters Are Indicated with Boxes)

of the indicated concentrations well away from the main body of the dye cloud. Tracking the concentration at a depth of 10–12 m from the south to the north, one observes a strong maximum, presumably associated with the early rapid phase of dye injection, followed by a second deeper and weaker local maximum that would appear to result from the second slower injection phase. It is unclear why the depths of the two maxima are different. The shape of the plume and the disposition of the peak concentration suggest that the river water carrying the dye initially has plunged to a depth of 12 m. Debris lines and water-color changes observed near the river mouth are the surface expressions of plunging. Mixing processes have nevertheless been effective in distributing the dye over top 20 m of the water column. The second panel of Fig. 6(b) shows the observed temperature distribution over the same transect. A composite of all water temperatures observed at the north end of the lake on the previous day, June 11 (Fig. 7) indicates the presence of three surface waters, each several meters thick, the warmest associated with the open lake to the south and the two cooler ones associated with river plumes. Fig. 7 also suggests the presence of a common deep-water structure at depths greater than 10 m. These data suggest that a patchy, variable, dynamic regime exists in the upper 20 m where the inflowing Duncan river directly impacts the lake.

Because of inaccuracies in the vessel positioning system, the ADCP velocity profiles do not indicate absolute velocities reliably in deep water. However, the profiles can yield a trustworthy picture of the velocity differences between layers (vertical shear of horizontal velocity). ADCP data, presented in Fig. 8 as the difference between the average horizontal velocity of the 16–20-m layer (layer influenced by river inflow) and the average horizontal velocity of the 21–25-m layer (layer associated with a presumably more static deep water), shows the river plume hugging the east shore of the lake with a well-defined boundary on the west side of the plume indicative of strong shear at the sides of the plume as well as the vertical shear directly indicated by the instrument. Velocity shears will enhance both vertical and transverse mixing.

Experiment of June 17

In a subsequent experiment on June 17, dye was injected into a different part of the river, an inflow that was significantly colder than that observed on June 12. The fluorometric plume associated with this inflow [Fig. 9(a)] manifested itself as a line of dye on the surface around the plunge line (y = 16.75 km in Fig. 9) and enhanced concentrations between depths of 10 and 27 m. The temperature contours [equivalent of Fig. 6(b)] provided no supporting evidence of the riverine inflow however a weak conductivity signal [Fig. 9(b)] was indicative of a different water mass entering the lake. While the resolution of the conductivity cell was such that no absolute significance can be attached to the data, the relative magnitude matches the dye distribution. The associated shear of the receiving water on June 17, displayed in Fig. 10, are less dramatic than for June 12 and suggest that there is much less shear at around 20 m deep. Thus, it is noteworthy that the injections in the river delta (shown in Fig. 2) on June 12 and June 17 took place only 100 m apart and at around the same time of day, yet their behavior is different in several ways.

First, the mean velocity of the bulk of the plume on this day was around one-third that of the June 12 experiment and

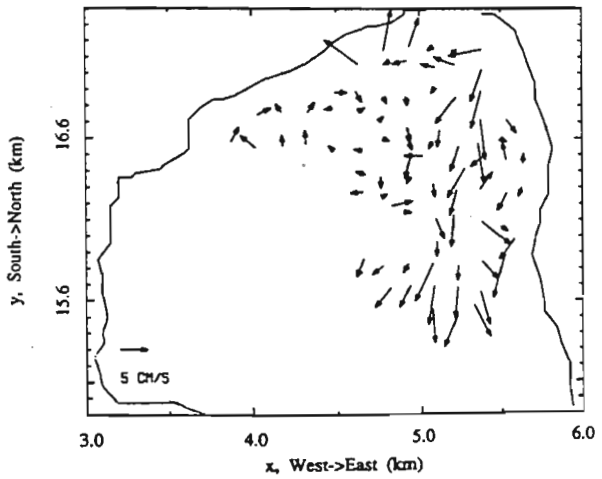

FIG. 8. Vectors Representing Vertical Shear in Water Column on June 12, 1992

as the input concentration (after initial river mixing) on June 17 was many times higher due to different injection periods, average dilution in the plume was smaller in this underflow than for comparable times with the surface flow. To illustrate this point, the injection on June 17 injected the same volume of dye as described by Fig. 4(b) but over a time of 90 s. Second, at comparable times, the total horizontal scale (a function of the standard deviation of the spatial distribution of vertically averaged dye concentration) of the introduced cloud of dye was around one-third of that observed in the surface experiment [Figs. 6(a) and 8].

RESULTS

The riverine flow was originally perceived as a steady and constant transport mechanism in the North Arm system (Carmack et al. 1986), creating velocities of the order of 2 cms^{-1} well away from the river mouth, and so it might be expected to carry nutrients over the full length of the North Arm if they were introduced either into the river upstream of the lake or close to the river mouth. However, the river inflow region is more hydrodynamically complex than presumed. At least two completely different waters were encountered entering the lake (Fig. 7). These could be traced back to the river delta region and, in fact, shared some of the network of channels in the delta region (Fig. 2). Therefore, the highly variable conditions depend strongly on dam release schedules. During the late-spring conditions encountered the entrance mixing is vigorous. For example, the tracer originally in the river water that has a depth of neutral buoyancy in the lake of around 10 m, appears at the lake surface for almost all of the plume region (Fig. 6).

The mixing associated with the inflow is parametrized by the densimetric Froude number, F (Chu and Baddour 1984):

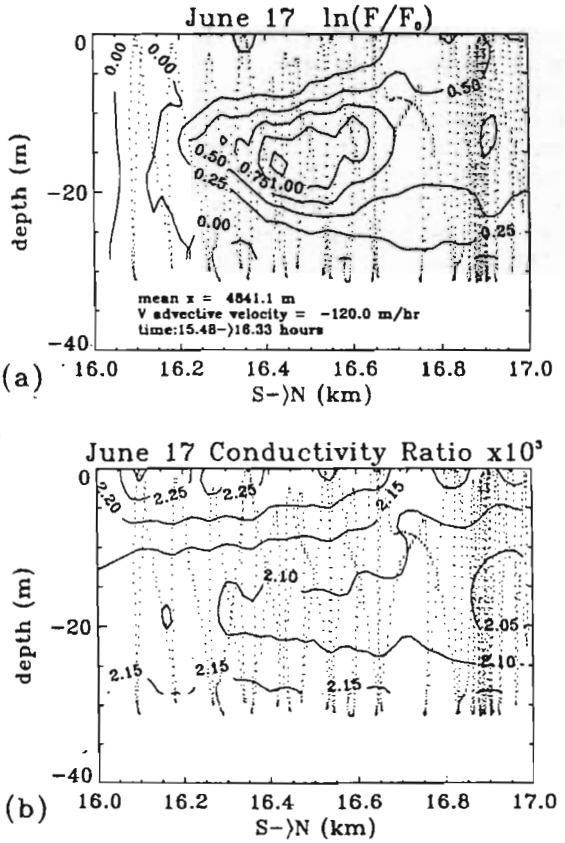

FIG. 9. Contour Plots of Data from June 17, 1992, Showing: (a) $\ln(F/F_0)$; (b) Conductivity Relative to Sea Water at 20°C

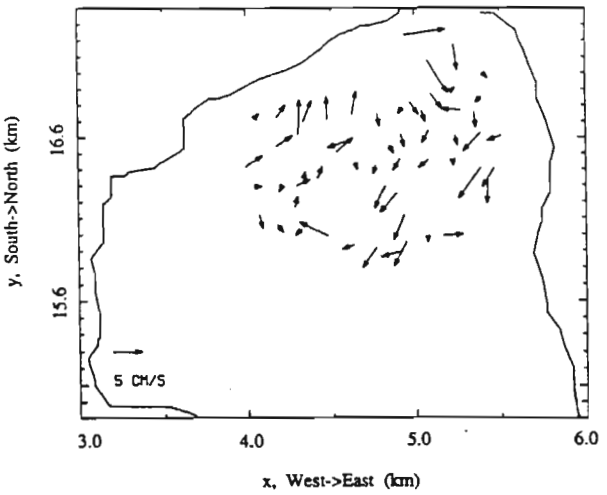

FIG. 10. Vectors Representing Vertical Shear in Water Column on June 17, 1992

$$F^2 = \frac{u^2}{dg'} \tag{3}$$

where d and u = the river inflow vertical thickness and vertically averaged horizontal velocity, respectively; and g' = the reduced gravitational acceleration. This reduced gravity represents the buoyancy effect (density contrast between lake and river) such that $g' = (\Delta\rho/\rho_0)g$, where $\Delta\rho$ is the density difference between the incoming water and the lake surface water (away from the river region) of density ρ_0, and g is gravitational acceleration. The parametrization indicates the magnitude of inertia relative to the stability provided by buoyancy. $F < 3$ indicates that the river inflow does not act in a jetlike fashion; rather, the river acts as a mixing layer (Chu and Baddour 1984).

For the late spring conditions that were encountered here, estimates (h = 20 m, u = 0.1 ms^{-1}, g' = 0.001 ms^{-2}, from Figs. 7 and 8) suggest that F = 0.7. Taking values typical of late summer conditions (h = 20 m, u = 0.1 ms^{-1}, g' = 0.01 ms^{-2}) F = 0.2. Thus, for the late summer conditions it is predicted that the river plume remains as a coherent flow at its depth of neutral buoyancy. These calculations are consistent with observations [e.g., Fig. 6 and Carmack et al. (1986)].

From the observed dye distributions at different distances from the river injection site it is possible to estimate eddy diffusion coefficients that are indicative of the relative vigor of mixing. Estimates of the standard deviation of concentration in the dye patch [a standard technique in which the dye concentration is viewed as the probability distribution of a cloud of dye particles and the standard deviation becomes the root-mean-squared distance of a dye particle from the center of the cloud; see Fischer et al. (1979)] show that it grows from just over 100 m to nearly 600 m. Okubo (1971) models the observed diffusion with a radially symmetric diffusion coefficient. If we replace the radially symmetric distribution with an average value based on the x- and y-directions we find that

$$\kappa_r = \frac{1}{4}\frac{\sigma_x^2 + \sigma_y^2}{t} \tag{4}$$

where $\sigma_{x,y}$ = the standard deviations of the dye cloud distribution; and t = the time after introduction. Kullenberg (1972) shows that as σ_x/σ_y increases the bi-directional value for diffusion is greater, by a factor between 1.3 and 8.4, than the radially symmetric value, calculated with (2).

For the experiments of June 12 and June 17, the values of κ_r found from observations using (4) were 2.5 m^2s^{-1} and 1.2

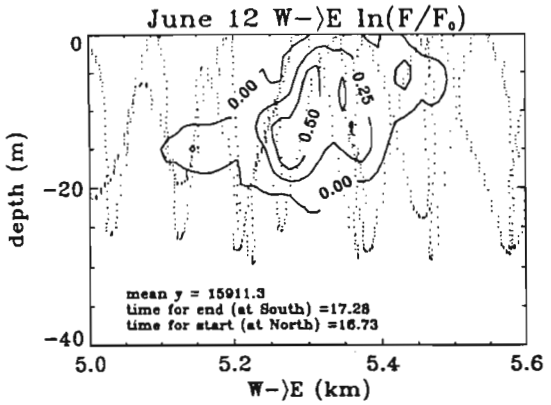

FIG. 11. Contours of $\ln(F/F_0)$ for East-West Transect on June 12, 1992

m^2s^{-1}, respectively. Comparison with (2) indicates that expected open-water diffusion coefficients are in the range of 0.4–0.7 m^2s^{-1}, somewhat less than observations. The σ_x/σ_y correction would bring the observations and the model closer, as Kullenberg's (1972) data show that for the $(\sigma_x/\sigma_y)^2$ ratio found here, it is expected that $(\sigma_x^2 + \sigma_y^2) \approx 2.5\sigma_r^2$.

It is instructive to explicitly estimate diffusion coefficients as generated by vertical and horizontal shear due to the river. Comparison for June 12 between Fig. 6(a) and the distribution of dye normal to the main flow (Fig. 11) shows that the plume is almost 1 km long but only a few hundred meters wide. Thus, the dispersion process is anisotropic. Fischer et al. (1979) show that the vertically averaged shear dispersion coefficient is an integrated function of the vertical velocity profile $u(z)$ and the vertical distribution of κ_z. This forms a new coefficient that includes the effect of shear and is given by

$$\kappa_x = \frac{h^2\overline{u'^2}}{\overline{\kappa_z}} I \tag{5}$$

where the overbar denotes a vertical average; the prime denotes departure from the vertical mean [e.g., $u'(z) = u(z) - \bar{u}$]; and I = a dimensionless triple integral, the value of which is typically around 0.1. If vertical diffusivity is initially assumed to be constant, $\kappa_z \approx hu_*$, where u_* is the friction velocity associated with shear at the base of the riverine layer and wind-driven turbulence. It is possible to infer u_* through consideration of Fig. 6(a). In the absence of diffusive processes, the riverine layer would spread out into the lake at a depth of neutral buoyancy of around 12 m. However, turbulent diffusion acts to mix this interflow so that it reaches the surface. The dye contours indicate that the nose of the dye cloud precedes the appearance of dye on the surface by 300 m. Given the advection in the plume of 0.1 ms^{-1}, this vertical diffusion process must take 3,000 s. κ_z scales as the square of the distance the material diffuses divided by the time taken. The κ_z, at the time of the data collection on June 12, transported dye from 12 m-deep to the surface in 3,000 s so that $\kappa_z \approx 4.8 \times 10^{-2}$ m^2s^{-1}. Furthermore, as $\kappa_z \approx hu_*$ and h = 20 m (the depth of the riverine affected layer), $u_* \approx 2.4 \times 10^{-3}$ ms^{-1}.

Substitution of $\kappa_z = u_*h$ into (5) results in a value for κ_x around 0.8 m^2s^{-1}. This calculation depends on the selected velocity profile, and here u is chosen as constant in the upper half of the riverine layer, then varies linearly to 0 at the base (I = 0.06). This calculated value is similar to that suggested by (2) but is still a factor of 3 less than the observed measurement. Incidentally, the time scale $0.4h^2/\kappa_z$ that represents the minimum duration for the application of integrated shear dispersion theory is less than the length of our observations. This suggests that (1) it is reasonable to use this approach to the observations; and (2) assuming an injection assimilation time scale of 1 day, shear dispersion processes act with sufficient rapidity as to affect the transport behavior in the river outflow.

Repeating the observational analysis for June 17 indicates that $\kappa_r = 1.2$ m^2s^{-1}, which is half that of the surface flow. The shear dispersion model, now assuming a parabolic profile (I = 0.025) and value for $\kappa_z \approx 1.5 \times 10^{-2}$ m^2s^{-1} results in $\kappa_x \approx 6.5 \times 10^{-2}$ m^2s^{-1}, only a few times greater than vertical diffusion. The suggestion here and for June 12 is that, while shear dispersion theory certainly indicates enhanced dispersion over and above that of turbulent diffusion, it is not sufficient to explain the observed rates.

The solution to this deficit must lie in the transverse shear, i.e., effectively variations of north-south velocity as an observer moves east or west in Fig. 8. In this analysis the transverse diffusion is more likely to be related to the river velocity; the combination of a larger lengthscale and larger diffusion results in an increased value for κ_x over that determined for vertical shear. However the resolution of quantitative values for this is beyond the scope of this paper, except to say that matching the magnitude of the observed κ_x requires the transverse κ_y to be on the order of the vertical thickness of the riverine layer multiplied by the velocity of the riverine layer. This in turn suggests large-scale structure in the riverine flow persists some way into the lake itself.

Comparison of the observed and modeled results with those of Hamblin and Carmack (1980), who describe a model of the mean field distribution of a tracer in the riverine flow, indicates between one and two orders of greater magnitude difference in the average diffusivity. The observations described here are lower than the value they infer from measurements even though the present data set was recorded in one of the most energetic regions of the lake. The reason for the disparity lies in the scale; Hamblin and Carmack (1980) considered the entire lake, whereas this study examines transport at a scale where some individual mechanisms can be discerned rather than applying the eddy-diffusion model to all processes. Processes that have persistent structure over the timescale in question (here this time is that for uptake of fertilizer) cannot be considered as turbulence, but they should be explicitly taken into account.

CONCLUSIONS

The study has two main conclusions. First, flow conditions and mixing properties are highly variable in time and space over scales as small as 1 km and 1 h. Such variability implies that relating day-to-day mixing properties to such elementary parameters as the seasonal flow are not likely to be successful. Second, the presence of strong velocity shears associated with wind stirring, basin geometry, internal waves, and river inflow would suggest that the stirring action of local turbulence is augmented through the phenomenon of shear dispersion. Field observations, including some of the first observations of vertical variations of tracer, in the portion of the lake directly influenced by the river yield effective diffusion coefficients that are consistent with available simple models of the shear dispersion process.

ACKNOWLEDGMENTS

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APPENDIX II. NOTATION

The following symbols are used in this paper:

C = concentration;
d = river inflow vertical thickness;
F = calibrated Fluorometer output for concentration;
F_0 = background (no dye) value of F;
F = densimetric Froude number;
g = gravitational acceleration;
g' = reduced gravity;
H = shear layer thickness;
h = river inflow depth;
l = patch size;
S = source/sink term in conservation equation;
t = time;
U = velocity vector in conservation equation;
u = river inflow velocity;
u_* = friction velocity;
x, y, z = spatial coordinates;
α, β = empirical coefficients in oceanic diffusion model;
$\Delta\rho$ = density difference;
$\boldsymbol{\kappa}$ = $(\kappa_x, \kappa_y, \kappa_z)$ = apparent diffusivity vector;
κ_r = radially symmetric diffusion coefficient;
ρ_0 = average density;
σ_r = standard deviation of dye cloud in radially symmetric distribution;
σ_x, σ_y = standard deviation of dye cloud in x- and y-directions; and
ν = molecular viscosity.