

QH
541.5
.R4
J64
1996

**Ecological Effects of Reservoir Operations
on Blue Mesa Reservoir**

Annual Progress Report

May 1, 1995-April 30, 1996

Prepared by

Brett M. Johnson
Principal Investigator

Michael J. Wise
Graduate Research Assistant

Brian Herwig
Research Technician

Glenn Szerlong, Derrek Faber, and Blake Byall
Undergraduate Research Assistants

Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, CO 80523



Colorado Division of Wildlife
RESEARCH CENTER LIBRARY
317 West Prospect Rd.
Fort Collins, CO 80526
USA

QH
541.5 Ecological effects
.R4 of reservoir
J64 operations on Blue
1996 Mesa Reservoir

DATE DUE

QH
541.5 Ecological effects
.R4 of reservoir
J64 operations on Blue
1996 Mesa Reservoir

B00w014 932

DATE	ISSUED TO



**COLORADO DIVISION OF WILDLIFE
RESEARCH CENTER LIBRARY**

317 West Prospect
Fort Collins, CO 80526 USA
(970) 472-4353

**Ecological Effects of Reservoir Operations
on Blue Mesa Reservoir**

Annual Progress Report

May 1, 1995-April 30, 1996

Prepared by

Brett M. Johnson
Principal Investigator

Michael J. Wise
Graduate Research Assistant

Brian Herwig
Research Technician

Glenn Szerlong, Derrek Faber, and Blake Byall
Undergraduate Research Assistants

Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, CO 80523

COLO DIV WILDLIFE RESEARCH CTR LIBRARY



B00W014932

TABLE OF CONTENTS

Acknowledgments	3
Summary	4
Introduction	6
Study Site	7
Part 1.	
Reservoir Limnology	
Methods	
Overview	8
Physicochemical Limnology	9
Primary Production	9
Zooplankton Dynamics	10
Spatial Variation	10
Temporal Variation	10
Zooplankton Sample Processing	11
Results and Discussion	
Physicochemical Limnology	12
Reservoir Operations	12
Temperature-Dissolved Oxygen	12
Secchi Disc	13
Primary Production	13
Chlorophyll a	13
Zooplankton Dynamics	14
The Zooplankton Community	14
Spatial Distribution/Vertical	14
Spatial Distribution/Horizontal	15
Temporal Dynamics	18
Overall	19
Seasonal/vertical	19
Seasonal/horizontal	20
Conclusions - Zooplankton	20

Part 2.
Fishery Investigations

Methods

Vertical Gill Netting	22
Diet and Growth Analysis	22
Hydroacoustics	23

Results and Discussion

Vertical Gill Netting	23
Diet and Growth Analysis	23
Hydroacoustics	34

Part 3.
Reservoir Thermal Ecology

Methods

Thermal Stratification Model	25
Reservoir Bioenergetics	26

Results and Discussion

Thermal Stratification Model	26
Reservoir Bioenergetics	27

Recommendations for Future Study	28
--	----

Literature Cited	29
----------------------------	----

List of Tables	33
--------------------------	----

Tables	34
------------------	----

List of Figures	40
---------------------------	----

Figures	45
-------------------	----

Appendix A.

Experimental Vertical Gill Netting	98
--	----

ACKNOWLEDGMENTS

The authors acknowledge the continued advice and assistance of Patrick Martinez (Aquatic Researcher, Colorado Division of Wildlife). Steve McCall (U.S. Bureau of Reclamation, Grand Junction Projects Office) coordinated the project. Graduate student Paul Weiss and Professor Darrel Fontane of the CSU Civil Engineering Department are assisting with the thermal modeling; their efforts are greatly appreciated. We thank Rick Harris and Lynn Cudlip (National Park Service, Curecanti National Recreation Area) for their logistical support and for providing housing, storage, and lab space, and the occasional field assistant. Steve Hiebert (U.S. Bureau of Reclamation) and Gordon Mueller (National Biological Service) helped us get up to speed on vertical gill netting, hydroacoustics and entrainment sampling. We appreciate the cooperation and assistance of Sherman Hebein (Aquatic Biologist, Colorado Division of Wildlife) and Dave Langlois (Senior Aquatic Biologist, Colorado Division of Wildlife). We are grateful for the help of Krista Bonfantine, Shaundy Mahorter, Lori Reimherr, Dana Pittman, Adam Craig, and Bob Dabkowski, who assisted with laboratory analyses and data processing. Dave Shuler aged kokanee scales collected in previous years.

The project is supported by a contract from the U.S. Bureau of Reclamation, Grand Junction Projects Office. Some capital equipment for this project was provided by College of Natural Resources, Colorado State University.

SUMMARY

- Reservoir discharge and surface elevation were far above the longterm average during 1995, due to above average inflow during May-September.
- Mean reservoir surface temperature in summer 1995 was about equal to the longterm average in Sapinero and above average in Cebolla and Iola.
- Mixing in the epilimnion appeared to be weaker in 1995 than in 1994.
- Metalimnetic oxygen minima occurred again in Cebolla throughout the sampling season.
- Water clarity was generally lower in 1995 than during 1994 but still better than during the 1980's, especially during September.
- Epilimnetic chlorophyll-a concentration was slightly lower in 1995 than in 1994, and peaked at 4-6 $\mu\text{g/l}$, depending on basin, in mid June and declined throughout the summer.
- About 80% of total *Daphnia* density in the top 30 m of water occurred in the top 10 m in 1995, similar to the vertical distribution observed in 1994.
- In 1995, *Daphnia pulex* was more abundant than *D. galeata mendotae* through most of the season just as it was in 1994.
- *Daphnia pulex* maintained a relatively constant proportion of the zooplankton community throughout the growing season.
- Patterns in the 1995 temporal dynamics of *Daphnia* spp. abundance in each basin were remarkably similar to those seen in 1994.
- During each of the three study years, *Daphnia* density was highest in Sapinero in May, highest in either Cebolla or Iola in June, then much lower, and similar in all three basins during July through September.
- *Bosmina* spp have progressively increased in relative abundance in the zooplankton community during the three years of the current study. *Bosmina* spp. were more abundant than either of the two *Daphnia* species in 1995.
- *Daphnia* abundance in Iola has ranged from 260% greater than Sapinero in 1993, to nearly equivalent in 1994, and 1995.
- As in 1994, *Daphnia* density was highest in the top 10 m of the water column on all dates, and in all basins in 1995.

- Kokanee continued to feed almost exclusively on large *Daphnia pulex* in Blue Mesa. Their high diet selectivity suggests an abundant food supply for planktivores.
- Based on experimental vertical gill netting, the pelagic fish community during summer 1994-1995 is dominated by kokanee salmon.
- At night in June over 97% of kokanee were distributed in the upper 15 m of the water column. In July about 80% of kokanee were caught at night in water 10-40 m deep, and in September most kokanee were distributed from 10 to 50 m.
- Rainbow trout occupied shallower water than kokanee in all months. Rainbow were captured in VGN in the top 5 m in June-September.
- Backcalculated growth rates of kokanee have changed little since the 1960's.
- Bioenergetics modeling suggests that relatively slight increases in epilimnetic temperatures could have important ecological consequences for kokanee growth and consumption.

INTRODUCTION

With the increasing demand for water in the West to serve an expanding range of purposes, it is reasonable to expect reservoir operations to be altered. Retention time, volume, morphometrics, and other reservoir characteristics will likely change. These physical changes could have important ecological consequences that could alter reservoir productivity, biotic communities, and ultimately the quality of the sport fisheries that can be sustained (Figure 1, 2).

Reservoir operations can have direct and indirect effects on reservoir productivity through a variety of mechanisms (Figure 3). Direct effects of water level management on reservoir productivity include reduced nutrient loading and internal recycling, retention times, and altered angler access to the fishery (boat access and distribution/catchability of fish). Indirect effects can alter food web interactions in two basic ways. 1) Water level influences interactions by changing epilimnetic, metalimnetic, and hypolimnetic volumes, and hence altering the density of organisms in each limnetic stratum. 2) Water level also influences epilimnetic warming which has implications for species interactions, altering zooplankton community composition, plankton production, consumption rates of planktivores, competition among planktivores, and predation rates of piscivores. This effect on reservoir thermal structure can be expected to have important consequences for productivity and sport fish yields.

Reservoir retention time, volume, basin morphometry, and climate interact to determine the thermal structure of reservoirs. Thermal structure is a critically important ecological factor in aquatic systems because it determines physiological rates of poikilothermal (cold-blooded) inhabitants. Thus, temperature drives production of food organisms as well as the consumption rates of predators. In addition, thermal structure controls internal nutrient cycling, and can isolate or concentrate predators and prey. Both have profound implications for reservoir productivity. While creel survey information is critical to assessing how a particular reservoir operation scheme affects yield of sport fish, it provides little insight into how the observed changes were brought about, nor does it suggest strategies that can optimize water management and reservoir productivity.

This study seeks to provide a better understanding of the mechanisms and pathways by which reservoir operations can impact reservoir productivity and the quality of the fishery the reservoir supports. This knowledge will be valuable for assessing ecological and fishery implications of alternative reservoir operation strategies in the future. The approach is fivefold: 1) Assemble historic datasets on hydrographics and limnology of Blue Mesa Reservoir (BMR) and determine relationships among surface elevation, storage, mean water column temperature, and thermocline depth. 2) Conduct a standardized limnological assessment program at sites throughout the reservoir, sampling temperature-dissolved oxygen profiles, chlorophyll, and zooplankton, and estimate zooplankton production rates. 3) Determine seasonal diet, depth distributions and growth of kokanee and rainbow trout using hydroacoustics and vertical gillnetting. 4) Incorporate sport fish diet, distribution, growth rate information into bioenergetics

models to estimate consumption demand and population production. 5) Help assess potential entrainment of young-of-year kokanee using hydroacoustics to determine distribution during high discharges in late May, and by assisting with drift net sampling below the dam during the same period.

This report documents the third year of progress on the research project investigating the influence of reservoir water operations on ecosystem structure and function in Blue Mesa Reservoir, Gunnison County, Colorado. The primary goal of the work in 1993 was to characterize the physicochemical and biological limnology of the reservoir. In 1994 and 1995, the objectives were to 1) continue monitoring seasonal changes in physicochemical and biological limnology of the reservoir, 2) investigate potential effects of dam operations on stratification patterns in the upper and lower basins of the reservoir, 3) quantify spatial and temporal patterns of zooplankton distribution and abundance, 4) obtain abundance estimates of pelagic fish stocks, 5) determine diet composition of kokanee salmon and rainbow trout, and 6) estimate growth, condition, and depth distribution of sport fishes. In 1995 we concentrated our zooplankton sampling on Sapinero basin to gather population parameters needed to estimate *Daphnia* production, and on modeling the impact of fish predation on zooplankton biomass.

STUDY SITE

Blue Mesa Reservoir is a mesotrophic, 3,700 ha (9,180 ac), 32 km (20 mi) long impoundment in southwestern Colorado. The earthen dam forming Blue Mesa was constructed in 1965 to store and control heavy spring flows of the Gunnison River, and rises 104 m (342 ft) above the streambed of the River. Two 40,000 kilowatt generating units operate at the base of the dam. The lake is one of three reservoirs in the Curecanti Unit of the Colorado River Storage Project, providing water for irrigation, power generation, and recreation. With a storage capacity of 1.16×10^9 m³ (940,700 ac-ft), Blue Mesa is the largest reservoir in Colorado. Most of the reservoir is within the National Park Service's Curecanti National Recreation Area.

The fish community in BMR consists primarily of kokanee salmon (*Oncorhynchus nerka*), rainbow trout (*O. mykiss*), lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*), cutthroat trout (*Oncorhynchus clarki*), and longnose sucker (*Catostomus catostomus*). The lake supports an extremely popular and productive kokanee salmon and rainbow trout fishery. For example, in 1993, the lake received over 612,000 angler-hours of fishing effort (ice and openwater angling; S. Hebein, CDOW, Gunnison, pers. comm.). About 340,000 fish were harvested, of which 75.3% (255,772 fish) were kokanee salmon, and 18.5% (83,898 fish) were rainbow trout. Angler caught kokanee were among the largest in the state with a mean length of 320 mm.

Part 1. Reservoir Limnology

METHODS

Overview

We began the 1995 field season on 20 May 1995 and collected data weekly until 17 August 1995. We returned to CSU on 20 August 1995, but conducted another sampling trip to BMR from September 9-12. Data were collected throughout the field season from each of the three main BMR basins: Sapinero (lower basin), Cebolla (central basin), and Iola (upper basin). Our objectives were to acquire information on: 1) BMR limnological parameters (temperature/dissolved oxygen profiles, secchi depth, chlorophyll a concentrations); 2) zooplankton distribution, abundance and population dynamics; 3) fish community composition; 4) kokanee growth rates and population age structure; 5) kokanee diets; 6) kokanee abundance (hydroacoustics); 7) kokanee vertical distributions; and 8) inflow and outflow water temperatures (Table 1). Roughly half of our work effort was allocated to the collection and processing of zooplankton samples.

The 1995 study plan included application of the (1968)-Paloheimo (1974) egg-ratio *Daphnia* production model (hereafter referred to as the E-P model). We are using this model to estimate the production of *Daphnia pulex*, the principal food resource of kokanee in BMR. We chose the Sapinero basin to collect the data necessary to run this model. Therefore, the bulk of our zooplankton work was concentrated in Sapinero basin.

The E-P model requires that population and egg count estimates be taken at intervals approximately equal to the brood development time, which is primarily temperature dependent (de Bernardi et al, 1978; Hall, 1964). According to the results of Hall (1964) the brood duration time at typical BMR temperatures is about one week. Because the model required weekly sampling in Sapinero, it was necessary to reduce sampling effort in the other two basins from what was done in 1994. Limnological data were collected weekly in Sapinero from May 21-August 17. These data were collected every three weeks during this time period in Cebolla and Iola basins instead of every two weeks as in 1994. During the September sampling trip, we fished vertical gill nets in all three basins in addition to collecting zooplankton and limnological data.

In 1995 we collected plankton and limnology data at the same standard stations in Cebolla (station 3) and Iola (station 5) basins as were used in 1993 and 1994 (Figure 4). In Sapinero, we collected zooplankton and limnological data from the standard station (station 1) for the first two sampling dates (May 21 and May 31). After May 31 Sapinero data was collected at six randomly selected stations (Table 2; Figure 4). These same six stations were used for all subsequent Sapinero sampling dates.

The six Sapinero stations were designated as 1-R1 (nearest the dam) through 1-R6 (upreservoir near the Cebolla-Sapinero high bridge). The number of Sapinero stations to sample

was based on the variability observed among 1994 samples and logistical considerations. We decided that sampling six stations was the most we could do, but we were not sure we'd have the time and resources to process samples from all six stations. Therefore, we randomly selected one station to refrain from processing (station 1-R2) until we were sure we would have time. This report is based on analysis of five Sapinero stations. The samples from the sixth station (1-R2) are currently being processed and entered into computer files.

In addition to zooplankton data, salmonid lengths, weights, scales and stomach samples were obtained from angler's catches biweekly throughout the summer. Vertical gill netting data were collected in June, August, and September. Hydroacoustics data were collected during the last week of July to gain information on fish distributions and abundance. Also, Lowrance depth finder data were recorded on a total of eight days over the season during dawn, mid-day, dusk, and late night sampling periods to obtain information on the diurnal pattern of pelagic fish vertical movements. Thermographs were deployed in June in the Gunnison River tailwater and the five main tributaries to the reservoir. Stream temperature data were collected continuously until September 20. We ended summer limnological and zooplankton sampling on 17 August 1995 and then returned in early September for the final suite of 1995 sampling.

Physicochemical Limnology

Reservoir water operations data were obtained from a variety of sources: USGS Water Resources Bulletins, Colorado Division of Wildlife Research Reports (Wiltzius 1974), and U.S. Bureau of Reclamation databases and reports.

Historic data on temperature and dissolved oxygen profiles were obtained from Cudlip et al. (1987), Wiltzius (1971). In 1995, seasonal progression in reservoir temperature and dissolved oxygen structure was recorded weekly in Sapinero basin and every three weeks in Cebolla and Iola basin as part of routine limnological monitoring. Temperature/dissolved oxygen profiles were obtained using a YSI Model 58 digital meter with 60 m probe cable. Measurements were taken at one meter intervals from 0 to 20 m and at 5 m intervals from 20 to 58 m of depth. In Sapinero basin on alternate weeks, temperature profiles were measured directly in front of the dam discharge tower to assist with calibration of the reservoir thermal model.

Secchi depth measurements were obtained with a standard 200 mm white and black limnological secchi disc (Wetzel and Likens 1991) by averaging two replicate readings taken on the shaded side of the boat.

Primary Production

Chlorophyll water samples were obtained by using a 10-m integrated water column sampler. Some samples were prefiltered through a 35 μ mesh sieve to separate them into the edible and inedible (to *Daphnia*) fractions of the total chlorophyll concentration. Water samples were filtered through glass microfiber filter paper (Whatman GF/F) using a vacuum pump

(Soranno and Knight 1993). The filter papers were frozen on dry ice and stored frozen until they were extracted and processed. Samples were analyzed for chlorophyll-a by the 24-hr methanol extraction (Holm-Hanson and Riemann 1978, Marker et al. 1980, Riemann 1980, Soranno and Knight 1993) and fluorometry method (Lind 1979, Soranno and Knight 1993, Axler and Owen 1994) using a Turner Designs Model 450 fluorometer.

Zooplankton Dynamics

Zooplankton were collected by oblique tows using a Wildco model 37-315 Clark-Bumpus plankton sampler with 130 mm diameter opening and 153 μ net. The flow meter on the Clark-Bumpus sampler was calibrated using a Schwaffer water velocity meter. One revolution of the Clark-Bumpus flow meter equaled 5.29 liters passing through the net. During May we collected three replicate samples from the 0-5 m, 5-10 m, and 10-15 m strata and two replicates from the 15-30 m stratum at each station. After May 31 we began taking samples from the 0-10 m and 10-30 m strata. In Sapinero we took one replicate per stratum at each of the six randomly selected stations. In Cebolla and Sapinero we collected three replicate samples from the 0-10 m stratum and two replicates from the 10-30 m stratum. All samples were taken between the hours of 0900 and 1200. Samples were preserved in sugared, buffered formalin to prevent osmotic explosion.

Sampling in 1995 assessed the magnitude of spatial and temporal variation in the distribution and abundance of macrozooplankton.

Spatial Variation

Spatial variation can occur at three scales: local horizontal, vertical, and longitudinal (large scale horizontal). Local horizontal spatial variation was assessed by comparing *Daphnia* densities among the six Sapinero stations. Vertical distribution of zooplankton was assessed by sampling four discrete depth strata during May, and two strata for the remainder of the season. May samples were taken from 0-5 m, 5-10 m, 10-15 m, and 15-30 m depth strata. Results from 1994 showed that roughly 90% of the *Daphnia* were found in the top 10 m of the water column. This fact, along with our need to add five more sampling stations in Sapinero, prompted us to reduce the number of strata sampled from four to two after May 31. In June through September we sampled the 0-10 m and 10-30 m strata at all stations. Longitudinal variation was assessed by comparison of *Daphnia* densities among the upper, middle, and lower reservoir basins. The possibility of a longitudinal gradient within a basin was assessed in Sapinero by examining *Daphnia* densities among the six stations.

Temporal Variation

Temporal variation may occur at two time scales: diel and seasonal. Variation in diel vertical distribution, or diel vertical migration (DVM), was assessed in 1994 by quantifying distributions over transitions from darkness to light and light to darkness. Results from the July

7, 1994 DVM sampling showed that DVM did not appear to be important in BMR at that time. Therefore, no DVM sampling was undertaken in 1995. Seasonal variation in zooplankton abundance was assessed by sampling at regular intervals (weekly in Sapinero and every three weeks in Cebolla and Iola) over the entire growing season.

Zooplankton Sample Processing

We encountered six different taxa of crustacean zooplankton in BMR in 1995. The two *Daphnia* present in BMR (*Daphnia pulex* and *Daphnia galeata mendotae*) were identified to species. Copepods (*Diacyclops* spp. and *Leptodiptomus* spp.), and the cladocerans *Bosmina* spp., and *Ceriodaphnia* spp. were all identified to genus. Egg counts and measurements were taken only from the two *Daphnia* species. *Diaphanosoma* spp., and *Alona* spp., which were rare in the 1994 samples, were not seen in 1995. By using the procedure described below, we collected abundance data on all six of the species encountered.

Each sample was diluted to a density that would provide 50-60 *Daphnia* in a single 1 ml aliquot taken with a Hensen-Stemple pipette. Aliquots were placed in a Sedgwick-Rafter counting cell where all species were identified and enumerated (Lind 1979, Soranno and Knight 1993) under a compound microscope. We processed three aliquots from each of the Cebolla and Iola samples. Sapinero samples were processed by doing aliquots until the coefficient of variation across aliquots was less than 0.20. We processed up to a maximum of six aliquots and a minimum of two from all samples collected in Sapinero. Zooplankton abundance data were computed as number per liter of lake water (density).

The reason that Sapinero samples were processed more intensively was because the results of a model sensitivity analysis we performed on the E-P model revealed that errors in *Daphnia* abundance estimates can be magnified ten fold by the exponential term in the model. In consideration of this, and because we wanted to make comparisons for statistically significant spatial and temporal differences in abundance among the six Sapinero stations, we needed to attain a higher level of precision for abundance estimates from these samples.

In addition to population abundance estimates, using the E-P model to estimate production requires the derivation of reproductive rate estimates to plug into the model. This necessitates obtaining estimates of the proportion of egg-bearers in the population and the mean clutch size. We estimated reproductive rate by following the methods of Soranno and Knight (1993) which called for collecting data from a minimum of 75 egg-bearers per sampling date. Therefore, we were targeting 15 egg-bearers per station as a minimum number of egg-bearers to collect data from.

We also measured the length of all egg-bearers encountered while gathering the egg-bearer and clutch size data. We did this because the average minimum length of egg-bearers can be an important indicator of habitat quality (Mills and Schiavone, 1982). In the Cebolla and Iola samples the first 5 individuals encountered in every aliquot were measured and their eggs counted. This yielded egg and measurement data on 45 individuals per station per date. Since mean

Daphnia lengths can be used as an index to predation pressure (Mills and Schiavone, 1982) we targeted 15 measurements per aliquot for Sapinero station samples as our processing objective thus giving 80 measurements per Sapinero date.

RESULTS AND DISCUSSION

Physicochemical Limnology

Reservoir Operations

Mean daily discharge (cubic feet per second; CFS) from BMR was below the long-term average (1972-1992) during October-March in water year (WY) 1995. Discharge was much higher than average during April-August, and about average in September (Figure 5). Mean daily discharge peaked at almost 7,000 CFS during July. During the pre-reoperation period of 1976-1992 peak discharge also occurred on average during July; however, a spring to early summer peak in discharge is less distinct during this period (Figure 6).

Mean surface elevation of the reservoir was higher in all months of WY 1995 than the long-term mean (Figure 7). The divergence from the mean was greatest in March, followed by February and April. Surface elevation rose sharply during May and remained relatively constant through the summer, despite the extremely high discharge in July. Monthly inflow (ac-ft) peaked during June 1995 at about 500 ac-ft (Figure 8). The temporal pattern of inflow was similar 1993-1995, but the magnitude of inflow was highest in 1995.

Temperature-Dissolved Oxygen

The reservoir was already weakly stratified when we began measuring temperature-dissolved oxygen (Temp-DO) profiles on 21 May (Figures 9-13); surface temperature at this time was approximately 9°C, or 3°C cooler than observed in May 1994. July surface temperature was generally higher in 1995 than the mean July temperature for eight years during 1967-1994 for which data were available (Figure 14). In 1995 the reservoir was warmest during August 14-18 (Figures 9-13). The mixed layer extended from the surface to about 10-12 m during late June through the third week in August when sampling ceased until mid September. Blue Mesa was still stratified in mid September and average temperature of the mixed surface layer had fallen to about 18°C. Stratification was generally weaker than in 1994.

Temperature profiles taken at the midlake station in Sapinero showed no consistent differences from profiles taken in front of the dam intake tower on the same day (Figure 15). There was no detectable alteration of deep stratification in front of the dam; thus, entrainment of warmer water from above into the intake structure was not evident from temperature data.

Dissolved oxygen levels were generally high (> 6 mg/l) in Sapinero throughout the season, but during August-September DO dropped under 6 mg/l below 10 m in Cebolla and Iola (Figures 16-19). Dissolved oxygen was sufficient for fish habitation (> 3 mg/l) from top to

bottom throughout the season and across the reservoir. The unusual pattern in DO measurements observed in Cebolla during 1994 was repeated in 1995, although less pronounced. The pattern indicated a metalimnetic oxygen minimum between 10-20 m; the pattern was again not evident in Iola basin, which showed a nearly continuous decline in DO with depth on all sampling dates.

Secchi Depth

As in 1993 and 1994 water transparency increased through the season in 1995 at all stations (Figure 20). Transparency was always lowest at Iola, otherwise there were no consistent interbasin trends in water transparency. Transparency was more variable in 1993-1995 than the average observed by Cudlip et al. (1987) during 1983-1985 (Figure 20). In general water transparency was lower in 1995 than in 1994 but higher than during 1983-85. The grand mean of all months and sites was lower in 1995 (4.1 m) than in 1994 (4.9) but higher than in 1993 (3.5 m) or in the 1983-85 period (3.0 m). Transparency increased nearly monotonically through the season in all three basins, and followed a similar pattern as observed in 1994 (Figure 21).

There is considerable variability inherent in secchi depth readings between observers and the method is sensitive to sampling conditions; however, there is a trend towards increasing water clarity in the available data. Whether this trend is real or artifactual is unknown at present. If the pattern is real then it could indicate either an increase in grazing pressure by the zooplankton community, lower input or mixing of inorganic material that causes turbidity, or reduced nutrient availability for primary production. The chlorophyll and zooplankton sampling we have undertaken should prove very helpful in determining an explanation for changes in the secchi depth data.

Primary Production

Chlorophyll a

As in 1994, calibrations of the fluorometer using a spectrophotometer and known dilution concentrations of a chlorophyll standard produced the required linear relationship between true chlorophyll concentration and the F_b-F_a fluorometer readings with R^2 values > 0.99 . Further, the strong relationship held for all fluorometer gain settings we tested, which encompassed the entire range of gains we anticipate needing for sample processing.

Variability in fluorometer measurements taken on replicate samples was usually very low. As a result, our measurements of chlorophyll concentration ($\mu\text{g}/\text{l}$) were quite precise (Figure 22). Chlorophyll concentration peaked in the third week of June in all three basins, slightly later than observed in Cebolla and Iola in 1994. As in 1994, chlorophyll concentration declined steadily after the June peak in Sapinero and Cebolla, but was more variable in Iola. The fraction of total chlorophyll of edible size ($< 35\mu$) for most crustacean zooplankton comprised most of the total chlorophyll in Sapinero and Cebolla, but only about half of total chlorophyll in Iola. This difference may be due to bluegreen algae blooms which are not uncommon in Iola basin.

Sampling on two occasions in August showed the presence of a metalimnetic chlorophyll peak at about 7-8 m in Sapinero basin (Figure 23).

Secchi depth is sometimes used as a convenient and inexpensive surrogate for chlorophyll measurements (Cole 1983). At BMR there was only a weak negative relationship evident between secchi depth and chlorophyll concentration in 1994 and that relationship was not apparent in 1995 when inflow was much higher than past study years (Figure 24). Variation in inorganic turbidity and in the size composition of the phytoplankton community may be responsible for the lack of correspondence between secchi depth and chlorophyll (Edmondson 1980).

Zooplankton Dynamics

The Zooplankton Community

During the 1995 field season we collected a total of 229 zooplankton samples including 150 from Sapinero, 42 from Cebolla, and 37 from Iola basin. Six species of crustacean macrozooplankton were sampled, two species of copepods, and four cladoceran species. As in 1993 and 1994, the zooplankton community in 1995 continued to be dominated by the copepod, *Diacyclops*, although to a progressively lesser degree in each year. When averaged across all basins, sampling dates, and strata, *Diacyclops* was more than four times more abundant than any other species in 1993, 2.6 times greater in 1994, and 2.1 times more abundant in 1995. While *Diacyclops* was decreasing relative to other species *Bosmina* has been increasing over these three years.

The most recent data available for BMR, including 1984, 1985 (Cudlip et al., 1987), and 1993, 1994, and 1995 of the current study, show that *Bosmina* was less abundant than the sum of *Daphnia* spp in the years 1984-1994. However, *Bosmina* increased relative to daphnids during 1993-1995. The daphnid:*Bosmina* ratio was 2.9:1 in 1993, 2.2:1 in 1994, and 1.4:1 in 1995. *Bosmina* became more abundant than either *Daphnia* spp alone for the first time in 1995. In 1995 *Bosmina* comprised about 21% of the total zooplankton community while *D. pulex* represented 18% and *D. galeata* 10% (Figure 25). Another notable change in 1995 was that *Leptodiptomus* spp. was more numerous than *Ceriodaphnia* spp, unlike 1994 when *Ceriodaphnia* was more abundant.

Mean length of *Daphnia pulex*, averaged across all stations, dates, and depths, was 1.29 mm which was 0.36 mm greater than the average of *Daphnia galeata mendotae*. Modal length of *Daphnia pulex* was 1.0 mm while *Daphnia galeata mendotae* had a modal length of 0.75 mm. *Daphnia pulex* size ranged from 0.40 to 2.49 mm (about the same as 1993 and 1994) and *Daphnia galeata mendotae* ranged from 0.45 to 1.96 mm (also nearly the same as 1993 and 1994). To our knowledge, no historic data on zooplankton population size structure are available.

Spatial Distribution- Vertical

Daphnia galeata mendotae mean clutch size was highest in the uppermost stratum and

decreased consistently with depth. However, *Daphnia pulex* mean clutch size averaged over the first two dates was highest and about equal in the 0-5 m and 15-30 m strata with intermediate clutch sizes in the 5-10 m and 10-15 m strata. For the dates from June 9 through September *D. pulex* mean clutch sizes were greater below 10 m than above (Table 3).

When all stations, sample times, and dates are combined all species of zooplankton were most abundant in the top ten meters of the reservoir (Figure 26). *Daphnia* density in the 0-5 m stratum for the first two dates of the season (the only dates that we collected 0-5 m samples in 1995) were four to five times greater than density in the 5-10 m stratum. In 1994 when the 0-5 m *Daphnia* density was averaged over the entire season *Daphnia* spp. were found to be about twice as abundant in the 0-5 m stratum as in the 5-10 m stratum while all non-*Daphnia* zooplankton were slightly more numerous in the 5-10 m than in the 0-5 m stratum in 1994.

In 1995 62% of all non-*Daphnia* sampled in the 0-30 m strata occurred in the top 10 m of the water column compared to 63% in 1994. The proportion of *Daphnia* in the top 10 m was similar in 1995 and 1994, at about 80% of total *Daphnia* density. As in 1993 and 1994, all species were least numerous in the 10-30 m stratum where 34% of the total zooplankton community were found during 1995 (Figure 26).

Spatial Distribution- Horizontal

To describe horizontal *Daphnia* distributions in BMR we define the following categories of patchiness scales modified from Pinel-Alloul (1995): macro scale (10-30 km); large-scale (1-10 km); and coarse-scale (10 m-1 km). We begin by reporting the patterns of macro-scale (comparisons among basins) horizontal distribution of BMR zooplankton community parameters starting with *Daphnia* mean clutch size. We are in the process of improving our egg count estimates, but preliminary analysis of the data we have now show that *Daphnia galeata mendotae* mean clutch size was highest in Iola basin. This is in contrast to our findings for *Daphnia pulex* which showed it's lowest mean clutch size in Iola and the highest in Cebolla basin (Table 3).

Estimates of intra-basin total zooplankton density were calculated by averaging the 0-10 m densities over all dates within each basin. Zooplankton relative density was similar across basins, but slightly greater at the Iola station (48), followed by Cebolla (46) and Sapinero (45) (Figure 27). As in 1993 and 1994, *Bosmina* density and relative abundance increased upreservoir in 1995. Among these three years this pattern was most pronounced in 1995 when *Bosmina* density in Cebolla was 1.5 times that of Sapinero while Iola *Bosmina* density was twice that of Sapinero (Figure 27). Intra-basin mean *Diatom* densities averaged over dates and strata were roughly equivalent in all three basins in 1995 (Figure 27).

The macro-scale distribution of *Daphnia* spp. (averaged across all dates for the 0-10 m stratum of each basin) was similar among basins in 1994 and 1995. The 1993 data showed an upreservoir increase in *Daphnia* density when Iola *Daphnia* spp. density was 2.6 times higher, and Cebolla density nearly two times higher than in Sapinero. In 1994 the 0-10 m *Daphnia*

density in Iola was about the same as that of Sapinero (Figure 27). In 1995 the seasonal mean *Daphnia* density in Iola was also similar to Sapinero. In 1994, *Bosmina* density in Iola was 1.5 times that of Sapinero and 2 times greater than Sapinero in 1995. The intra-basin means (averaged across dates) of *Daphnia* densities in the top 10 m of each basin were similar among basins in 1995 as they were in 1994 (unlike 1993). The 1995 overall means by basin were: Sapinero 13.3/L, Cebolla 14.4/L and Iola 11.9/L. These were lower than the 1994 means which were: Sapinero 17.7/L, Cebolla 17.0/L and Iola 15.5/L.

The nature of coarse scale patchiness was estimated for Sapinero basin in 1995 by examining coefficients of variation (CV's) of *Daphnia* density means across replicates taken within dates on May 21 and May 31 at 1995 station 1-00 (1994 station 1; replicates taken approximately 100-300 m apart), and the CV's from the averages of station 1R4, and 1R5 *Daphnia* densities within dates. The distance between Sapinero stations 1R4 and 1R5 was about 350 m. We will have additional information from comparisons between station 1R1, and 1R2 (400 m apart) *Daphnia* densities once the 1R2 sample data are added to the data set.

The average CV of 1995 Sapinero samples taken less than 30 minutes apart and within 400 m of one another was 17% (n=17 CV's). This is the same as the 1994 mean CV (n=19) across sampling dates of the *Daphnia* density estimates per station per date which were computed by averaging three replicate sample densities. The 1994 triple replicated samples were also taken less than 30 minutes apart and within 400 m of one another. The 1995 mean CV across dates of the CV's from means of triple replicated samples in Cebolla and Iola basins was 26% (n=7).

Large scale variability (i.e., within an entire basin) on any given day was somewhat greater than the variation observed among replicate hauls. When the *Daphnia* density estimates from the five Sapinero stations were averaged to obtain a basin density estimate and CV for each sampling date, the mean of these individual-date CV's was 0.35 and ranged from 0.17 to 0.71. This 35% CV is close to the across station CV of 39% which we obtained in Iola basin on July 12, 1994 from 16 randomly chosen stations distributed across the entire basin.

Although station to station variability of *Daphnia* density in Sapinero tended to be fairly high on a given date (Figure 28), when the density estimates for each station were averaged across all dates, the differences among station densities were much less (Figure __ (black bar graph). Furthermore, there did not appear to be any longitudinal spatial gradient in *Daphnia* density in Sapinero (Figure 29) as was found in Iola in July, 1994. *Daphnia* patches appeared to be randomly distributed among the Sapinero stations from date to date. The CV across seasonal mean densities at each station was only 0.117, which is only a third of the 0.352 mean CV across stations per individual date.

Macro-scale variability (among basins) in *Daphnia* densities over the season has varied from as much as a three fold difference from Sapinero to Iola in 1993, to being nearly equal in 1994 and 1995. However, we have seen that inter-basin differences in density have been as much as fifteen fold on individual days in late May 1994 and generally four to five fold differences in

June 1994, 1995 (Figure 30). These large among basin differences in early season *Daphnia* density are due to the differential timing and magnitude of peak *Daphnia* densities among basins. In both 1994, and 1995 Cebolla peak *Daphnia* density was more than twice that of Sapinero. Peak *Daphnia* density in Iola basin in 1994 was also about twice the seasonal peak density in Sapinero.

We could not determine whether or not peak density in Iola exceeded that of Sapinero in 1995 since we may not have sampled Iola at the time of maximum abundance. However, it is probably safe to assume that density peaked in Iola sometime between May 31 and June 24, 1995. It should also be noted that we most likely did not measure peak density in Cebolla, which probably occurred sometime between June 9, and June 30 (Figure 21).

Even though we don't know the exact time that peak *Daphnia* abundance occurred, nor the level it may have attained in Cebolla and Iola, the 1995 data clearly show that peak *Daphnia* abundance in Sapinero was attained one to two weeks prior to the peak in Cebolla (Figure 30). A similar time lag between the peak density in Sapinero, and Cebolla, Iola was seen in 1994. Even in years such as 1994, and 1995 when the seasonal mean *Daphnia* densities were very similar among basins, there can be large differences in *Daphnia* abundance during May and June due to the time lag in peak *Daphnia* density in the upper two basins, and to the level of density achieved (Figure 30).

The upreservoir time lag in peak *Daphnia* abundance can most likely be explained by the heavy suspended sediment load brought into the upper portions of the reservoir by the spring runoff. Suspended particulate matter supplies abundant nutrients to the upper basin, but also creates turbidity which restricts light penetration thereby limiting phytoplankton production (Goldman 1966). Suspended sediments also interfere with *Daphnia* filter feeding. Haney (1971) found that ingestion rates varied along the longitudinal axis of a reservoir in direct proportion to concentration of suspended sediments. Suspended sediments may even reduce food availability for *Daphnia* to starvation levels (Lampert 1977).

Sedimentation of particulate matter creates a down-reservoir gradient of increasing light penetration which allows higher early season algal productivity (Thornton et al.1990). Our data show a downreservoir gradient of increasing secchi depths in May for both 1994, and 1995. On May 21, 1995 secchi depth in Iola was 1.3 m, while Cebolla measured 1.7 m, and Sapinero 3.0 m. Secchi depths for May 21-23, 1994 were 1.5 m in Iola,3.7 m in Cebolla, and 4.5 m in Sapinero (Figure 21).

Decreasing suspended sediment concentrations often result in a downreservoir gradient of increasing autochthonous algae production Thornton et al.(1990). These conditions can result in progressively higher *Daphnia* densities downreservoir during the early part of the season. Thornton et al.(1990) note that zooplankton populations increase near the source of food. On May 21, 1995 the estimated *Daphnia* density was 19.1 *Daphnia* per liter in Sapinero, which was 5.5 times greater than the 3.5/L estimated for Cebolla on the same date (Figure 30). Since we did not

sample Iola on May 21, 1995 we cannot document a longitudinal gradient in *Daphnia* density then. However in May 1994, a downreservoir gradient of increasing *Daphnia* density was observed. On May 21, 1994 *Daphnia* density in the top 15 m of Iola was only 1 daphnid/L, while Cebolla was 10/L, and Sapinero was 15/L.

During the latter part of June in 1994 and 1995 the longitudinal (macro-scale) pattern of density was reversed and much higher abundances of *Daphnia* were found in the two upper basins than in Sapinero. This reversal in longitudinal *Daphnia* distributions can be explained by the different environmental conditions that exist during and after runoff.

Once spring snowmelt subsides suspended sediments precipitate from the water column allowing greater light penetration. The heavy load of dissolved nutrients and colloidal organic matter brought by runoff into the upper portions of the reservoir remains in the epilimnion providing nutrients to phytoplankton. This influx of raw materials in conjunction with clearing water, and increasingly warm temperatures induce an explosion in phytoplankton production (Wetzel, 1983).

The increase in primary production initiates a positive response in secondary production that can "cascade" (sensu Carpenter et al, 1985) up the food chain to benefit tertiary consumers (Carpenter et al, 1985), particularly in mesotrophic lakes (McQueen et al, 1986) such as Blue Mesa Reservoir (Cudlip et al, 1987). When primary production increases, *Daphnia* quickly capitalize on the increase in their food supply and the warmer temperatures which facilitate rapid reproduction (Hall, 1964; Orcutt and Porter, 1984) and increase their numbers dramatically. Their remarkable ability to multiply very rapidly is a life history strategy that allows *Daphnia* to coexist with their predators (O'Brien, 1987),

Our data show examples of this *Daphnia* population explosion. During a 15 day period in June, 1995, *Daphnia* density in the top 10 m of Cebolla increased from 19.3/L on June 9 to 32.5/L on June 24. We have better documentation of this rapid population growth during June, 1994 when we sampled Cebolla biweekly. On May 21, 1994 we measured Cebolla basin *Daphnia* density as 10/L. Two weeks later on June 6, 1994 the estimated *Daphnia* density was 48/L. Inter-basin temperature differences were probably not a factor since on that date there was only a 0.4°C differential among basins in the upper five meter mean temperature of each basin.

Temporal Dynamics- Overall

More intensive *Daphnia* egg counting procedures in 1995 reduced variance in our egg counts by about 50% compared to 1994. Preliminary analysis of data we have now show that mean clutch size was highest in May and then declined over the summer for both *Daphnia pulex* and *Daphnia galeata mendotae* (Table 3). Current data show no increase in mean clutch size for August which is when *Daphnia* density began to increase gradually through September.

The overall abundance of zooplankters declined continuously from June to August (Figures

31). There was a general trend of increasing abundance of zooplankton from mid-August to mid-September. Seasonal dynamics in relative abundance in 1995 were very similar to those found in each of the basins over the 1994 field season. Probably the most notable difference in community structure between the two years is the near absence of *Ceriodaphnia* spp. in 1995. In 1994 *Ceriodaphnia* exhibited a profound increase from mid-August to mid-September as it went from less than 5% of the zooplankton community in late July, to comprising roughly half of the total zooplankton density in mid-September. The 1995 data show that *Ceriodaphnia* were rare until August and increased to only about 5% of the total community in September. The copepod, *Diacyclops*, which was the species that decreased in relative abundance as *Ceriodaphnia* increased in 1994, maintained its proportion of the community at the end of the summer in 1995.

In 1995, relative abundance of *Daphnia pulex* remained fairly constant in Sapinero, and in Iola from early July through September, but decreased slightly in Cebolla toward the end of the season (Figures 32). In 1995, *Daphnia* comprised a larger proportion of the zooplankton community in Cebolla (about 40%) after mid-June than it did during the same time period in 1994 (roughly 20% of total zooplankton). During the 1995 season, *Leptodiptomus* was the only taxon to show a clearly increasing seasonal trend in abundance. *Daphnia pulex* in Iola basin may have increased in proportion in Iola in September. *Leptodiptomus* was rare (<1%) in May through July and increased to about 5-10% of total zooplankton in September 1995 (Figures 31, 32).

Daphnia pulex was more abundant than *Daphnia galeata mendotae* in 1995 at nearly every temporal or spatial scale of analysis. The only exception was early June in Iola basin when *Daphnia pulex* was 20-50% of total *Daphnia* density (Figures 31, 32). Otherwise the proportion of *Daphnia pulex* ranged from 52% in early June in Cebolla (60% in July, 88% in August) to 92% in August in Iola basin. Proportion of *D. pulex* in Sapinero basin ranged 62-83% for the entire season which was greater than the proportion of Sapinero *Daphnia* in 1994 which was 47-72%. The overall average (across all times, locations) percentage of *Daphnia* that were *D. pulex* was 67%, compared 65% in 1994.

Temporal Dynamics- Seasonal/Vertical

Daphnia spp remained consistently more abundant in the upper depth strata throughout the season in all basins. The pattern of fluctuations in *Daphnia* density in the top ten meters of the water column in Sapinero was similar in 1994 and 1995 (Figures 30). In fact, the only differences are exact dates of the maximum and the two minima, and the magnitude of maxima and minima.

Daphnia density in Cebolla and Iola also show a minimum in late July/early August and increasing density after the early August nadir. However, in Cebolla this increase does not last as density begins to drop again in mid August (Figure 30). Interestingly, the 1994 data also show that Cebolla was the only basin not to show increasing *Daphnia* density in late August through September. *Daphnia* density was nearly equivalent in all three basins from mid-July to mid-August (Figure 30).

The relative abundance of *Daphnia* spp. in 1995 shows the same general pattern over the season as in 1994 (Figures 32). In 1995 *Daphnia* started out at about 40% of the total zooplankton community in Sapinero, and at only about 10% in Cebolla and Iola, and then increased to become roughly 40% (20% in 1994) in mid-June. Thereafter, *Daphnia* retained their relative proportion in the community until September.

The data suggest that in spring *Daphnia* density increases first in the 0-5 m stratum, followed by an elevated rate of increase in the 5-10 m stratum which narrows the density difference between these two strata in subsequent days (Figures 33-36). During the spring period of rapidly increasing density, density in the 5-10 m stratum in both Cebolla and Iola was about 25% of the density in the 0-5 m stratum. Two weeks later in each basin density in the 5-10 m stratum was 62% of density in the 0-5 m stratum.

Temporal Dynamics- Seasonal/Horizontal

Mean length declined by about 20% for both *Daphnia* species in early June in Cebolla and Sapinero basins, followed by a period of increase in mean length then another drop in mean length in late July (Figure 37). These are not large changes and are only mentioned because they occur in both basins and species at the same time. The mean length of *Daphnia galeata mendotae* increased by about 30% from May 21 to June 21 then dropped again by about 20% to another low in early August. Since we have not yet statistically tested these data we can't make inferences as to the significance of these patterns at this time.

Large *Daphnia* are the principal prey of kokanee. *Daphnia* > 1.5 mm in length in the top 30 m averaged about 0.5/L over the sampling season and ranged from < 1/L to 2.5/L (Figure 38).

Conclusions - Zooplankton

As was the case in 1994, the current evidence seems to indicate that kokanee did not have a strong influence on the zooplankton community in 1995. The spatial and temporal zooplankton patterns we observed can be explained without invoking planktivory as a factor. For example, the differential timing and magnitude of peak *Daphnia* abundance among basins can be explained by bottom-up factors in the food web. It is possible that planktivory may be a factor in the zooplankton population and community dynamics that we observed; however, so far there is little evidence to support this hypothesis.

The Size Efficiency Hypothesis (Brooks and Dodson, 1965), has been cited to explain increases in the relative abundance of small cladocerans (Brooks and Dodson, 1965). Dynamic community patterns like the progressive yearly increase in the relative abundance of *Bosmina* spp. seen in BMR in 1993-1995, or the increase in *Ceriodaphnia* spp. that was observed near the end of the season in 1994, are examples of the types of community changes that could be explained by the Size Efficiency Hypothesis. This hypothesis predicts that smaller cladocerans such as *Bosmina* and *Ceriodaphnia* will to increase due to competitive release as planktivores reduce abundance of large, filter feeding *Daphnia* such as *Daphnia pulex*. *Daphnia* densities do appear

to be negatively correlated to *Bosmina* densities in BMR in 1994, and 1995.

However, Naumann (1921) and more recent papers (Neill 1975; Lynch 1978, 1979; Kerfoot and DeMott 1980; Bogdan and Gilbert 1982; DeMott 1982; DeMott and Kerfoot 1982) support an alternative explanation for the relative increase in *Bosmina* founded on the following aspects of *Bosmina/Daphnia* ecology. *Bosmina* utilize a mode of feeding which allows them to feed more selectively than *Daphnia* (Naumann 1921; DeMott and Kerfoot 1982). In addition, *Bosmina*'s manner of feeding is highly motile, in contrast to *Daphnia* spp., which remain more or less stationary as they feed (Naumann 1921). When the food supply is patchily distributed, *Bosmina*'s high feeding mobility enables them to better exploit the food resource and gives them an advantage over *Daphnia* spp. (DeMott and Kerfoot 1982). While we do not have the necessary resolution in our phytoplankton data to evaluate this explanation, our current evidence supporting planktivory as a factor in the early season dominance of *Bosmina* appears rather weak.

Evidence for planktivore effects on daphnids are not compelling either. Currently, all indications are that kokanee are not exerting a strong effect on the abundance of *Daphnia pulex*, their principal prey item. *Daphnia pulex* remained dominant over *D. galeata mendotae* from mid-June to mid-September in both 1994 and 1995. This pattern would not be expected if kokanee were exerting control over *D. pulex* abundance. The lack of any salient decreases in the proportion of *D. pulex* in the total zooplankton community does not support top-down control of *Daphnia pulex* by kokanee. Further, creel data suggest that kokanee abundance in 1995 was lower than in 1994, yet there was also a slight decrease in overall *Daphnia* density from 1994 to 1995. If kokanee had been exerting any control over *Daphnia* abundance in 1994, then with fewer kokanee in 1995, one would expect a higher *Daphnia* density in 1995, not a lower one. The fact that the temporal population dynamics of *Daphnia* were so similar in 1994, and 1995 while kokanee abundance declined, may be an indication that *Daphnia* spp. population dynamics in these years were primarily controlled by similar environmental factors rather than planktivory.

Part 2. Fishery Investigations

METHODS

Vertical Gill Netting

Vertical gill netting was conducted during four dates in June at Sapinero basin to study day-night distributions, and to gather diet and growth information. We netted on four dates in July in all three basins, again to study day-night distributions, and to gather diet and growth information, but also to complement hydroacoustic surveys performed by CSU, CDOW, and USBOR personnel. We set nets on three dates in September in all three basins. A gang of nets was fished during day or nighttime hours at a midlake station (Table 2). Nets floated on the surface and extended to within about 1-2 m of the lake bottom. Nets measured 60 m long and 3 m wide and were constructed with two mesh sizes (0.5 in, 0.75 in, 1.0 in, 1.25 in, 1.5 in, or 2.0 in) per net. Depth at which each fish was caught was recorded. Gill net caught fish were measured and weighed. Otoliths and stomachs were removed from all kokanee and a subsample of other salmonids. Head lengths were taken to develop a head length:body length regression model for use in the entrainment study.

Diet and Growth Analysis

Kokanee stomach samples were obtained during May-September from vertical gill net sampling and by sampling the angler catch at cleaning stations at each lake basin. We sampled Sapinero more intensively (12 dates) than either Cebolla (6 dates) or Iola (3 dates) basins to complement the zooplankton production dynamics work being conducted in Sapinero. Stomachs were excised and preserved in 10% formalin. Kokanee samples were grouped into three size classes (<250 mm, 250-349 mm, or >349 mm); approximately five stomachs from fish of each size class from each date and sampling location were aggregated for analysis.

Proportions (by volume) of fish, macroinvertebrate, and zooplankton were visually estimated. Non-zooplankton prey were preserved for future analysis. The zooplankton contents were diluted to a density that would yield approximately 20-30 measurable zooplankters, and one aliquot was placed in a Sedgwick-Rafter cell. All identifiable organisms were counted. Cladocerans of genera *Ceriodaphnia*, *Bosmina*, *Diaphanosoma*, were all lumped into a group called "other *Daphnia*" and counted as such. *Daphnia* were identified to species if possible. The first 10 specimens of each *Daphnia* species encountered was measured. When there was only one species of *Daphnia* present the first 20 individuals of that species was measured. Only *Daphnia* with an intact carapace were measured. If after counting the entire slide 10 measurements of each *Daphnia* species was not obtained we went back through the slide and measured *Daphnia* (the ones that were passed over because they were not identifiable to species) until a total of 20 *Daphnia* measurements were taken and recorded. Copepods were counted and not identified further because of their rarity in diets.

We took scale samples from kokanee sampled in vertical gill nets, and from a stratified (by length) sample of fish in the anglers' creel. A complete complement of otoliths across all kokanee

sizes was also taken, and provided to Pat Martinez, CDOW. Scales were pressed onto acetate slides and examined in a microfiche reader at about 42X. Each scale was read by two trained scale readers. Annuli were determined and scale radii were measured to develop a scale-body length relationship. We transformed the scale/body length data and fit a Fraser-Lee function that we used in backcalculations (Everhart and Youngs 1981). Scale samples obtained by CDOW in 1989 were read by CSU undergraduate Dave Shuler. Historic data on kokanee backcalculated length at age were obtained from Wiltzius (1971, 1974).

Hydroacoustics

A BioSonics ES-105 dual beam echo sounder and 420 kHz with 6/15° transducer mounted in a towed body were used to collect hydroacoustic data at night during the new moon on 23-24 July. Data were recorded on a digital audio tape recorder and processed using BioSonics Echo Signal Processing software, by Richard Thorne of BioSonics, Seattle, Washington. Transects (Table 5) coincided with those employed by CDOW on the same nights.

We also performed transects with a Lowrance X-16 computer depth sounder to evaluate its utility in studying diel vertical migrations of fishes. Transects were performed at day and night in Sapinero basin on June 28-29, at night only in Cebolla and Iola basins in July, at dawn and dusk in Sapinero on August 8-9, and during the day and night at Sapinero on August 16 and 24. Colorado State University undergraduate student Derrek Faber compared the results from Lowrance transects with vertical gill netting, and is preparing an independent study project report on his findings.

RESULTS AND DISCUSSION

Vertical Gill Netting

Kokanee salmon comprised between 57-88% of all fish captured in experimental vertical gill nets (Figures 39-41, Appendix Table A1), a somewhat lower fraction than observed in 1994. About 28% of the catch in June was brown trout, 9.2% lake trout, and suckers and rainbow trout each comprised 1-2% of the June catch (Table A1). In July lake trout were about 1% of the catch and rainbow trout 4%; in September lake trout increased to 3.2% and rainbow trout catch remained the same (Table A1). In all months over 90% of the catch was of fish <450 mm (Figures 39-41).

Greater than 80% of the fish caught in June were taken in water <20 m deep (Table A2-A9). Kokanee were normally distributed throughout the top 20 m with the mode at about 10 m in June. During July the majority of the catch was taken in 10-40 m depths and in September fish were normally distributed throughout the water column between 10-50 m, with a mode at 20 m (Table A2-A9). Rainbow trout were always caught in water <10 m deep. Six lake trout were caught between 5 and 30 in June and July; four lake trout in September were caught at 45-50 m.

Diet and Growth Analysis

The preferred prey of kokanee is *Daphnia pulex* (Finnell and Reed 1969). Blue Mesa kokanee of all sizes were highly selective for their preferred prey at all basins, through the entire season. Just as in 1994, kokanee consumed about 97% *Daphnia pulex* and 3% *Daphnia galeata*. Only trace quantities of copepods were found in a few kokanee stomachs. Kokanee were also selective for the larger individuals among the zooplankton populations. Kokanee in BMR fed almost exclusively on *Daphnia pulex* over 1.5 mm in length in 1994 and 1995. Reservoir densities of *D. pulex* in this size class ranged between $< 1/L$ and $2.5/L$ for all sampling dates. The mean size of *Daphnia pulex* in kokanee stomachs was always greater than the mean size of *D. pulex* in the lake (Figures 42-44). During June and July there was little or no overlap between the lower 25th percentile of *D. pulex* size in guts and the mean of *D. pulex* in the lake at all three basins (Figures 42-44). The abundance of *Daphnia* over 1.5 mm may be an important variable in quantifying food resources for kokanee.

The extreme selectivity of kokanee for only the largest individuals of a single species of zooplankton, when high densities of other species and size classes were present, suggests that the kokanee population is not food limited, and that during summer kokanee are well below the food-imposed carrying capacity of the lake.

Based on scale samples, the backcalculated mean length-at-age of kokanee has changed little since the reservoir was impounded (Figure 45, Table 4). Growth of age-1 kokanee appeared to be greatest in 1989 and least in 1966-69. We have yet to compare scale ages with those obtained from otoliths so these conclusions should be considered until this validation exercise is completed. Backcalculation will allow us evaluate the potential influence of the reservoir's water budget on growth, as water records and scale samples are available for a large number of years.

Hydroacoustics

Results of hydroacoustics surveys conducted during the August 1994 survey are provided in Figures 46-49. Fish density (fish/1,000 m³) was lowest in Sapinero basin, intermediate in Cebolla, and highest in Iola basin. Fish density was highest in the 20-25 m stratum in each basin, and ranged 4-12 fish/1,000 m³.

Maximum target strengths were observed at 20-35 m in each basin. Average target strength within a stratum ranged from about -65 to -42 dB at Sapinero, from -60 to -42 dB at Cebolla, and from -55 to -44 dB at Iola. Smallest mean target strengths always occurred in depths of 2-10 m. Many of the targets acquired in the 2-10 m strata are probable zooplankton concentrations rather than fish. Zooplankton sampling showed maximum plankter densities in the top 10 m of the water column in all basins during July. We hope to compare results of the BioSonics survey with those obtained by CDOW and BOR researchers using different hydroacoustics systems.

We found surprisingly good correspondence between fish depth distributions measured by the Lowrance depth sounder and the vertical gill nets in day-night comparisons during June and among basins at night during July (Figure 50-51). However, the Lowrance measurements consistently underestimated the proportion of fish below 20 m, as compared to vertical gill nets.

Part 3. Reservoir Thermal Ecology

METHODS

Thermal Stratification Model

We are implementing and calibrating a reservoir thermal stratification model called CE-THERM (Environmental Laboratory 1986) for Blue Mesa Reservoir. This model is actually a subroutine in the larger model CE-QUAL, a thermal-biological-chemical model for studying vertical distribution of energy and materials in reservoirs. The basic framework of CE-THERM is a heat budget and hydrodynamic equations that distribute the heat in the water column. The heat budget requires the following primary inputs: quantity and temperature of water inflow and outflow, daily meteorologic data (wind, cloud cover, air temperature, etc.), and water quality parameters (water transparency and total dissolved solids, suspended solids, etc.). Insolation, conduction, evaporation, diffusion and entrainment are among the physical processes that are explicitly incorporated in the model (Figure 52).

Paul Weiss, CSU Civil Engineering graduate student, has developed a regression model relating air and tributary temperatures, that was used to generate predictions for the 1994 stratified period. In 1995 we deployed electronic temperature loggers at 4 input streams and 1 at the reservoir outflow to refine estimates of aquatic thermal inputs and outputs.

Reservoir Bioenergetics

We are applying bioenergetics models (Hewett and Johnson 1992; Bevelhimer and Adams 1993) to examine the influence of various reservoir thermal stratification patterns on fish and invertebrate trophic dynamics, habitat quality, and hypothetical depth distributions of the organisms. These models provide the linkage between abiotic effects of climate/reservoir operations and biotic responses of the pelagic consumer assemblage.

Bioenergetics models use principles of thermodynamics and physiology to construct energy budgets for individuals and populations of aquatic consumers (Brett 1971, Kitchell et al. 1974). Bioenergetics models compute the energy budget based on a mass balance equation relating consumption to respiratory costs, wastes products, and growth:

$$C = R_s + R_a + SDA + F + U + \Delta B$$

where: C is amount of food consumed
R_s is standard metabolic costs
R_a is metabolic costs of activity
SDA is specific dynamic action (apparent heat increment)
F is amount of egestion (feces)

U is amount of excretion (nitrogenous wastes)
 ΔB is change in body weight (growth)

Extensive research has provided species-specific functions for modeling consumption, respiration, egestion/excretion of over 25 species of fish and invertebrates. Models have been parameterized for all the major components of the BMR foodweb: kokanee salmon, lake trout, rainbow trout, and *Mysis relicta*.

To implement the model we input age-specific estimates of growth rate, diet composition, and abundance with seasonal water temperature data (i.e., thermal history) for each scenario into a simulation package containing all the necessary physiological functions and species-specific parameters (Hewett and Johnson 1992). The model computes the components of the fish energy budget on a daily time step. Data on 44 demographic and physiological variables, including the biomass of each prey type consumed each day by each fish in the simulation, are recorded. We are using an alternative formulation of the same basic framework that computes the energy budget on a 30-minute timestep for kokanee salmon (Bevelhimer and Adams 1993), allowing us to study the physiological effects of diel vertical migration on growth and consumption.

When the models are run with the consumption rate set to the physiological maximum for a given temperature and body size (C_{max}) they can be used to compute the theoretical upper bound on the net energy gain possible (scope for growth) for those conditions. We are using this approach to evaluate pelagic habitat quality based on temperature and food density patterns arising from reservoir operations and climatic influences.

To simulate the warming effect of reservoir reoperation in a dry year or the effect of global climate change we increased 1995 epilimnial temperatures by up to 2°C. For each sampling date during May and June 1995, two degrees celsius was added to observed temperatures from 0-10 m depth. Temperature additions from 10-25 m depth were (approximately) exponentially decreased from two degrees so that the simulated temperature at 25 m depth was the same as the observed temperature at that depth. For each sampling date after June, observed surface temperature plus two degrees celsius was used as the mean epilimnetic temperature down to approximately 10 m depth. This was done to simulate a deepening of the epilimnion expected with global climate warming and possible alterations in dam operations. Temperatures between 10-25 m depth were altered to simulate a strong thermocline, with temperature at 25 m depth similar to the observed temperature at that depth. Observed temperatures at depths > 25 m were used in the simulation.

RESULTS AND DISCUSSION

Thermal Stratification Model

Model parameterization and calibrations using all available 1994 data are complete, and we were able to obtain close agreement between simulated and observed temperature profiles.

The model with these coefficients was used to predict 1995 stratification at biweekly intervals with considerable success. Some refinements of parameters are still needed (e.g., better data on wind speed and direction, and air light extinction coefficients). We will attempt to improve our input measurements in 1996, and will deploy temperature loggers in major tributaries this May. We will complete model calibration and sensitivity analysis this year, and conduct simulations to predict the influence of various climate and reservoir operation scenarios on thermal stratification.

Reservoir Bioenergetics

As a preliminary investigation into the ecological effects of reservoir warming we have computed the maximum scope for growth of two sizes of kokanee throughout the water column at two thermal regimes: 1) 1995 observed water temperatures, and 2) 1995 plus 2°C in the epilimnion (Figure 53). Maximum scope for growth of large (750 g) kokanee occurs at greater depths than for small (100 g) kokanee because optimal physiological temperatures decrease with increasing body size in fishes. In a warmer reservoir both sizes of kokanee exhibit about a 40% decrease in the size of the zone of maximal scope for growth (Figure 53). Profitability (in terms of scope for growth) of the top 15 m decreases greatly in the plus-2°C scenario for both large and small kokanee.

These results suggest that relatively small increases in the reservoir thermal regime could have large consequences for consumption and growth of kokanee. These simulations are independent of food density, i.e., are driven solely by water temperature. Ecological effects could be compounded by increasing epilimnial temperatures which prevent kokanee from accessing the upper 10 m of the water column, a zone we have documented to contain a vast majority of the *Daphnia pulex* biomass in the reservoir. Our work in 1996 is incorporating predator-prey interactions to provide a more comprehensive analysis, focusing on the interaction between temperature and prey distribution.

RECOMMENDATIONS FOR FUTURE STUDY YEARS

We should continue with work predicting the importance of climate on reservoir structure and function by implementing a reservoir thermal model that predicts thermal structure from weather data, inflow volume and temperatures, and discharge patterns. Continuing to refine links between direct physical effects of reservoir reoperation with the ecological implications via bioenergetics modeling approaches will be insightful. This framework is allowing us to study to potential interplay between direct anthropogenic and climatic influences in determining reservoir trophic dynamics and productivity, and also to forecast some implications of global climatic change for reservoir management. We should continue our collaboration with national experts in reservoir thermal modeling at the Civil Engineering Department at CSU to study reservoir operations influences on the thermal structure of the lake and its food web.

To improve inputs to the thermal models and thereby improve model predictions, we must acquire additional equipment. A light intensity meter is needed to measure incident solar radiation and light extinction in the water column. Because wind is a dominant physical force in the models, a recording device to gather more accurate measures of wind speed and direction is required. A towable temperature logger would allow us to study the horizontal and vertical thermal structure of the reservoir simultaneously, to corroborate model predictions.

Work on Blue Mesa Reservoir should continue for several reasons. Blue Mesa is one of the top kokanee salmon fisheries in the world, and a significant proportion of the Colorado's sport fishery resource. There are indications that the BMR fish assemblage is changing. Kokanee abundance may be declining, while piscivorous lake trout have increased dramatically. We should continue to gather information on fish abundance, diet, and growth rates. Creel survey information will be needed to obtain information on mortality rates. The sampling program implemented in 1994 to gather fish stomach samples and growth information from angler caught fish should be continued. Hydroacoustics surveys for estimating fish abundance and distribution, and vertical gillnetting for "groundtruthing" hydroacoustics data, species identification and to provide diet samples should be continued.

A wealth of data and understanding of reservoir patterns and processes has accumulated during this project. Blue Mesa is serving as a proving ground for modeling techniques being implemented to link physical and biological processes. Additional study years with a wider range of environmental conditions than have already been observed would strengthen the evaluation of this approach. As western reservoir water management policies and objectives change, these techniques could prove to be invaluable for assessing ecological responses to reservoir reoperation.

LITERATURE CITED

- Axler, R.P. and C.J. Owen. 1994. Measuring chlorophyll and phaeophytin: whom should you believe? *Lake and Reservoir Management* 8:143-151.
- Bevelhimer, M. S. and S. M. Adams. 1993. A bioenergetics analysis of diel vertical migration by kokanee salmon, *Oncorhynchus nerka*. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2336-2349.
- Bogdan, K. G., and J. J. Gilbert. 1982. Seasonal patterns of feeding by natural populations of *Keratella*, *Polyarthra*, and *Bosmina*: clearance rates, selectivities and contributions to community grazing. *Limnology and Oceanography* 27:918-934.
- Brett, J. R. 1971. Energetic responses of salmon to temperature: a study of the thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). *American Zoologist* 11:99-113.
- Carpenter, S.R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity: fish predation and herbivory can regulate lake ecosystems. *Bioscience* 35:634-639.
- Cole, G.A. 1983. *Textbook of Limnology*. Third Edition. Waveland Press, Inc. Prospect Heights, Illinois.
- Cudlip, L.S., R.D. French, and D. Hickman. 1987. Blue Mesa Reservoir, Colorado: a historical review of its limnology, 1965-1985. U.S. Bureau of Reclamation Technical Report 85-9, Denver, CO.
- de Bernardi, R., P. Lacua and E. Soldavini. 1978. Effects of temperature and food on development times and growth in *Daphnia obtusa* Kurz and *Simocephalus vetulus* (O. F. Muller) (Crustacea, Cladocera). *Memorie dell'Istituto Itaiano di Idrobiologia* 36: 171-191.
- DeMott, W.R. 1980. An analysis of the precision of birth and death rate estimates for egg-bearing zooplankters. Pages 337-345 in W.C. Kerfoot, editor. *Evolution and ecology of zooplankton communities*. University Press of New England, Hanover, New Hampshire.
- DeMott, W. R. 1982. Feeding selectivities and relative ingestion rates of *Daphnia* and *Bosmina*. *Limnology and Oceanography* 27:518-527.
- DeMott, W.R., and W. C. Kerfoot. 1982. Competition among cladocerans: nature of the interation between *Bosmina* and *Daphnia*. *Ecology* 63:1949-1966.
- Edmondson, W.T. 1980. Secchi disc and chlorophyll. *Limnology and Oceanography* 25:378-

- Edmondson, W. T. 1968. A graphical model for evaluating the use of the egg ratio for measuring birth and death rates. *Oecologia* 1:1-37.
- Environmental Laboratory. 1986. CE-QUAL-R1: A numerical one-dimensional model of reservoir water quality; user's manual. Instruction Report E-82-1 (Revised), U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
- Everhart, W.H. and W.D. Youngs. 1981. Principles of fishery science. 2nd edition. Cornell University Press.
- Finnell, L. M., and E.B. Reed. 1969. The diel vertical movements of kokanee salmon (*Oncorhynchus nerka*), in Granby Reservoir, Colorado. *Transactions of the American Fisheries Society* 98:245-252.
- Goldman, C. R. 1966. Primary productivity in aquatic environments. University of California Press, Berkeley,
- Hall, D.J. 1964. An experimental approach to the dynamics of a natural population of *Daphnia galeata mendotae*. *Ecology* 45:94-112.
- Haney, J.F. 1971. An in situ method for measurement of zooplankton grazing rates. *Limnology and Oceanography* 13:476-484.
- Hewett, S.W. and B.L. Johnson. 1992. A generalized bioenergetics model of fish growth for microcomputers, Model 2. University of Wisconsin, Sea Grant Report WIS-SG-92-250, Madison.
- Holm-Hansen, O. and B. Riemann. 1978. Chlorophyll a determination: improvements in methodology. *Oikos* 30:438-447.
- Kerfoot, W.C., and W. R. DeMott. 1980. Foundations for evaluating community interactions: the use of enclosures to investigate the coexistence of *Daphnia* and *Bosmina*. Pages 725-741 in W. C. Kerfoot, editor. *Evolution and ecology of zooplankton communities*. University Press of New England, Hanover, New Hampshire.
- Kitchell, J.F., J.F. Koonce, R.V. O'Neill, H.H. Shugart, Jr., J.J. Magnuson, and R.S. Booth. 1974. Model of fish biomass dynamics. *Transactions of the American Fisheries Society* 103:786-798.
- Lampert, W. 1977. Studies on the carbon balance of *Daphnia pulex* as related to environmental conditions. IV. Determination of the "threshold" concentration as a factor controlling the

- abundance of zooplankton species. Arch. Hydrobiol. suppl. 48:361-368.
- Lind, O.T. 1979. Handbook of common methods in limnology, second edition. C.V. Mosby, Co., Saint Louis, MO.
- Lynch, M. 1978. Complex interactions between natural coexploiters-*Daphnia* and *Ceriodaphnia*. Ecology 59:552-564.
- Lynch, M. 1979. Predation, competition, and zooplankton community structure: an experimental study. Limnology and Oceanography 24:253-272.
- Marker, A.F.H., E.A. Nusch, H. Rai, and B. Riemann. 1980. The measurement of photosynthetic pigments in freshwater and standardization of methods: conclusions and recommendations. Arch. Hydrobiol. Beih. Ergebn. Limnol. 14:91-106.
- McQueen, D.J., J.R. Post, and E.L. Mills. 1986. Trophic relationships in freshwater pelagic ecosystems. Canadian Journal of Fisheries and Aquatic Sciences 43:1571-1581.
- Mills, E.L., and A. Schiavone, Jr. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. North American Journal of Fisheries Management 2:14-27.
- Naumann, E. 1921. Spezielle Untersuchungen über die Ernährungsbiologie destierischen Limnoplanktons. I. Über die Technik des Nahrungserwerbs bei den Cladoceran und ihre Bedeutung für die Biologie der Gewassertypen. Kungliga Fysiografiska Sällskapet I Lund Forhandlingar 32:1-27.
- Neill, W. E. 1975. Experimental studies of microcrustacean competition, community composition and efficiency of resource utilization. Ecology 56:809-826.
- O'Brien, W. J. 1987. The predator-prey interaction of planktivorous fish and zooplankton: recent research with planktivorous fish and their zooplankton prey shows the evolutionary thrust and pary of the predator-prey relationship. American Scientist 67:572-581.
- Orcutt, J.D., and K.G. Porter. 1984. The synergistic effects of temperature and food concentration on life history parameters of *Daphnia*. Oecologia 63:300-306.
- Paloheimo, J. E. 1974. Calculation of instantaneous birth rate. Limnology and Oceanography 19:692-694.
- Pinel-Alloul, B. 1995. Spatial heterogeneity as a multiscale characteristic of zooplankton community. Hydrobiologia 300/301: 17-42.

- Riemann, B. 1980. A note on the use of methanol as an extraction solvent for chlorophyll a determination. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 14:70-78.
- Soranno, P.A. and S.E. Knight. 1993. *Methods of the Cascading Trophic Interactions Project.* University of Wisconsin, Center for Limnology, Madison, WI.
- Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. *Reservoir limnology: ecological perspectives.* John Wiley and Sons, New York, NY.
- Wetzel, R.G. and G.E. Likens. 1991. *Limnological Analyses.* Springer-Verlag, New York.
- Wiltzius, W.J. 1974. *Final Report: Post-impoundment Fishery Investigations, Curecanti Unit, Upper Colorado Storage Project, Colorado Division of Wildlife, Fort Collins, Co.*
- Wiltzius, W.J. 1971. *Job Completion Report: Post-impoundment Fishery Investigations, Curecanti Unit, Upper Colorado Storage Project, Colorado Division of Wildlife, Fort Collins, Co.*

LIST OF TABLES

- Table 1. Overview of sampling conducted on Blue Mesa Reservoir in 1995.
- Table 2a. Location of standard sampling stations on Blue Mesa Reservoir visited during 1994 and 1995. GPS coordinates were recorded using Garmen GPS-75 without differential correction
- Table 2b. Location of randomly selected, Sapinero basin sampling stations established on Blue Mesa Reservoir and visited during June through September, 1995. GPS coordinates were recorded using Garmen GPS-75 without differential correction.
- Table 3. Mean *Daphnia* egg counts and coefficients of variation (CV) grouped by month, station, or depth stratum in 1995. The 0-5, 5-10, 10-15, and 15-30m strata were sampled only on the first two sampling dates (May 21 and 31). During June through September, 0-10 and 10-30m samples were taken..
- Table 4. Backcalculated mean lengths at age for kokanee from Blue Mesa Reservoir. Backcalculations performed using the transformed Fraser-Lee method, $v=0.7073$. N Obs is the number of fish of a given age in the sample; N is the number of scale measurements at a given annulus obtained from the sample.
- Table 5. Standardized transects used during hydroacoustics surveys at Blue Mesa Reservoir during June, August, and October 1994 and July 1995.

Table 1. Overview of sampling conducted by CSU on Blue Mesa Reservoir in 1995.

Parameter	Standard Monitoring
Temperature*	Profiles At two to three week intervals May-Aug, at sites 3, 5. Weekly at site 1-R3 Jun-Aug. Every three weeks at the dam May-Aug. Monthly in Sep at all four sites.
Dissolved oxygen	Profiles At two to three week intervals May-Aug, at sites 3, 5. Weekly at site 1-R3 Jun-Aug. Monthly in Sep at sites 1-R3, 3, 5.
Secchi depth	Measurements At two to three week intervals May-Aug, at sites 3, 5. Weekly at site 1-R3 Jun-Aug. Monthly in Sep at sites 1-R3, 3, 5.
Chlorophyll	0-10 m Integrated Water Column Samples At two to three week intervals May-Aug, at sites 3, 5. Weekly at site 1-R3 Jun-Aug. Monthly in Sep at sites 1-R3, 3, 5.
Zooplankton	Depth-stratified Samples Three replicate hauls per site at sites 3 and 5. One replicate haul at each of the six Sapinero sites, 1-R1...1-R6. At two to three week intervals May-Aug, at sites 3, 5. Weekly at sites 1-R3...1-R6 Jun-Aug. Monthly in Sep at all eight sites.
Fish (salmonids)	Vertical Gill Nets (six meshes) 11 sets: one-two nights per basin in June, July, September. Diet Sampling at fish cleaning stations every two weeks at each basin.
Hydroacoustics	Lakewide Survey Three basins during 23-24 July Diel Vertical Migration Study Transects in Sapinero on 28 June
Stream Temperatures	Maintained temperature loggers in the Gunnison River input, Lake Fork of the Gunnison, Cebolla Cr., Soap Cr., and the Gunnison River tailwater May-Sept.

*Intensive temperature measurements made at three sites in Soap Creek Arm, four in Lake Fork Arm on 07-Jul.

Table 2a. Location of sampling stations established on Blue Mesa Reservoir and visited during 1994, 1995. GPS coordinates were recorded using Garmen GPS-75 without differential correction.

Station Name	Purpose	Depth (m)	Waypoint Name	GPS Coordinates (UTM)		
				Zone	Easting	Northing
Iola Basin	Zooplankton, chlorophyll, temp-DO profiles, secchi	20	IOLAZP	13 S	0317192	4260939
Iola VGN	Vertical gill nets	21	IOLVGN	13 S	0317379	4260984
Cebolla Basin	Zooplankton, chlorophyll, temp-DO profiles, secchi		CEBZP	13 S	0308310	4261123
Cebolla VGN	Vertical gill nets	50	CEBVGN	13 S	0308329	4261032
Cebolla Arm VGN	Vertical gill nets	23	none	13 S	0308400	4257900
Sapinero Basin (May only, #1)	Zooplankton, chlorophyll, temp-DO profiles, secchi		SAPZP	13 S	0298077	4259910
Sapinero VGN	Vertical gill nets	54	SAPVGN	13 S	0297774	4259573

Table 2b. Location of randomly selected, Sapinero basin sampling stations established on Blue Mesa Reservoir and visited during June through September, 1995. GPS coordinates were recorded using Garmen GPS-75 without differential correction.

Station Name	Purpose	Depth (m)	Waypoint Name	GPS Coordinates (UTM)		
				Zone	Easting	Northing
Sapinero, 1-R1	Zooplankton	95	ZP1	13 S	0296900	4259000
Sapinero, 1-R2	Zooplankton	45	ZP2	13 S	0297400	4259100
Sapinero, 1-R3	Zooplankton, chlorophyll, temp-DO profiles, secchi	95	ZP3	13 S	0298400	4260000
Sapinero, 1-R4	Zooplankton	40	ZP4	13 S	0300600	4260500
Sapinero, 1-R5	Zooplankton	50	ZP5	13 S	0300900	4260500
Sapinero, 1-R6	Zooplankton	55	ZP6	13 S	0302700	4260400

Table 3. Mean *Daphnia* egg counts and coefficients of variation (CV) grouped by month, station, or depth stratum in 1995. The 0-5, 5-10, 10-15, and 15-30m strata were sampled only on the first two sampling dates (May 21 and 31). During June through September, 0-10 and 10-30m samples were taken.

Class	<i>Daphnia galeata mendotae</i>		<i>Daphnia pulex</i>	
	Mean	CV	Mean	CV
May	3.25	0.70	2.59	0.83
June	1.37	0.56	1.8	0.55
July	1.00	0.00	1.88	0.59
Aug	1.27	0.37	1.16	0.32
Sept	1.00	0.00	1.00	0.00
Sapinero basin	1.56	0.71	1.91	0.61
Cebolla basin	1.67	0.79	2.55	1.23
Iola basin	2.93	0.96	1.74	0.75
0-5 m	4.37	0.86	3.13	0.79
5-10 m	2.56	0.51	2.22	0.68
10-15 m	2.30	0.46	1.85	0.53
15-30 m	2.00	0.71	3.23	0.87
0-10m	1.23	0.44	1.42	0.49
10-30m	1.08	0.26	1.96	0.59

Table 4. Backcalculated mean lengths at age for kokanee from Blue Mesa Reservoir. Backcalculations performed using the transformed Fraser-Lee method, $v=0.7073$. N Obs is the number of fish of a given age in the sample; N is the number of scale measurements at a given annulus obtained from the sample.

Year	Actual Age	N Obs	Backcalculation Age	Mean Length	N	Std Error	
1989	1	3	1	186.8	3	5.72	
			2	1	199.9	132	2.02
				2	269.8	132	2.64
	3	44	1	186.4	44	3.54	
			2	262.7	44	4.59	
			3	326.1	44	3.83	
	1994	1	18	1	177.2	18	5.99
				2	285.9	15	7.49
		2	15	1	199.2	15	9.01
2				285.9	15	7.49	
3				326.0	1	.	
3		1	1	175.5	1	.	
			2	290.6	1	.	
			3	326.0	1	.	
1995		1	66	1	167.2	66	3.56
	2			247.3	123	4.58	
	2	124	1	165.5	124	3.05	
			2	247.3	123	4.58	
			3	330.5	54	5.27	
	3	54	1	169.3	54	3.80	
			2	260.2	54	6.57	
			3	330.5	54	5.27	
	4	5	1	158.1	5	10.7	
			2	242.1	5	12.1	
			3	322.4	5	17.1	
			4	366.8	5	14.5	

Table 5. Standardized transects used during hydroacoustics surveys at Blue Mesa Reservoir during June, August, and October 1994 and July 1995.

Lake Basin	Waypoint Name	UTM Zone	UTM Easting	UTM Northing	Transect Length (m)	Approx. time (min.)
Iola	DOW017	13 S	0319284	4261659	Start	0
	DOW018	13 S	0318334	4260700	1350	14
	DOW019	13 S	0317055	4261339	1430	17
	DOW020	13 S	0316129	4260128	1524	16
	DOW021	13 S	0313657	4259509	?	27
Cebolla	DOW107	13 S	0310067	4259394	Start	0
	DOW108	13 S	0309284	4260817	1624	17
	DOW007	13 S	0307782	4261437	1666	18
	DOW109	13 S	0307404	4259814	1603	18
	DOW110	13 S	0306220	4260894	1582	16
	DOW111	13 S	0305332	4259585	2970	20
Sapinero	DOW010	13 S	0302448	4260294	Start	0
	DOW011	13 S	0301536	4261506	1517	19
	DOW012	13 S	0300093	4260623	1692	18
	DOW013	13 S	0299306	4262244	1802	26
	DOW014	13 S	0298977	4260700	1579	17
	DOW015	13 S	0297348	4259580	1977	21
	DOW016	13 S	0298700	4258534	1709	?

LIST OF FIGURES

- Figure 1. Conceptual figure depicting mechanisms linking reservoir operations to reservoir productivity and fish yield.
- Figure 2. Conceptual figure showing links between reservoir operations and sport fish yields.
- Figure 3. Direct and indirect effects of reservoir operations on food web dynamics in Blue Mesa Reservoir.
- Figure 4. Map of Blue Mesa Reservoir showing locations of stations sampled in 1995.
- Figure 5. Mean daily discharge from Blue Mesa Reservoir in water year 1994 (WY94) and WY 95, the mean daily discharge for the period 1976-1992 (upper panel); and the difference between 1995 discharge and the longterm mean (lower panel).
- Figure 6. Mean daily discharge from Blue Mesa Reservoir in water year 1977-92.
- Figure 7. Surface elevation of Blue Mesa Reservoir in water year 1995 (WY95) and the mean surface elevation for the period 1966-1979 (upper panel); and the difference between 1995 surface elevation and the longterm mean (lower panel).
- Figure 8. Mean daily inflow into Blue Mesa Reservoir in water years 1993-1995.
- Figure 9. Blue Mesa Reservoir temperature profiles ($^{\circ}\text{C}$) at the Sapinero station during May 21 through June 16, 1995
- Figure 10. Blue Mesa Reservoir temperature profiles ($^{\circ}\text{C}$) at the Sapinero station during June 24 through July 21, 1995.
- Figure 11. Blue Mesa Reservoir temperature profiles ($^{\circ}\text{C}$) at the Sapinero station during July 28 through September 11, 1995.
- Figure 12. Blue Mesa Reservoir temperature profiles ($^{\circ}\text{C}$) at the Cebolla station during May through September 1995.
- Figure 13. Blue Mesa Reservoir temperature profiles ($^{\circ}\text{C}$) at the Iola station during May through September 1995.
- Figure 14. July surface temperatures in the three main lake basins on Blue Mesa Reservoir in 1995, and eight previous years.

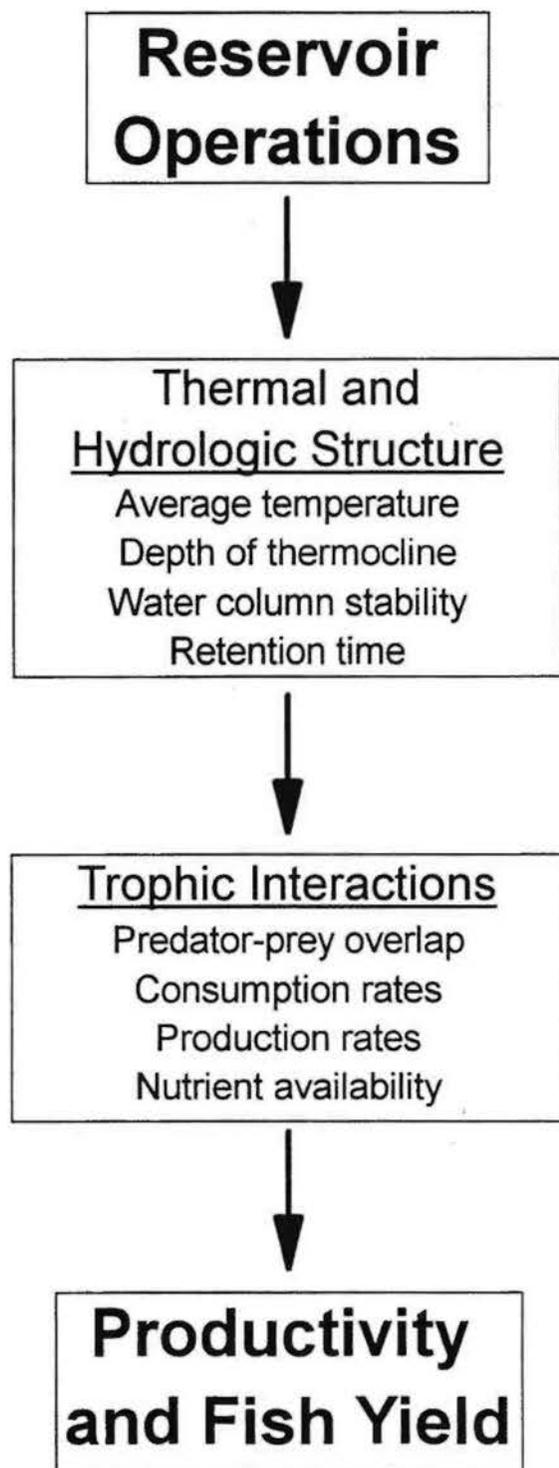
- Figure 15. Temperature profiles taken at a station directly in front of the dam intake tower and a mid-basin station at Sapinero basin.
- Figure 16. Dissolved oxygen (mg/l) profiles taken during May-June 1995 at Sapinero basin.
- Figure 17. Dissolved oxygen (mg/l) profiles taken during July-August 1995 at Sapinero basin.
- Figure 18. Dissolved oxygen (mg/l) profiles taken during May-September 1995 at Cebolla basin.
- Figure 19. Dissolved oxygen (mg/l) profiles taken during May-September 1995 at Iola basin.
- Figure 20. Secchi depth values (m) from the three main lake basins in Blue Mesa Reservoir during 1994, 1995, and the mean secchi readings at the three basins during 1983-1985 (from Cudlip et al. 1987) and 1993 (Johnson 1994).
- Figure 21. Seasonal secchi depth (m) in the three main basins in Blue Mesa Reservoir during 1994 and 1995.
- Figure 22. Chlorophyll-a concentration ($\mu\text{g/l} \pm 2\text{SE}$) in 0-10 m integrated samples in three stations in Blue Mesa Reservoir during 1994 and 1995. In 1995 the edible fraction ($< 35\mu$ diameter; open circles) is also shown.
- Figure 23. Chlorophyll-a concentration ($\mu\text{g/l}$) by depth on two dates in August, 1995 at Sapinero basin.
- Figure 24. Relationship between secchi depth (m) and chlorophyll-a concentration ($\mu\text{g/l}$) at three stations in Blue Mesa Reservoir during 1994-1995.
- Figure 25. Relative abundance of the eight zooplankton taxa sampled in the top 10 m of the water column of Blue Mesa Reservoir averaged over all stations, times and depth strata in 1994, 1995.
- Figure 26. Relative abundance of the eight zooplankton taxa sampled from Blue Mesa Reservoir averaged over all stations, and times for four depth strata in 1994, and two depth strata in 1995. The 15-30 m stratum in 1994 and the 10-30 m stratum in 1995 are data from Sapinero and Cebolla only.
- Figure 27. Relative abundance of eight zooplankton taxa in the 0-10 m depth stratum averaged over all times for three stations in Blue Mesa Reservoir in 1994, 1995.

- Figure 28. *Daphnia* density in the 0-10 m stratum at five randomly selected stations in Blue Mesa Reservoir during 1995.
- Figure 29. Mean *Daphnia* density in the 0-10 m stratum at five randomly selected stations in Blue Mesa Reservoir during 1995.
- Figure 30. Mean *Daphnia* density in the upper depth strata at three basins in Blue Mesa Reservoir during 1994-1995.
- Figure 31. Relative abundance of nine zooplankton taxa in the top 10 m of the water column averaged by month during 1994 and 1995.
- Figure 32. Seasonal dynamics in relative abundance of nine zooplankton taxa sampled from Sapinero, Cebolla, and Iola basins in the 0-10 m strata in 1995.
- Figure 33. Mean density of *Daphnia* spp. among two or four depth strata of Sapinero basin during May 21-July 7, 1995.
- Figure 34. Mean density of *Daphnia* spp. among two depth strata of Sapinero basin during July 14-September 11, 1995.
- Figure 35. Mean density of *Daphnia* spp. among two depth strata of Cebolla basin for all sampling dates in 1995.
- Figure 36. Mean density of *Daphnia* spp. among two depth strata of Iola basin for all sampling dates in 1995.
- Figure 37. Mean length of *Daphnia pulex* and *D. galeata mendotae* sampled from all depth strata in Blue Mesa Reservoir for each station at all dates in 1995.
- Figure 38. Mean density of *Daphnia* > 1.5 mm length by date in each basin in Blue Mesa Reservoir in 1995.
- Figure 39. Length-frequency of brown trout (LOC), kokanee (KOK), longnose sucker (LGS), lake trout (MAC), rainbow trout (RBT), and white sucker (WHS) sampled in experimental vertical gill nets in June 1995.
- Figure 40. Length-frequency of brown trout (LOC), kokanee (KOK), longnose sucker (LGS), lake trout (MAC), and rainbow trout (RBT) sampled in experimental vertical gill nets in July 1995.

- Figure 41. Length-frequency of brown trout (LOC), kokanee (KOK), longnose sucker (LGS), lake trout (MAC), and rainbow trout (RBT) sampled in experimental vertical gill nets in September 1995.
- Figure 42. Mean length (mm) of *Daphnia* in Sapinero basin (open squares) and in kokanee stomachs sampled at Sapinero (closed squares) and the 25th and 75th percentiles around the mean in stomachs (shaded regions).
- Figure 43. Mean length (mm) of *Daphnia* in Cebolla basin (open squares) and in kokanee stomachs sampled at Sapinero (closed squares) and the 25th and 75th percentiles around the mean in stomachs (shaded regions)..
- Figure 44. Mean length (mm) of *Daphnia* in Iola basin (open diamonds) and in kokanee stomachs sampled at Iola (closed squares) and the 25th and 75th percentiles around each mean (shaded regions).
- Figure 45. Mean backcalculated length at age of kokanee from five time periods in Blue Mesa Reservoir.
- Figure 46. Fish density (fish/1,000 m³) and target strength (dB) by depth strata averaged across all transects by lake basin in August 1994.
- Figure 47. Fish density (fish/1,000 m³) and target strength (dB) by depth strata averaged by transects in Sapinero basin in August 1994.
- Figure 48. Fish density (fish/1,000 m³) and target strength (dB) by depth strata averaged by transects in Cebolla basin in August 1994.
- Figure 49. Fish density (fish/1,000 m³) and target strength (dB) by depth strata averaged by transects in Iola basin in August 1994.
- Figure 50. Comparison of vertical gill net catch by depth and fish depth distributions estimated from sonar transects with a Lowrance X-16 depth sounder during day and night, in June 1995 in Sapinero basin.
- Figure 51. Comparison of vertical gill net catch by depth and fish depth distributions estimated from sonar transects with a Lowrance X-16 depth sounder during night, in July 1995 in Iola and Cebolla basins.
- Figure 52. Schematic representation of the processes modeled in CE-THERM reservoir thermal model.

Figure 53. Seasonal thermal regime in Sapinero basin of Blue Mesa reservoir in 1995 and after a hypothetical 2°C increase in epilimnetic temperatures, and maximum scope for growth as a function of temperature alone, of small and large kokanee under these thermal regimes.

Mechanisms linking reservoir operations to reservoir productivity and fish yield



Abiotic-Biotic Linkages Between Reservoir Operations and Sport Fisheries

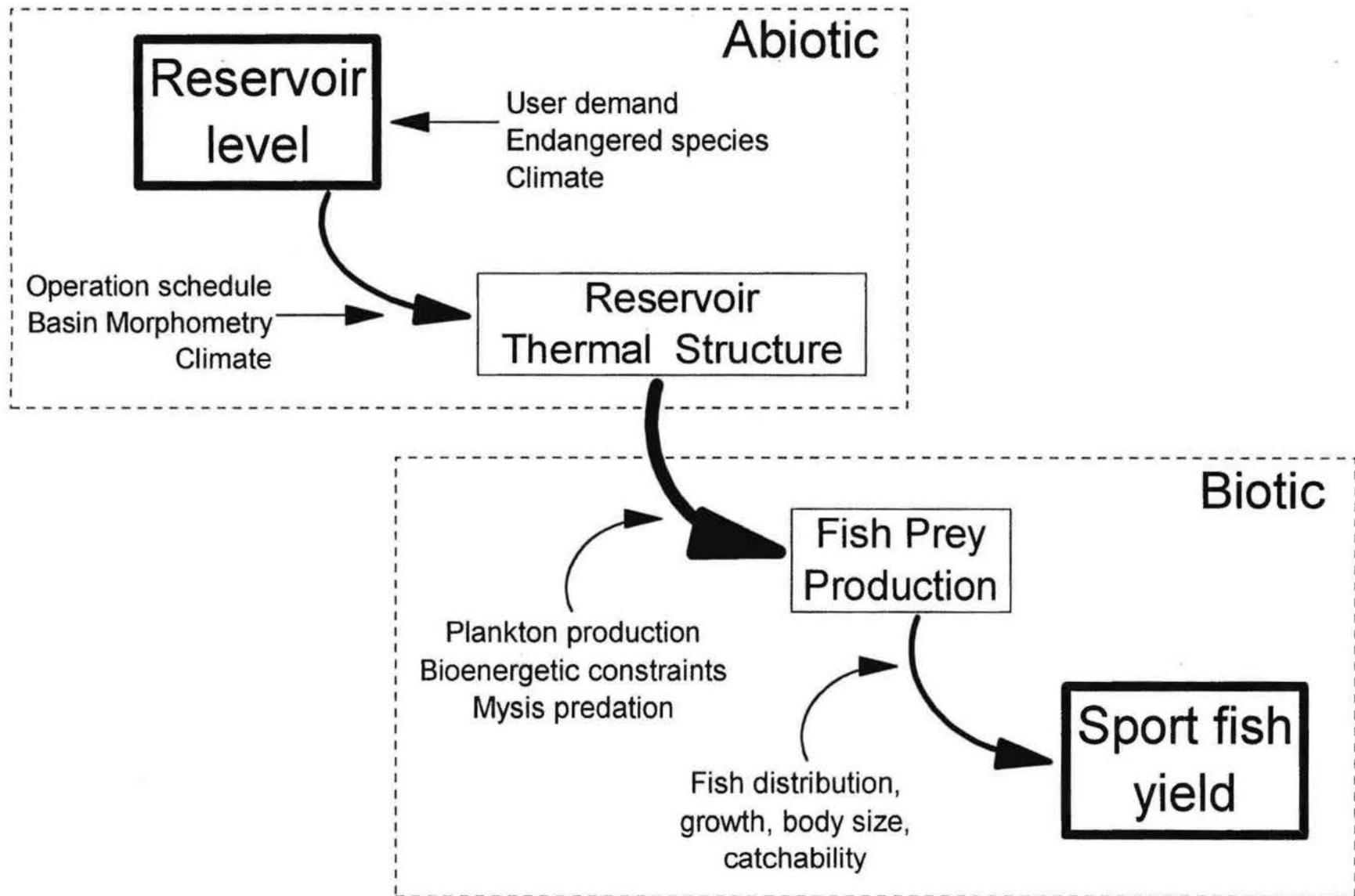


Figure 2.

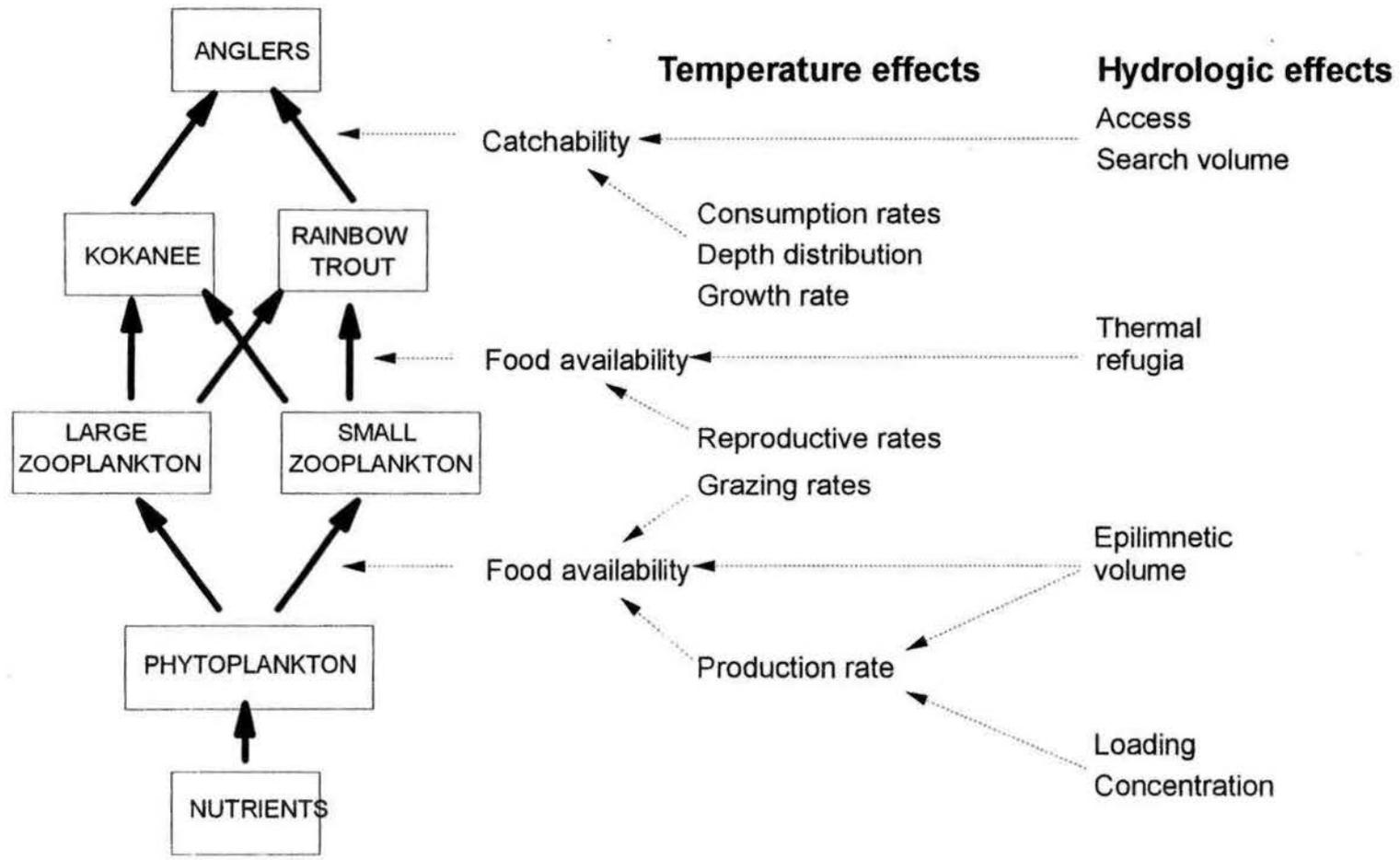


Figure 3.

Blue Mesa Reservoir

Gunnison County, CO.

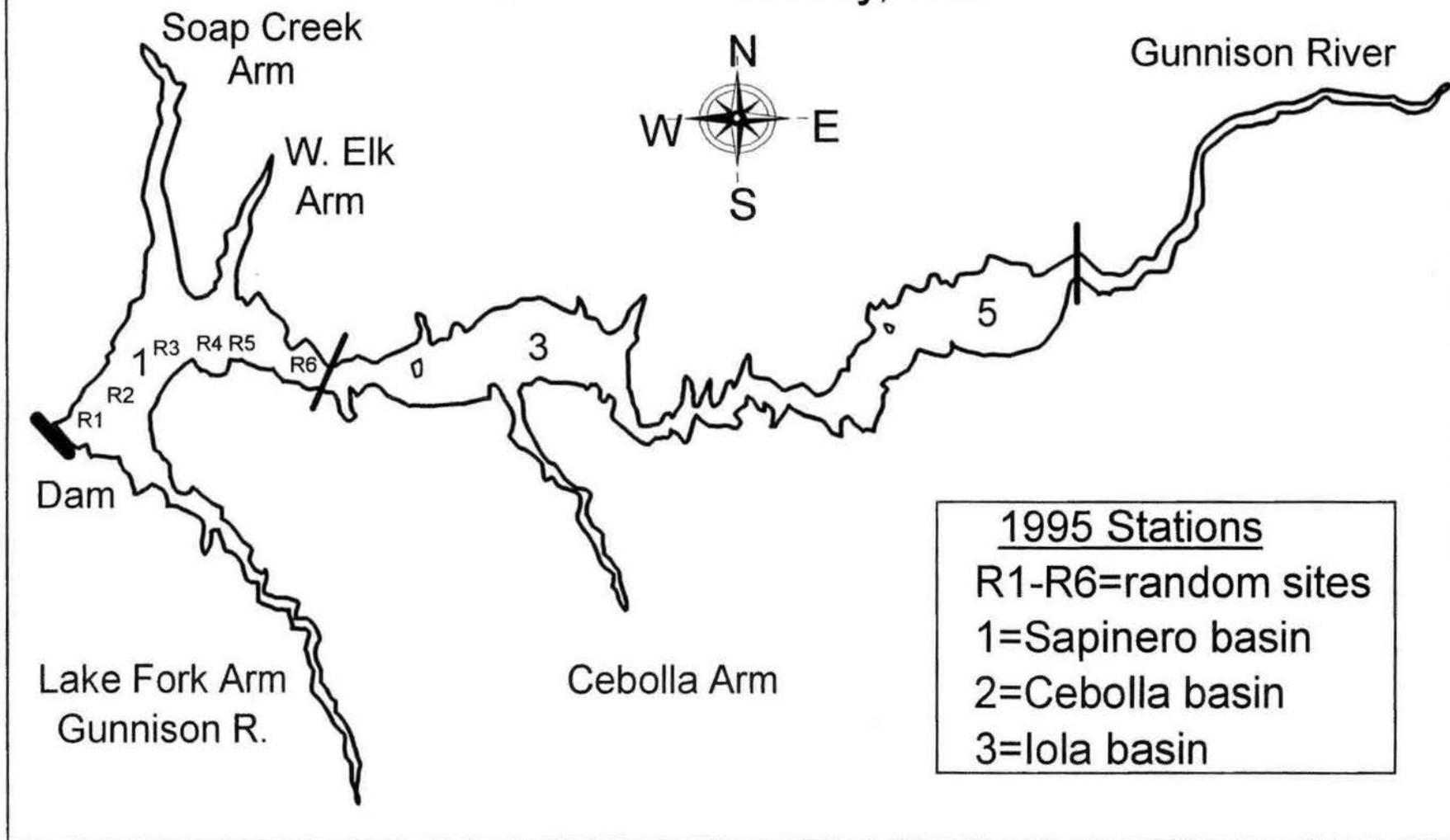


Figure 4.

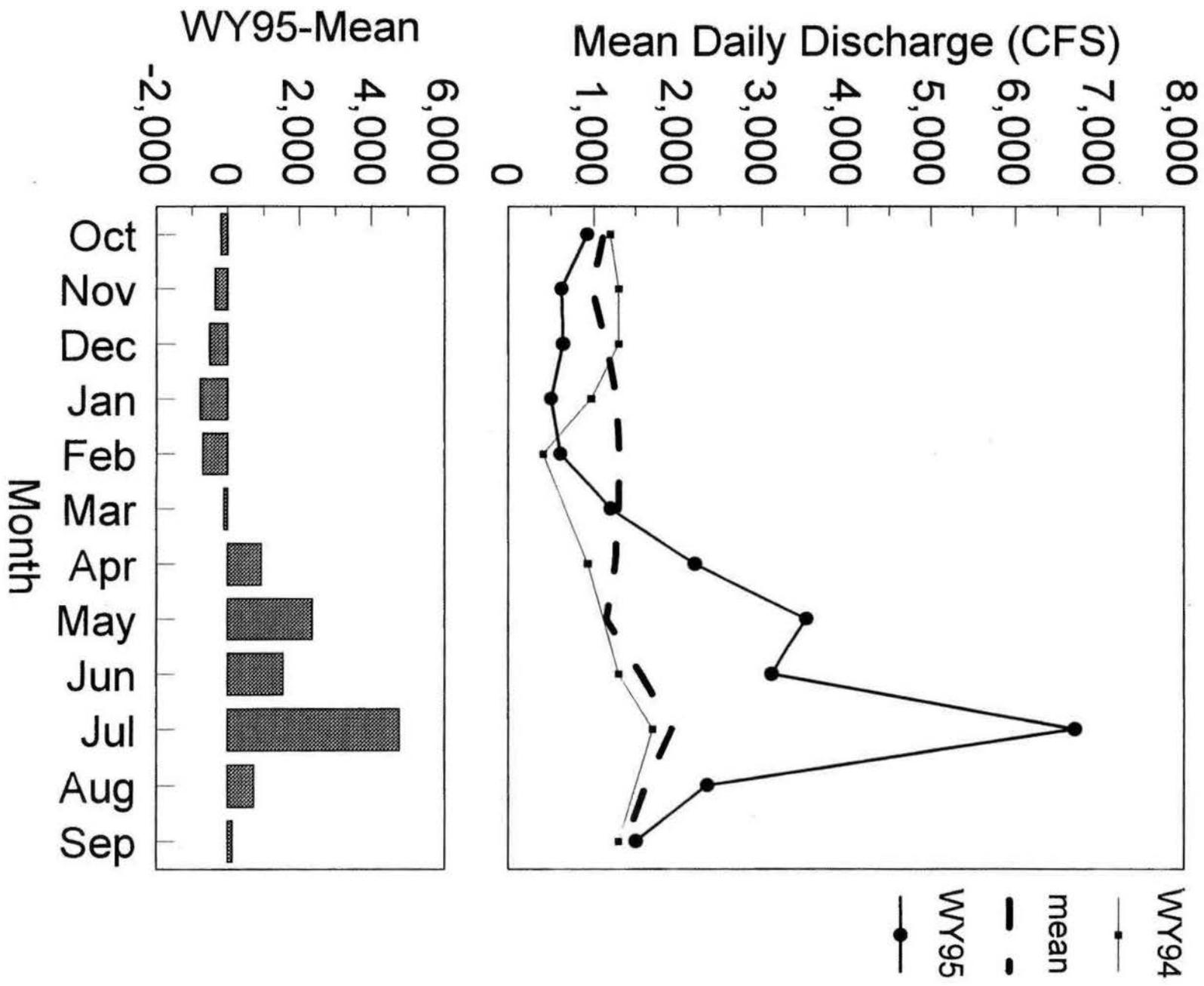
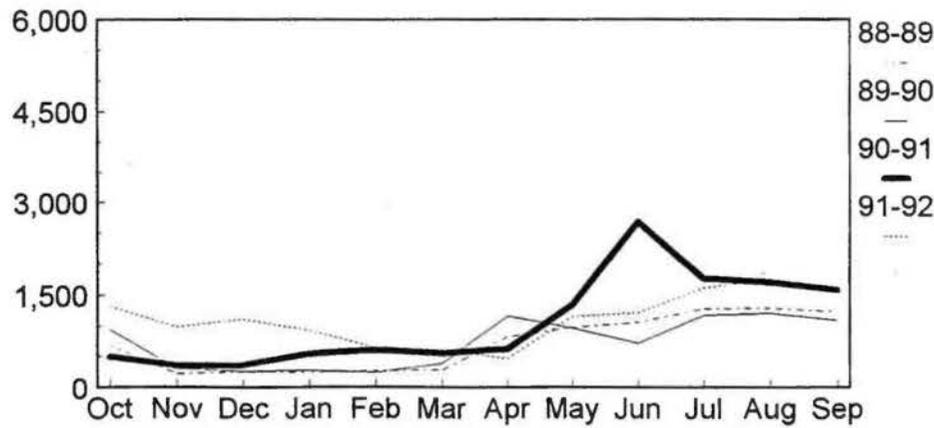
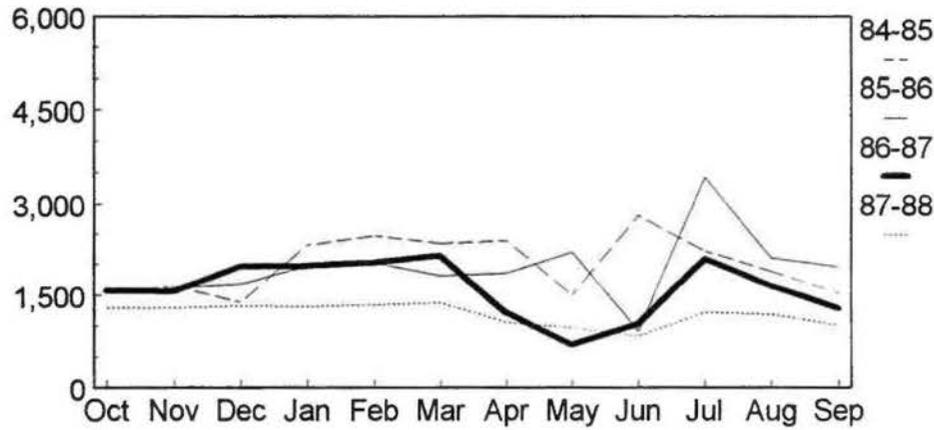
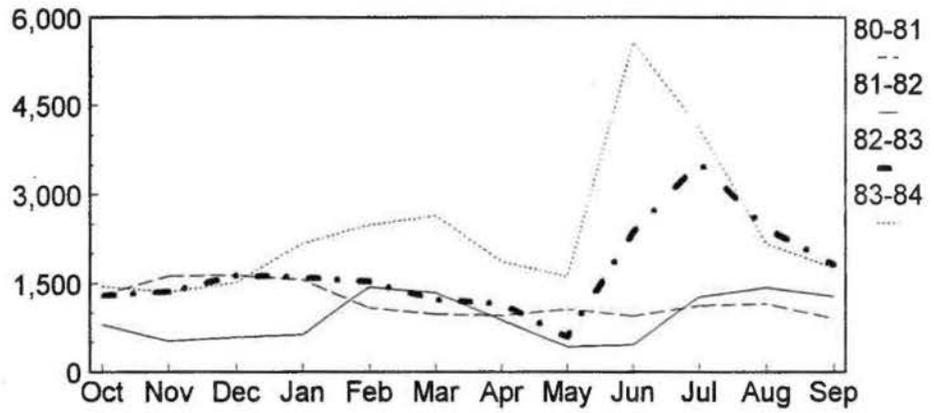
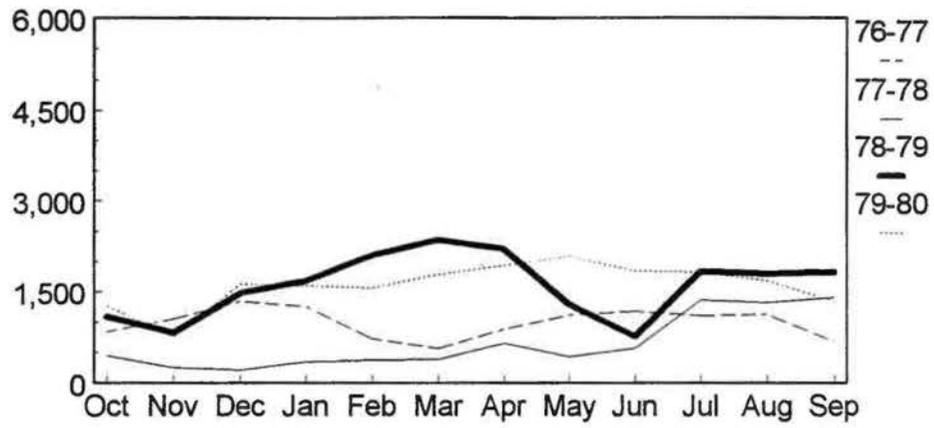


Figure 5.

Figure 6.

Discharge volume (CFS)



Month

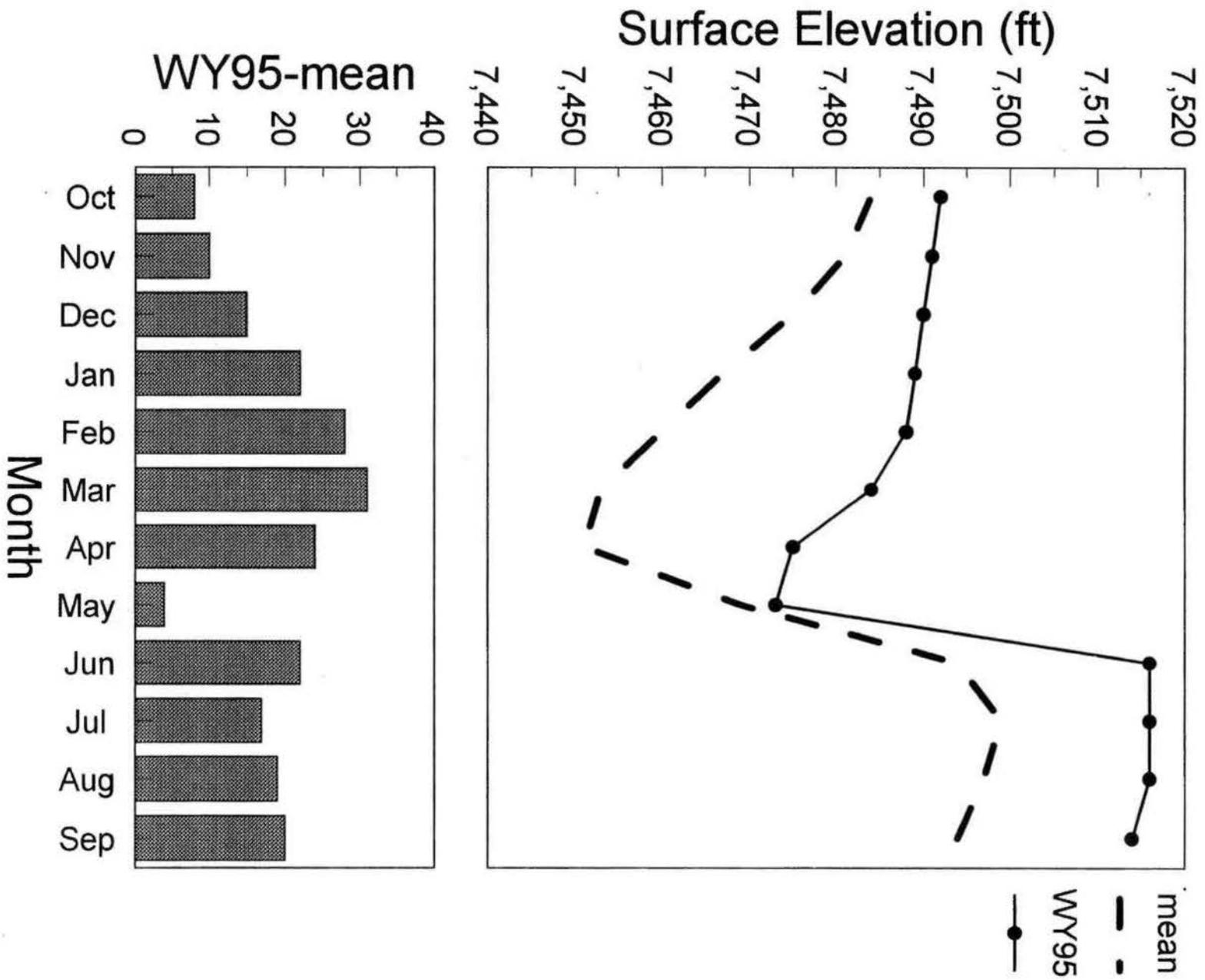


Figure 7.

Figure 8.

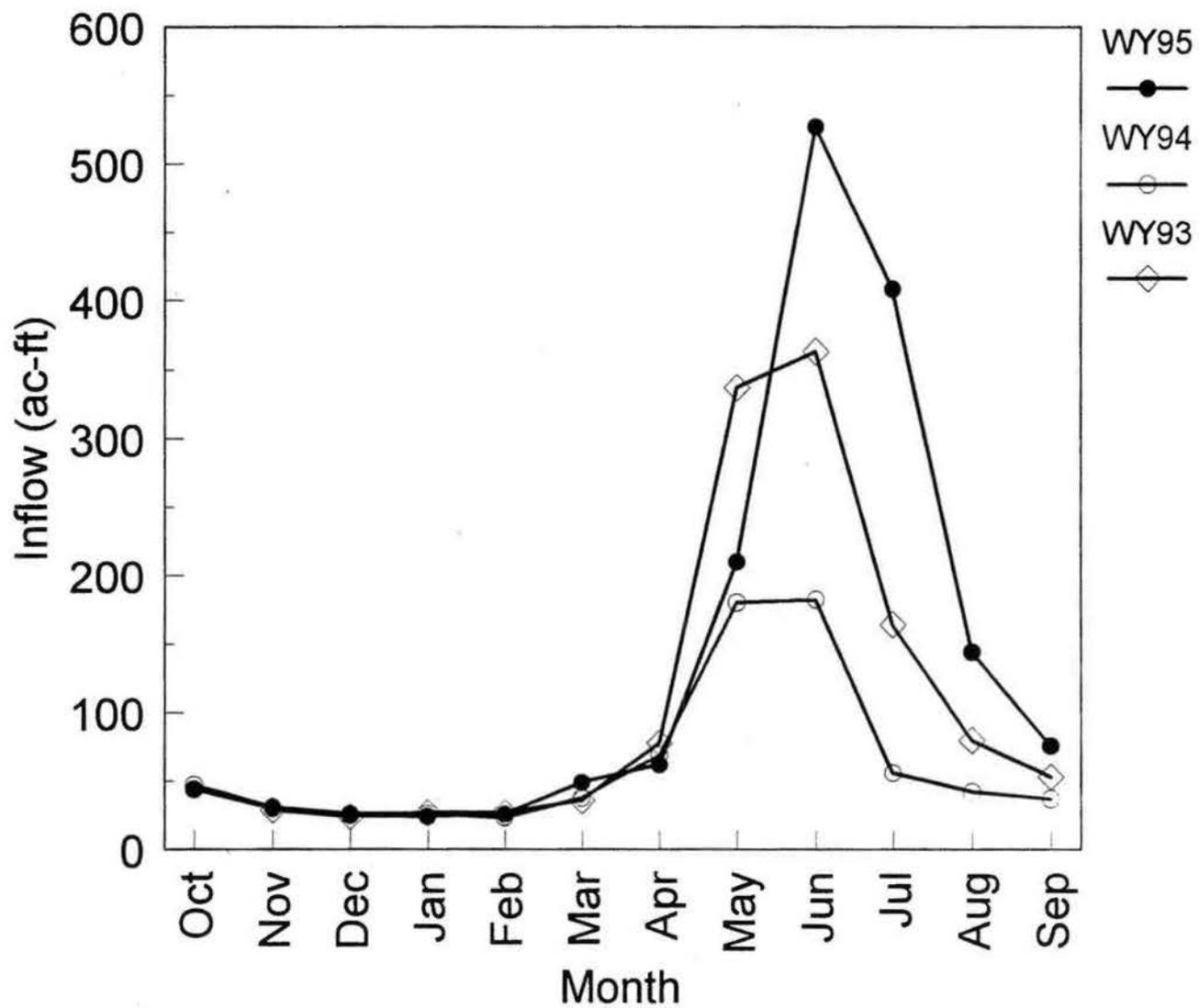


Figure 9.

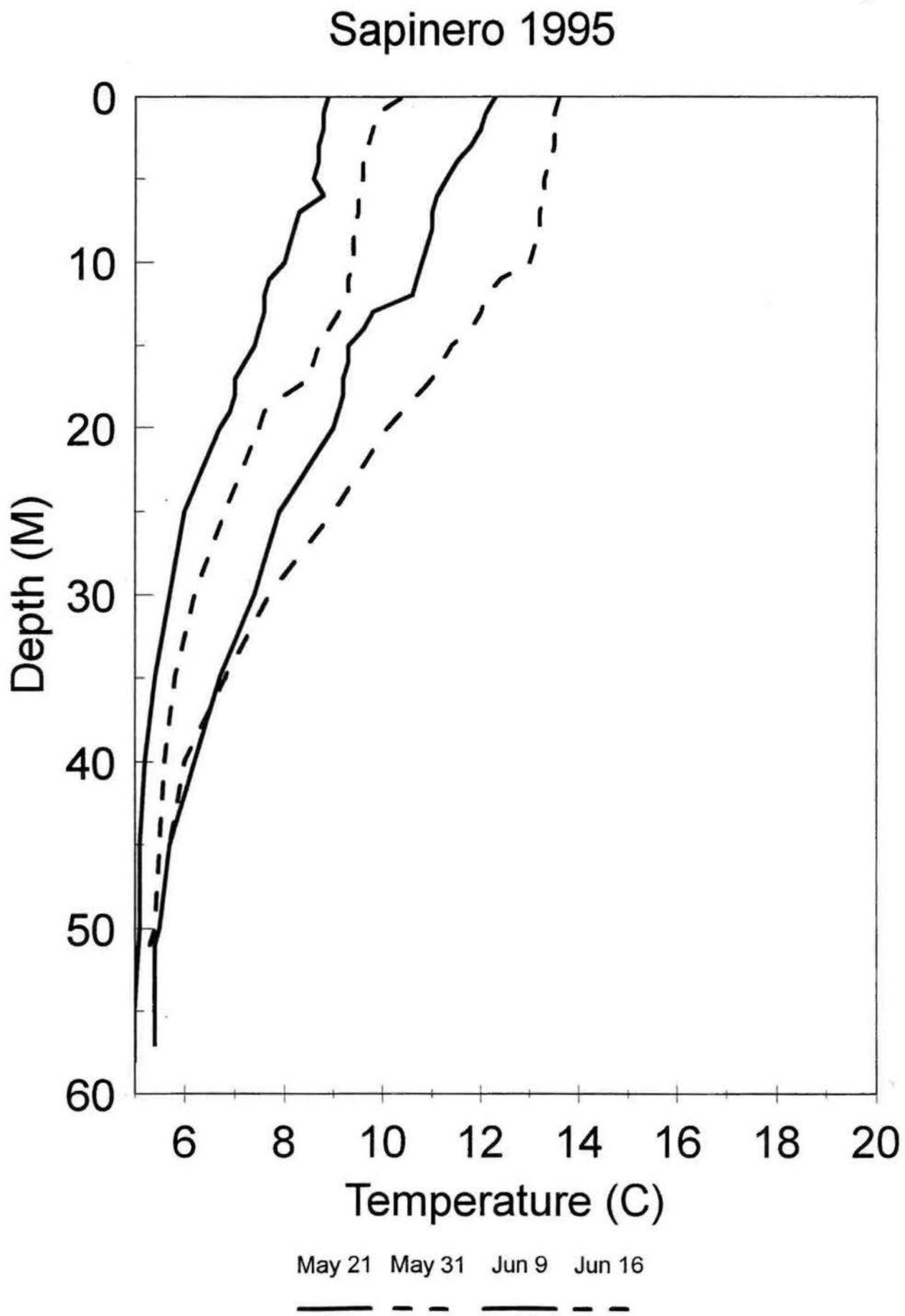


Figure 10.

Sapinero 1995

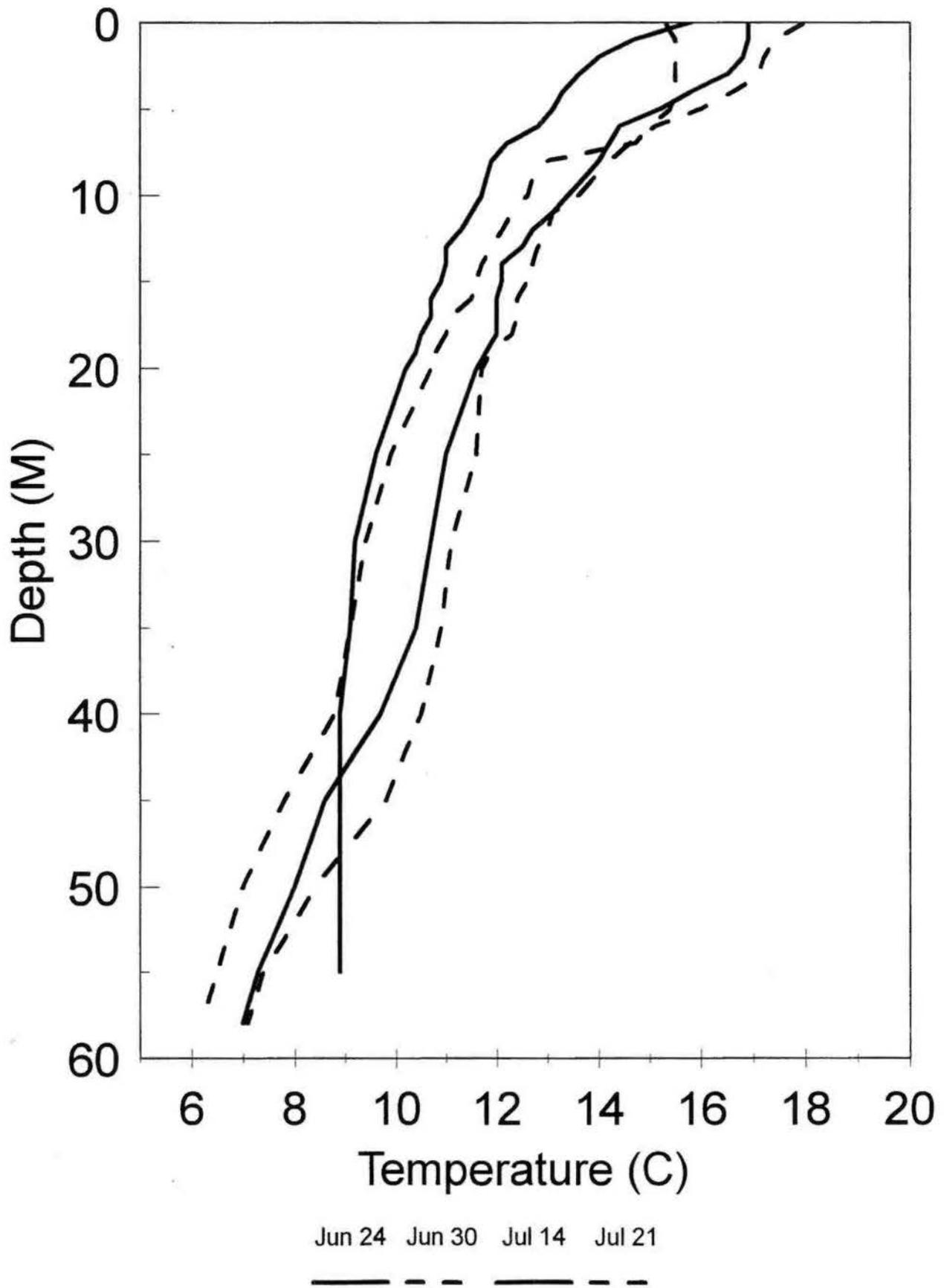
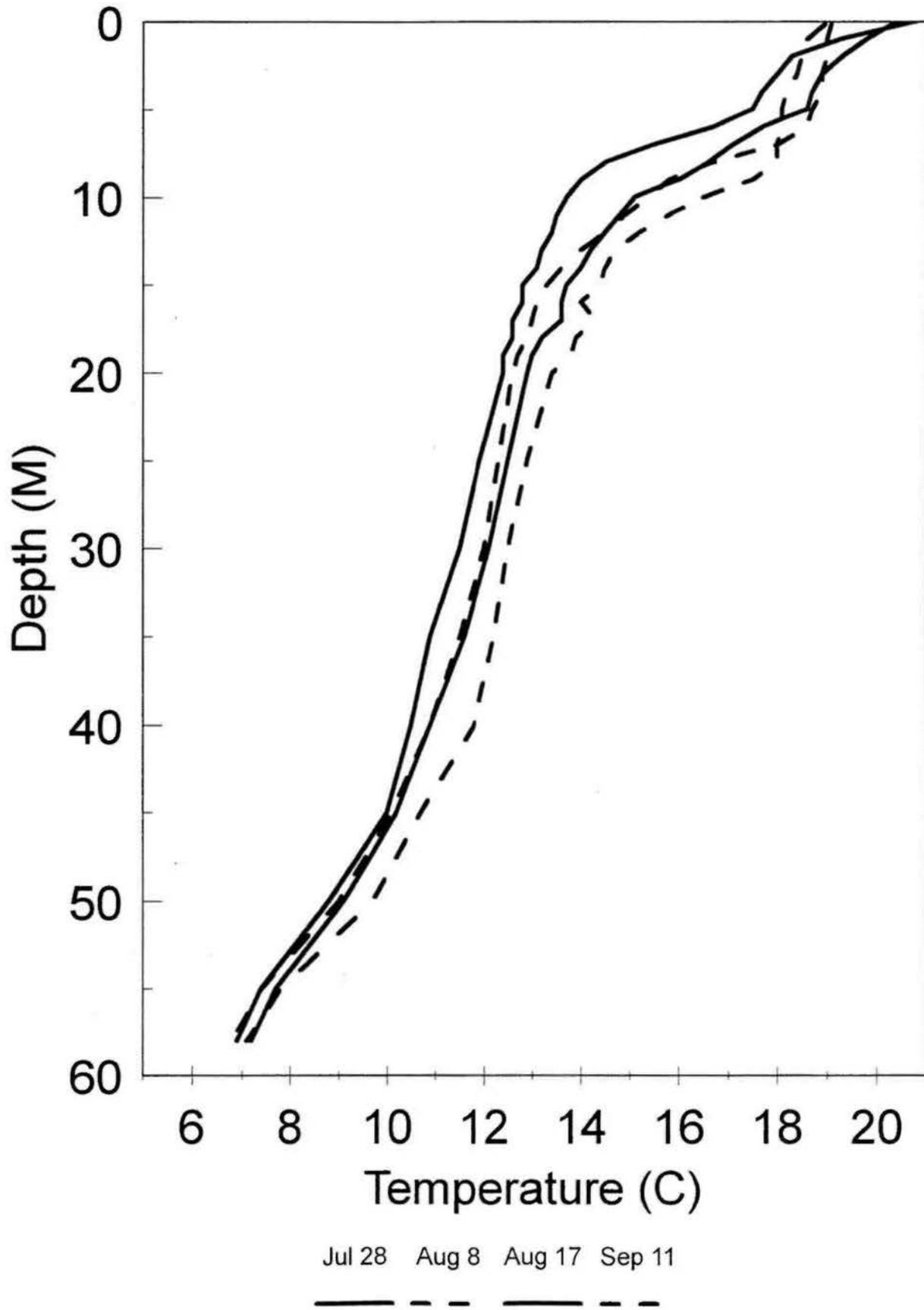


Figure 11.

Sapinero 1995



Cebolla 1995

Figure 12.

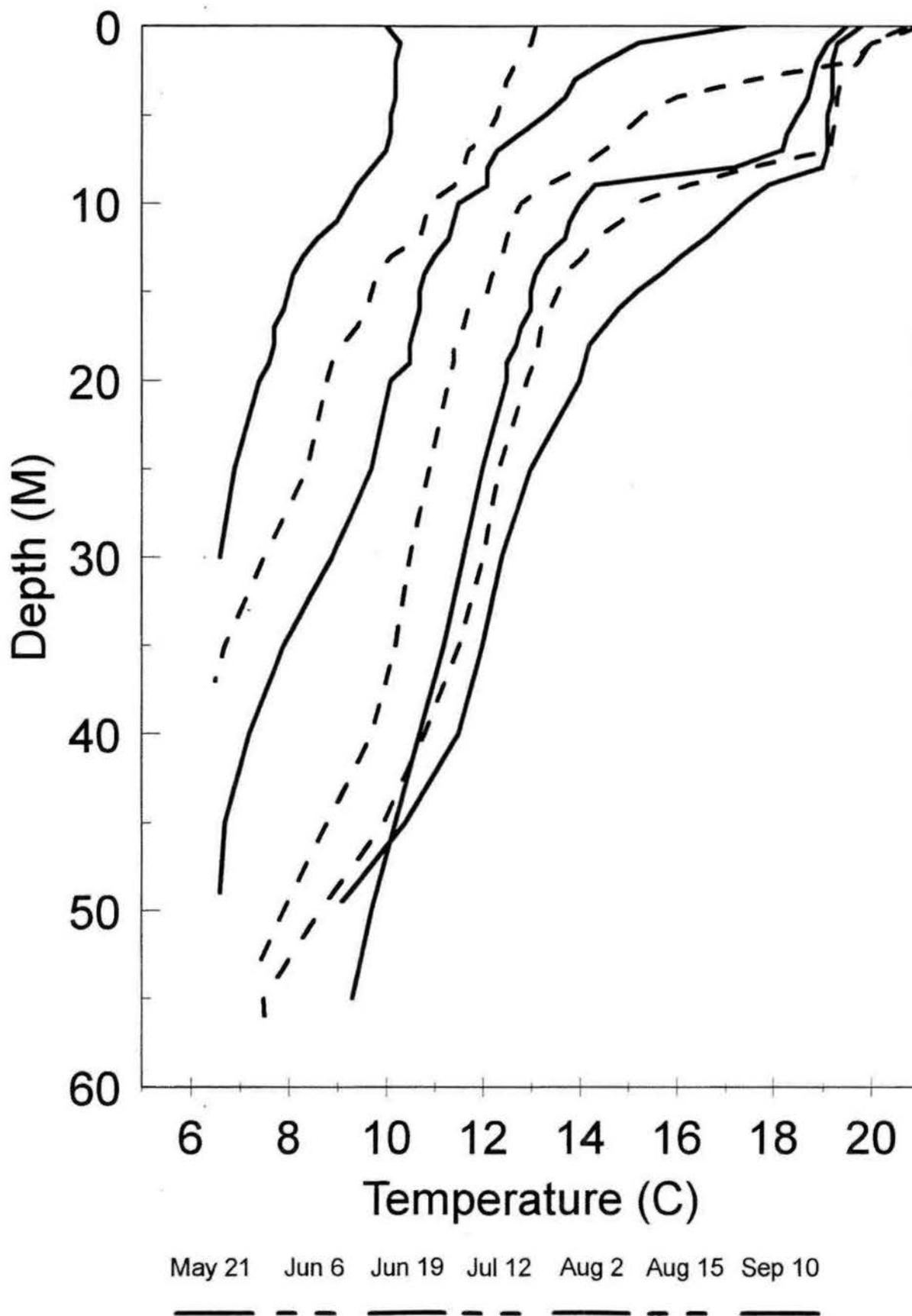


Figure 13.

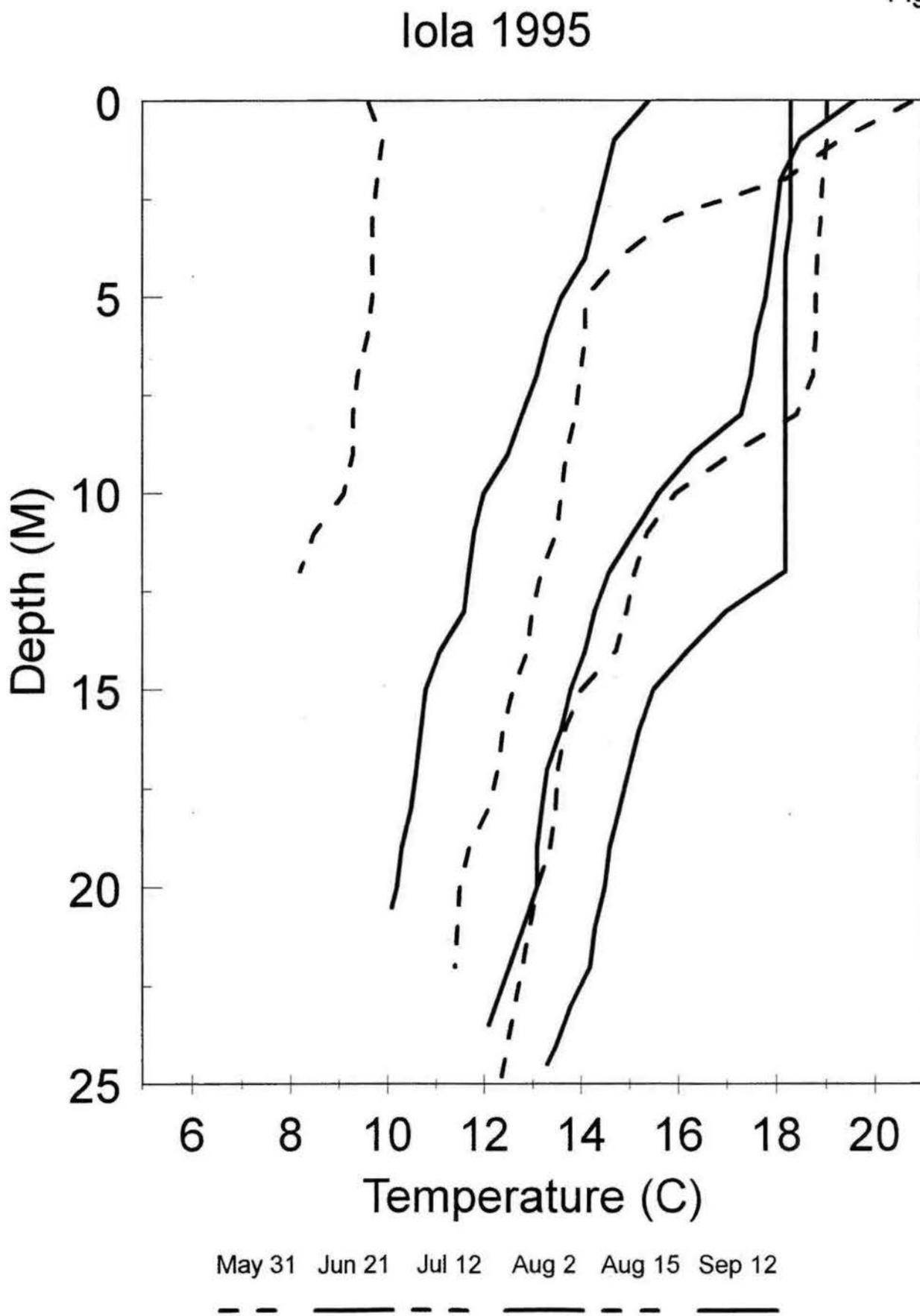


Figure 14.

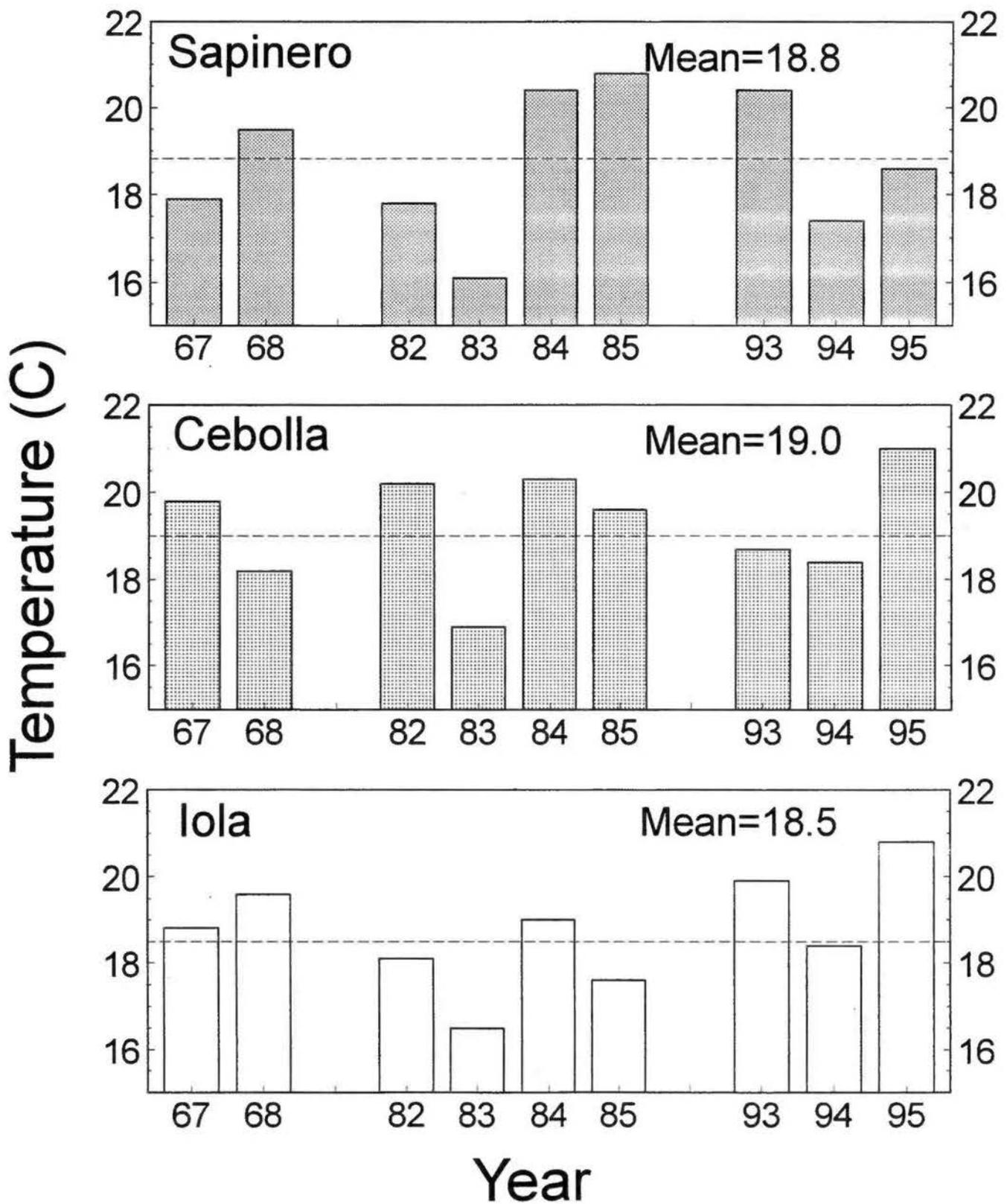


Figure 15.

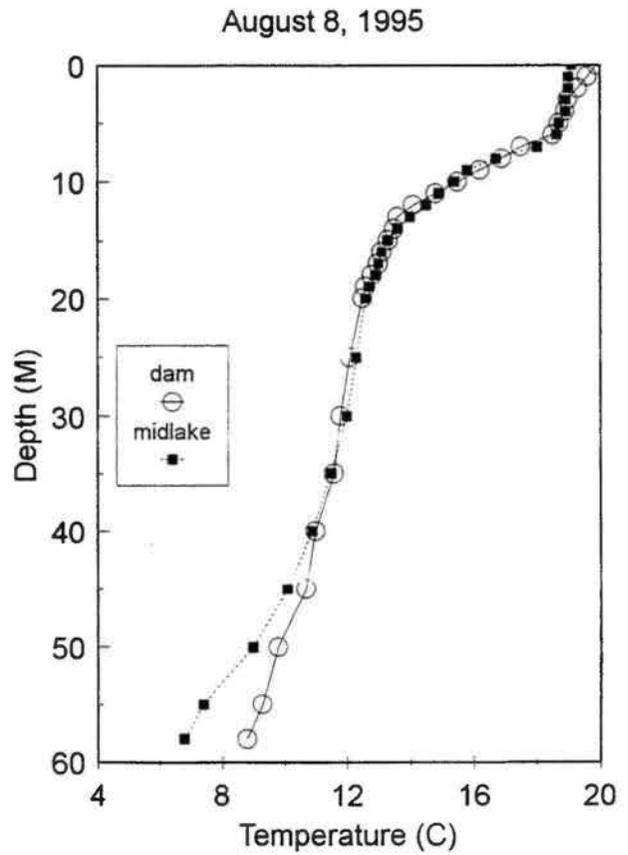
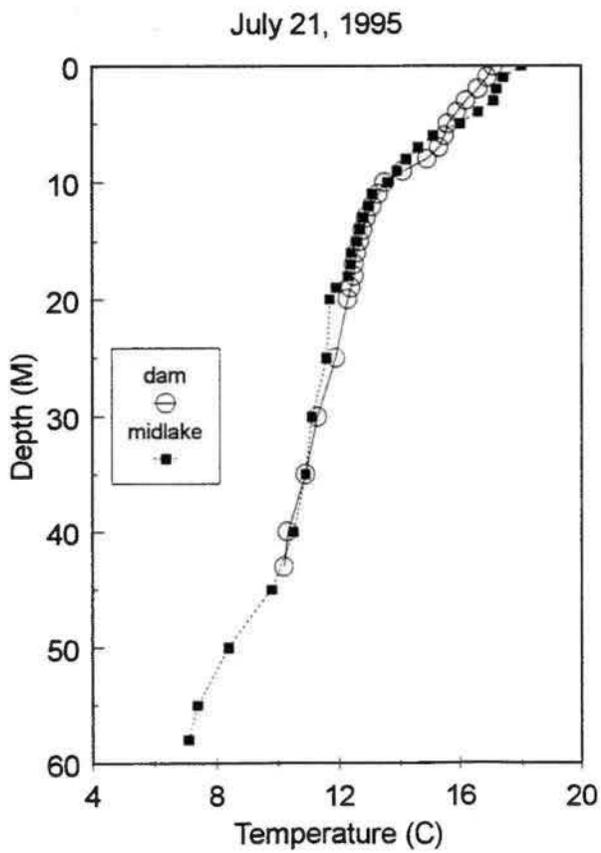
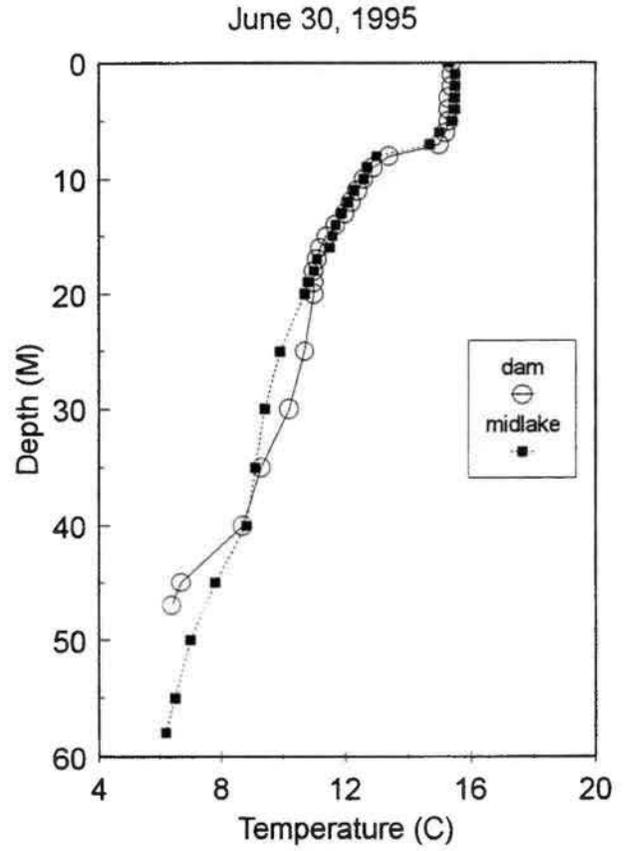
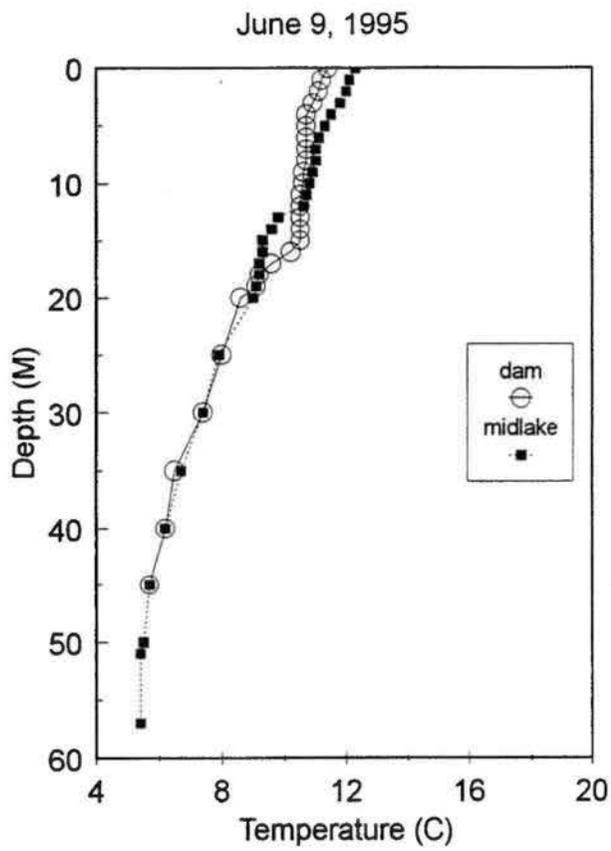


Figure 16.

Sapinero 1995

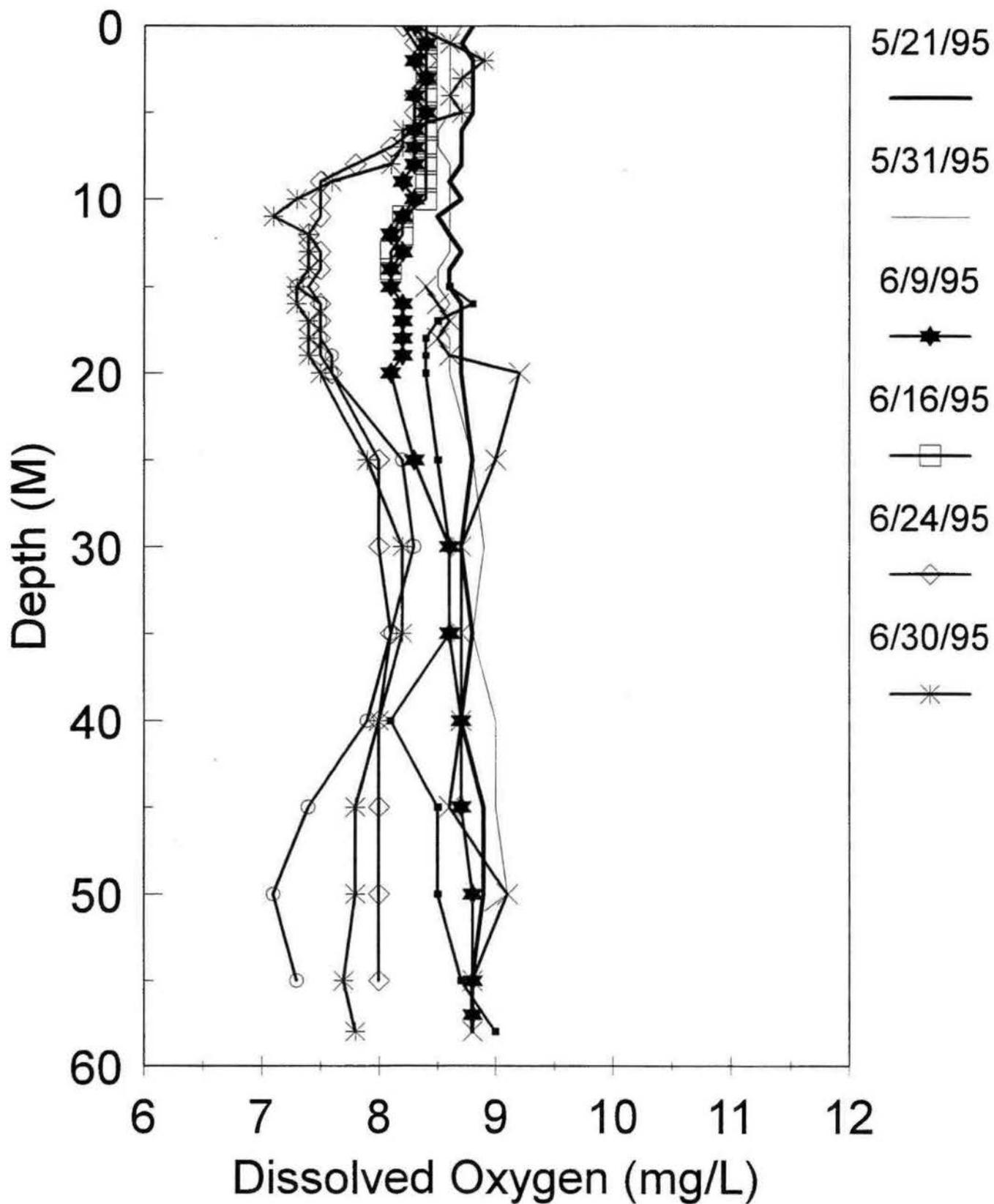


Figure 17.

Sapinero 1995

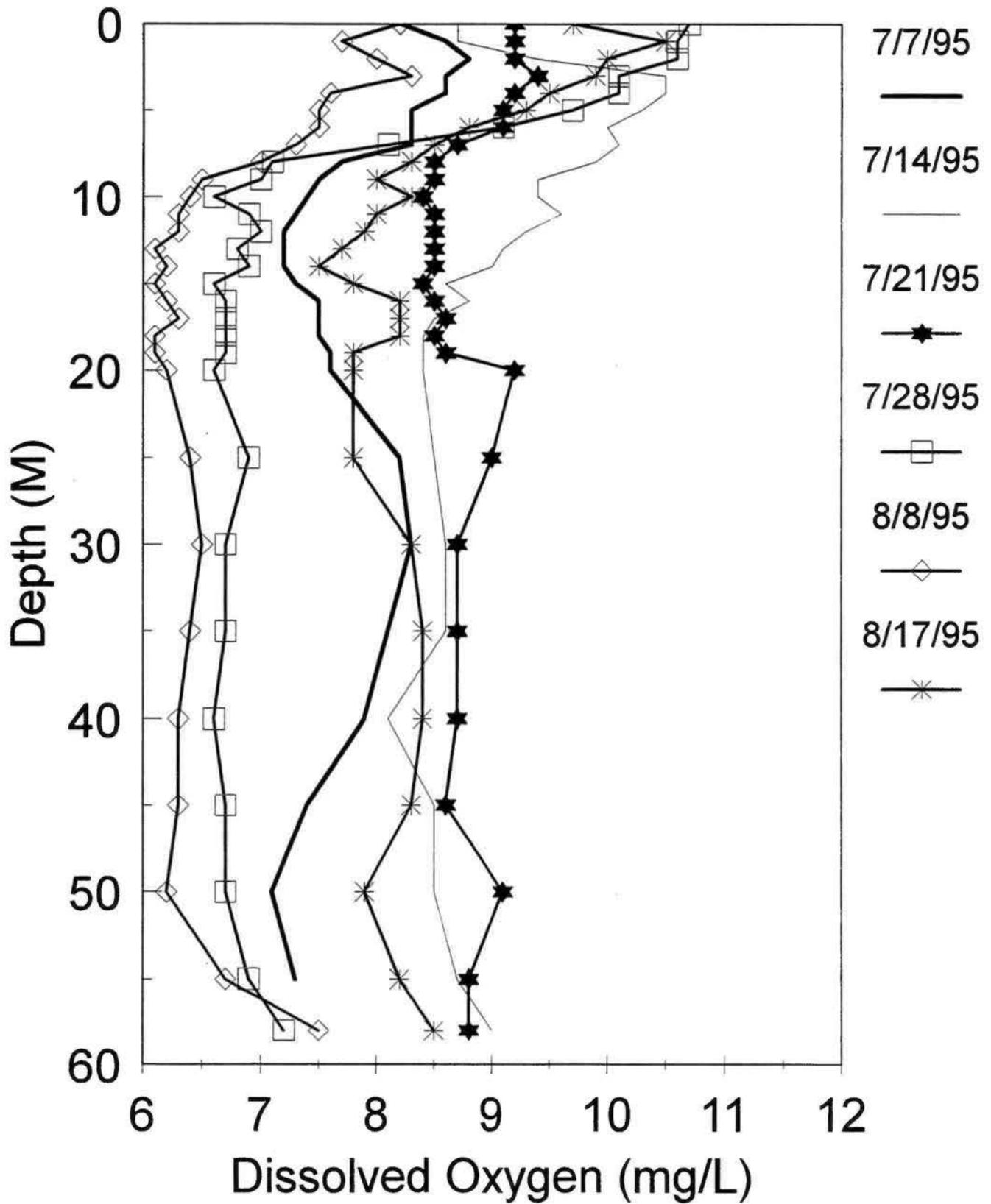


Figure 18.

Cebolla 1995

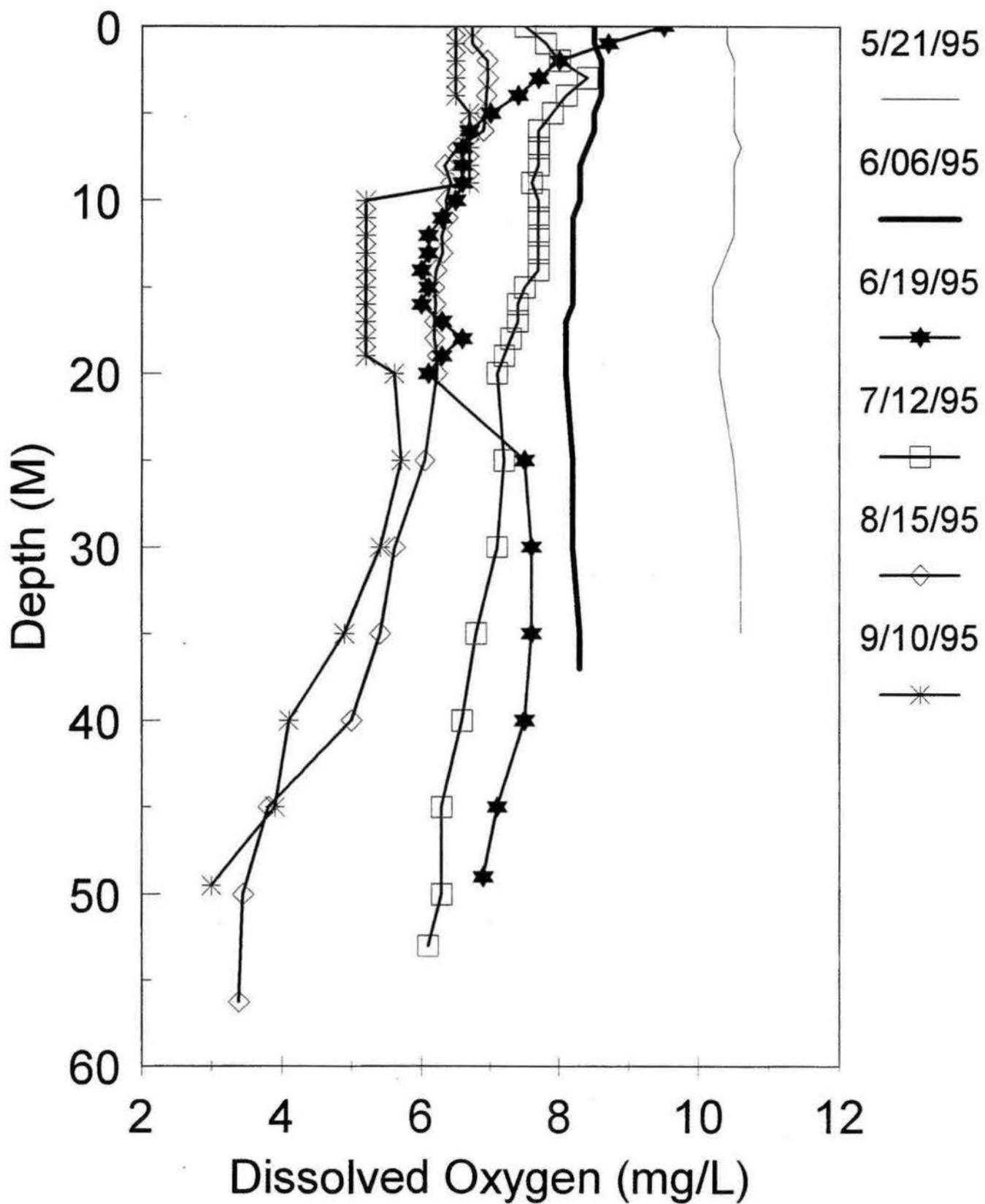


Figure 19.

Iola 1995

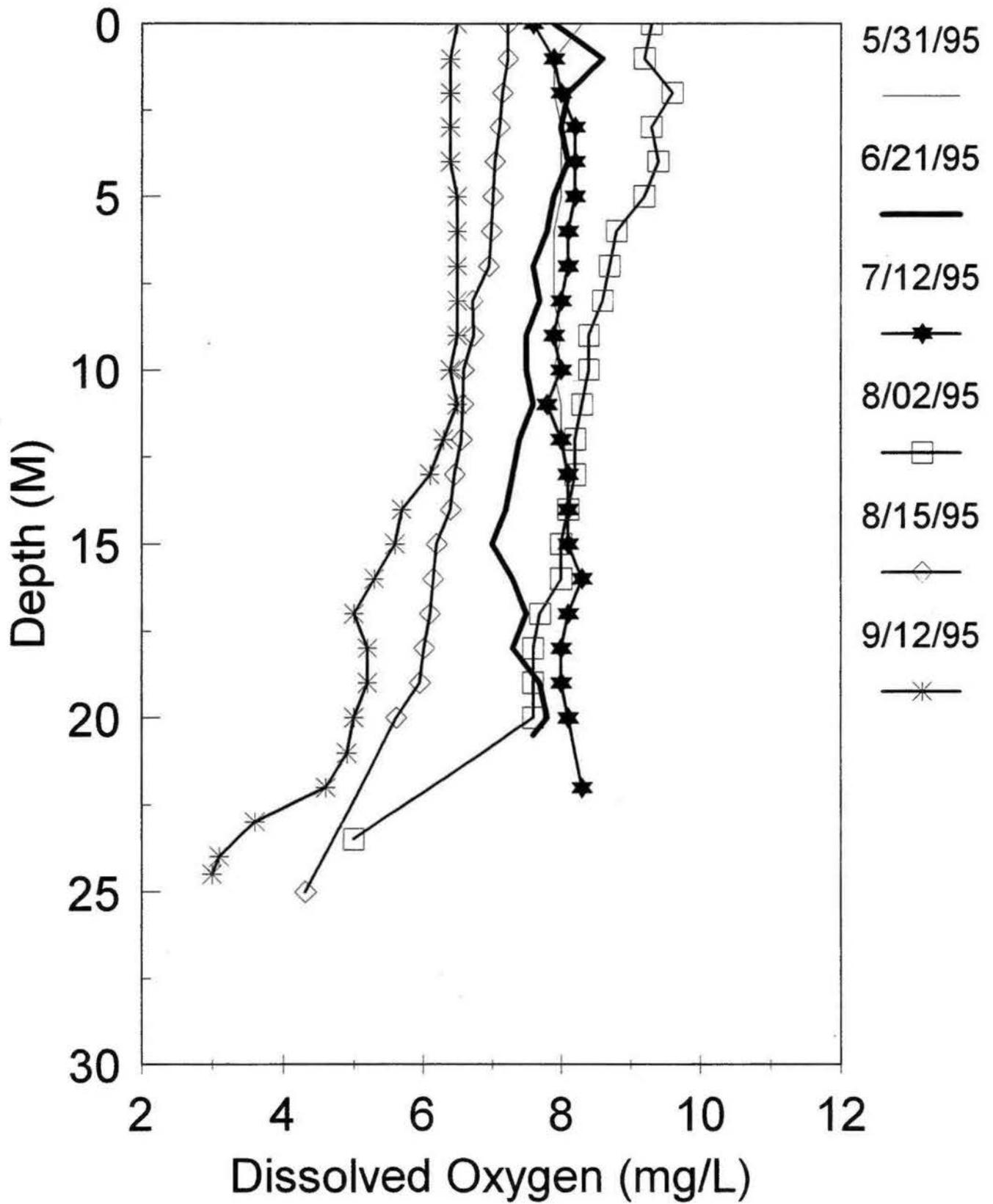


Figure 20.

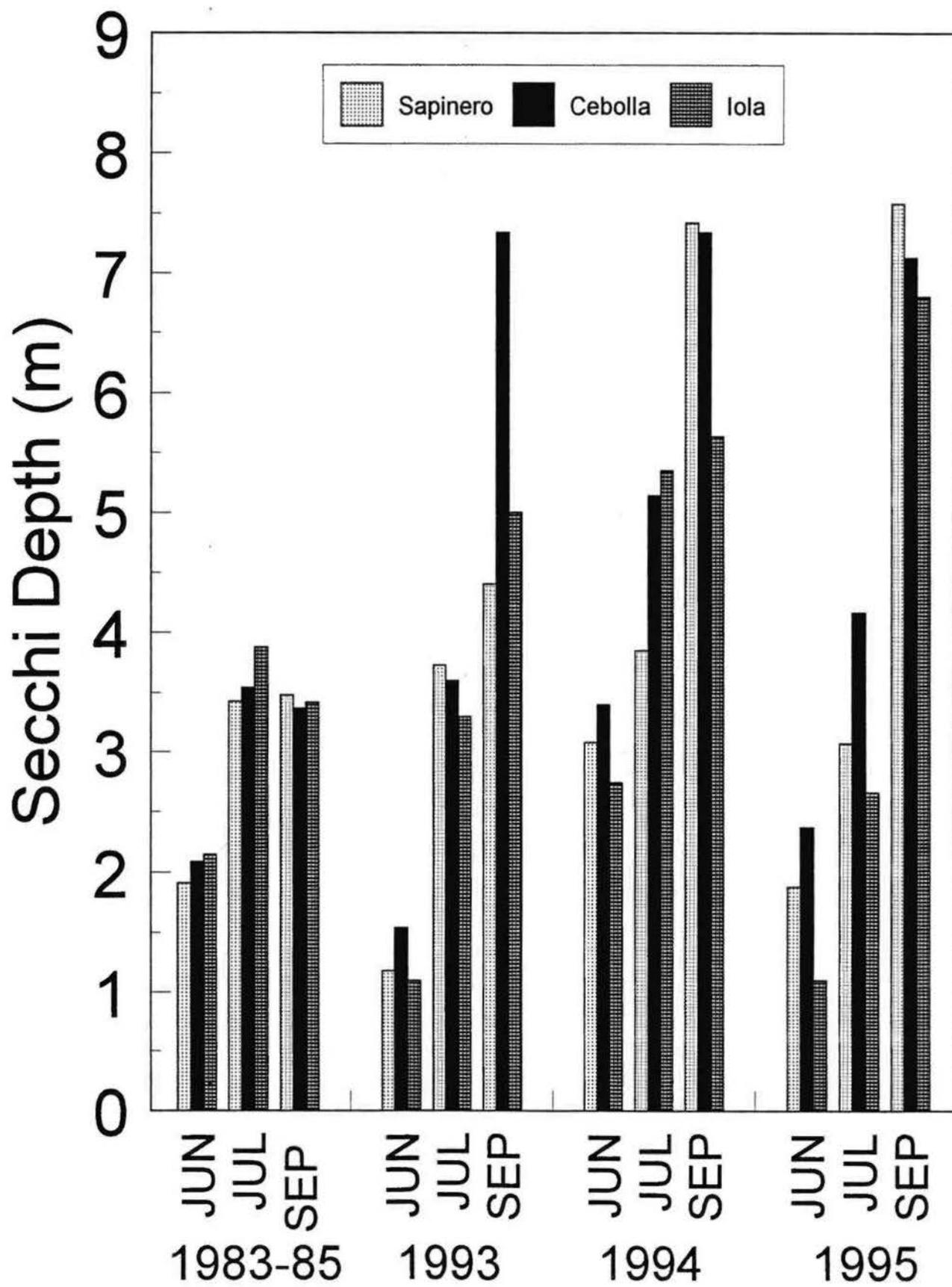


Figure 21.

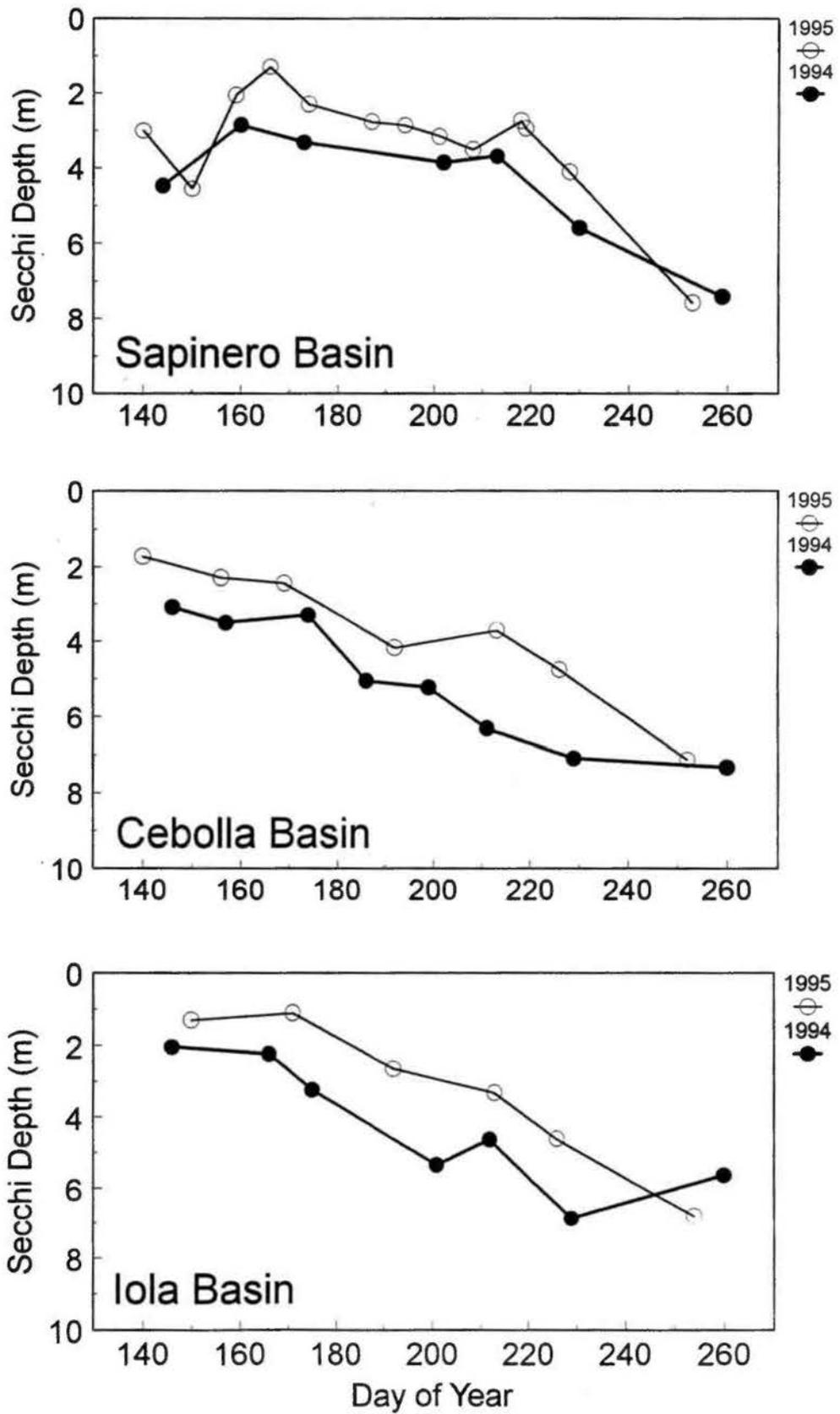
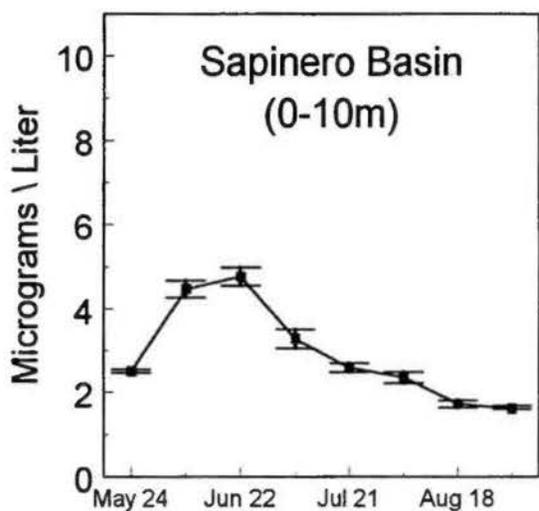


Figure 22.

1994



1995

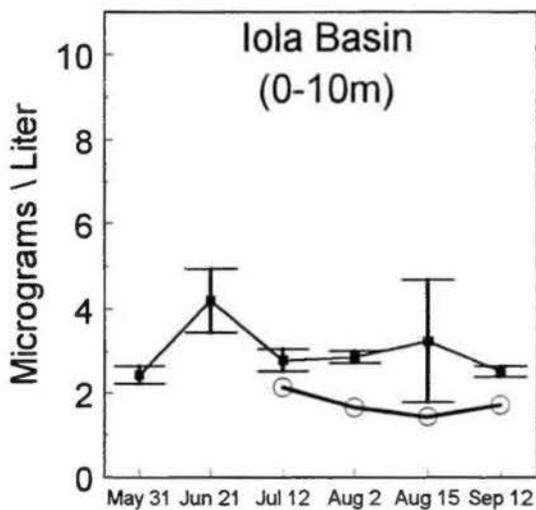
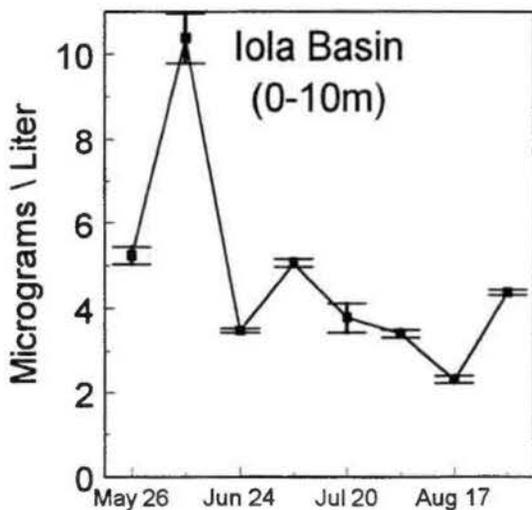
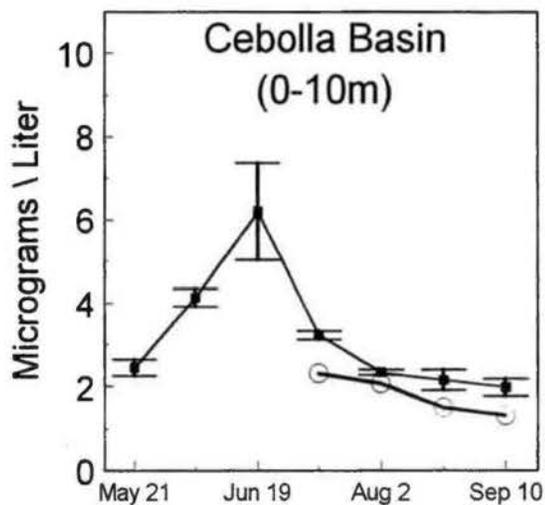
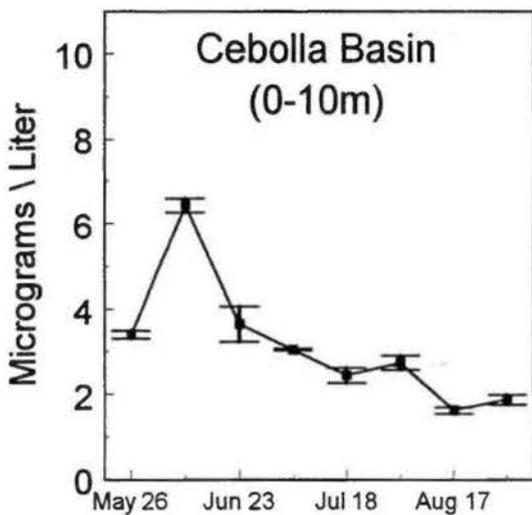
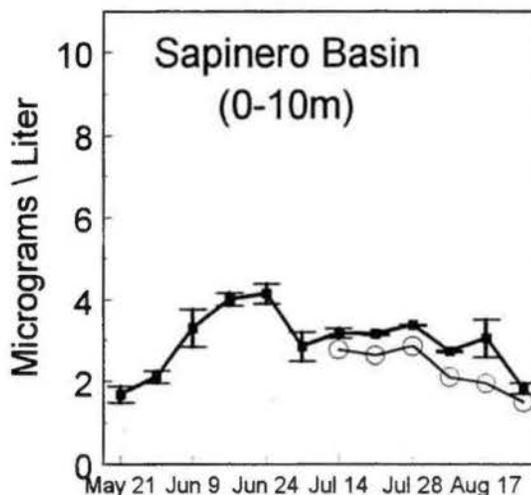


Figure 23.

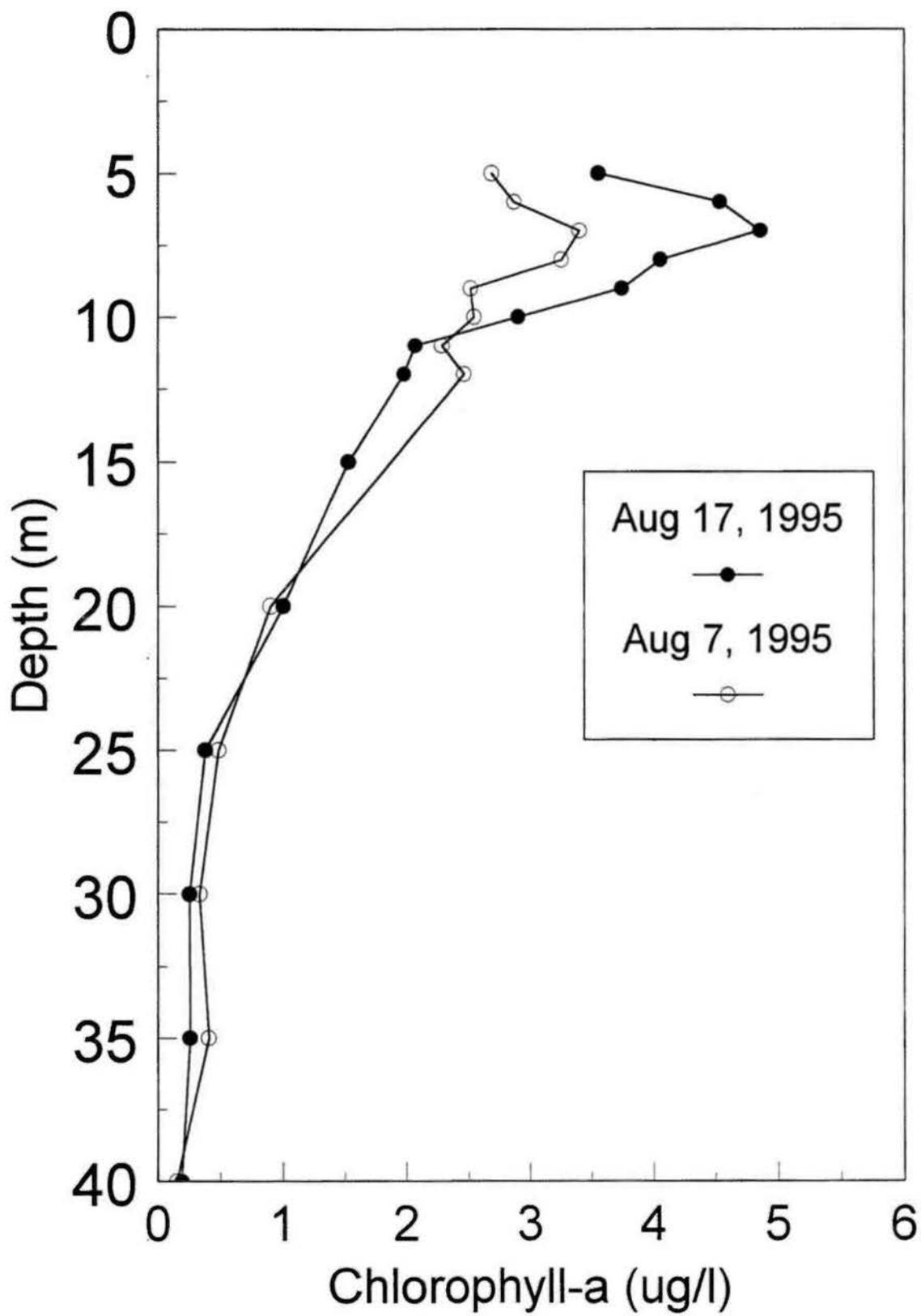
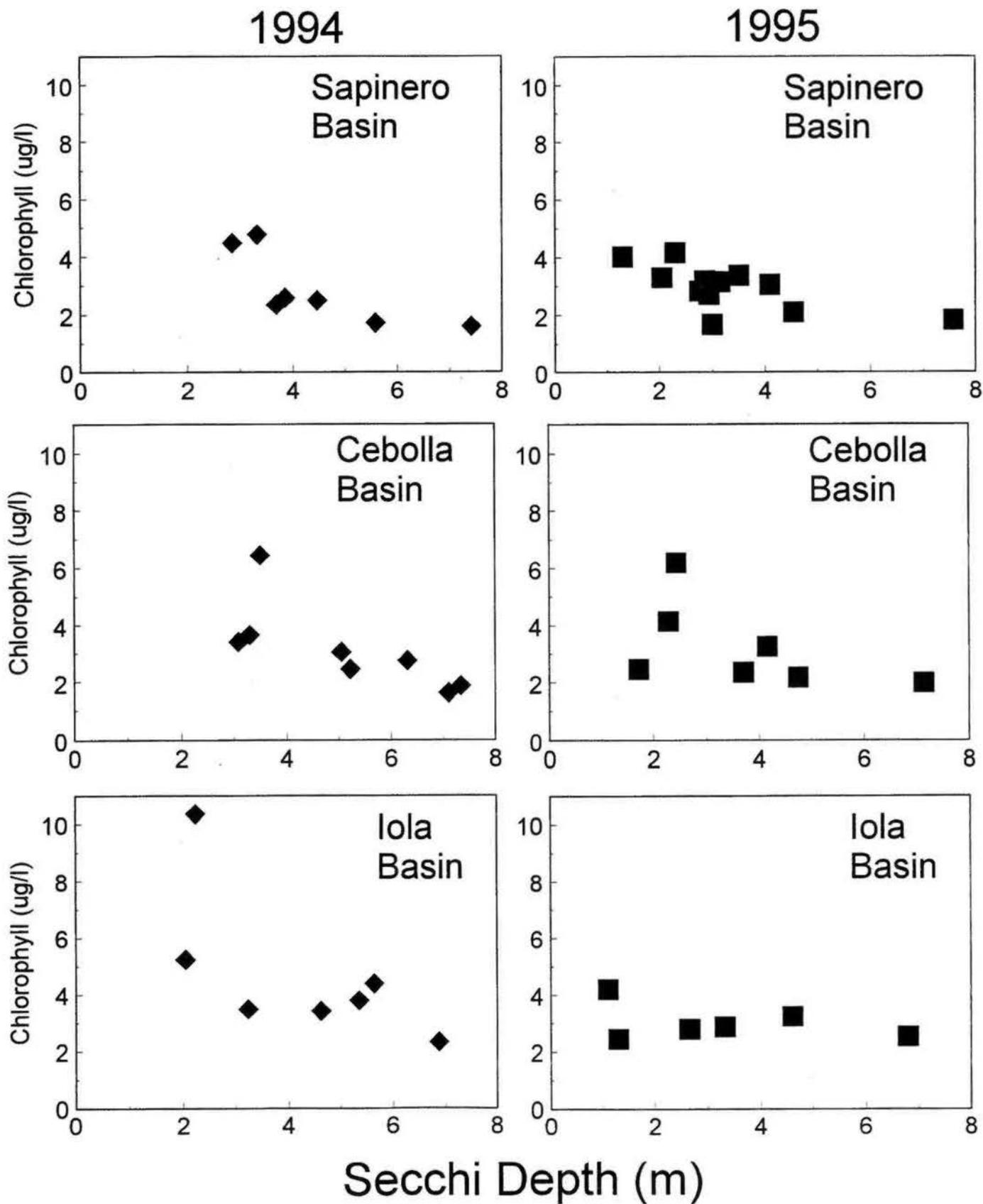
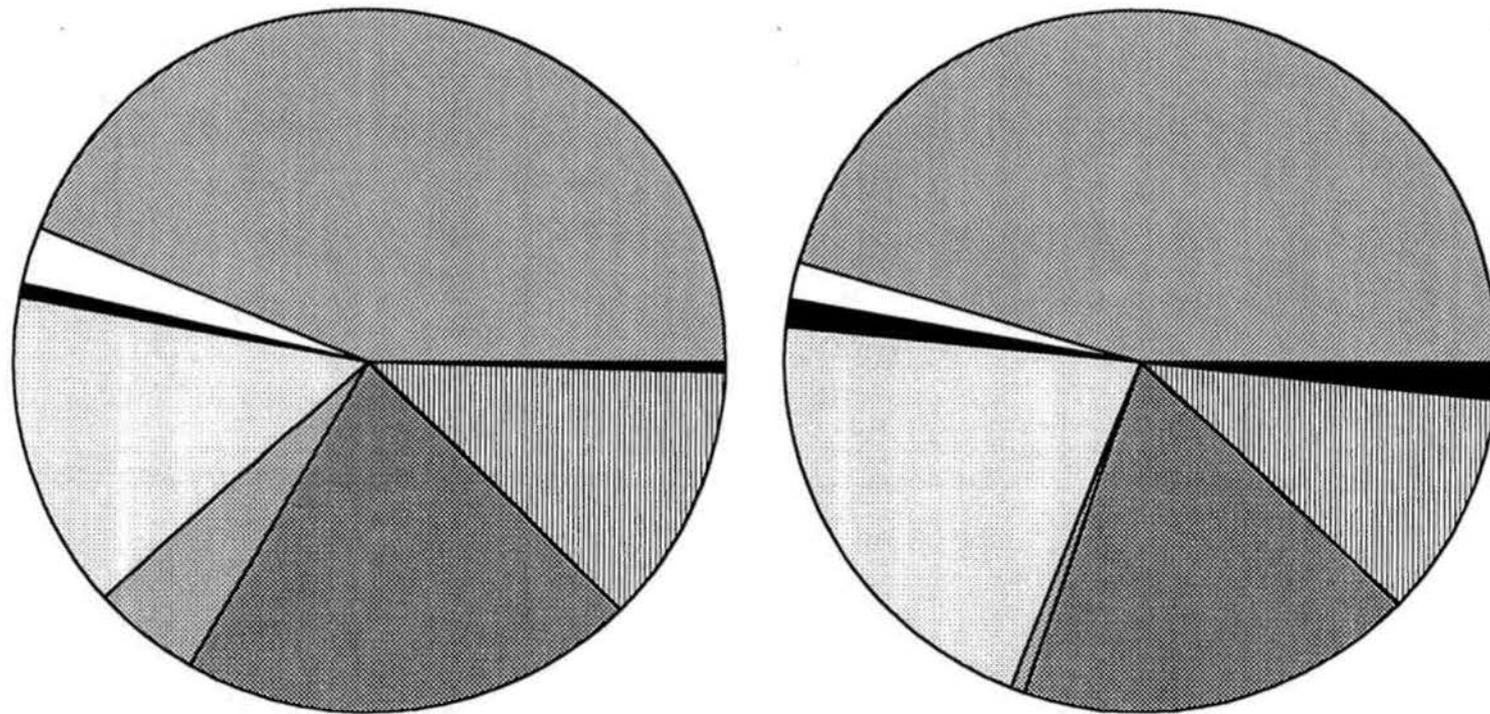


Figure 24.



Zooplankton Community Composition

All dates, basins, for the 0-10m stratum



1994

1995

- | | | | |
|--------------|----------------|-----------------|------------------|
| Diacyclops | Leptodiaptomus | Copepod nauplii | Bosmina |
| Ceriodaphnia | Daphnia pulex | Daphnia galeata | Daphnia neonates |

Figure 25.

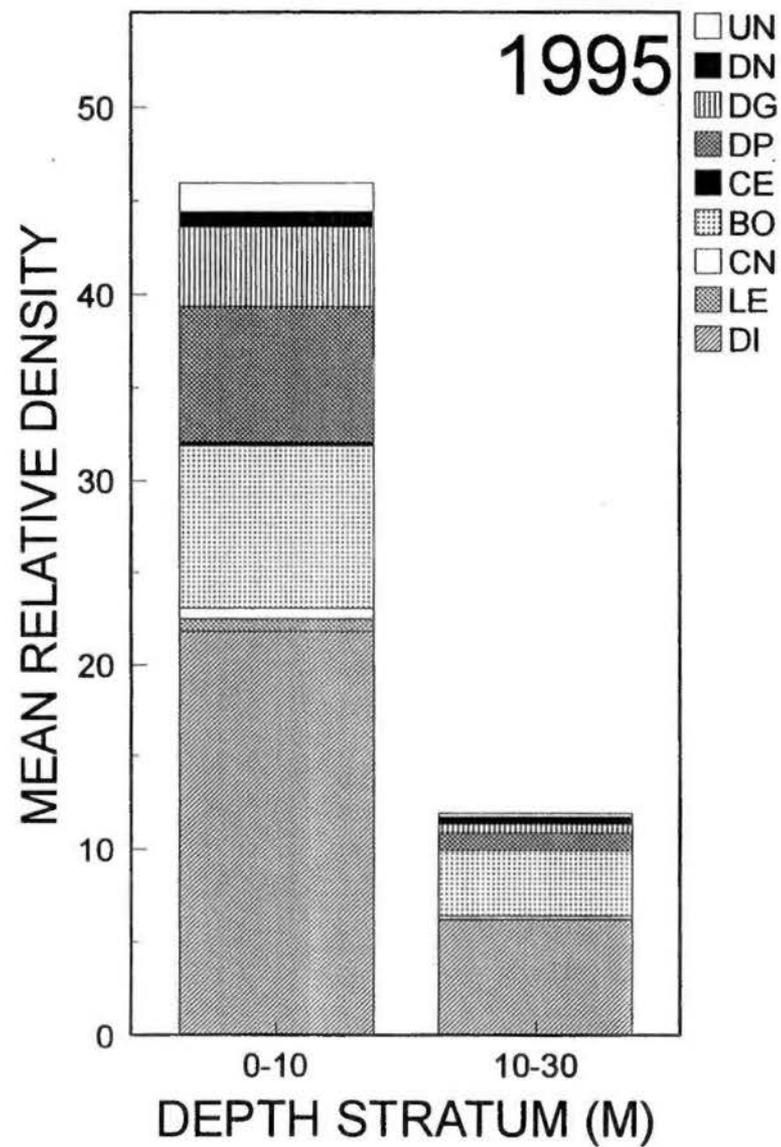
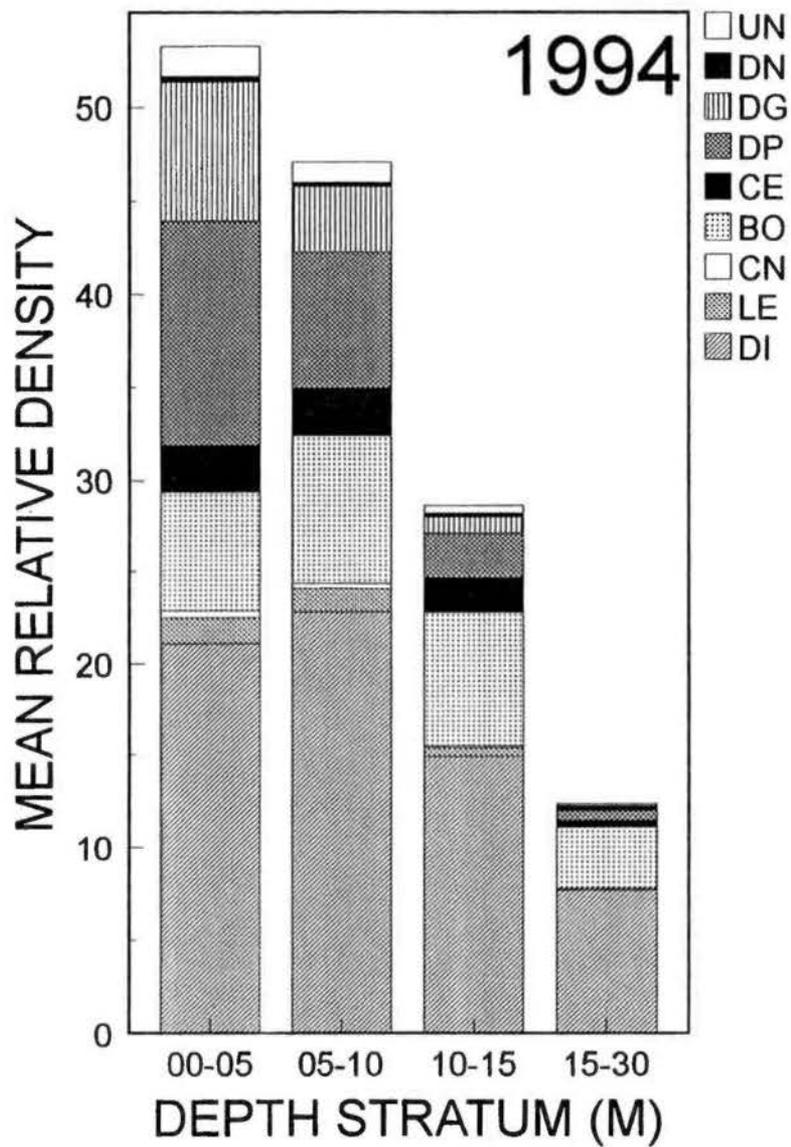


Figure 26.

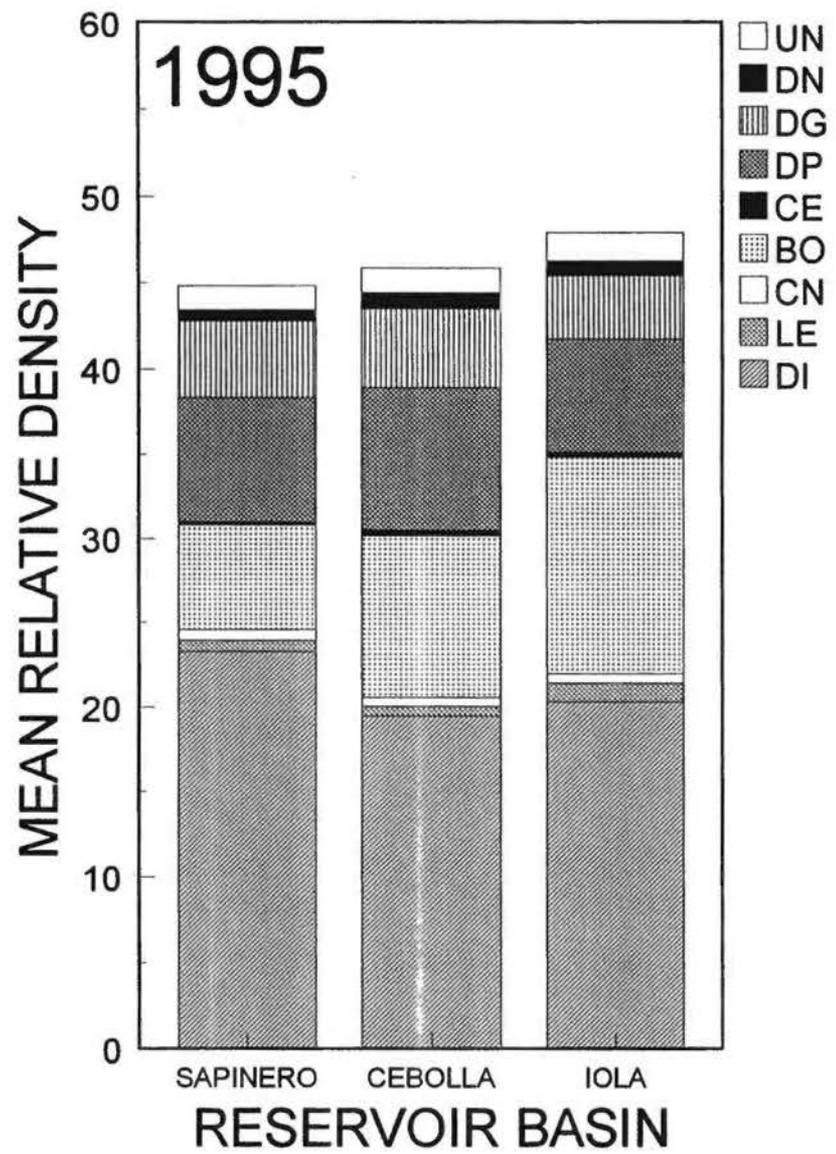
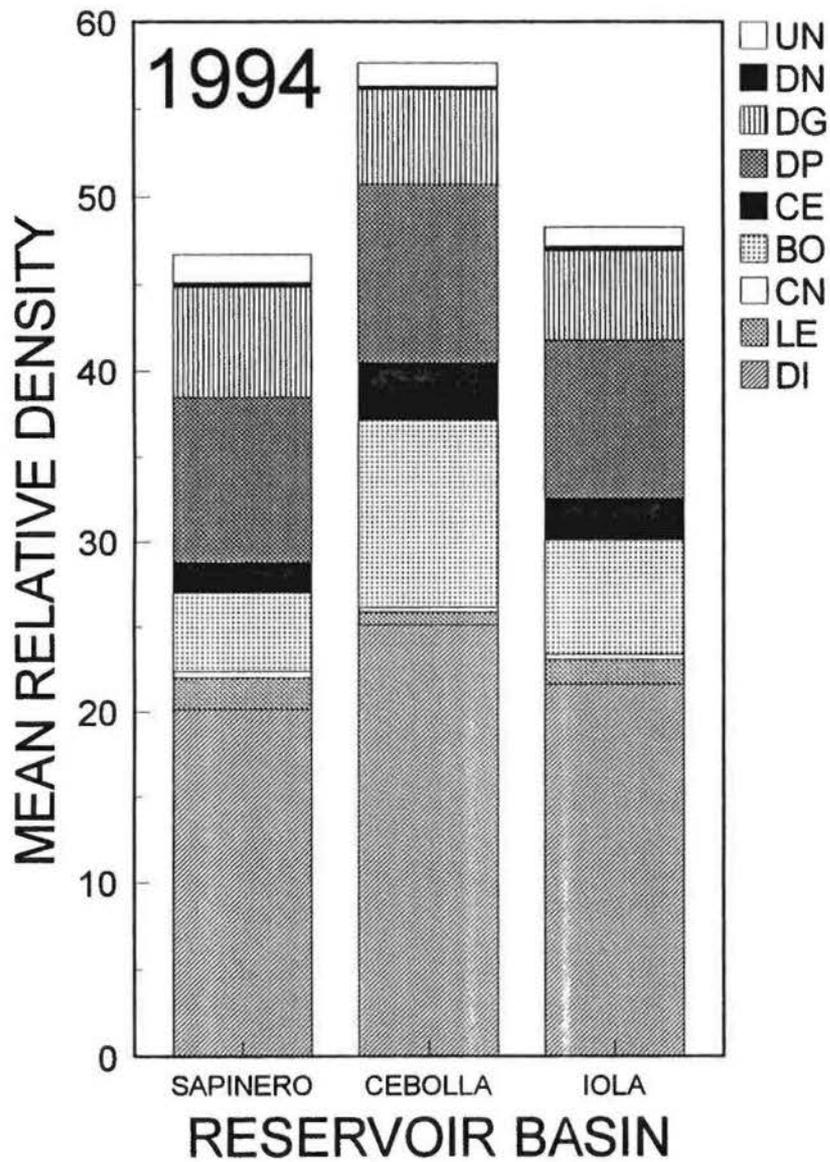


Figure 27.

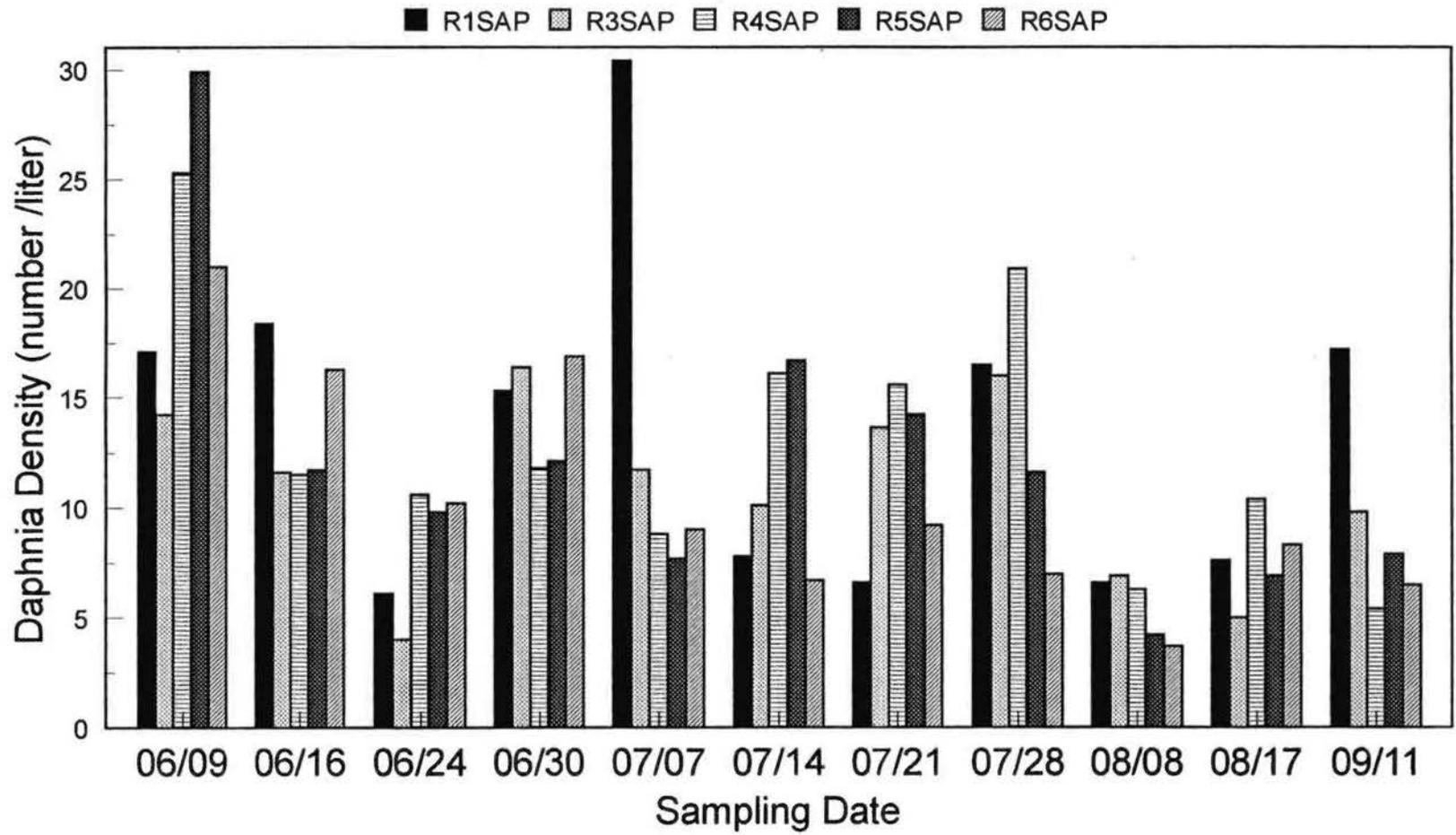


Figure 28.

SAPINERO BASIN

(AVERAGED ACROSS DATES FOR EACH STATION)

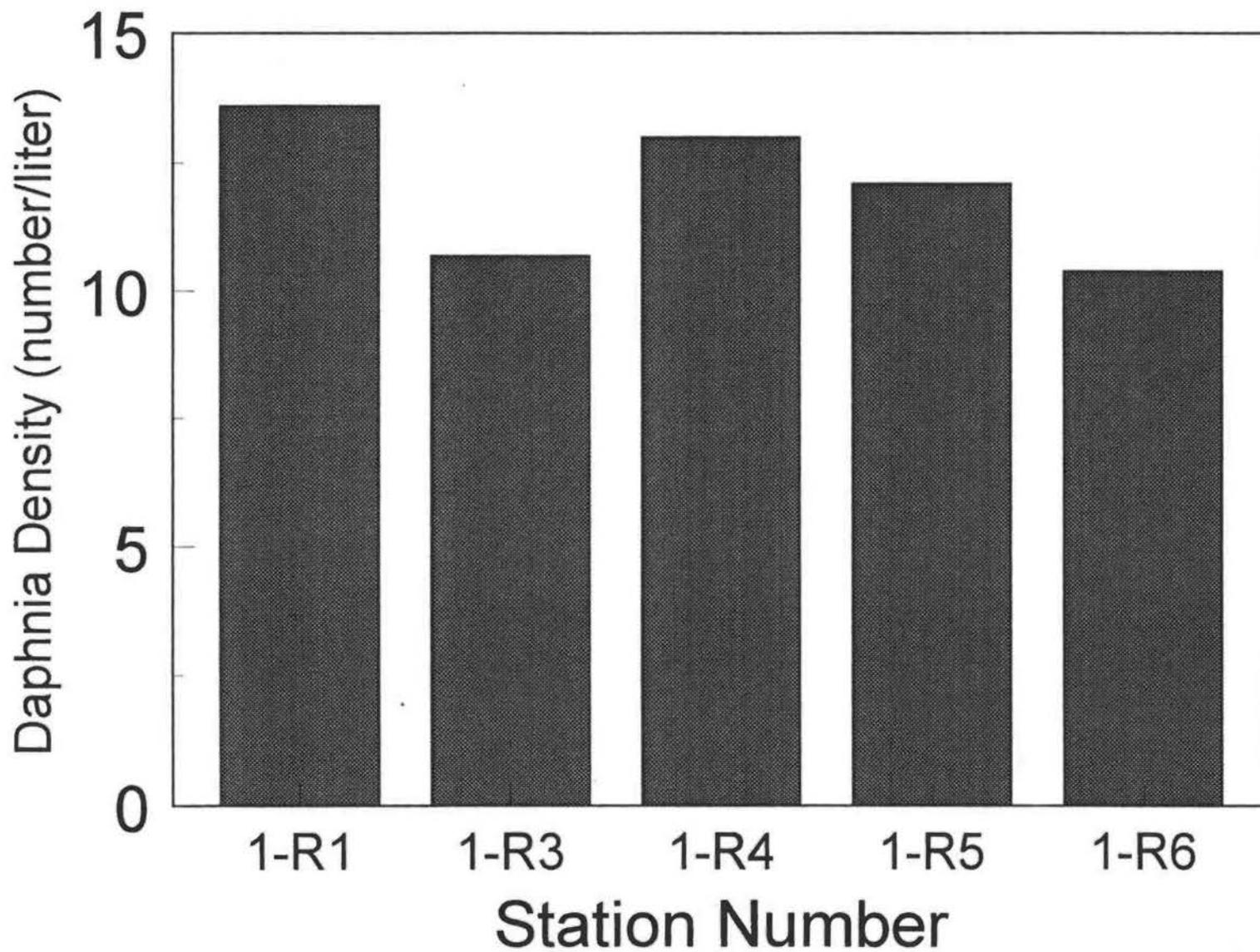
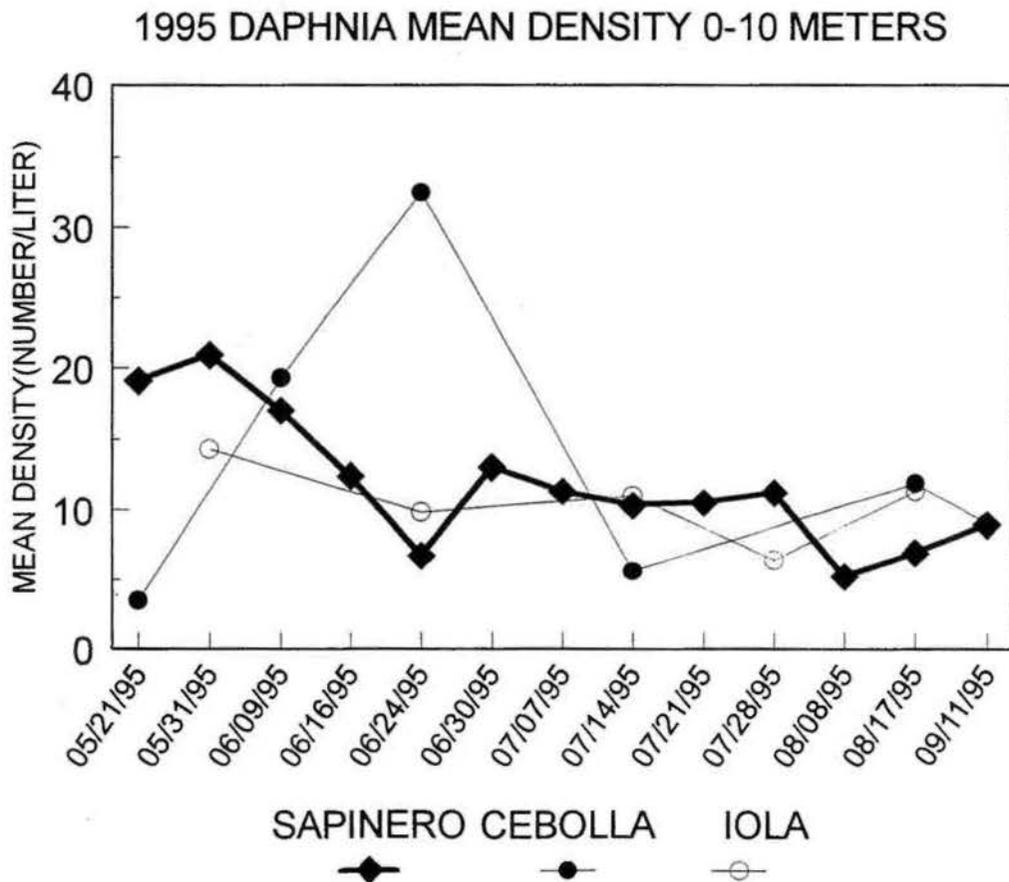
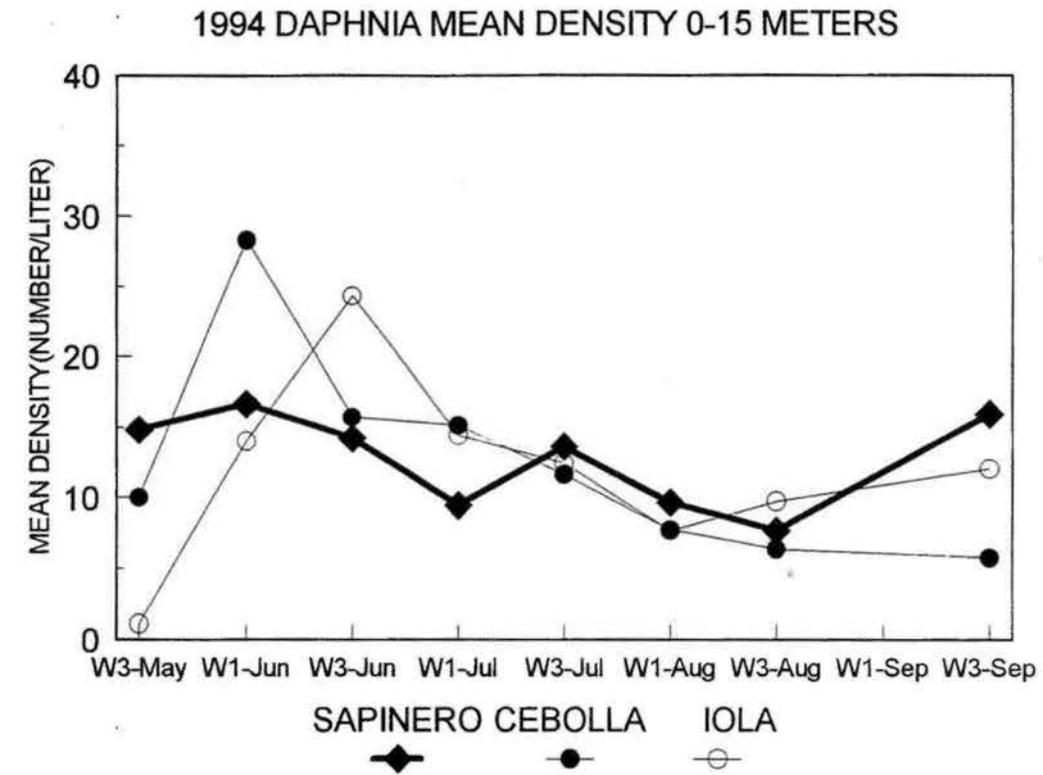


Figure 29.

Figure 30.



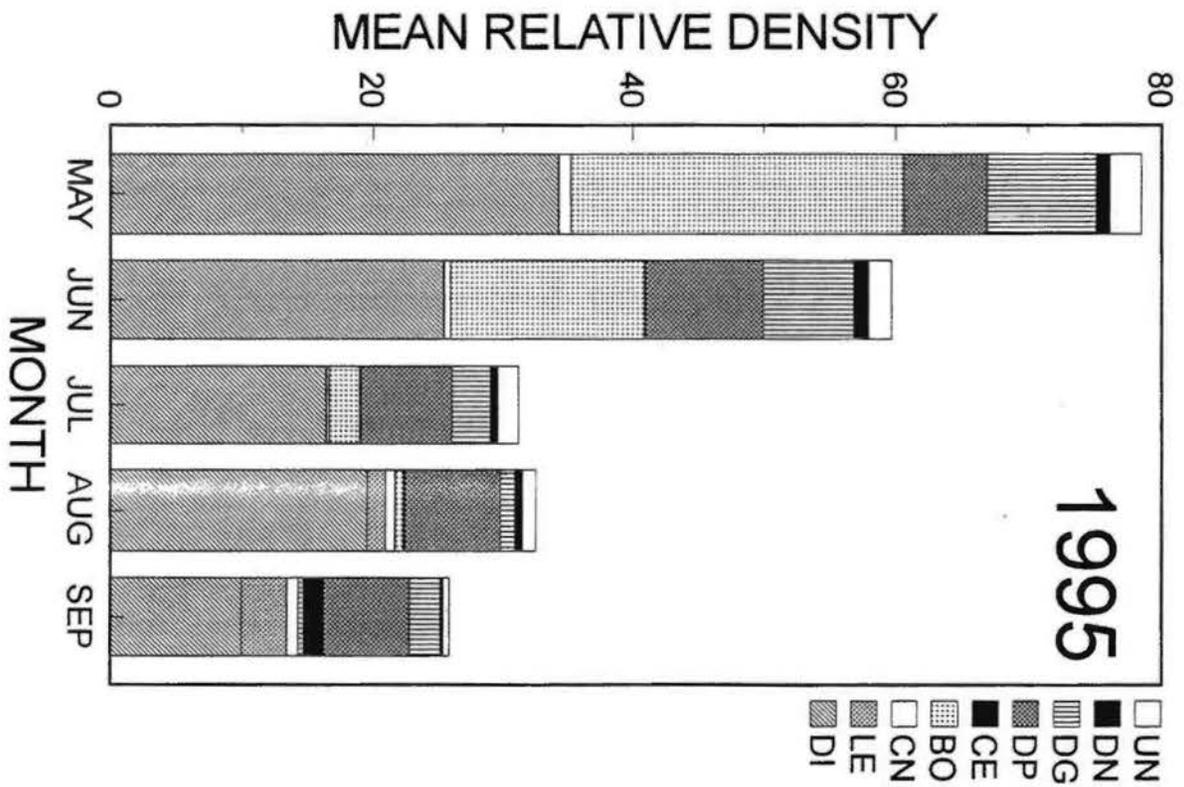
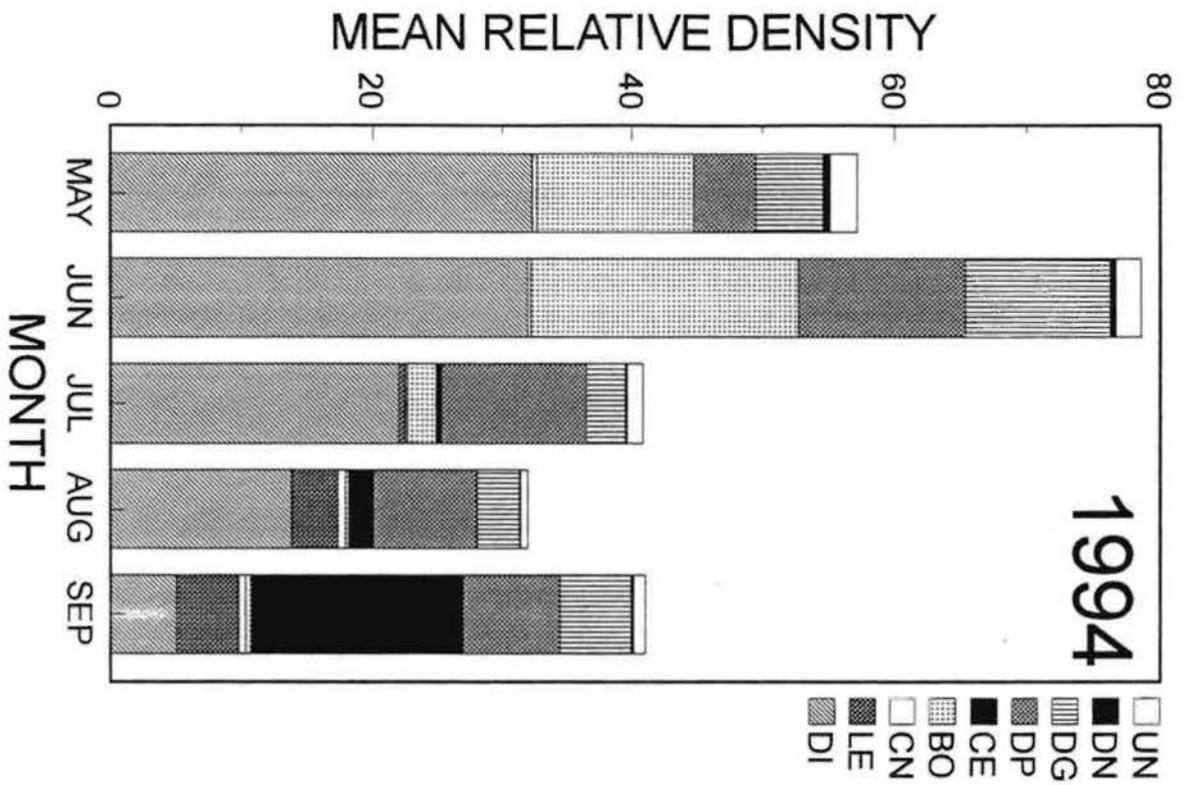


Figure 31.

Figure 32.

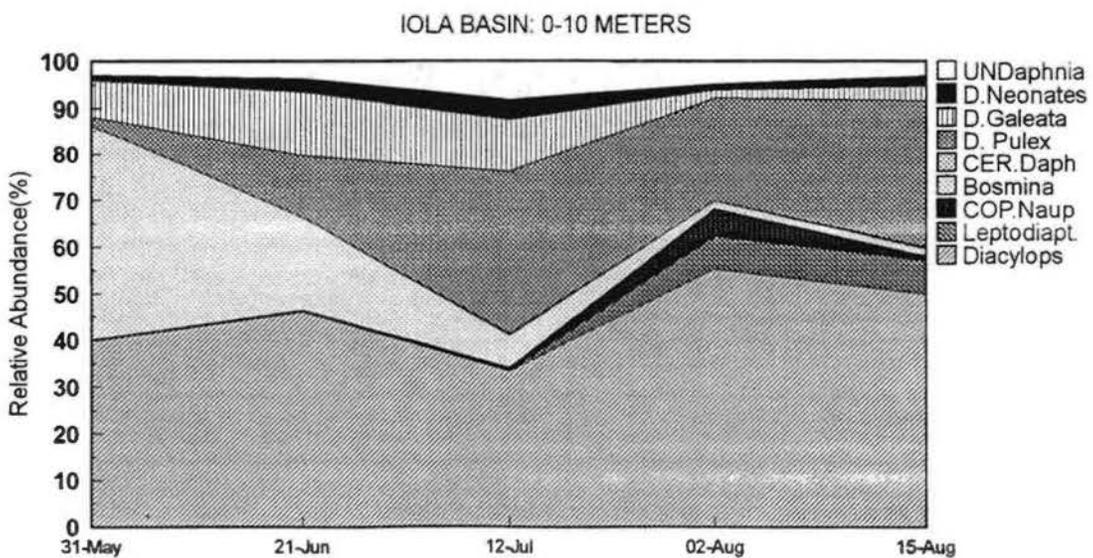
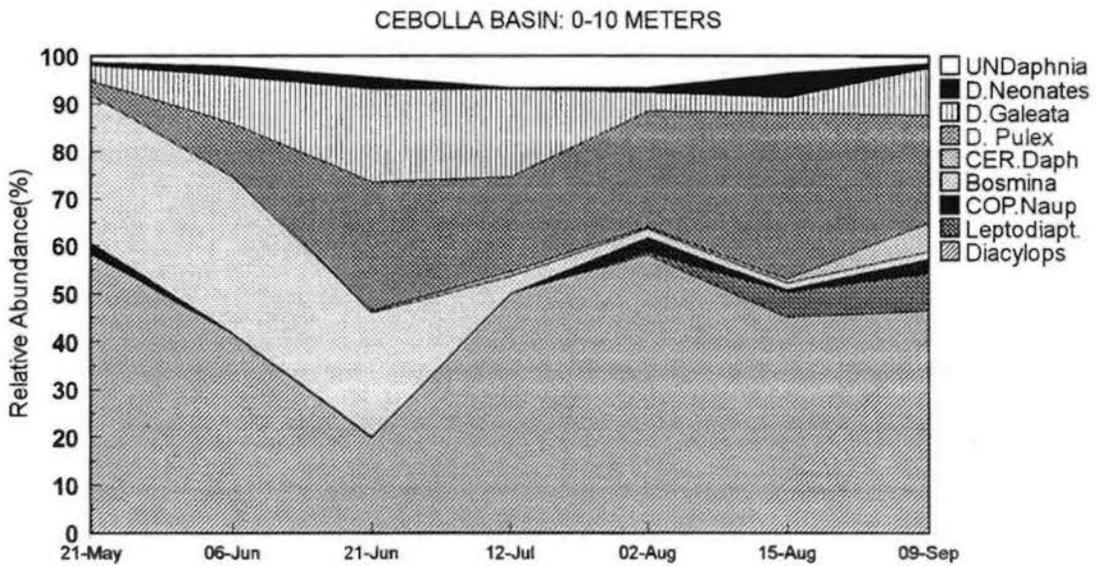
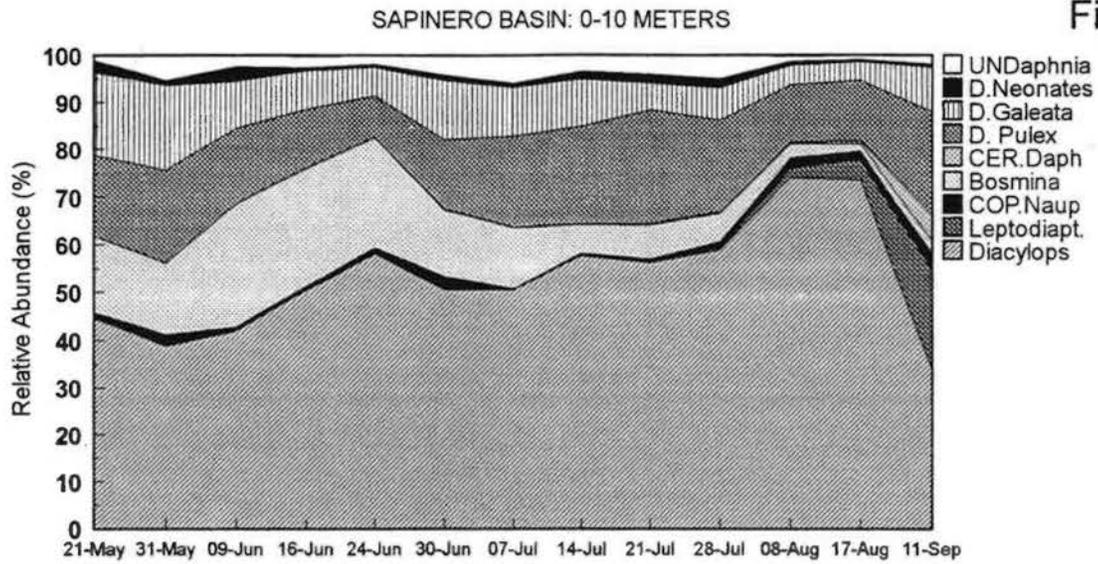


Figure 33.

SAPINERO BASIN

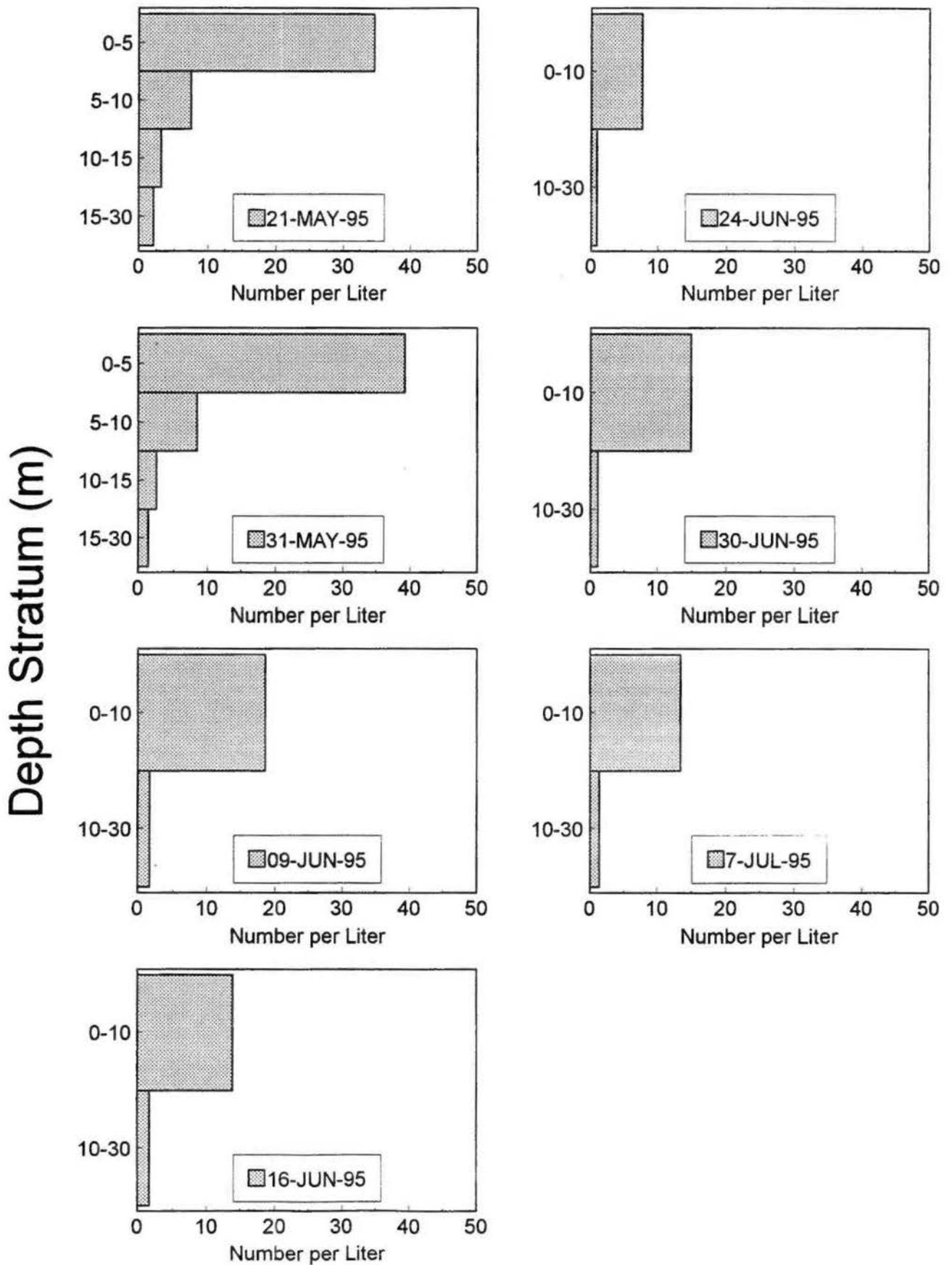


Figure 34.

SAPINERO BASIN

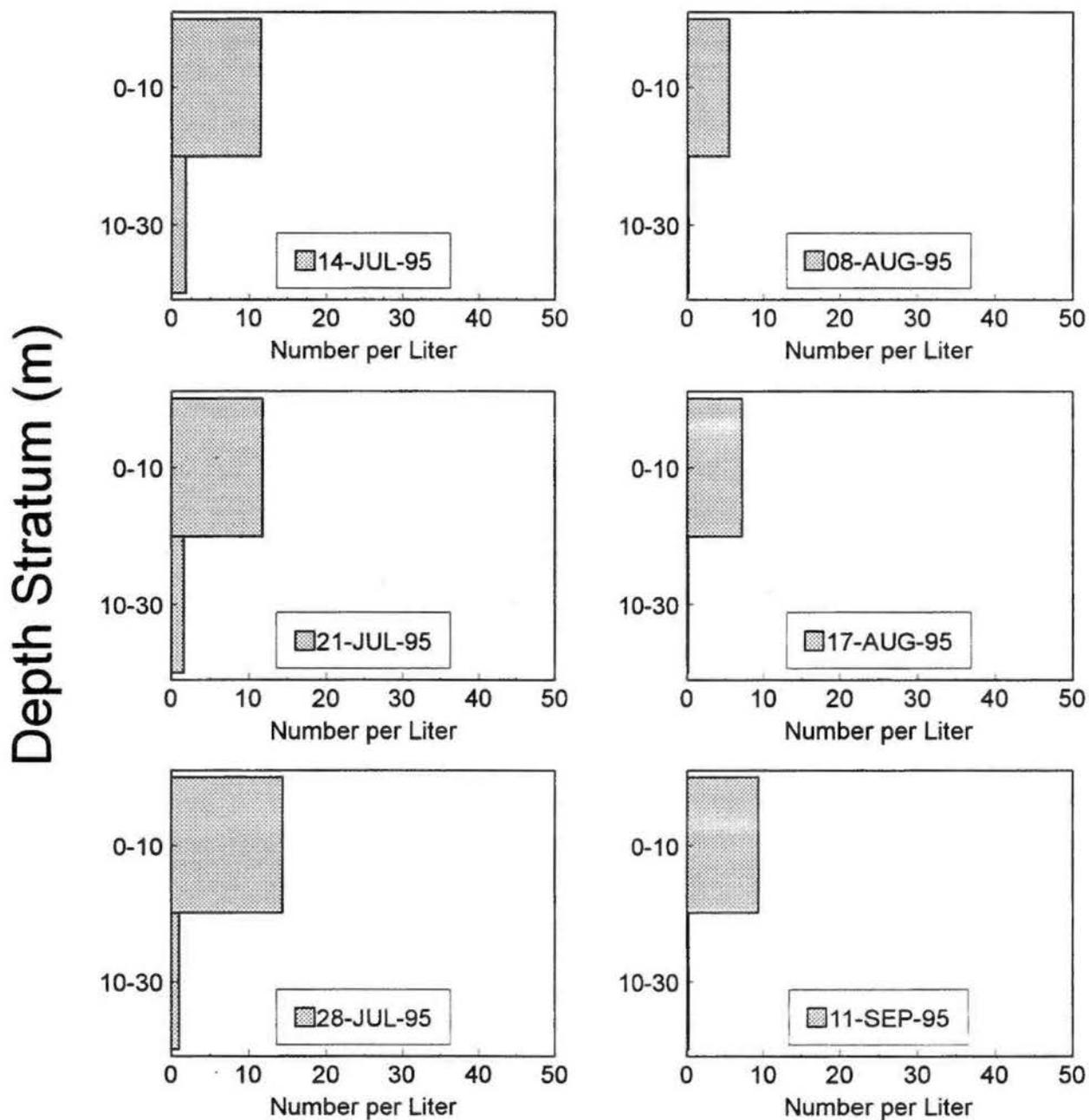


Figure 35.

CEBOLLA BASIN

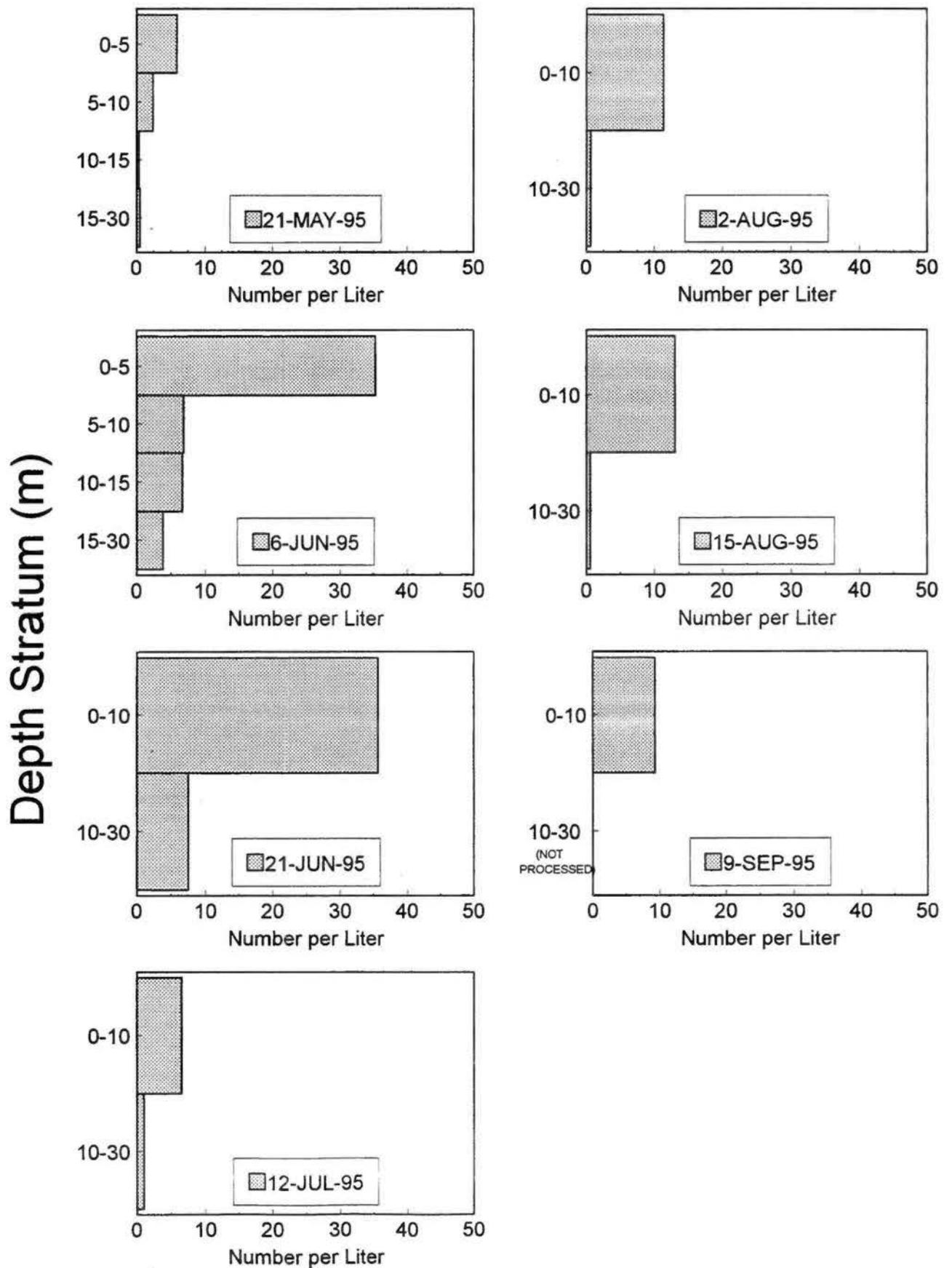


Figure 36.

IOLA BASIN

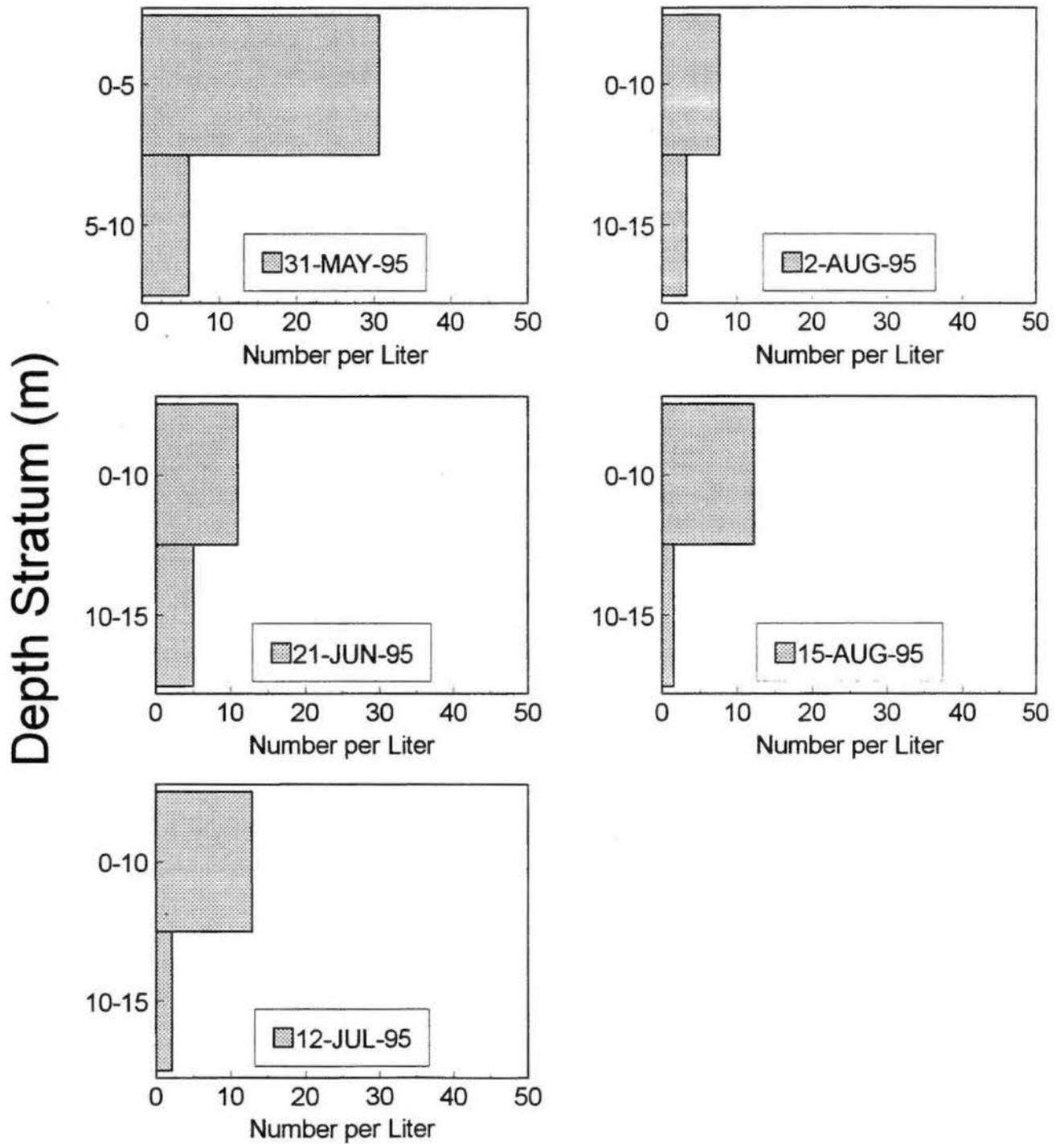
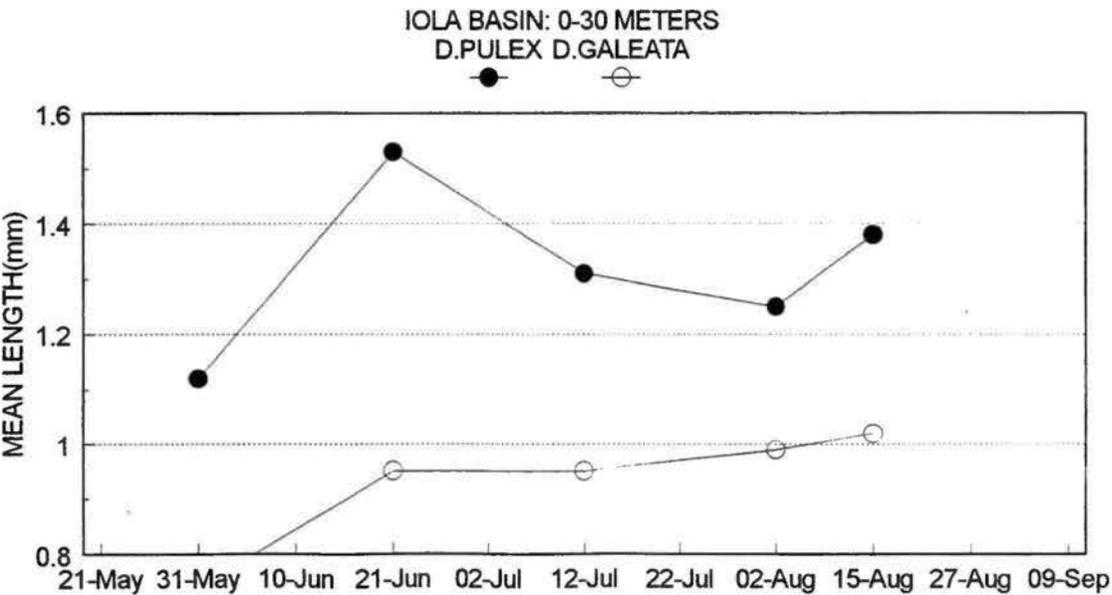
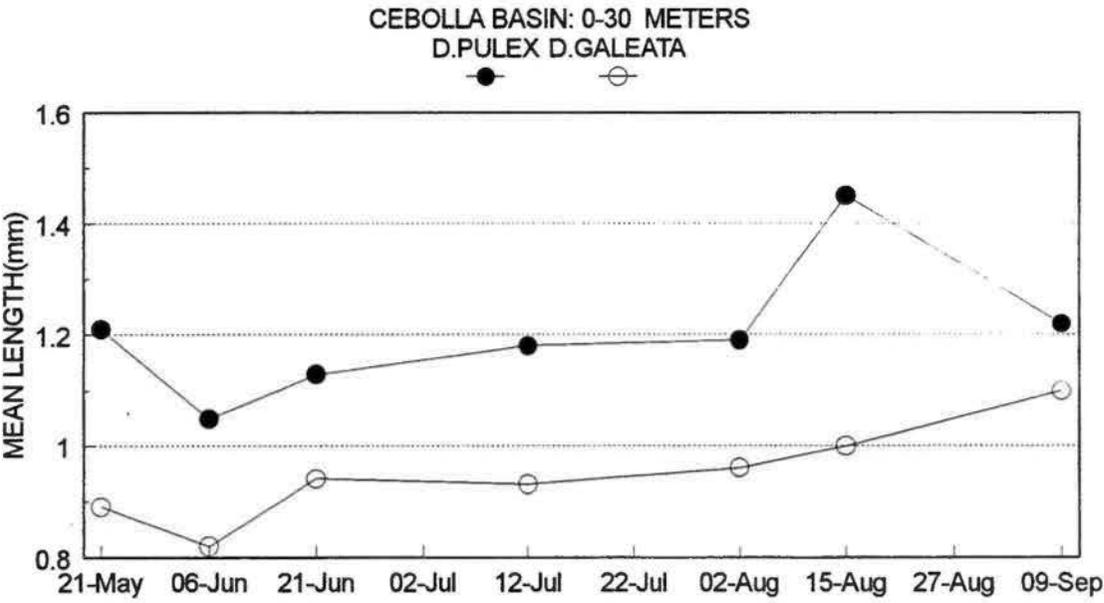
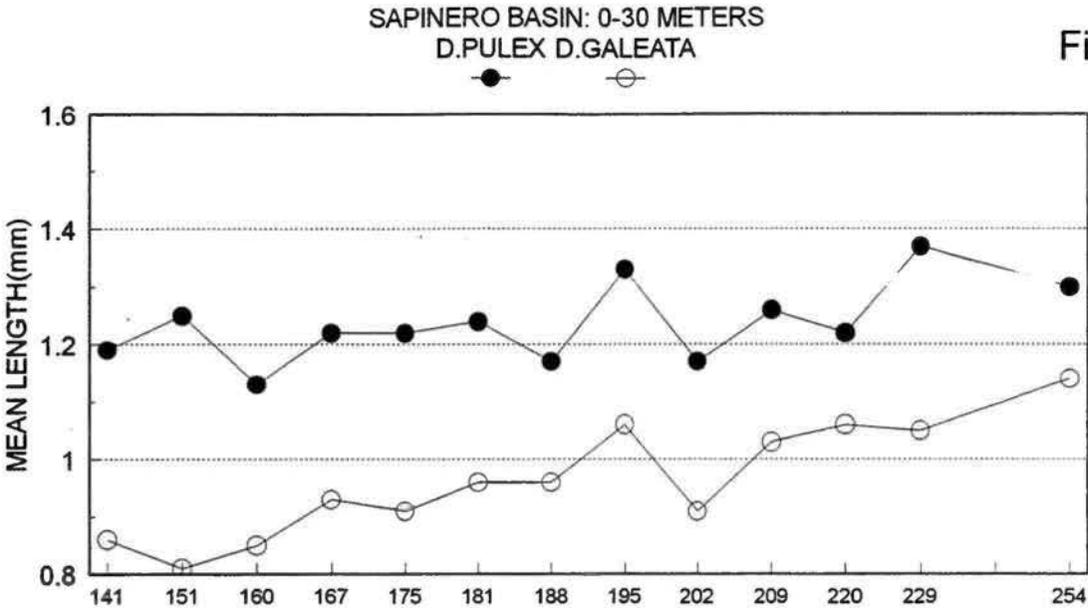


Figure 37.



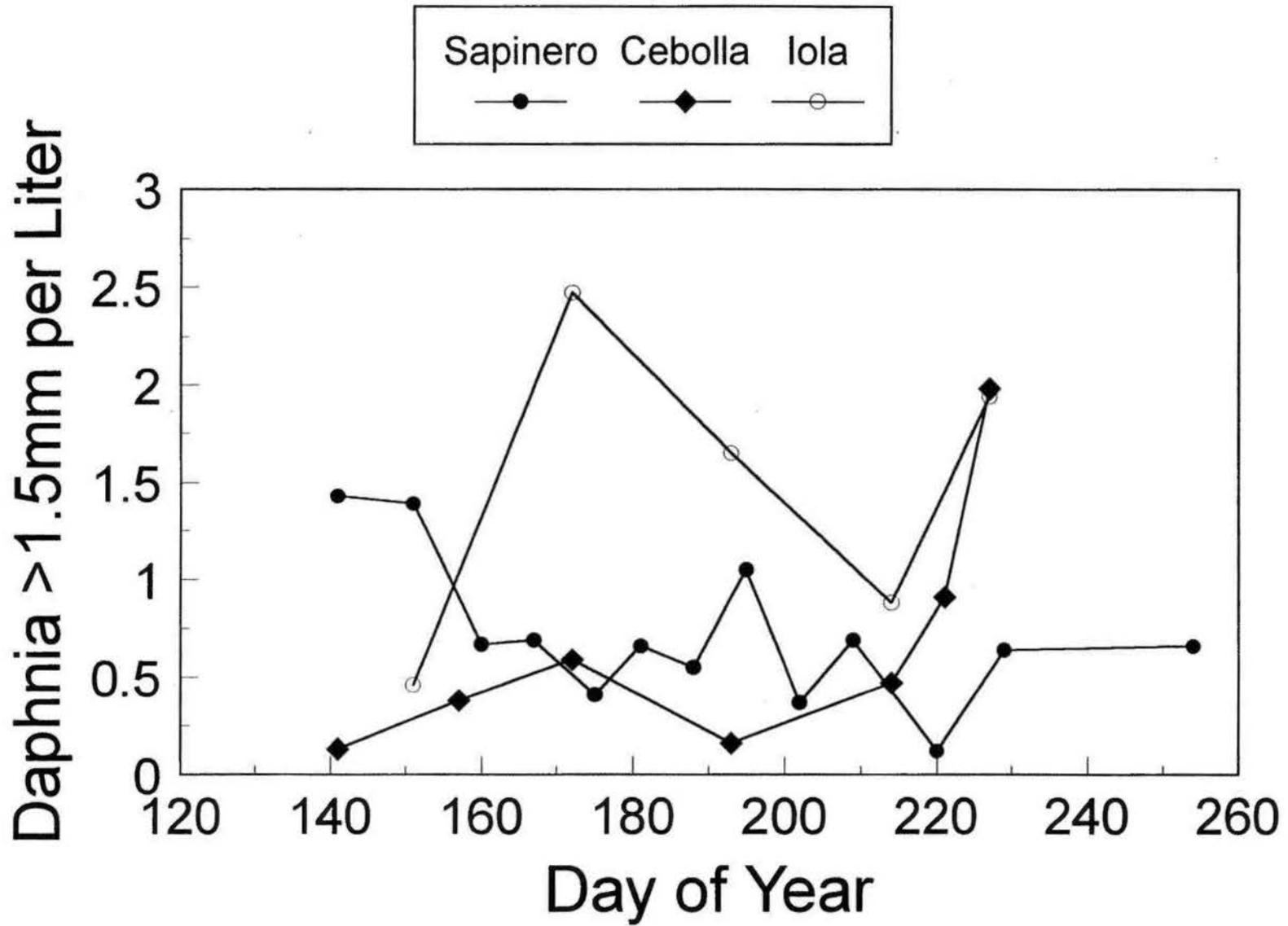


Figure 38.

Figure 42.

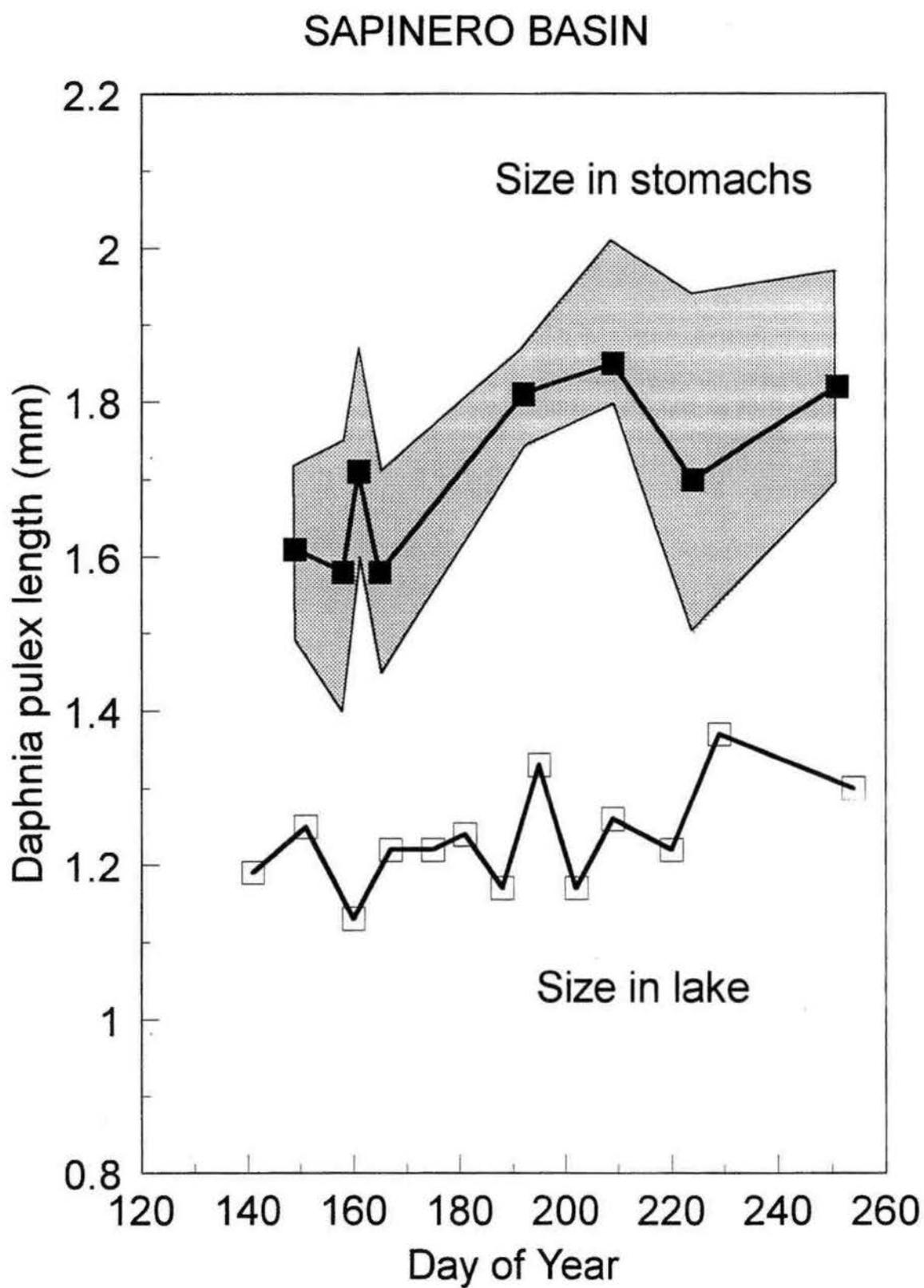


Figure 43.

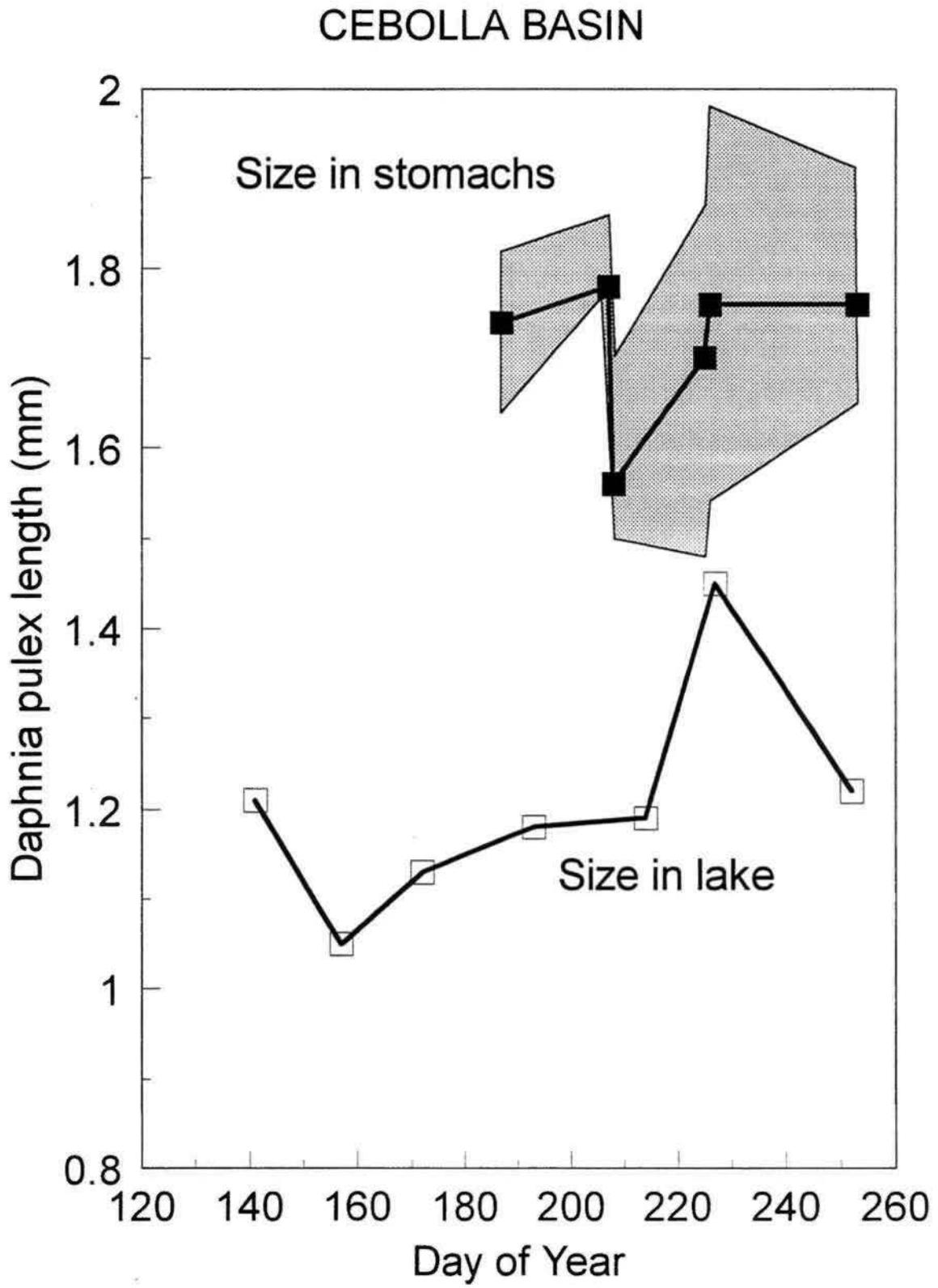
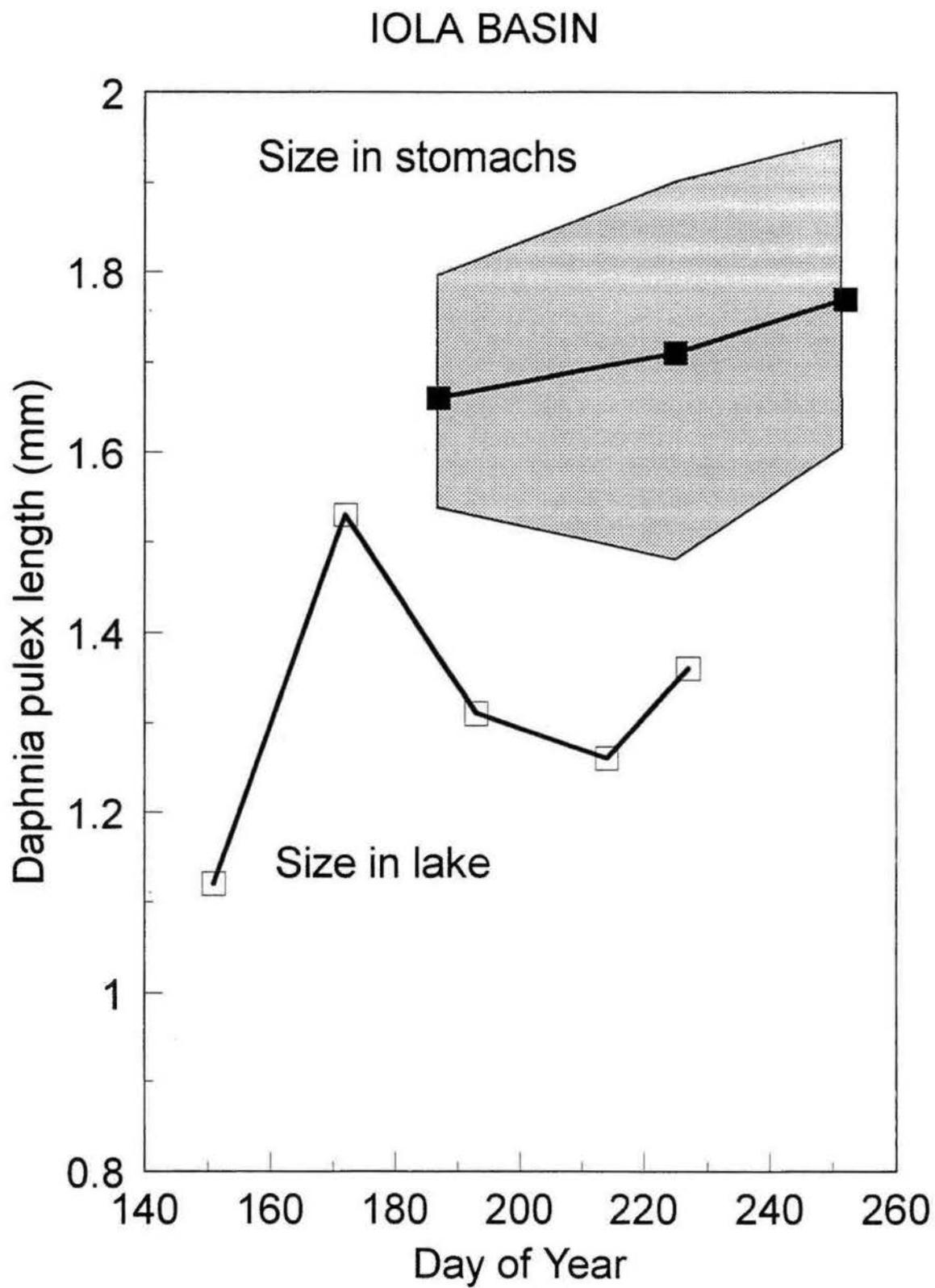
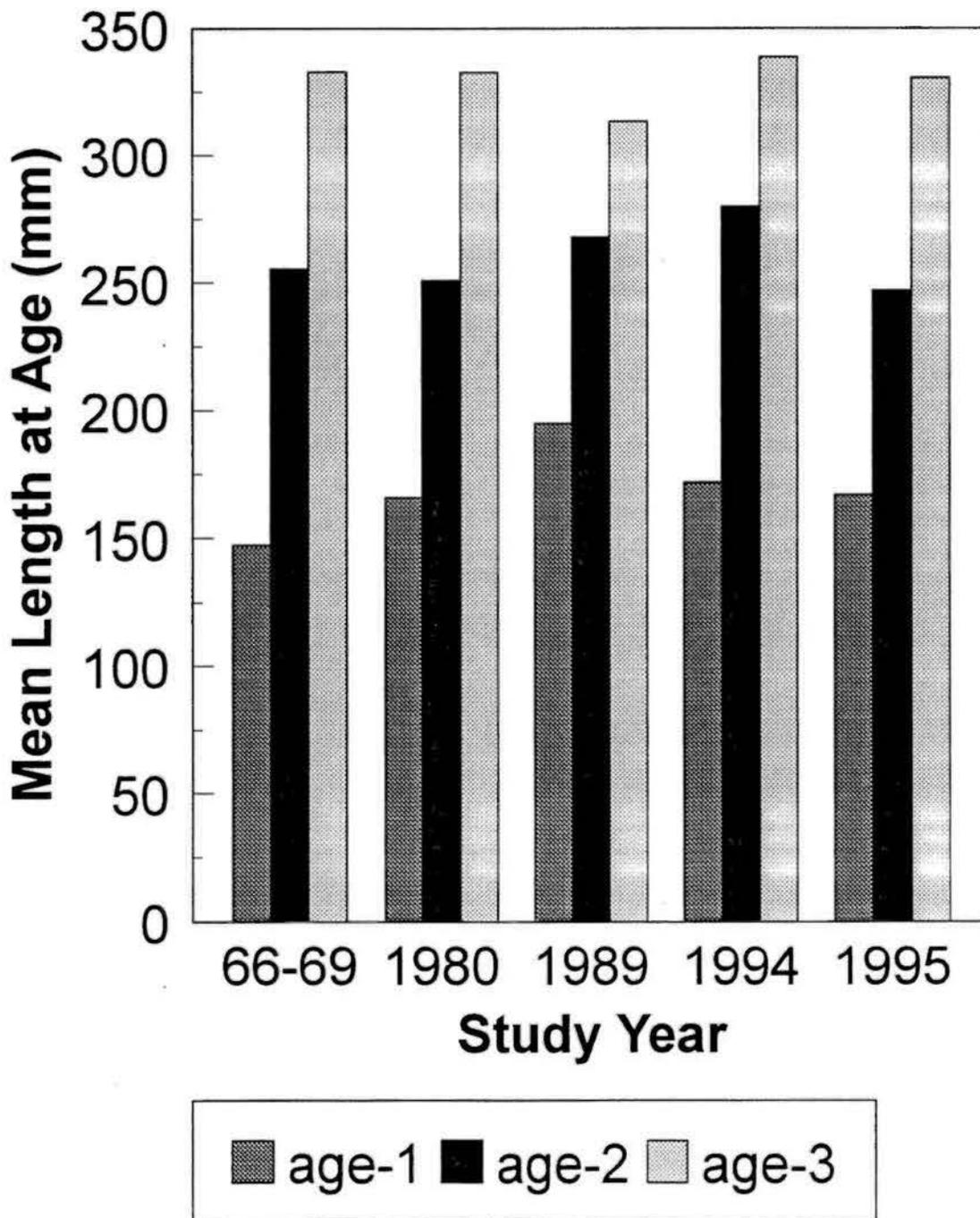


Figure 44.



Blue Mesa Kokanee

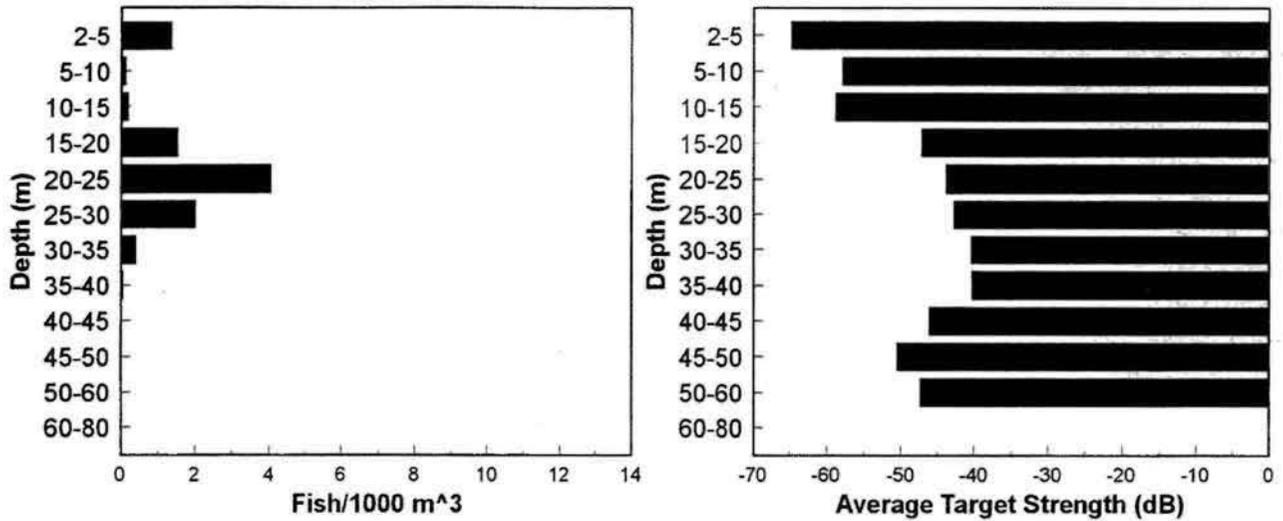
Backcalculated growth from scales



Sapinero Sonar Survey - Aug 1994

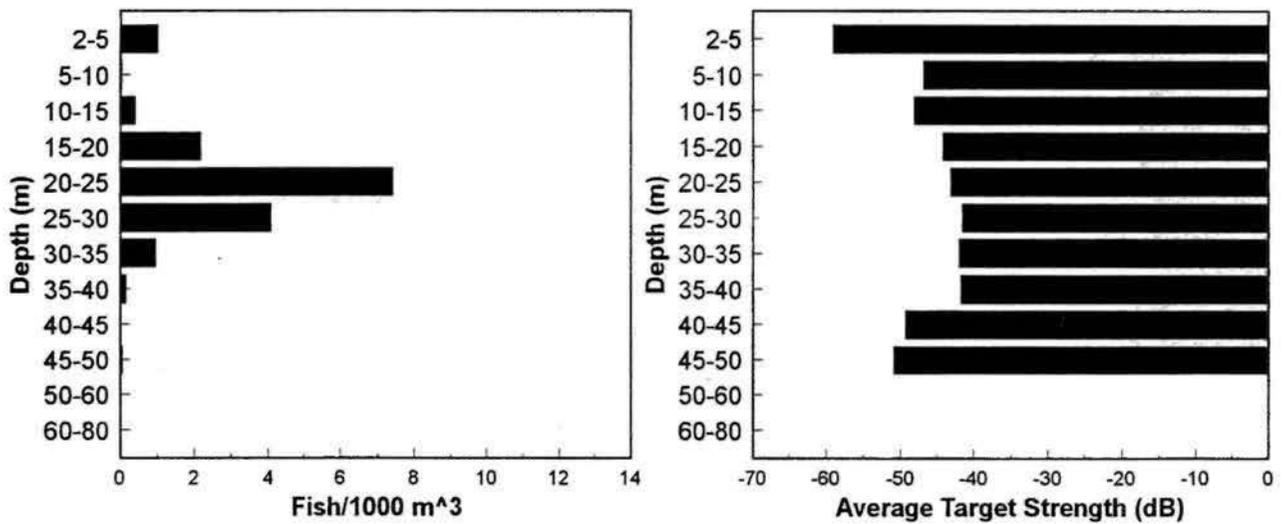
Figure 46.

Mean of all 6 transects



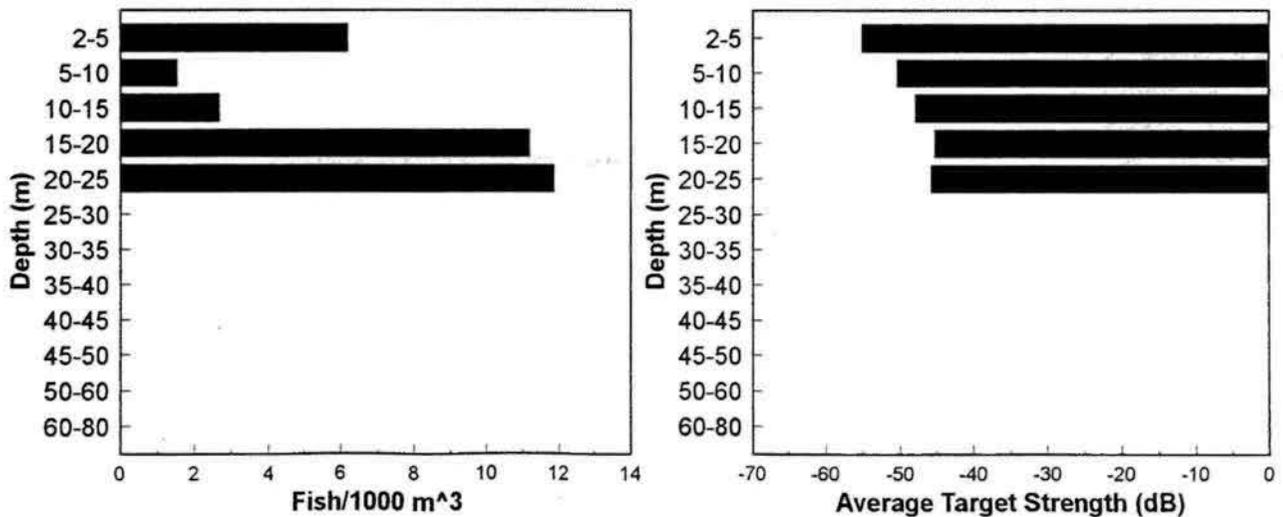
Cebolla Sonar Survey - Aug 1994

Mean of all 5 transects

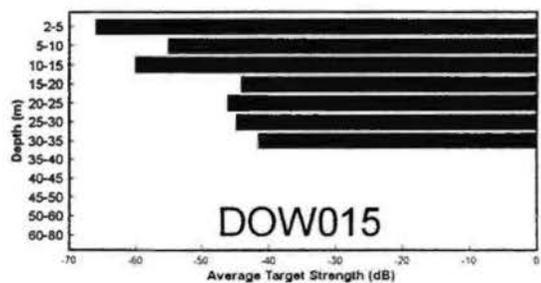
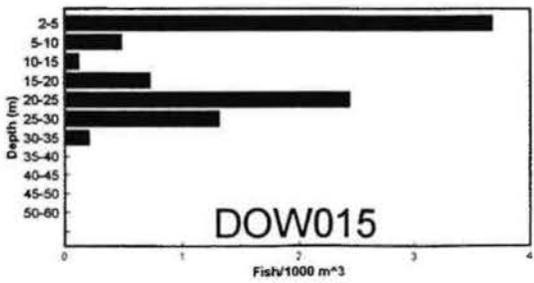
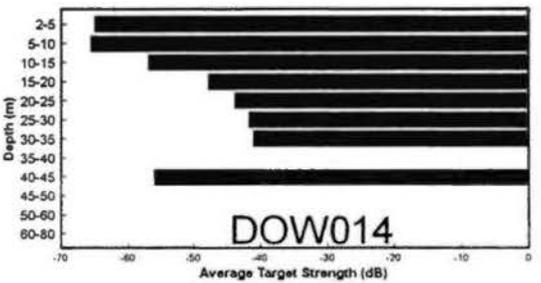
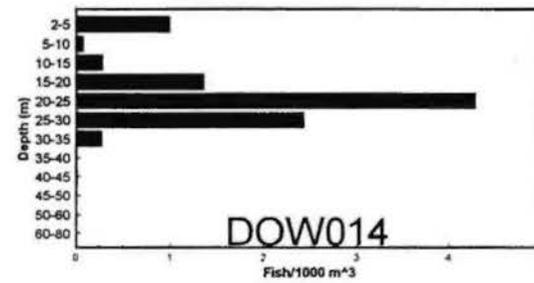
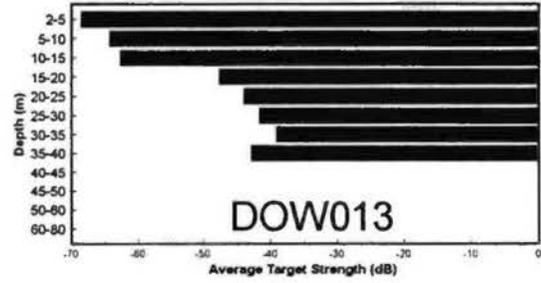
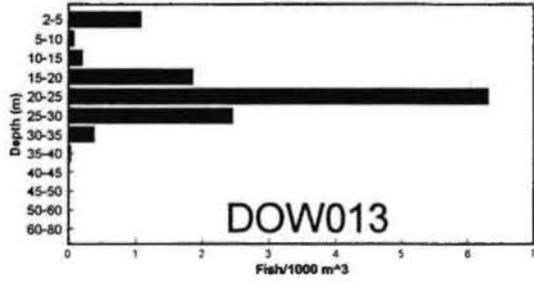
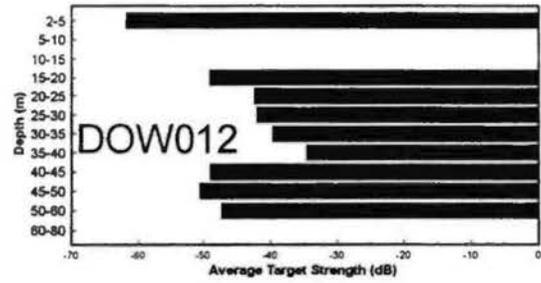
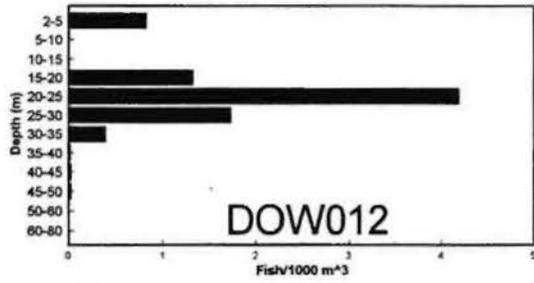
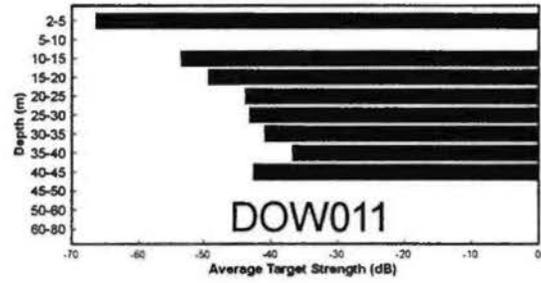
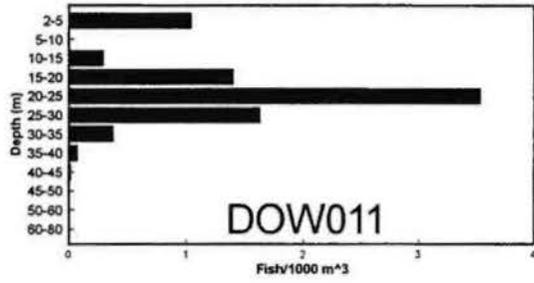
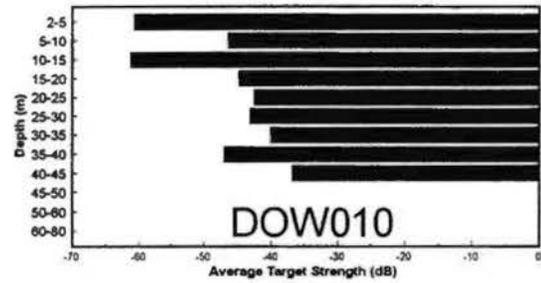
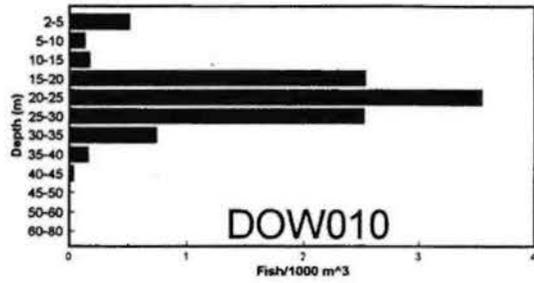


Iola Sonar Survey - Aug 1994

Mean of all 4 transects

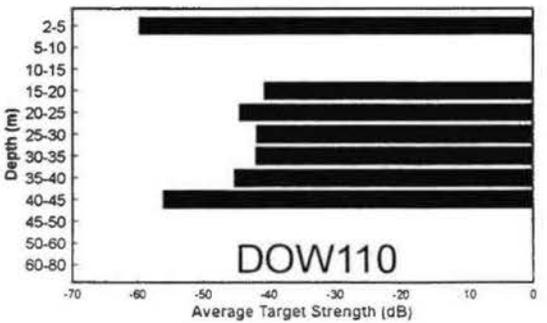
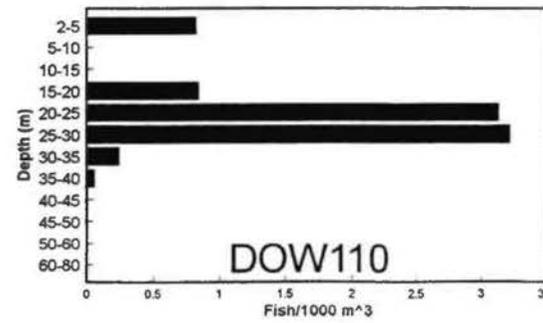
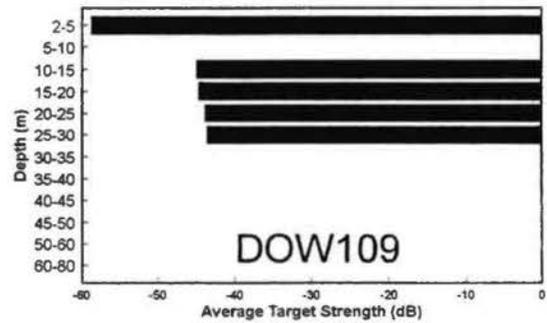
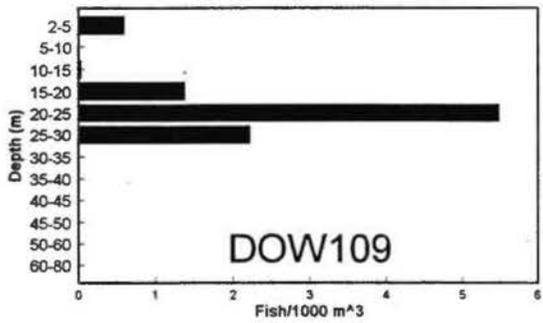
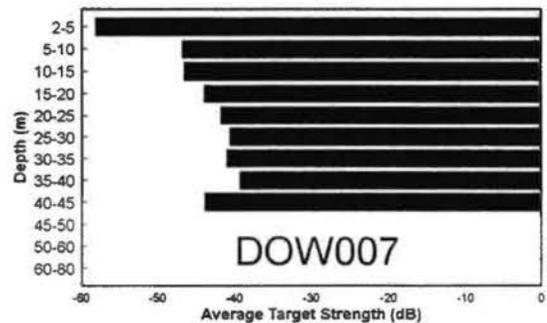
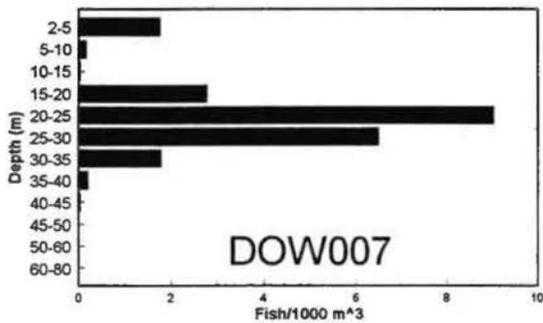
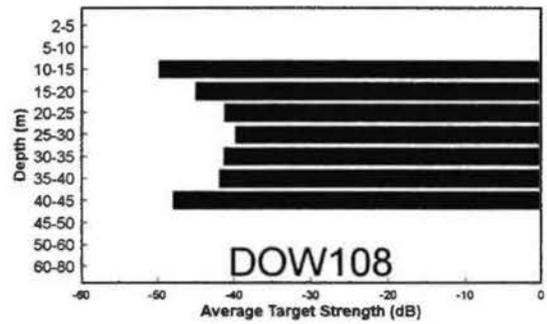
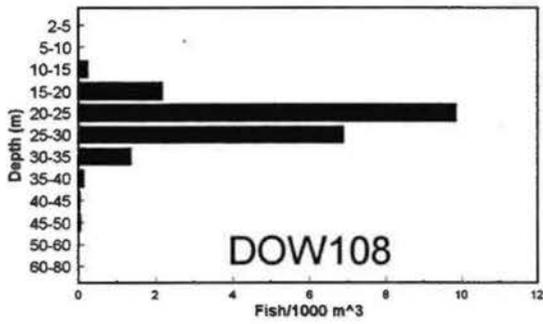
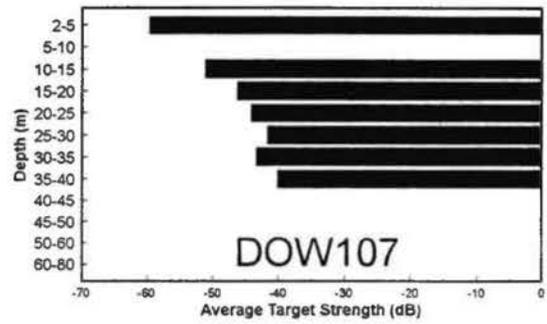
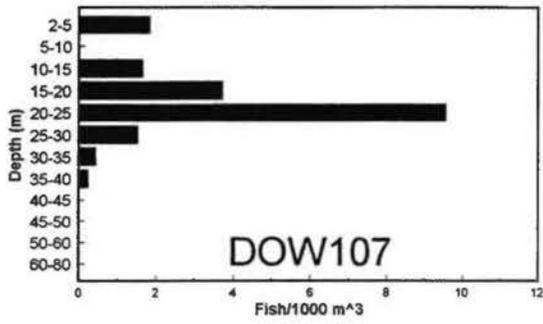


Sapinero Sonar Survey - Aug 1994 Figure 47.

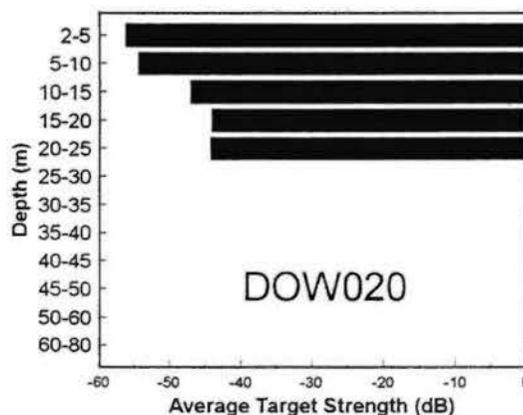
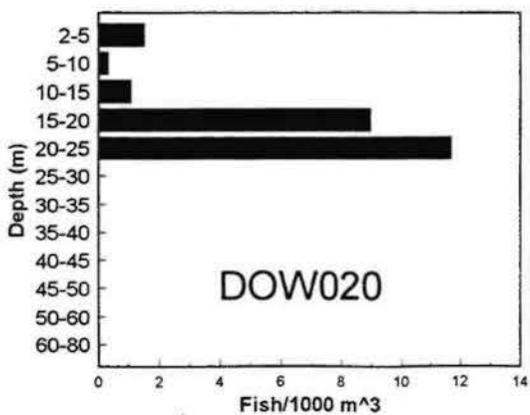
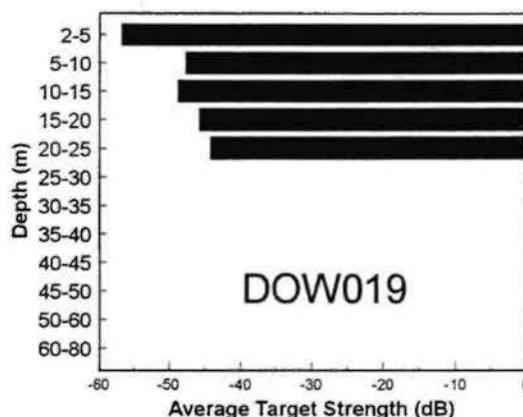
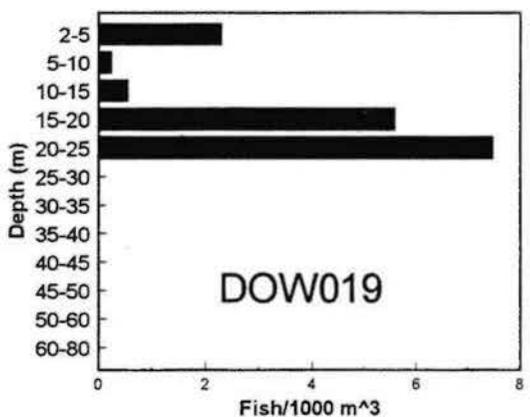
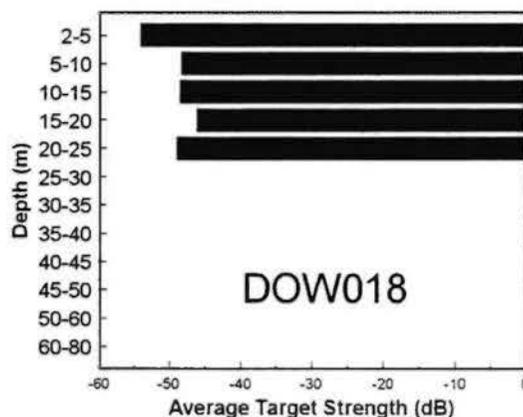
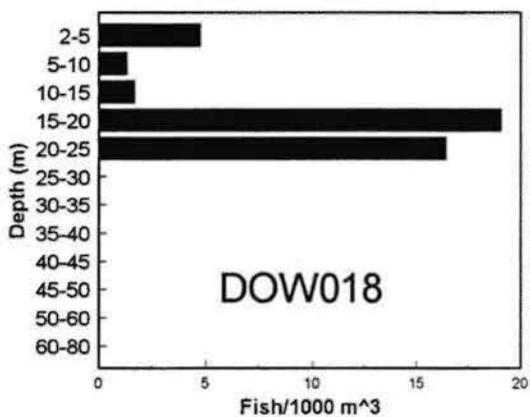
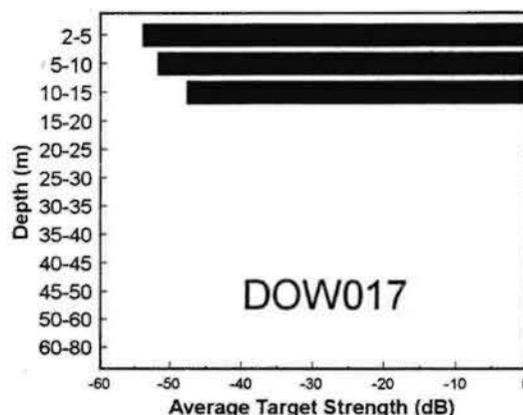
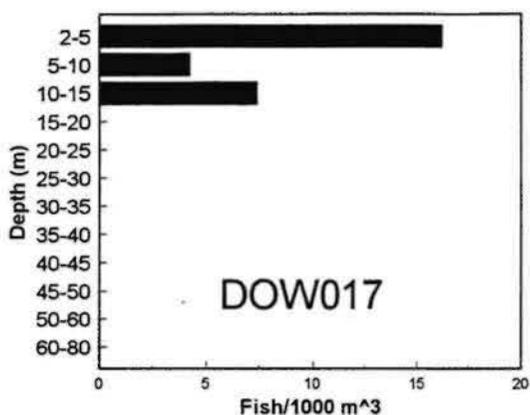


Cebolla Sonar Survey - Aug 1994

Figure 48.



Iola Sonar Survey - Aug 1994



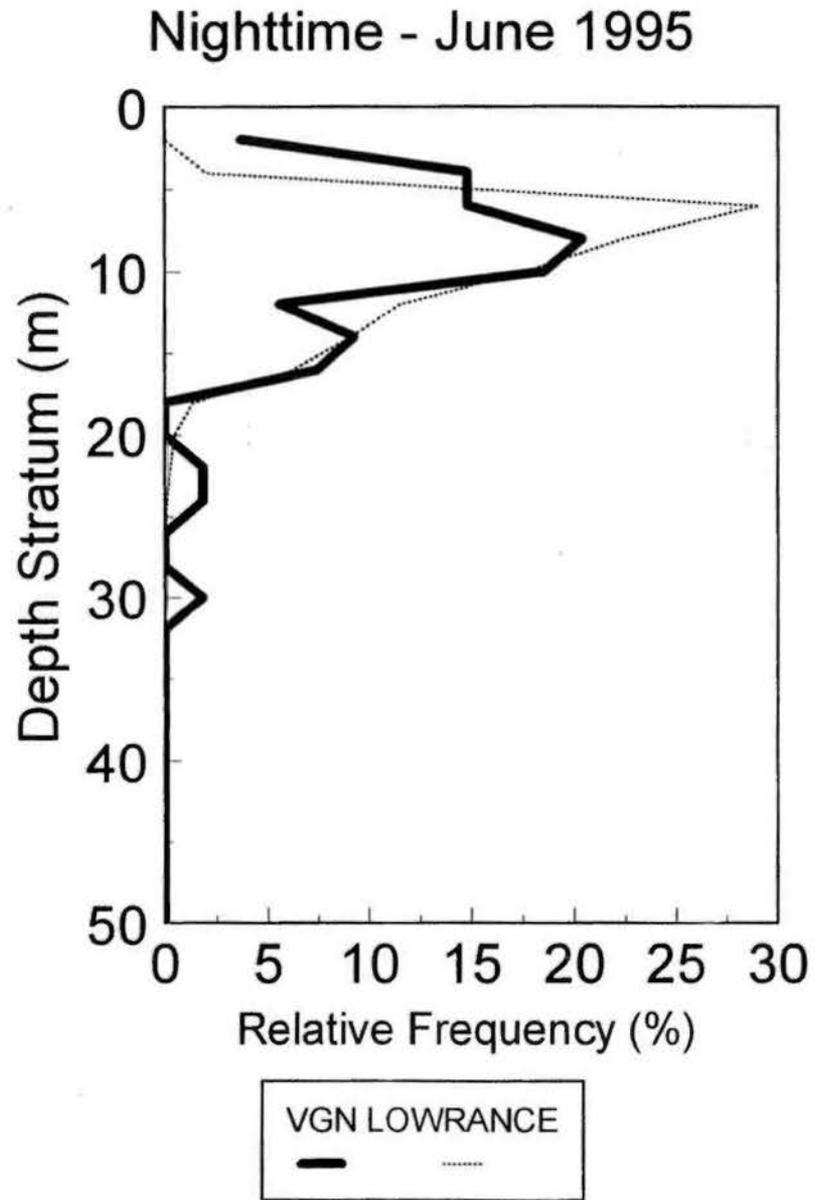
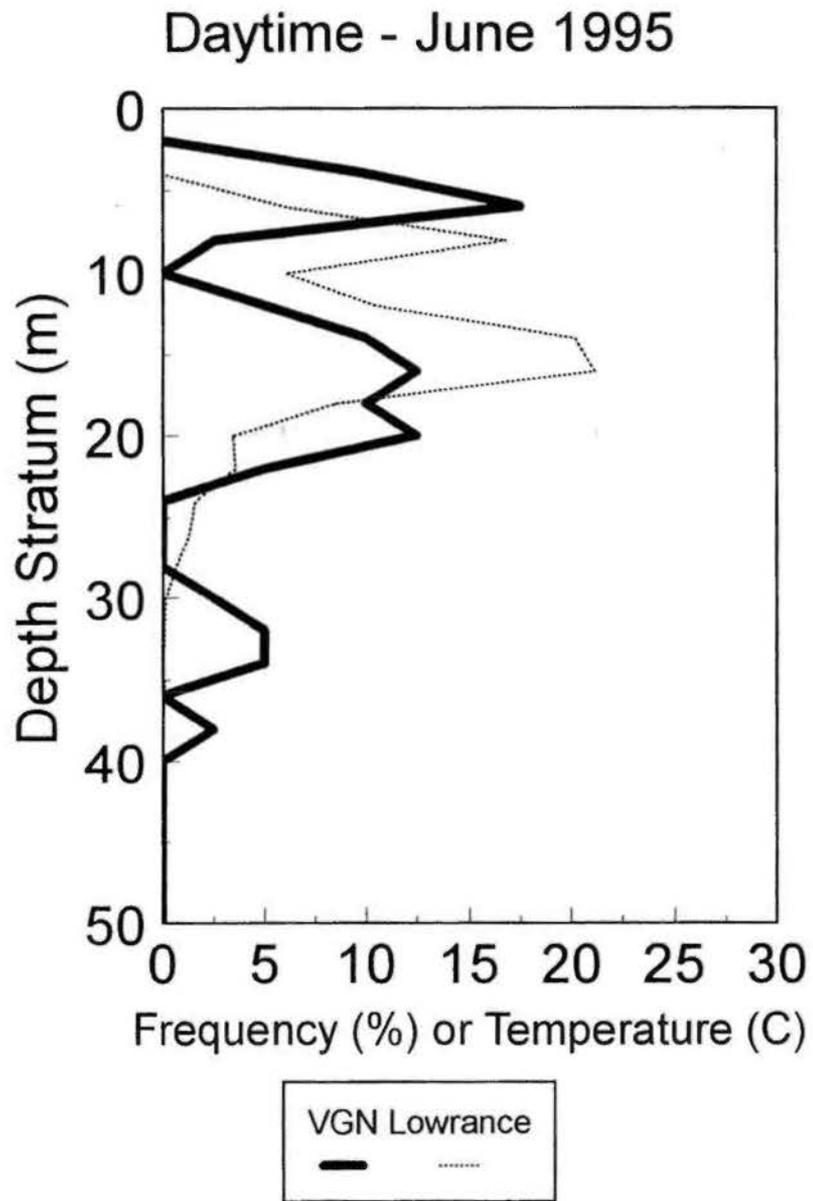


Figure 50.

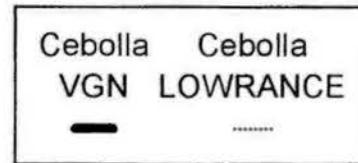
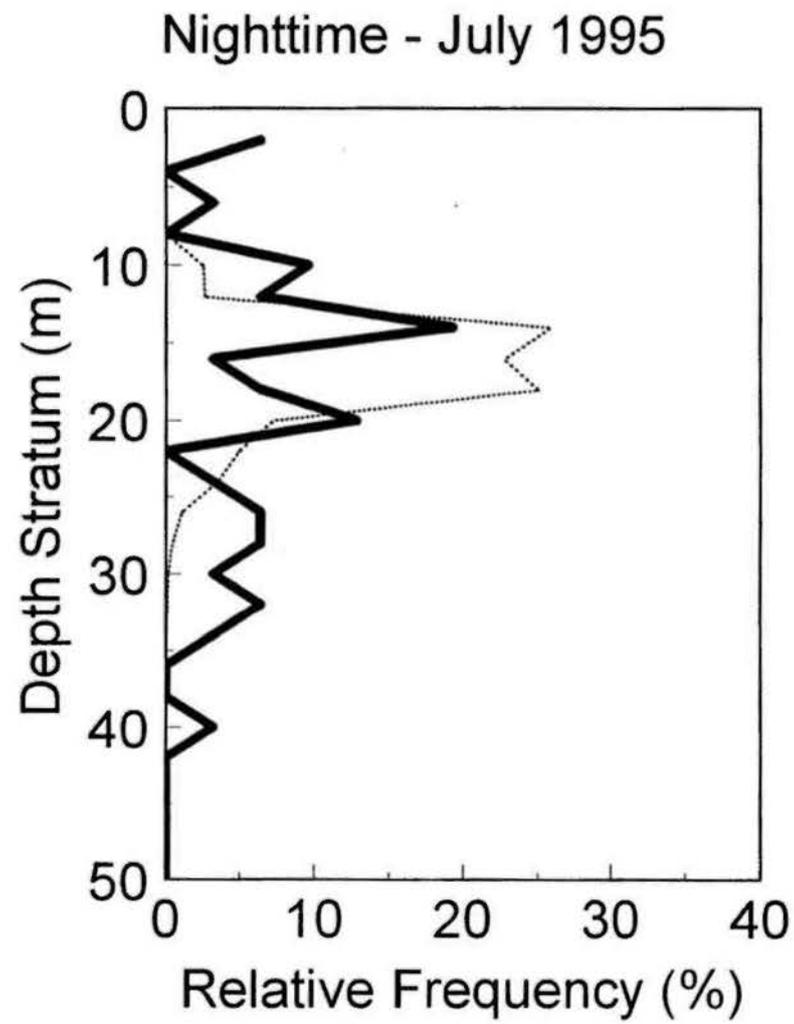
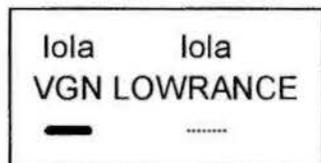
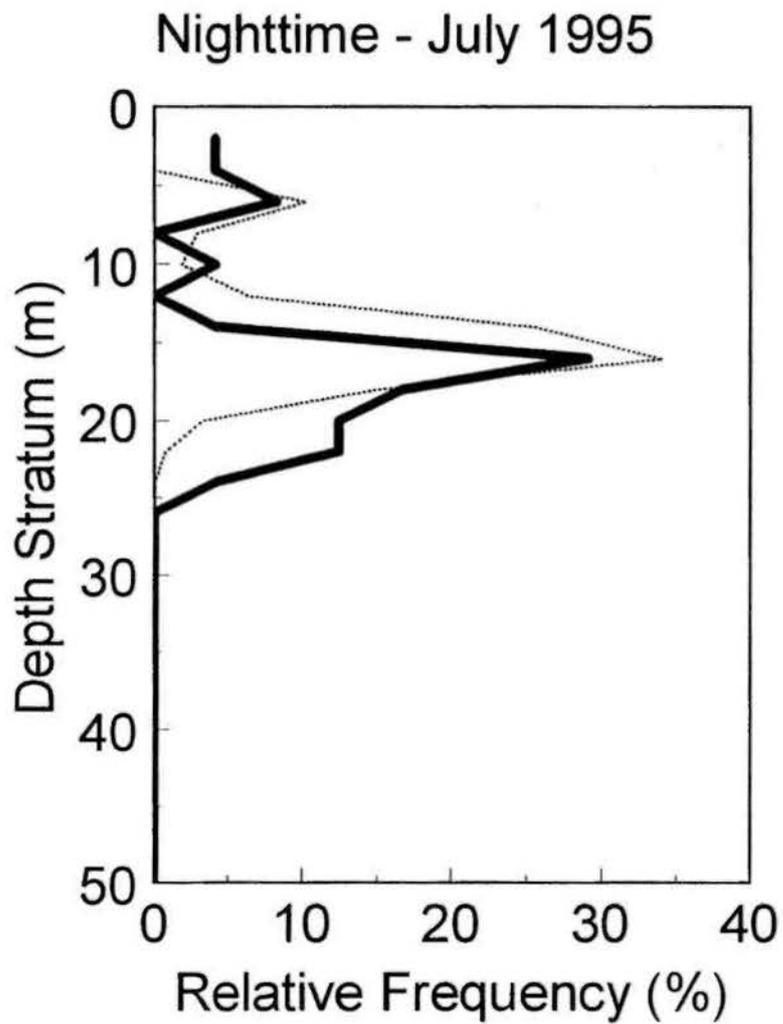


Figure 51.

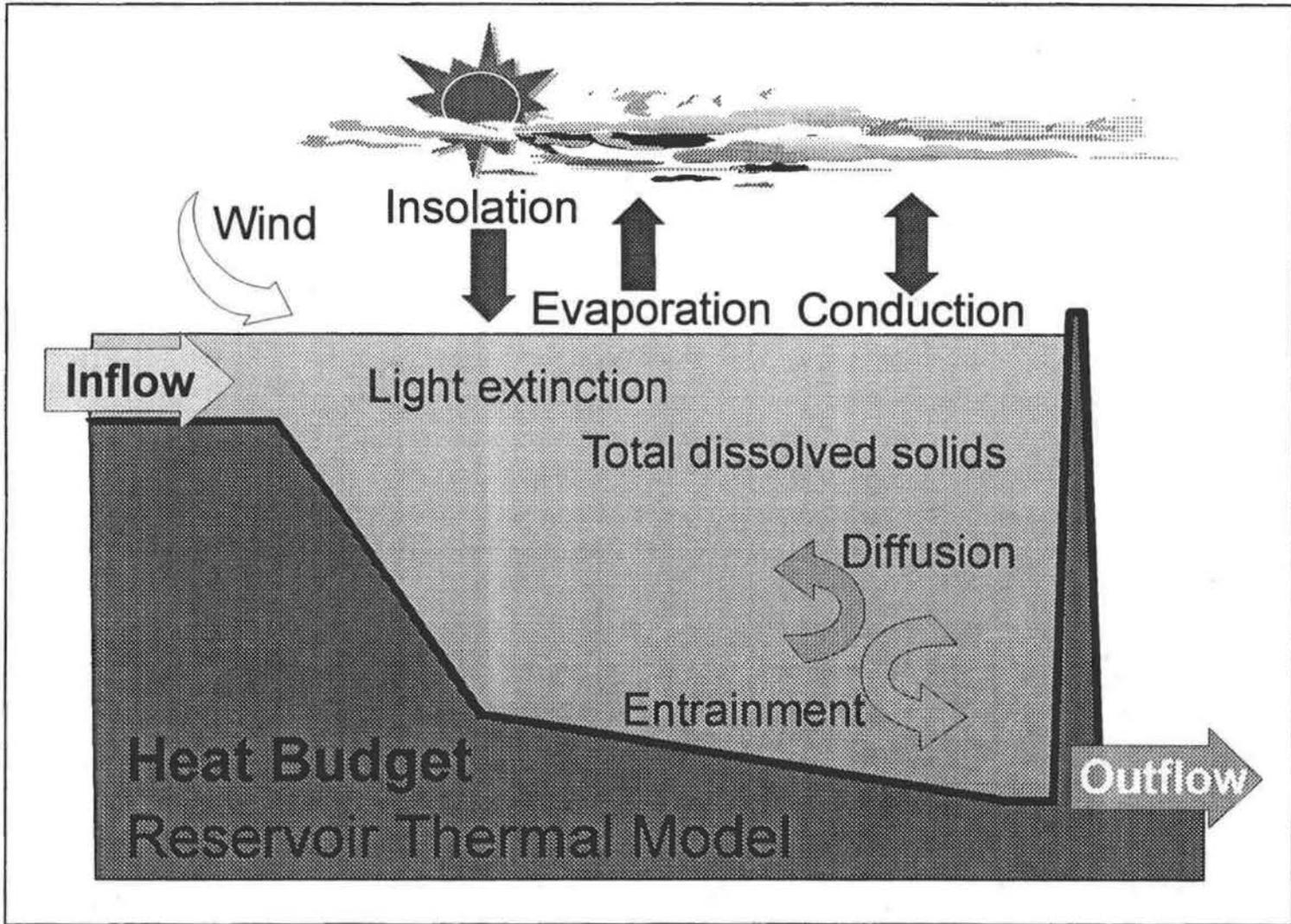


Figure 52.

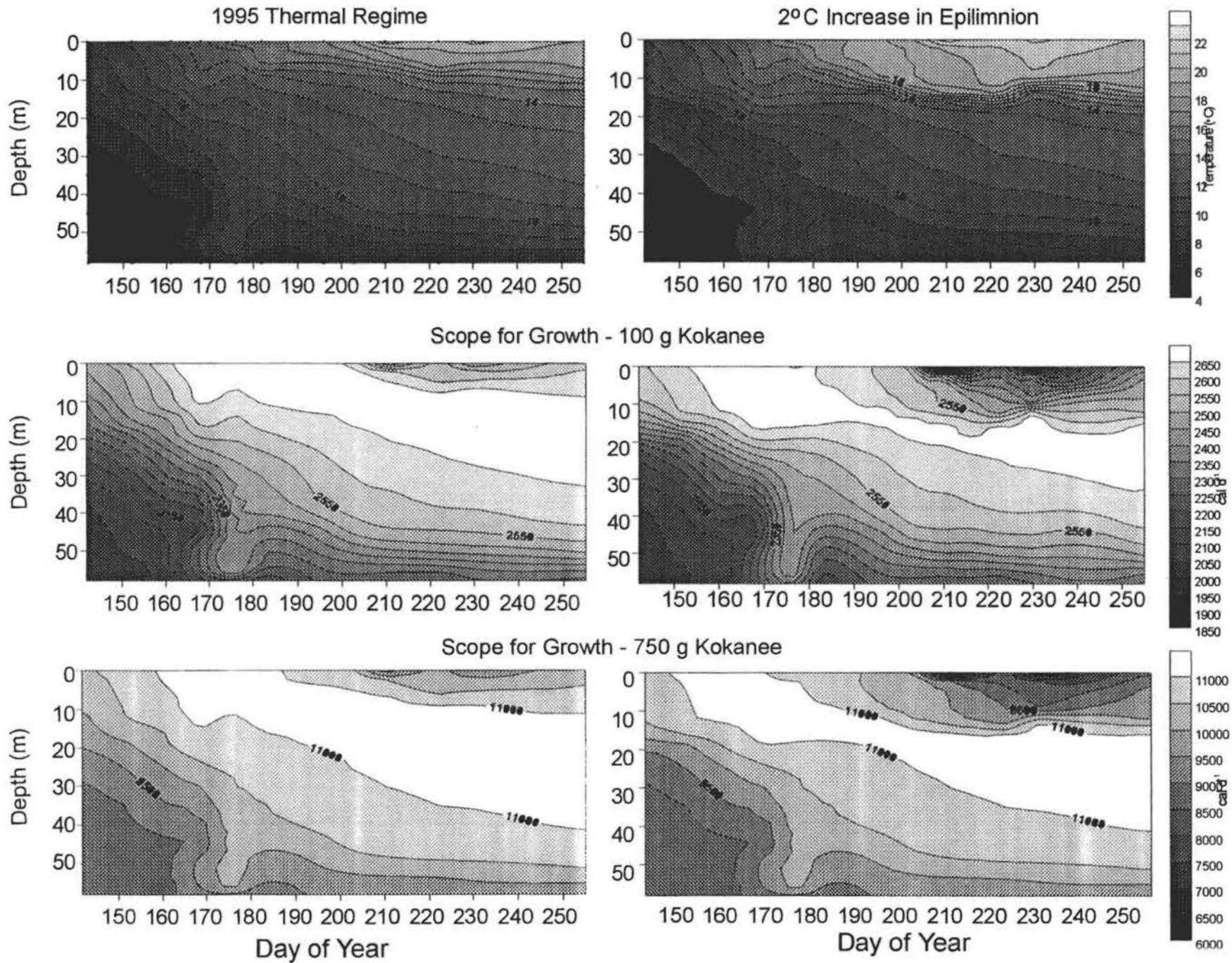


Figure 53.

APPENDIX A.
Experimental Vertical Gill Net Results

Table A1. Capture frequencies of fishes sampled in vertical gill nets during June, July, September 1995 at Blue Mesa Reservoir.

Month	SPP	Frequency	Percent	Cumulative Frequency	Cumulative Percent
June	KOK	31	57.4	31	57.4
	LGS	1	1.9	32	59.3
	LOC	15	27.8	47	87.0
	MAC	5	9.3	52	96.3
	RBT	1	1.9	53	98.1
	WHS	1	1.9	54	100.0
July	KOK	74	87.1	74	87.1
	LGS	1	1.2	75	88.2
	LOC	6	7.1	81	95.3
	MAC	1	1.2	82	96.5
	RBT	3	3.5	85	100.0
September	KOK	114	88.4	114	88.4
	LGS	6	4.7	120	93.0
	LOC	3	2.3	123	95.3
	MAC	4	3.1	127	98.4
	RBT	2	1.6	129	100.0

Table A2. Depth distribution (m) of kokanee salmon sampled in nighttime vertical gill net sets at Blue Mesa Reservoir during 1995. SPP=fish species, MN=month.

----- SPP=KOK MN=6 -----

FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	*****	3	3	9.68	9.68
5	*****	11	14	35.48	45.16
10	*****	10	24	32.26	77.42
15	*****	6	30	19.35	96.77
20	**	1	31	3.23	100.00

+-----+-----+-----+-----+
2 4 6 8 10
Frequency

----- SPP=KOK MN=7 -----

FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	**	2	2	2.70	2.70
5	*	1	3	1.35	4.05
10	*****	13	16	17.57	21.62
15	*****	20	36	27.03	48.65
20	*****	13	49	17.57	66.22
25	*****	8	57	10.81	77.03
30	*****	9	66	12.16	89.19
35	***	3	69	4.05	93.24
40	*****	5	74	6.76	100.00

+-----+-----+-----+
5 10 15 20
Frequency

Table A5. Depth distribution (m) of lake trout sampled in nighttime vertical gill net sets at Blue Mesa Reservoir during 1995. SPP=fish species, MN=month.

----- SPP=MAC MN=6 -----

FISHDEP Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
0	0	0	0.00	0.00
5	1	1	20.00	20.00
10	0	1	0.00	20.00
15	2	3	40.00	60.00
20	1	4	20.00	80.00
25	0	4	0.00	80.00
30	1	5	20.00	100.00

-----+-----
1 2
Frequency

----- SPP=MAC MN=7 -----

FISHDEP Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
15	0	0	0.00	0.00
20	1	1	100.00	100.00

-----+-----
1
Frequency

----- SPP=MAC MN=9 -----

FISHDEP Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
35	0	0	0.00	0.00
40	0	0	0.00	0.00
45	3	3	75.00	75.00
50	1	4	25.00	100.00

-----+-----+-----+-----
1 2 3
Frequency

Table A6. Depth distribution (m) of rainbow trout sampled in nighttime vertical gill net sets at Blue Mesa Reservoir during 1995. SPP=fish species, MN=month.

		SPP=RBT MN=6			
FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0		0	0	0.00	0.00
5	*****	1	1	100.00	100.00
10		0	1	0.00	100.00
15		0	1	0.00	100.00
		+ 1			
		Frequency			

		SPP=RBT MN=7			
FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	*****	3	3	100.00	100.00
		+ + + 1 2 3			
		Frequency			

		SPP=RBT MN=9			
FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	*****	1	1	50.00	50.00
5	*****	1	2	50.00	100.00
		+ 1			
		Frequency			

Table A7. Depth (FISHDEP, m) distribution of all fish sampled in vertical gill nets at Blue Mesa Reservoir during day (Period=D) and night (Period=N) by month (MN) in 1995.

----- MN=6 PERIOD=D -----

FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	**	1	1	2.50	2.50
5	*****	10	11	25.00	27.50
10	*****	4	15	10.00	37.50
15	*****	12	27	30.00	67.50
20	*****	7	34	17.50	85.00
25		0	34	0.00	85.00
30	*****	5	39	12.50	97.50
35	**	1	40	2.50	100.00

+-----+-----+-----+-----+-----+
2 4 6 8 10 12
Frequency

----- MN=6 PERIOD=N -----

FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	*****	5	5	9.26	9.26
5	*****	23	28	42.59	51.85
10	*****	15	43	27.78	79.63
15	*****	8	51	14.81	94.44
20	**	2	53	3.70	98.15
25		0	53	0.00	98.15
30	*	1	54	1.85	100.00
35		0	54	0.00	100.00
40		0	54	0.00	100.00

+-----+-----+-----+-----+
5 10 15 20
Frequency

Table A9. Depth (FISHDEP, m) distribution of all fish sampled in vertical gill nets at Blue Mesa Reservoir during day (Period=D) and night (Period=N) by month (MN) in 1995.

----- MN=9 PERIOD=N -----

FISHDEP Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0	**	2	2	1.55	1.55
5	**	2	4	1.55	3.10
10	*****	6	10	4.65	7.75
15	*****	20	30	15.50	23.26
20	*****	37	67	28.68	51.94
25	*****	22	89	17.05	68.99
30	*****	11	100	8.53	77.52
35	*****	13	113	10.08	87.60
40	***	3	116	2.33	89.92
45	*****	7	123	5.43	95.35
50	*****	6	129	4.65	100.00
55		0	129	0.00	100.00

-----+-----+-----+-----+-----+-----+-----+-----

5 10 15 20 25 30 35

Frequency

Table A10. Mean Fulton's condition factor ($K \times 10,000$) for fish sampled in experimental vertical gill nets at Blue Mesa Reservoir during 1995. MN=month, N=number of fish included in the mean.

Species	MN	N Obs	Mean	N	Std Dev
Kokanee	6	46	0.0976283	46	0.0148681
	7	75	0.1080707	75	0.0464577
	9	114	0.1079752	109	0.0302243
Lake trout	6	18	0.0935280	18	0.0324613
	7	1	0.0748698	1	.
	9	4	0.0750619	4	0.0047807
Brown trout	6	28	0.0911064	28	0.0351108
	7	6	0.0852041	6	0.0061861
	9	3	0.0818805	3	0.0141888
Rainbow trout	6	1	0.0880408	1	.
	7	3	0.1046415	2	0.0026564
	9	2	0.1016970	2	0.0101021
Longnose sucker	6	1	0.1164915	1	.
	7	1	.	0	.
	9	6	0.1052111	6	0.0053012
White sucker	6	1	0.1132168	1	.

Table A11. Regression output of natural logarithm of head length as a function of total length in fishes sampled in vertical gill nets at Blue Mesa Reservoir. KOK=kokanee salmon, LOC=brown trout, MAC=lake trout, RBT=rainbow trout.

----- SPP=KOK -----

Model: MODEL1

Dependent Variable: LNHL

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	13.84391	13.84391	1851.187	0.0001
Error	187	1.39846	0.00748		
C Total	188	15.24237			
Root MSE	0.08648	R-square	0.9083		
Dep Mean	3.49043	Adj R-sq	0.9078		
C.V.	2.47757				

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	2.403321	0.02603784	92.301	0.0001
TLENGTH	1	0.003848	0.00008943	43.025	0.0001

----- SPP=LOC -----

Model: MODEL1

Dependent Variable: LNHL

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.57595	0.57595	38.590	0.0001
Error	33	0.49252	0.01492		
C Total	34	1.06848			
Root MSE	0.12217	R-square	0.5390		
Dep Mean	3.82441	Adj R-sq	0.5251		
C.V.	3.19442				

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	2.452135	0.22186711	11.052	0.0001
TLENGTH	1	0.004386	0.00070609	6.212	0.0001

Table A12. Regression output of natural logarithm of head length as a function of total length in fishes sampled in vertical gill nets at Blue Mesa Reservoir. KOK=kokanee salmon, LOC=brown trout, MAC=lake trout, RBT=rainbow trout.

----- SPP=MAC -----

Model: MODEL1
Dependent Variable: LNHL

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	2.27277	2.27277	133.384	0.0001
Error	20	0.34079	0.01704		
C Total	21	2.61356			
Root MSE	0.13053	R-square	0.8696		
Dep Mean	4.21348	Adj R-sq	0.8631		
C.V.	3.09803				
Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	3.160369	0.09533689	33.149	0.0001
TLENGTH	1	0.002111	0.00018277	11.549	0.0001

----- SPP=RBT -----

Model: MODEL1
Dependent Variable: LNHL

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.30599	0.30599	24.700	0.0156
Error	3	0.03716	0.01239		
C Total	4	0.34315			
Root MSE	0.11130	R-square	0.8917		
Dep Mean	3.65371	Adj R-sq	0.8556		
C.V.	3.04628				
Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	2.209072	0.29490891	7.491	0.0049
TLENGTH	1	0.004517	0.00090894	4.970	0.0156

Table A15. Length-frequency of brown trout (LOC) sampled in experimental vertical gillnets fished at Blue Mesa Reservoir during three months in 1995. TLENGTH is fish total length, MN= month.

----- SPP=LOC MN=6 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
210	0	0	0.00	0.00
230	0	0	0.00	0.00
250	0	0	0.00	0.00
270	*****	2	7.14	7.14
290	*****	7	25.00	32.14
310	*****	7	25.00	57.14
330	*****	9	32.14	89.29
350	*****	2	7.14	96.43
370		0	0.00	96.43
390		0	0.00	96.43
410		0	0.00	96.43
430	****	1	3.57	100.00
450		0	0.00	100.00

-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
 1 2 3 4 5 6 7 8 9

----- SPP=LOC MN=7 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
170		0	0.00	0.00
190		0	0.00	0.00
210		0	0.00	0.00
230	*****	1	16.67	16.67
250		0	0.00	16.67
270		0	0.00	16.67
290		0	0.00	16.67
310	*****	3	50.00	66.67
330	*****	2	33.33	100.00
350		0	0.00	100.00
370		0	0.00	100.00

-----+-----+-----+
 1 2 3

----- SPP=LOC MN=9 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
290		0	0.00	0.00
310	*****	1	33.33	33.33
330	*****	2	66.67	100.00
350		0	0.00	100.00
370		0	0.00	100.00

-----+-----+
 1 2

Table A16. Length-frequency of lake trout (MAC) sampled in experimental vertical gillnets fished at Blue Mesa Reservoir during three months in 1995. TLENGTH is fish total length, MN= month.

----- SPP=MAC MN=6 -----					
TLENGTH			Cum.		Cum.
Midpoint		Freq	Freq	Percent	Percent
150	*****	1	1	5.56	5.56
170		0	1	0.00	5.56
190		0	1	0.00	5.56
210		0	1	0.00	5.56
230		0	1	0.00	5.56
250		0	1	0.00	5.56
270	*****	1	2	5.56	11.11
290		0	2	0.00	11.11
310		0	2	0.00	11.11
330		0	2	0.00	11.11
350		0	2	0.00	11.11
370	*****	1	3	5.56	16.67
390	*****	1	4	5.56	22.22
410	*****	1	5	5.56	27.78
430	*****	1	6	5.56	33.33
450	*****	2	8	11.11	44.44
470	*****	2	10	11.11	55.56
490		0	10	0.00	55.56
510		0	10	0.00	55.56
530	*****	1	11	5.56	61.11
550		0	11	0.00	61.11
570	*****	2	13	11.11	72.22
590		0	13	0.00	72.22
610	*****	1	14	5.56	77.78
630		0	14	0.00	77.78
650		0	14	0.00	77.78
670		0	14	0.00	77.78
690	*****	1	15	5.56	83.33
710	*****	1	16	5.56	88.89
730		0	16	0.00	88.89
750	*****	1	17	5.56	94.44
770		0	17	0.00	94.44
790		0	17	0.00	94.44
810	*****	1	18	5.56	100.00
	-----+-----				
	1 2				
----- SPP=MAC MN=7 -----					
TLENGTH			Cum.		Cum.
Midpoint		Freq	Freq	Percent	Percent
470		0	0	0.00	0.00
490	*****	1	1	100.00	100.00
510		0	1	0.00	100.00
	-----+-----				
	1				
----- SPP=MAC MN=9 -----					
TLENGTH			Cum.		Cum.
Midpoint		Freq	Freq	Percent	Percent
390		0	0	0.00	0.00
410	*****	1	1	25.00	25.00
430	*****	1	2	25.00	50.00
450		0	2	0.00	50.00
470	*****	1	3	25.00	75.00
490		0	3	0.00	75.00
510		0	3	0.00	75.00
530		0	3	0.00	75.00
550	*****	1	4	25.00	100.00
	-----+-----				
	1				

Table A17. Length-frequency of rainbow trout (RBT) sampled in experimental vertical gillnets fished at Blue Mesa Reservoir during three months in 1995. TLENGTH is fish total length, MN= month.

----- SPP=RBT MN=6 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
370	0	0	0.00	0.00
390	1	1	100.00	100.00
410	0	1	0.00	100.00
430	0	1	0.00	100.00

-----+-----
1

----- SPP=RBT MN=7 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
310	0	0	0.00	0.00
330	2	2	66.67	66.67
350	1	3	33.33	100.00
370	0	3	0.00	100.00
390	0	3	0.00	100.00

-----+-----+-----
1 2

----- SPP=RBT MN=9 -----

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
190	0	0	0.00	0.00
210	0	0	0.00	0.00
230	1	1	50.00	50.00
250	0	1	0.00	50.00
270	0	1	0.00	50.00
290	0	1	0.00	50.00
310	1	2	50.00	100.00
330	0	2	0.00	100.00
350	0	2	0.00	100.00

-----+-----+-----
1

Table A18. Length-frequency of white sucker (WHS) and longnose sucker (LGS) sampled in experimental vertical gillnets fished at Blue Mesa Reservoir during three months in 1995. TLENGTH is fish total length, MN= month.

----- SPP=WHS MN=6 -----

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
290		0	0	0.00	0.00
310	*****	1	1	100.00	100.00
330		0	1	0.00	100.00
350		0	1	0.00	100.00
	-----+				
		1			

----- SPP=LGS MN=6 -----

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
310		0	0	0.00	0.00
330	*****	1	1	100.00	100.00
350		0	1	0.00	100.00
370		0	1	0.00	100.00
	-----+				
		1			

----- SPP=LGS MN=7 -----

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
310		0	0	0.00	0.00
330	*****	1	1	100.00	100.00
350		0	1	0.00	100.00
370		0	1	0.00	100.00
	-----+				
		1			

----- SPP=LGS MN=9 -----

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
210		0	0	0.00	0.00
230	*****	1	1	16.67	16.67
250		0	1	0.00	16.67
270	*****	1	2	16.67	33.33
290	*****	1	3	16.67	50.00
310		0	3	0.00	50.00
330	*****	2	5	33.33	83.33
350	*****	1	6	16.67	100.00
370		0	6	0.00	100.00
	-----+				
		1	2		

Table A19. Length-frequency (mm) of all fishes sampled in vertical gill nets in Blue Mesa Reservoir during June, 1995.

TLENGTH Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
0	0	0	0.00	0.00
50	0	0	0.00	0.00
100	1	1	1.05	1.05
150	8	9	8.42	9.47
200	10	19	10.53	20.00
250	3	22	3.16	23.16
300	33	55	34.74	57.89
350	16	71	16.84	74.74
400	11	82	11.58	86.32
450	5	87	5.26	91.58
500	1	88	1.05	92.63
550	1	89	1.05	93.68
600	2	91	2.11	95.79
650	0	91	0.00	95.79
700	2	93	2.11	97.89
750	1	94	1.05	98.95
800	1	95	1.05	100.00
850	0	95	0.00	100.00

Table A20. Length-frequency (mm) of all fishes sampled in vertical gill nets in Blue Mesa Reservoir during July, 1995.

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0		0	0	0.00	0.00
50		0	0	0.00	0.00
100	**	2	2	2.33	2.33
150		0	2	0.00	2.33
200	*****	8	10	9.30	11.63
250	*****	22	32	25.58	37.21
300	*****	15	47	17.44	54.65
350	*****	17	64	19.77	74.42
400	*****	18	82	20.93	95.35
450	***	3	85	3.49	98.84
500	*	1	86	1.16	100.00
550		0	86	0.00	100.00
600		0	86	0.00	100.00
650		0	86	0.00	100.00
700		0	86	0.00	100.00
750		0	86	0.00	100.00
800		0	86	0.00	100.00
850		0	86	0.00	100.00

-----+-----+-----+-----+-----
 5 10 15 20
 Frequency

Table A21. Length-frequency (mm) of all fishes sampled in vertical gill nets in Blue Mesa Reservoir during September, 1995.

TLENGTH Midpoint		Freq	Cum. Freq	Percent	Cum. Percent
0		0	0	0.00	0.00
50		0	0	0.00	0.00
100	*	2	2	1.61	1.61
150	*	1	3	0.81	2.42
200	***	6	9	4.84	7.26
250	*****	56	65	45.16	52.42
300	*****	32	97	25.81	78.23
350	*****	20	117	16.13	94.35
400	**	3	120	2.42	96.77
450	**	3	123	2.42	99.19
500		0	123	0.00	99.19
550	*	1	124	0.81	100.00
600		0	124	0.00	100.00
650		0	124	0.00	100.00
700		0	124	0.00	100.00
750		0	124	0.00	100.00
800		0	124	0.00	100.00
850		0	124	0.00	100.00

Frequency

Figure A1. Head length (mm, natural log) as a function of total length (TLENGTH, mm) in kokanee salmon from vertical gill nets sampled in Blue Mesa Reservoir.

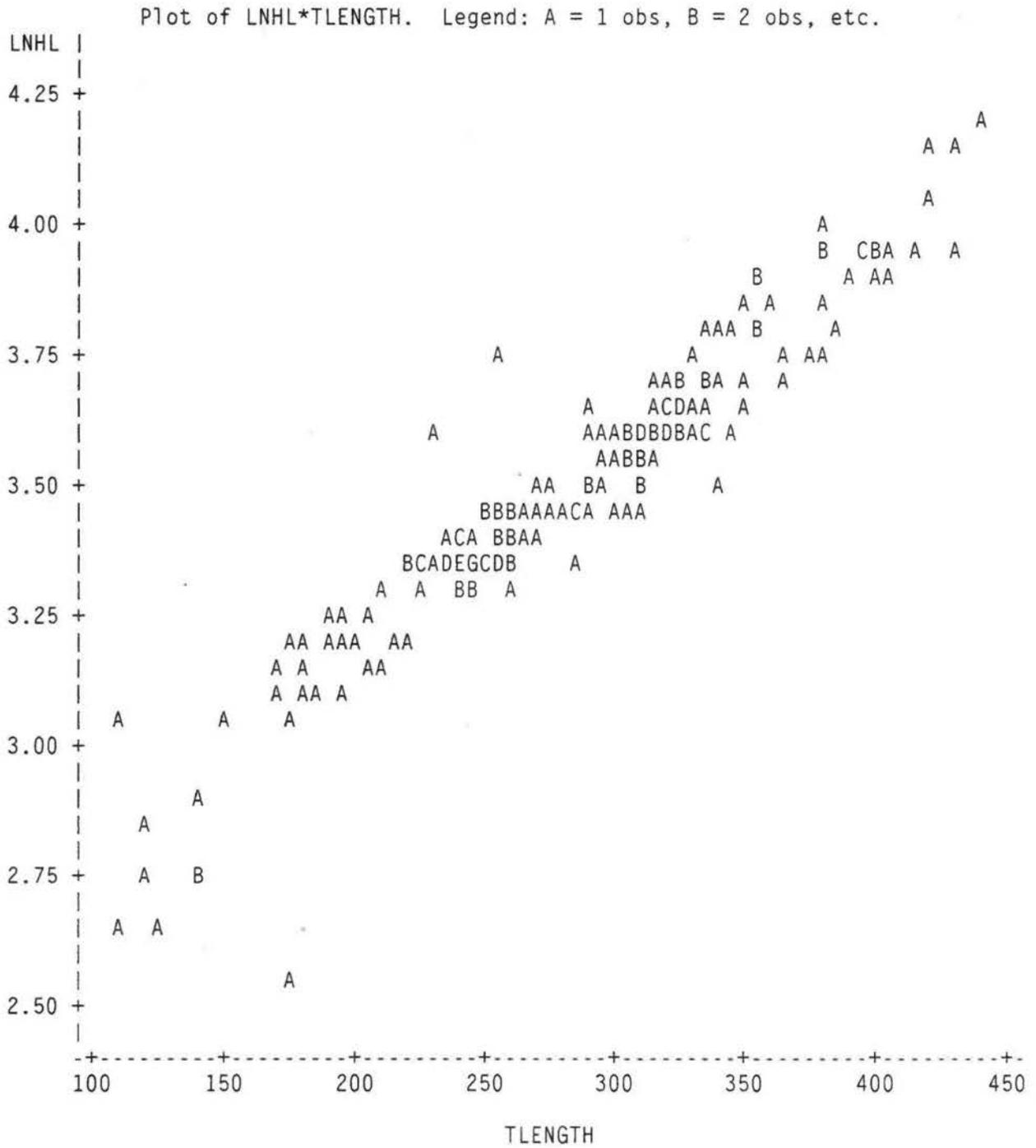


Figure A2. Head length (mm, natural log) as a function of total length (TLENGTH, mm) in brown trout from vertical gill nets sampled in Blue Mesa Reservoir.

Plot of LNHL*TLENGTH. Legend: A = 1 obs, B = 2 obs, etc.

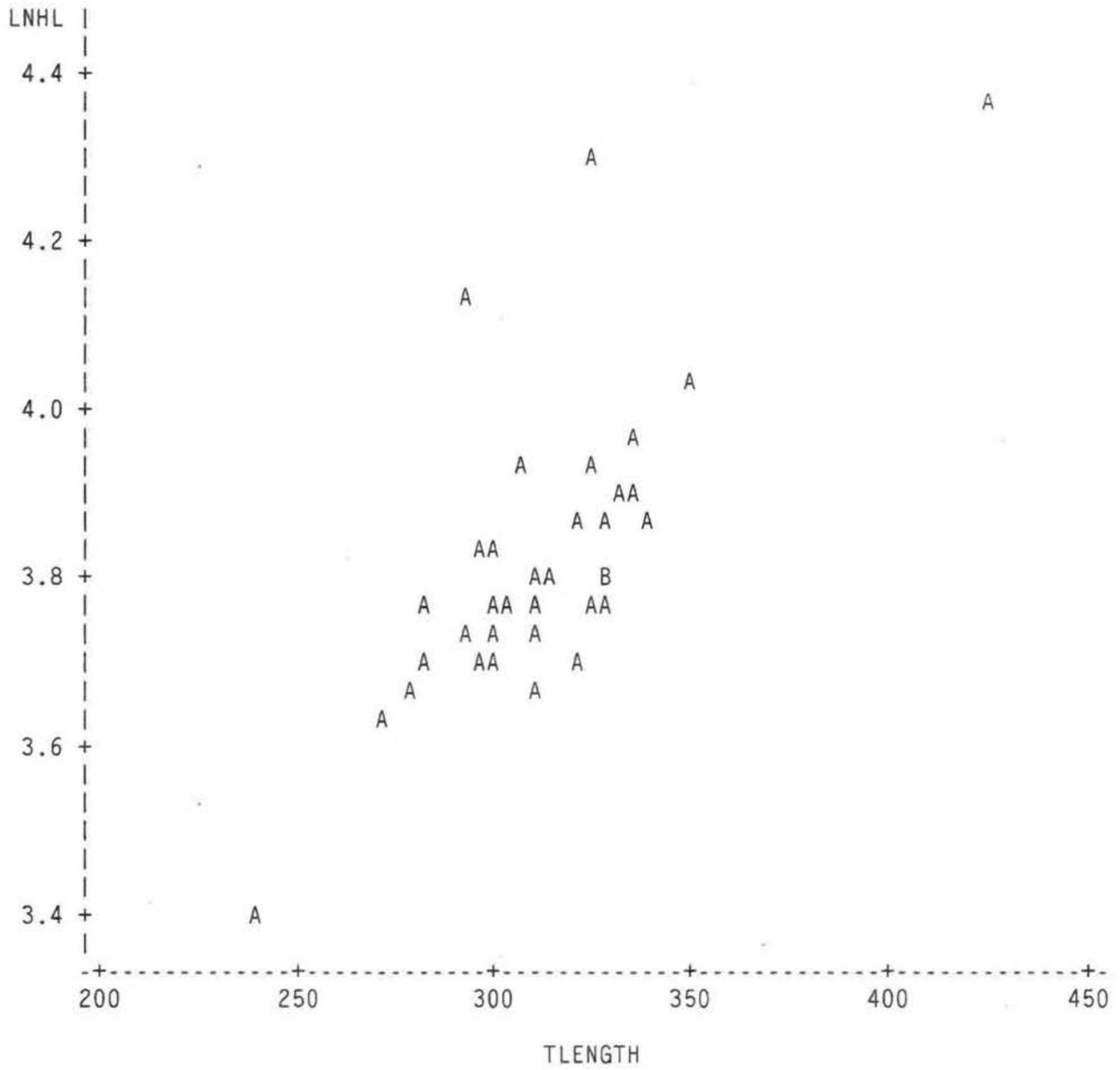


Figure A3. Head length (mm, natural log) as a function of total length (TLENGTH, mm) in lake trout from vertical gill nets sampled in Blue Mesa Reservoir.

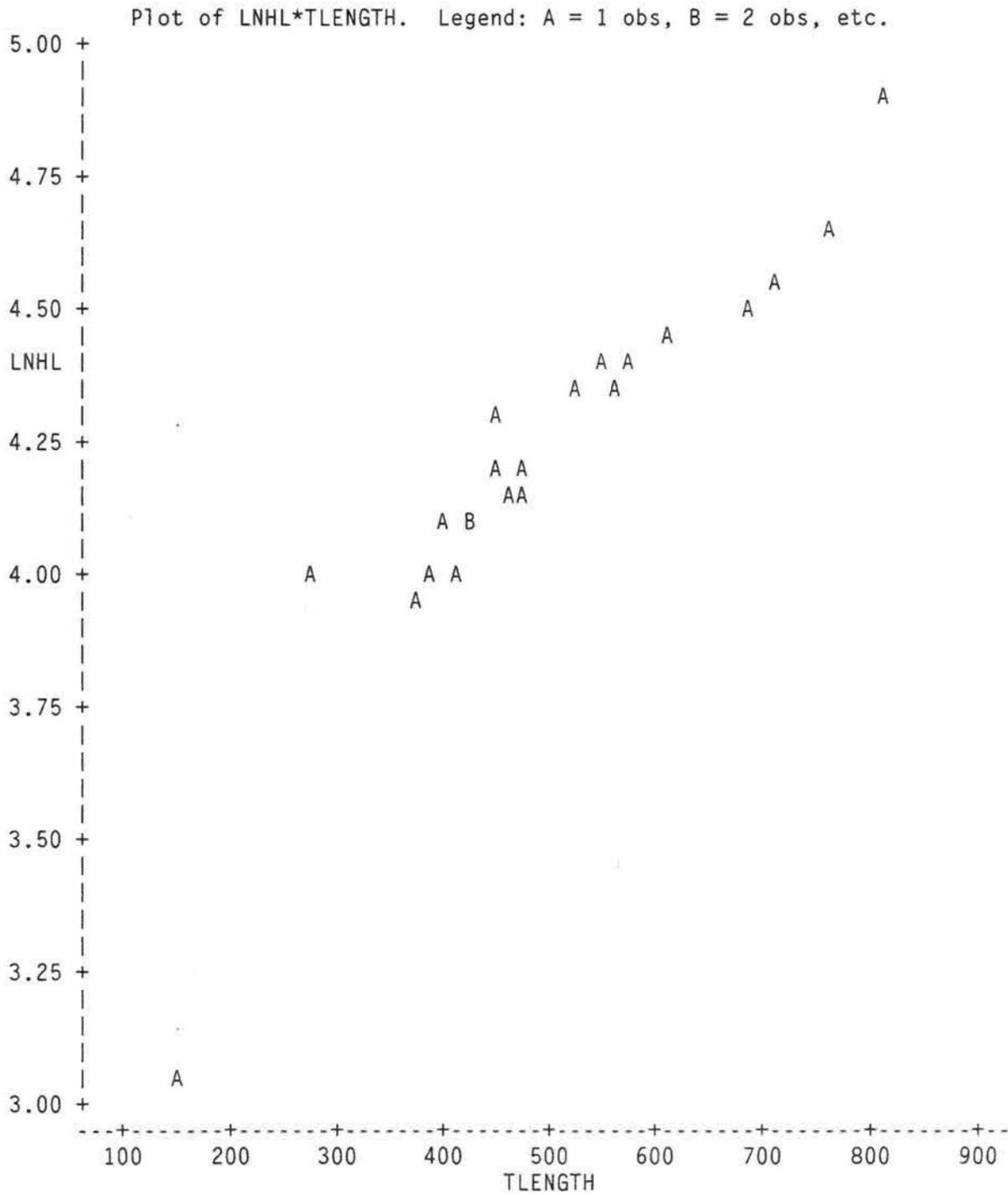


Figure A4. Head length (mm, natural log) as a function of total length (TLENGTH, mm) in rainbow trout from vertical gill nets sampled in Blue Mesa Reservoir.

