Special Publication SJ 92-SP12

HISTORICAL ASSESSMENT OF CULTURAL EUTROPHICATION IN LAKE WEIR, FLORIDA

By

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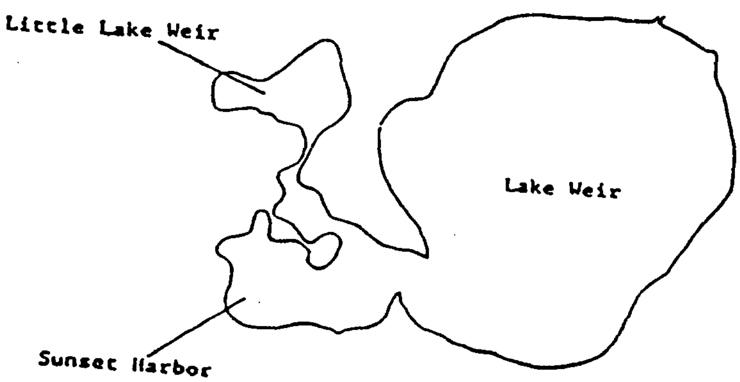

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ERRATA

Table 3-1. The headings for this table legend should be reversed.

Table 4-3. Data for pH have been omitted from this table because they were taken by field meters, the reliability of which are extremely suspect. We feel it is better to error on the side of the conservative.

Page 140. Rather than what was stated in the text, historical TSI for CHL and TKN were higher than present, and those for TP and Secchi were lower than present.

Table 4-4. This table appears twice in this report, page 95 and page 121.

The following citations were missing from the bibliography:

American Public Health Association (APHA). 1971. Standard methods for the examination of water and wastewater. 14th edition. 1779 pp.

Anderson, J.M. 1976. An ignition method for determining total phosphorus in lake sediments. Water Res. 10:329-331.

Appleby, P.G. and F. Oldfield. 1983. Assessment of ^{210}Pb from sites with varying sediment accumulation rates. Hydrobiologia 103:29-35.

Archeological Consultants, Inc. 1987. Archeological survey of Marion County, Florida. Prepared in conjunction with with Florida Preservation Services for the Marion County Historical Commission. Sarasota, Florida. 71 pp.

Beck, W.M., Jr. 1954. Studies in stream pollution biology: I. A simplified ecological classification of organisms. Quart. Journ. Fla. Acad. Sci. 17:211-227.

Cummins, K.W. 1973. Trophic relations of aquatic insects. Ann. Rev. Ent. 18:183-206.

Fenchel, T. 1980a. Suspension feeding in ciliated protozoa: Feeding rates and their ecological significance. Microb. Ecol. 6:13-25.

Fenchel, T. 1980b. Suspension feeding in ciliated protozoa: Functional response and partical size selection. Microb. Ecol. 6:1-11.

Fenchel, T. 1986. Protozoan filter feeding. Prog. Protistology 1:65-113.

Frey, D.G. 1960a. The ecological significance of cladoceran remains in lake sediments. Ecology 41:684-699.

Frey, D.G. 1960b. Developmental history of Schleinsee. Verh. Internat. Verein. Limnol. 14:271-278.

Frey, D.G. 1967. Cladocera in space and time. pp. 29-37, Proc. Symposium on Crustaceae, India

Goldman, C.R. 1988. Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada. Limnol. Oceanogr. 33:1321-1333.

Hutchinson, G.E. 1969. Eutrophication, past and present. pp 17-25 IN: G.A. Rohlich (ed.). Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Philadelphia, PA. 658 pp.

Maceina, M.J. and J.V. Shireman. 1980. The use of a recording fathometer for determination of distribution and biomass of hydrilla. J. Aquatic Plant Manage. 18:34-39.

Milanich, J.T. and C.H. Fairbanks. 1980. Florida Archeology. Academic Press. New York. 290 pp.

Pejler, B. 1983. Zooplanktonic indicators of trophy and their food. Hydrobiologia 101:111-114.

Pourriot, R. 1977. Food and feeding habits of Rotifera. Arch. Hydrobiol. Beih. Ergebn. Limnol. 8:243-260.

Rama, K.M. and E.D. Goldberg. 1961. Lead-210 in natural waters. Science 134:98-99.

Thompson, D.M. 1981. Distribution of heavy metals in selected Florida lake sediments. M.S. Thesis, University of Florida, Gainesville. 160 pp.

United States Environmental Protection Agency (EPA). 1979. Phytoplankton water quality relationships in U.S. lakes Part IV: The common phytoplankton genera from eastern and southeastern lakes. EPA 600/3-79-051. Washington, D.C.. 82 pp.

Vollenweider, R.A. 1971. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorous as factors in eutrophication. OECD, Paris. 158 pp.

Wetzel, R.G. 1982. Limnology. Second Edition. Saunders Publishing, Philadelphia, PA. 767 pp.

Whiteside, M.C. 1969. Chydorid (Cladocera) remains in surficial sediments of Danish lakes and their significance to paleolimnological interpretations. Mitt. Internat. Verein. Limnol. 17:193-201.

Revisions to Special Publication SJ92-SP12
Historical Assessment of Cultural
Eutrophication in Lake Weir, Florida
November 1993

PAGE 141 FIGURE 4-24, THE REPORTED VALUE FOR TP IN 1987-1989 IS INCORRECT. THE CORRECT VALUE IS 37.52 (SEE CORRECTED TABLE 4-6)

PAGE 142 REPLACE DATA IN TABLE 4-6 AS NOTED BELOW

Parameter	Historical Value[a] Mean ± S.D (N)	Current Value[b] Mean ± S.D (N)
Chlorophyll a (μg/L)	8.01 ± 1.30 (32)	6.47 ± 1.99 (24)
Total phosphorus (μg/L)	28.08 ± 16.29 (34)	37.52 ± 25.31 (23)
Total Kjeldahl (μg/L)	854.17 ± 180.44 (32)	658 ± 102.9 (24)
Secchi depth (m)	1.94 ± 0.34 (35)	1.65 ± 0.22 (24)

[a] Historical values based on data from 1969, 1975, 1979, 1980, 1984-85.

[b] Current values based on averages of data from 1987-1989.

PAGE 144 REPLACE DATA IN TABLE 4-8 AS NOTED BELOW

TSI	Historical Value	Current Value	Trophic* State
Chlorophyll a	46.76	43.69	O-M
Total phosphorus	43.63	49.02	M
Total Kjeldahl nitrogen	52.88	47.73	M
Secchi depth (m)	40.12	44.98	M

* O = oligotrophic, M = mesotrophic

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ACKNOWLEDGMENTS

This final report reflects the efforts of many persons who contributed their time and energies to its completion. Funding was provided by St. Johns River Water Management District, Marion County, and the Save Lake Weir Association.

We are indebted to the residents of Lake Weir for their enthusiastic support of the project. We applaud the efforts of Del Wood who supervised the Secchi disk monitoring program. We would especially like to thank Nancy MacCarter, Shirley Little, and Ed Anderson, whose energetic involvement in the Save Lake Weir Association has made a real difference.

The staff of University of Florida's Archives Library was of great assistance in locating historical maps and references. The historical photographs were provided by Jay Dopkin of the University of South Florida's Special Collections. We thank Dr. Armstrong of U.F.'s map library who graciously made aerial photographs of the Florida Citrus Surveys available to us. In addition, the Marion County Tax Assessment Office contributed the aerial photographs for the 1980 and 1985 land use study.

Finally, we are indebted to David Billett and Chris Taylor who assisted with this investigation in the library and in the laboratory, and to Dan Peterson for his help with the captions. We are particularly grateful to Uli Crisman for her laboratory expertise and assistance in the preparation of this document.

FOREWORD

Residents of the Lake Weir area have noted a degradation in water quality in the past five years. This study was conducted to assess the history of cultural eutrophication in Lake Weir, the important causes responsible for deterioration of water quality, the current status of the lake, and, using these data, to develop management recommendations to preserve water quality in the lake.

A recent deterioration in water quality of Lake Weir would most likely be due to increased residential development in the watershed. Between 1970 and 1980 over 350 houses were built in the watershed. Unfortunately, the area lacks a central sewer system, and relies on septic tanks for waste treatment. Other potential contributors to the nutrient levels of the lake are agriculture and runoff from the extensive road system completed since 1970.

CHAPTER ONE:
Physical and Biological Setting of Lake Weir

1.1 PHYSICAL SETTING

Located 57 feet above sea level at 29^{o} 01′ N--81^{o} 55′ W, Lake Weir falls within the intermediate zone between warm temperate and subtropical climates (Beaver et al. 1981). This 2100 hectare lake system is comprised of three distinct basins: Little Lake Weir, Sunset Harbor, and Lake Weir proper. Lake Weir proper is nearly circular with a diameter of approximately seven kilometers. The lake has a relatively small vegetated littoral zone; the sides of the lake basin drop off quickly to a flat bottom ranging from six to eight meters in depth.

Lake Weir is a seepage lake with no permanent tributaries. It receives water and nutrients through groundwater seepage, surface runoff, and precipitation (Messer 1975). There is intermittent outflow north to the Oklawaha River over a weir structure located on the north shore.

The Lake Weir watershed, defined on the basis of topographic highs surrounding the lake, was determined to be 4500 hectares in area (Figure 1-1). Several small enclosed wetlands occupy topographic lows in the upper watershed. Messer (1975) did not include these in his calculations, and hence arrived at a smaller watershed area. Because of the low nutrient affinity of the soils (Messer 1975), nutrient loading from the entire 4500 hectare watershed may impact the lake.

Soils in the Lake Weir region are well-drained, being comprised of thick layers of acid sands, and erosion is not generally a problem throughout this gently sloping watershed (Brezonik and Messer 1975). Two distinct aquifers are present: the deep Floridan aquifer and a shallow, unconfined aquifer (Figure 1-2).

The lake is thought to be isolated from the phosphate-rich Floridan aquifer by impermeable clays in the Hawthorn Formation (Messer 1975). Although it is likely that Lake Weir originally had a sand bottom (personal opinion), much of the basin is now covered by up to a meter of flocculent organic sediment. While we feel that the lake's trophic state was oligotrophic prior to European colonization in the last century, it has likely been mesotrophic for the past several decades (Flannery et al. 1982). The lake is currently classified as being in the upper mesotrophic range, but, as will be discussed later, the current investigation has identified several biological indicators of advancing eutrophication.

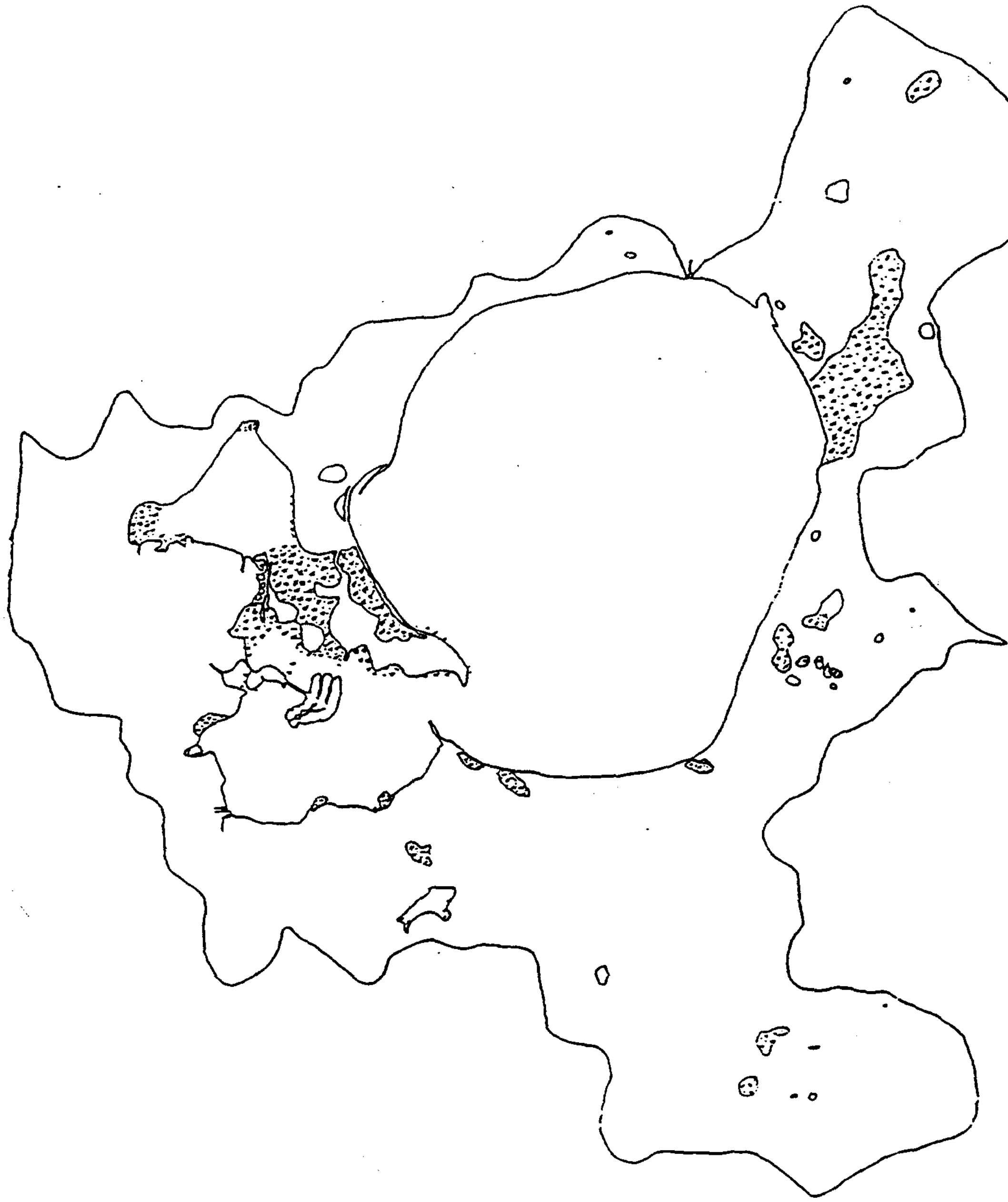


Figure 1-1. Map of Lake Weir's watershed, as defined by topographic highs surrounding the lake. Wetland areas are denoted.

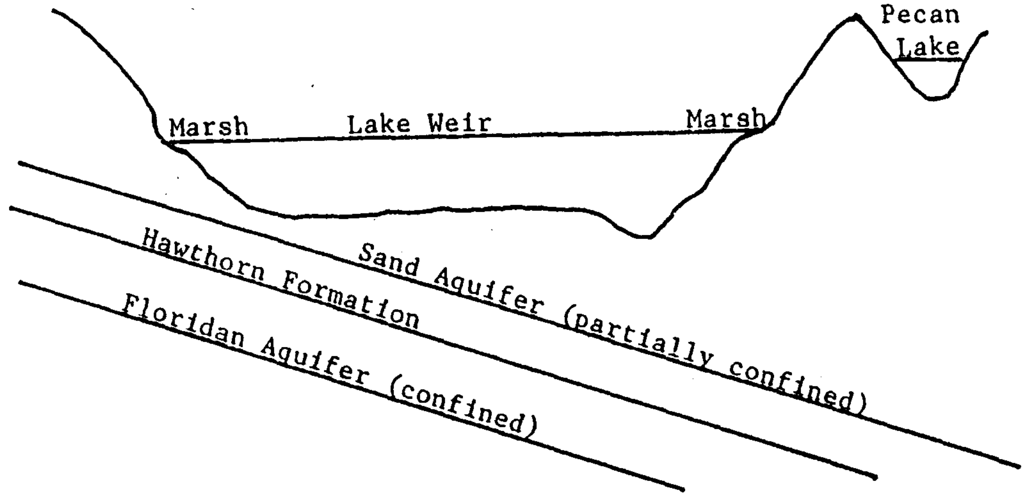


Figure 1-2. Geologic map of Lake Weir watershed showing the Floridan aquifer and an unconfined sand aquifer (adapted from Messer, 1975).

Rainfall data have been compiled for Ocala (30 Km NW of Lake Weir) since 1892. Annual precipitation varied from 40 to 75 inches over the past century, showing a cyclical pattern of apparently three to six year intervals, but this has not been confirmed by spectral analysis (Figure 1-3). Lake surface levels, monitored since 1943 at Oklawaha by the USGS, showed similar fluctuations (Figure 1-4). Surface elevation reached its lowest recorded levels (less than 54 feet above mean sea level) during 1956-1958. Water levels rebounded to a recorded high of over 59 feet in 1961.

Annual rainfall displayed no significant ($P<0.05$) correlation ($R^2 = 0.02$) with mean annual lake levels (Figure 1-5). However, mean annual lake levels were somewhat correlated to rainfall from the previous year ($R^2 = 0.34$). This relationship became even stronger by using a weighted average precipitation ($P_{Y\ avg}$) over the three previous years:

$$P_{Y\ avg} = \{ [3*(P_{Y-1}) + 2*(P_{Y-2}) + (P_{Y-3})] / 6 \}$$

where P_{Y-n} = mean annual precipitation for n years prior to year Y. This weighted average produced an R^2 value of 0.41.

These relationships suggest that water level was not influenced as much by contemporaneous rainfall as by rainfall from the previous year. The lag time was probably due to the absence of overland runoff into the lake, illustrating the importance of groundwater seepage as Lake Weir's source of water recharge (Messer 1975). Additionally, there seemed to be some cumulative effect of rainfall on water level for up to three years. Therefore, successive years of lower-than-average rainfall could make a pronounced impact on lake water level.

Installation of the weir structure and dredging of the overflow channel in 1938 changed the character of Lake Weir's surface level and flow regime. Prior installation of the weir, Lake Weir had gradual outflow into wetlands, probably even during periods of relatively low water level. After impoundment, outflow occurred only when lake levels were highest, generally during late summer. During high water episodes, water would be rapidly discharged to the Oklawaha River, without the nutrient mitigating effects of the wetlands. Because lake stage data were not recorded prior to installation of the weir, it is difficult to reconstruct lake levels for a given year pre-1938 based solely on rainfall data.

Old maps and aerial photographs of Lake Weir provide one clue to historical lake levels. As the water level has fluctuated through time, the shoreline has been significantly altered. Comparison of the shoreline in Shackleford's map of 1883 to that on a recent topographic

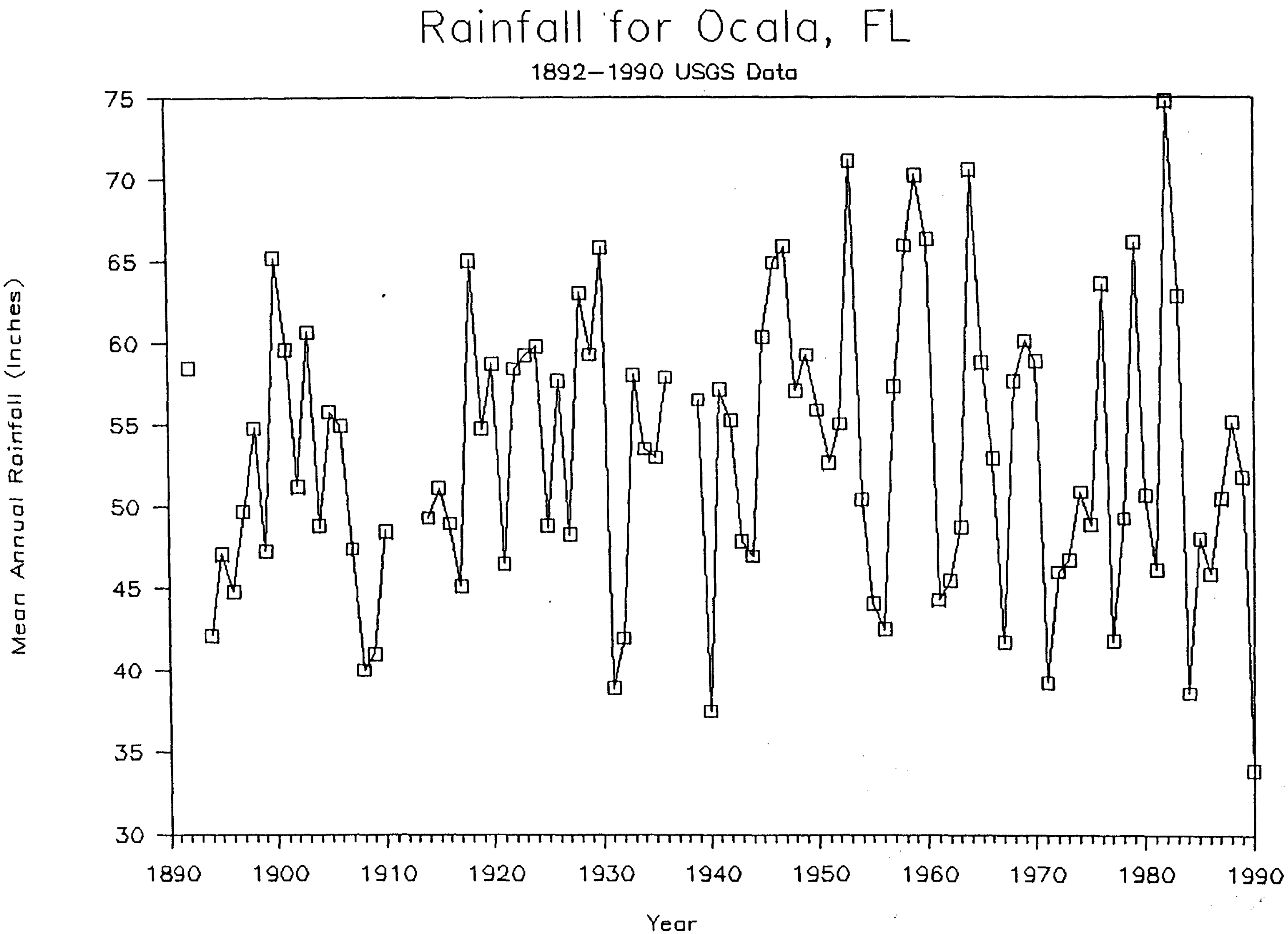


Figure 1-3. USGS annual rainfall data for Ocala, Florida for the period 1892 to 1990.

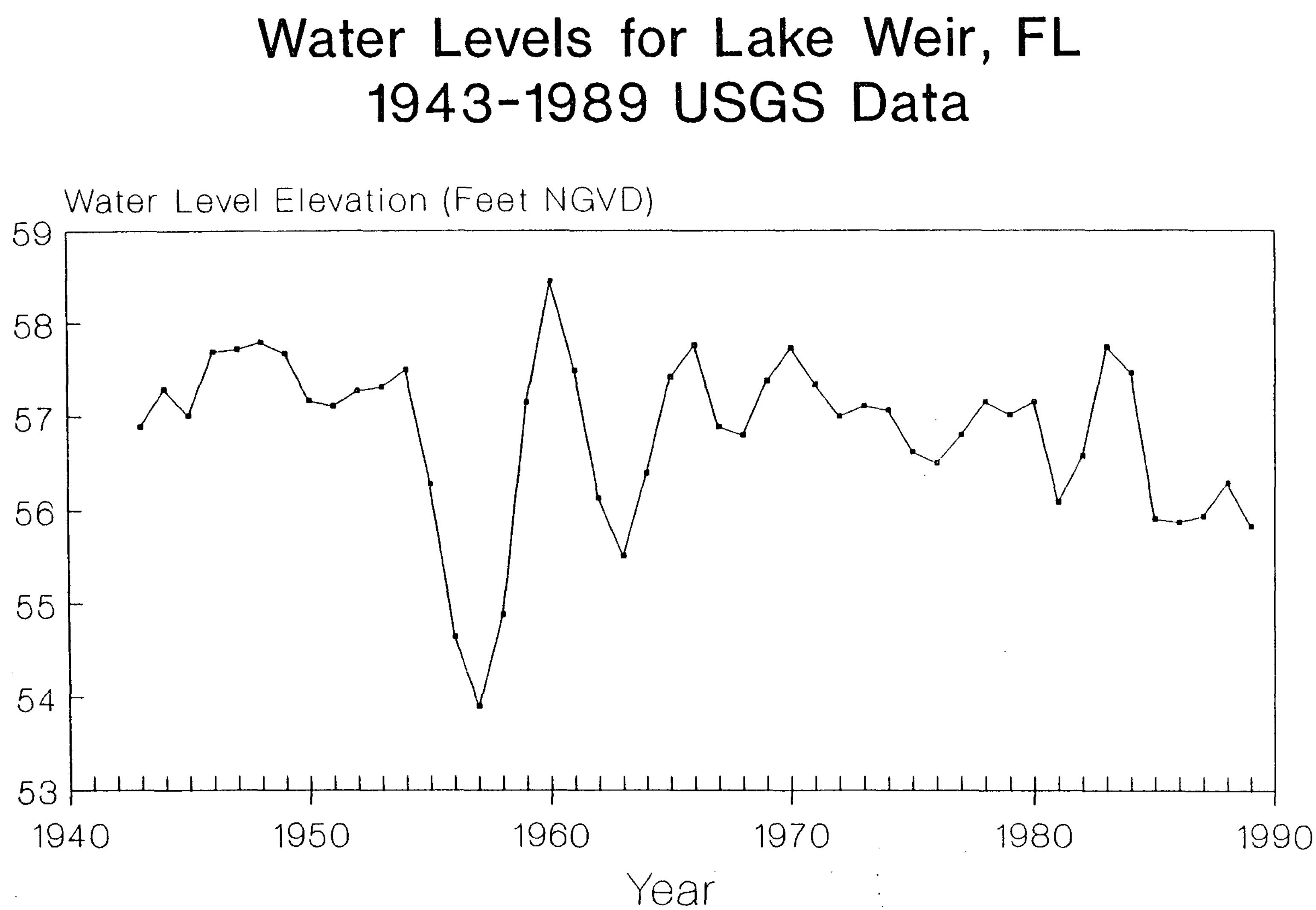


Figure 1-4. USGS records of water levels for Lake Weir for the period 1943 to 1989.p

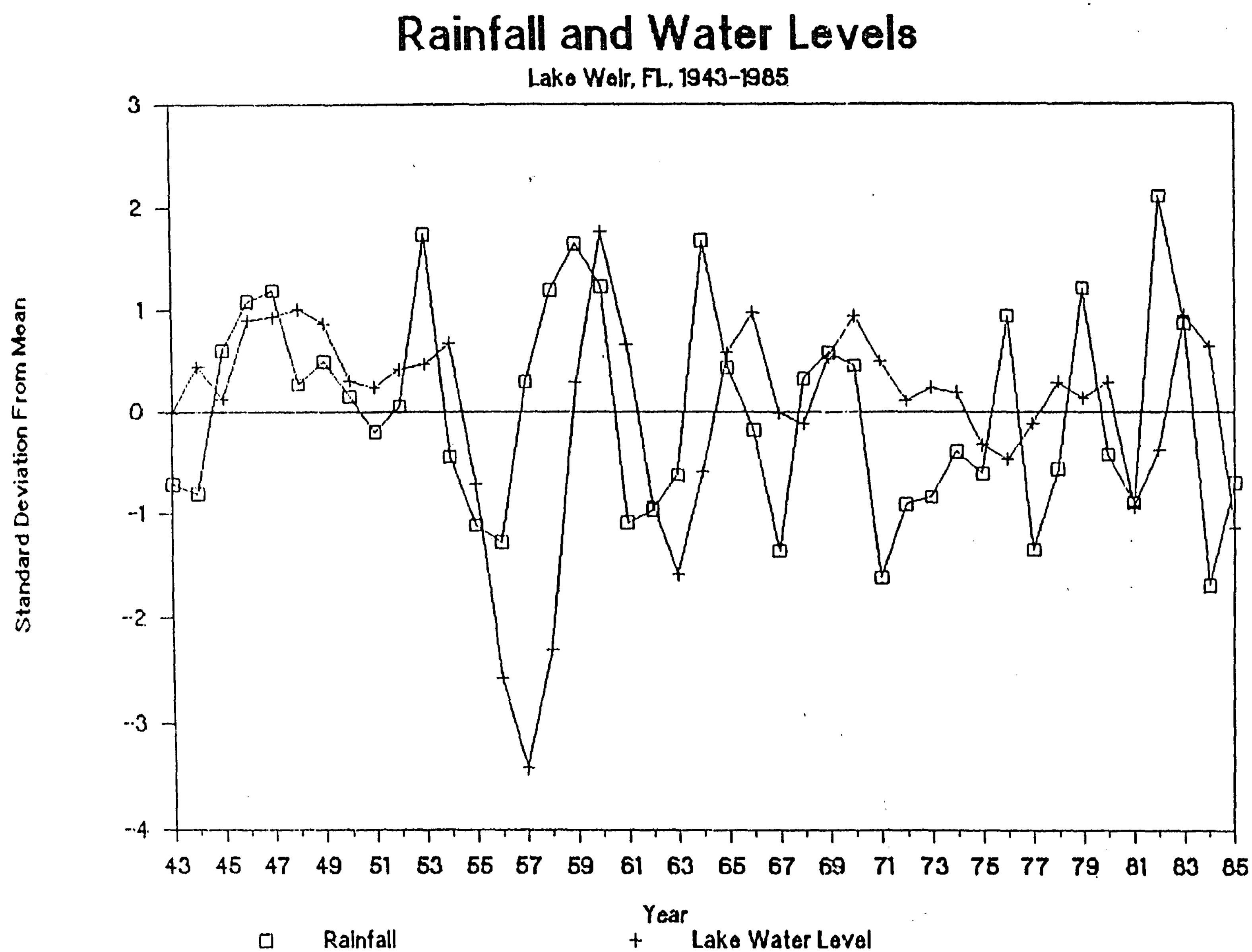


Figure 1-5. Annual rainfall and mean water levels for Lake Weir, expressed as standard deviations from their mean values since 1943. Note that water levels closely echo rainfall, after a lag time of one year.

map showed that the water level in 1883 had been as high as 61 feet, higher than any level recorded since at least 1943. Little Lake Weir was directly connected to Lake Weir proper, isolating four islands which now are part of the peninsula. Shackleford noted, however, that US government maps prior to 1883 depicted lower water levels.

Lake level has been dropping since 1983 and is now at one of the lowest recorded levels. Periods of low water can exert a significant short-term increase in nutrient availability. In perched lakes such as Lake Weir, most exchange between lake and ground water occurs through sediment in the littoral zone (Wetzel 1982). As lake stage decreases there is less flushing by ground water, leading to increased nutrient concentrations. Further, the shallower water levels are more conducive to sediment mixing and concomitant nutrient recycling. Finally, a lower water level temporarily reduces the extent of wetlands and shallow littoral zones around Lake Weir, which act as filters to mitigate nutrient loading.

Episodes of low water levels can also have long-term beneficial effects on lake water quality. These periods may serve to consolidate and oxidize littoral sediment, sealing the nutrients from future recycling into the lake water column. Low lake stage also allows the rejuvenation of shoreline vegetation, which traps nutrients from watershed activities.

Nevertheless, the adverse effects of low water levels at Lake Weir appear to outweigh the benefits in the short term. Lower lake stage may result in a significant short-term nutrient loading. The current water quality of Lake Weir may be due in part to the cumulative impact of five years of lower water levels.

1.2 BIOLOGICAL SETTING

The native vegetation around Lake Weir was dominated by pine forests (Shackleford 1883). Yellow pine was reported to be a valuable timber resource throughout that region (Marion County Surveyor's Map of 1888). Hammock associations of live oak, water oak, magnolia, sweetgum, hickory, bay and holly occurred on the peninsula, islands, and in strips along the lake's margin (Shackleford 1883). The Marion County map of 1888 showed wetlands consisting of hammock, bay, cypress, saw grass, and "scrub" north of the lake (Figure 2-4). A photograph taken circa 1900 of Lake Weir's southeastern shoreline shows a dense strip of natural hardwood hammock vegetation (Figure 1-6). Also, stumps of dead cypress trees were present in the shallow littoral area. The Vegetation and Land Use Map (SJRWMD 1973) showed

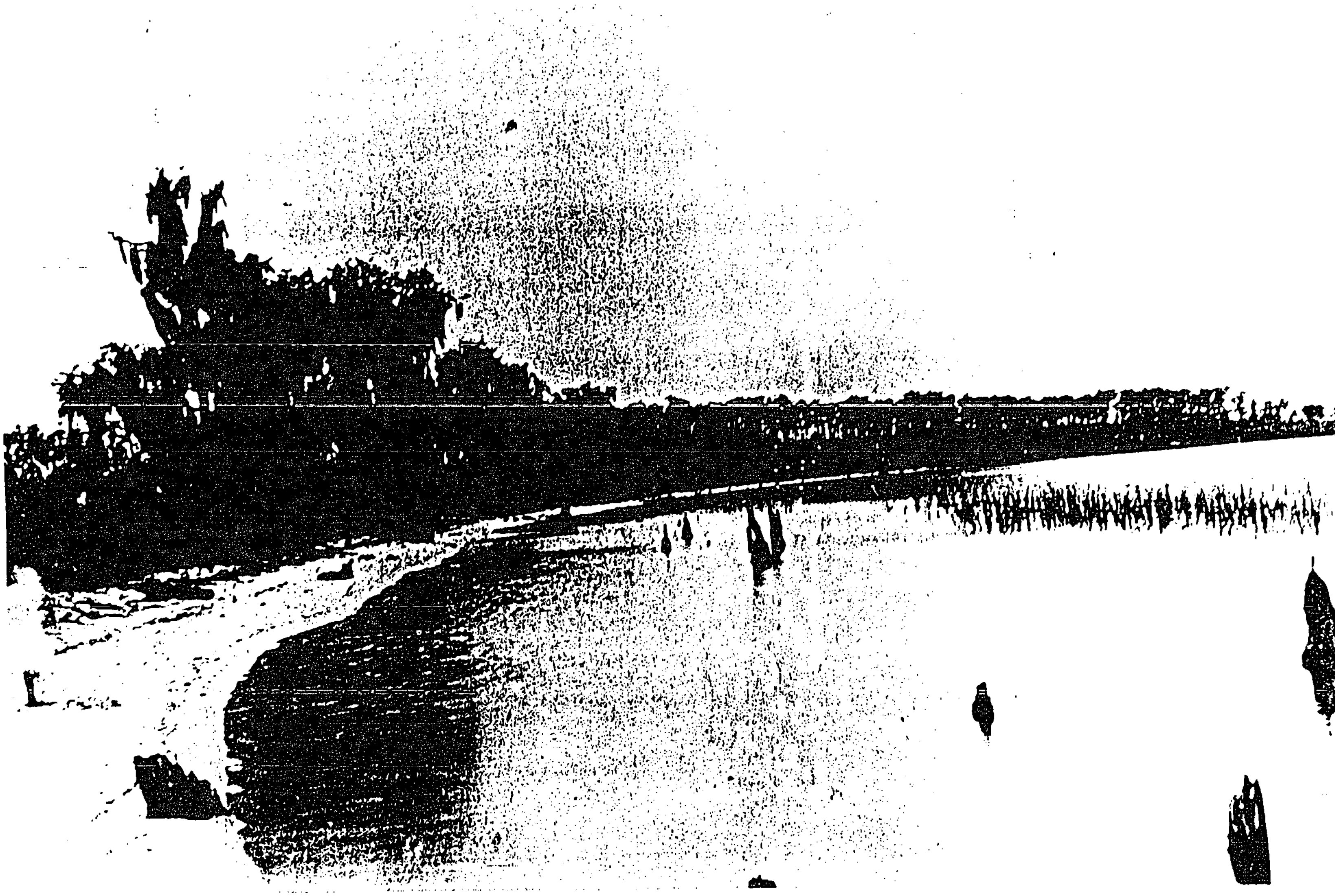
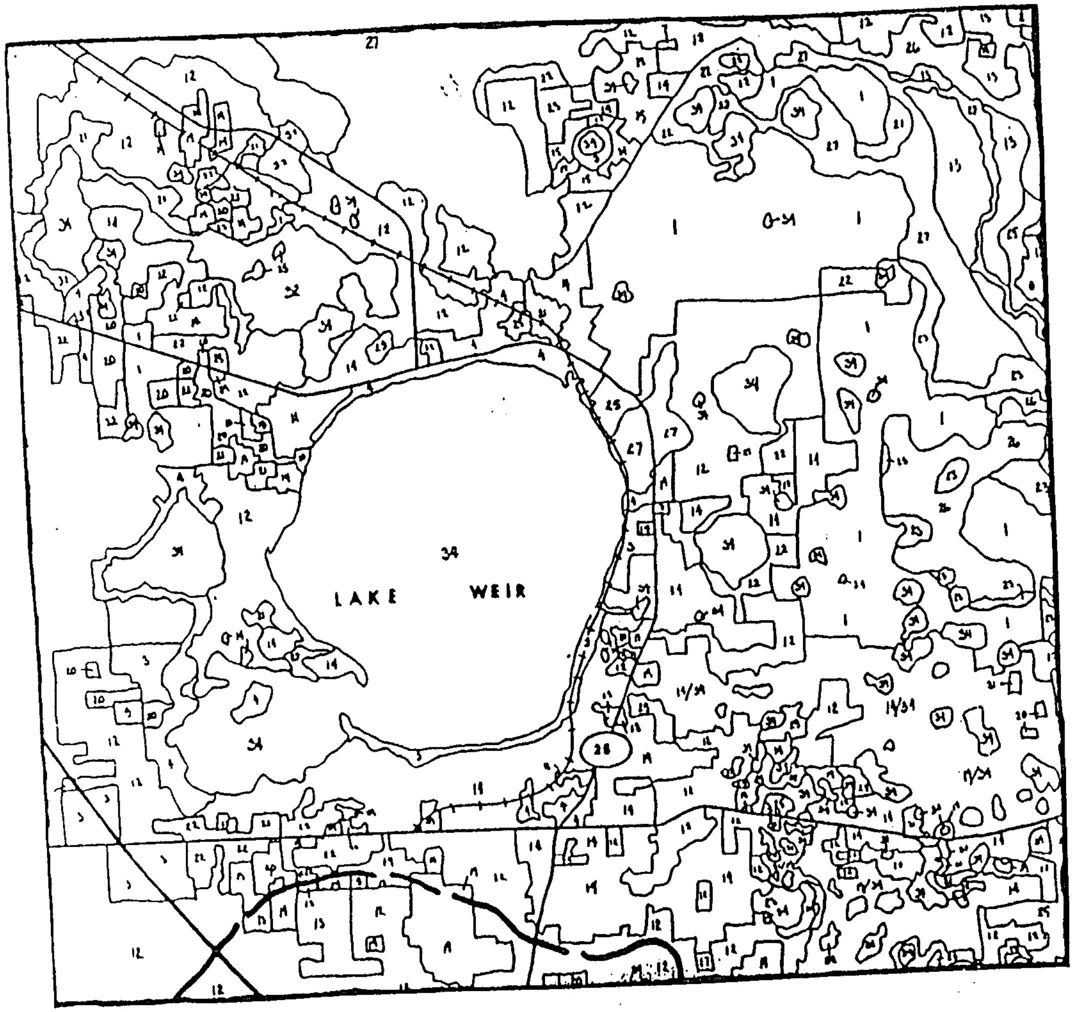


Figure 1-6. Photograph (ca. 1900) of Lake Weir's southeastern shoreline showing dense hardwood hammock vegetation. Note cypress stumps in the foreground.

very little mesic hammock or sand pine scrub remaining in the early 1970's (Figure 1-7).

Lake Weir's fertile hardwood hammocks were highly regarded for their rich organic soils and great suitability for citrus (Shackleford 1883). Wild oranges found on these lands were not indigenous, as believed by settlers of the late 1800's, but rather had been introduced to Florida by the Spanish. While the hammock forests provided the best soils for citrus, pine lands could also support citrus agriculture with additional fertilization.

Concerning fish populations, Shackleford (1883) described Lake Weir as being "well stocked with fish, consisting of trout [largemouth bass], bream, perch [crappie], pike, cat, and freshwater mullet." Sportfish populations today are similar, with the notable exception of the loss of crappie. Whether the "freshwater mullet" was indeed mullet remains uncertain, but if resolved would provide evidence for a natural connection to the Oklawaha River.



Legend

1	Open land
3	Residential, low density
4	Residential, high density
12	Improved pasture
13	Crop lands
14	Citrus groves
21	Sand pipes scrub
22	Sandfill community
25	Mesic Hammock
27	Hardwood swamp
32	Freshwater marsh
34	Lakes and ponds

Figure 1-7. Vegetation and Land Use Map of 1973 by St. Johns River Water Management District. Scale: 1"= 2 mi (1:80,000).

CHAPTER TWO: HISTORICAL DEVELOPMENT OF LAKE WEIR'S WATERSHED AND ASSOCIATED NUTRIENT INPUTS TO THE LAKE

2.1 HISTORY OF WATERSHED DEVELOPMENT

2.1.A INTRODUCTION

In order to assess the historical impact of various land use practices on the water quality of Lake Weir, watershed history must be delineated. With such a database, it becomes possible to correlate water quality to the type and degree of development around the lake for a given time period. This information can then be used to establish future land management policies to preserve Lake Weir from further eutrophication.

Eutrophication is an additive process whereby increased nutrient yields due to changes in watershed land use practices will increase nutrient concentrations in a lake. Any practices which introduce nutrients or increase erosion will contribute to nutrient loading. Common disturbances include land clearance, agricultural practices, and urbanization. The amount of rainfall and water level also affect the concen-tration of nutrients in a lake.

Lake Weir's watershed development over the past century was documented from old maps, aerial photographs, government records, and published reports. We were especially interested in changes in land clearance, citrus agriculture (areal extent and management practices), and urbanization (residential area, human population, dredging, and road construction) as well as historical trends in rainfall and water level. With such an approach we were able to establish a detailed chronology of potential nutrient sources from Lake Weir's watershed.

2.1.B SETTLEMENT OF LAKE WEIR

Lake Weir may have been home to a number of past Indian cultures. Today, at least four prehistoric archaeological sites, including two lithic scatter type sites, are known around Lake Weir (Archaeological Consultants, Inc. 1987). Shackleford (1883) claimed that it was not uncommon to find pottery fragments, arrow heads, spear heads, and other Indian relics.

Spanish missionaries began to frequent this region around 1600. Groups of Timucuan Indians known as the Ocale and Potono Tribes occupied Marion County at that time (Milanich and Fairbanks 1980). The agricultural Timuqua were decimated about 1630 by diseases introduced by Europeans.

Around 1700, the British forced the Creek Indians out of Alabama and Georgia. These peoples relocated into north central Florida and became known as the Seminoles. Some settled around Lake Weir, raising cattle and farming the fertile hammocks. They named the lake Amaskohegan, meaning Bright Moon Lake (Shackleford 1883).

Early maps of the Oklawaha River region were made by the US Army Corps of Engineers during the Seminole Indian Wars of 1818 and 1835-1842. These maps are now preserved in the National Archives. An undated early map (Figure 2-1) described the unnamed lake: "a lake 3 1/2 miles in diameter" with "a bay gall extending [north] from lake to the [Oklawaha] river hammock." The term "gall" probably refers to a forested wetland. An 1836 map (Figure 2-2) showed a stream connecting "Lake Ware" north to the Oklawaha River. This suggests that there may have been at least an intermittent stream predating the weir structure and canal of 1938.

Shackleford (1883) stated that the lake was named "in honor of Lieutenant Weir of the US Army who was killed near its borders by the Seminoles during one of their wars with the United States." Like the 1836 map, a Florida map of 1834 in Marion County's Regional Library depicted "Ware's Lake." This indicates that the lieutenant was killed before the Second Seminole Indian War, and that his name may have been "Ware." If this was the case, "Weir" was probably a corruption of "Ware".

The U.S. Army registry listed two men for whom the lake may have been named. The most likely candidate is William F. Ware of Georgia, who was honorably discharged as a Captain on January 15, 1815. He may have come out of retirement in 1818 to join Jackson's Tennessee Volunteers during the First Seminole War. Lake Weir may also be the namesake of Second Lieutenant Lewis Weir of Tennessee who died on November 14, 1809. However, the location of his death was not specified, and his death predates the Seminole Indian wars.

Shackleford (1883) provided a detailed account of Lake Weir's early plantation owners. In 1843, under the "Armed Occupation Act," Col. S.F. Halladay became the first European settler on Lake Weir. The few early settlers experimented unsuccessfully with different forms of agriculture, particularly cotton and various vegetables. By 1870, Lake Weir was still virtually uninhabited due to its distance from all means of transportation. The nearest

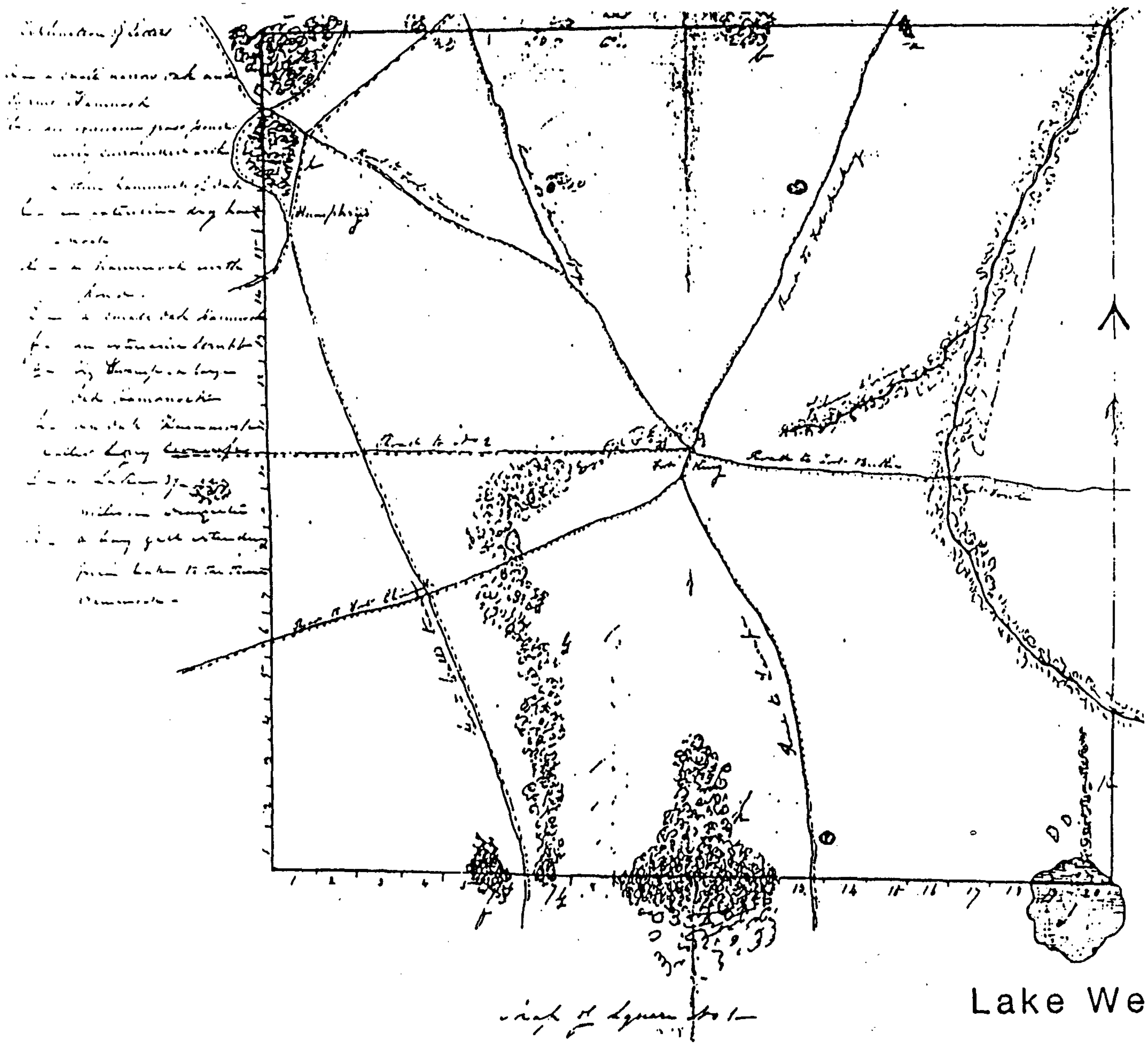


Figure 2-1. Map (circa 1835) of the Oklawaha River region of Central Florida by the U.S. Army Corps of Engineers. Lake Weir, in the lower right corner, was described as "a lake 3 1/2 miles in diameter" and the area to the north was labelled "a bay gall extending from the lake to the river hammock."

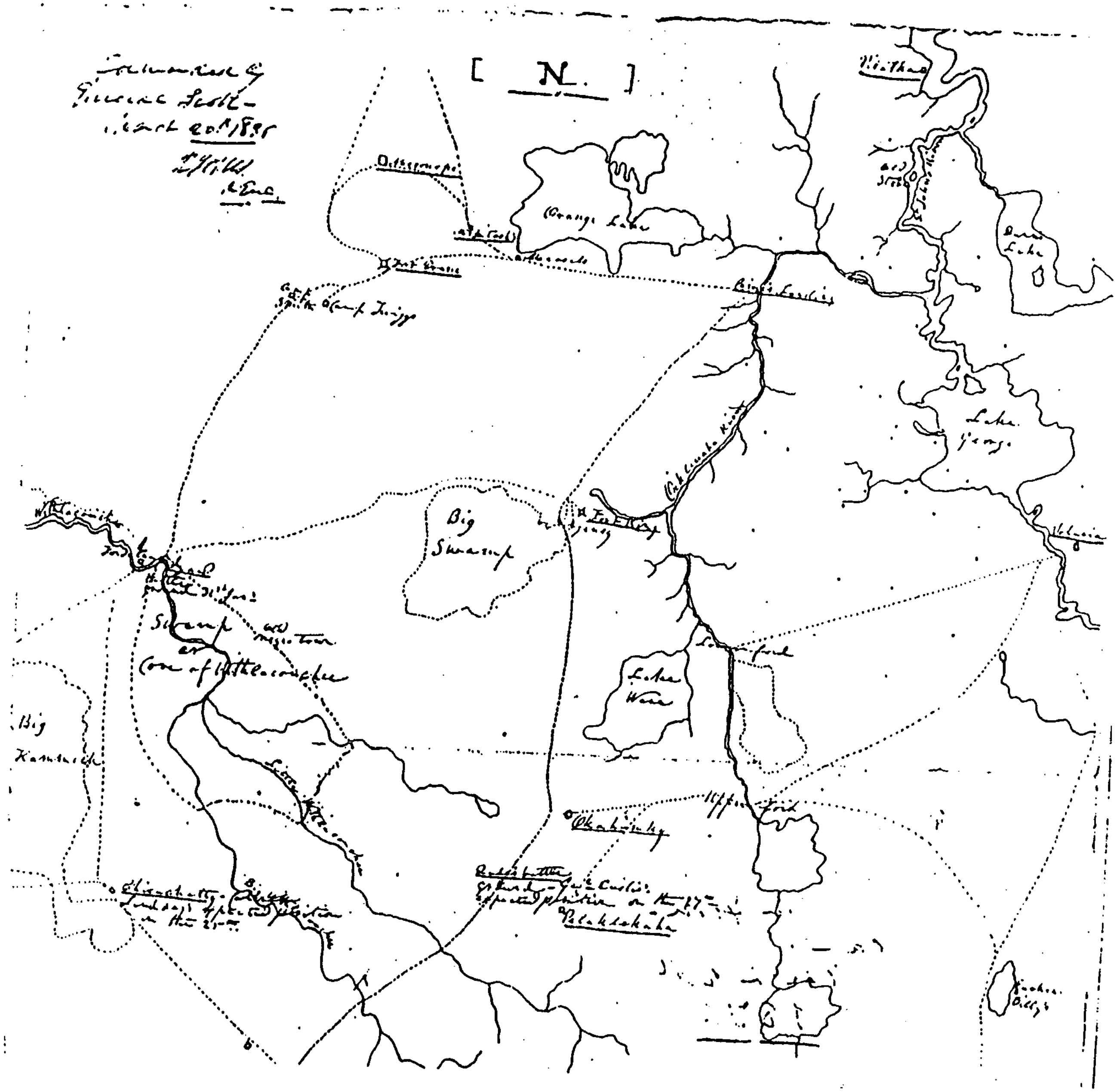


Figure 2-2. 1836 map of the Oklawaha River region of Central Florida by the U.S. Army Corps of engineers. Note the river connecting "Lake Ware" to the Oklawaha River.

steamboat landing and railroad station were in Silver Springs, and the post office was in Ocala.

Captain John L. Carney became the first citrus grower at Lake Weir in 1874 when he purchased 400 acres on Hammock Peninsula and Orange and Lemon Islands (now part of the peninsula dividing Lake Weir from Little Lake Weir). Lake Weir's great suitability for citrus was not appreciated for a few more years, until news of Carney's success brought a rush of entrepreneurs starting in 1880.

The Lake Weir watershed developed rapidly in the 1880's as a number of families purchased and cleared plots of land around the lake, as depicted on the map from Shackleford's book (1883) (Figure 2-3). By 1888, a number of small towns had been incorporated within the watershed (Figure 2-4). Photographs taken circa 1900 show a number of fine houses, stores, and community buildings (Figure 2-5).

2.1.C WATERSHED DEVELOPMENT

Shackleford (1883) and the 1890's photographs provided baseline hectarage of citrus and land clearance. Subsequent changes in land use within Lake Weir's watershed were measured from aerial photographs using a Micro-plan II digitizing computer. Florida Citrus Survey photos (1:20,000) were used for 1940, 1957, and 1964. More detailed aerial photos (1:7920) were available for 1980 and 1985, courtesy of Marion County's Tax Assessor's Office.

Multiple measurements of Lake Weir's total watershed area (excluding lake surface) averaged 4500 hectares. Variation was less than two percent for the 1980 and 1985 photos, with values ranging from 4481 to 4557 hectares. Error due to measurement was greater in the smaller scale photos, and total watershed area varied from 4000 to 5000 hectares.

Five land use categories were defined for the watershed:

Residential	clusters of four or more houses or buildings, including lawns.
Citrus	plots of viable citrus trees, not stumps or seedlings.
Pasture	all open land: grazing pastures, prairies, miscellaneous borders, some non-citrus agriculture.

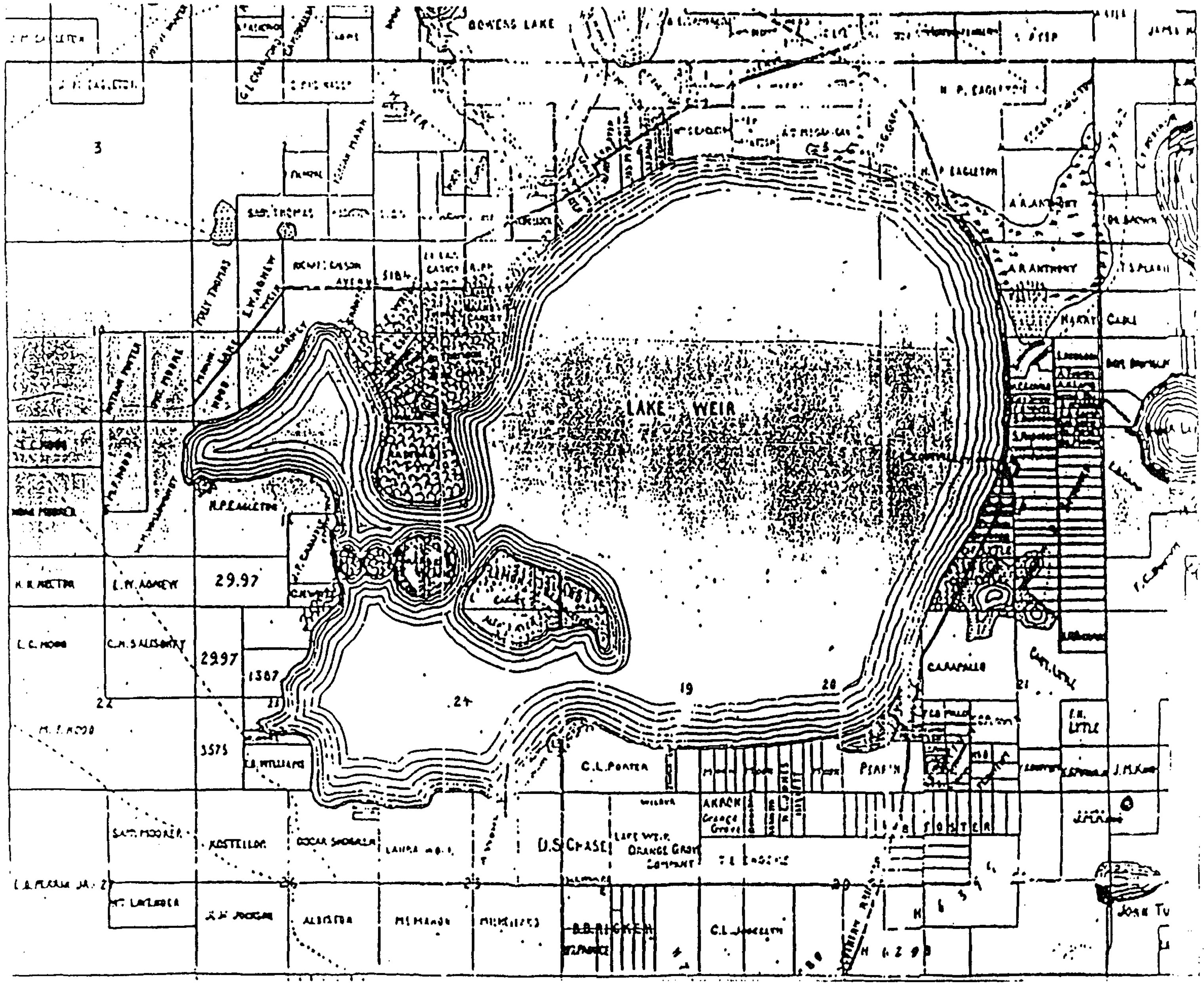


Figure 2-3. 1883 map of Lake Weir showing property divisions (Shackleford, 1883). A plot typically contained one house, a citrus grove, forest, and some cleared land. Note the high water level which divided the peninsula into islands.

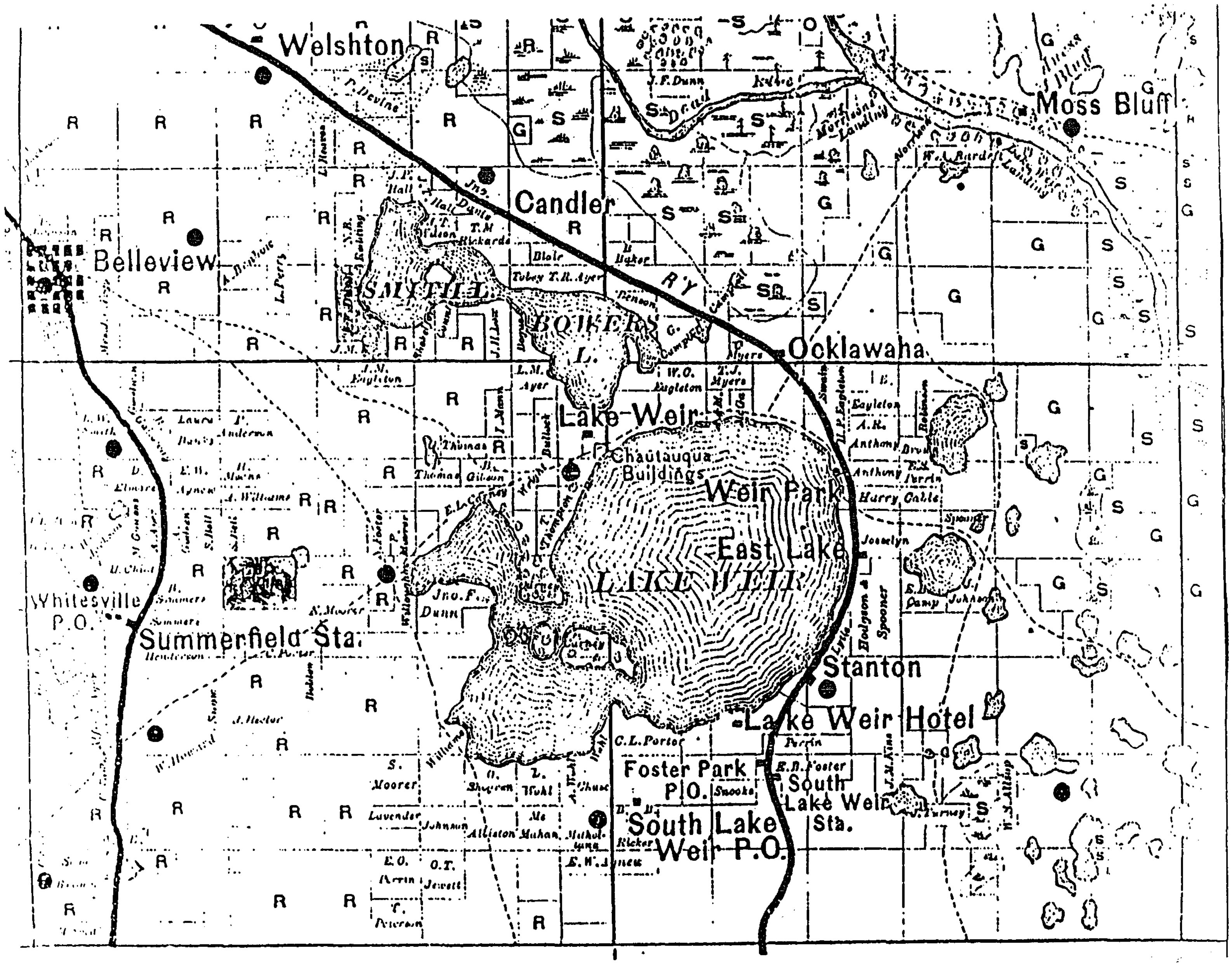


Figure 2-4. Portion of Marion County map of 1888 showing Lake Weir and numerous small towns which had been established within its watershed.

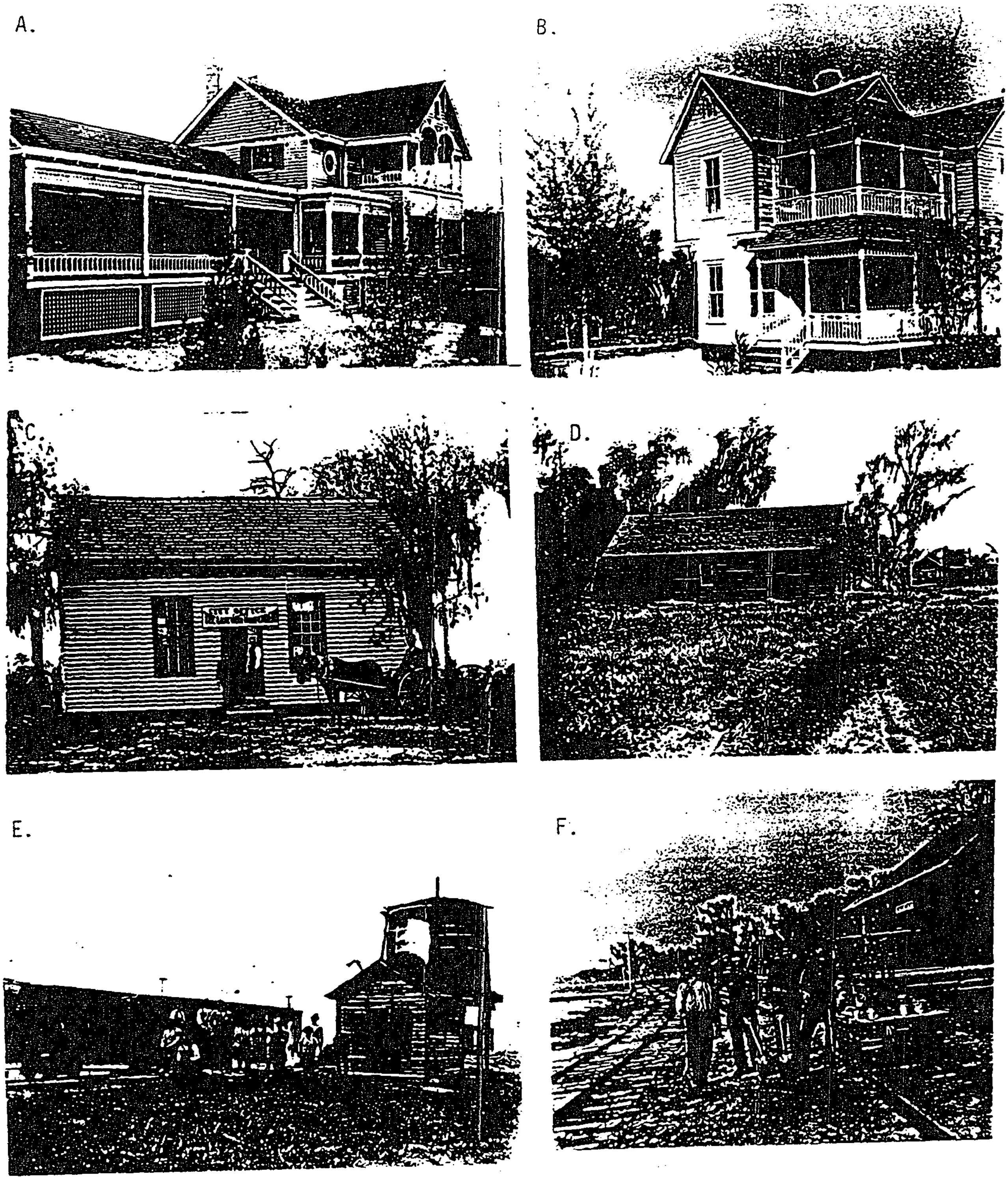


Figure 2-5. Photographs taken circa 1900 showing nice houses, buildings, and the new railroad near Lake Weir.

A. Buffum's house in Stanton (Weirsdale)
B. Dr. Henry's residence in Eastlake Weir
C. Lake Weir Printing Office
D. First old railroad depot in Eastlake Weir
E. First pumping station at Eastlake Weir
F. First Eastlake Station (before it burned)

Forest	clusters of trees over one hectare, including forested wetlands and a few commercial pine plots.
Wetlands	marshes and small ponds.

Pasture area, which was fragmented and difficult to measure, was calculated by subtracting the other land use areas from the mean watershed size of 4500 hectares. This simplified measurement and compensated for differences in watershed size estimates, permitting direct comparison between years.

The results revealed several trends and a few dramatic changes in watershed land use (Figure 2-6). A severe pulse of deforestation occurred after 1883. Forest area continued to decrease from 1940 to 1957, then rebounded slightly to date. Pasture area peaked in 1957 and again in 1985. Citrus was well established by 1883, increased in area through 1964, and was decimated between 1980 and 1985. Residential area increased tenfold from 1940 to 1985, with most of that expansion after 1964. These trends will be discussed in detail in the following sections.

Land use areas smaller than three hectares could not be measured on the small scale photographs. Smaller plots of trees and houses were easier to identify and measure on the larger scale photos of 1980 and 1985. This may account in part for the increase in forest and residential areas (and the relative decrease in citrus) from 1964 to 1980.

2.1.D Land Clearance

Early descriptions of Lake Weir (Shackleford 1883) and Marion County (Surveyor's map of 1888) characterize the region as being covered by pineland and hammock forest, with little natural upland pasture. Two saw mills were in full time operation by the 1880's and 1890's, clearing land for pasture and citrus groves while providing wood for construction of houses. Photographs taken around the turn of the century showed large tracts of cleared land with only a few solitary pine trees surviving (Figure 2-7).

The late 1800's marked the most rapid pulse of deforestation in Lake Weir's history; forest area was reduced to perhaps half of its original area. Forest area declined from 1200 to under 600 hectares between 1940 and 1957 (Figure 2-6). After 1957, the areal extent of forest increased slightly with a few commercial tracts of pine.

Pasture acted as a transitional land use between forest and citrus. Pasture area peaked following deforestation

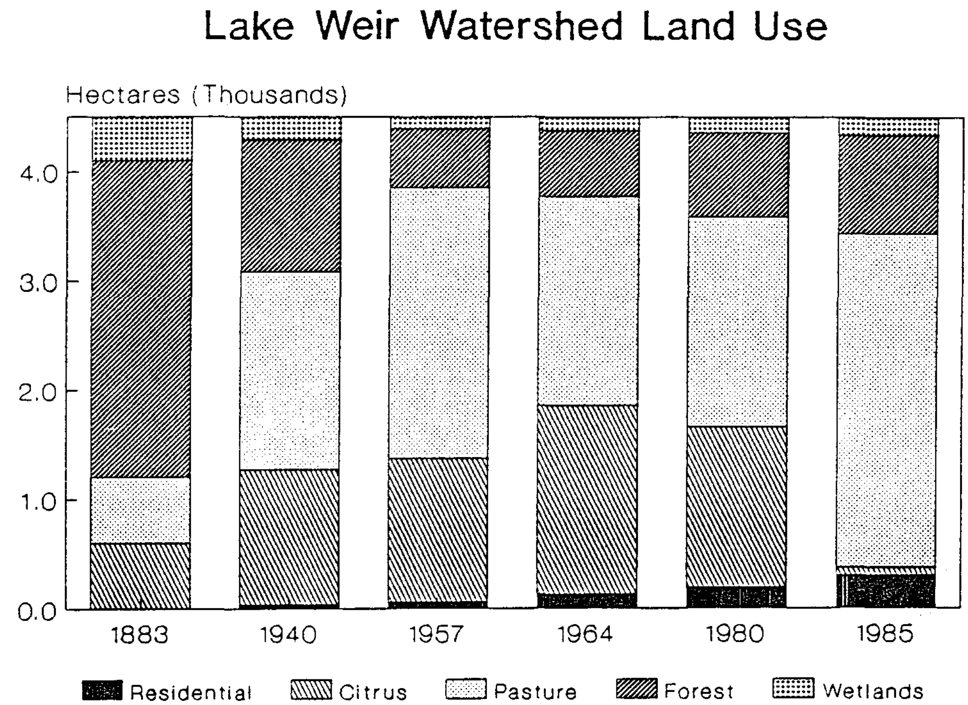


Figure 2-6. Historical watershed land use practices for Lake Weir. Pasture area, including all open lands and misc. land uses, was adjusted slightly to bring each year's watershed size to the mean value of 4500 hectares. Land use areas for 1883 were estimated from Shackleford's book. Values for 1940, 1957, and 1964 were computer digitized from Florida Citrus Survey aerial photographs (scale 1:20000). Land uses for 1980 and 1985 were digitized from Marion County tax assessment aerial photos (scale 1:7920).

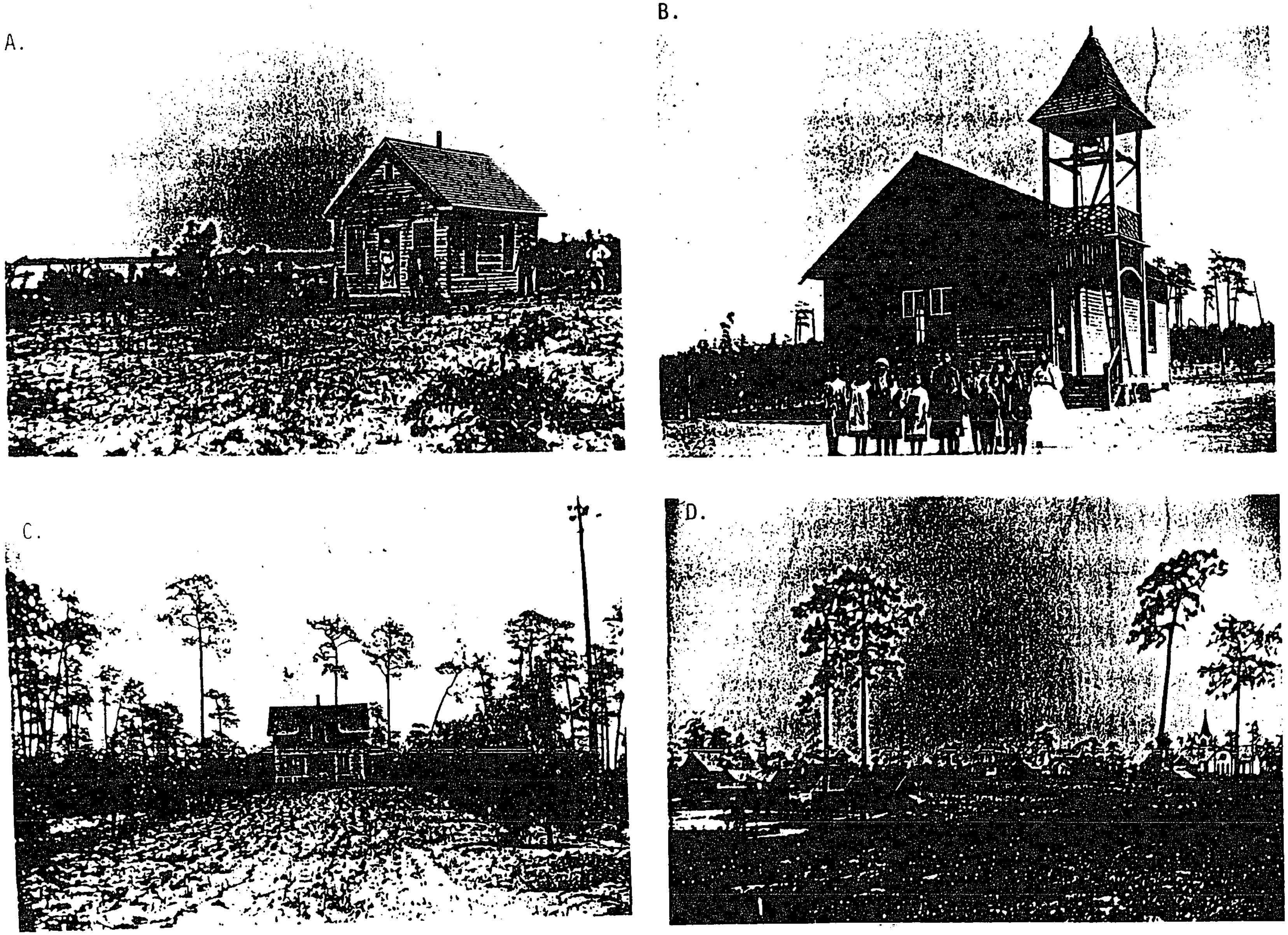


Figure 2-7. Photographs taken circa 1900 showing extensive amount of deforestation around Lake Weir. Note solitary pine trees where pine forest originally stood.
A. House in Eastlake Weir (lake in background)
B. School/Church in Weirsdale
C. House in South Weir
D. View of Weirsdale (Mr. Douglas' store on left)

activities of the 1940's and was partially replaced by citrus by 1964. Pasture dominated the watershed following the citrus crash in 1983.

2.1.E Citrus Industry

In order to assess the impact of nutrient loading from citrus agriculture on the lake, two factors need to be considered: the total amount of citrus in the watershed at a given time (Figure 2-6) and contemporary citrus management practices (Table 2-1).

The citrus industry was firmly established by 1883, comprising 150,000 orange and lemon trees in 600 hectares of groves surrounding the lake, with many more groves soon to be started. Citrus groves were decimated by the freezes of 1894, but were reestablished by the turn of the century. By 1940, citrus groves covered a quarter of the watershed (Figure 2-6). Citrus expanded and remained a prominent part of the watershed until the freezes of 1983 and 1984. By 1985, less than two percent of the watershed contained viable citrus.

Various methods of land clearance, citrus planting, fertilization, and pest control may have different effects on erosion and nutrient loading to the lake. Shackleford's 1883 book contained an entire chapter describing the best ways to plant and manage an orange grove. Comparison of these methods to modern practices may account for changes in the impact of citrus on Lake Weir.

Shackleford (1883) prescribed two different methods for land clearance for citrus groves. In the fertile hammock areas, cleared vegetation was stacked to decompose and release nutrients. The more acidic pineland areas were burned off, creating a much more rapid rise in nutrients following clearance.

Techniques of planting citrus groves also varied around the lake. Sweet orange scions were often grafted onto the "wild" orange trees which grew in the hammock areas. Many groves were started with young trees from nurseries. Prior to planting, holes seven feet wide would be left exposed for a week to equilibrate so that the trees would all be the same height. This practice would have left large areas subject to erosion in the event of heavy rainfall.

Changing fertilizer types and application rates could have influenced nutrient loading to the lake. Cattle manure and other nitrogenous fertilizers were most commonly used in the 1800's. Manure was applied particularly heavily on pineland groves. Also at that time it was common to plant

Table 2-1. Historical changes in citrus management practices within the Lake Weir watershed.

1600's	Spanish introduced sour oranges which were later thought to be indigenous or "wild".
1874	Captain John Carney established Lake Weir's first commercial orange grove.
1880-1890	Many more orange groves were started, totaling 600 hectares of citrus by 1883. Methods of clearing land and planting groves varied with land type. Pineland areas to the south and east of Lake Weir were burned off and young trees were set in large holes. Hammock areas on the islands and peninsula were cleared by hand and sweet orange scions were grafted onto existing wild orange trunks. Highly nitrogenous fertilizers such as manure were most commonly applied; commercial fertilizers were rarely imported to the area. Rows of beans were planted then plowed under to provide nitrogen for young groves. Insects may have been controlled by the spraying of heavy metals (Cu, Cd, As), as was the practice in that era.
1894	Freezes obliterated the citrus trees around Lake Weir. Nutrients were possibly released to the lake from the dead trees and soil.
1895-1900	All groves were restarted. Heavy nitrogenous fertilization presumably occurred.
1940	Citrus groves covered 1200 hectares. Commercial fertilizers containing N and P became common.
1945	Commercial herbicides and pesticides containing organo-phosphorus were introduced. Episodes of massive fertilization occurred in Florida.
1964	Citrus groves exceeded 1700 hectares.
1984	Freezes decimated Lake Weir's citrus to 68 hectares of viable trees. Nutrient release from dead trees and soil may have had a significant impact on the lake.
1980's	Many citrus owners have switched to fertilizers containing no phosphorus.

rows of beans between rows of young citrus trees. The beans, nitrogen fixers, would be plowed under to fertilize the ground.

Phosphorus rich commercial fertilizers were rarely used around Lake Weir during the 1800's, due to the expense and difficulty in transporting them to the lake. Heavy application of commercial fertilizers became more widespread after World War II. Therefore, current citrus management practices yield more nutrients and provide a higher ratio of phosphorus to nitrogen.

In the 1800's, a common method for controlling insect damage was to spray heavy metals (such as copper, arsenic or cadmium) as insecticides. It is reasonable to assume that this practice may have been conducted at Lake Weir, though Shackleford (1883) made no mention of it. Commercial pesticides and herbicides were introduced at the end of World War II. These contained organo-phosphorus, which would have increased nutrient loading to the lake.

One other potential source of nutrient loading to the lake occurs after citrus killing freezes as the rotting trees release significant amounts of nutrients. The freeze of 1894 killed over ninety percent of the citrus in central Florida, but there is no detailed record of tree mortality within the Lake Weir watershed. More recently, the freezes of 1983 and 1984 may have made such an impact.

2.1.F Urbanization

Urban growth is another factor which may have affected the lake's water quality. Changes in residential area, human population, road construction, and dredging activities were examined.

At the time of Shackleford's book (1883), Lake Weir's watershed hosted three stores, two saw mills, and two post offices. By 1888, the Lake Weir watershed had ten stores, seven post offices, three hotels, two railroad stations, the Chautauqua Buildings, a bank, and a seminary.

Residential area was absent in 1883 and grew to less than one percent of the total watershed by 1940. Residential area doubled by 1957, doubled again by 1964, and more than doubled again by 1985 (Figure 2-6). The residential areas were concentrated in the vicinity of Oklawaha, Weirsdale, and Sunset Harbor.

Shackleford (1883) reported: "Ten years ago there were no citizens. . .on Lake Weir. Now over one thousand people dwell upon its shores or in its immediate vicinity." His figure included Belleview, which lies just outside the watershed. Judging by the relative growth rates of Belleview and the Weir watershed, it is reasonable to estimate that 300 people lived in the watershed at that time.

Decennial census data were available for Lake Weir starting in 1900. From 1900 to 1940, precinct number nine was the town of Lake Weir (now part of Oklawaha). Precinct nineteen was Stanton, which was later renamed Weirsdale.

In 1950 and 1960, Marion County was divided into five sections, so population data could not be derived separately for the Weir watershed. The increase in population for this time was probably proportional to the increase in residential area (Figure 2-6).

In 1970 and 1980, Enumeration Districts (E.D.) were initiated, showing Lake Weir's watershed population. Data from 1970 were not available at UF's library. The 1980 E.D. tract included a few areas of low population outside the watershed, so the population was estimated at 4600, instead of 4721.

The population growth rate has accelerated in recent years (Figure 2-8). Such population expansion could have exerted a significant effect on the lake's nutrient loading, especially because there is no central sewage treatment facility. Septic tanks, even if operated properly, release nutrients into the lake. Septic tank contributions were estimated to have an average daily effluent of 475 liters, having concentrations of 36 mg/l N and 8 mg/l P (Messer 1975, Brezonik and Shannon 1971). Messer (1975) assumed that 25% of the N and 10% of the P was transported from shoreline septic tanks to the lake.

Aerial photos showed that increased road construction roughly paralleled the expansion of residential area until 1971 to 1972, when a huge network of roads was built in the northeast corner of the watershed. Road lengths were digitized on the topographic maps of 1970 and 1977. Whereas the length of roads in the entire watershed increased by 45% during this time, there was a 200% increase within the northeast corner (Figure 2-9). Phosphate-rich clays from the Hawthorn Formation are commonly used for road beds in Central Florida, and road construction often leads to increased erosion. Therefore, this episode of development may have impacted the northeast section of the lake.

Dredging is another developmental activity which could affect the lake's water quality (Figure 2-10). Aerial photos showed that the canal between Little Lake Weir and Sunset Harbor was first dredged between 1949 and 1957. This canal was widened and lengthened by 1964. The bridge and

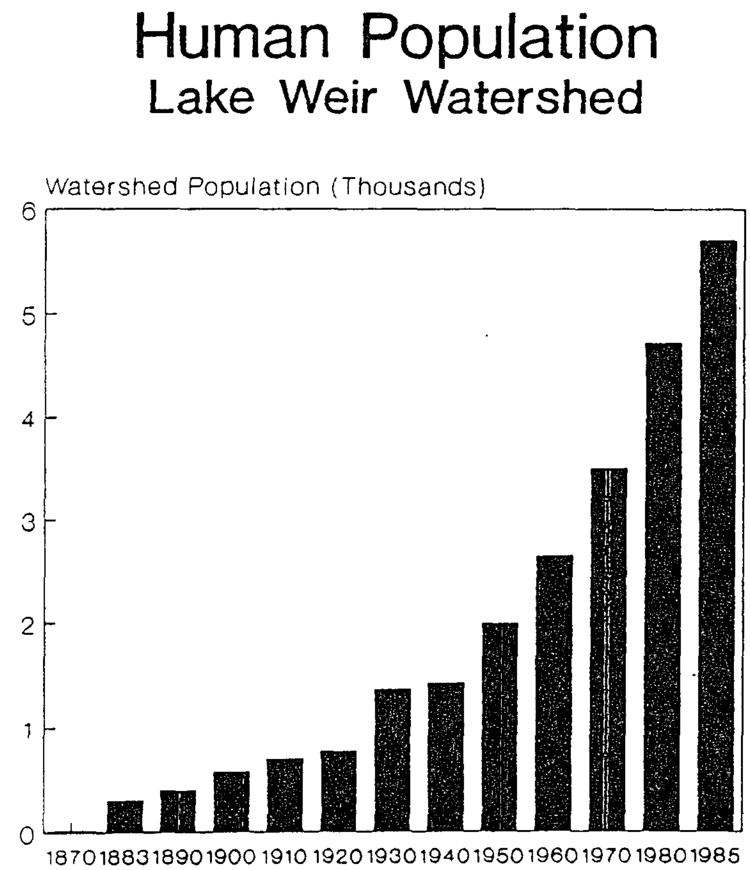


Figure 2-8. Human population within the Lake Weir watershed from 1870 to 1985. Figures for 1870 and 1883 were from Shackleford's book. Decennial census data were available for 1900 through 1980. All other values were estimated as a function of residential area as depicted in Figure 2-6.

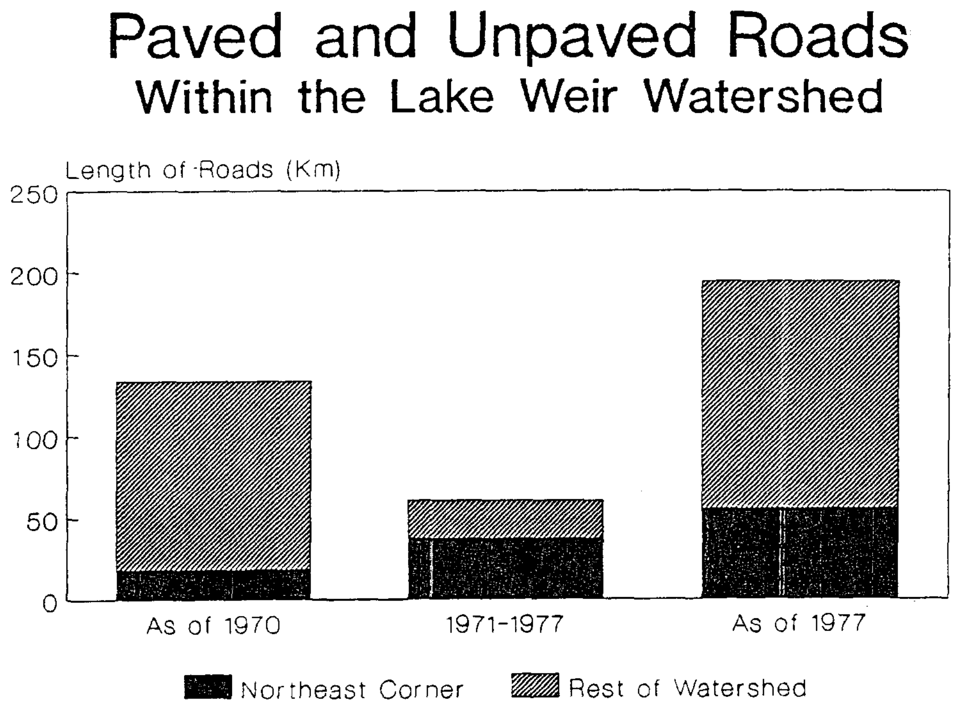


Figure 2-9. Length of paved and unpaved roads in the Lake Weir watershed, in km. Distances were computer digitized from 1970 USCS topographic map (photorevised 1980, with 1977 photos). Note the extreme degree of road development which occurred in the northwest watershed around 1972.

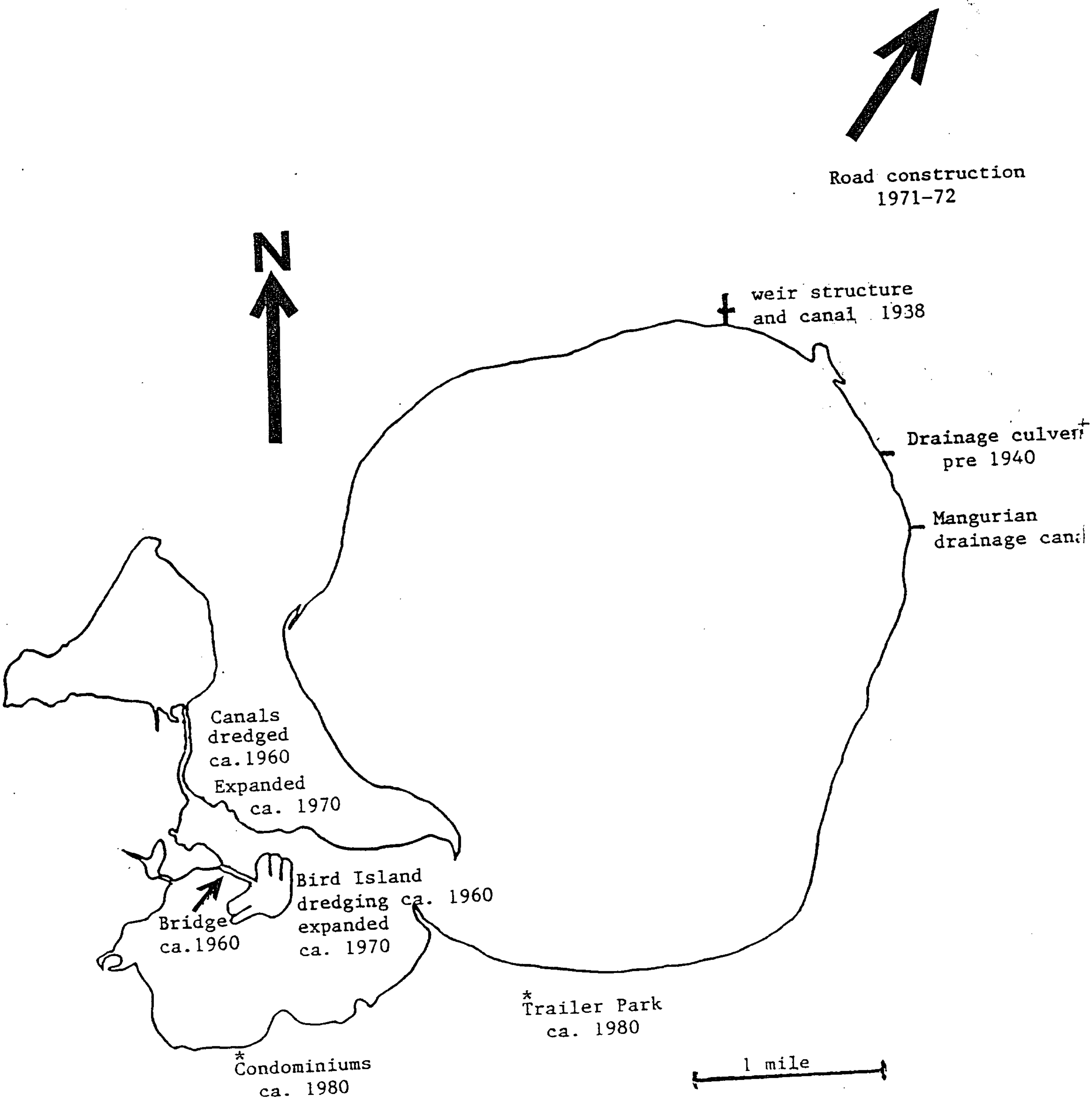


Figure 2-10. Map of Lake Weir showing dates of dredging and construction around Lake Weir.

canals on Bird Island were also made between 1957 and 1960. By 1972, more cross channels were dredged in the Little Lake Weir canal, and the canal west of Sunset Harbor was dredged. The weir structure and its canal were constructed on the northern shore in April of 1938.

In summary, the history of Lake Weir's watershed has been punctuated by several distinct periods of potential increases in nutrient loading to the lake (Table 2-2). Commencement of citrus agriculture in the 1880's, the citrus-killing freeze of 1894, and rapid deforestation during the 1890's may have significantly increased erosion and nutrient loading. Extremely low lake water level in 1957 may have increased lake nutrient concentrations. Dredging activities in the early 1960's and extensive road construction around 1972 also may be marked by pulses of nutrient loading. Rapid population growth and concomitant urban expansion highlight the 1980's potential sources of nutrients.

2.2 Nutrient Budget

Loading rates of N and P for the Lake Weir watershed were calculated using Brezonik and Messer's (1975) areal yield coefficients (Table 2-3). Their estimates were based on a number of assumptions, but these values appear to be the best available for Florida, and provide a basis for comparison between periods in the watershed's development. Brezonik and Messer used a much smaller watershed area for Lake Weir than the current study and hence arrived at much lower nutrient loading rates.

Human septic input was calculated using Vollenweider's (1968) human nutrient yields of 12 g N and 2.25 g P per person per day. It was assumed that 25 percent of the nitrogen and 10 percent of the phosphorus were transported to the lake.

Rates of nutrient removal by wetlands adjacent to the lake were not estimated. Brezonik and Messer (1975) speculated that these wetlands acted as nutrient sinks during the growing season and nutrient sources during the winter. Later studies have shown that wetland systems in subtropical environments act as nutrient sinks throughout the year. Therefore, the reduction in wetland area around Lake Weir since 1883 would have increased nutrient loading to the lake.

These loading values of N and P do not include input from precipitation or water fowl. Several residents have noted that herring gull populations have increased substantially in recent years, especially during winter.

Table 2-2. Summary of historical events in Lake Weir watershed potentially affecting nutrient loading to the lake.

1880's	Citrus management practices (land clearance, planting, fertilization, insect control).
1894	Citrus freeze.
1890-1910	Massive deforestation.
1938	Construction of broad-crested weir structure and canal.
1940's	Massive application of commercial fertilizers containing nitrogen and phosphorus.
1945	Introduction of orthophosphate-based herbicides and pesticides.
1956-1958	Extremely low lake water levels.
1960-1961	Extremely high lake water levels.
1962	Dredging of canals on peninsula and bird island. Bridge built.
1972	Extensive road construction in northeastern watershed.
1975-1988	Population boom! Condominiums, trailer parks, housing developments. Significant increase in population and residential area.
1983-1984	Citrus freeze.
1985-1988	Lake water level falling.

Table 2-3. Nitrogen and phosphorus loading coefficients for watershed land use practices and human population at Lake Weir. Land use nutrient loading values were based on Messer 1975. Human septic input was estimated by Brezonik and Shannon (1971), assuming that only 25% of the nitrogen and 10% of the phosphorus was transported to the lake (Messer 1975).

	--------ANNUAL	YIELD--------
NUTRIENT SOURCE	NITROGEN	PHOSPHORUS
+ Residential	0.88 g/m2	0.110 g/m2
+ Citrus	2.24 g/m2	0.018 g/m2
+ Pasture	0.75 g/m2	0.065 g/m2
+ Forest	0.37 g/m2	0.060 g/m2
* Total produced	4380. g/person	821. g/person
* Amount reaching lake	1095. g/person	82.1 g/person

+ Land use
* Human waste

This may also have had a significant nutrient impact.

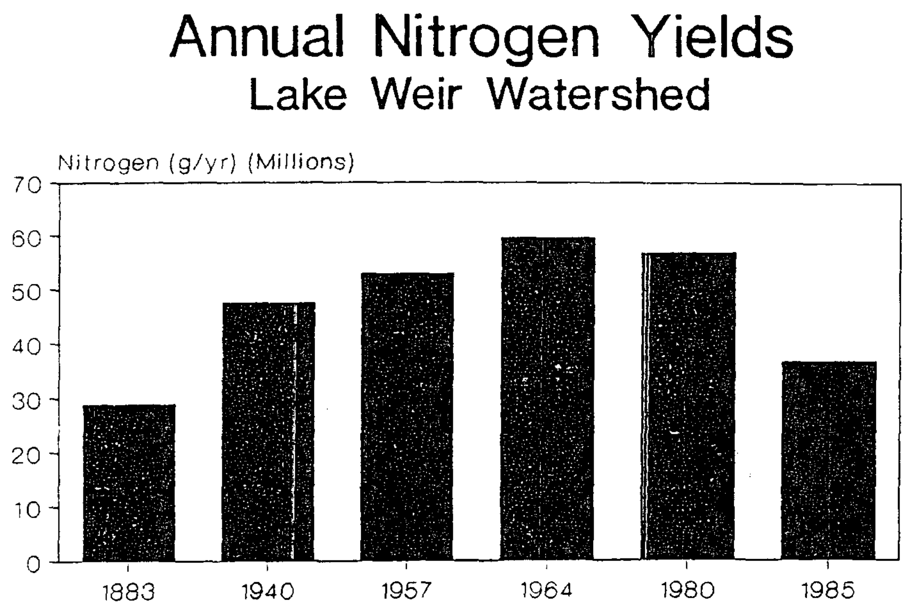
Annual nitrogen loading to Lake Weir from the watershed doubled from 3 x 10^7 g in 1883 to 6 x 10^7 g in 1964 (Figure 2-11). Following peak values in 1964, nitrogen loading appears to have decreased throughout the 1980's. Our final calculation year (1985) was intermediate in value between 1883 and 1940 estimates.

Annual phosphorus input from the watershed remained fairly constant at around 2.0-2.5 x 10^6 g from 1883 to 1964, then appears to have increased progressively through at least 1985 to a peak of 3.3 x 10^6 g (Figure 2-11). These loading estimates are considered conservative, as only ten percent of the phosphorus in human waste was assumed to reach the lake.

Historical changes in nitrogen and phosphorus loading from the Lake Weir watershed have been estimated separately for citrus, forest, pasture, residential, and septic tanks (Figure 2-12). Both nitrogen and phosphorus loading from citrus increased progressively from 1883 to peak values in 1964. Between 1964 and 1980 values declined slightly, then plummeted by 1985 to a level that was only a fraction of the 1883 value. Expressed as a percentage of total loading to the lake, citrus accounted for 46-65% of total nitrogen and 5-14% of total phosphorus loading to the lake for the period 1883-1980, then declined to 4% and <1%, respectively, by 1985. The latter date was immediately following the citrus freeze of 1984.

The contribution of forest to total phosphorus and nitrogen loading to the lake was greatest in 1883, declined until 1957, then increased progressively through 1985 (Figure 2-12). On a percentage basis, the forest contribution was greatest in 1883 (37%N, 77%P) and lowest in 1957 (4%N, 13%P). The contribution of pasture to both nutrients increased progressively from 1883 through 1957, after which values were reduced in 1964 and 1980 before increasing in 1985. Maximum pasture contribution to nitrogen and phosphorus loadings were in 1985 (63%) and 1957 (66%), respectively.

Watershed loadings for both nitrogen and phosphorus associated with residential development increased progressively from 1883 through at least 1985 (Figure 2-12), with the maximum contribution (1985) of residential activity to total nitrogen and phosphorus loading of 8% and 10%, respectively. As with residential development, the contribution of the related parameter, septic tanks, has also increased progressively since 1883 to peak in the 1980's at 17% and 15% of total nitrogen and phosphorus loading to the lake, respectively. Although not the dominant contributor to the nitrogen and phosphorus budgets of the



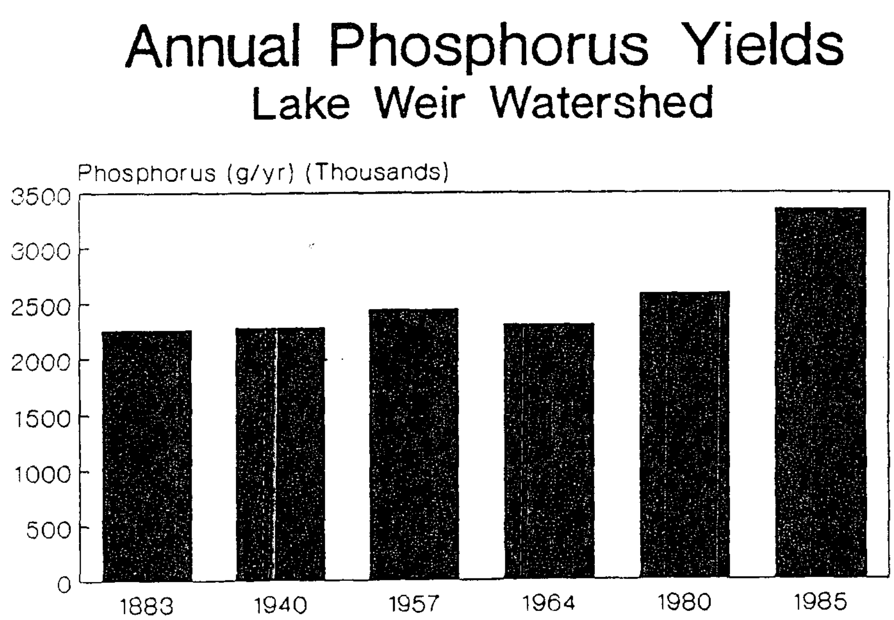


Figure 2-11. Historical annual loading of nitrogen and phosphorus into Lake Weir from the watershed. Nutrient loading coefficients for land use practices and human population are listed in Table 2-3. These values do not include aerial or groundwater nutrient contributions, and do not quantify the nutrient uptake by wetland areas surrounding the lake.

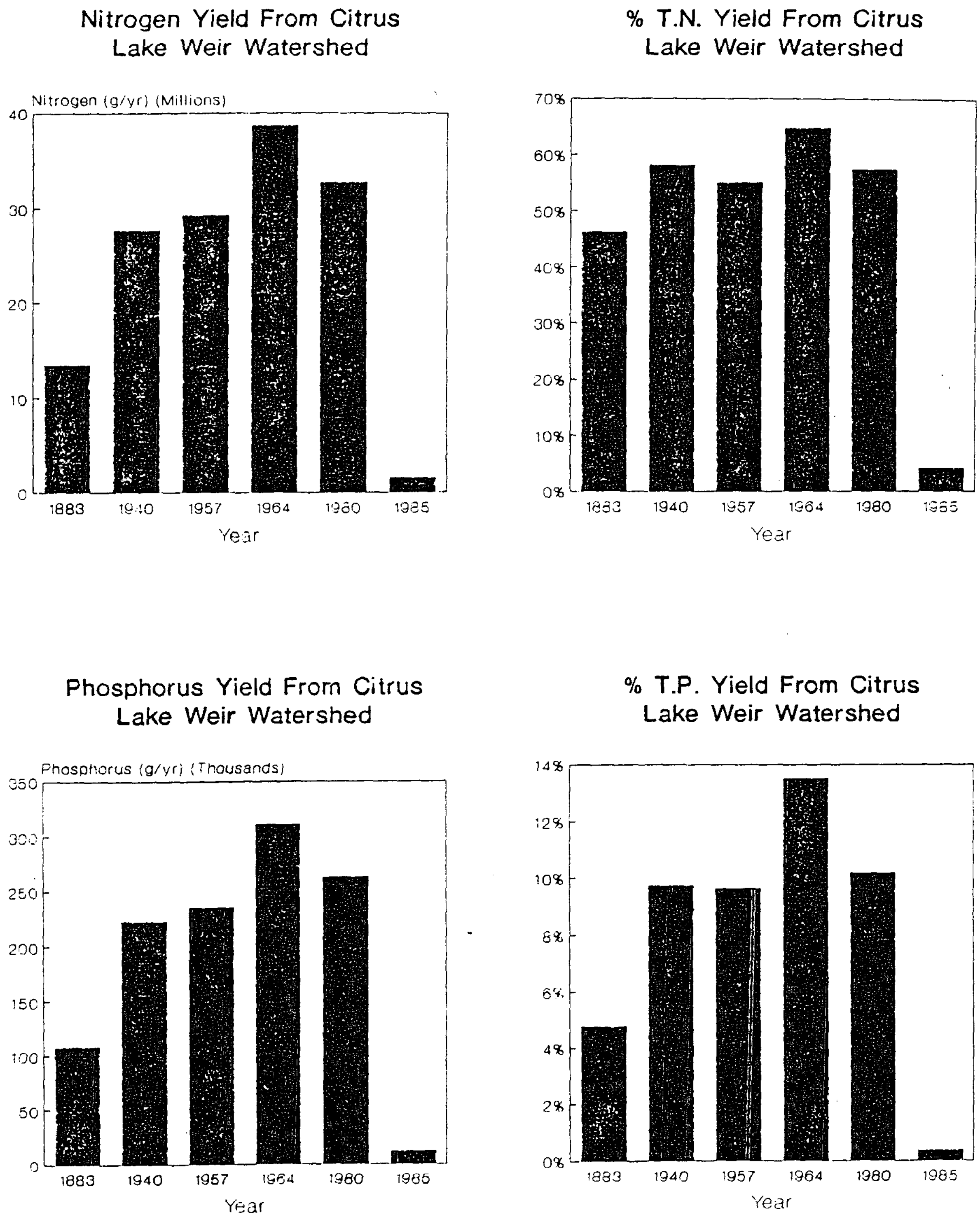


Figure 2-12. Historical changes in the loading of nitrogen and phosphorus into Lake Weir from various land use categories.

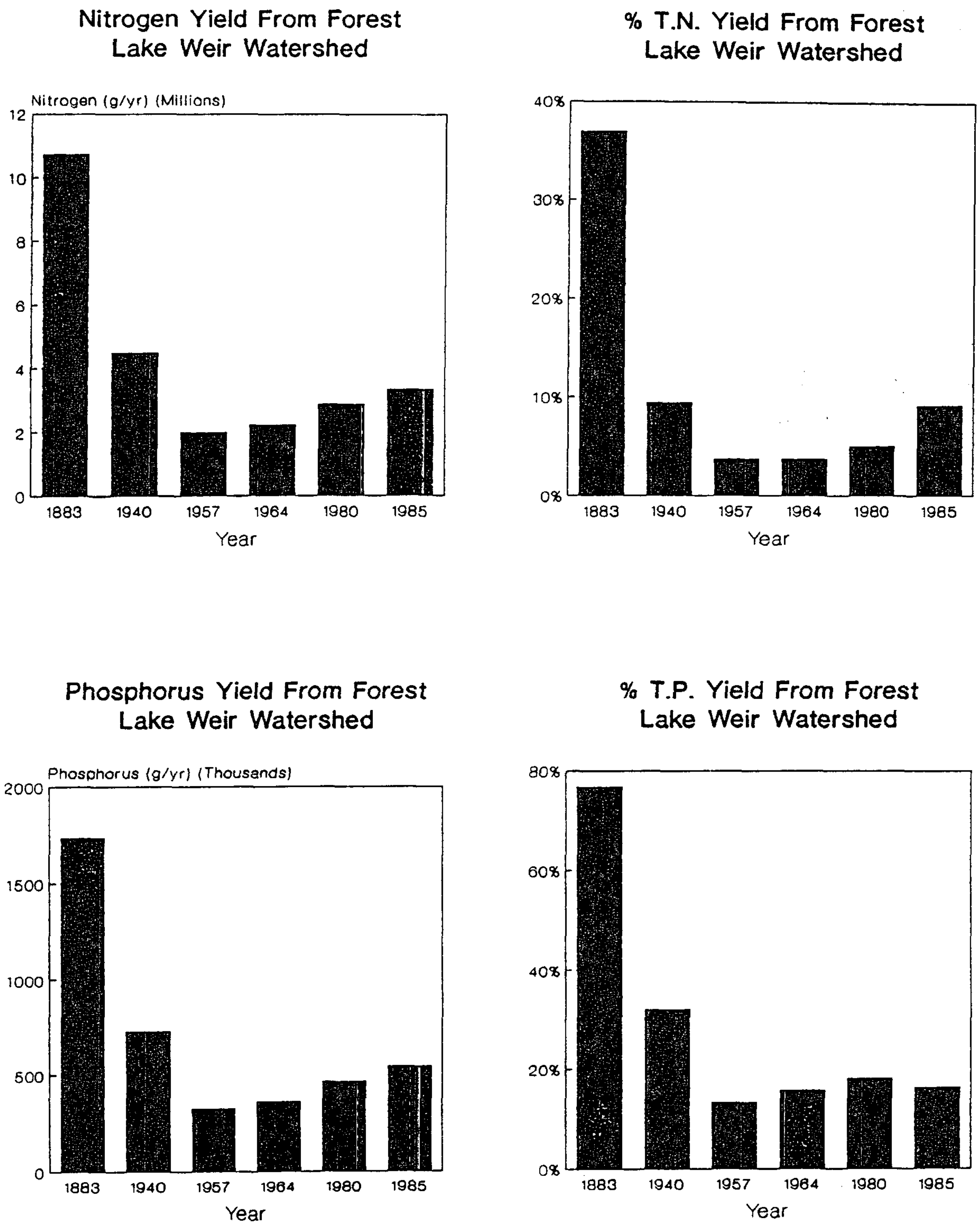
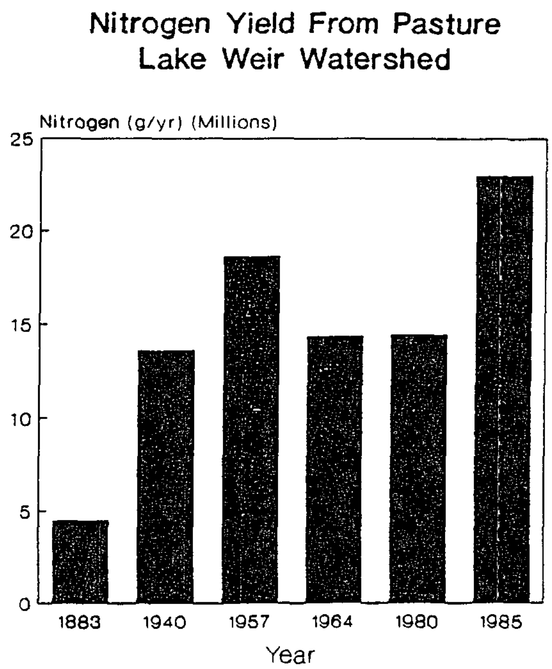
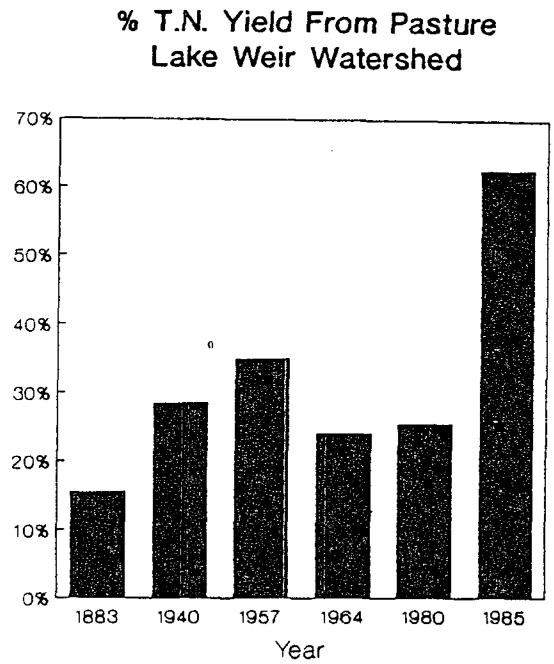
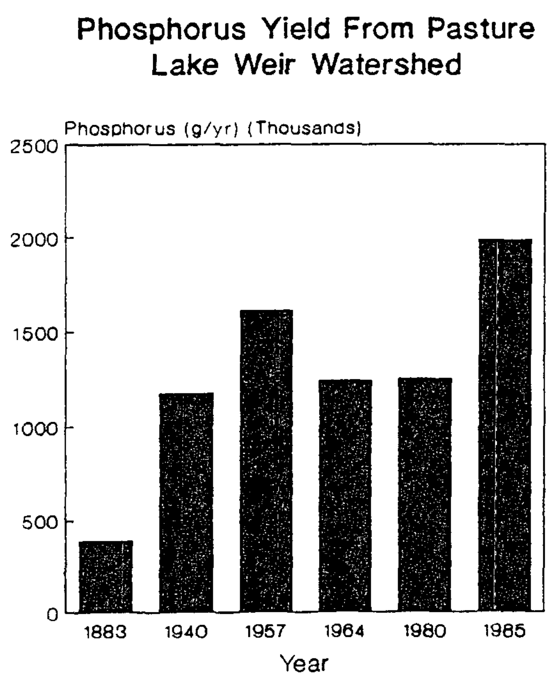
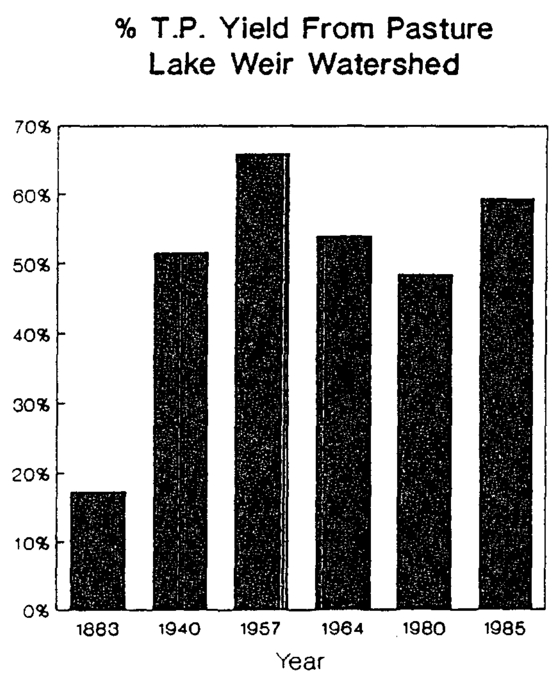


Figure 2-12. Continued.









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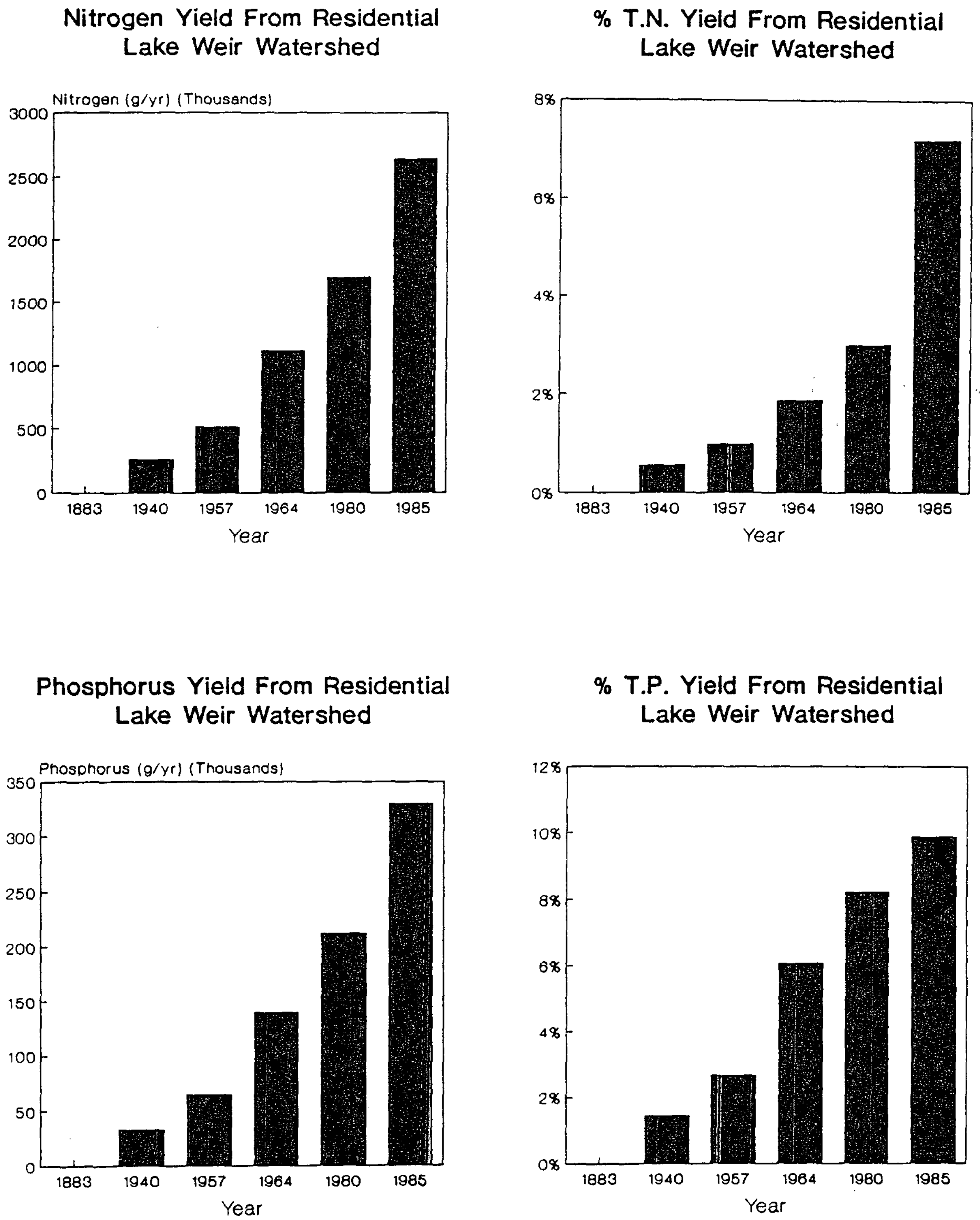

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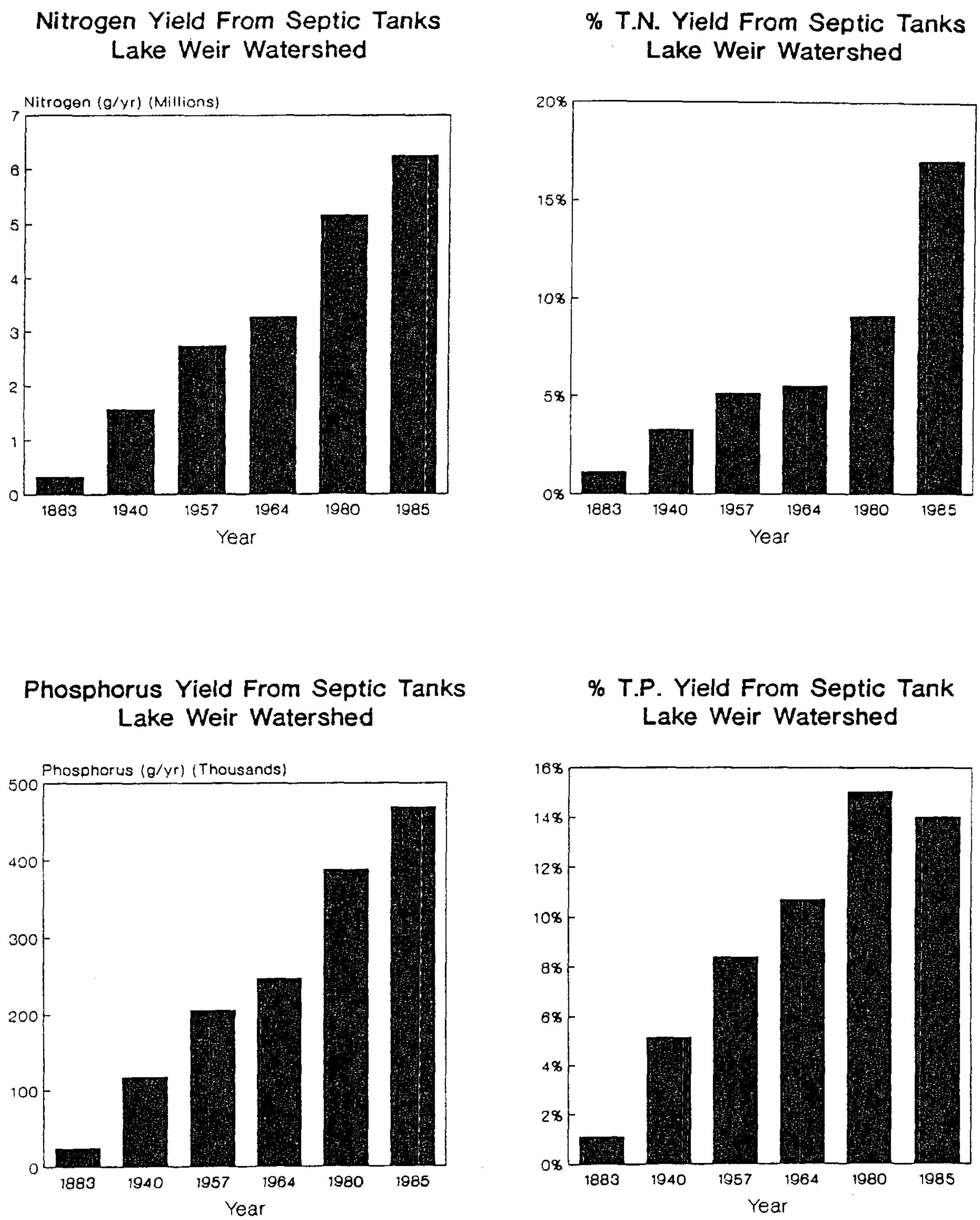


Figure 2-12. Continued.

lake, it is important to note that residential development including septic tanks has increased progressively for at least the past 100 years, while other contributors have either increased or stabilized. The impact of future residential development on Lake Weir must be monitored closely.

Citrus remained as the dominant contributor to total nitrogen loading from 1883 until approximately 1985 when it was replaced by pasture (Figure 2-13). Regarding phosphorus loading, forest was the dominant contributor in 1883, but was quickly replaced by pasture as land clearance proceeded.

It must be emphasized that the historical nutrient budget for Lake Weir was developed from published export coefficients that have been applied in earlier estimates of watershed nutrient export for Lake Weir. No attempt was made either to develop or test previously published coefficients. The estimates presented here are, therefore, subject to change both as more refined coefficients specific to Florida are developed and as the importance of individual land uses is altered.

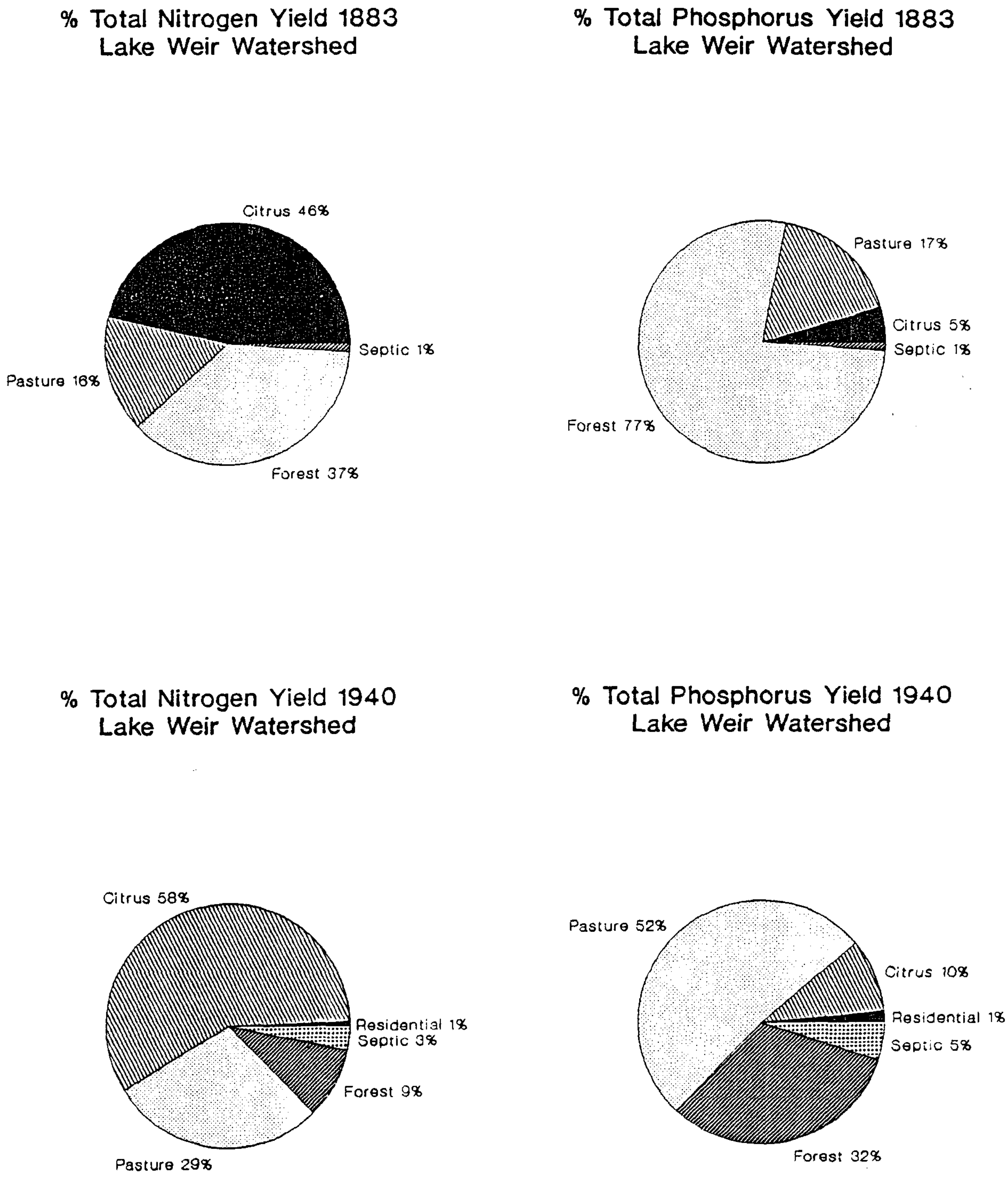
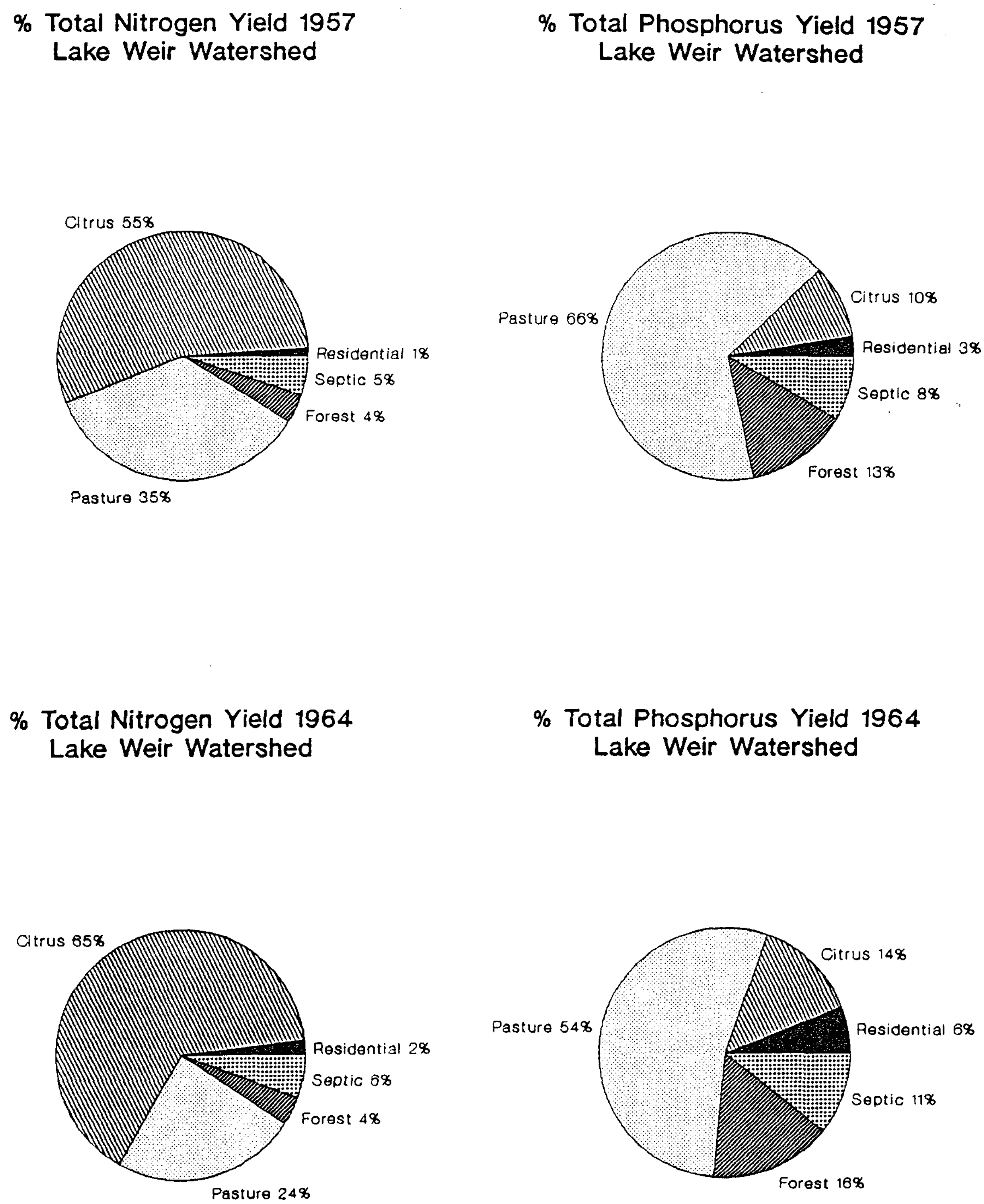


Figure 2-13. Historical changes in the contribution of various land use categories to the nitrogen and phosphorus loading to Lake Weir.



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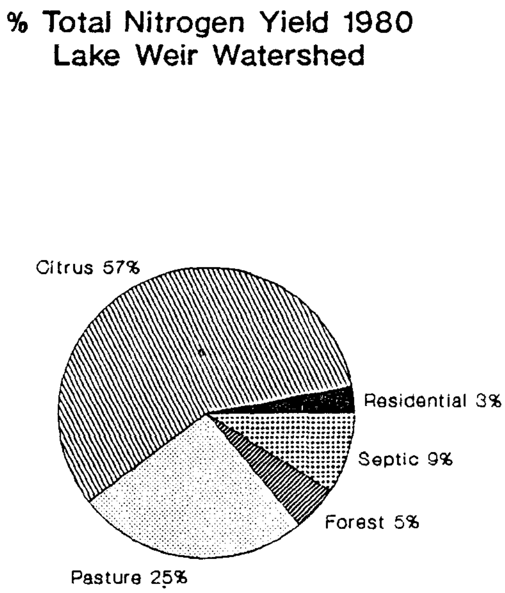
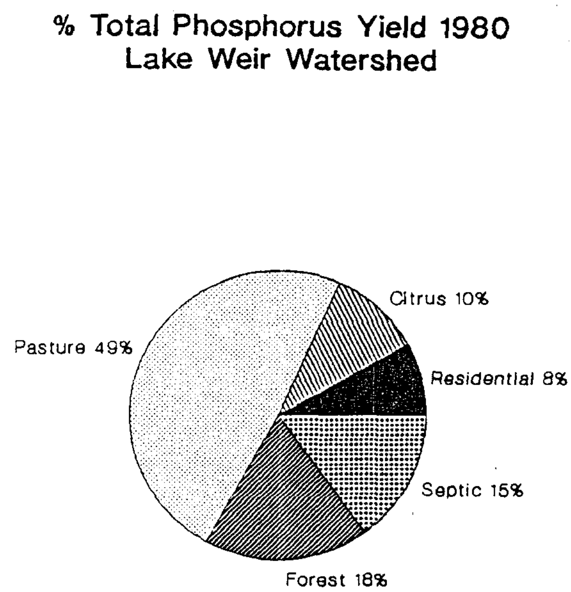
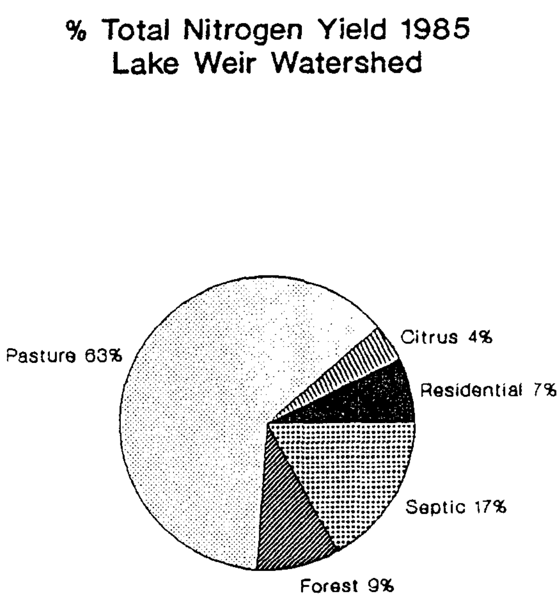






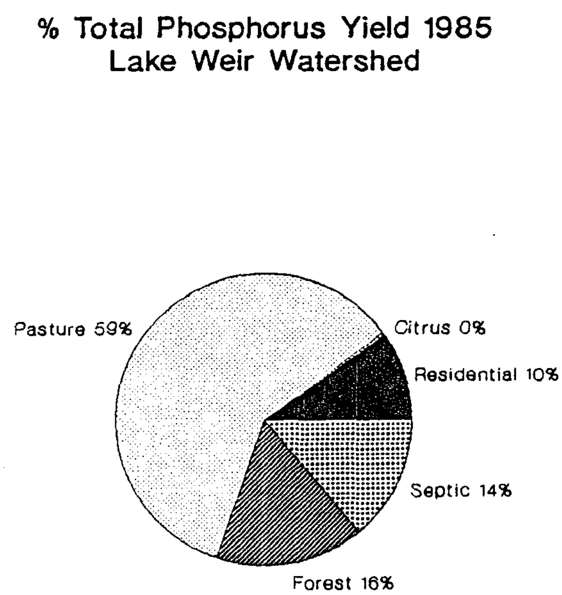


Figure 2-13. Continued

CHAPTER THREE:

SECCHI DISK SURVEY

3.1 INTRODUCTION

Shapiro et al. (1975) were the first to suggest initiation of a citizen based program for monitoring historical changes in water quality. Volunteers were sought to record Secchi disk transparency throughout the summer and to report the data to a central office for analysis. In most cases only a single station was monitored per lake. Not only could individual lakes be evaluated relative to the entire lake database, but historical water quality trends could be established for each lake after data collection for multiple years. Public support for the Minnesota program was encouraging with 250 lakes participating after the first two years.

Because the Minnesota program was based largely on a single station per lake, it was assumed that clarity at that station was broadly representative of the lake as a whole and that interyear variability in mean clarity would be indicative of historical trends in water quality. While providing a valuable database, such a study does not address the degree of intralake variability in water clarity and whether such differences can be used to assess the extent of point and nonpoint sources of pollution.

The current investigation presents the results of a citizen based Secchi disk program for Lake Weir. The data from this multi-station close interval study have been used to assess point and nonpoint sources of nutrients and turbidity. Particular emphasis has been placed on the role played by septic effluent and power boats.

Nutrient loading at Lake Weir is largely from non-point sources. It is difficult to separate out the impact of each individual watershed use practice, especially since nutrients can enter the lake through ground-water seepage. Studies of nutrient contributions from non-point sources are expensive and time consuming, often involving construction of detailed nutrient budgets for a lake. Secchi disk surveys may provide a fast, cost effective alternative for ranking the relative importance of non-point sources.

Secchi disks are used to measure water clarity, and readings may be related to water quality (APHA 1971). Three factors influence water clarity: dissolved color, inorganic turbidity, and algal biomass. Water color and turbidity were not considered important variables in Lake Weir. Dissolved water color was low and uniform throughout the lake, and all of the stations were in areas deep enough to minimize resuspension of bottom sediments. Therefore, water clarity was assumed to be closely related to algal biomass and hence to nutrient concentrations in Lake Weir. Our Secchi survey at Lake Weir also accounted for additional variables (weather, sea state, time of day) that may alter the intensity of light impinging on the lake surface and thus alter Secchi depth.

Based on the assumption that algal biomass in Lake Weir reflects nutrient loading, it was felt that Secchi disk depths at different sections of the lake basin could be compared to assess the intensity of nutrient contributions from various land uses practices. Agricultural activities such as citrus groves and grazing pastures have dominated Lake Weir's watershed for almost a century. Residential development around the lake has increased four-fold over the past thirty years, yet all houses in the watershed remain on septic tanks. There is no central sewage treatment facility. Lake Weir is considered to be phosphorus-limited (Messer 1975), and there has been a shift toward higher P:N loading with recent urbanization.

3.2 DATABASE AND ANALYSES

Secchi disk depths were monitored weekly for an entire year at 32 stations throughout the Lake Weir system (Figure 3-1). Over 1400 Secchi disk readings were recorded from 20 July 1985 to 5 July 1986. This extensive effort was coordinated by Mr. Del Wood. Several teams of residents shared the responsibility of monitoring the stations, which were marked by buoys. The stations were set up in a radial pattern to identify "hot spots" of water quality degradation and to isolate their non-point sources.

Residents participating in the study were given a list of specific instructions to insure that all readings were taken in a uniform manner (Figure 3-2). Readings were to be made each Saturday, close to noon, while standing on the sunny side of the boat. Sunglasses were prohibited.

On at least ten occasions, Mr. Wood personally replicated readings made by the investigators and found almost all of their observations to be within two inches of his own. Although Mr. Wood did not record these observations, he acknowledged that there was no difference among the groups of observers. Therefore, error was assumed to be randomly distributed across the stations.

Figure 3-1. Map of Lake Weir showing the radial pattern of Secchi disk stations by numbers. Station #28 was not included in the data analyses.

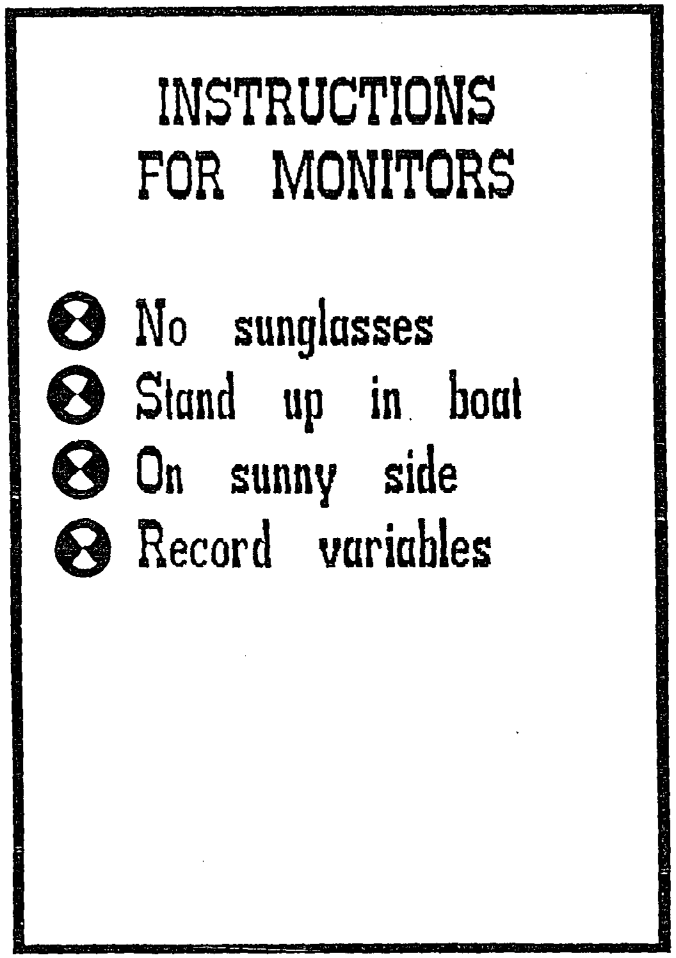


Figure 3-2. Instructions given to Secchi disk monitoring teams.

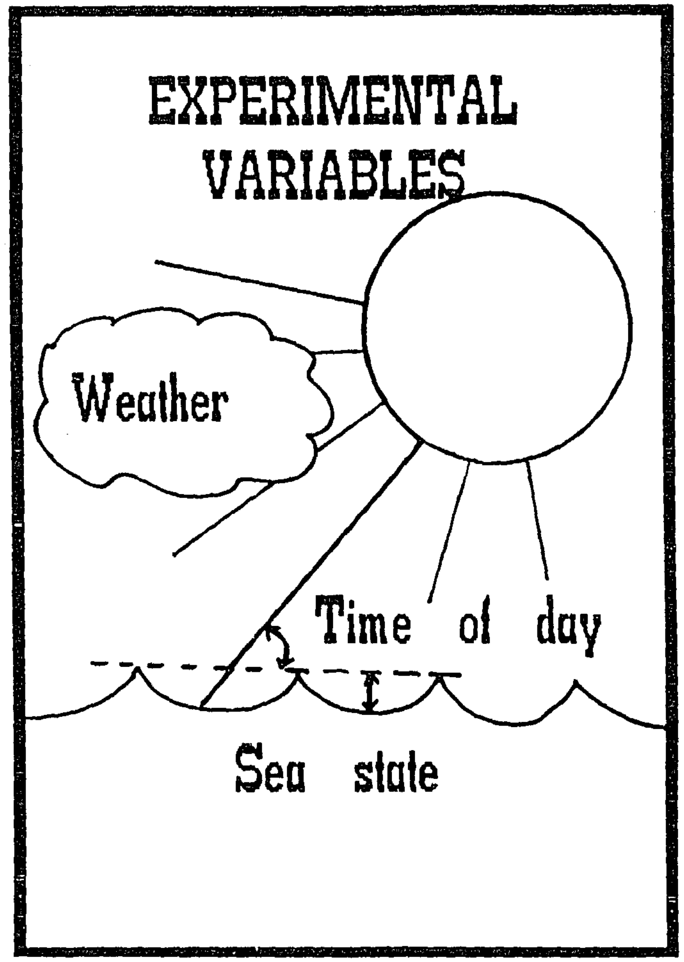


Figure 3-3. Three variables influencing the penetration of light through the water column (and hence, Secchi disk depth).

Dr Daniel Canfield recently assessed the extent to which observer bias influences Secchi disc readings being reported by individual citizens as part of the Florida Lake Watch Program. On over two hundred separate occasions, Canfield compared Secchi readings collected concurrently with those of a professional biologist. The results of this study will soon be submitted for publication in the refereed literature. The significantly strong relationship between citizen and professional biologist readings (r^2=0.976) clearly demonstrates that observer bias is likely to play an insignificant role in Secchi values being reported as part of the Florida Lake Watch Program. Based on this investigation, we feel that citizen generated Secchi values collected for Lake Weir provide a true estimate of water clarity in the lake.

For each observation, investigators recorded three experimental variables which may have influenced the degree of light penetration into the water column: weather condition, sea state, and time of day (Figure 3-3). Weather was recorded as a code of 1 to 4, with 1 representing a bright sunny day and 4 being heavily overcast. Sea state was a measure of wave amplitude, recorded in inches. Time of day was related to the angle of the sunlight's incidence on the lake surface.

The objective of this study was to identify statistically groups of stations having significantly lower Secchi disk depths. In order to accomplish this, experimental variables had to be factored out, then groups of stations having significantly lower water clarity could be related to the type and degree of watershed development immediately onshore.

Four readings which were made after 6:00 p.m. on a single sampling day were omitted, as they were anomalously low. Also, station #28 was eliminated from the study because over half of the readings at this shallow site were on the lake bottom. All other stations were in at least three meters of water (Figure 3-4). In all, 1349 observations were included in the study.

Data were entered into Lotus 123 and transferred to SAS for statistical analyses. All data analyses utilized SAS (SAS 1985). Ward's hierarchical (minimum variance) cluster analysis was applied as follows: Station groupings were identified for Lake Weir using station monthly means for 10 months. The Secchi data were first analyzed for homogeneity of variance using the Cochran's C test (Winer et al. 1991). Of the variables tested (sea state, weather, time of day, lake division), all but time were not considered homogeneous. Winer et al. (1991) do note, however, that in data sets that have equal sample sizes, heterogeneity of variance is not an important problem for statistical

Figure 3-4. Map of Lake Weir Secchi disk stations and 3 meter bathymetric contour. Only stations 28 and 25 were in less than 3 m of water.

analyses. With this in mind, we then utilized GLM and Tukey's standardized range test for determining statistical relationships within the Secchi data base. All tests were deemed to be significant at $p < 0.05$.

3.3 RESULTS AND DISCUSSION

Analyses of variance were performed to determine whether weather, sea state, or time of day significantly influenced Secchi disk transparency. Weather code showed a negative correlation with Secchi depth that proved to be highly significant at all levels except between codes 1 and 4, 2 and 4, and 3 and 4 for both the entire Lake Weir system and Lake Weir proper (Table 3-1). Secchi depths were affected significantly by the degree of cloud cover. Rain did not significantly affect Secchi depth, but this may have been due to the small sample size. Both sea state and time of day also significantly affected Secchi depths (Table 3-2 and 3-3).

Regression analyses of Secchi disk depth versus the independent variables were run (Table 3-4). Variation due to regression of Secchi depths with time of day and with sea state was not significant at alpha of five percent. However, regression of Secchi depths by weather code showed a high degree of variation attributable to regression, with an alpha of less than 0.0001. Because weather codes were evenly distributed across all stations, remaining analyses were performed on the raw data.

The annual means were calculated for each station (Figure 3-5). Sixteen stations had a mean Secchi depth less than the overall lakewide average of 1.928 meters. Using Ward's hierarchical cluster analysis, these stations were clustered near the areas of greatest shoreline population (Figure 3-6). All seven stations in the highly populated Little Lake Weir and Sunset Harbor basins were below the lakewide mean. Eight of the nine below-average stations in Lake Weir proper were clustered along the northeastern shore of the lake, adjacent to the town of Oklawaha. The single exception, station #15, was barely below the lakewide mean and was located immediately offshore of the highest concentration of citrus near the lake.

Next, mean Secchi depths of the three lake basins were compared throughout the year (Figure 3-7). Sunset Harbor had a markedly lower Secchi depth throughout the year than Lake Weir proper. Little Lake Weir displayed a high degree of seasonality, unlike the other two basins. Analysis of the data demonstrated that although Lake Weir proper did not

Table 3-1. GLM and Tukey's Standardized Range Test between Secchi depths and weather codes in Lake Weir proper and the entire Lake Weir system.

Weather Code 1 = clear, sunny
Weather Code 2 = partly overcast
Weather Code 3 = overcast; no sun
Weather Code 4 = rain

Lake Weir System

Secchi Depth vs Weather Code for Lake Weir System

Group	#observ	Mean	std dev
Weather Code 1	548	1.946	0.2092
Weather Code 2	349	1.909	0.1819
Weather Code 3	104	1.822	0.1481
Weather Code 4	1	1.830	

GLM: Secchi vs Weather

F value	p > F	
23.66	0.0001	***

Tukey's Standardized Range Test for Weather

a = 0.05; Confidence = 0.95; DF = 1345; MSE = 0.0574
Critical Range = 3.630

1 vs 2 **
1 vs 3 **
1 vs 4 n.s.
2 vs 3 **
2 vs 4 n.s.
3 vs 4 n.s.

Table 3-1 (Continued)

Lake Weir Proper

Secchi Depth vs Weather Code for Lake Weir Proper

Group	#observ	Mean	std dev
Weather Code 1	751	1.971	0.2591
Weather Code 2	420	1.899	0.2188
Weather Code 3	173	1.818	0.1999
Weather Code 4	5	1.708	0.1291

GLM: Secchi vs Weather

F value	p > F	
29.80	0.0001	***

Tukey's Standardized Range Test for Weather

a = 0.05; Confidence = 0.95; DF = 1078; MSE = 0.035985
Critical Range = 3.639

1 vs 2 **
1 vs 3 **
1 vs 4 n.s.
2 vs 3 **
2 vs 4 n.s.
3 vs 4 n.s.

** = p<.05
*** = p<.01

Table 3-2. GLM and Tukey's Standardized Range Test between Secchi depths and sea state in Lake Weir proper and the entire Lake Weir system.

Lake Weir System

Secchi Depth vs Sea State for Lake Weir System

Group	#observ	Mean	std dev
A. 0-1 inches	566	1.969	0.2705
B. 2-5 inches	363	1.861	0.2482
C. 6-11 inches	200	1.917	0.2021
D. 12-17 inches	165	1.945	0.1884
E. >18 inches	55	1.930	0.1486

GLM: Secchi vs Sea State

F value	p > F	
4.51	0.0001	***

Tukey's Standardized Range Test for Sea State

a = 0.05; Confidence = 0.95; DF = 1329; MSE = 0.0574
Critical Range = 5.022

A vs B	**	B vs D	**
A vs C	**	B vs E	n.s.
A vs D	n.s.	C vs D	**
A vs E	n.s.	C vs E	**
B vs C	n.s.	D vs E	n.s.

Table 3-2 (Continued)

Lake Weir Proper

Secchi Depth vs Sea State for Lake Weir Proper

Group	#observ	Mean	std dev
A. 0-1 inches	428	1.976	0.2148
B. 2-5 inches	184	1.903	0.2206
C. 6-11 inches	178	1.922	0.1744
D. 12-17 inches	157	1.958	0.1816
E. >18 inches	55	1.930	0.1486

GLM: Secchi vs Sea State

F value	p > F	
6.60	0.0001	***

Tukey's Standardized Range Test for Sea State

a = 0.05; Confidence = 0.95; DF = 1077; MSE = 0.0452
Critical Range = 3.864

A vs B	n.s.	B vs D	**
A vs C	**	B vs E	**
A vs D	n.s.	C vs D	n.s.
A vs E	n.s.	C vs E	n.s.
B vs C	**	D vs E	n.s.

** = p<.05
*** = p<.0001

Table 3-3. GLM and Tukey's Standardized Range Test between Secchi depths and time-of-day intervals in Lake Weir proper and the entire Lake Weir system.

Lake Weir System

Secchi Depth vs Time of Day for Lake Weir System

Group	#observ	Mean	std dev
A. 845-959	136	1.870	0.2831
B. 1000-1059	398	1.950	0.2945
C. 1100-1159	289	1.950	0.2140
D. 1200-1259	244	1.950	0.1896
E. 1300-1359	152	1.900	0.2121
F. 1400-1459	106	1.860	0.2065
G. 1600-1659	24	1.857	0.2373

GLM: Secchi vs Time of Day

F value	p > F	
4.65	0.0001	***

Tukey's Standardized Range Test for Time of Day

a = 0.05; Confidence = 0.95; DF = 1342; MSE = 0.059
Critical Range = 4.176

A vs B **	C vs D n.s.
A vs C **	C vs E n.s.
A vs D **	C vs F **
A vs E n.s.	C vs G n.s.
A vs F n.s.	D vs E n.s.
A vs G n.s.	D vs F **
B vs C n.s.	D vs G **
B vs D n.s.	E vs F n.s.
B vs E n.s.	E vs G n.s.
B vs F **	F vs G n.s.
B vs G n.s.	

Table 3-3 (Continued)

Lake Weir Proper

Secchi Depth vs Time of Day for Lake Weir Proper

Group	#observ	Mean	std dev
A. 845-959	73	2.009	0.1552
B. 1000-1059	161	1.992	0.2115
C. 1100-1159	250	1.963	0.2000
D. 1200-1259	243	1.952	0.1892
E. 1300-1359	145	1.914	0.2058
F. 1400-1459	106	1.860	0.2065
G. 1600-1659	24	1.857	0.2373

GLM: Secchi vs Time of Day

F value	p > F	
7.67	0.0001	***

Tukey's Standardized Range Test for Time of Day

a = 0.05; Confidence = 0.95; DF = 995; MSE = 0.0395
Critical Range = 4.178

A vs B n.s.	C vs D n.s.
A vs C n.s.	C vs E n.s.
A vs D n.s.	C vs F **
A vs E **	C vs G n.s.
A vs F **	D vs E n.s.
A vs G **	D vs F **
B vs C n.s.	D vs G n.s.
B vs D n.s.	E vs F n.s.
B vs E **	E vs G n.s.
B vs F **	F vs G n.s.
B vs G **	

** = p<.05
*** = p<.01

Table 3-4.. Multiple regressions of Secchi depth by independent variables Weather Code, Sea State, and Time of Day for Lake Weir.

(m)
Regression of Secchi depth by Weather Code

Intercept	2.0478	Regr Coeff	-0.0760
Std Err Y Estim	0.2396	Std Er Rgr Coef	0.0090
R-Squared	0.0500	Corr X vs. Y	-0.2236

ANOVA for regression

Source of Error	DF	SS	MS	F	Alpha
Due to R.	1	4.0702	4.0702	70.8909	0.0001 **
Devn fr R.	1347	77.3380	0.0574		
Total	1348	81.4082			

(m)
Regression of Secchi depth by Sea State

Intercept	1.9329	Regr Coeff	-0.0012
Std Err Y Estim	0.2458	Std Er Rgr Coef	-0.0012
R-Squared	0.0007	Corr X vs. Y	-0.0255

ANOVA for regression

Source of Error	DF	SS	MS	F	Alpha
Due to R.	1	0.0530	0.0530	0.8772	0.3491
Devn fr R.	1347	81.3550	0.0604		
Total	1348	81.4080			

(m)
Regression of Secchi depth by Time of Day

Intercept	2.0102	Regr Coeff	-0.0001
Std Err Y Estim	0.2456	Std Er Rgr Coef	0.0000
R-Squared	0.0023	Corr X vs. Y	-0.0477

ANOVA for regression

Source of Error	DF	SS	MS	F	Alpha
Due to R.	1	0.1856	0.1856	3.0777	0.0796
Devn fr R.	1347	81.2220	0.0603		
Total	1348	81.4076			

** significant at alpha = .01

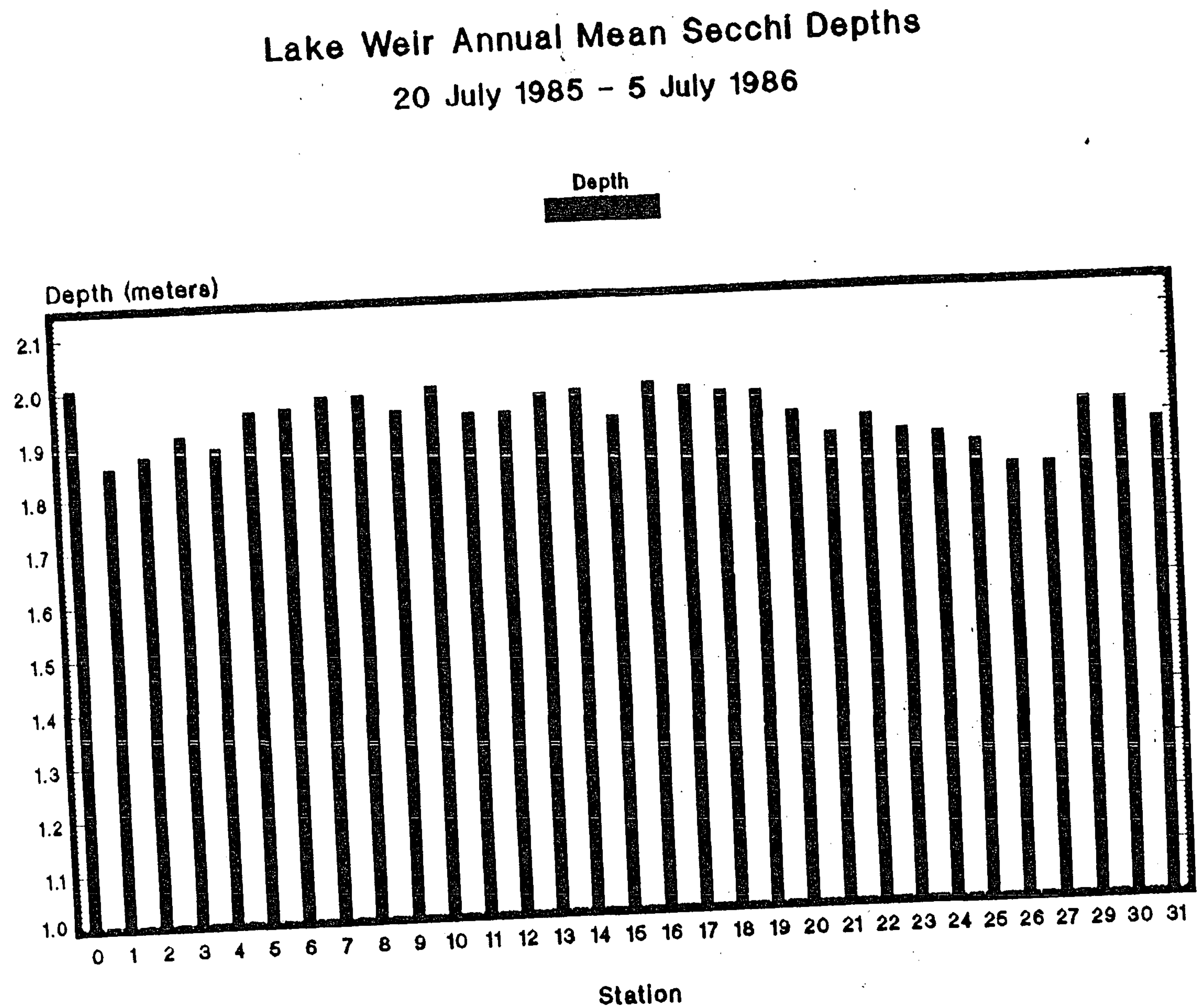


Figure 3-5. Annual mean Secchi disk depths by station. Each bar represents up to 50 observations. Lakewide mean Secchi depth was 1.93 m.

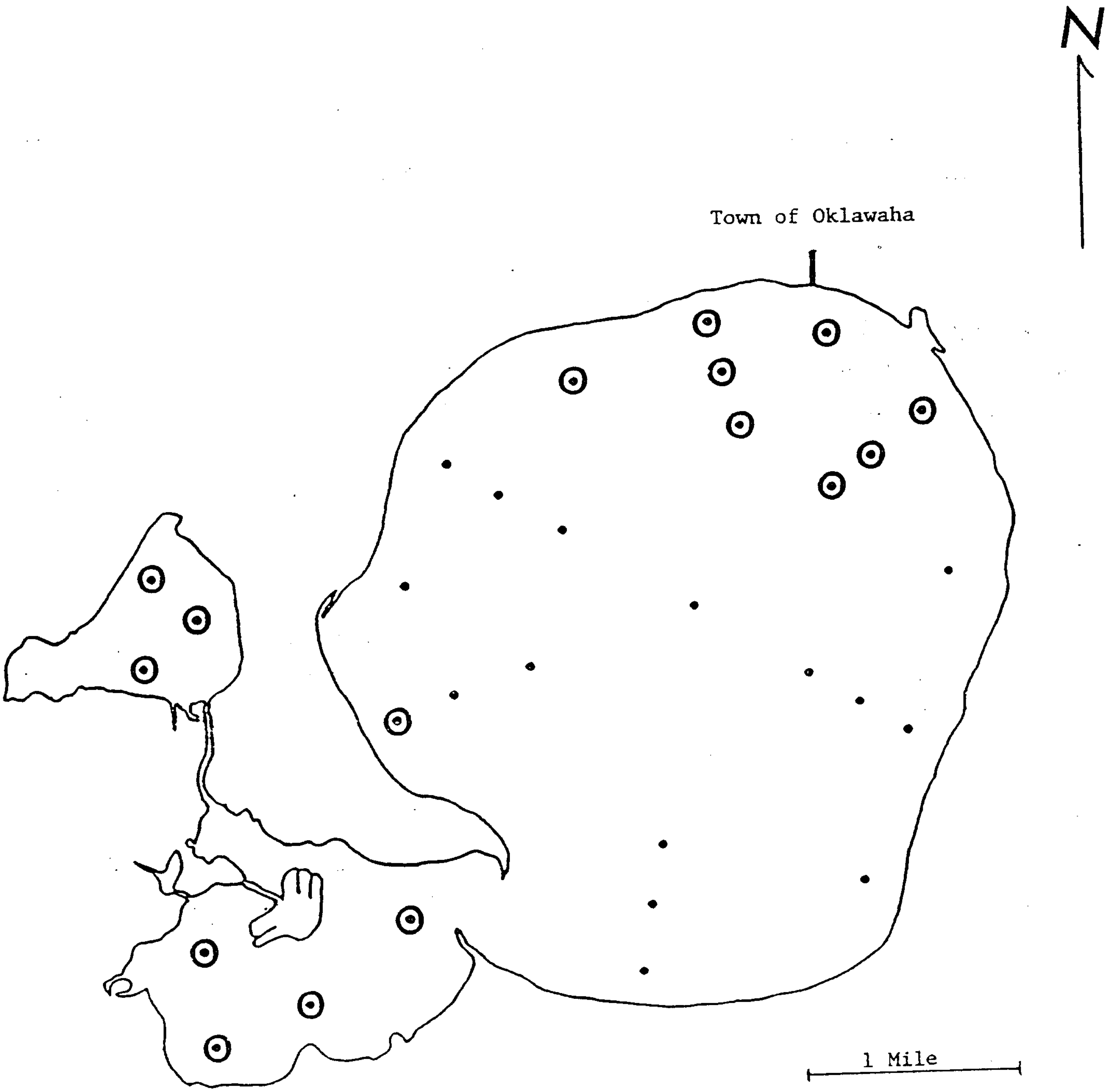


Figure 3-6. Map of Lake Weir Secchi disk stations. Circled stations are those with a mean annual Secchi depth less than the lakewide mean of 1.93 m.

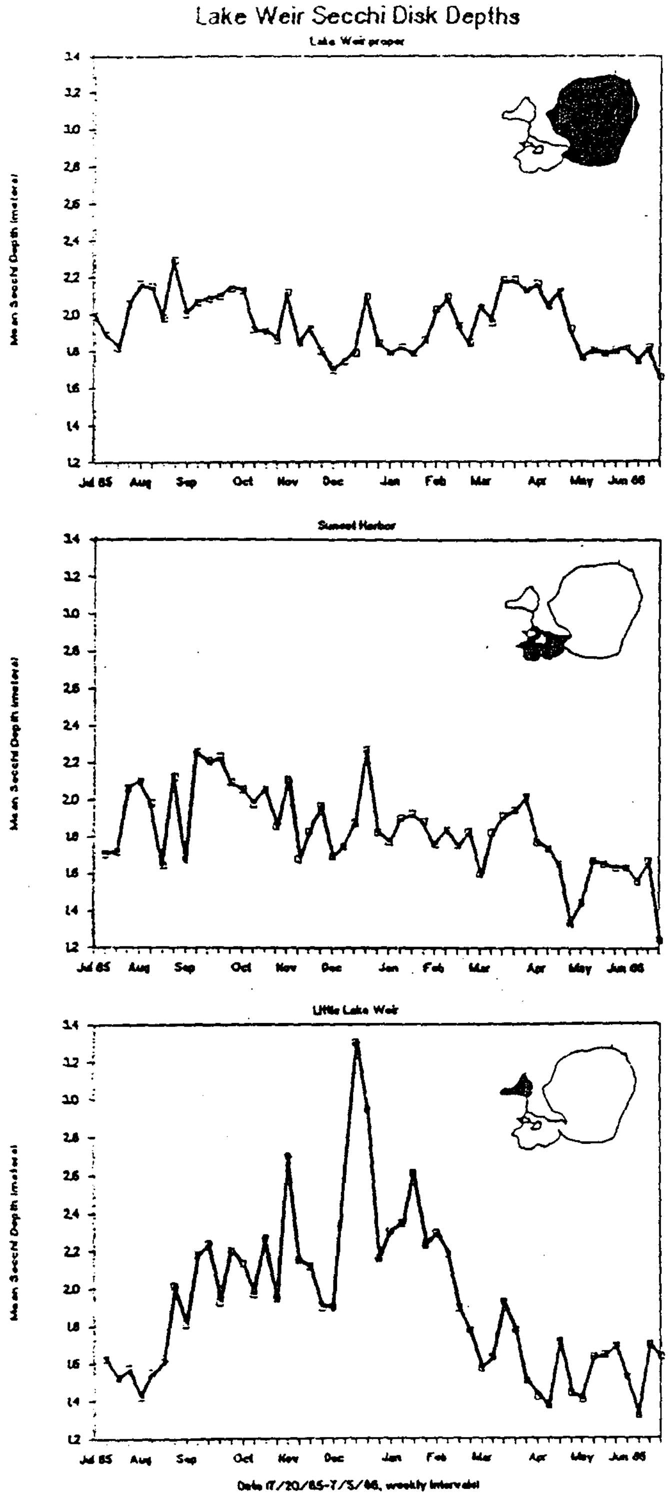


Figure 3-7. Mean Secchi disk depths for each of Lake Weir's three basins at weekly intervals throughout the year.

have significantly different Secchi values from Little Lake Weir, Sunset Harbor displayed significantly lower values than either of these two lake divisions. (Table 3-5).

During summer, Little Lake Weir exhibited the lowest water clarity of the entire system. This may have been due to the higher watershed to lake surface ratio and the shallower water depth. Thus, nutrients from a proportionately larger watershed would be delivered to a smaller volume of water, yielding higher nutrient concentrations and hence greater algal biomass. During winter, Little Lake Weir showed the greatest water clarity, with Secchi depths greater than three meters on 28 December 1985. Several lake residents have noted the presence of a spring in Little Lake Weir, which could account for a higher degree of groundwater flushing during the winter, and hence greater water clarity.

Owing to Lake Weir's nearly circular shape, small littoral area, and uniform station depth around the lake, there is no reason to believe that morphometric factors would exert a bias on Secchi depth from one side of the lake to the other. To determine the influence of proximity to shoreline, stations in Lake Weir were grouped into three concentric rings (Figure 3-8). Neither GLM nor Tukey's standardized range tests revealed any significant differences among these rings (Table 3-6). Therefore, direct comparisons could be made between stations regardless of distance from shore.

Cluster analysis for Secchi stations at Lake Weir was approached in two ways. First, a three cluster model was developed based on all 32 stations. Because of obvious interbasin trophic state differences, the three clusters were defined as Little Lake Weir, Sunset Harbor, and Lake Weir. In an effort to obtain greater resolution for Lake Weir proper, an additional three cluster model was developed based solely on the 23 stations of this lake (Figure 3-9).

Cluster I consisted of the 11 stations in the southern half of the lake having the highest mean transparency (1.97 m). The shoreline of this part of the lake is either single family residences with large lots or is undeveloped. Stations of second worst mean Secchi transparency (1.95 m) are found in Cluster II. With one exception, these are located in the northwest corner of the lake just west of the town of Oklawaha. The lone station excluded from this group is located along the western lake shore immediately offshore from a pump station for citrus irrigation. Those stations having the poorest mean Secchi (1.90 m) are along the north shore of Lake Weir either immediately in front of the town of Oklawaha or just to the east.

The possible linkage between water clarity and

Table 3-5. GLM and Tukey's Standardized Range Test between Secchi depths for Lake Weir proper, Sunset Harbor, and Little Lake Weir.

Secchi Depth vs Lake Division

Group	# Observations	Mean	Std Dev
Overall	1349	1.928	0.246
Lake Weir Proper	1002	1.948	0.204
Sunset Harbor	200	1.838	0.242
Little Lake Weir	147	1.913	0.424

GLM: Secchi vs Lake Division

Source of Error	DF	SS	MS	F	P>F
Between	2	2.0267	2.0133	17.18	0.0001 ***
Within	1346	79.3808	0.0589		
Total	1348	81.4076			

Tukey's Standardized Range Test for Lake Division

a = 0.05; Confidence = 0.95; DF = 1346; MSE = 0.0589
Critical Range = 3.318

Weir vs Little Lake Weir	n.s.
Weir vs Sunset Harbor	**
Sunset Harbor vs Little Lake Weir	**

** = p<.05
*** = p<.01

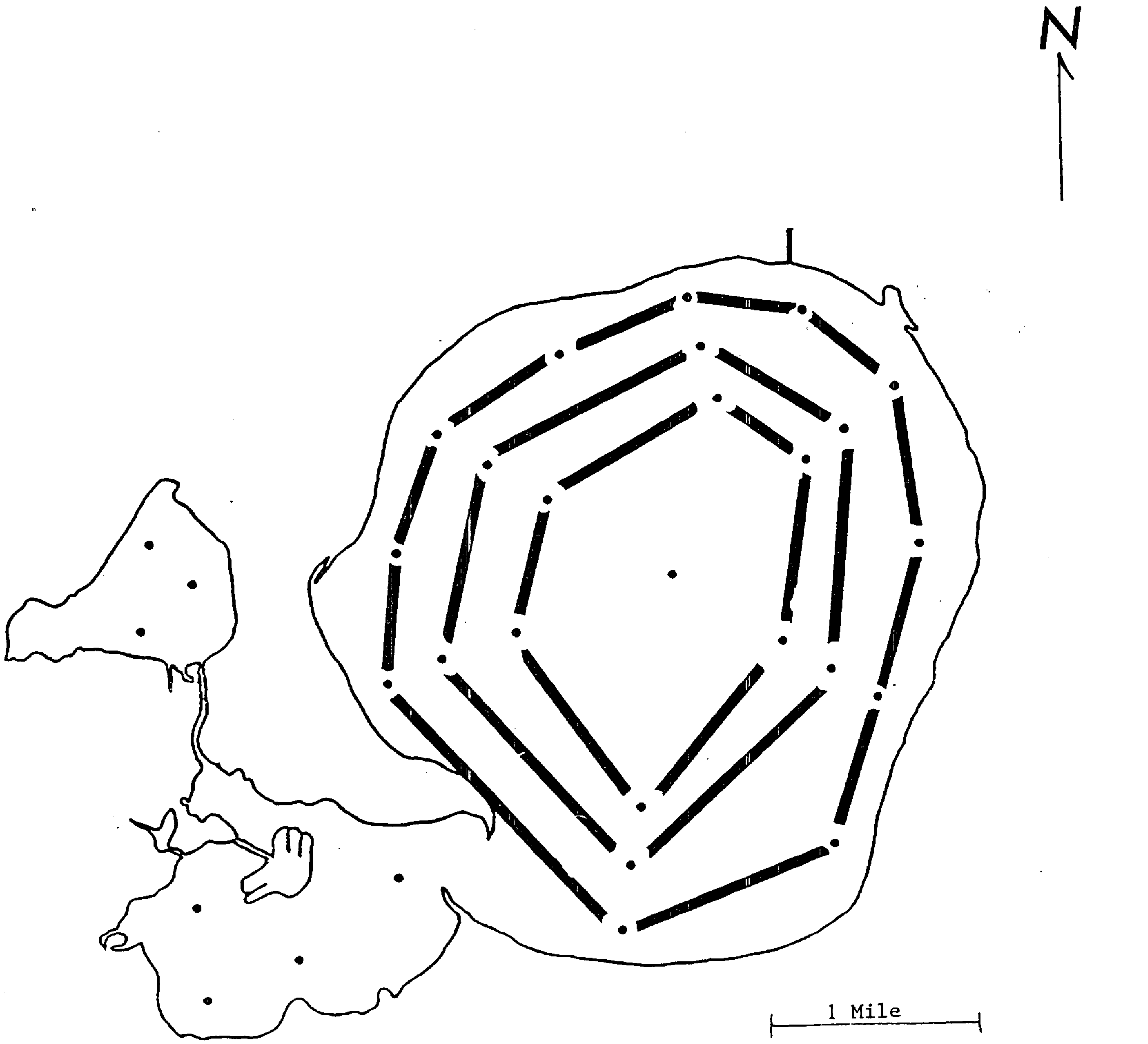


Figure 3-8. Map of Lake Weir Secchi disk stations grouped in three concentric rings to test the effect of proximity to shoreline.

Table 3-6. GLM and Tukey's Standardized Range Test between Secchi depths for concentric rings of stations at different distances from shore.

Secchi Depth vs Shoreline Proximity for Lake Weir Proper

Group	# Observations	Mean	Std Dev
OR = Outer Ring	457	1.937	0.2072
MR = Middle Ring	249	1.952	0.2011
IR = Inner Ring	248	1.951	0.2000
C = Lake Center	48	2.009	0.1779

GLM: Secchi vs Concentric Rings

F Value	P>F
1.89	0.1296

Tukey's Standardized Range Test for Concentric Rings

a = 0.05; Confidence = 0.95; DF = 998; MSE = 0.0410
Critical Range = 3.639

C vs MR	n.s.	IR vs MR	n.s.
C vs OR	n.s.	IR vs OR	n.s.
C vs IR	n.s.	MR vs OR	n.s.

** = p<.05
*** = p<.01

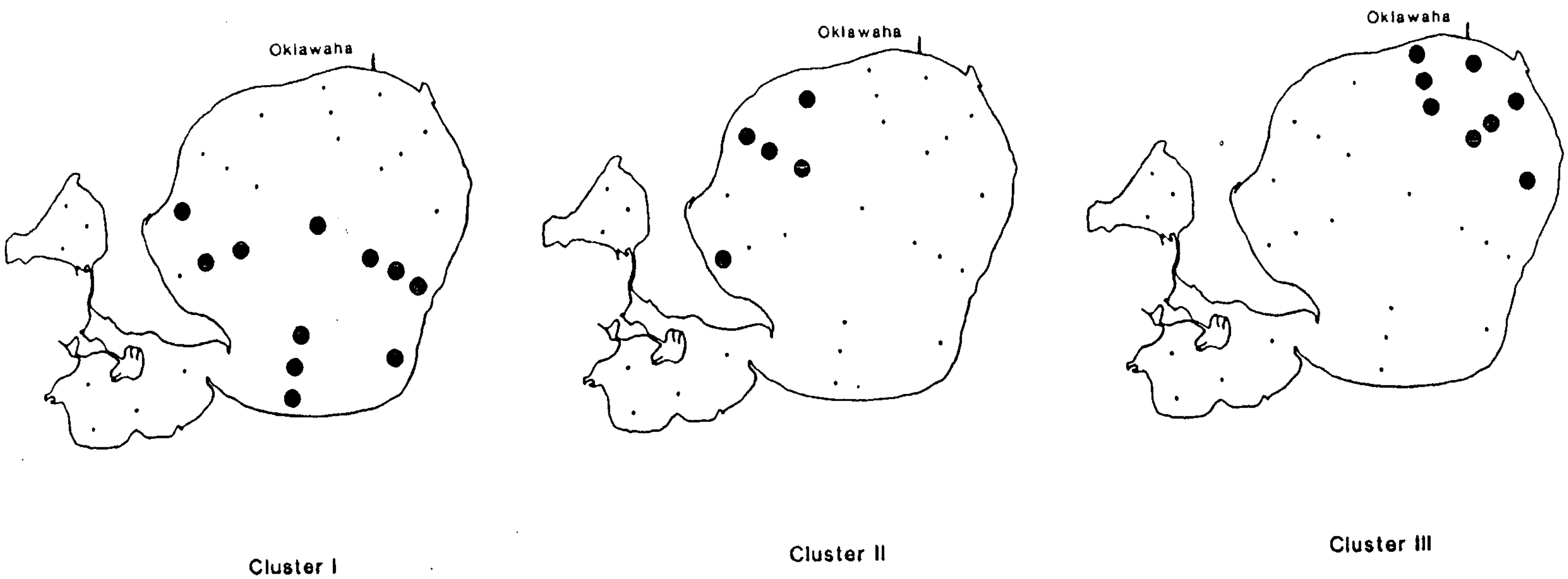


Figure 3-9. Results of a three cluster model of Secchi data from Lake Weir proper.

residental development was quantified by relating Secchi clarity for the 11 stations closest shore to the number of houses in an onshore area defined as 0.6 km along the shore on either side of a perpendicular from the Secchi station to the shore by 0.42 km inland from the shore. Total area for quantifying residences relative to a Secchi station was 0.5 km^2 (Figure 3-10). The number of houses was determined from the 1985 tax assessment map. Two stations were removed from the database: the first immediately in front of a citrus irrigation pumping station and grove and the second immediately offshore of the entry point for storm water drainage. The uniqueness of the former station was demonstrated in the cluster analysis described earlier. The strong inverse correlation (r^2=0.88) between house density and offshore water clarity suggests that septic tanks do influence water quality significantly and given the fact that the entire watershed including the town of Oklawaha is on septic tanks, likely plays a major role in defining the three clusters based on individual Secchi stations. Clarity offshore from the town of Oklawaha is also likely influenced by storm water discharge.

3.4 SUMMARY AND CONCLUSIONS

Secchi disk depths measure water clarity, which is a composite of dissolved water color, inorganic turbidity and algal biomass. The latter reflects nutrient loading into the lake system. All of the stations in this survey were in areas deep enough to minimize turbidity due to resuspension of bottom sediments by boating or wave action. Therefore, Secchi disk depths in this survey were assumed to indicate relative amounts of nutrient loadings to Lake Weir.

Sunset Harbor, Little Lake Weir, and the Oklawaha area of Lake Weir exhibited markedly reduced water clarity. These areas coincided with areas of higher population along the shoreline. Different baseline conditions existed between the lake divisions. For Lake Weir proper, stations near Oklawaha had markedly lower water clarity.

Little Lake Weir and Sunset Harbor appeared to behave as isolated systems. Both had much higher shoreline to surface area ratios and were shallower than Lake Weir proper. Therefore, nutrients would be more concentrated than in the big lake. Little Lake Weir exhibited much greater seasonal changes in water clarity than Lake Weir. Little Lake Weir had many of the lake system's most turbid readings during the spring and summer; yet had by far the highest water clarity during the winter. There may have been increased flushing by groundwater during the winter

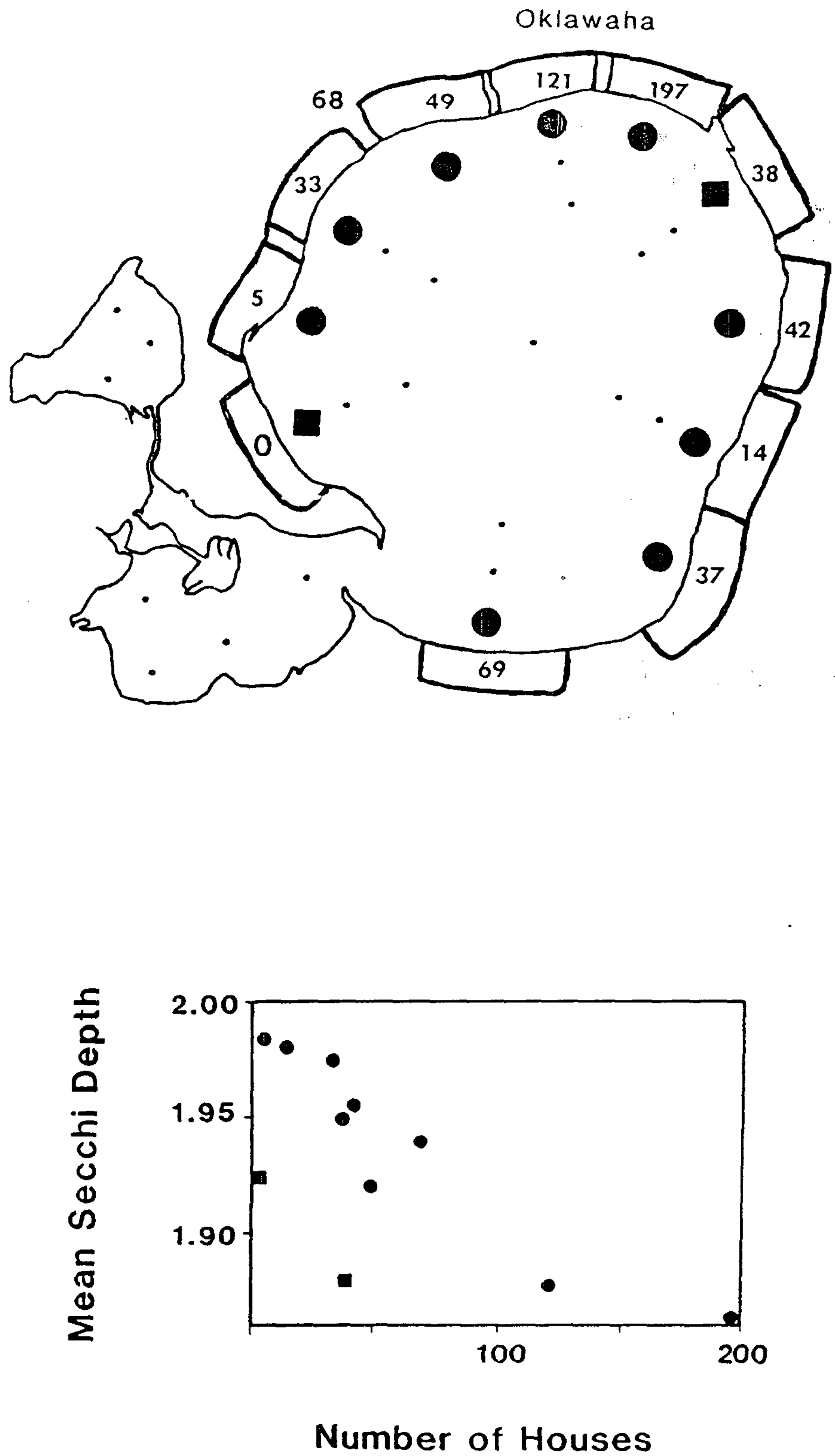


Figure 3-10. Relationship between shoreline population and mean Secchi depth immediately offshore. Squares designate to shoreline where Secchi transparency does not agree well with on shore population: the northeast corner of Lake Weir, where a major storm drain enters the lake and the southwest corner immediately in front of an orange grove.

months.

Reduction in water clarity was closely correlated to shoreline population, with an R-squared value of 0.88 after excluding stations #2 and #15, which were subject to other sources of nutrient loading. Septic tank input and possibly storm water discharge seems to have been responsible for this effect. Weirsdale appeared to have no significant impact on water clarity. Distance of development from the lake may have been a major factor governing the nutrient impact.

Citizen-based Secchi disk programs such as this one can provide an effective, low cost approach to evaluating impacts of land use practices. Programs such as this are easy to organize, and are a good way to involve the public in lake management.

CHAPTER FOUR:
PHYSICAL-CHEMICAL PARAMETERS AND HISTORICAL DATABASE

4.1 METHODS

4.1.A FIELD SAMPLING METHODS

Physical and chemical parameters were measured monthly at 7 stations (Figure 4-1). Five stations were established in Lake Weir, and a midlake station was used in both Sunset Harbor and Little Lake Weir. Dissolved oxygen and water temperature were measured at 1 m intervals at each station. Secchi disk transparency and bottom depth were recorded at each station.

Water chemistry samples were taken from 0.5 m depth in acid-washed nalgene bottles, acid-preserved (Total Phosphorus, Total Kjeldahl Nitrogen) or not (Orthophosphate, alkalinity, pH, conductivity) as required for the various analyses and put on ice. Upon returning to the laboratory, chemistry samples were stored at 4 C until analyzed.

4.1.B LABORATORY ANALYSES

Water samples were analyzed for total phosphorus (EPA method 365.2), ortho-phosphate (EPA method 362.2), total Kjeldahl nitrogen (EPA 351.2), Chlorophyll a concentration (A.P.H.A. method 1002G), alkalinity (EPA method 310.1), and pH (A.P.H.A. method 423).

Standards were run before and after each analysis (where applicable). Samples were run in duplicate. Reference standards obtained from EPA were also run with samples for TKN, and TP analyses. Values determined for these reference standards all fell within the 95% confidence intervals established by EPA. Chemistry data were analyzed for significant differences between stations and months using GLM and Duncan's multiple range test.

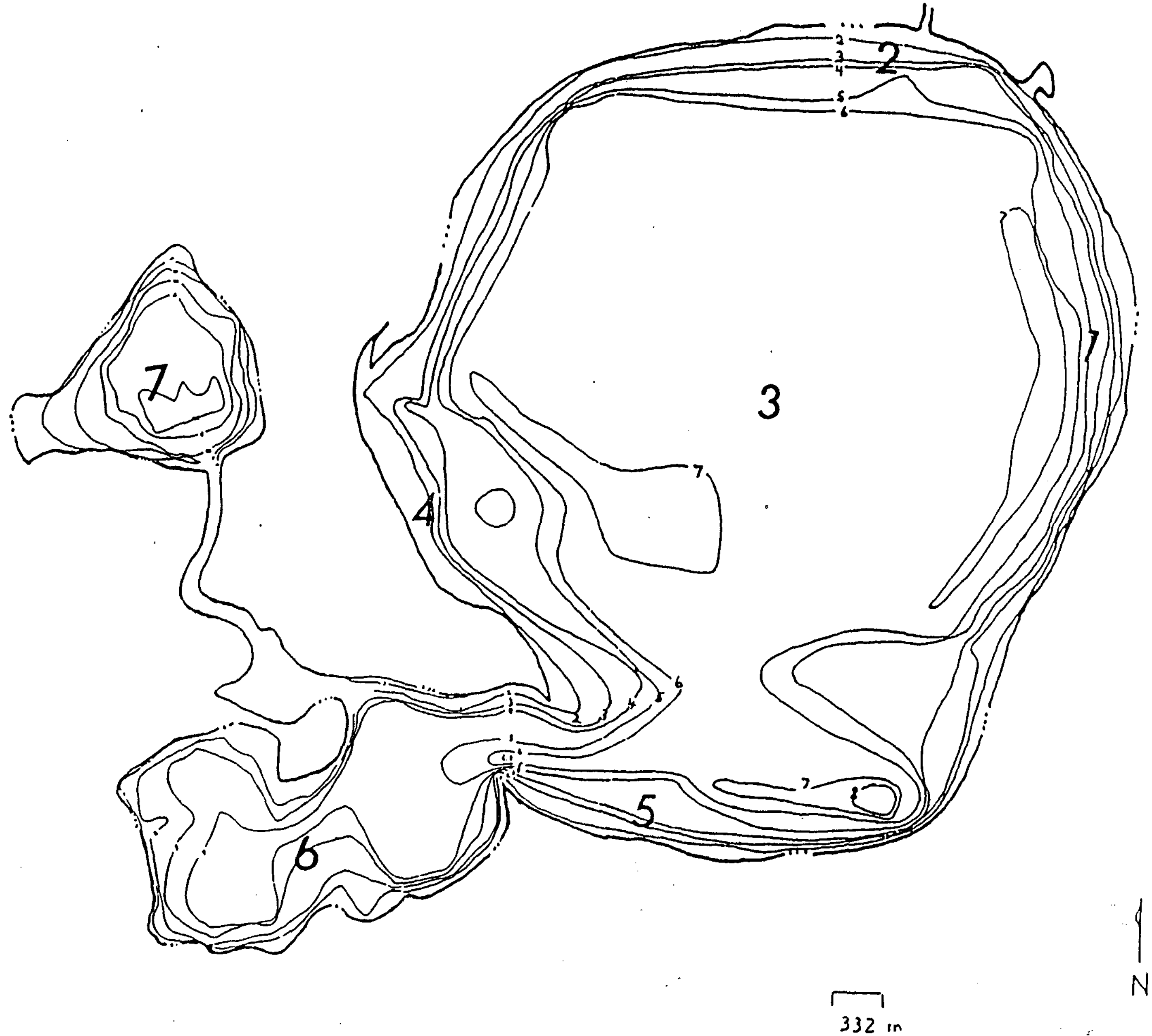


Figure 4-1. Bathymetric map of Lake Weir developed from fathometric tracings, 1988. Seven stations for monthly limnological monitoring are marked.

4.2 PHYSICAL PARAMETERS 1987-1989

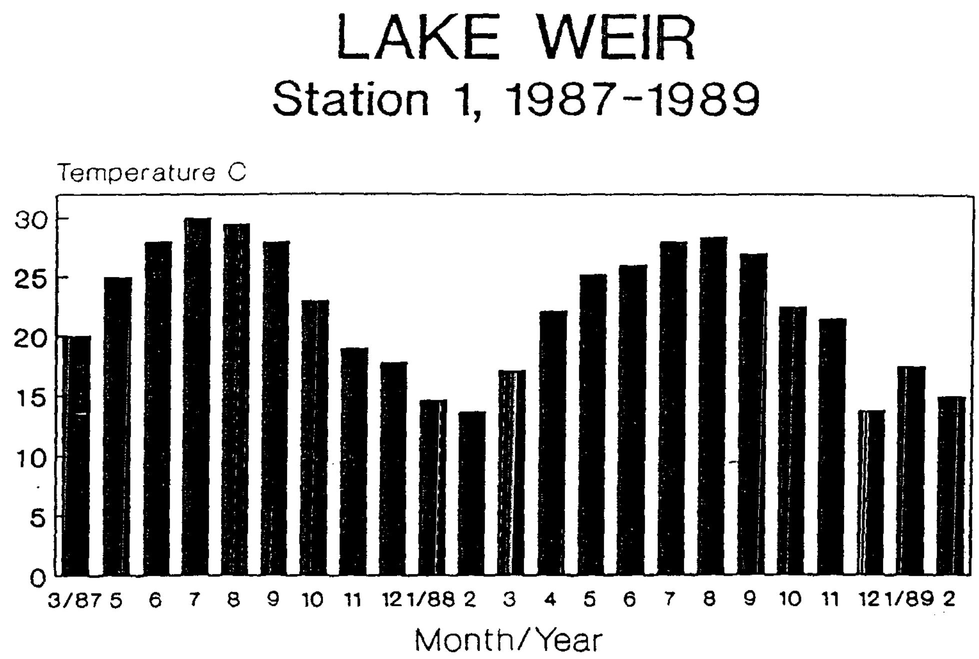
4.2.A TEMPERATURE

The seasonality of temperature for each of the stations of the Lake Weir system was comparable was comparable during 1987-1989 (Figure 4-2). The range and amplitude of temperature each year was comparable, thus interyear differences cannot be ascribed to temperature related phenomena. No long term stratification was noted during the current investigation and appeared to be limited by wind action. Based on monthly means, temperature was lowest during February and greatest during July-August (Figure 4-3). Such a pattern is consistent with the temperature model developed for Florida lakes by Beaver et al. (1981) and assigns Lake Weir to the statistically defined central Florida zone. Finally, mean annual temperature was comparable (22^{o} C) among all seven stations and appeared little influenced by either depth or basin size (Figure 4-4).

4.2.B DISSOLVED OXYGEN

As with temperature, the seasonality of mean water column concentrations of dissolved oxygen at individual stations was comparable throughout the 1987-1989 study period (Figure 4-5). All stations displayed only minor short term periods of thermal stratification, and dissolved oxygen concentrations remained above 5 mg/L throughout the water column for the most part. Expressed as a mean for individual months, dissolved oxygen was greatest during winter, especially February, and lowest during mid summer, usually August (Figure 4-6). Such a pattern is expected as high algal productivity in surface waters increases plankton rain to the bottom and this in turn uses profundal oxygen as it decomposes. It is interesting to note that eutrophication in the Lake Weir system has not progressed to the stage that pronounced profundal anoxia is characteristic of the basins during mid summer.

Mean water column concentrations for dissolved oxygen at all seven sampling stations during the study period were >7 mg/L (Figure 4-7). The lowest mean value was displayed by Little Lake Weir, and the second lowest was for the center of Lake Weir proper. The latter station was also the deepest station and thus the most likely to display some degree of



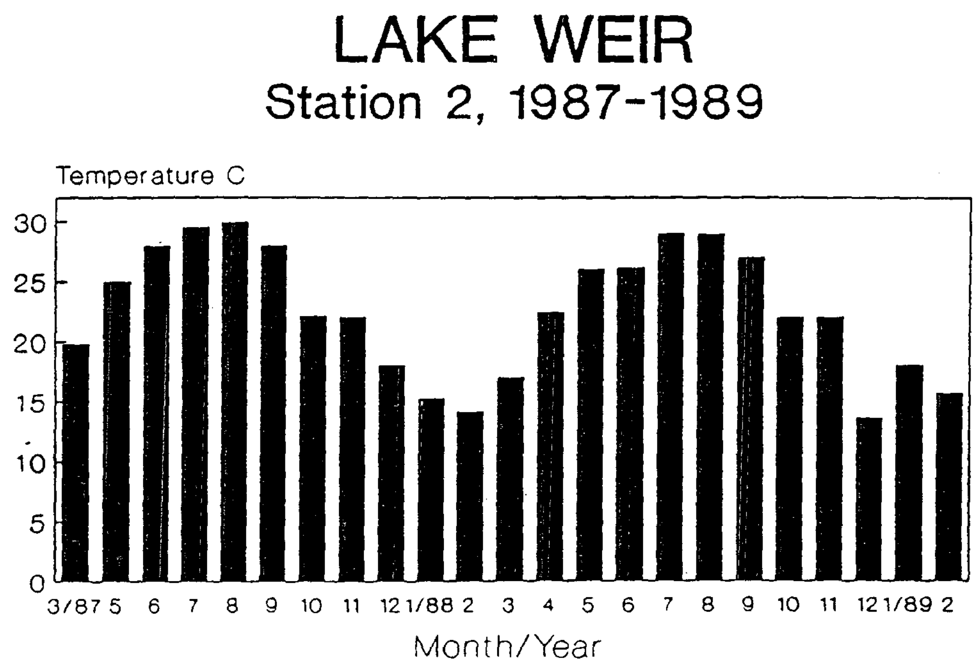
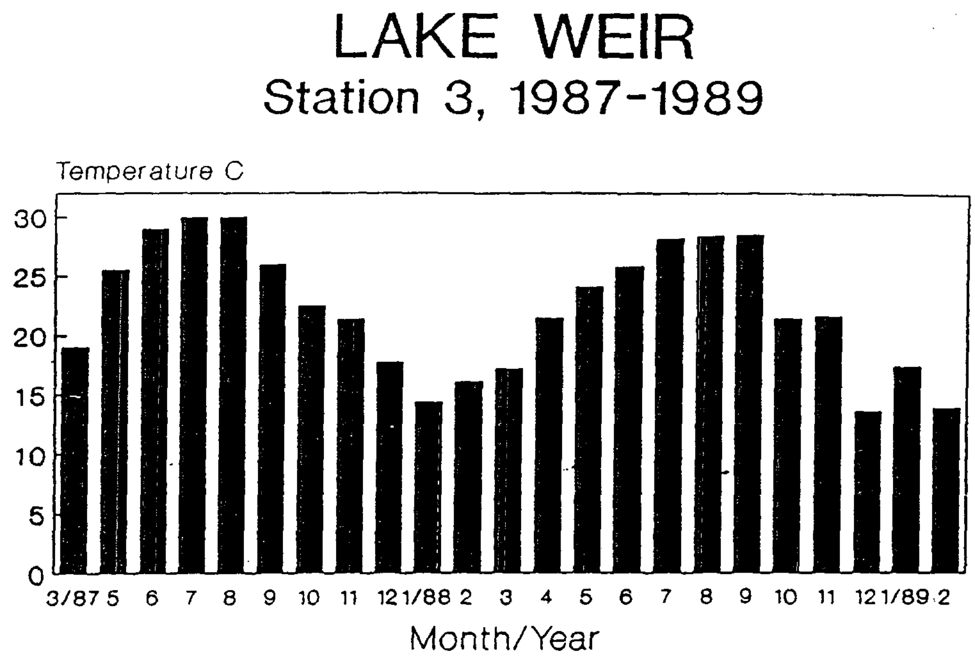


Figure 4-2. Mean water column temperature at individual stations of the Lake Weir system during 1987-1989.



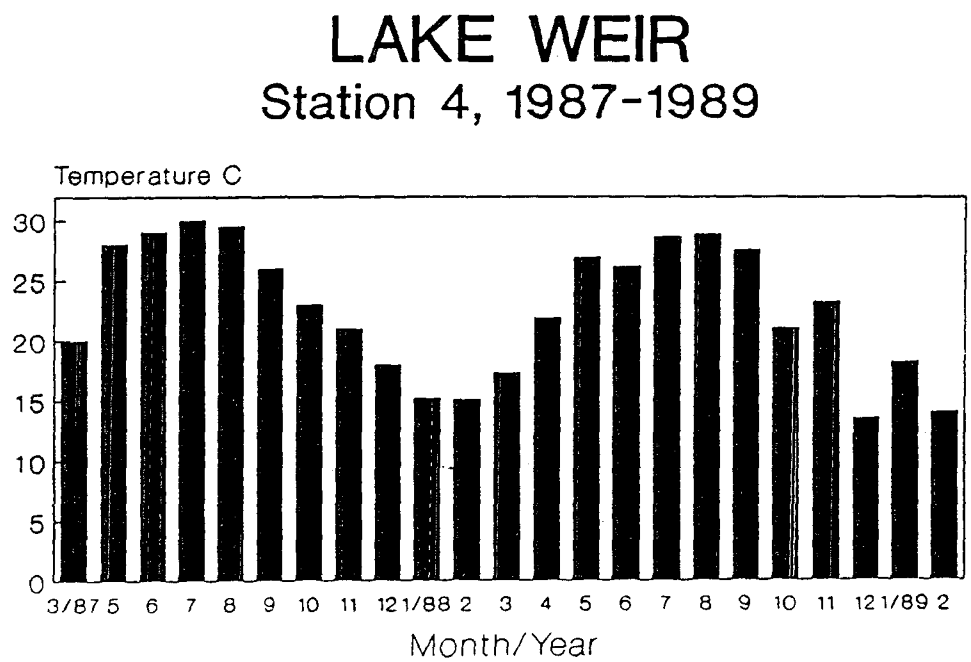
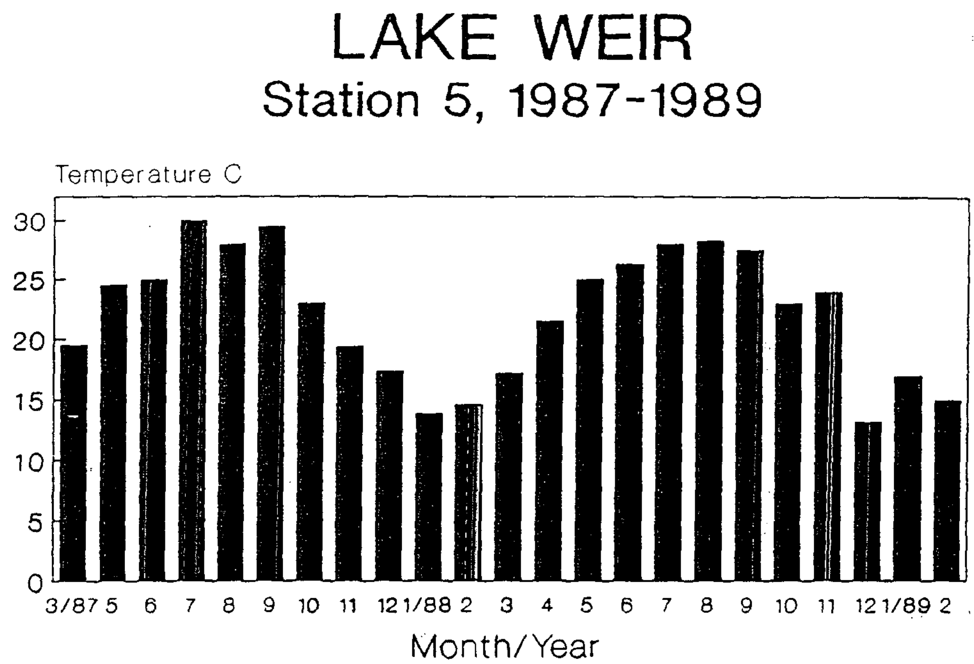


Figure 4-2. Continued.



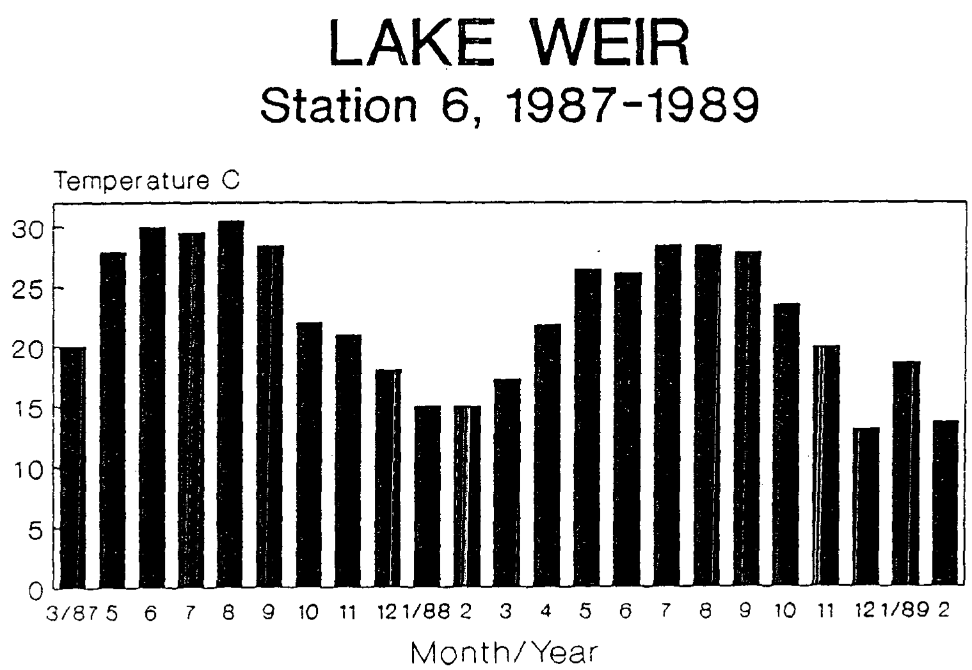


Figure 4-2. Continued.

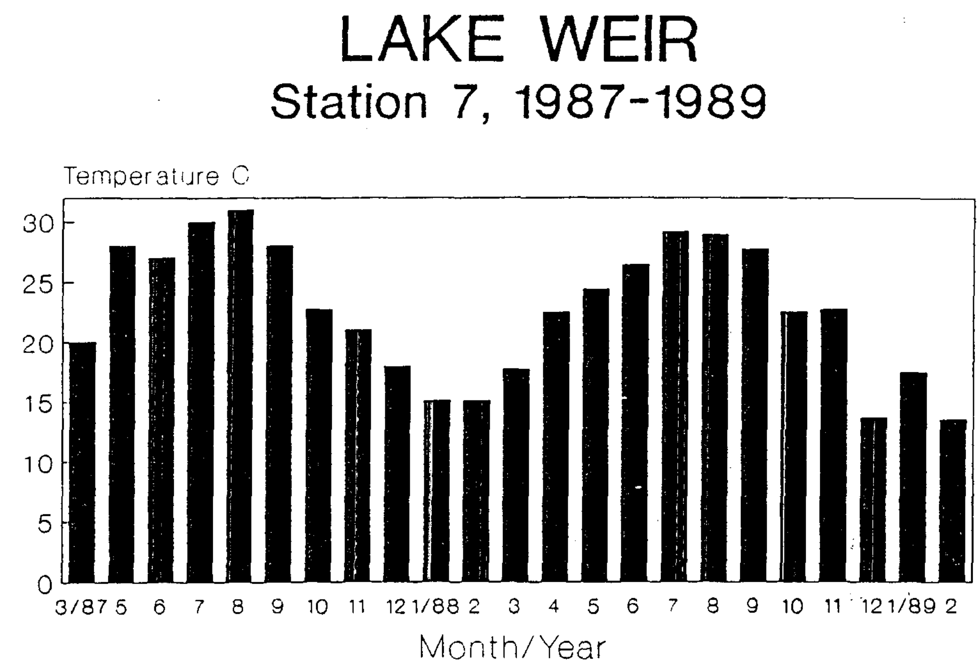
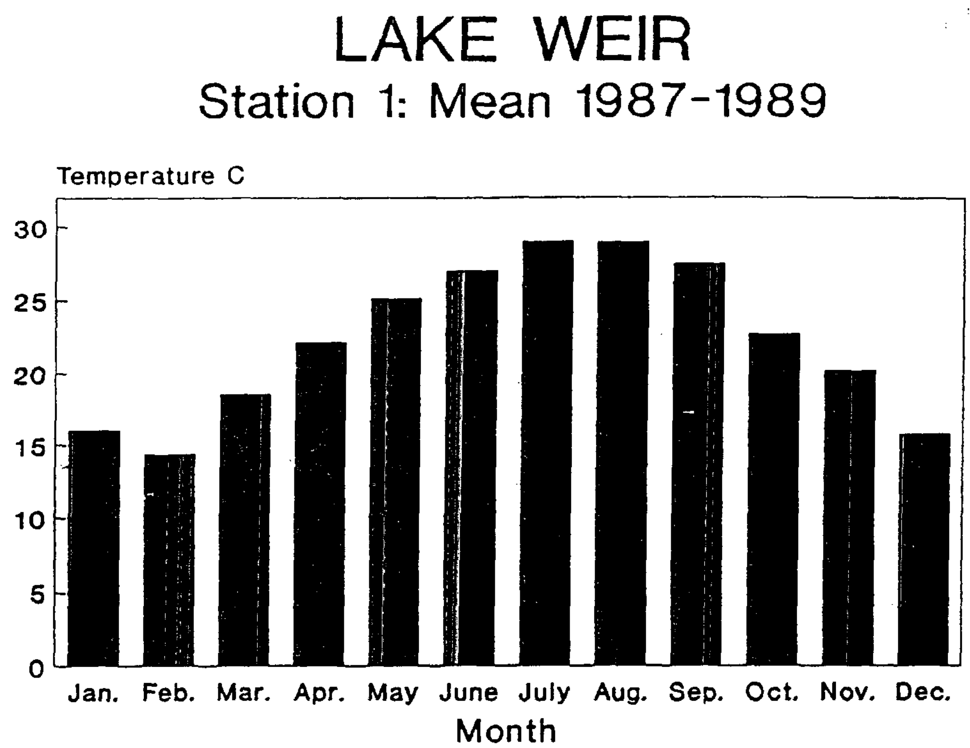


Figure 4-2. Continued.



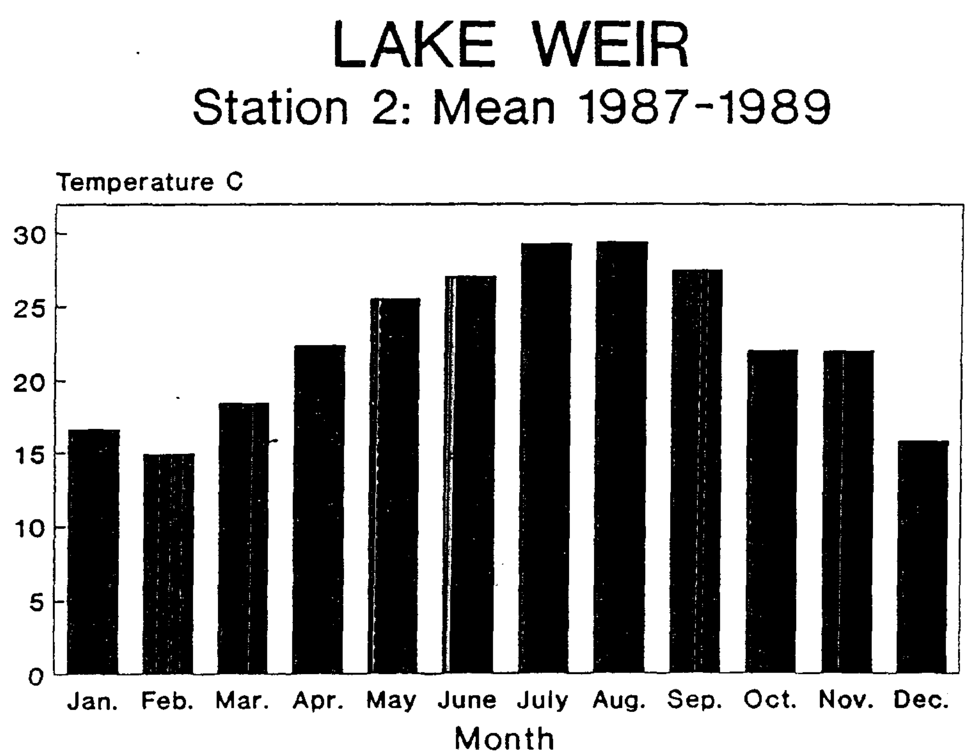
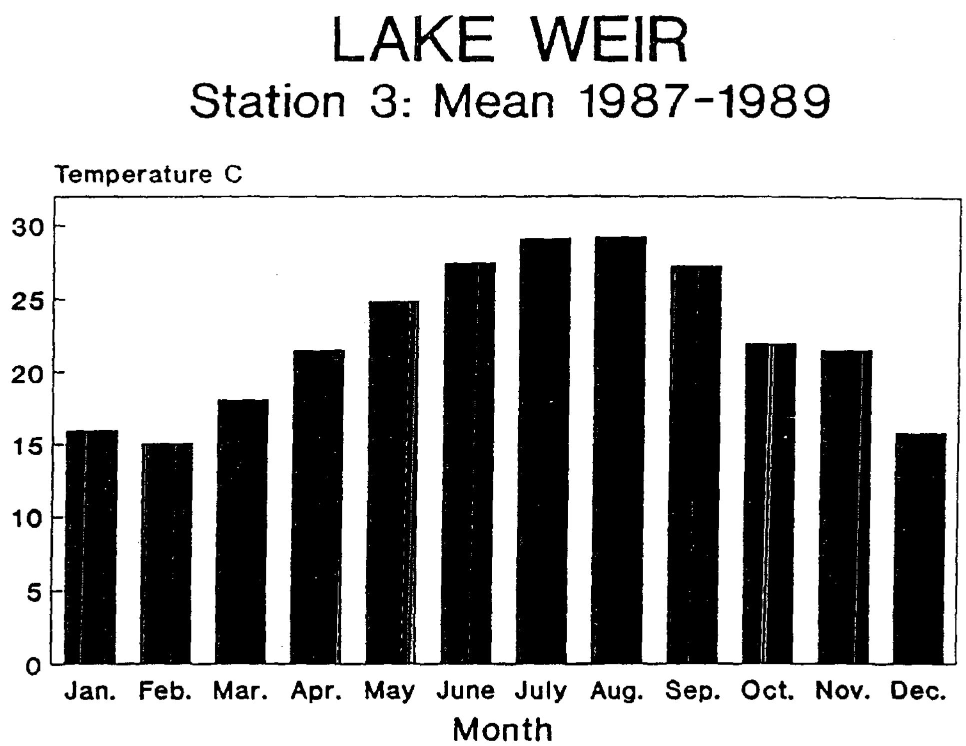
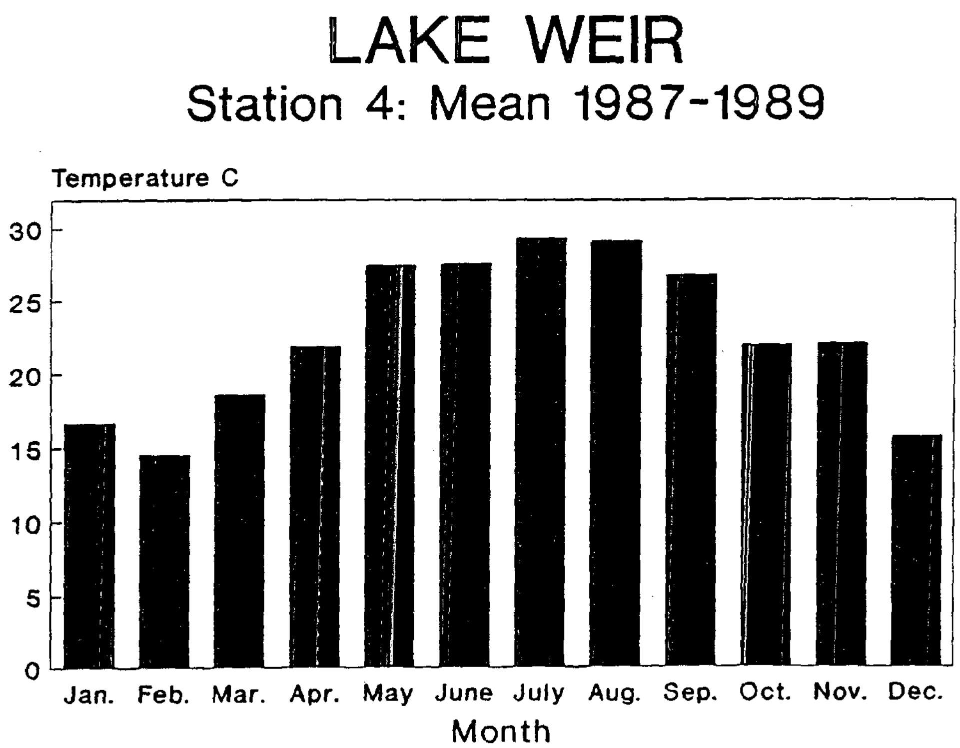


Figure 4-3. Mean water column temperature for individual months for each station of the Lake Weir sytem.





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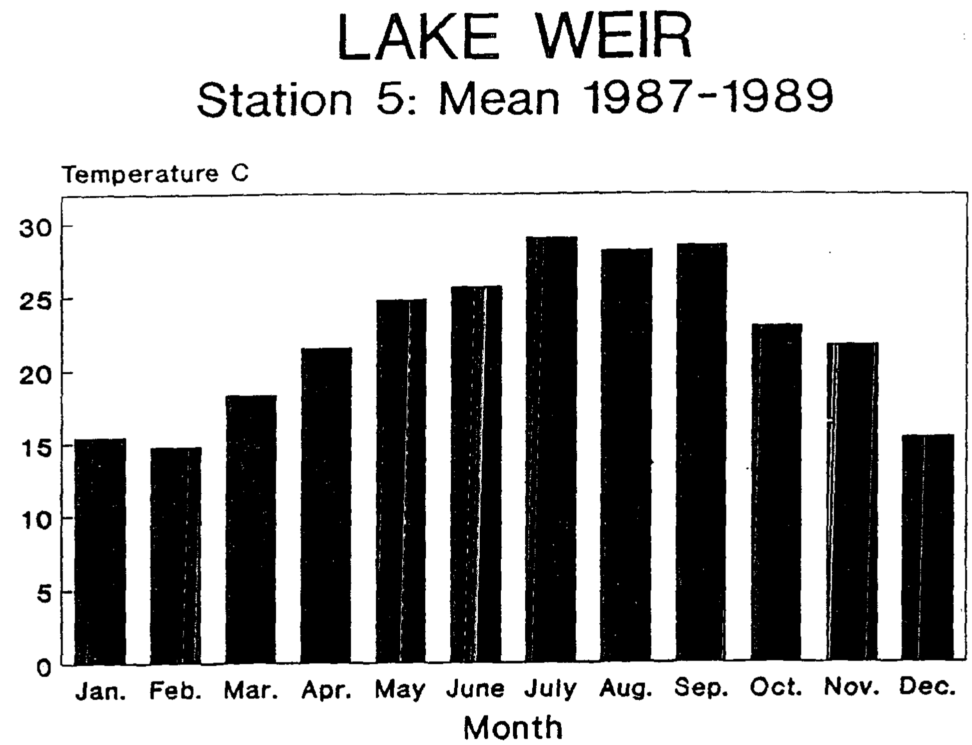

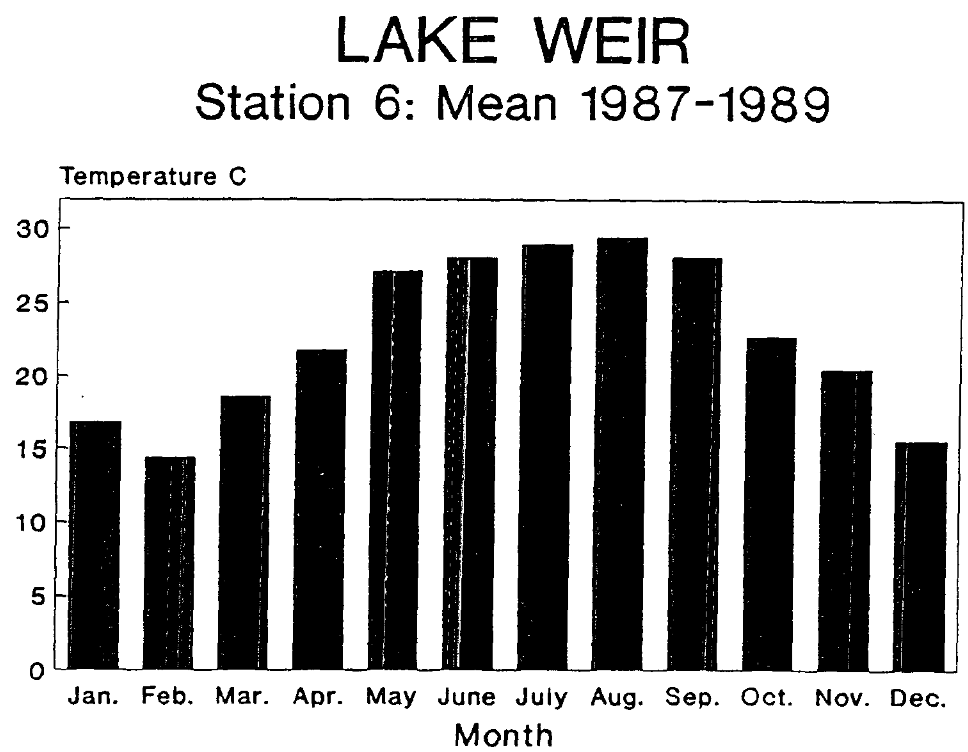

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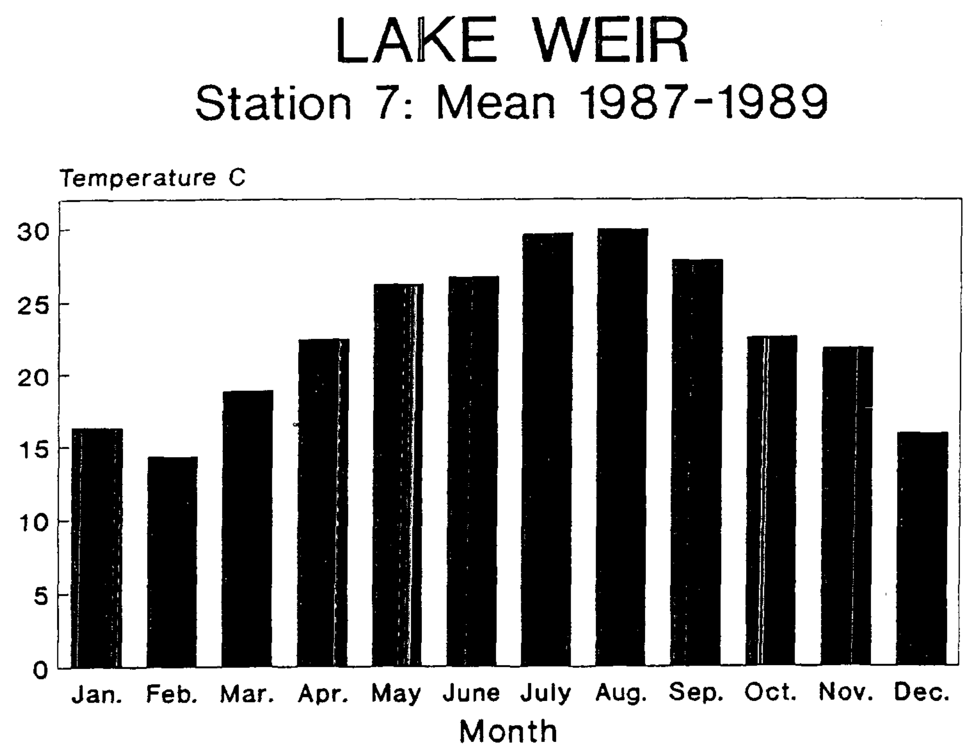

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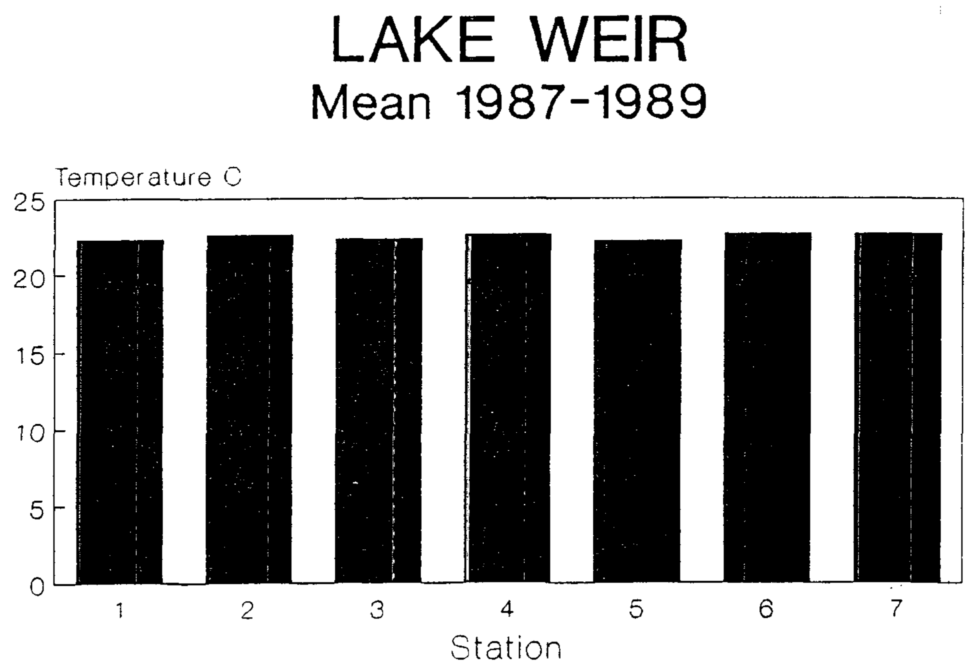
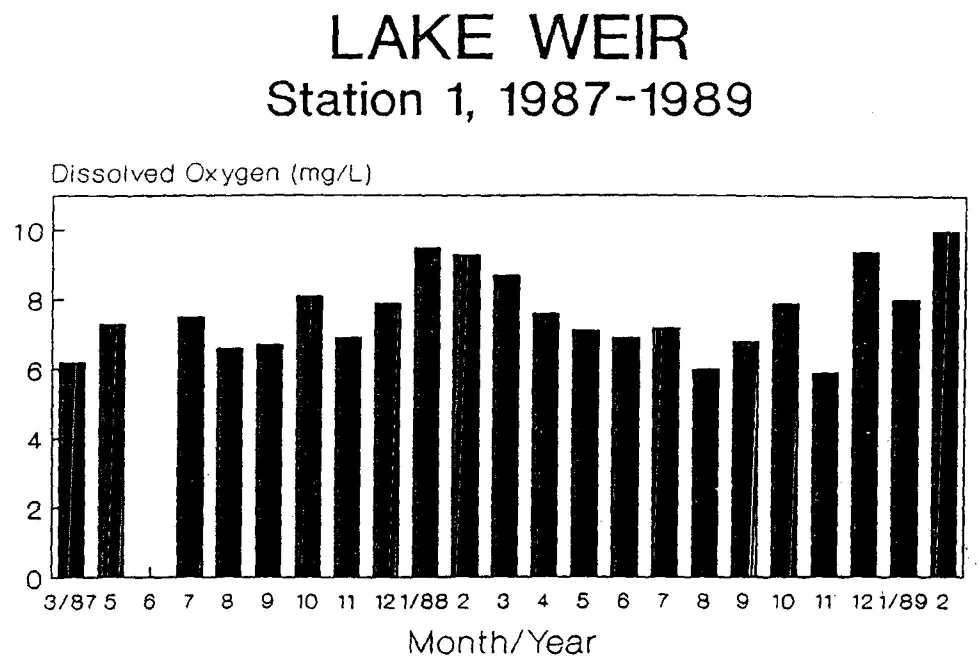


Figure 4-4. Mean temperature at individual stations of the Lake Weir system for 1987-1989.



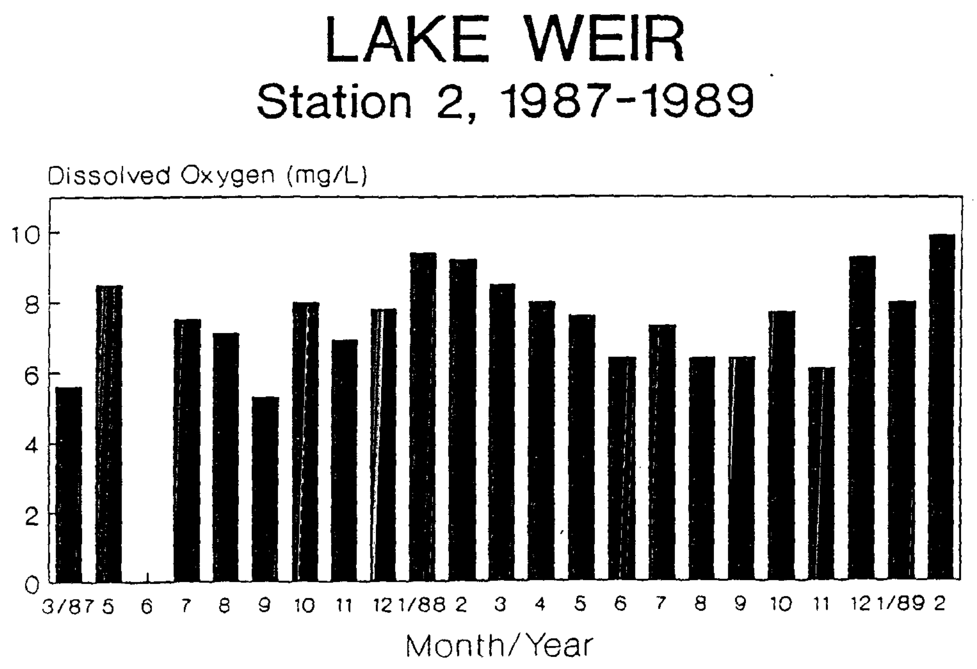
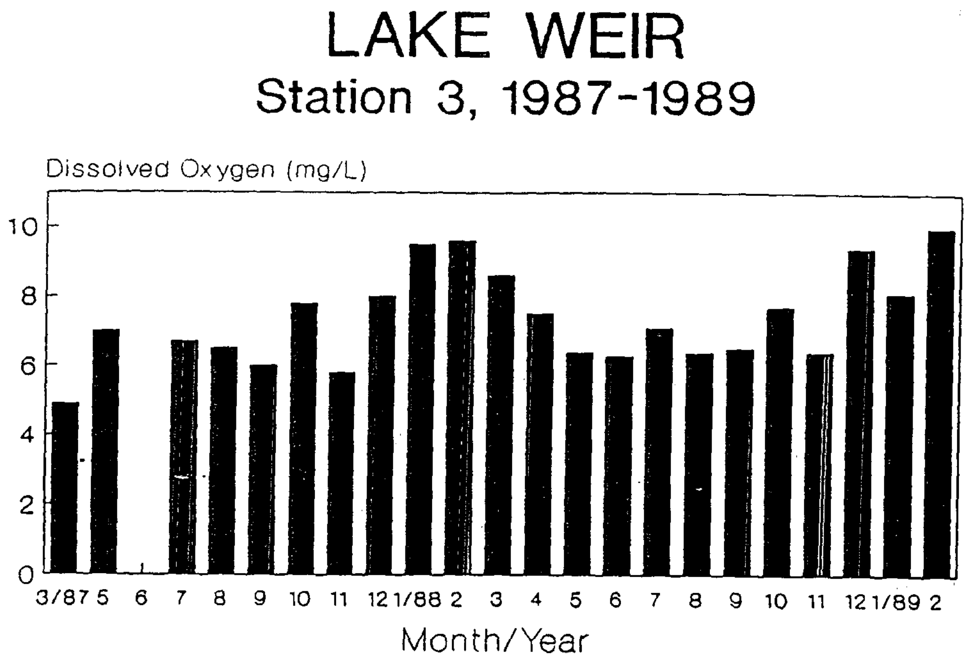


Figure 4-5. Mean water column dissolved oxygen concentrations at individual stations of the Lake Weir system during 1987-1989.



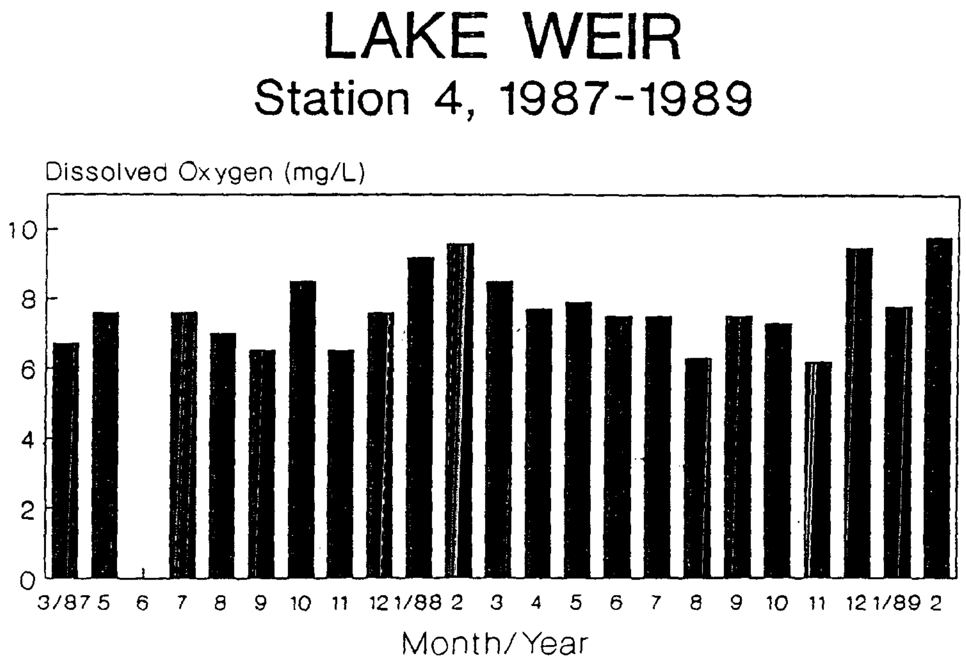
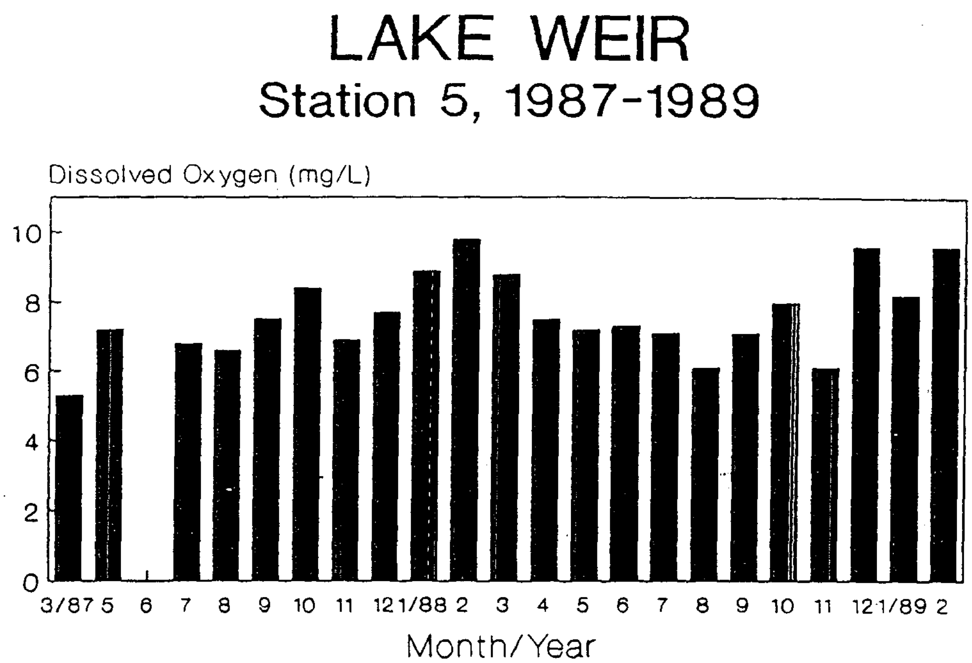


Figure 4-5. Continued.



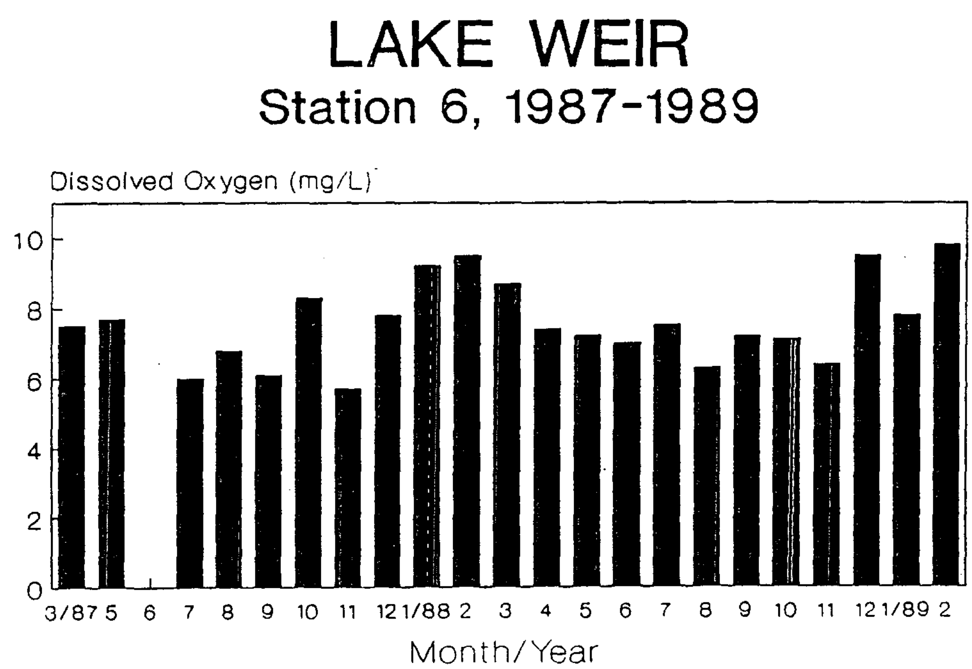
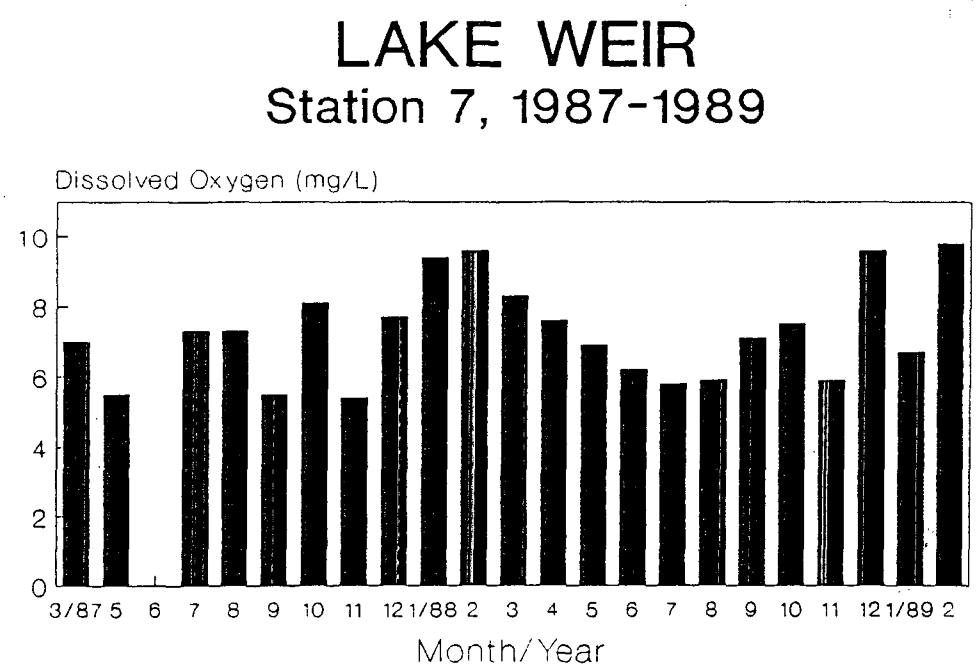


Figure 4-5. Continued.



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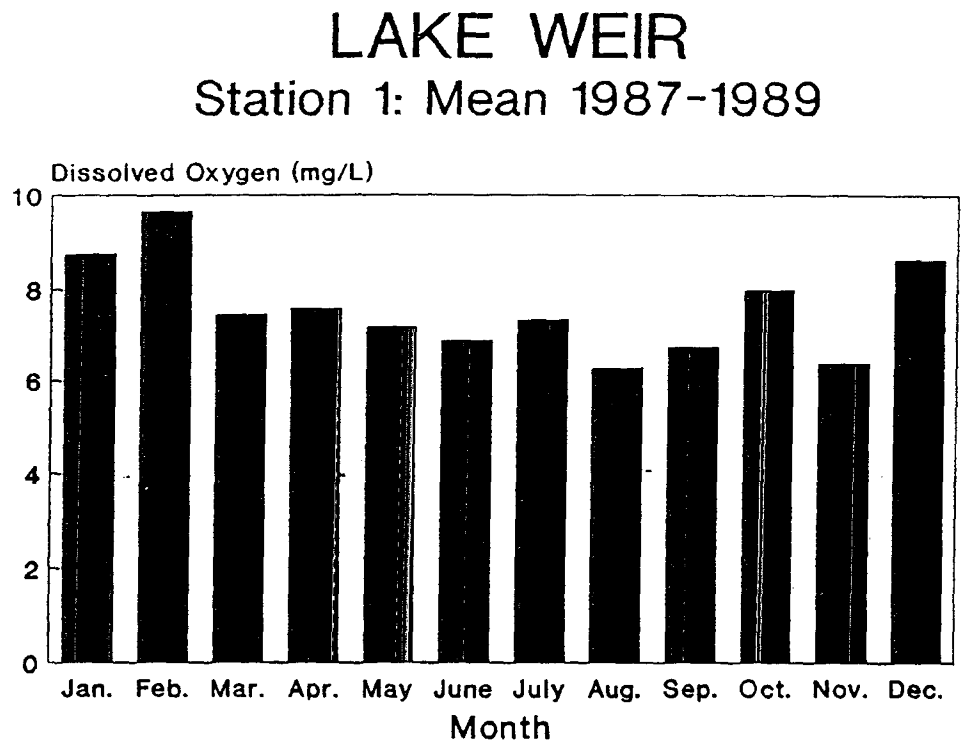


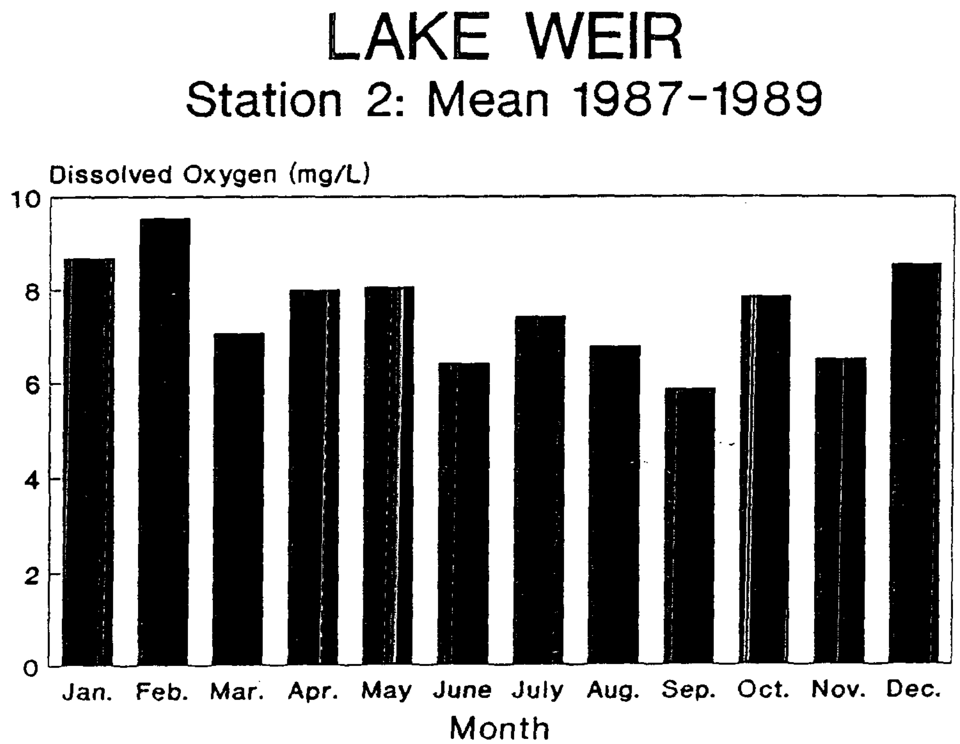
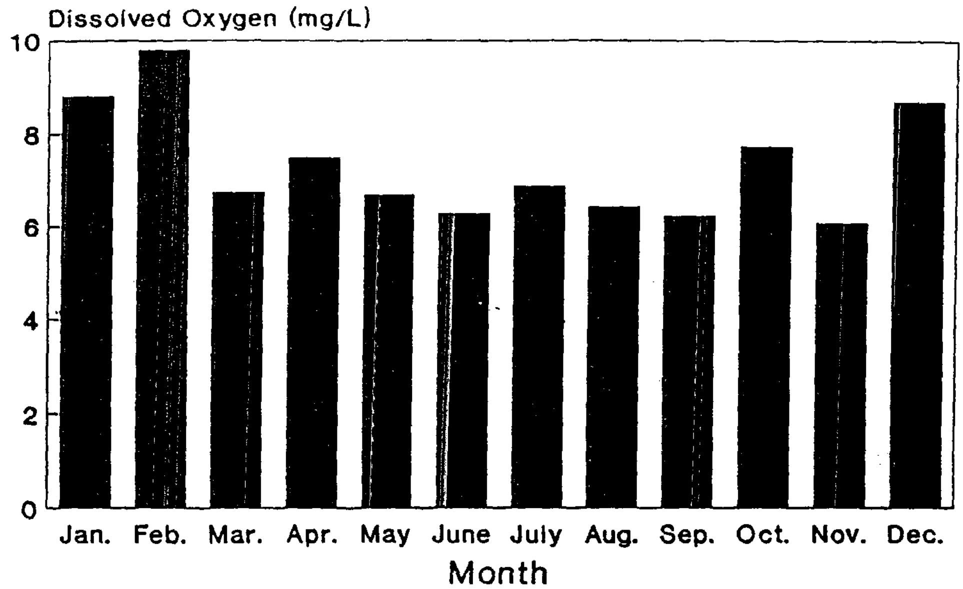


Figure 4-6. Mean water column dissolved oxygen for individual months for each station of the Lake Weir system.

LAKE WEIR
Station 3: Mean 1987-1989



LAKE WEIR
Station 4: Mean 1987-1989

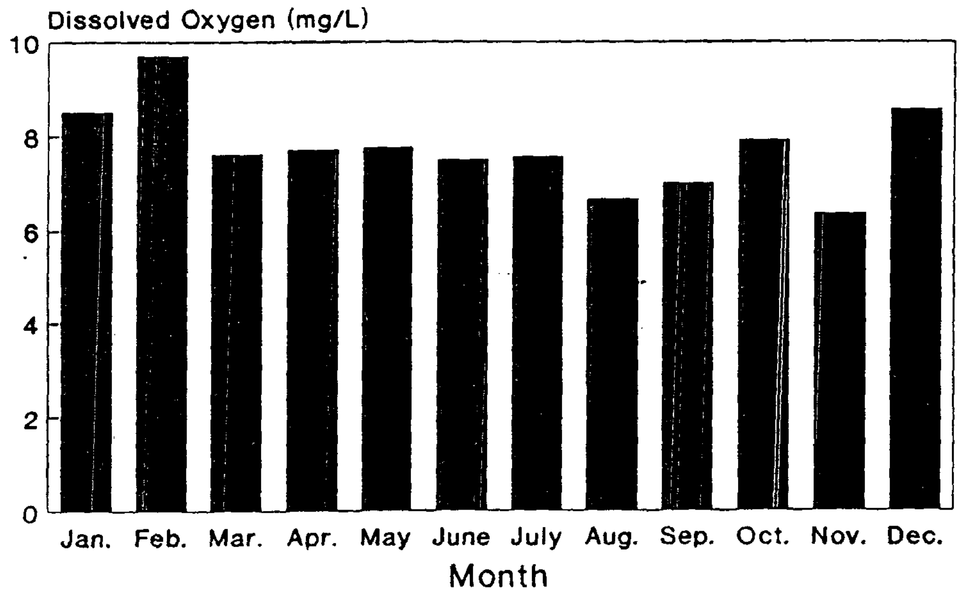
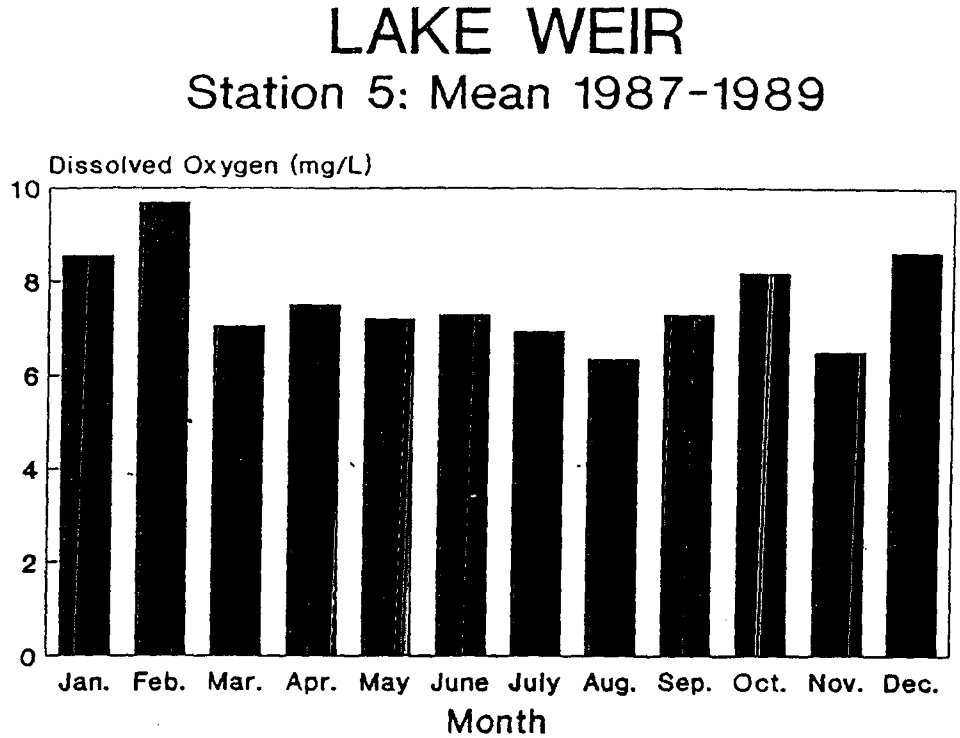
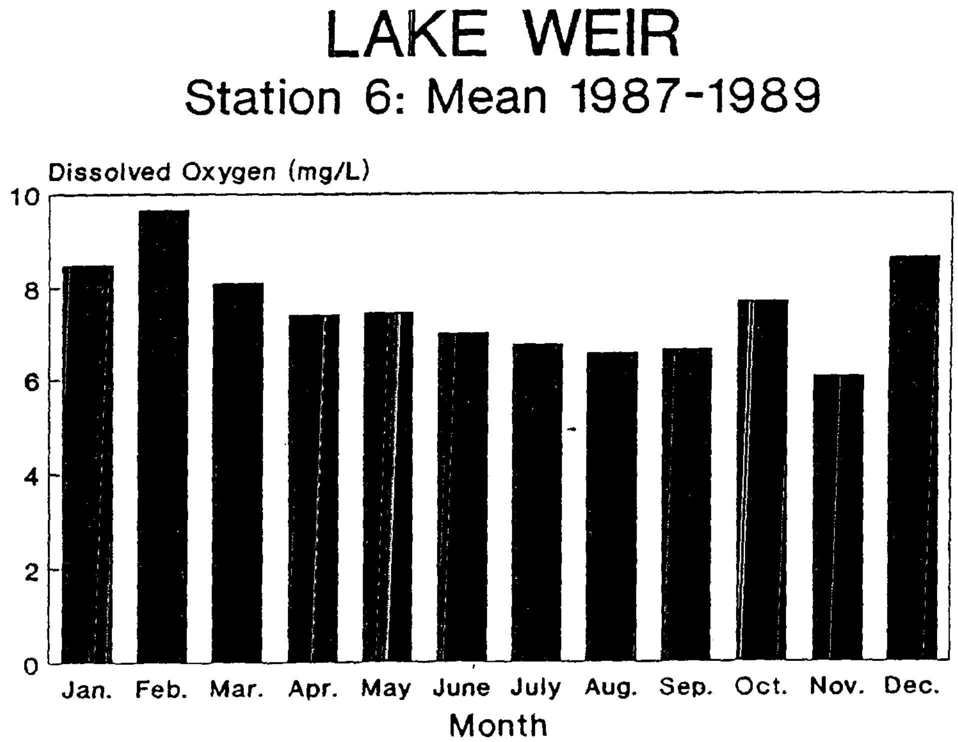


Figure 4-6. Continued.





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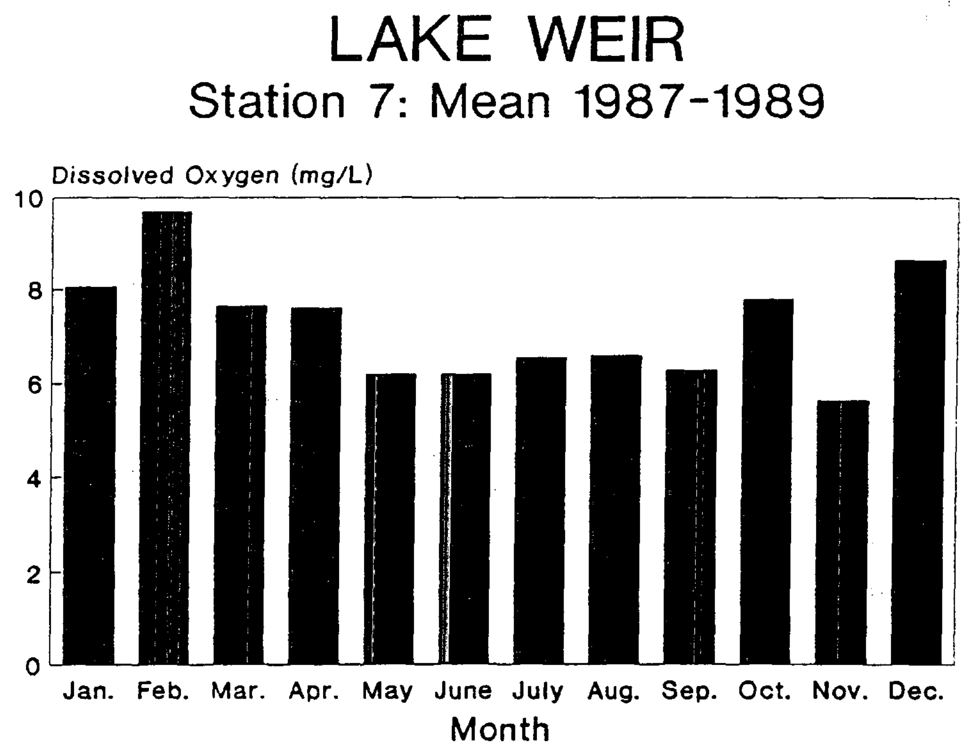


Figure 4-6. Continued.

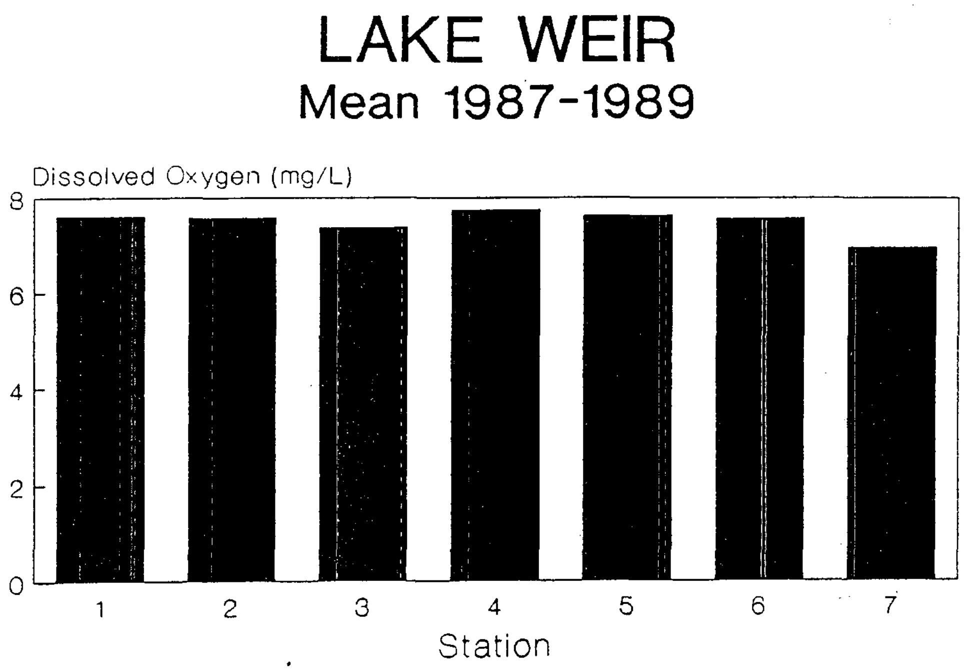


Figure 4-7. Mean water column dissolved oxygen concentrations at individual stations of the Lake Weir system for 1987-1989.

profundal anoxia during mid summer. The remainder of the stations were essentially of equal value. The were no statistical differences between stations for this parameter.

4.2.C SECCHI DISK TRANSPARENCY

Although intramonthly differences were noted between stations, Secchi disk transparency at all stations was greatest during winter and least during summer (Figure 4-8). Statistical differences were noted between months, especially during the transitional periods of spring and fall (Tables 4-3, 4-4). The least pronounced seasonality was displayed by Little Lake Weir. Although mean Secchi transparency seemingly displayed little variation among stations (Figure 4-9), the detailed statistical treatment presented in Chapter 3 demonstrated that variability was evident that was related in part to the human population immediately onshore.

4.3 CHEMICAL PARAMETERS 1987-1989

4.3.A pH

Intermonthly variability was minor at all stations for pH, but all seven stations displayed lowest values during May (Figure 4-10). The mean pH for the study period at all stations was circumneutral with the lowest pH being recorded at Little Lake Weir (Figure 4-11). Although pH did not change significantly between months for individual stations (Table 4-3), Little Lake Weir was significantly lower than the other stations of the Lake Weir system (Tables 4-1, 4-2).

4.3.B CONDUCTIVITY

Conductivity at all stations displayed a similar seasonality with lowest values in winter-spring and highest values during mid summer (Figure 4-12). Summer values (June-August) were significantly greater than the rest of the year (Tables 4-3, 4-4) and likely reflect increased rainfall and

Table 4-1. Results of analyses of differences between sampling stations for current chemistry data in Lake Weir, FL by GLM and Duncan's procedure.

Parameter	N	F Value	Significance
Secchi depth	157	0.57	n.s.
Chlorophyll *a*	157	1.43	n.s.
Conductivity	151	0.52	n.s.
Total Kjeldahl nitrogen	158	0.20	n.s.
Total phosphate	152	0.81	n.s.
Orthophosphate	149	1.56	n.s.
Total alkalinity	158	230.2	**
pH	157	44.56	**

n.s.=not significant.
*=significant at $p \leq 0.05$.
**=significant at $p \leq 0.01$.

Table 4-2. Results of Duncan's multiple range test for significant differences between water chemistry data at the seven sampling stations in Lake Weir, FL. (Stations that are connected by the same underline are not significantly different).

Total Alkalinity

Station

4 6 3 5 1 2 7

pH

Station

5 1 4 3 6 2 7

Table 4-3. Results of GLM for monthly comparisons of water chemistry at the seven sampling stations in Lake Weir, Florida.

Parameter	N	F	Significance
Secchi	157	4.93	**
Chlorophyll a	157	2.40	**
Specific conductivity	151	5.18	**
Total Kjeldahl nitrogen	158	1.76	n.s.
Total phosphorus	152	5.04	**
Orthophosphate	149	11.70	**
Total alkalinity	158	0.26	n.s.

** $p \leq 0.01$; * $p \leq 0.05$; n.s.= not significant.

Table 4-4. Results of Duncan's multiple range test for chemistry by month. Months connected by underlines were not significantly different.

Secchi depth

12 2 1 11 8 5 10 3 7 4 6 9

Chlorophyll a

6 3 8 4 1 9 12 7 5 11 10 2

Specific conductivity

7 8 6 9 5 10 11 4 12 2 1 3

Total Kjeldahl nitrogen

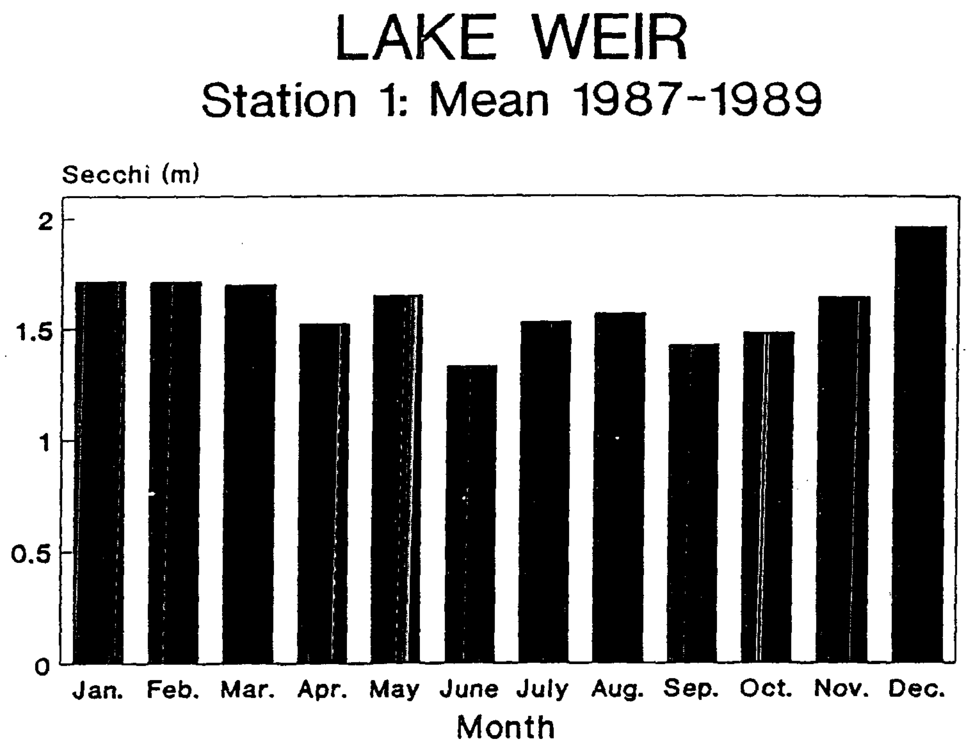
11 5 12 6 4 9 7 8 10 1 3 2

Total phosphorus

8 11 12 10 7 9 1 2 4 5 3 6

Orthophosphate

1 12 11 2 4 3 7 5 9 6 10 8



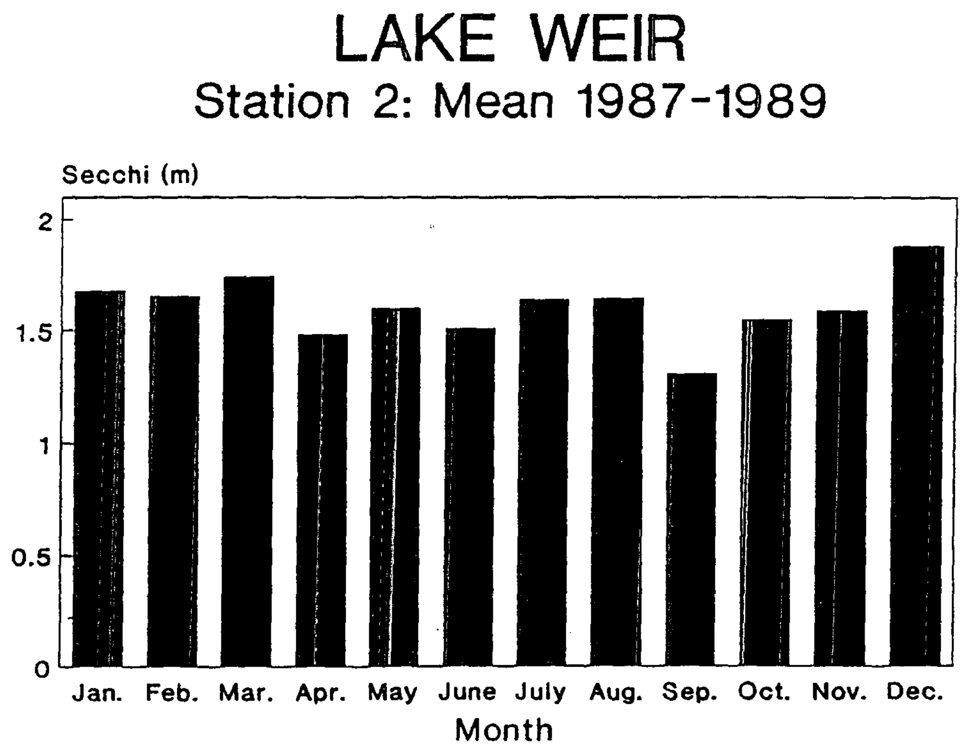
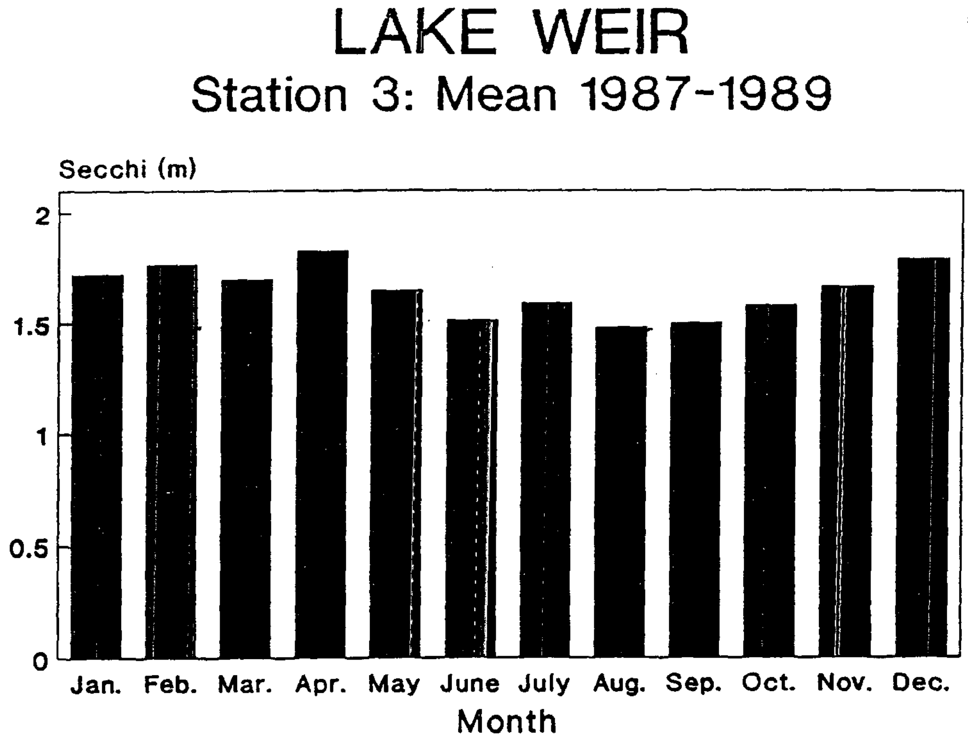


Figure 4-8. Mean Secchi disk readings for individual months for each station of the Lake Weir system.



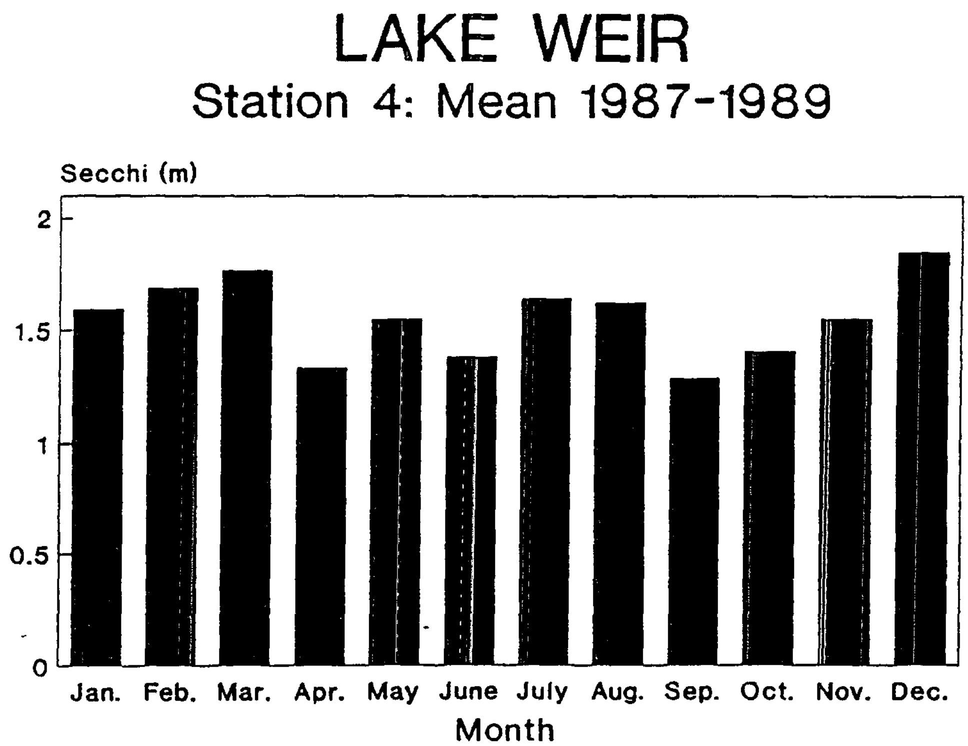
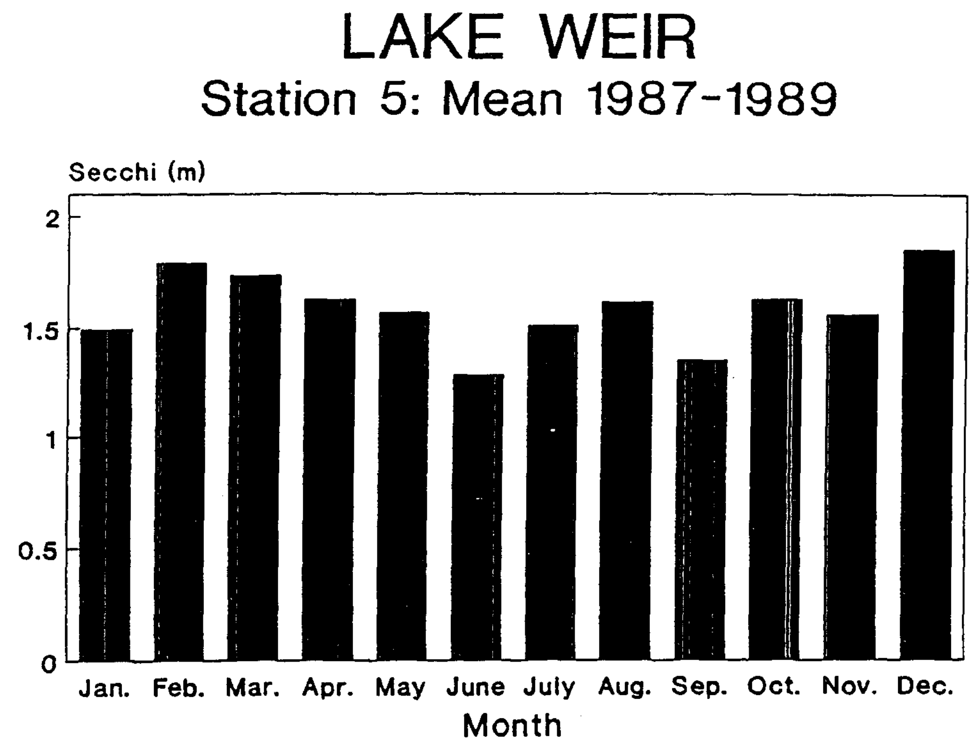


Figure 4-8. Continued.



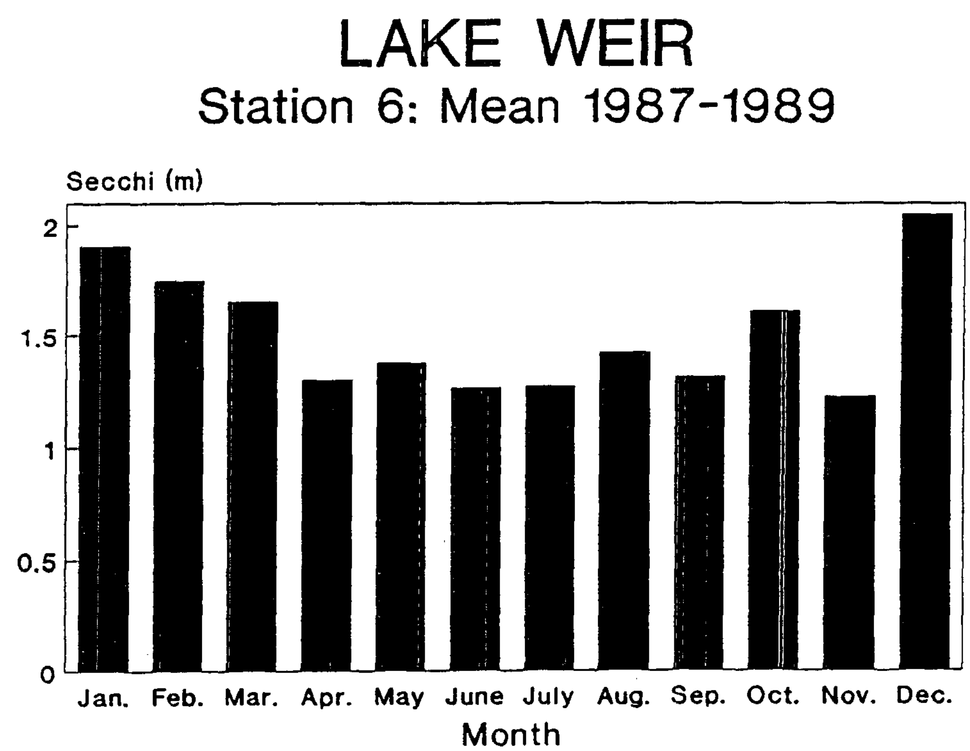


Figure 4-8. Continued.

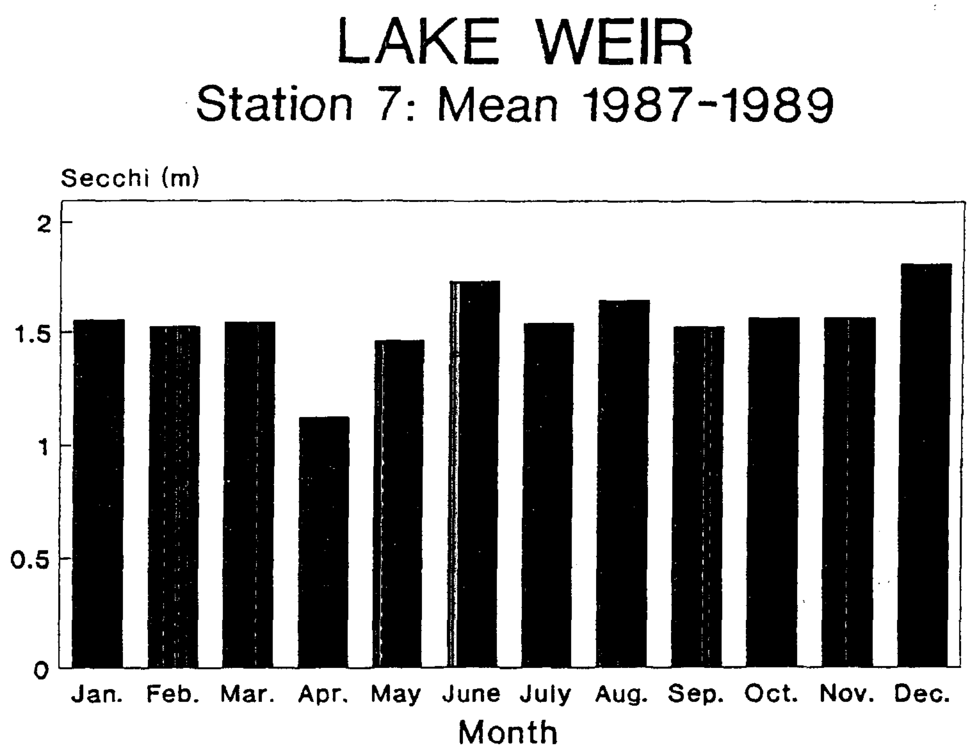


Figure 4-8. Continued.

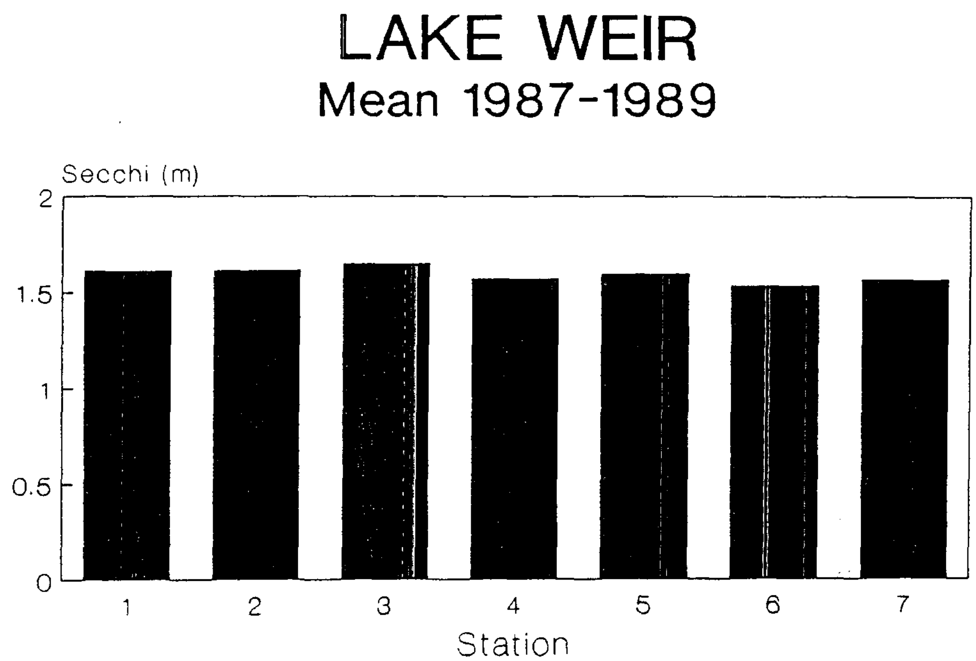


Figure 4-9. Mean Secchi disk readings for individual stations of the Lake Weir system for 1987-1989.

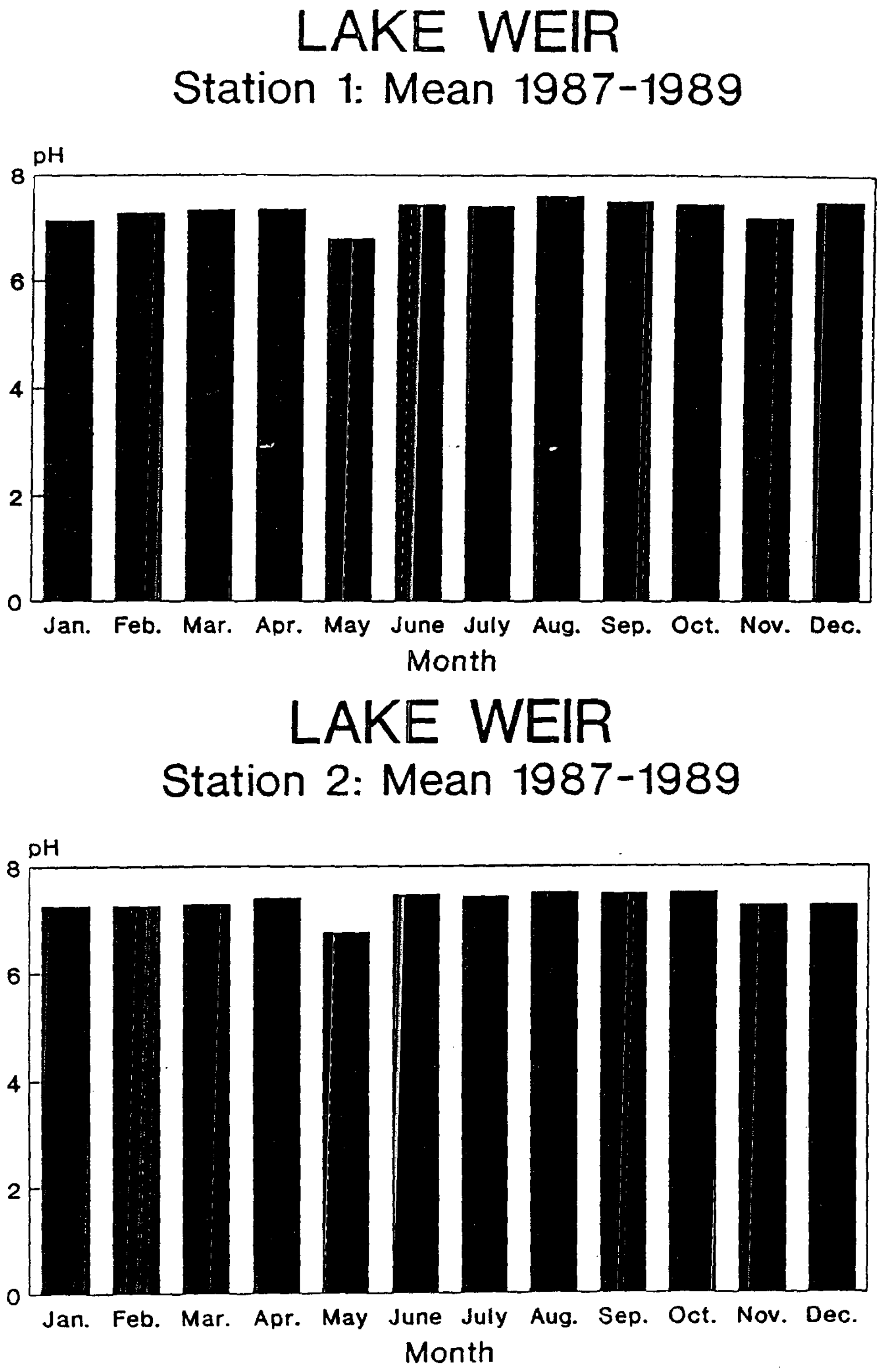
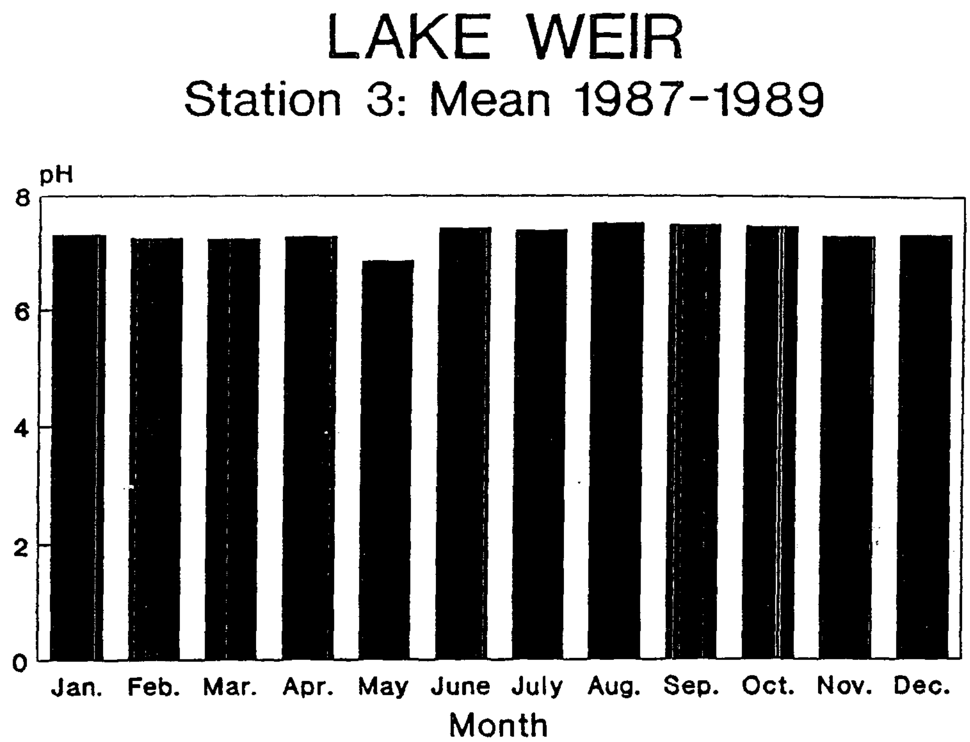


Figure 4-10. Mean pH for individual months for each station of the Lake Weir system during 1987-1989.



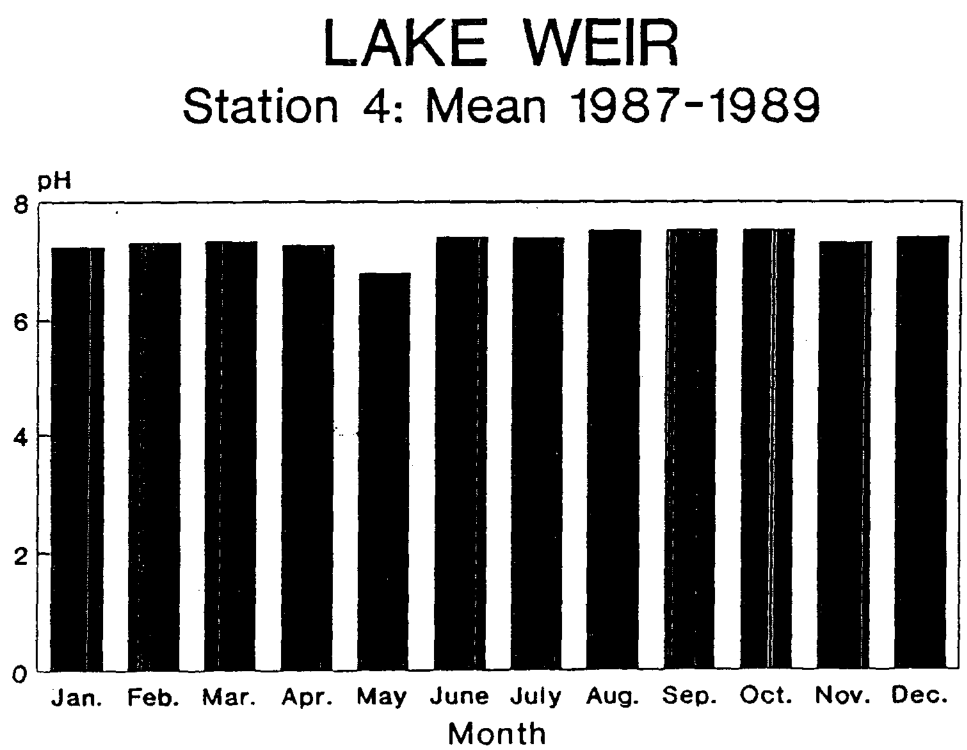
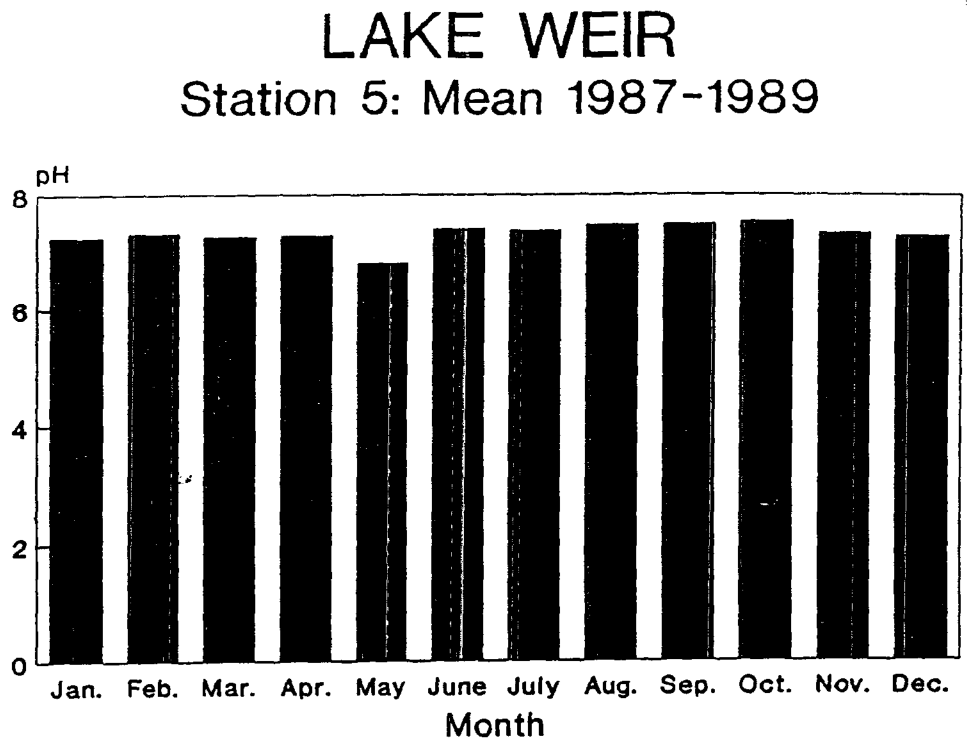
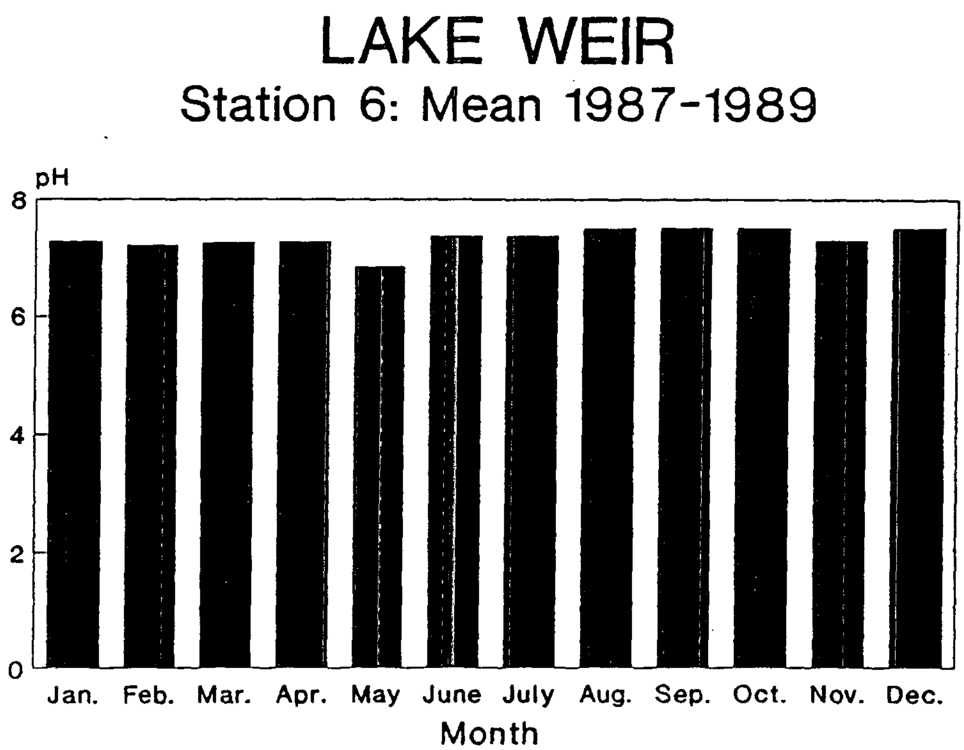


Figure 4-10. Continued.





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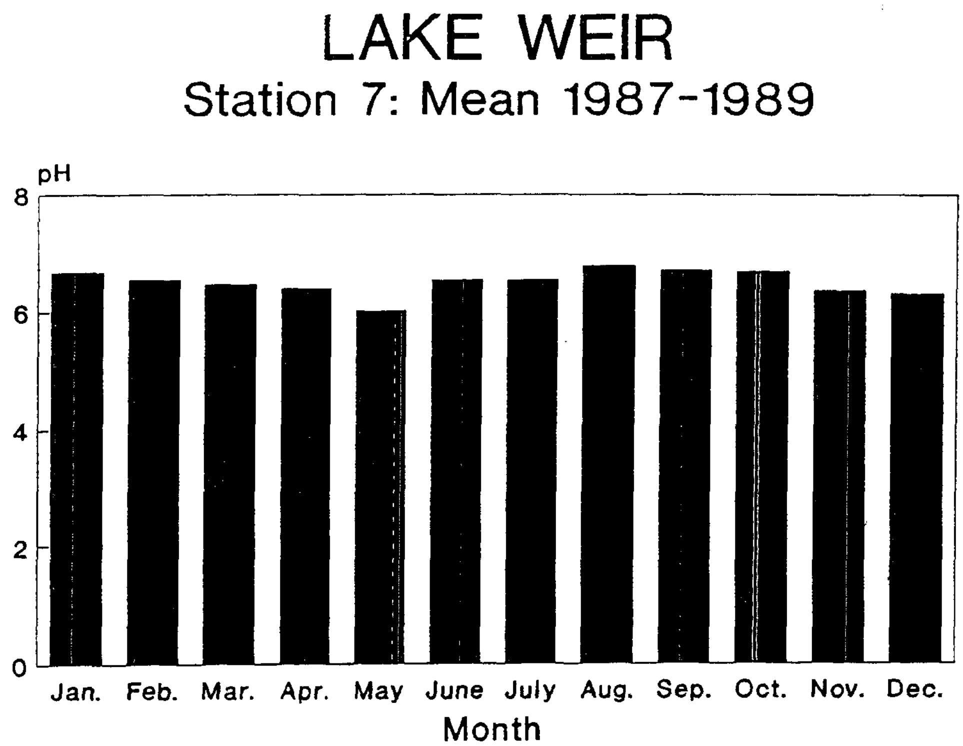


Figure 4-10. Continued.

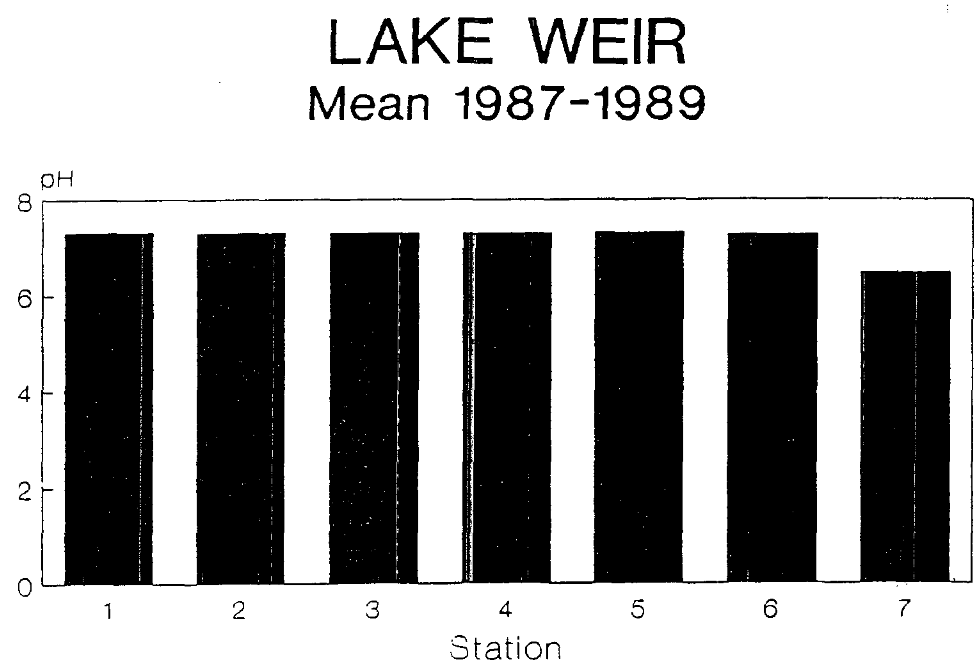


Figure 4-11 Mean pH for each station of the Lake Weir system during 1987-1989.

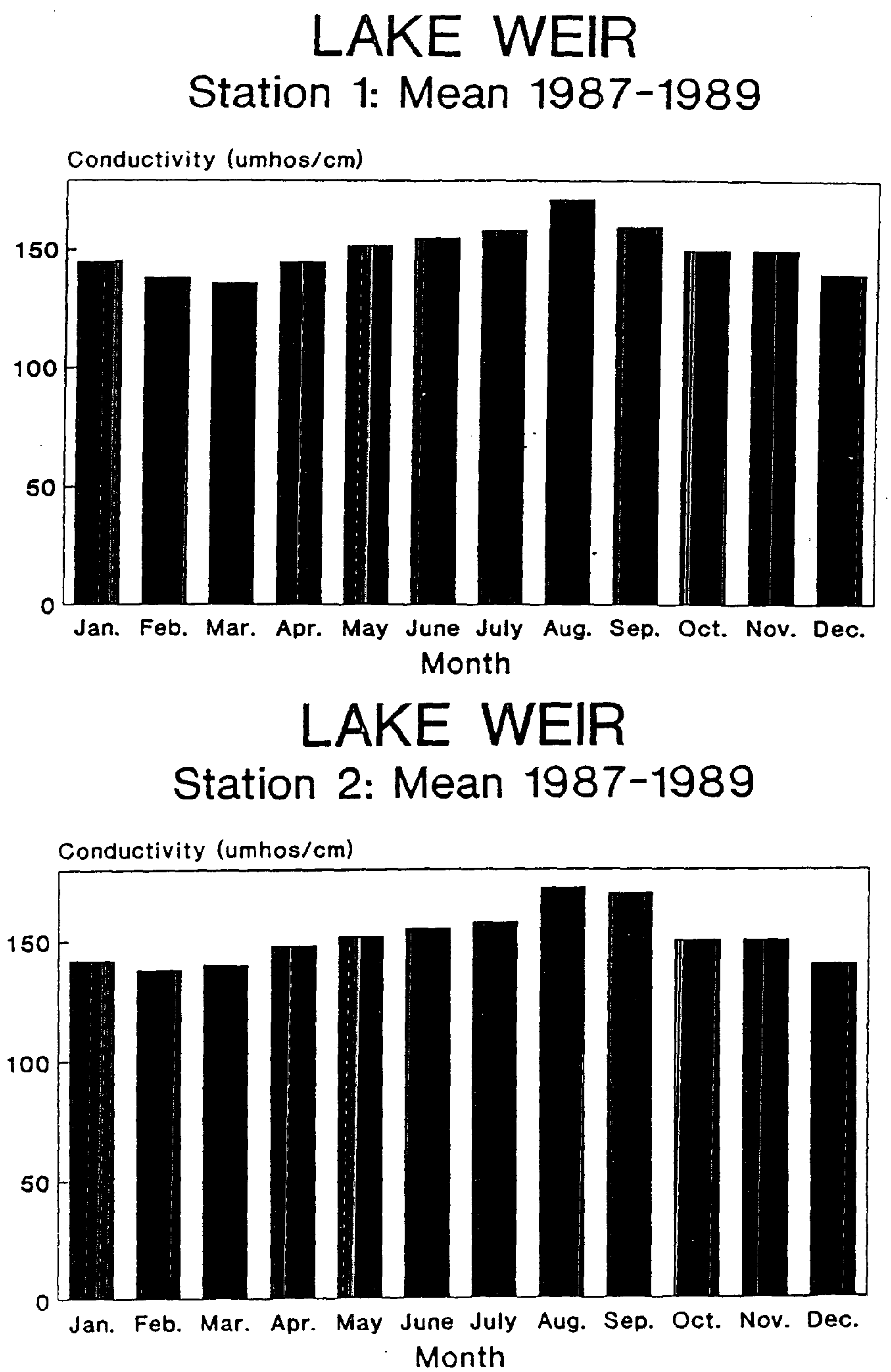
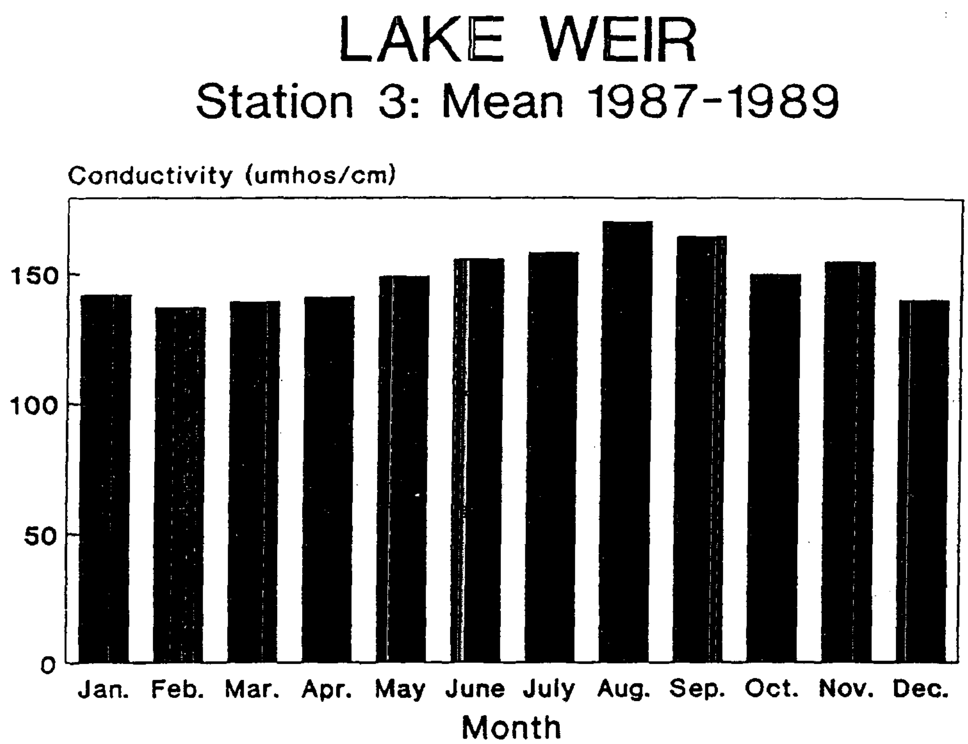


Figure 4-12. Mean conductivity for individual months for each station of the Lake Weir system during 1987-1989.



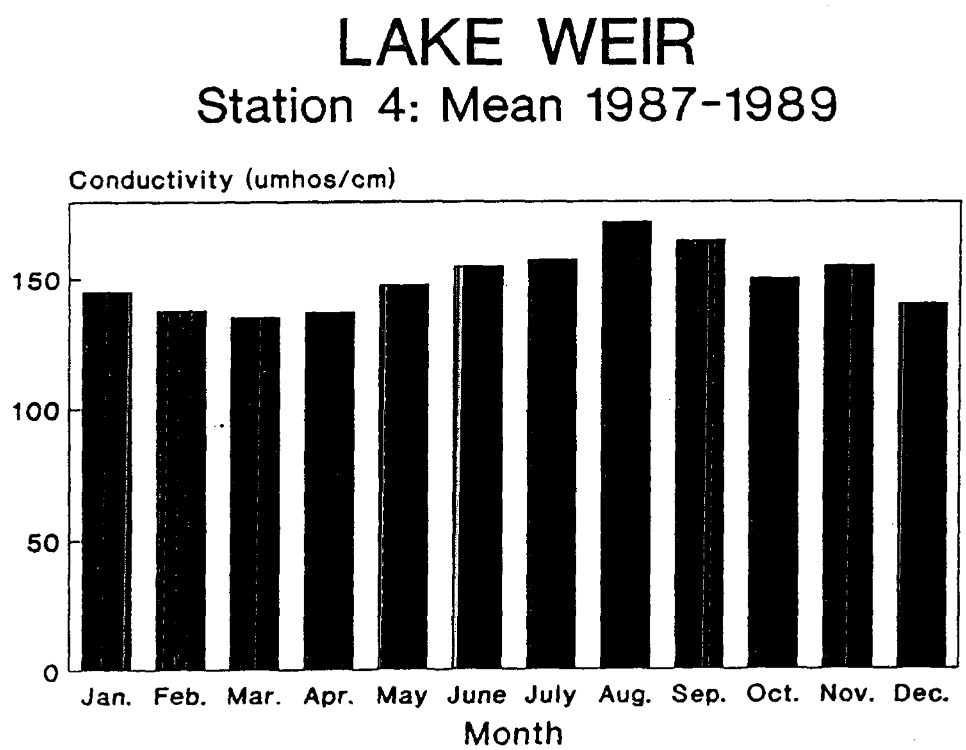
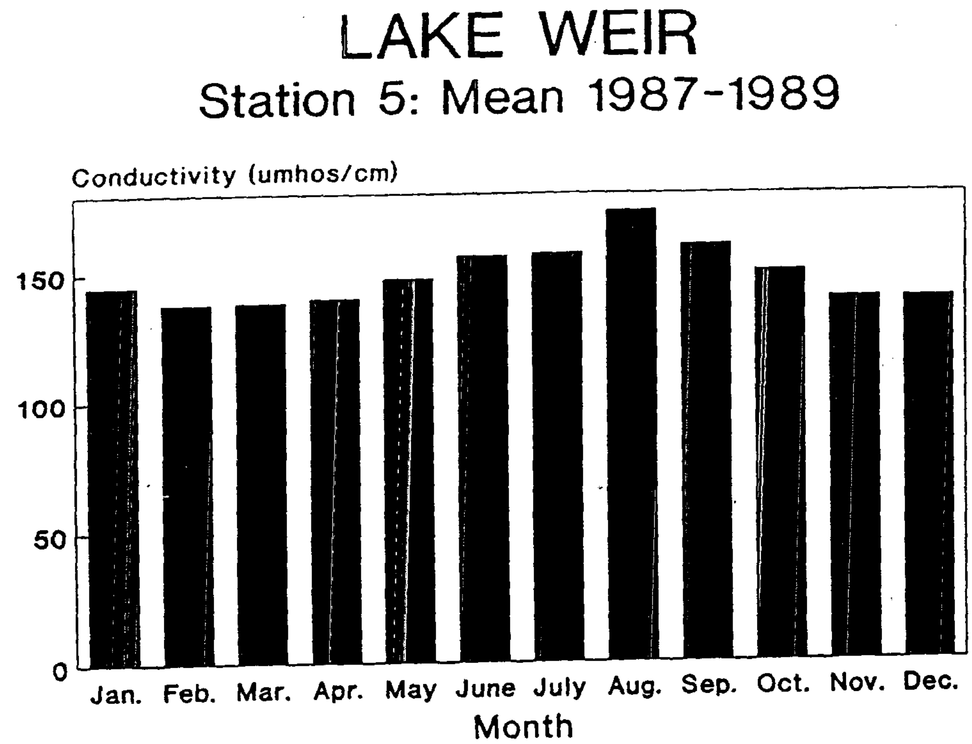


Figure 4-12. Continued.



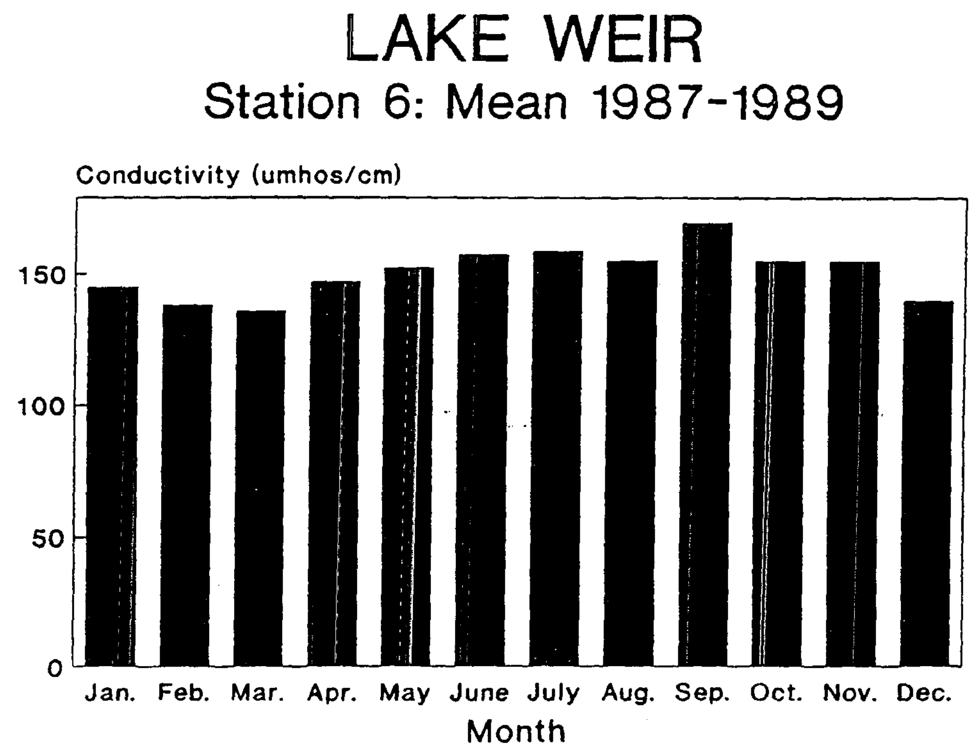


Figure 4-12. Continued.

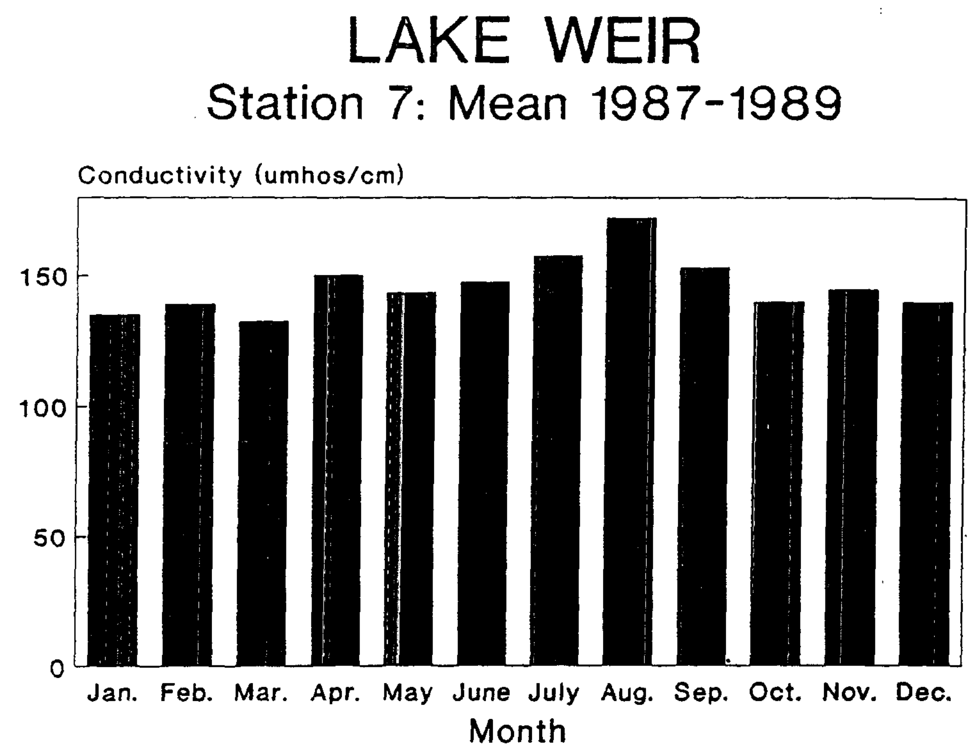


Figure 4-12. Continued.

runoff during this typical wet season. Mean conductivity at all stations was 140-150 umhos/cm (Figure 4-13) and no significant differences were apparent between stations (Tables 4-1, 4-2).

4.3.C ALKALINITY

Alkalinity at all stations was lowest during May (Figure 4-14), but, unlike the related parameter, conductivity, failed to display a decline during the winter months. Intermonth differences in the Lake Weir system were not statistically significant (Table 4-3). With the exception of Little Lake Weir which had a mean alkalinity of 6 mg/L, all other stations had mean values of 15-17 mg/L (Figure 4-15). The Little Lake Weir value was significantly lower than the other stations (Tables 4-1, 4-2).

4.3.D TOTAL KJELDAHL NITROGEN

All stations displayed higher total Kjeldahl nitrogen values during late fall to mid winter than at any other time of the year (Figure 4-16). On a seasonal basis, TKN values did not display significant intermonthly differences (Tables 4-3, 4-4). Mean TKN values at all stations during the study period were 620-700 ug/L (Figure 4-17), and although Little Lake Weir was greater than all other stations, no significant differences were noted between individual stations (Table 4-1).

4.3.E TOTAL PHOSPHORUS

Although a great deal of interstation variability was noted, total phosphorus values tended to be greater during late summer and fall than at any other time of the year (Figure 4-18). August had the highest total phosphorus of any month. Total phosphorus was greatest in Sunset Harbor and Little Lake Weir (Figure 4-19), but no statistically significant interstation differences were evident between any of the seven stations of the study (Table 4-1).

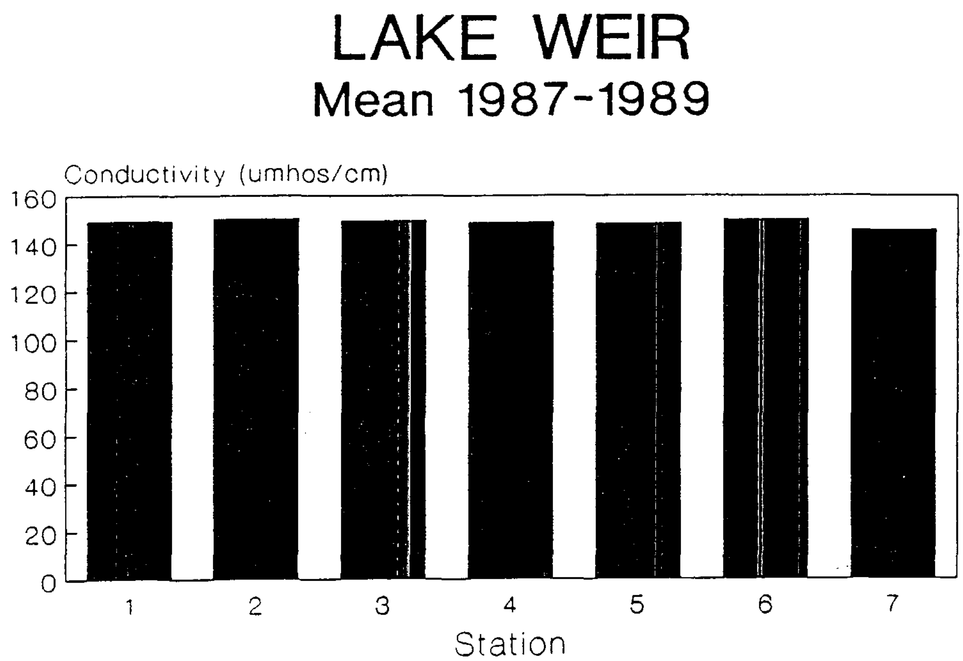
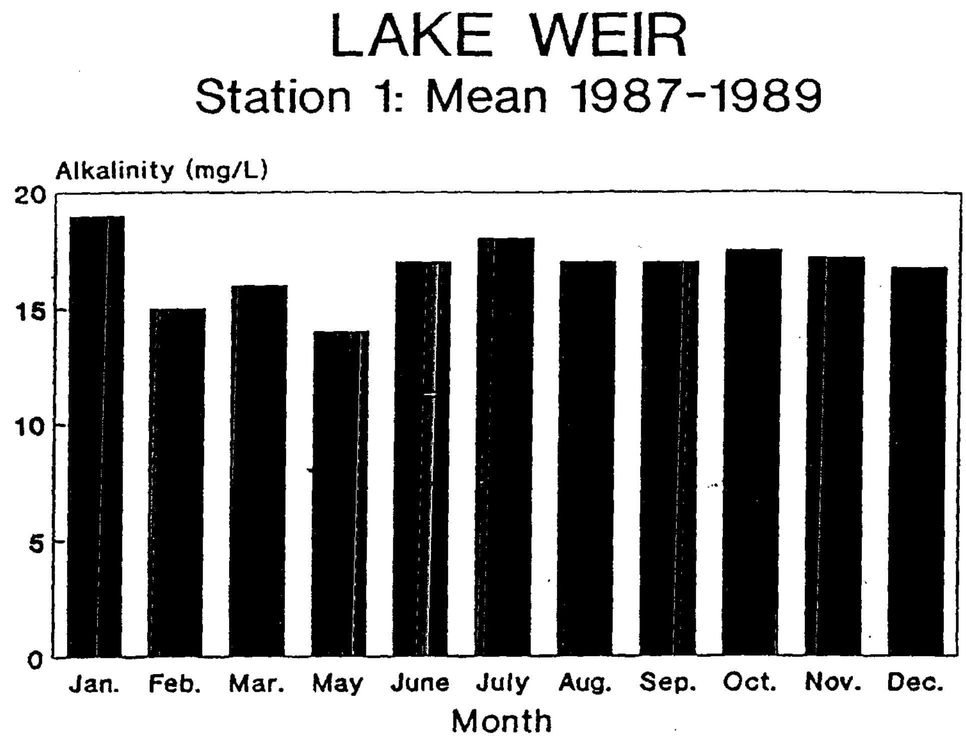


Figure 4-13 Mean conductivity for each station of the Lake Weir system during 1987-1989.



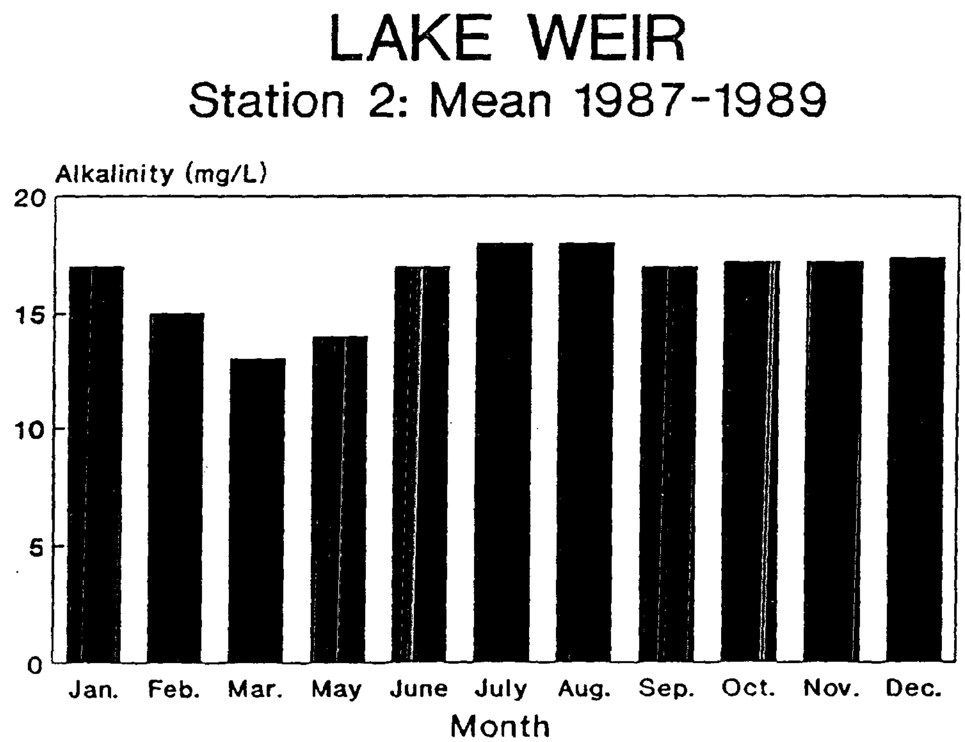
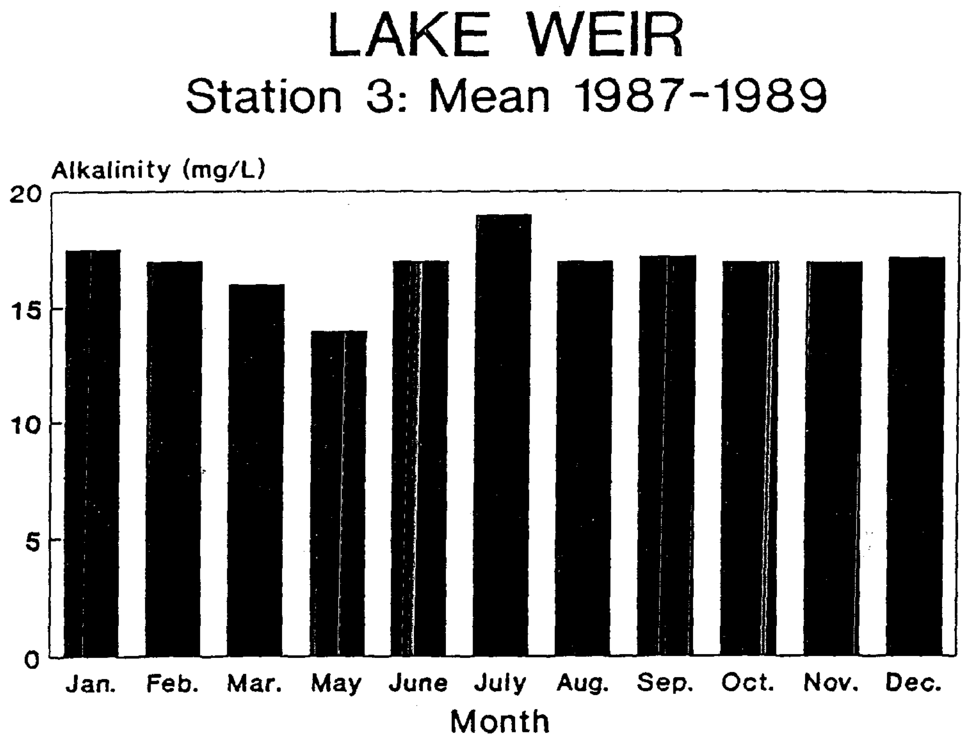


Figure 4-14. Mean alkalinity for individual months for each station of the Lake Weir system during 1987-1989.



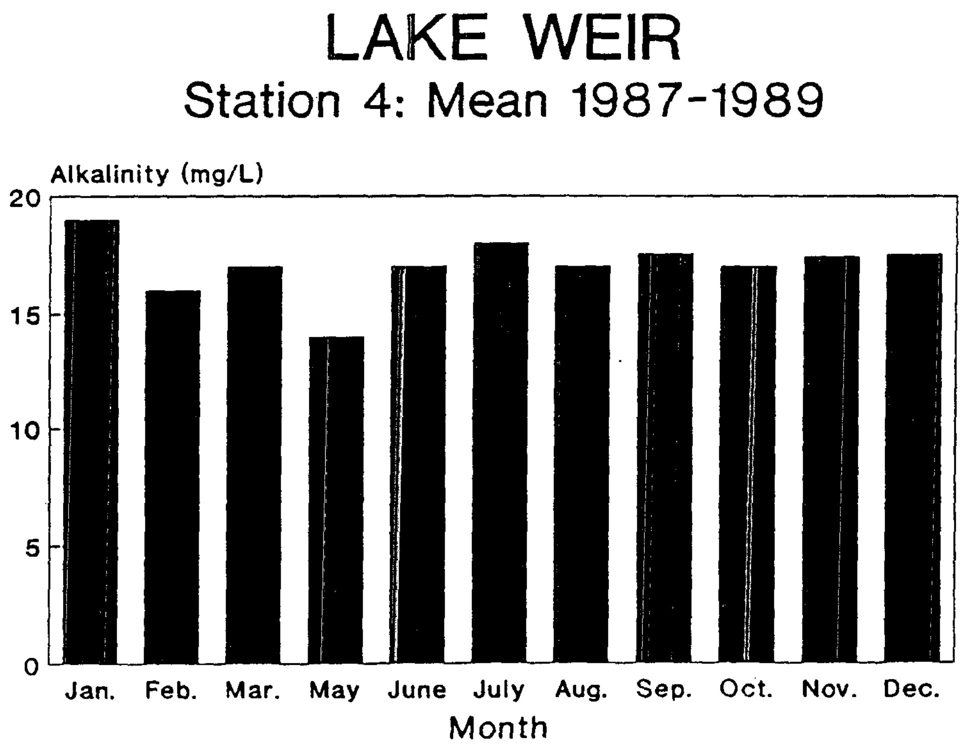
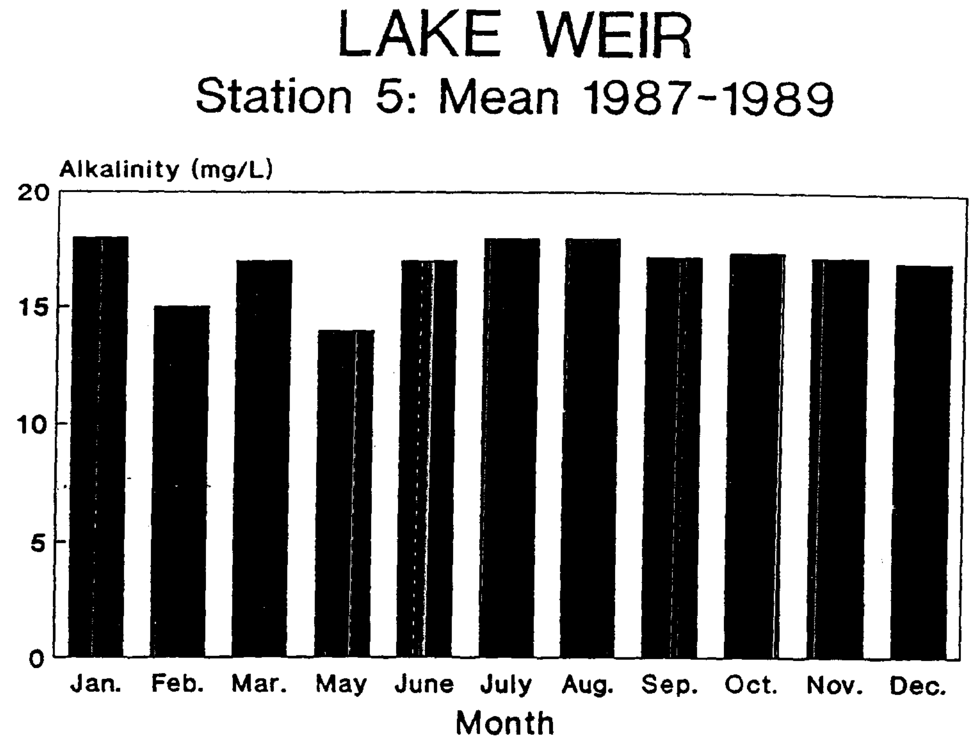


Figure 4-14. Continued.



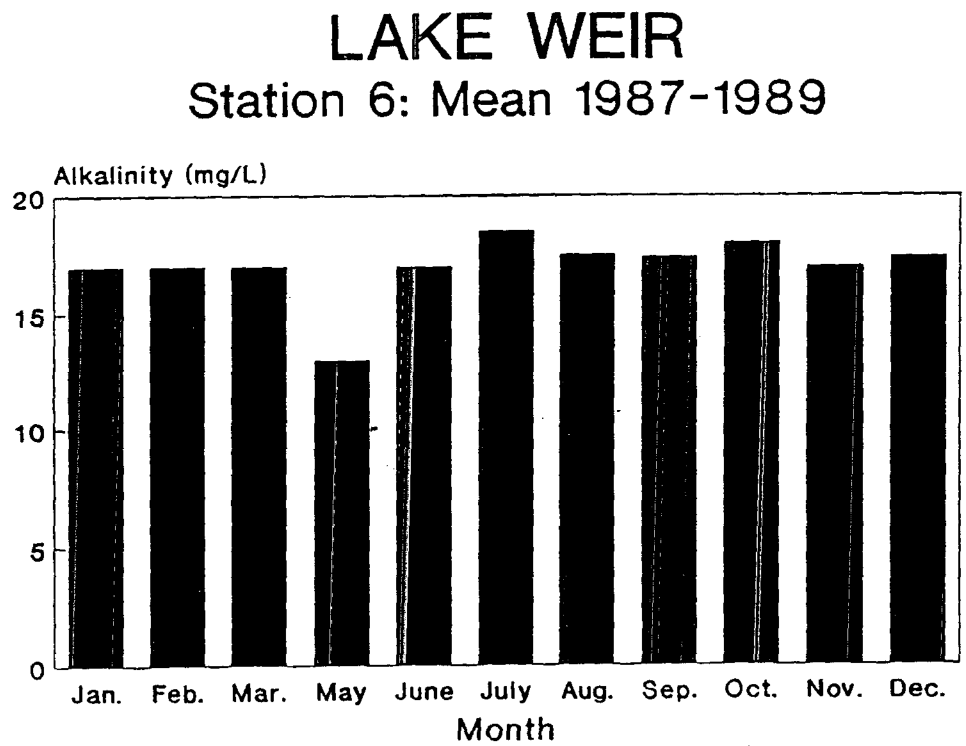


Figure 4-14. Continued.

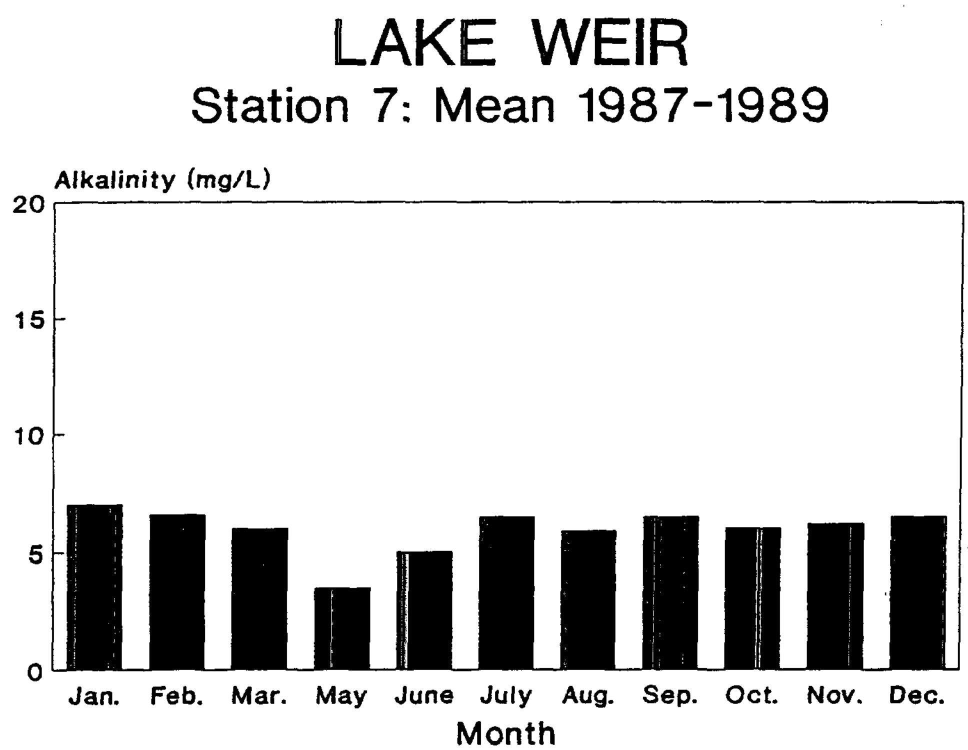


Figure 4-14. Continued.

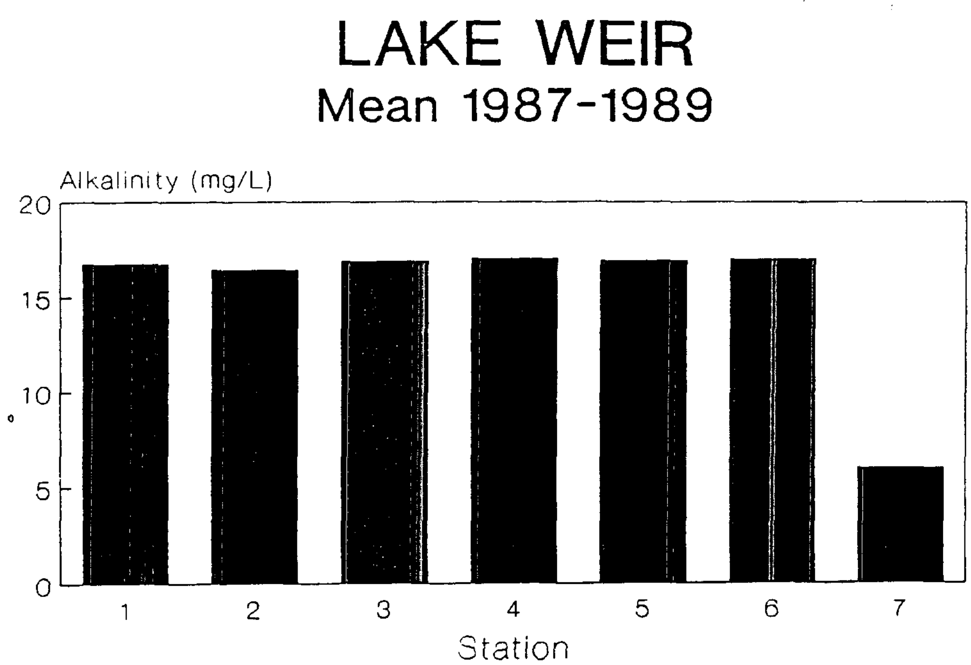
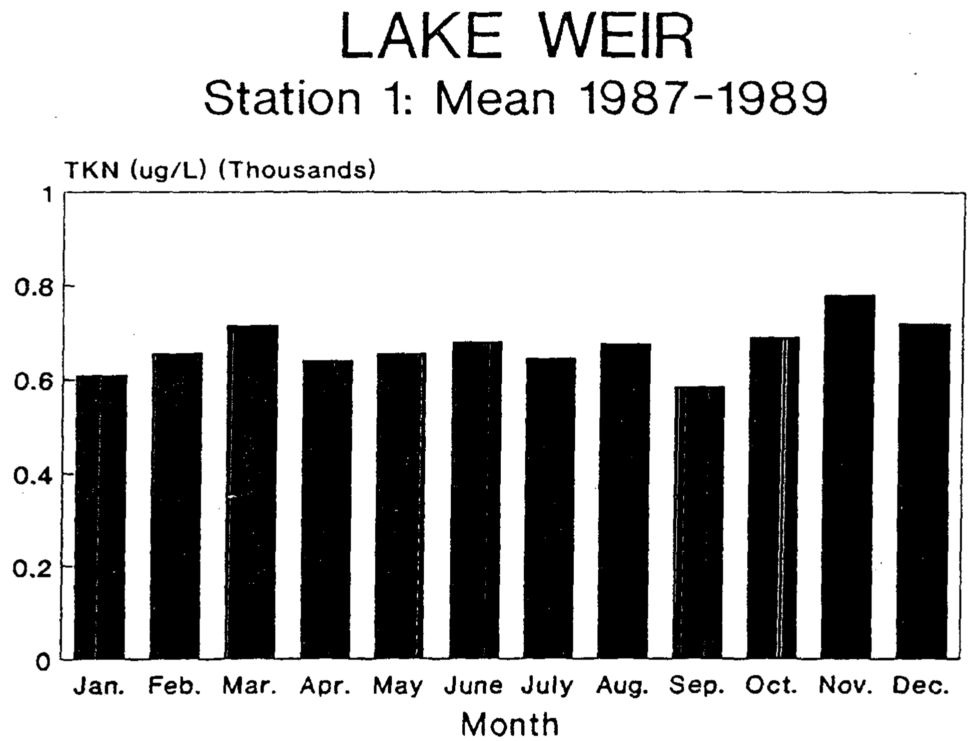


Figure 4-15 Mean alkalinity for each station of the Lake Weir system during 1987-1989.



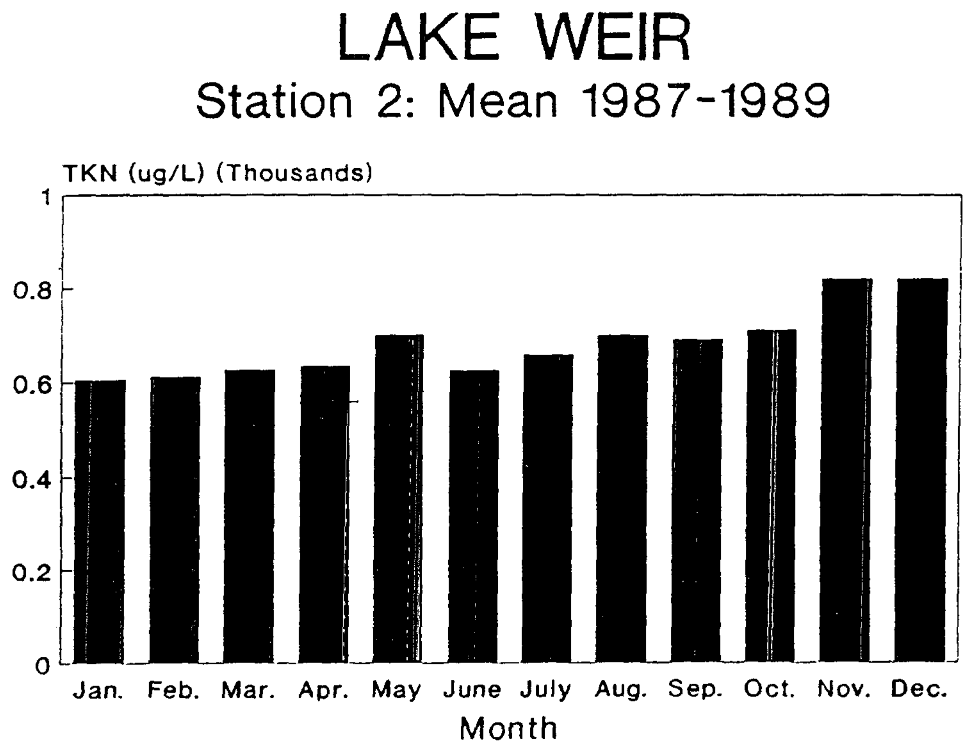
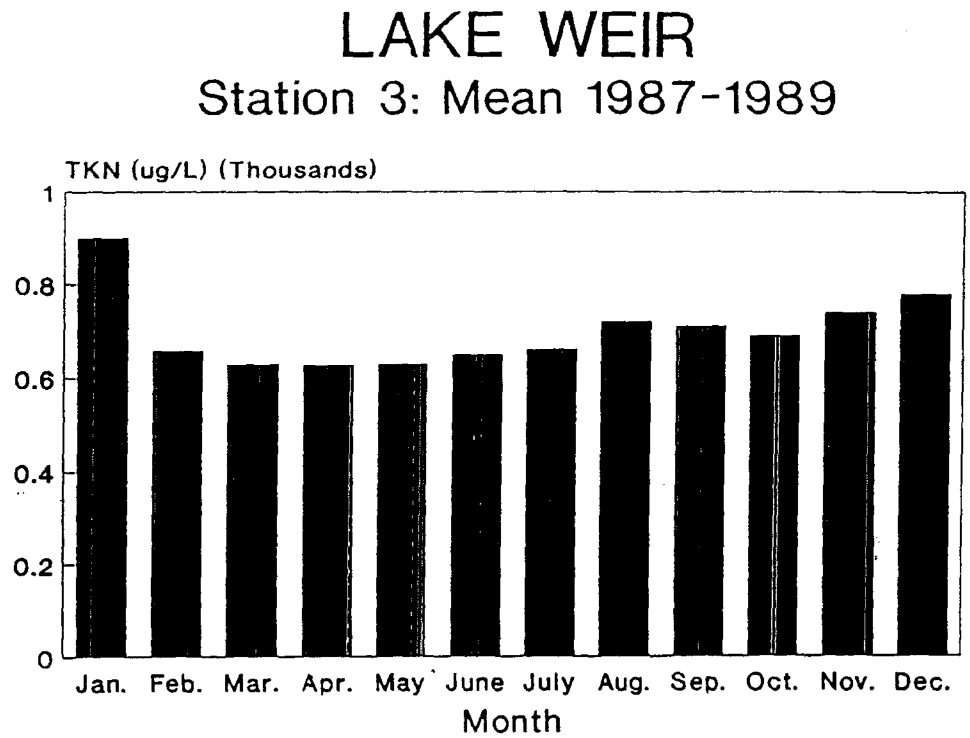


Figure 4-16. Mean total Kjeldahl nitrogen (TKN) for individual months for each station of the Lake Weir system during 1987-1989.



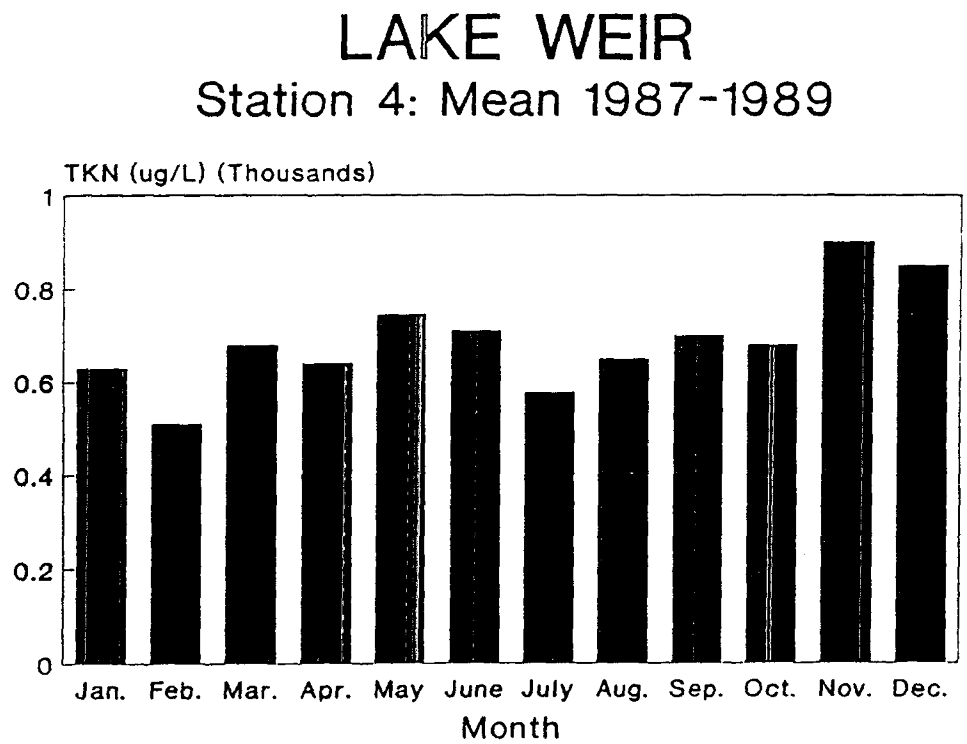
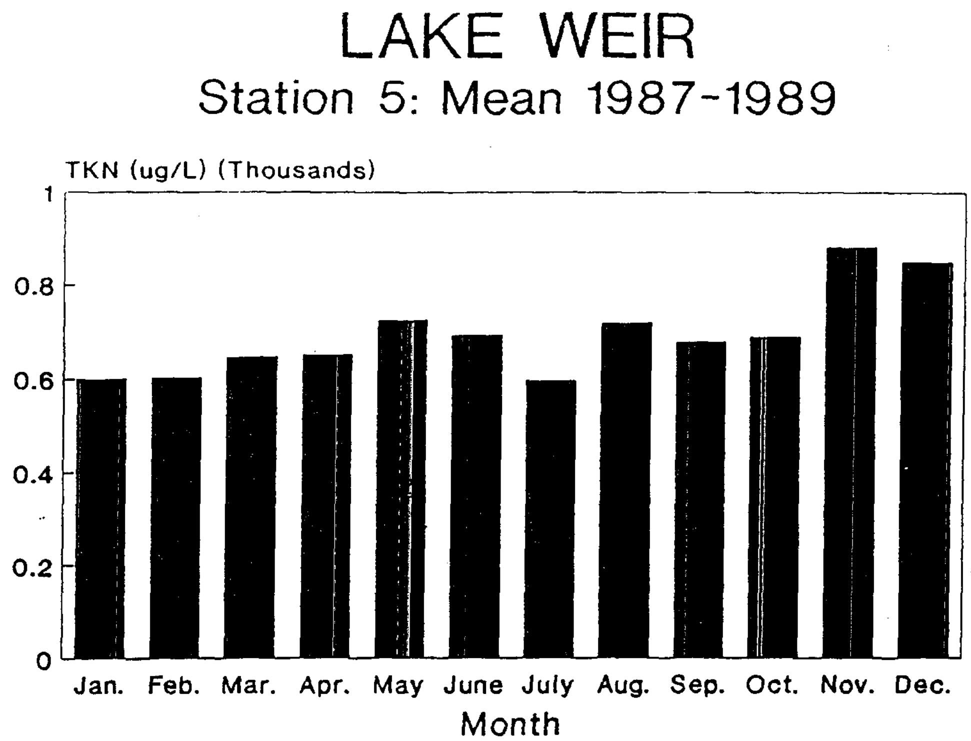


Figure 4-16. Continued.



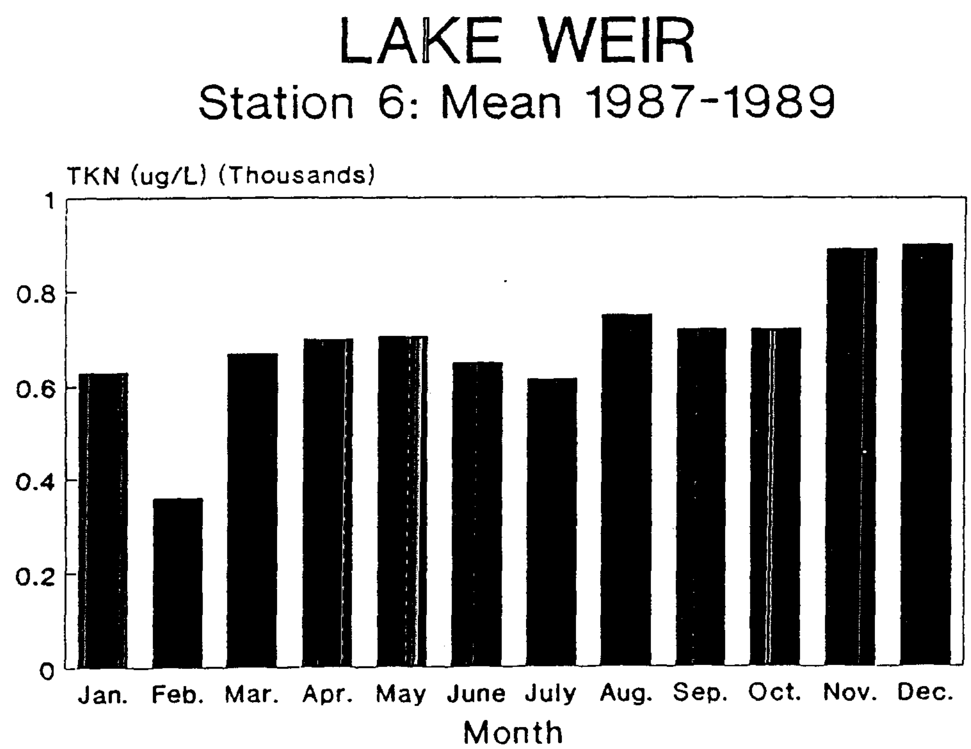


Figure 4-16. Continued.

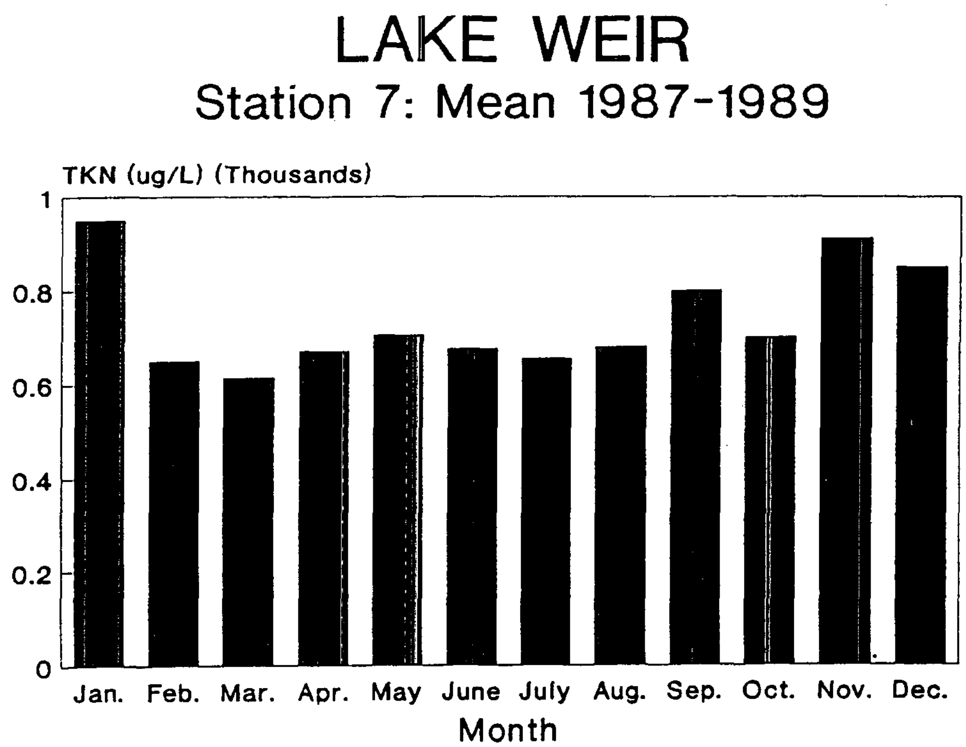


Figure 4-16. Continued.

Table 4-4. Results of Duncan's multiple range test for chemistry by month. Months connected by underlines were not significantly different.

Secchi depth

12 2 1 11 8 5 10 3 7 4 6 9

Chlorophyll a

6 3 8 4 1 9 12 7 5 11 10 2

Specific conductivity

7 8 6 9 5 10 11 4 12 2 1 3

Total Kjeldahl nitrogen

11 5 12 6 4 9 7 8 10 1 3 2

Total phosphorus

8 11 12 10 7 9 1 2 4 5 3 6

Orthophosphate

1 12 11 2 4 3 7 5 9 6 10 8

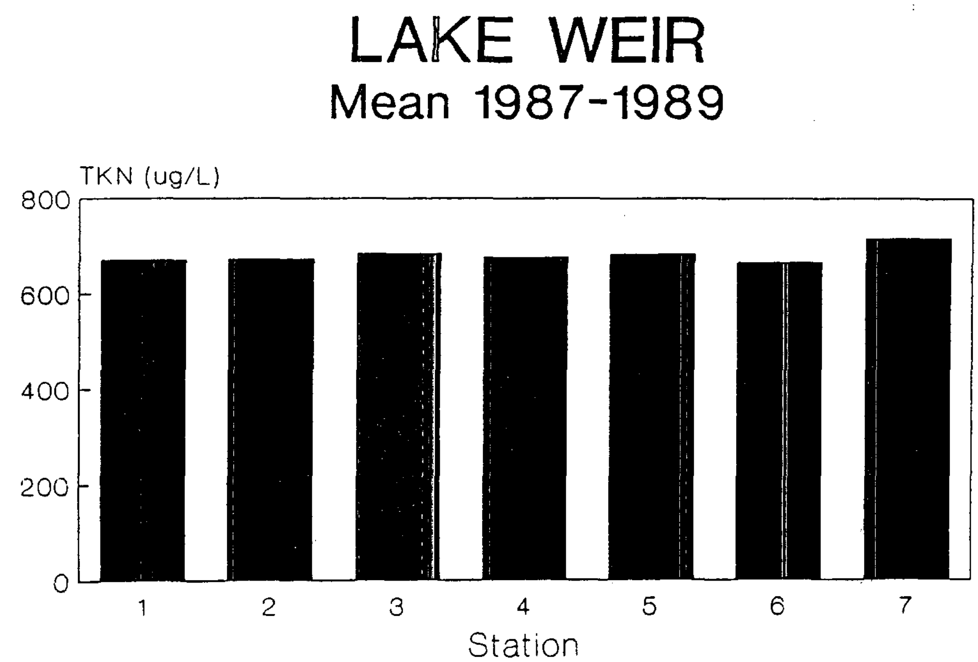
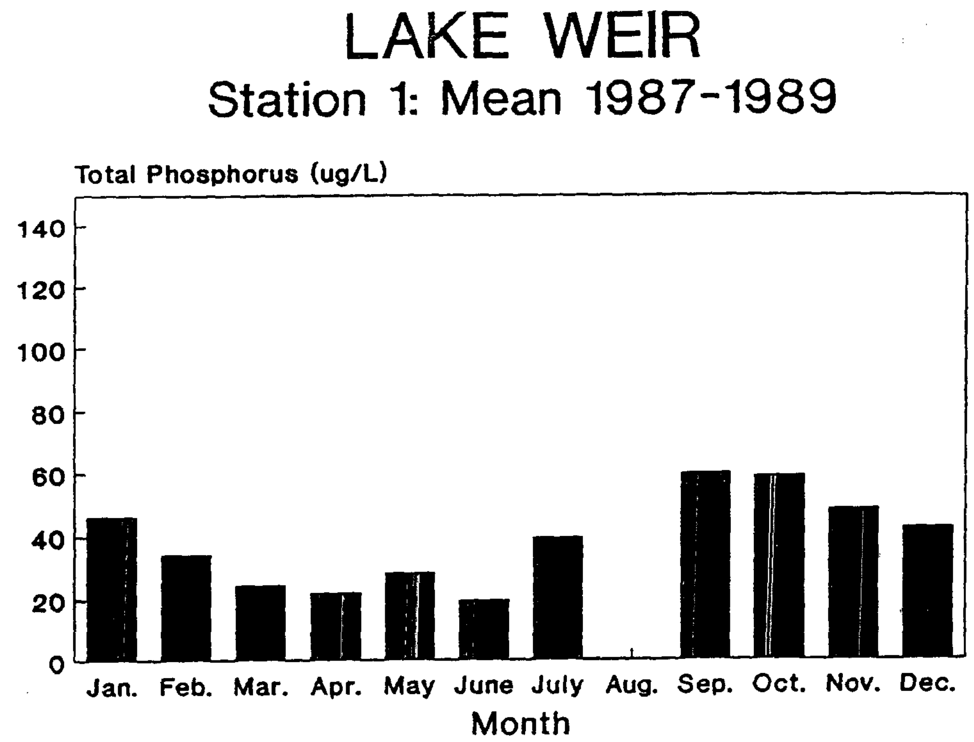


Figure 4-17 Mean total Kjeldahl nitrogen (TKN) for each station of the Lake Weir system during 1987-1989.



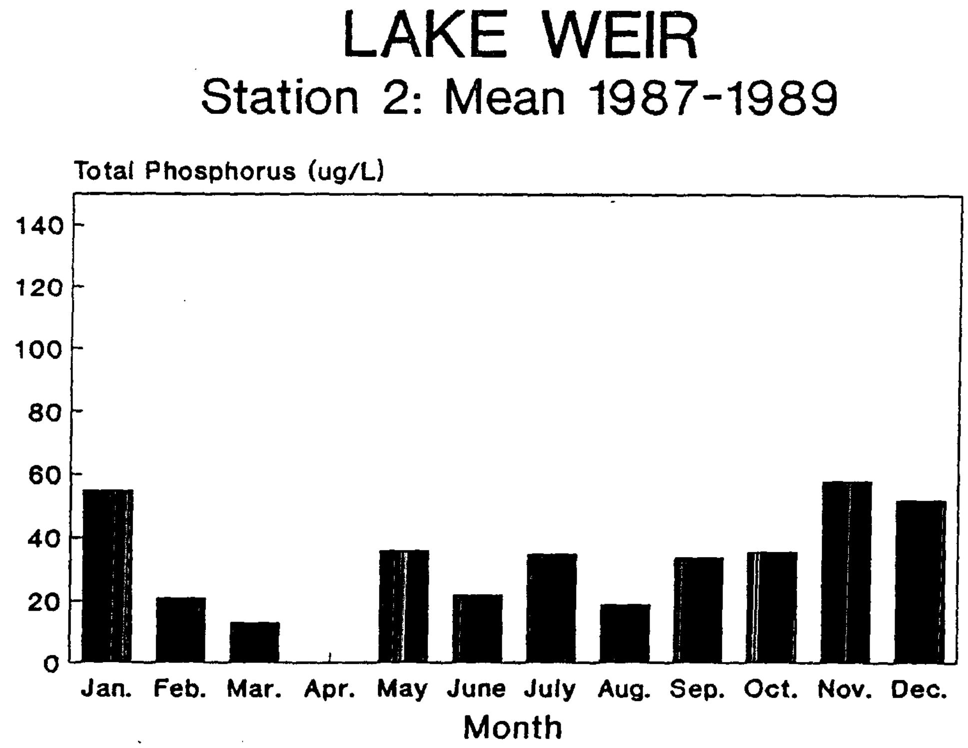
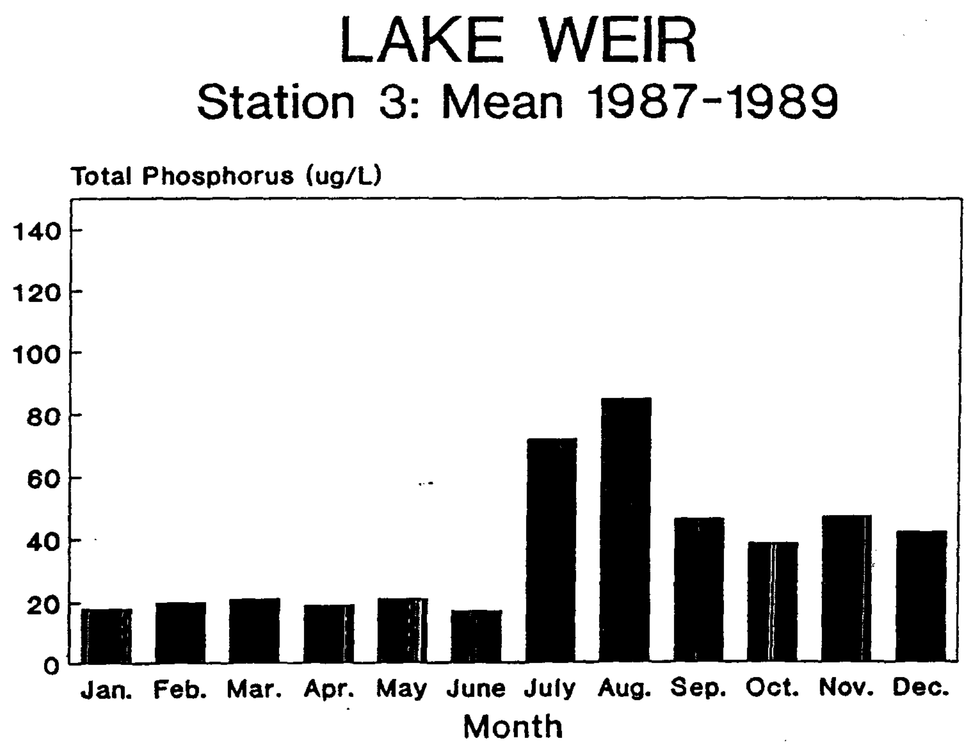


Figure 4-18. Mean total phosphorus for individual months for each station of the Lake Weir system during 1987-1989.



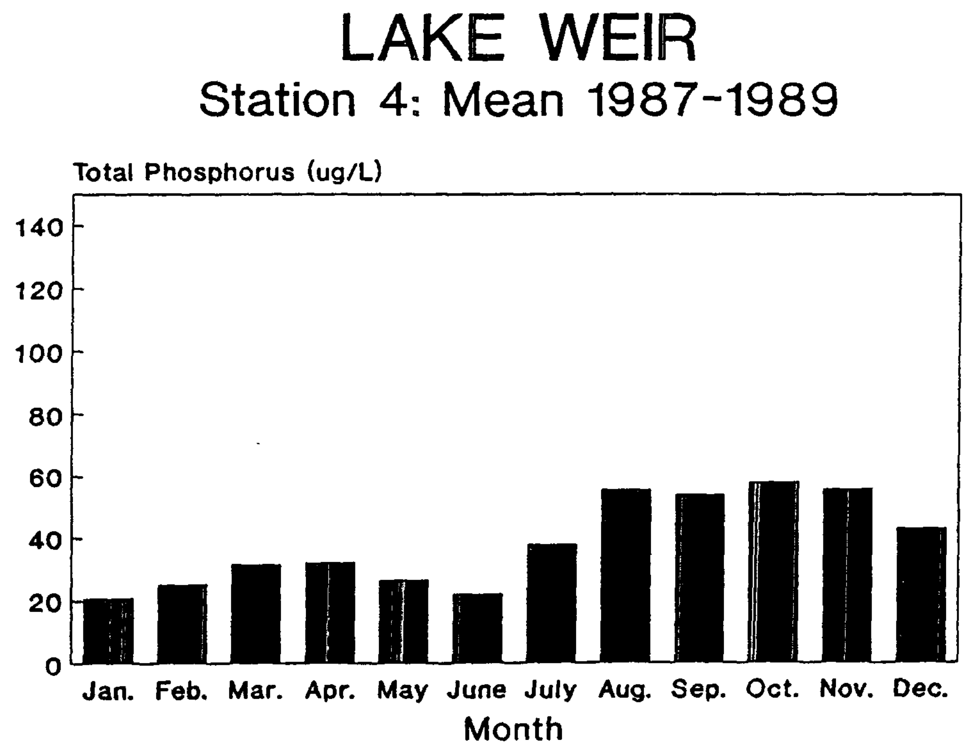
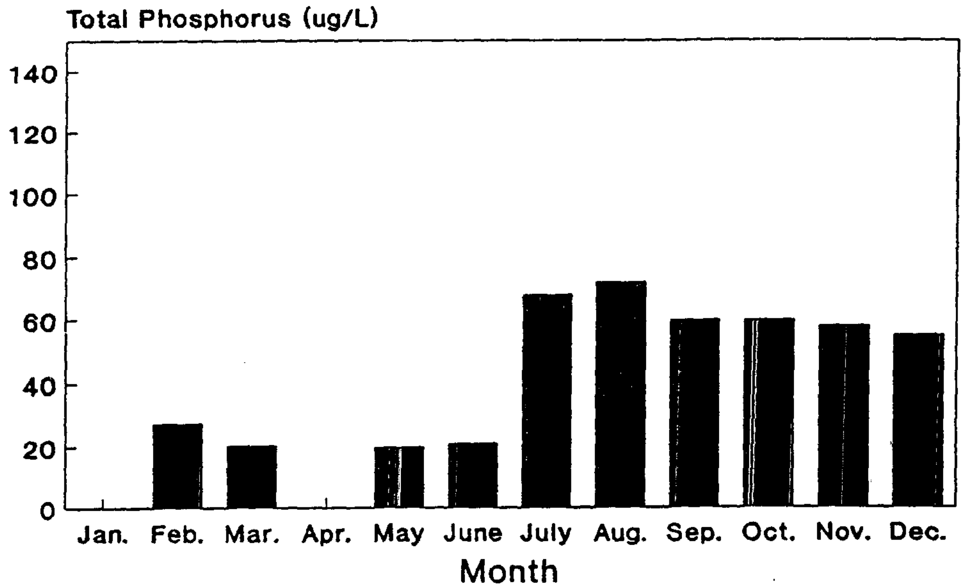


Figure 4-18. Continued.

LAKE WEIR
Station 5: Mean 1987-1989



LAKE WEIR
Station 6: Mean 1987-1989

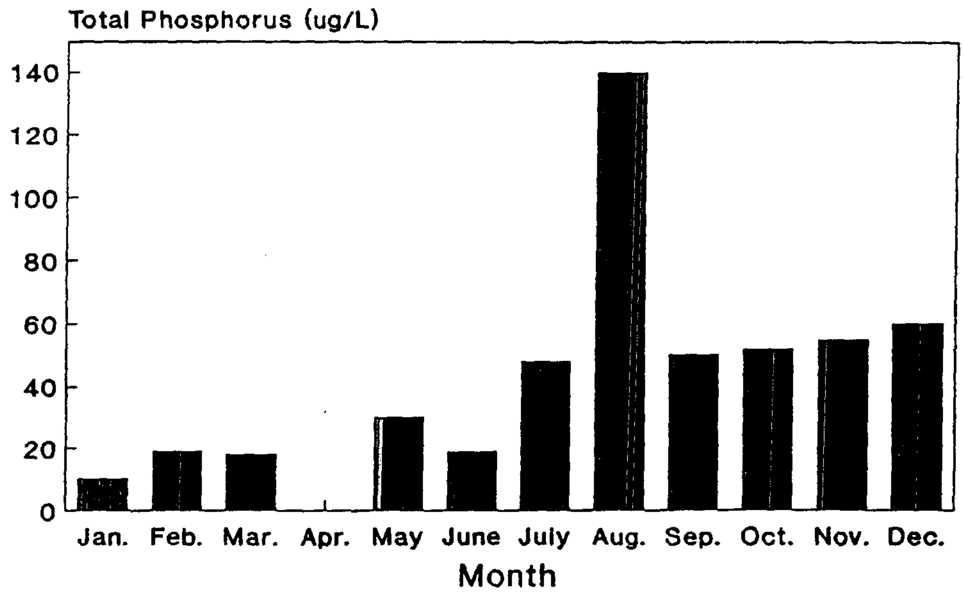


Figure 4-18. Continued.

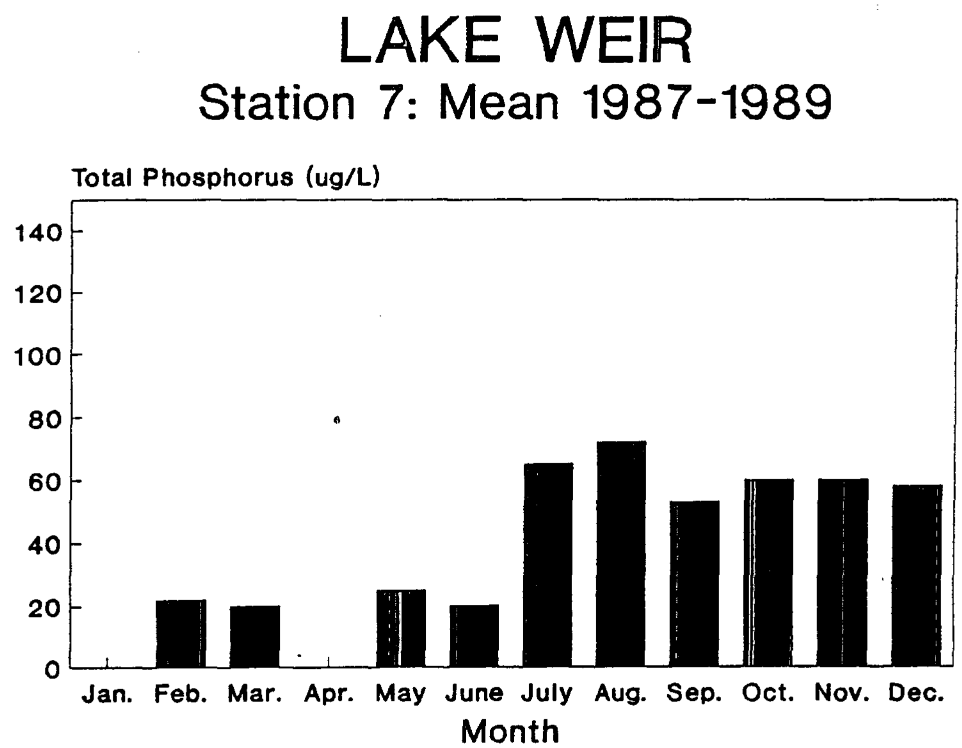


Figure 4-18. Continued.

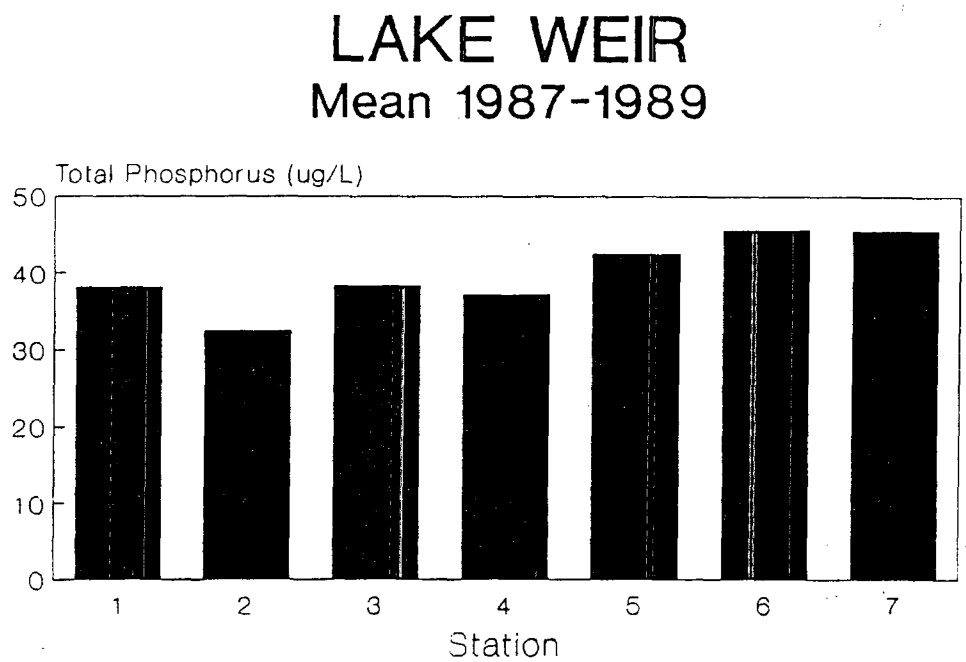


Figure 4-19 Mean total phosphorus for each station of the Lake Weir system during 1987-198

4.3.F ORTHOPHOSPHATE

Orthophosphate concentrations were maximal at all stations during November and December and minimal during August (Figure 4-20). January and December were significantly greater than all other months, and August was significantly lower than winter months (Table 4-3, 4-4). Although orthophosphate values were lowest in Little Lake Weir (Figure 4-21), no significant differences were noted in values among any of the stations of the study (Table 4-1).

4.3.G CHLOROPHYLL

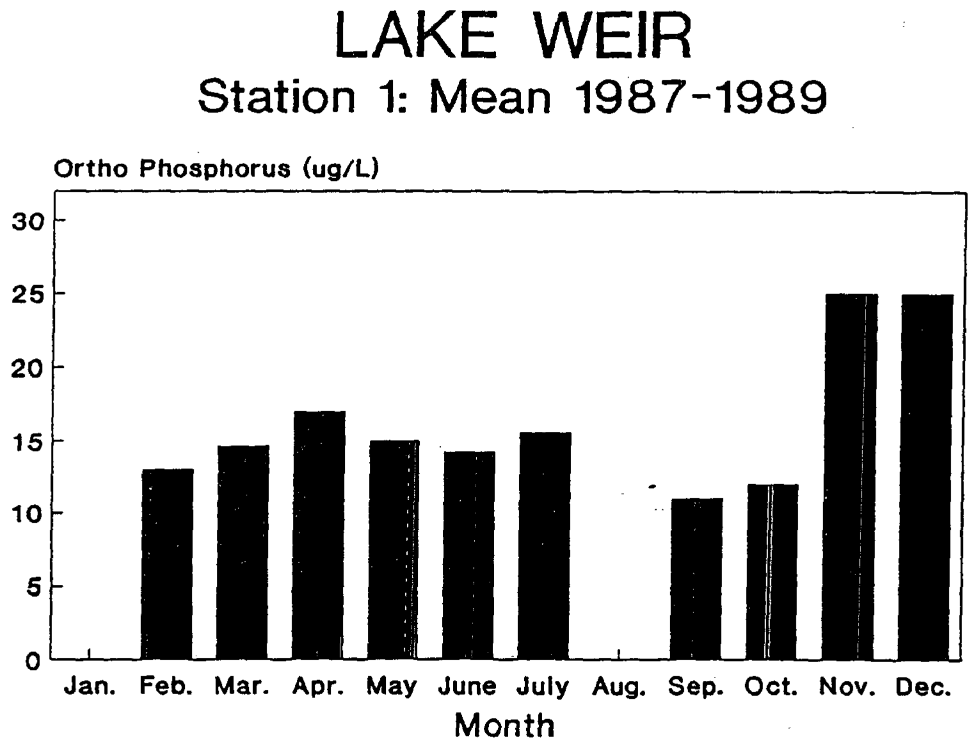
Chlorophyll a concentrations at most stations were lowest during late fall and late winter and greatest during mid summer (Figure 4-22). On a system basis, values were lower during February and March than the rest of the year. Mean chlorophyll values (6-7 mg/L) for the study period were representative of upper mesotrophic conditions (Figure 4-23). Although values were lowest in Little Lake Weir, there were no significant differences in chlorophyll means among individual stations of the survey (Table 4-1).

4.4 COMPARISON WITH HISTORICAL LIMNOLOGICAL DATABASE

4.4.A INTRODUCTION

Data were extracted from various University of Florida theses, and reports and unpublished data from the Florida Department of Environmental Regulation, Florida Game and Fresh Water Fish Commission, United States Geological Survey and the St. Johns River Water Management District for analysis of trends in water quality changes over the past 30 years (Table 4-5). Means were calculated by year, and station numbers were assigned to correspond to our current sampling stations. Statistical analyses were performed using SAS (1986).

Comparisons between current and past records of phytoplankton (Messer 1975), and macrophyte abundance and species lists (Garren 1982, FGFWFC 1985 and 1986) were made using data from several University of Florida theses, and reports



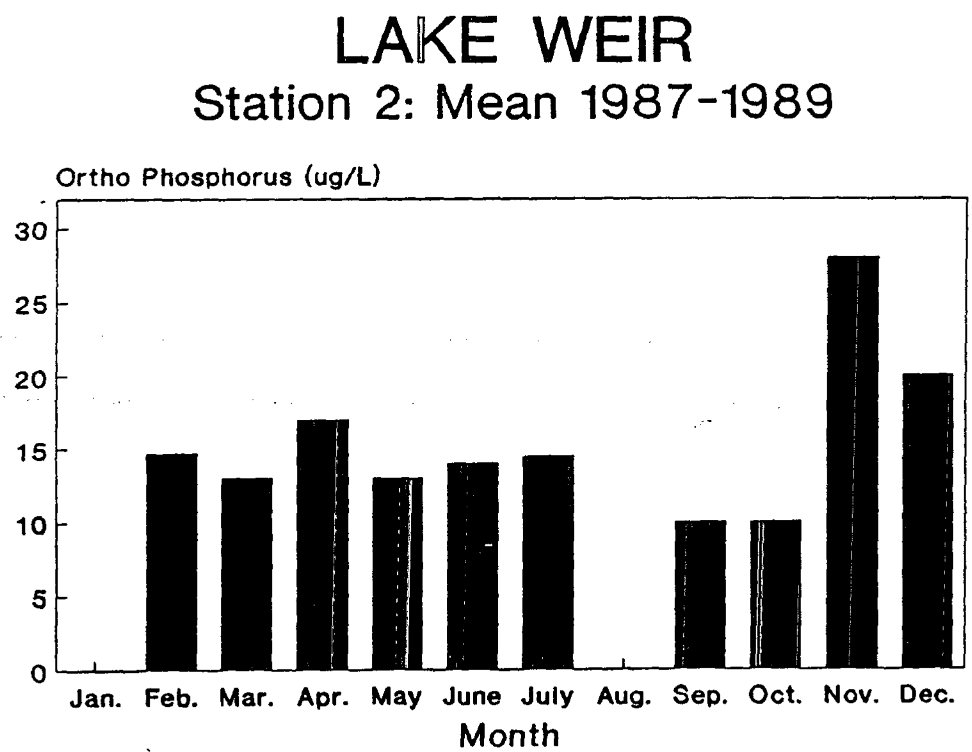
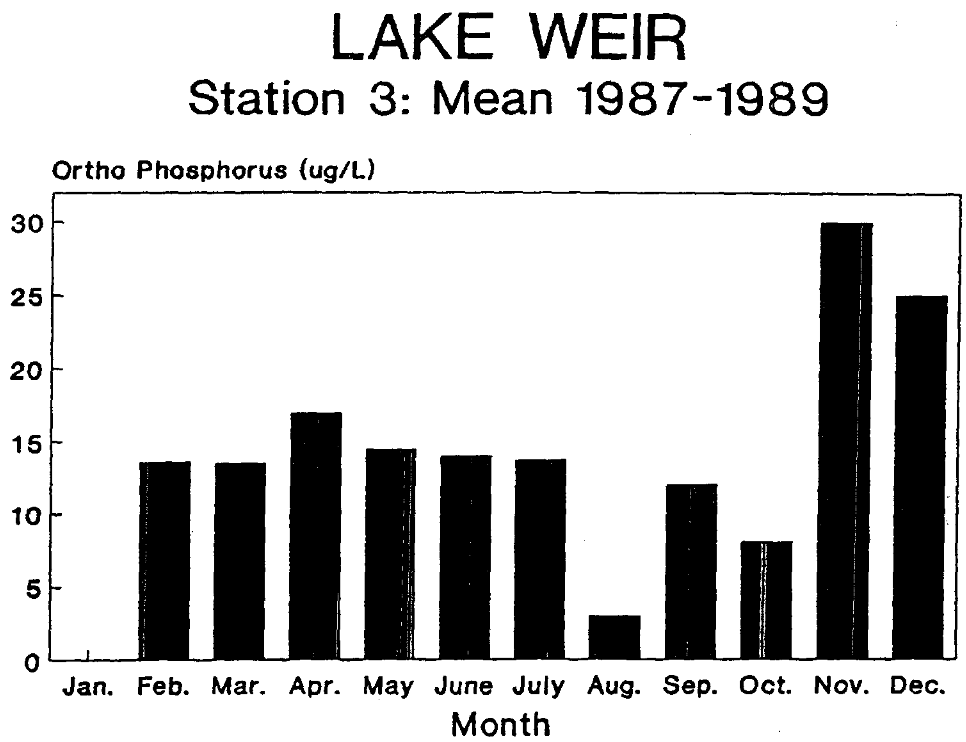


Figure 4-20. Mean ortho phosphorus for individual months for each station of the Lake Weir system during 1987-1989.



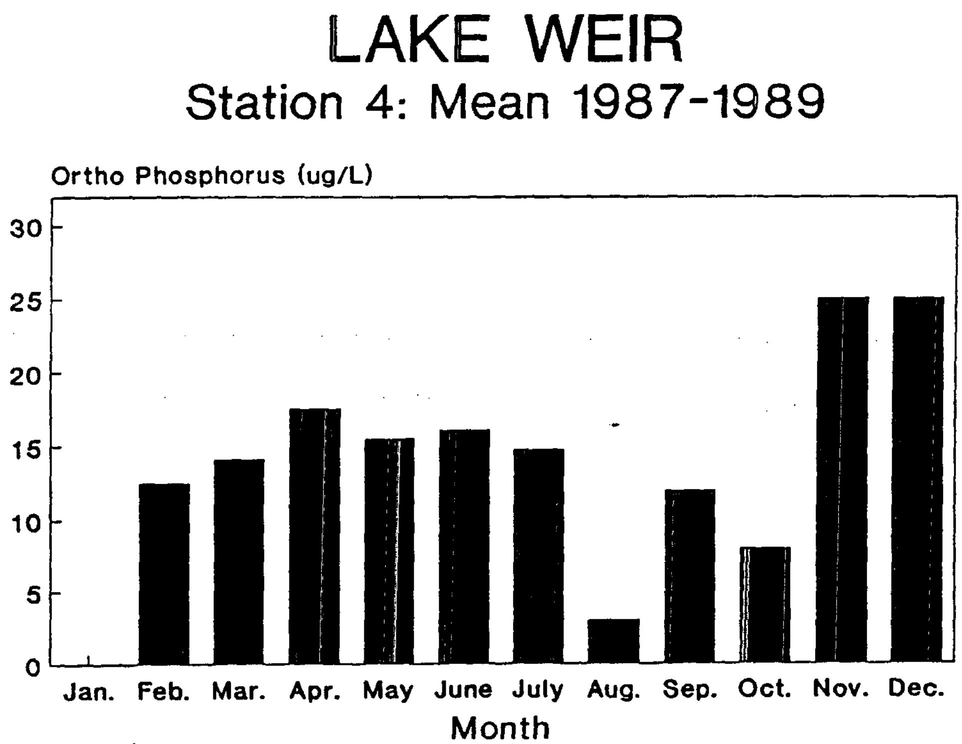
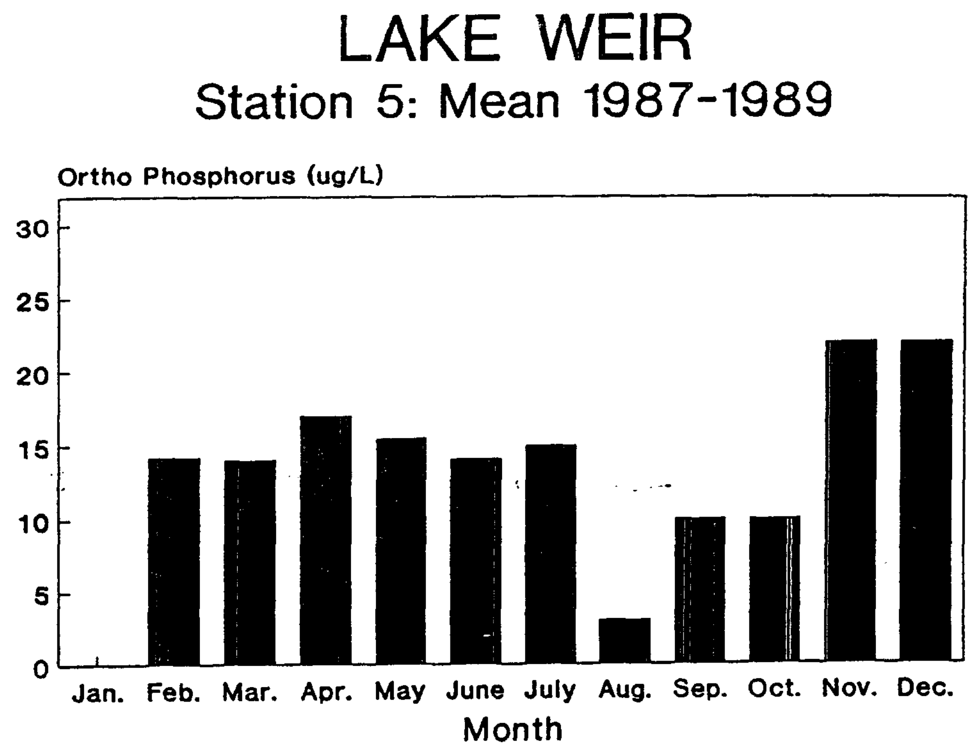


Figure 4-20. Continued.



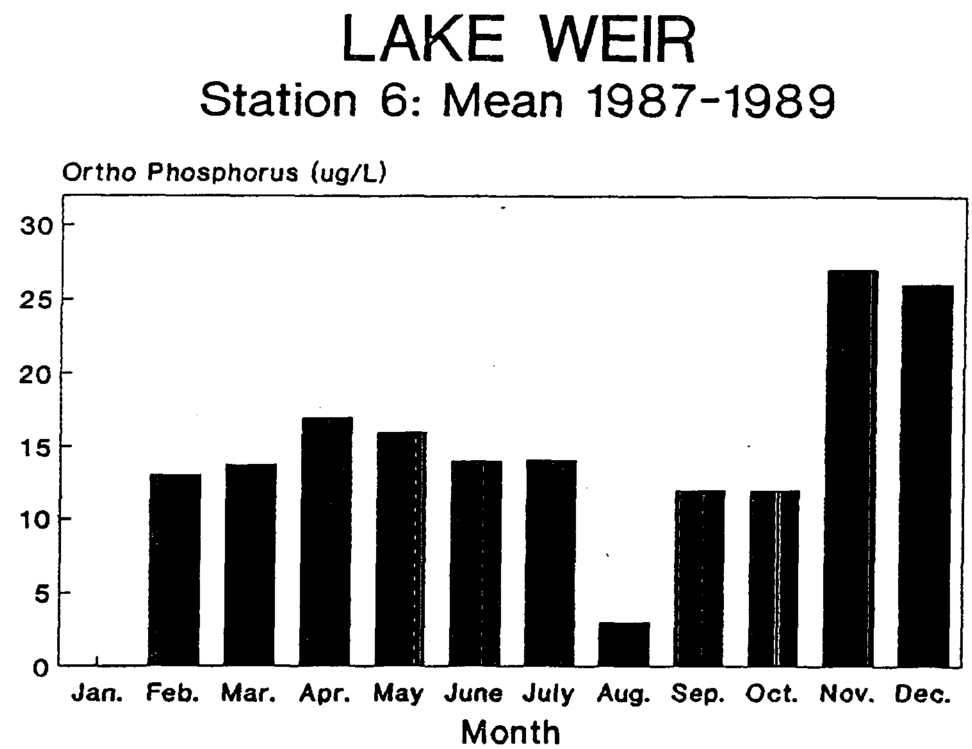


Figure 4-20. Continued.

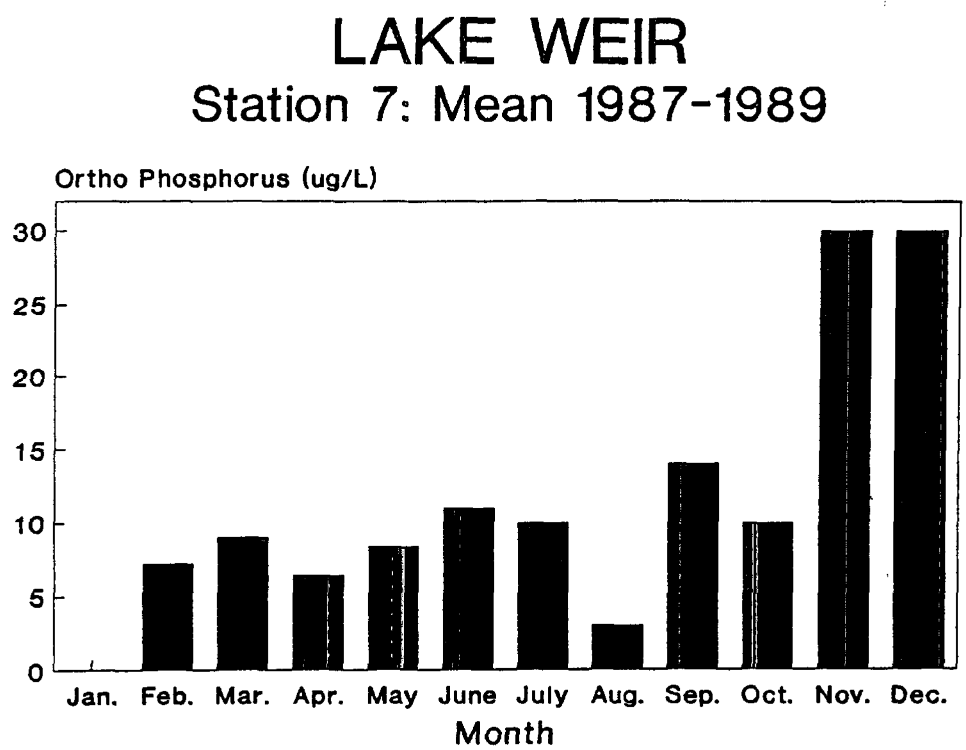


Figure 4-20. Continued.

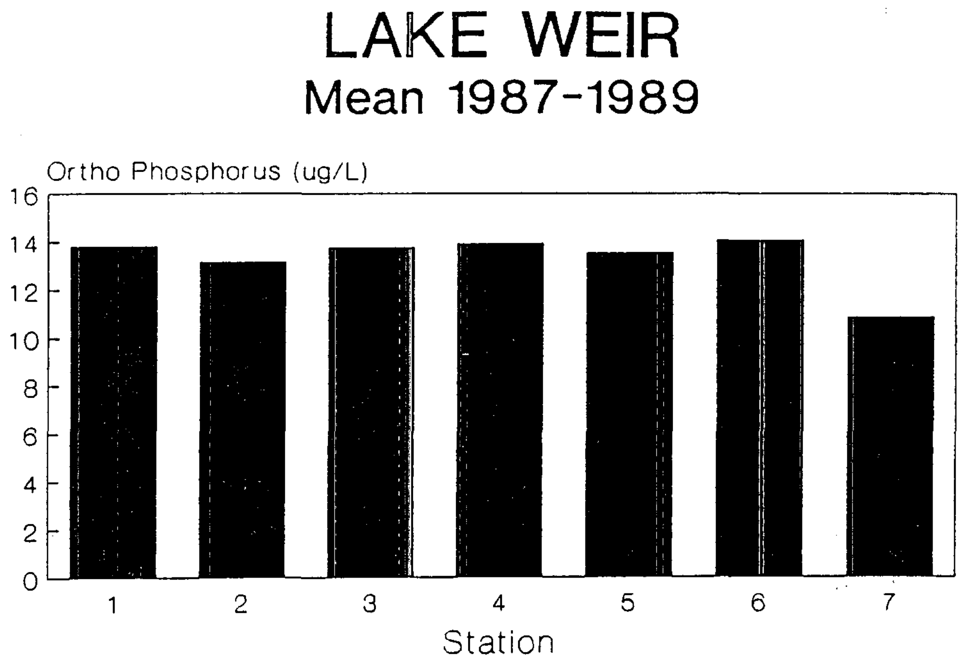
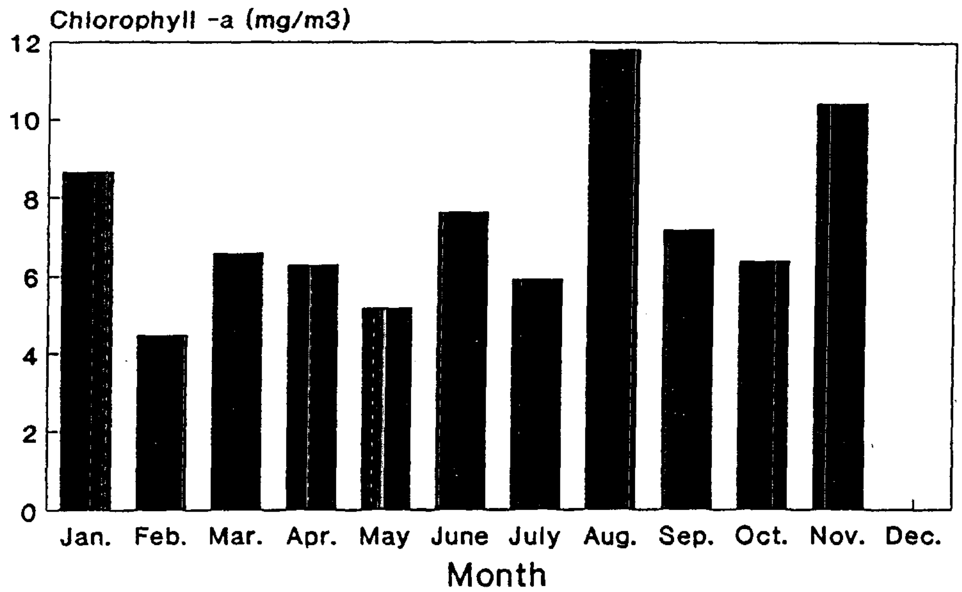


Figure 4-21. Mean ortho phosphorus for each station of the Lake Weir system during 1987-198

LAKE WEIR
Station 1: Mean 1987-1989



LAKE WEIR
Station 2: Mean 1987-1989

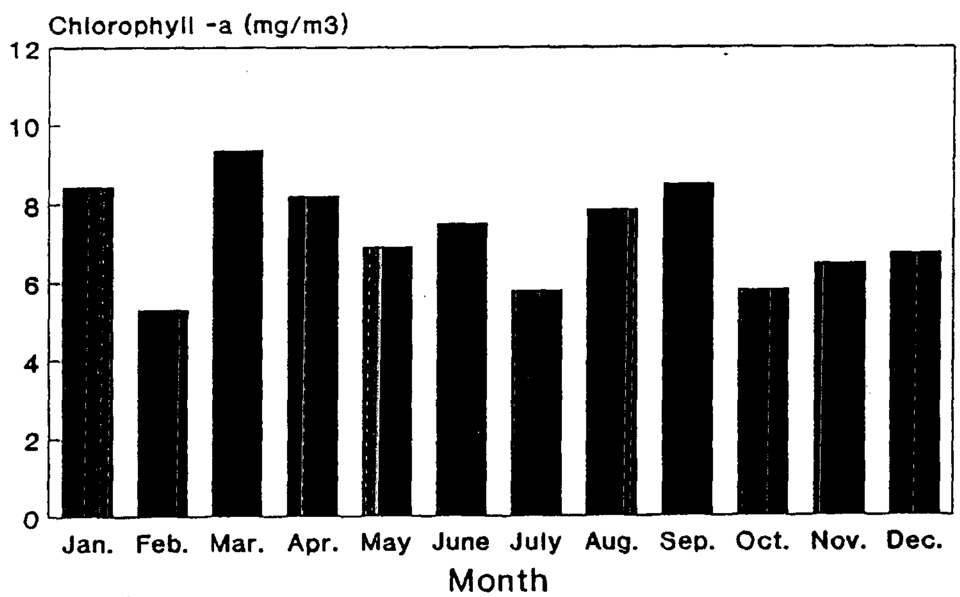
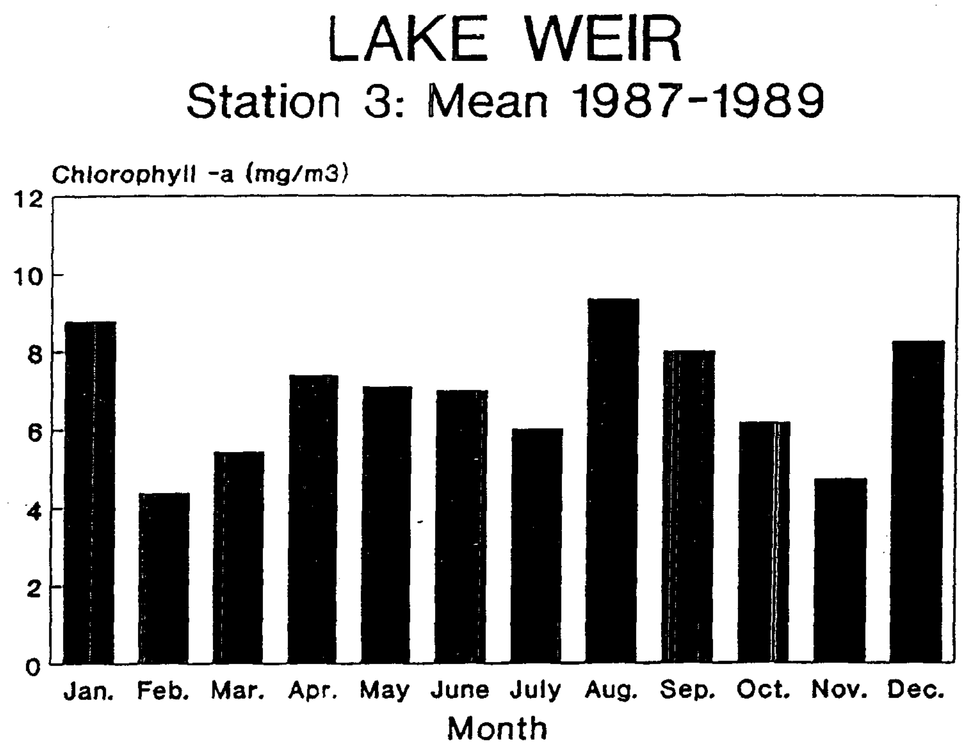


Figure 4-22. Mean chlorophyll-a for individual months for each station of the Lake Weir system during 1987-1989.



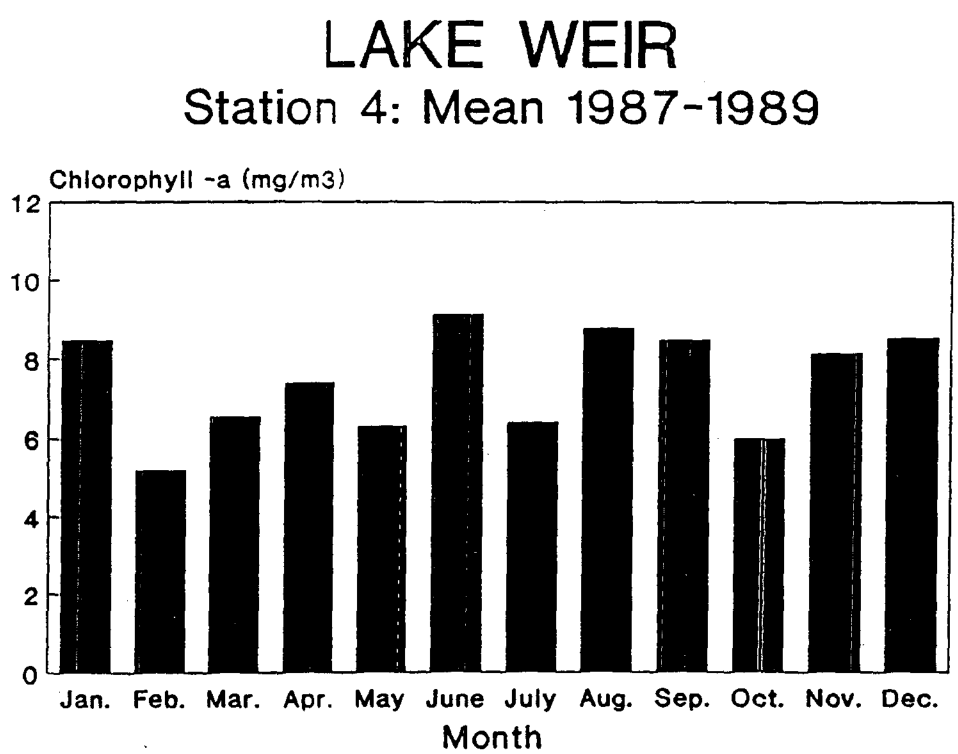
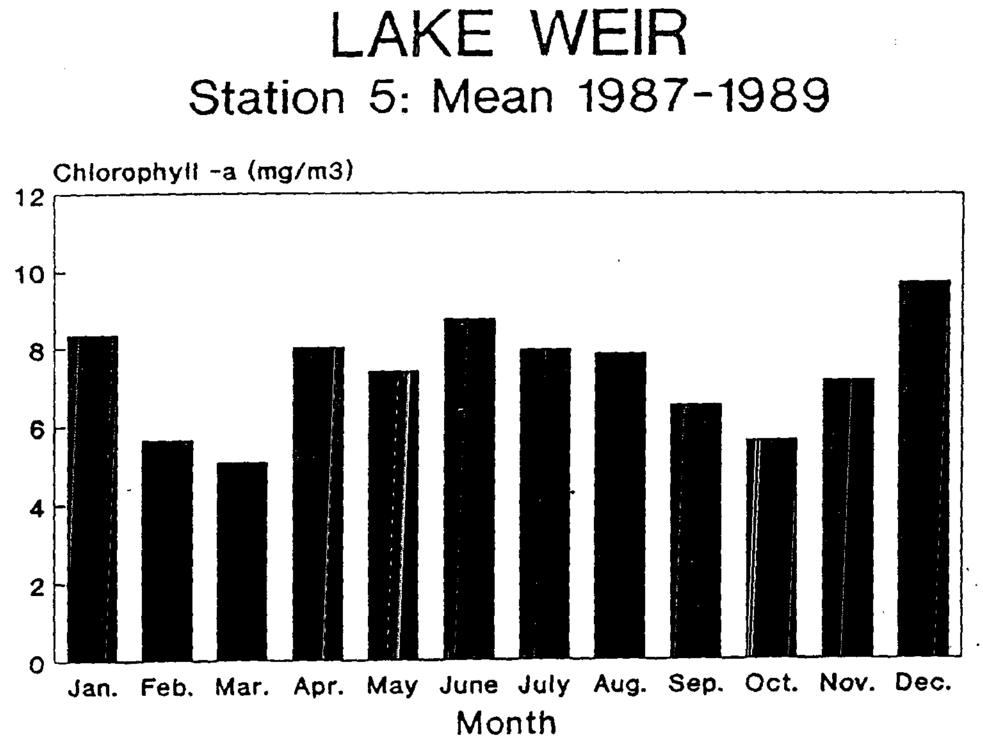


Figure 4-22. Continued.



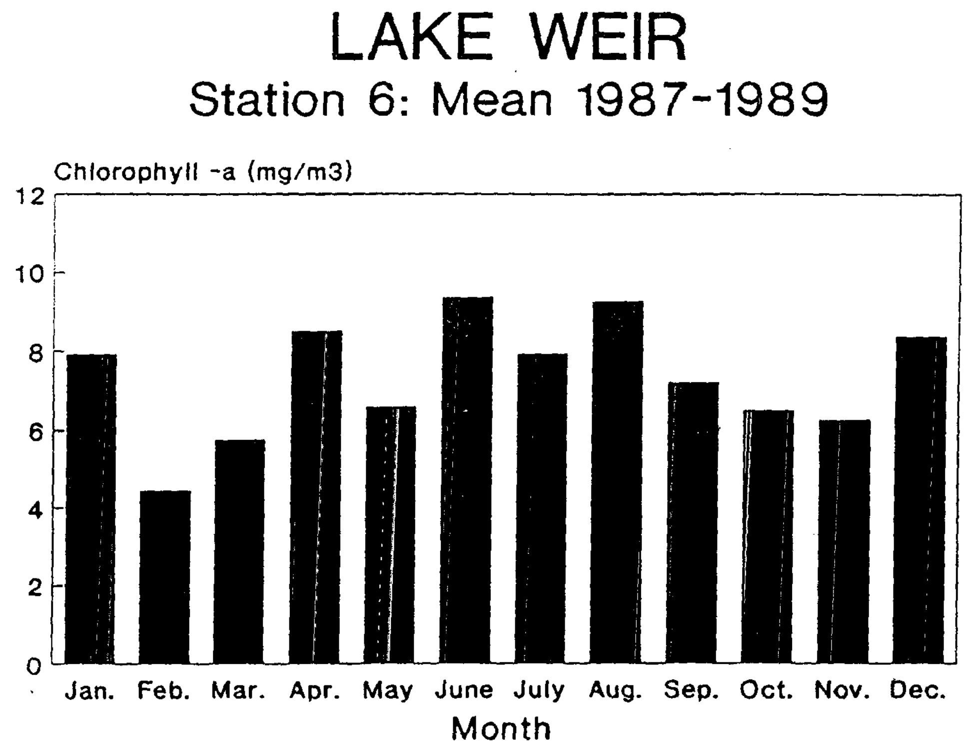


Figure 4-22. Continued.

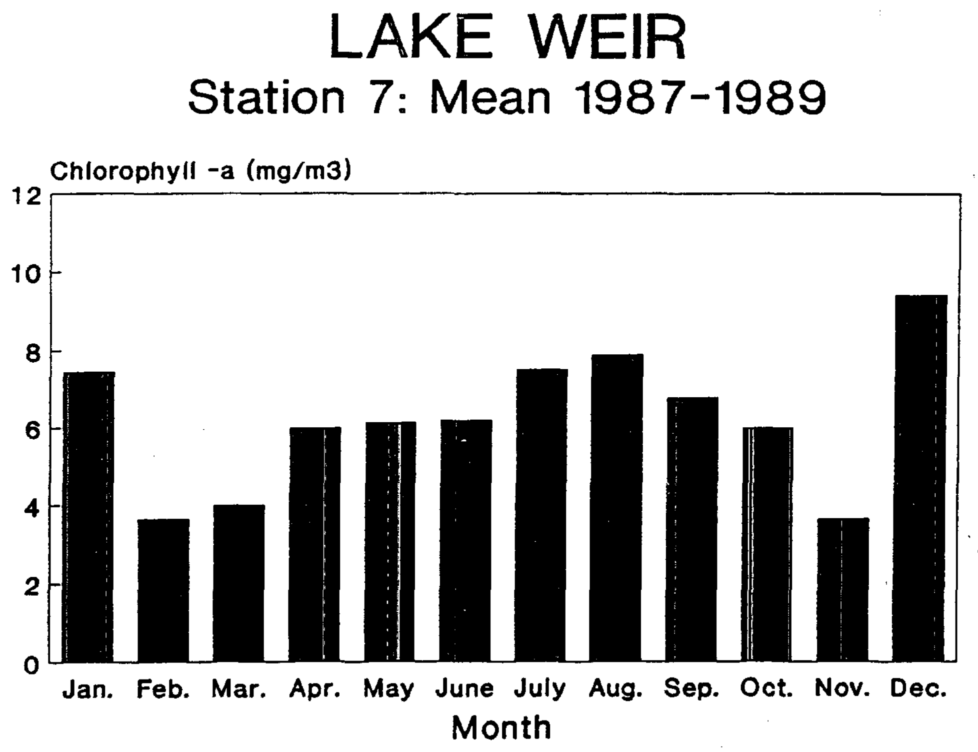


Figure 4-22. Continued.

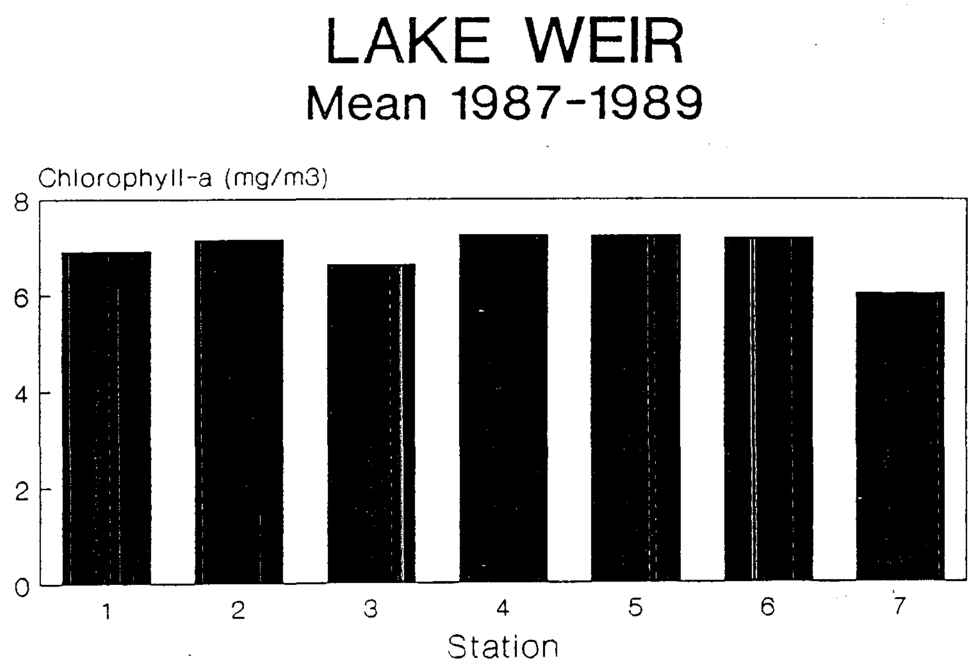


Figure 4-23. Mean chlorophyll-a for each station of the Lake Weir system during 1987-198

Table 4-5. List of studies containing water chemistry data from Lake Weir from 1968-1987.

Reference[a]	Study Date	No. Sample Dates	Sample[b] Station
FGFWFC 1968	1967-1968	26	2,4,6
Shannon 1971	1969-1970	6	3[c]
FGFWFC 1973	1972-1973	2	3
Messer 1975	1974-1975	12	3[c]
Beaver 1980	1979	12	3[c]
Canfield 1981	1979-1980	3	3[c]
Garren 1982	1981	1	3
FDER 1987	1975-1986	46	3,5,6[c]
USGS 1987	1956-1983	40	2

[a] Complete citation in Literature Cited. [b] Stations designated to correspond to current sampling stations in Lake Weir. [c] Data used for comparison between historical and current water chemistry parameters.

by the Florida Game and Fresh Water Fish Commission.

4.4.B TROPHIC STATE PARAMETERS

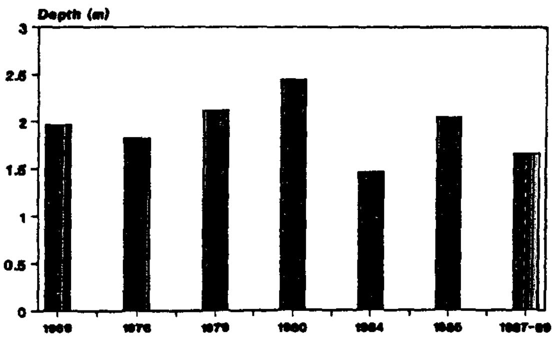
Records of water quality parameters in Lake Weir have been maintained by various agencies since 1956. However, virtually no measurements of chlorophyll a are available for years prior to 1969, and other parameters were only intermittently recorded over the years (e.g. Secchi depth, turbidity and alkalinity). Numerous samples were taken at multiple stations in some years, while for others only 1 mid lake sample was analyzed. Therefore, comparisons between these past data and current conditions in Lake Weir were based on means calculated for 1969, 1975, 1979, 1981, and 1984-1985 from the midlake station, and those of the current 1987-89 database. Data were most abundant for that station, and it is more indicative of overall conditions in Lake Weir due to its location and depth. We have, however, included the entire historical database in our analyses where deemed appropriate.

Analyses of past and current annual means of chlorophyll a, TKN, TP, and Secchi depth in Lake Weir by GLM and Duncan's procedure indicated that there are no significant differences among the years except for chlorophyll a and total phosphorus (Tables 4-6, 4-7, Figure 4-24). Sampling frequency, station locations, and analytical methodologies used by various agencies and researchers whose historical data were used may also have dampened our ability to see statistical differences.

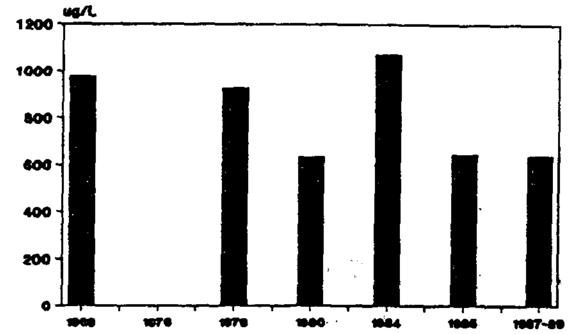
Trophic state indices (TSI) were calculated from both historical and current means of Secchi depth, chlorophyll a concentration, total nitrogen and total phosphorus (Table 4-8). These indices take into account the relationship between lake primary production and nutrient concentrations, chlorophyll a levels, and water clarity (Huber et al. 1982). As lake production increases, the TSI rises. Comparisons of these values enabled us to evaluate changes in the overall trophic level of Lake Weir based on several parameters.

Little difference existed among the indices based on past data and those calculated from current measurements. All values placed Lake Weir in the mesotrophic category. Historical TSI estimates for chlorophyll and TKN were slightly lower than current TSI calculations, while those for TP and Secchi were higher than present.

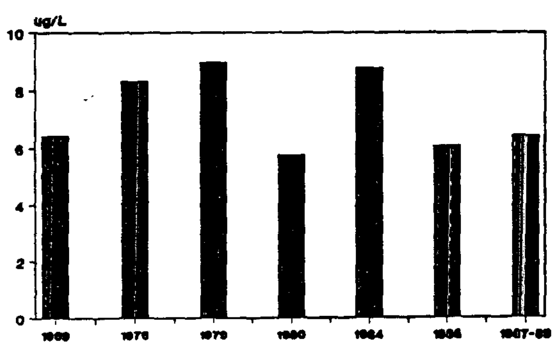
Lake Weir Historical Secchi
Annual Means for 1969-1989, Station 3



Lake Weir Historical TKN
Annual Means for 1969-1989, Station 3



Lake Weir Historical Chlorophyll-a
Annual Means for 1969-1989, Station 3



Lake Weir Historical TP
Annual Means for 1969-1989, Station 3

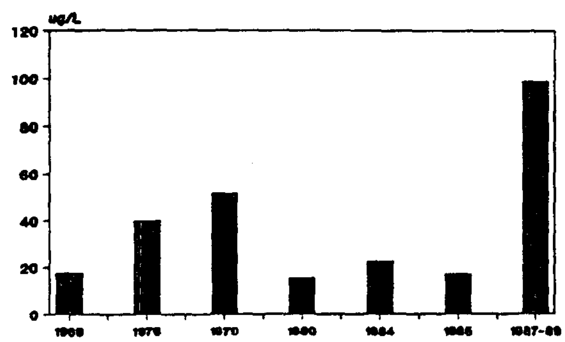


Figure 4-24. Historical water chemistry for Lake Weir expressed as annual means for 1969-1989.

Table 4-6. Summary of historical and current values for four water quality indicators at Station 3 in Lake Weir, FL.

Parameter	Historical Value[a] Mean ± S.D (N)	Current Value[b] Mean ± S.D (N)
Chlorophyll a (ug/L)	8.01 ± 1.30 (32)	6.42 ± 1.36 (24)
Total phosphorus (ug/L)	28.08 ± 16.29 (34)	98.60 ± 13.99(23)
Total Kjeldahl nitrogen (ug/L)	854.17 ± 180.44 (32)	641 ± 50.48 (24)
Secchi depth (m)	1.94 ± 0.34 (35)	1.67 ± 0.14 (24)

[a]Historical values based on data from 1969, 1975, 1979, 1980, 1984-85.

[b]Current values based on averages of data from 1987-1989.

Table 4-7. Results of comparisons of indicators of historical and current trophic state in Lake Weir (Station 3) by GLM and Duncan's procedure. Years connected by the same underline are not significantly different.

Parameter	N	F	Significance
Chlorophyll *a*	47	41.12	**
Total Kjeldahl nitrogen	46	1.65	n.s.
Total phosphorus	47	1.85	*
Secchi depth	44	1.29	n.s.

Chlorophyll *a*

76 73 84 72 79 74 69 87 88 89 78 85 80 86 70

Total phosphorus

74 87 79 73 72 75 88 84 78 69 89 85 80 86 70

n.s.=not significant; * Significant at $p \leq 0.05$.

Table 4-8. Trophic state indices (Huber _et al_. 1982) calculated from historical and current values for Lake Weir water quality at Station 3.

TSI	Historical Value	Current Value	Trophic* State
Chlorophyll _a_	46.76	44.36	O-M
Total phosphorus	43.63	61.04	M
Total Kjeldahl nitrogen	52.87	51.22	M
Secchi depth (m)	40.05	47.43	M

* O=oligotrophic, M=mesotrophic;

4.4.C BACTERIA

No historical water column bacteria data for Lake Weir have been located. Thus, no comparisons between current and past bacteria data are possible.

4.4.D PHYTOPLANKTON

Messer (1975) collected monthly samples at a mid lake station in Lake Weir during 1974-1975. The dominant algal species at that time were the cyanophytes *Chroococcus rufescens*, *Lyngbya diqueti*, *L. contorta*, *L. putealis*, and *Microcystis aeruginosa*, and the dinoflagellate *Glenodinium quadriens* (Table 4-9). There was little relationship between chlorophyll *a* levels and phytoplankton cell densities (Figure 4-25).

4.4.E MACROPHYTES

Macrophytes were identified during four surveys conducted on Lake Weir (Messer 1975, Garren 1982, FGFWFC 1985 and 1986). Seventeen species were encountered in 1975, 9 in 1982, 15 in 1985, and 17 in 1986. The change in number of species recorded in 1982 (9 species) compared to the other years (15-17 species) is probably the result of less complete sampling and identification during 1982 (Table 4-10). Compared to 14 Florida lakes studied by Garren (1982), the macrophyte community of Lake Weir is similar to that of other neutral pH lakes.

While no detailed survey of macrophyte species has been undertaken at Lake Weir during this study, we have noted the presence of most of the listed species. Emergent plants (*Panicum sp.*, *Juncus sp.*, *Cladium sp.*, *Peltandra sp.*, *Pontederia sp.* and *Typha sp.*) dominate the narrow littoral zone and the channel connecting Sunset Harbor with Little Lake Weir. Submergent plants have been found in conjunction with the emergents and are apparent in the canal, as well as in areas of Sunset Harbor. Water lilies (*Nymphaea odorata*, *Nuphar luteum* and *Nymphoides aquaticum*) have colonized the shoreline in patches, most significantly near Bird Island, in the canal to Little Lake Weir and in various areas of Lake Weir itself. Water hyacinth (*Eichhornia crassipes*) has infested protected waters connected to the Sunset Harbor-

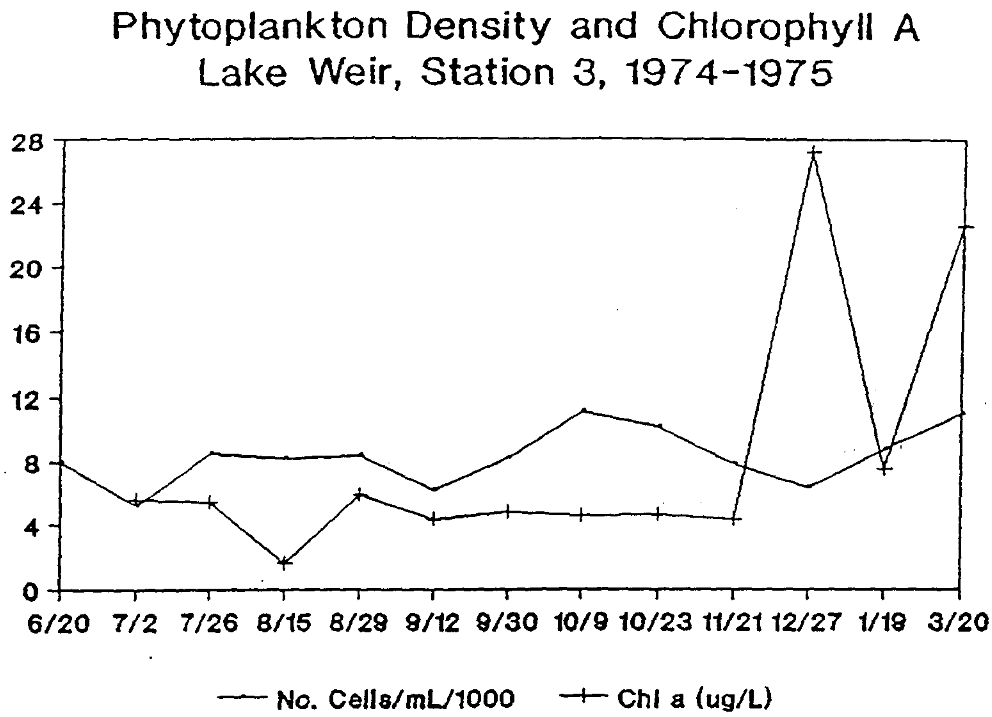
Table 4-9. Historical phytoplankton abundance and chlorophyll *a* data for Lake Weir, Florida.*

Date	Station [a]	Mean No. Cells/mL	Dominant Species [b]	Chlorophyll *a* Concentration [c]
6-20-74	3	8,022	L	-
	6	9,541	L	-
	7	6,573	L	-
7-2-74	3	5,175	L	5.57
	6	3,680	L	8.25
	7	11,563	L	3.71
7-26-74	3	8,518	L,C	5.40
8-15-74	3	8,265	L,C	1.61
	6	3,174	L,C	-
	7	8,268	L,C	-
8-29-74	3	8,364	L,C	5.92
	7	3,048	L,C	1.14
9-12-74	3	6,187	L,C,L',L"	4.33
	7	4,710	C,L	2.57
9-30-74	3	8,223	L,C	4.77
	6	4,562	L,C	4.06
	7	3,834	L,C	3.92
10-9-74	3	11,088	L,C	4.57
	6	9,452	L,M,C	1.51
	7	4,494	L,C	2.03
10-23-74	3	10,169	L,C,M	4.65
	7	5,203	L,S,C,M	3.66
11-21-74	3	7,843	L,C	4.33
	6	5,458	L,C,M	3.55
	7	5,063	L,C,D	3.54
12-27-74	3	6,320	M,L	27.26
	6	3,625	M,L,G	-
	7	5,422	C,G,L	-

Table 4-9. Continued

Date	Station [a]	Mean No. Cells/mL	Dominant Species [b]	Chlorophyll *a* Concentration [c]
1-19-75	3	8,809	M,L,G,C	7.56
	6	6,650	M,G,L	5.49
	7	2,184	M,L,G,Q	12.76
3-20-75	3	10,946	M,G,L	22.54
	6	8,855	M,G,L	17.57
	7	3,427	M,G	11.31

*From: Messer 1975. [a] Station numbers were reassigned here to coincide with current monitoring stations.
[b] C = *Chroococcus rufescens*, D = Pennate Diatom, G = Coccoid Green Alga, L = *Lyngbya diqueti*, L′ = *L. contorta*, L" = *L. putealis*, M = *Microcystis aeruginosa*, Q = *Glenodinium quadriens*, S = *Synedra ulna*. [c] ug/l. Samples are from water column composites at 0, 1, 3, and 5 m (7 m included for station 3).



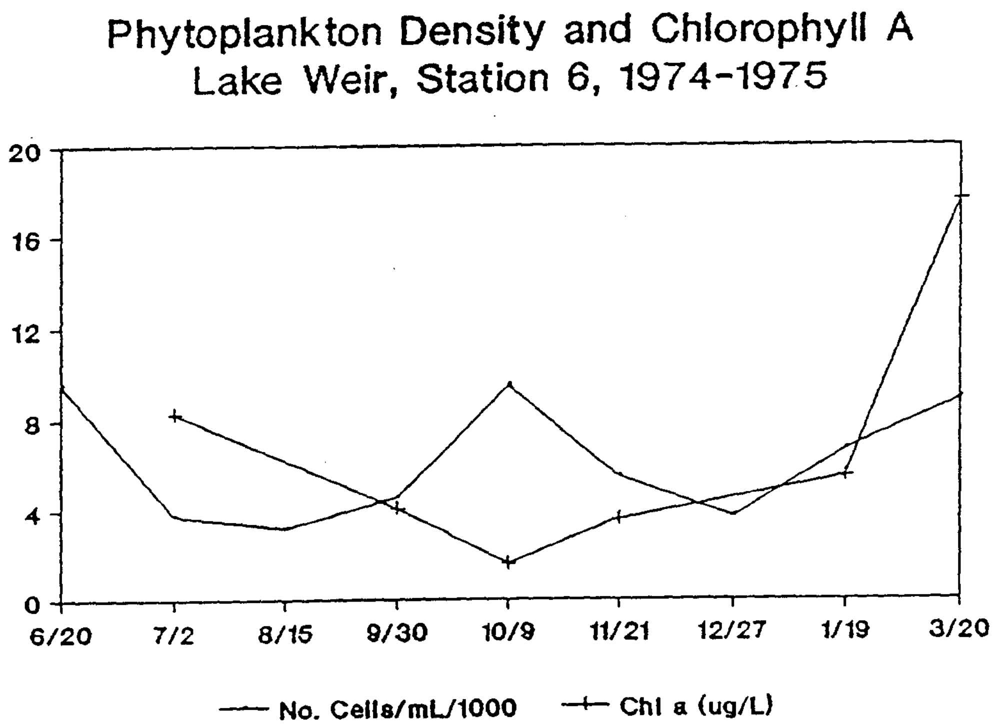


Figure 4-25. Phytoplankton density and chlorophyll-a for stations of Lake Weir during 1974-1975.

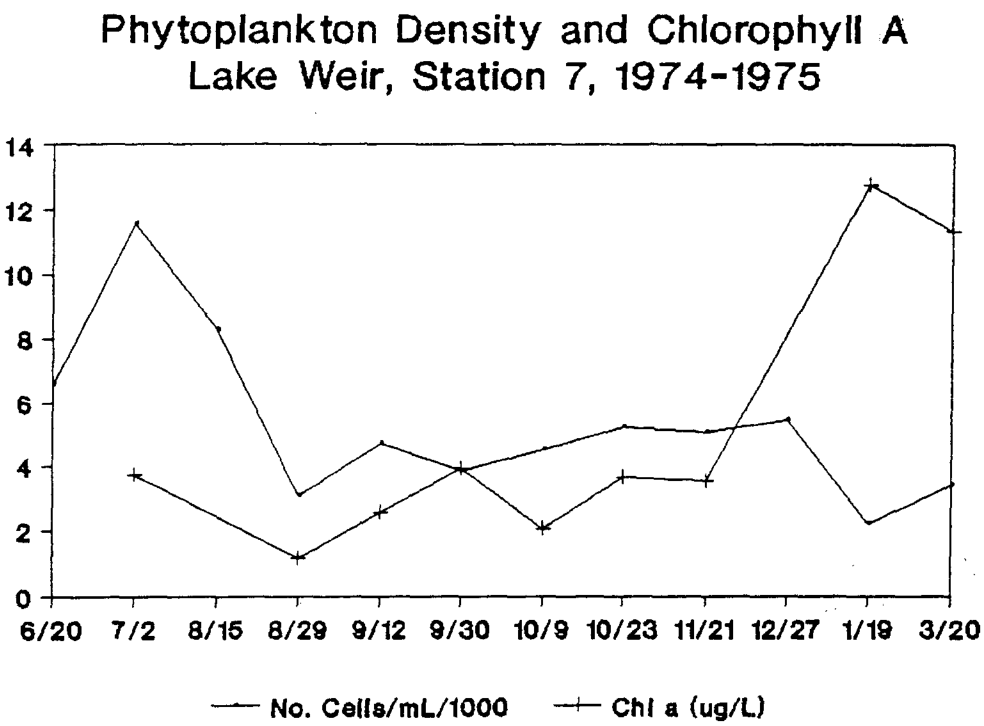


Figure 4-25. Continued.

Table 4-10. Macrophyte composite species list from various studies of Lake Weir.

	SURVEY YEAR*			
	1974	1982	1985	1986
EMERGENT SPECIES				
Panicum hemitomon	X			
Panicum sp.			X	X
Cyperus lecontei		X		
Cladium jamaicensis	X		X	X
Fuirena scirpoidea	X			
Juncus effusus	X			
Saururus cernus		X		
Scirpus sp.	X			
Eleocharis elongata	X	X	X	X
Peltandra virginica	X			
Pontederia lanceolata	X		X	X
Sagittaria lancifolia	X	X	X	X
Typha latifolia	X			
Typha sp.			X	X
SUBMERGENT SPECIES				
Hydrilla verticillata	X		X	
Ludwigia sp.	X			
Potamogeton illinoensis	X	X	X	X
Utricularia floridana	X			
Utricularia sp.		X	X	X
Eleocharis baldwinii				X
Bacopa caroliniana		X	X	X
Vallisneria americana			X	
Najas guadalupensis			X	
Sagittaria subulata			X	X
Nitella sp.			X	X
Chara sp.			X	X
FLOATING-LEAVED SPECIES				
Nymphoides aquaticum	X	X		
Nuphar luteum		X	X	X
Nymphaea odorata	X		X	X
FLOATING SPECIES				
Eichhornia crassipes	X			

* Messer (1975); Garren (1982); FGFWFC (1985); FGFWFC (1986).

Little Lake Weir canal.

4.4.F CONCLUSIONS

Water quality in Lake Weir appears not to have changed significantly over the last 20 years, based on nutrient concentrations, chlorophyll a and Secchi depth. While trophic state indices calculated from some of these parameters have increased slightly, Lake Weir is still classified as mesotrophic. The macrophyte community appears to be stable in both extent and species composition and is typical of moderately productive Florida lakes. However, biological (Chapter 5) and paleolimnological (Chapter 6) parameters suggest that the lake is undergoing progressive cultural eutrophication, that if not arrested, may shift the lake into the eutrophic category.

CHAPTER FIVE:

BIOLOGICAL PARAMETERS

5.1 METHODS

5.1.A SAMPLING DESIGN

Monthly collection of bacterioplankton, zooplankton and benthic invertebrates were made at the same seven stations utilized for physical-chemical parameters (Figure 4-1). Five stations were established in Lake Weir, and a midlake station was used in both Sunset Harbor and Little Lake Weir.

5.1.B MAPPING OF SUBMERSED MACROPHYTES

Fathometric tracings were made along nine transects in Lake Weir, twelve transects in Sunset Harbor and ten transects in Little Lake Weir (Figure 5-1) to estimate the percent of the water column infested by submersed macrophytes (Maceina and Shireman 1980). Biovolume (Maceina and Shireman 1980), is the percent of the water column occupied by submersed plants. It provides data on the presence and location of submersed macrophytes. Along with water chemistry, biovolume measurements help to identify factors controlling the spread of macrophytes in a lake. For example, if plants are absent below a particular depth, it may be due to a physical limit (including pressure tolerance) on littoral zone expansion based on basin morphometry. This is likely in lakes where low to moderate water column chlorophyll a (0-10 ug/L) concentrations are measured. When high levels of chlorophyll a are present, the growth of submersed plants may be limited solely by algal shading. The extent of the littoral zone may also have an impact on the accuracy of lake trophic state indicators based on water column chlorophyll a levels or nutrient concentrations (Canfield et al. 1984). A current bathymetric map of each basin was drafted depicting the extent of the littoral zone (Figure 5-2).

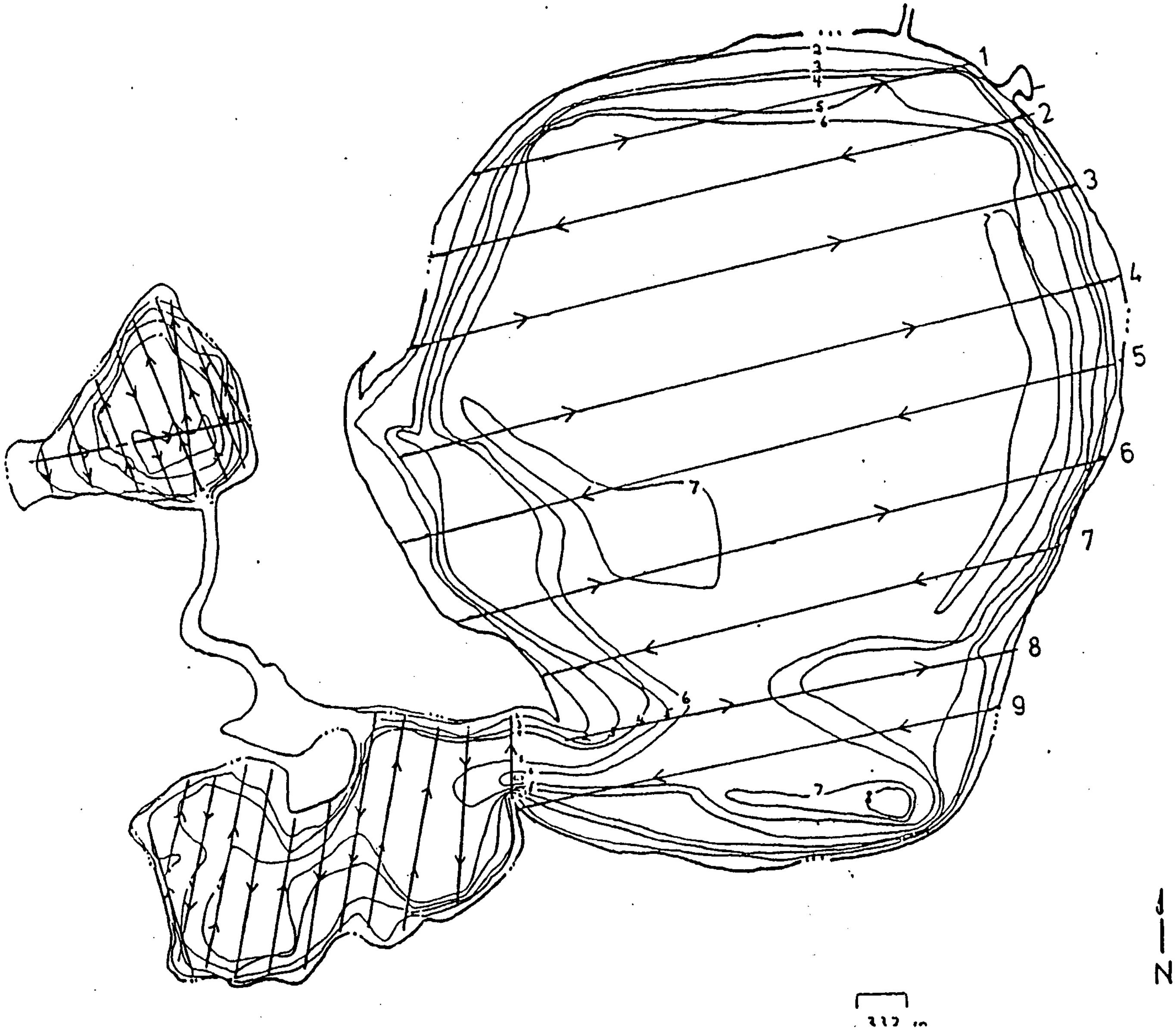


Figure 5-1. Transects used for bathymetric study of Lake Weir, Sunset Harbor, and Little Lake Weir during summer 1987.

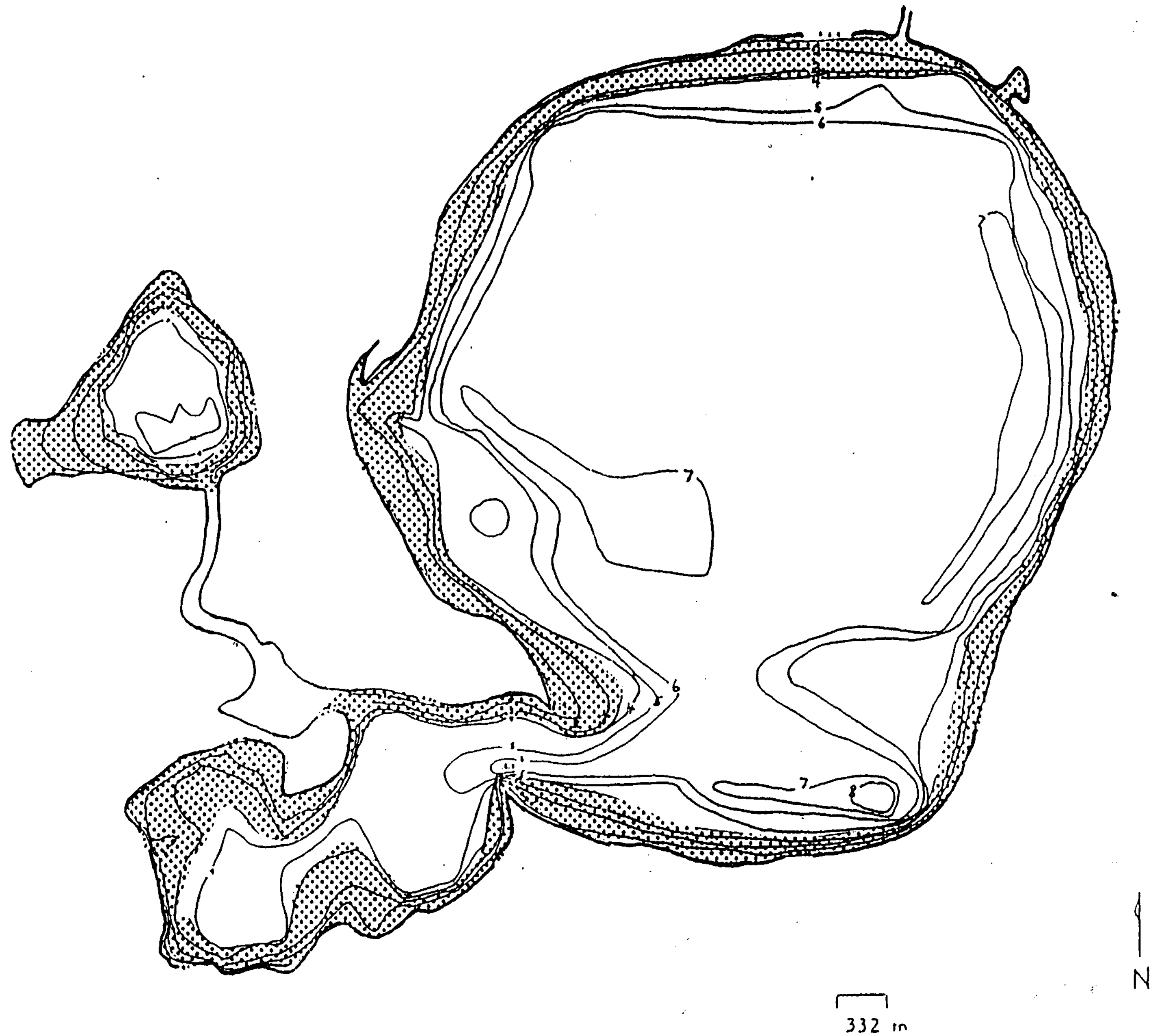


Figure 5-2. Current bathymetric map of Lake Weir showing extent of the vegetated littoral zone (shaded).

5.1.C BACTERIA

Bacterial populations were sampled monthly from each of the seven stations. Composite water samples were taken from each station and represented a pooling of 2.2 liter samples collected at each meter of the water column by a Kemmerer bottle. The samples were preserved with 0.1 % formalin in the field and transported on ice to the laboratory for analysis.

Slides were prepared using the technique of Hobbie et al. (1977). The samples were filtered through 0.2 um Nucleopore filters which were prestained with 0.2 % Irgalan Black to prevent autoflourescence. The flourescent stain used was 0.01 % Acridine Orange. The prepared slides were then observed under the epiflourescent microscope. Counts were made on triplicate 1 mL subsamples for each station. At least 200 cells or 5 random fields were counted on each slide. ANOVA and Duncan's Multiple Range tests were performed on the station and monthly means of bacteria densities to determine if any of them were significantlydifferent from the rest.

5.1.D ZOOPLANKTON

Zooplankton communities were sampled approximately monthly at the seven lake stations. Water samples were taken at 1 m intervals from the surface to the bottom of the water column (exclusive of the sediments) with a 2.2 L Kemmerer bottle and pooled.

Rotifer and crustacean populations were determined by passing 3 liter portions from this composite through an 80 um mesh Wisconsin plankton net, and the concentrate was preserved with 2 mL of Lugol's solution. It is possible that the choice of an 80 um mesh may not lead to a true quantification of rotifers because of their small body size. 1 mL aliquots from this concentrate were enumerated in a Sedgwick-Rafter chamber at 100x. If the total tally was less than 150 organisms, an additional aliquot was counted. Identification followed the keys of Ruttner-Kolisko (1974), Edmondson (1959), and Deevey and Deevey (1971). Dry weight biomass of rotifers and crustaceans was assigned by using published conversion factors (Dumont et al. 1975, Maslin 1969) as well as values empirically determined in this laboratory (Bays 1983).

76 mL subsamples for ciliated protozoa were also taken

from this composite, stained with several drops of bromothymol blue and preserved with 2 mL saturated $HgCl^2$. Appropriate aliquots were settled into Utermohl chambers and enumerated. The volume examined varied seasonally but was always between 3 mL and 10 mL, with each count representing at least 150 individual ciliates. Biomass values were obtained using previously published volumes for individual taxa (Beaver & Crisman 1982) or direct measurement, then the volumes were converted to dry weight biomass using a 0.279 pg d.w. um^3 conversion factor (Gates et al. 1982). Ciliate taxonomy was based on Kahl (1930-1935), Maeda (1986), and Maeda and Carey (1985). Prior to analyses, plankton counts and chemical variables were normalized by a LOG (n+1) transformation.

5.1.E BENTHIC INVERTEBRATES

Macroinvertebrate samples were taken in triplicate at each station with a petit ponar grab (0.023 m^2), sieved in the field (600 um mesh) and preserved in 70% ethanol containing Rose bengal. Upon returning to the laboratory, samples were stored at 4^oC until analyzed.

In the laboratory, macroinvertebrate samples were sorted in white enamel pans under a magnifying glass with fluorescent lighting. Picked specimens were kept in glass vials with 70% ethanol. Specimens were enumerated and identified to the generic level using keys of Pennak (1978), Parrish (1968), Merritt and Cummins (1984) and Brigham et al. (1982). The mean number of organisms of the three grab samples collected at each station each month was recorded. The collected invertebrates were also categorized into functional groups based on their mode of food acquisition (Merritt and Cummins, 1984).

5.2 SUBMERSED MACROPHYTES

Biovolume, the percent of submersed plant infestation of the water column, was low in all three lake basins (Figure 5-2). Macrophytes occupied 8% of the water column in Lake Weir, 14% in Sunset Harbor and 15.5% in Little Lake Weir. Plants were essentially absent below 3.5 m (Table 5-1). Only 16% of Lake Weir was shallower than 3.5 m, while 51% of Sunset Harbor and 56% of Little Lake Weir were that shallow. These data suggest that basin morphometry is limiting the extent of the littoral zone in the big lake,

Table 5-1. Summary of morphometric characteristics, mean annual water quality data and biovolume (percent vertical plant infestation) values for Lake Weir, Sunset Harbor and Little Lake Weir, FL.

Parameter	Lake Weir	Sunset Harbor	Little Lake Weir
Secchi depth (m)	1.52	1.44	1.56
TP (ug/L)	36.4	40.7	41.7
TKN (ug/L)	646	626	651
Chlorophyll *a* (ug/L)	6.7	6.8	6.1
Surface area (hectares)	2,086	350	151
Maximum depth (m)	8.4	6.7	5.5
Mean depth (m)	4.27	2.13	1.95
Lake volume ($m^3 \times 10^6$)	89	7.45	2.95
Biovolume (%)	8	14	15.4

and that algal shading is likely to prevent the movement of macrophytes into deeper water in Sunset Harbor and Little Lake Weir.

In lakes with a high biovolume (percent vertical plant infestation), trophic state indices based on water column nutrient or chlorophyll a concentrations may be inaccurate because they do not account for nutrient levels in plant tissue (Canfield et al. 1984). Since percent vertical plant infestation is low in all three basins, water column chlorophyll a concentrations can be used as accurate indicators of trophic state.

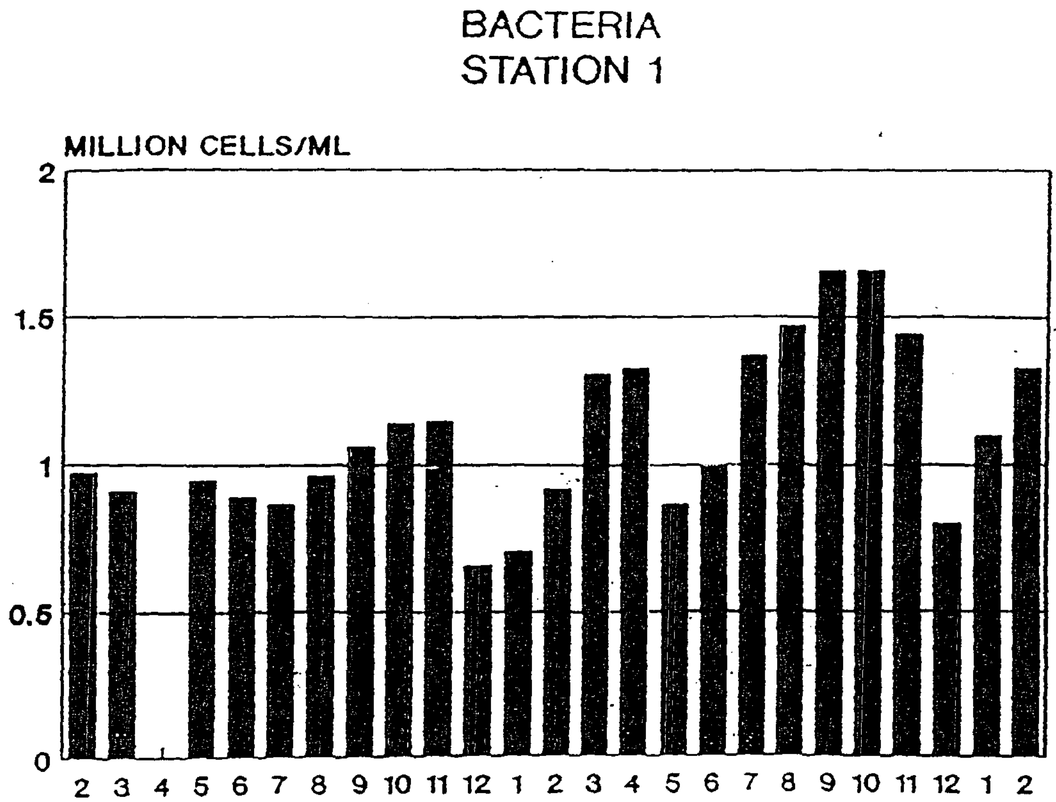
The distributions of individual submersed macrophyte species were not mapped but appeared to be generally the same as in recent FGFWFC surveys. There was a relatively dense growth of Websteria near the east side of Bird Island, and Potamogeton and Chara were noted along much of the shoreline in Sunset Harbor. Potamogeton and Bacopa were prevalent on the shallower north and south shores of Lake Weir.

In contrast to the two larger basins, Little Lake Weir contained not only Potomogeton and Bacopa, but was infested with Utricularia from the shoreline to 3.5 m depth. Whether the presence of the latter species in Little Lake Weir reflects a nitrogen imbalance in the lake or just that the species is able to survive in the more sheltered environment of Little Lake Weir is not clear. However, there was no significant difference in nitrogen or phosphorus levels among the three lakes (Table 4-1).

5.3 BACTERIA

While a pronounced seasonality was noted for bacteria abundance at all stations (Figure 5-3), values peaked during spring and fall (1.03 -1.74 x 10^6/mL) and were lowest during summer and winter (0.80 - 1.15 x 10^6/mL). The generalized lakewide mean bacterial abundance by month and season (Table 5-2, Figure 5-4) is similar to that summarized for mesotrophic Florida lakes by Crisman et al. (1991) (Figure 5-5). Not even the most productive stations of the Lake Weir system, stations 5-7, displayed a bacterial seasonality that resembled the spring maximum-winter minimum suggested by Crisman et al. (1991) for typical eutrophic Florida lakes. Duncan's Multiple Range test demonstrated significant intermonth differences for the Lake Weir system that paralleled seasonal trends just described (Table 5-3)

Station 7 displayed the highest mean bacterial



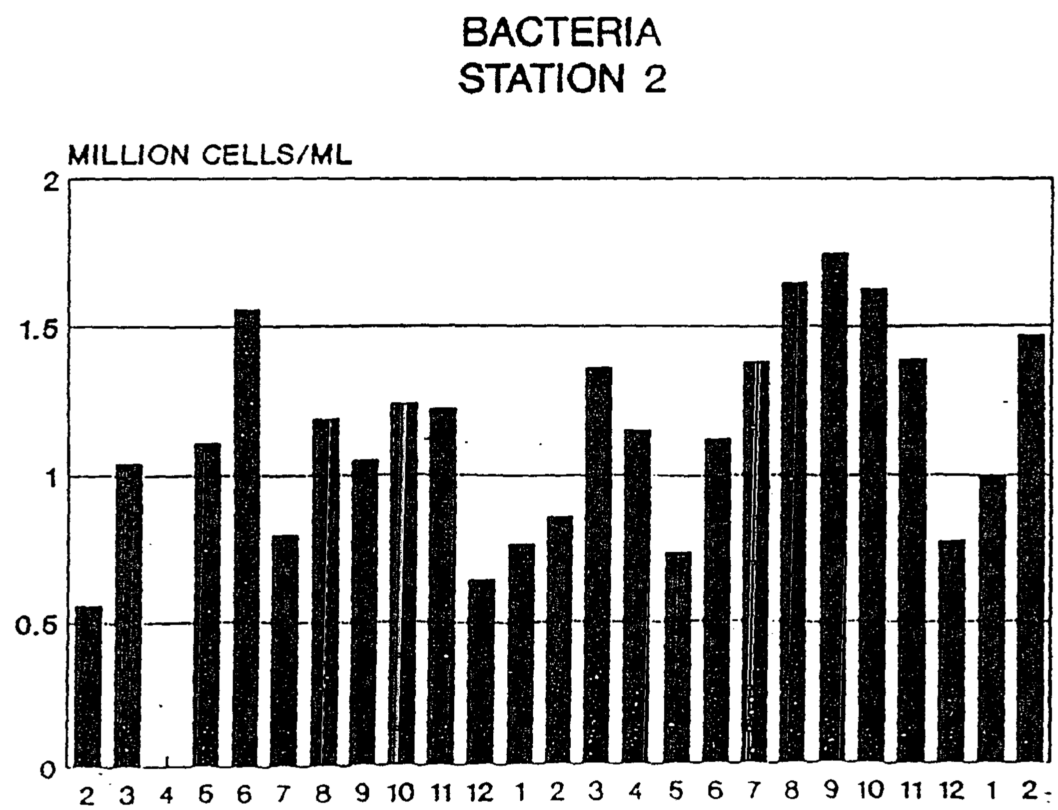
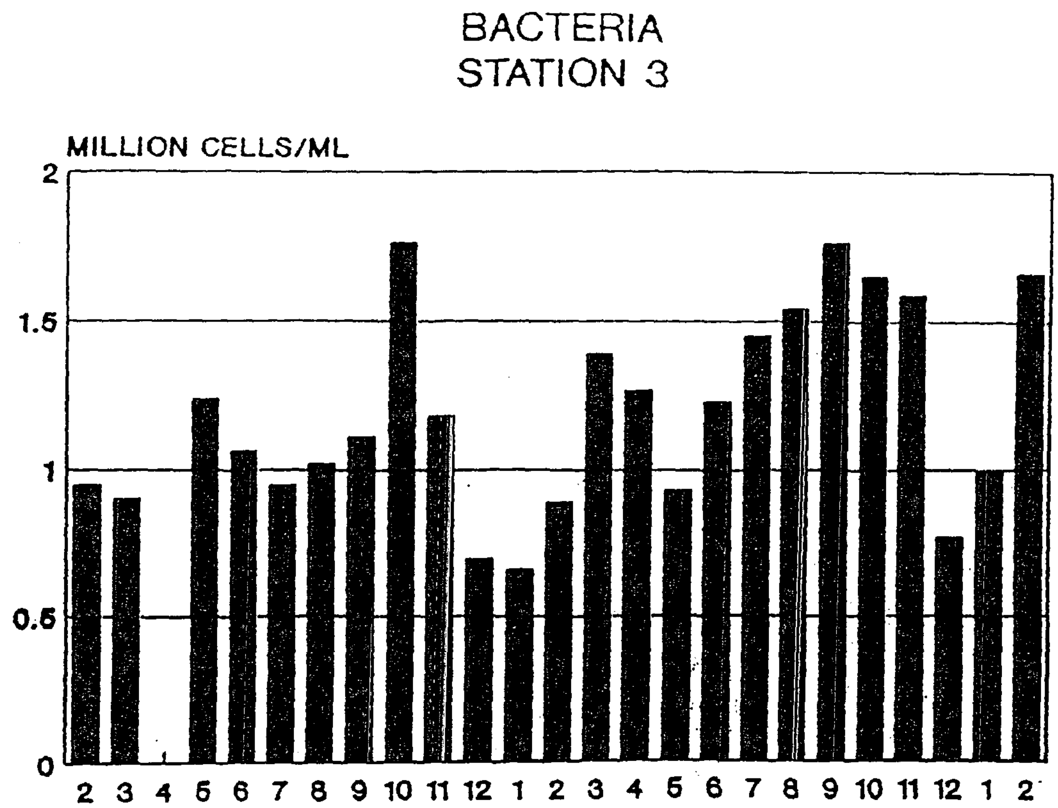


Figure 5-3. Bacterioplankton abundance at individual stations of the Lake Weir system for individual months of 1987-1989.



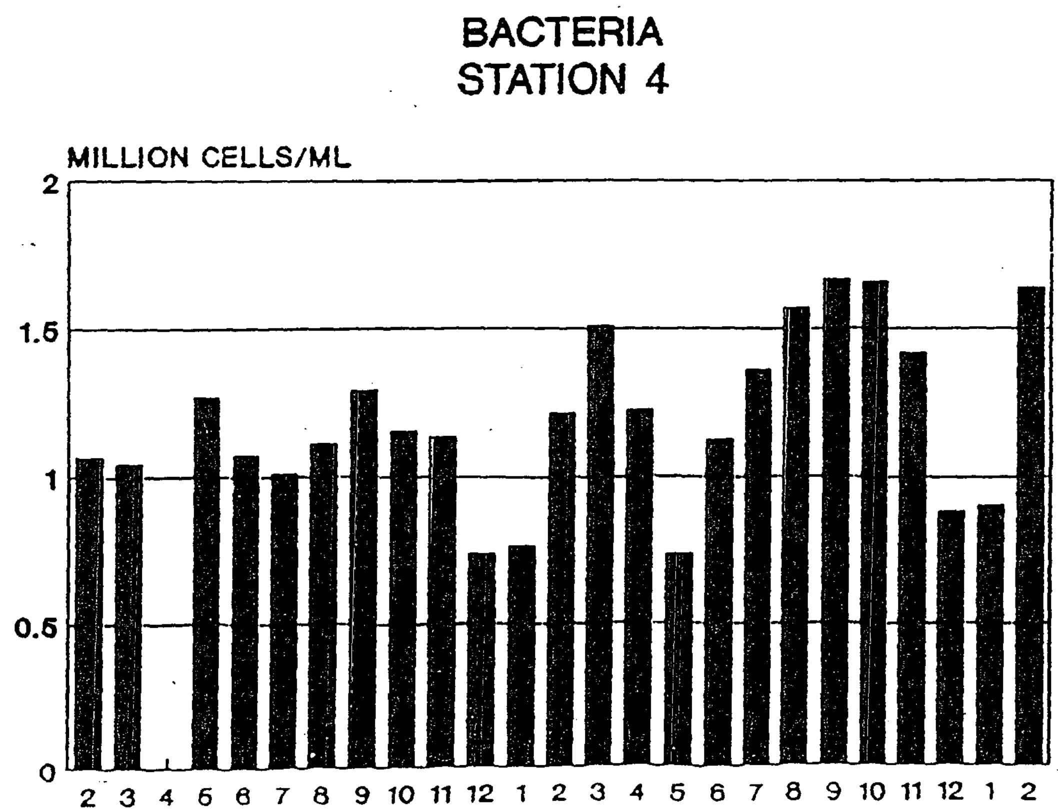
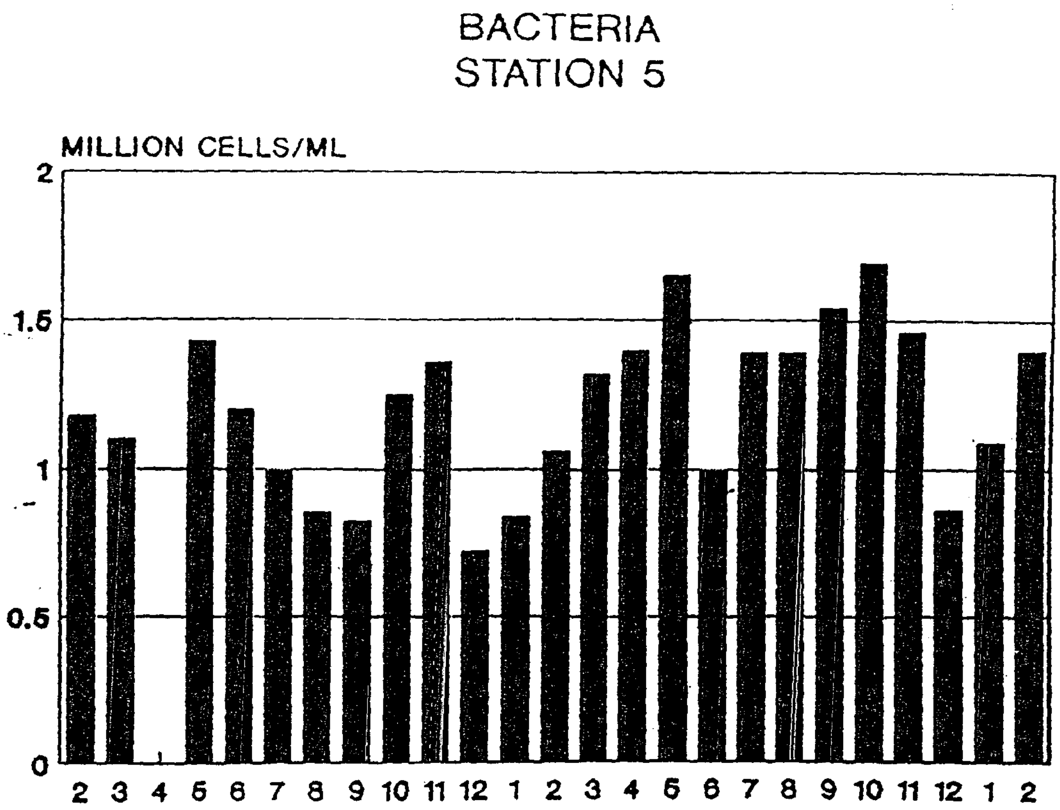


Figure 5-3. Continued.



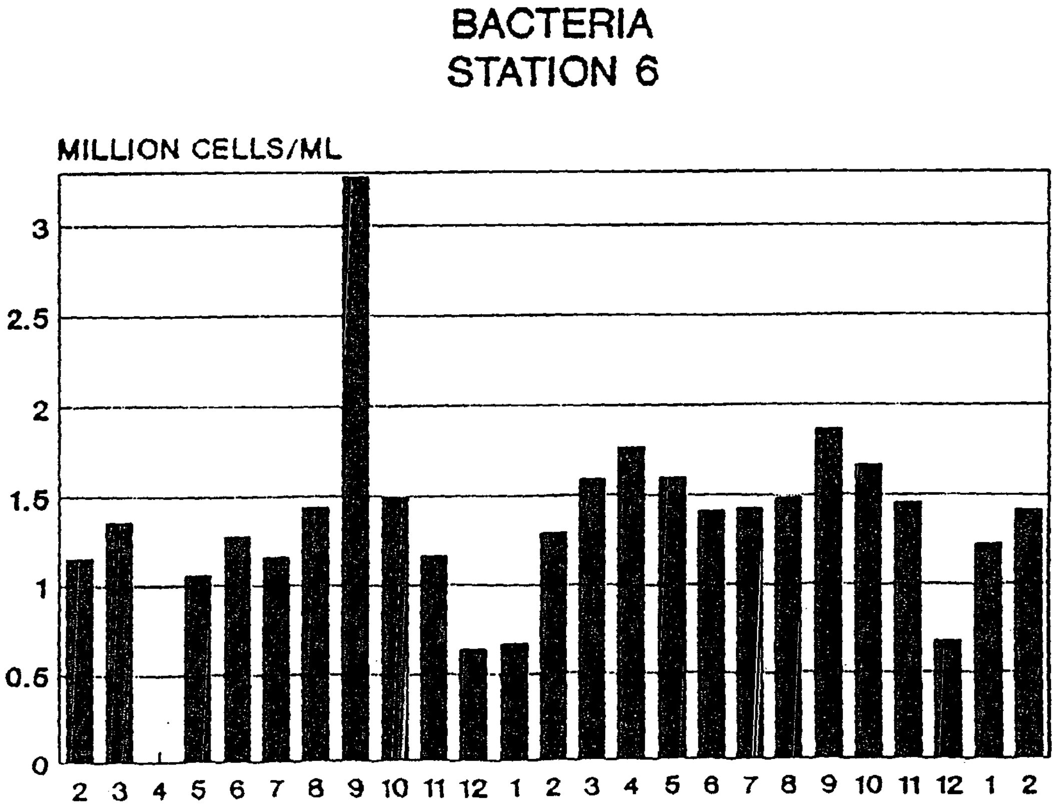


Figure 5-3. Continued.

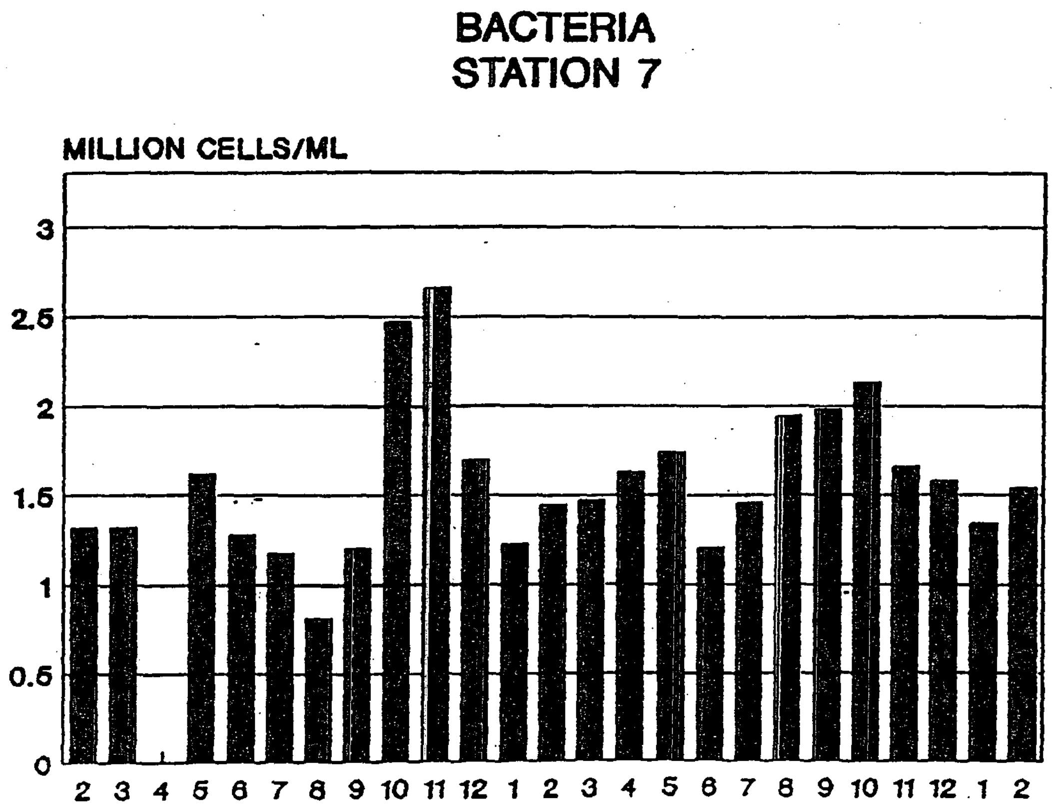


Figure 5-3. Continued.

Table 5-2. Lakewide mean (S.D.) bacterial density (No./mL) by month in Lake Weir , Florida 1987 - 1989.

MONTH	N	Mean (*10^6)	S.D (*10^6)	TEMP C
February	14	1.03	0.23	
March	14	1.10	0.27	19.6
May	14	1.24	0.21	26.3
June	14	1.20	0.20	27.7
July	14	9.93	0.13	29.7
August	14	1.05	0.20	30.1
September	21	1.40	0.77	27.5
October	21	1.50	0.45	22.6
November	21	1.41	0.51	20.7
December	21	8.28	0.35	17.8
January	21	8.75	0.35	15
February	21	1.17	0.37	14.6
March	21	1.85	1.08	17.2
April	21	1.73	0.94	22.2
May	21	1.67	0.15	25.5
June	21	2.08	0.13	26.2
July	21	1.52	0.33	28.5
August	21	1.57	0.17	28.6
September	21	1.54	0.24	27.3
October	21	1.62	0.25	22.5
November	21	1.50	0.23	22.5
December	21	1.57	0.30	13.7
January	21	1.73	0.30	16.4
February	21	1.70	0.32	14.9

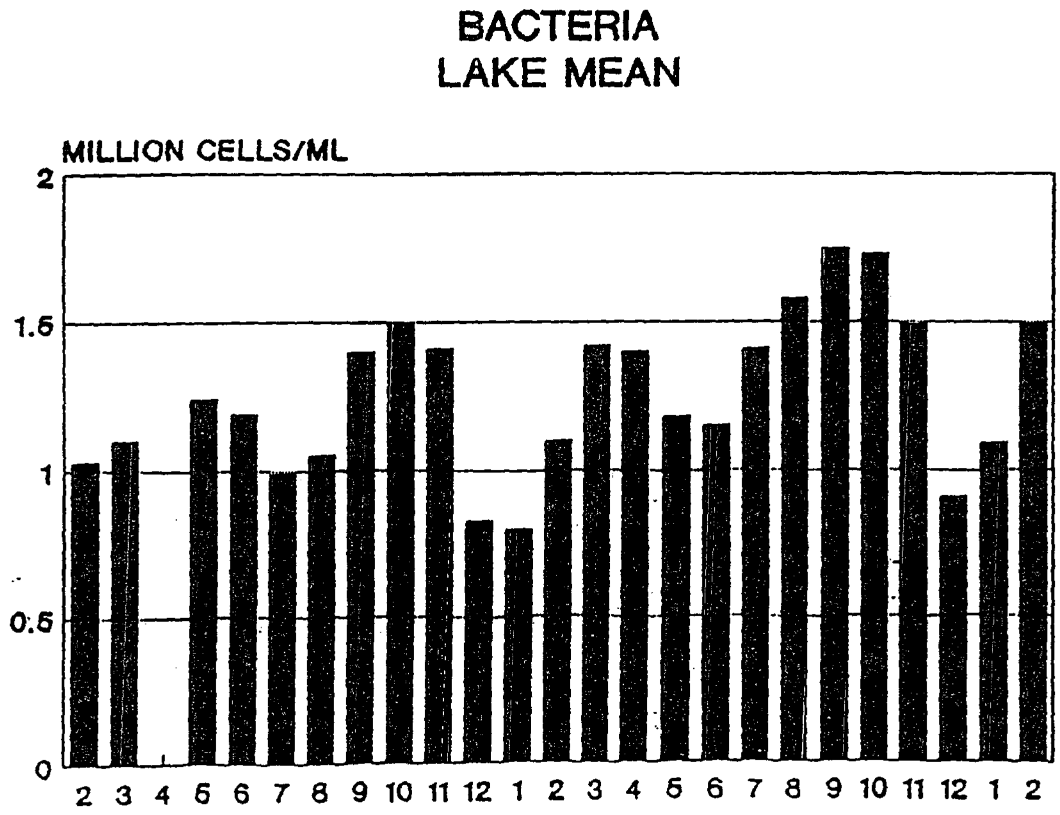


Figure 5-4. Mean bacterioplankton abundance for the Lake Weir system for individual months 1987-1989.

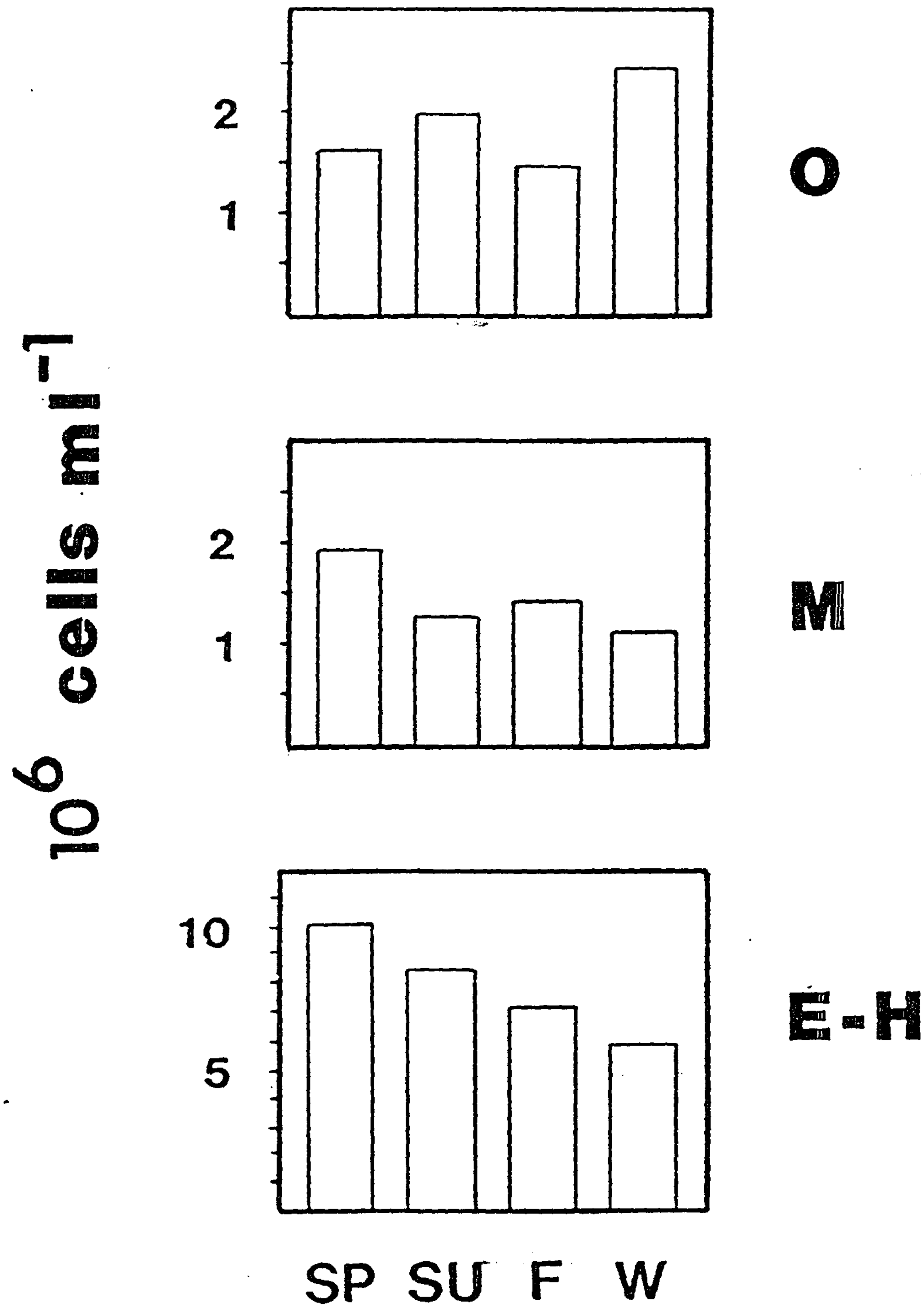


Figure 5-5. Seasonality of bacterioplankton in Florida lakes of various trophic states.

Table 5-3. Results of inter-station and inter-month comparisons of bacterial density (No./mL) in Lake Weir, Fl by ANOVA and Duncan's procedure. Means connected by the same line are not significantly different.

Parameter	N	F	Significance
Station	168	5.34	0.05

Station							
Station	7	6	5	4	3	2	1

Parameter	N	F	Significance
Month	168	6.20	0.05

Month												
Month	10	9	11	4	8	3	5	2	7	6	1	12

abundance for the 1987-1989 study period (2.24×10^6 cells\mL), while station 1 had the lowest (1.21×10^6) (Table 5-4). Mean bacterial concentrations at stations 1-3 in Lake Weir were significantly lower than found at stations 6 (Sunset Harbor) and 7 (Little Lake Weir), but no significant differences were noted between the latter two stations (Table 5-3). Sunset Harbor (station 6) bacterioplankton abundance, however, was not significantly different from the western (station 4) and southern (station 5) sampling stations in Lake Weir proper. Bacterial numbers for the center lake stations i.e. station 3 (midlake station of Lake Weir), station 6 (Sunset Harbor), and station 7 (Little Lake Weir) were also compared. Sunset Harbor and Little Lake Weir had significantly higher bacterioplankton abundances than Lake Weir proper during the study period.

Bacterial densities also were compared with temperature (Figure 5-6). Although there was no significant correlation between season and mean bacteria density, on a station by station basis bacterial numbers appeared to track positively lake water temperature. This pattern was observed for Stations 3, 6 and 7. At all three stations, there was an increase in density with increasing temperature till the water temperature reached 24^{o} C. Above this temperature, bacterial densities dropped until summer/fall when the temperature of the water also decreased. This positive correlation of bacterial densities with temperature up to 24^{o} C has been observed for other Florida Lakes (Crisman et al. 1984). The reason for the decrease in bacterial numbers above 24^{o} C is not clearly defined yet. They may be controlled by increasing water temperature, greater zooplankton grazing or some other factor.

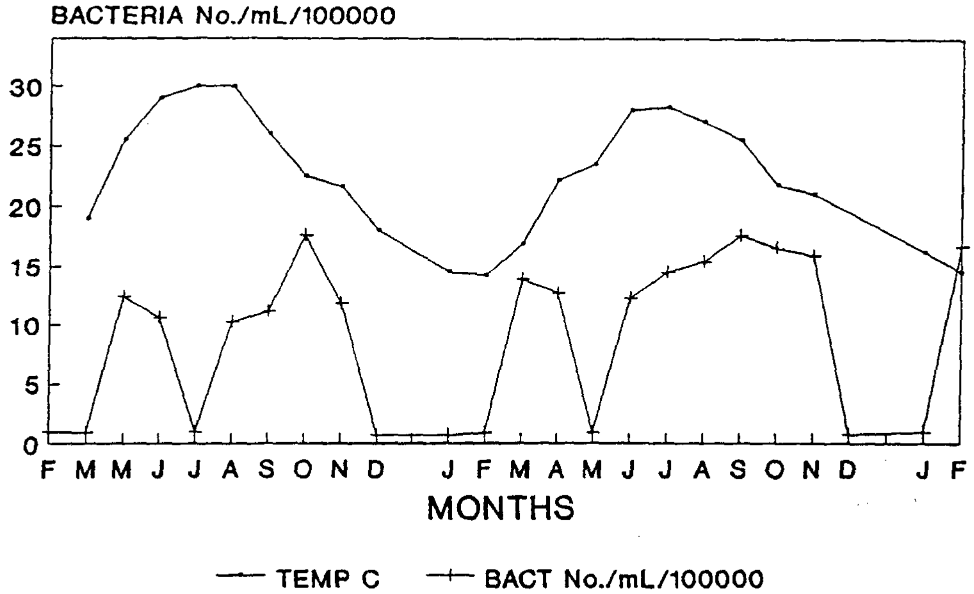
With the exception of station 7 which displayed peak bacterial numbers during 1988, mean bacterial numbers increased progressively at all stations during the study period (Figure 5-7). Such trends, however, should be viewed with caution in that 1988 was the only year during which 12 months were consecutively sampled.

Crisman et al. (1991) developed a predictive model for mean annual bacterial abundance in clear water Florida lakes spanning the entire trophic spectrum from oligotrophic to hypereutrophic. The estimated mean annual bacterial abundance for the Lake Weir system during 1988 (2.21×10^6 cells/mL) was somewhat greater than observed in other Florida lakes of comparable trophic state, but was within one standard deviation of the predicted mean for the model (Figure 5-8).

Table 5-4.Mean (S.D.) bacterial density (No./mL) by station in Lake Weir , Florida 1987 - 1989.

Station	N	Mean (*10^6)	S.D (*10^6)
1	27	1.21	0.25
2	27	1.35	0.36
3	27	1.34	0.32
4	27	1.35	0.28
5	27	1.34	0.28
6	27	1.47	0.58
7	27	2.24	1.20

BACTERIA DENSITY AND TEMPERATURE VS TIME, STATION 3, 1987 - 1989



BACTERIA DENSITY AND TEMPERATURE VS TIME, STATION 6, 1987 - 1989

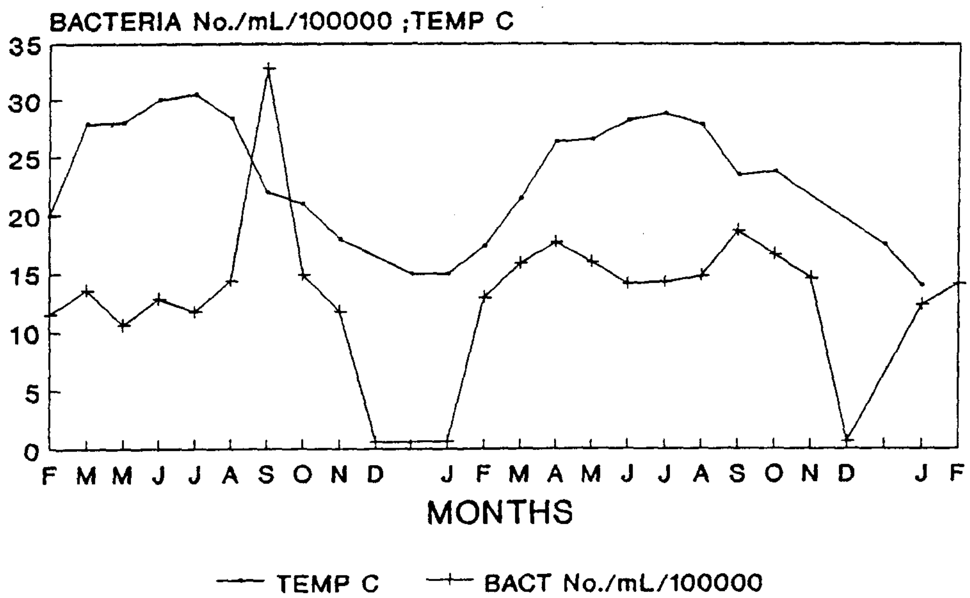
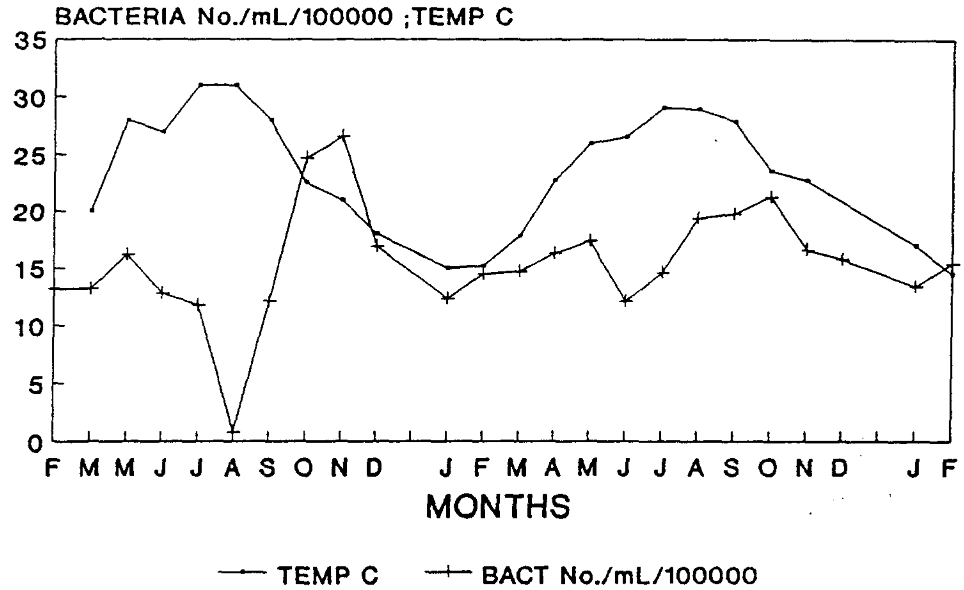


Figure 5-6. Bacteria-temperature relationships for individual stations of the Lake Weir system during 1987-1989.

BACTERIA DENSITY AND TEMPERATURE
VS TIME, STATION 7, 1987 - 1989



BACTERIA DENSITY AND TEMERATURE
MONTHLY MEANS

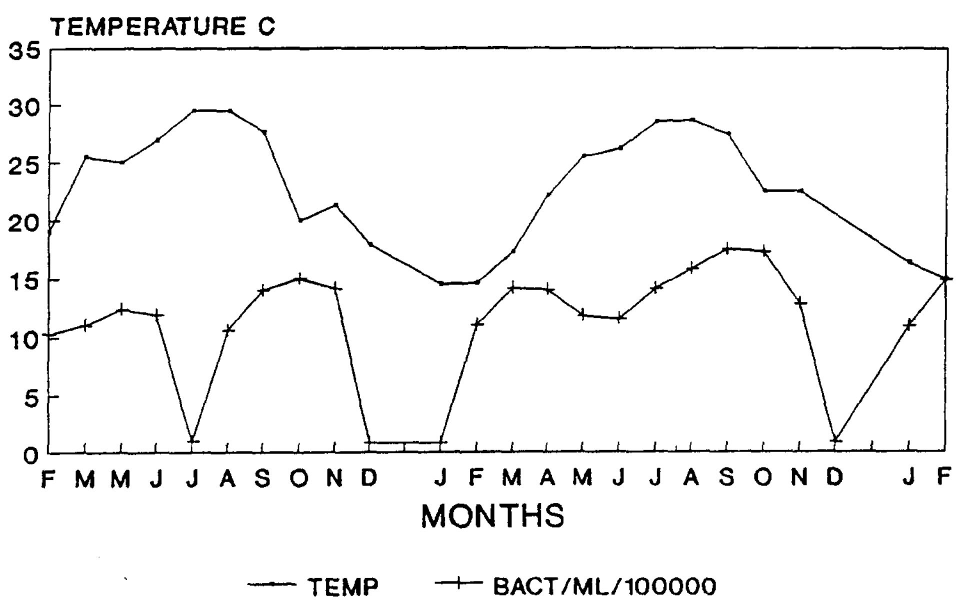


Figure 5-6. Continued.

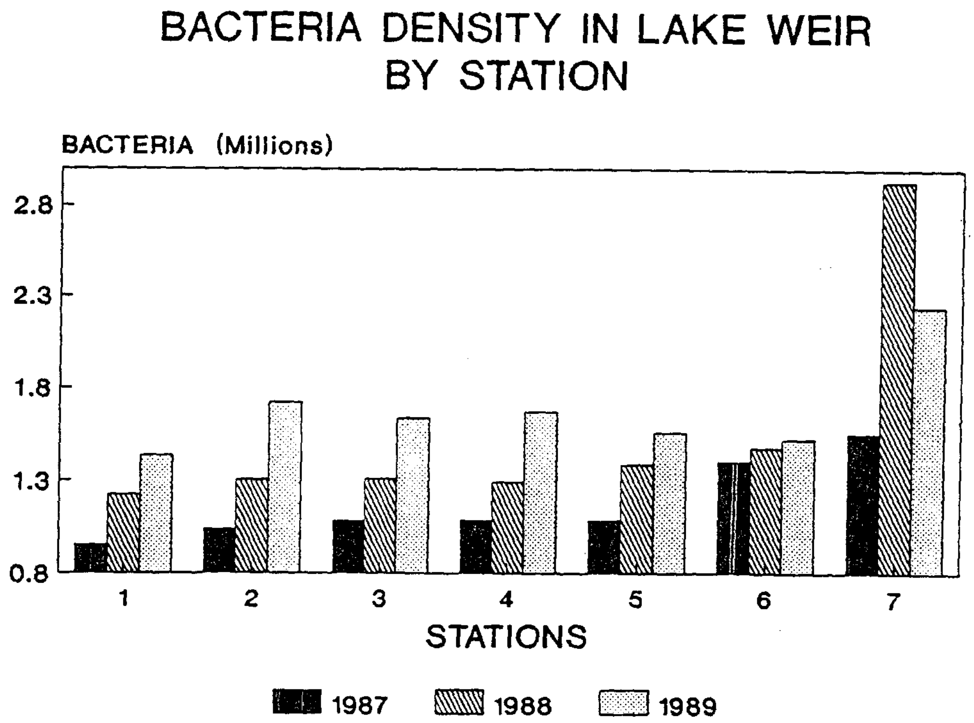


Figure 5-7. Mean annual bacterioplankton abundance for individual stations during 1987-1989.

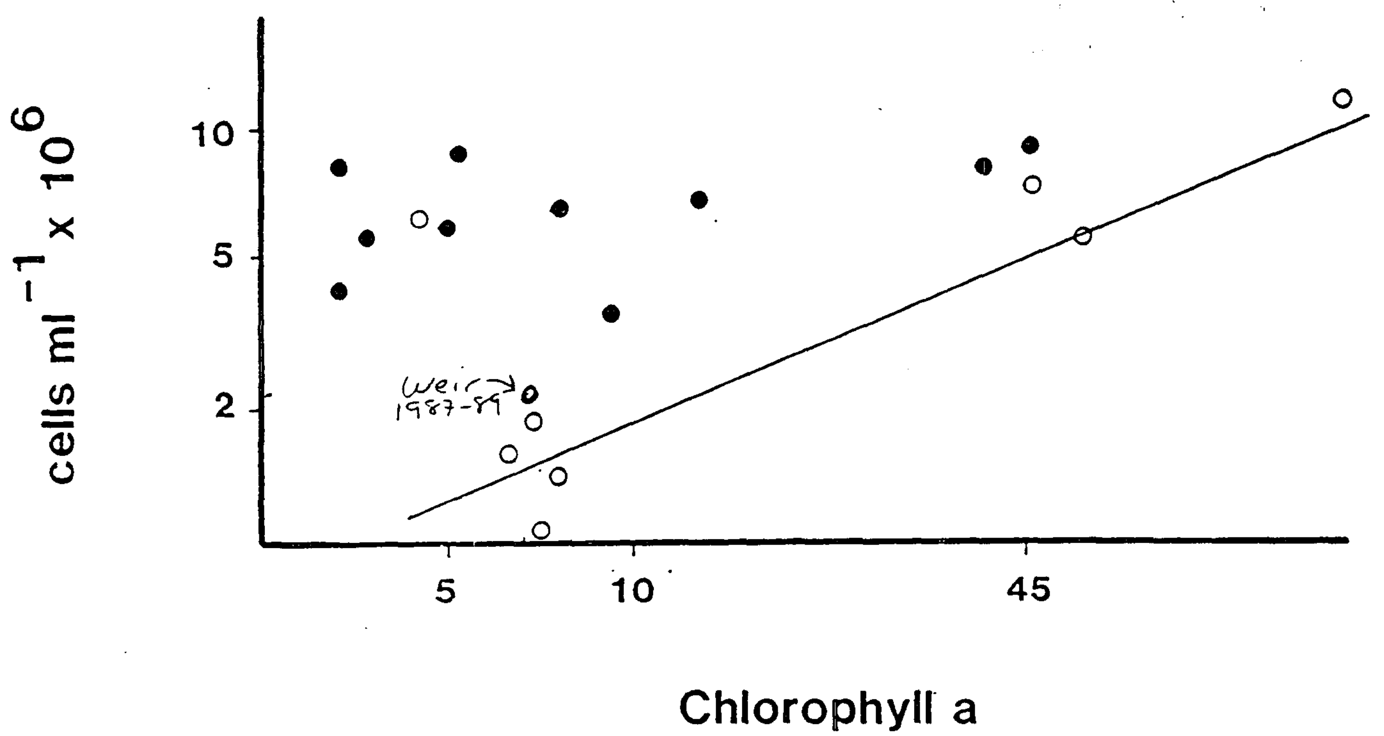


Figure 5-8. Bacteria-chlorophyll relationships for clear (open) and colored (closed) Florida lakes.

5.4 ZOOPLANKTON

5.4.A INTRODUCTION

Numerous investigations of temperate and subtropical lakes have documented changes in zooplankton community structure associated with increasing eutrophication. Typically, total zooplankton biomass increases with lake productivity and is accompanied by species replacements within the Cladocera and Copepoda (O'Brien & de Noyelles 1974, Hall et al. 1970). Within the macrozooplankton, calanoid copepods decrease in proportional abundance (McNaught 1975, Gliwicz 1969), while small-bodied cladocerans and cyclopoid copepods dominate the zooplankton communities of eutrophic lakes (Brooks 1969). The overalll importance of macrozooplankton decreases to favor dominance by microzooplankton, especially rotifers and ciliated protozoa (Gannon & Stemberger 1978, Bays & Crisman 1983). Major changes have also been documented for ciliated protozoan populations. Oligotrophic lakes are usually dominated by large-bodied oligotrichs which graze both bacteria and nannoplankton but are replaced by small-bodied bactivorous scuticociliates (Beaver & Crisman 1982, Beaver & Crisman 1989).

Compositional shifts in zooplankton community structure associated with eutrophication are believed to be controlled by alterations in both the intensity of invertebrate and vertebrate predation pressures (Brooks 1969, Brooks and Dodson 1965) and the structure and biomass of the principal zooplankton foods, bacterioplankton and phytoplankton (Richman and Dodson 1983, Bays and Crisman 1983, Beaver and Crisman 1982, Crisman 1991). Since planktivorous fish abundance increases with lake productivity (Larkin & Northcote 1969, Crisman 1991), large-bodied zooplankton are often eliminated due to their higher susceptibility to vertebrate predation. Invertebrate predators such as *Chaoborus* and cyclopoid copepods also increase with eutrophication and may alter zooplankton community size structure through selective predation (Zaret 1980). Unfortunately, however, it is not always to separate the relative importance of predation versus food quantity and quality as structuring variables of zooplankton communities. As clearly demonstrated from investigations on the calanoid copepod genus *Diaptomus* in Florida, even intrageneric replacements observed along trophic state gradients in Florida lakes are clearly related to both parameters acting in consort (see review by Crisman 1991).

In addition to the observed shifts in zooplankton community structure associated with eutrophication, ciliated protozoan populations have been shown to be altered by lake productivity changes. Oligotrophic lakes are usually dominated by large-bodied oligotrichs which graze both bacteria and nannoplankton but are replaced by small-bodied scuticociliates which are specialized on bacteria (Beaver & Crisman 1982, Beaver & Crisman 1989).

This section of the report examines the zooplankton and protozooplankton community of Lake Weir, and contrasts the present community with historical measures of these communities. In addition, the zooplankton population of Lake Weir will be compared with other mesotrophic Florida lakes as well as other Florida lakes of different trophic states.

5.4.B ANNUAL MEAN BIOMASS FOR ZOOPLANKTON COMPONENTS

The average biomass of zooplankton components are given in Table 5-5. Total biomass ranged from 120 mg d.w. m^{-3} at station 1 to 141 mg d.w. m^{-3} at station 6. ANOVA indicated no significant differences between stations, and the lake average for total zooplankton biomass was 126 mg m^{-3}.

Macrozooplankton (adult copepods, copepodites, cladocerans) biomass ranged from 17 mg d.w. m^{-3} at station 3 to 25 mg d.w. m^{-3} at station 5. In general, macrozooplankton biomass decreased in Lake Weir from south to north, but no significant differences were noted between stations.

Microzooplankton (nauplii, rotifers, ciliates) biomass displayed very little variation between stations (range 96 - 116, mean= 104 mg d.w. m^{-3}), with the highest biomass found at station 6. The contribution of microzooplankton biomass to total zooplankton biomass averaged 82.6% for the lake.

Cladocerans were relatively rare in Lake Weir and had the smallest mean biomass of any zooplankton component. No intralake distribution patterns were evident, although cladoceran biomass was exceptionally low at stations 2 and 3.

Likewise, calanoid copepods displayed little variation by station (range 8 - 10, mean= 9 mg d.w. m^{-3}). They were, however, the dominant crustacean group comprising 9.7% of the total zooplankton biomass. The only calanoid copepod found in Lake Weir was Diaptomus dorsalis.

Cyclopoid copepods tended to be the least abundant at the north end of the lake and most abundant at the south end of the lake. Station 7 displayed significantly higher cyclopoid biomass (12 mg d.w. m^{-3}) when compared to the remaining stations. The dominant cyclopoid found in Lake Weir was Tropocyclops prasinus, a relatively small-bodied, omnivorous copepod.

Copepod nauplii were frequently abundant but because of their small size contributed only negligibly to total zooplankton biomass (5.4%). No distribution patterns were evident for this component.

Rotifers were a co-dominant with ciliated protozoa in the Lake Weir zooplankton community. They comprised 23.7% of the total zooplankton biomass. Average values ranged from 32 mg d.w. m^{-3} at station 7 to 46 mg d.w. m^{-3} at station 6. The lake wide average was 36 mg d.w. m^{-3} and no significant differnces were noted between stations.

Total ciliate biomass varied little between stations. This taxonomic group was the major contributor to biomass in the lake with a mean value of 60 mg d.w. m^{-3}. The three dominant orders of ciliates - Oligotrichida, Scuticociliatida, and Haptorida - generally differed little between stations. One exception to this trend was oligotrich biomass at station 7 which was significantly higher when contrasted with station 4.

5.4.C ZOOPLANKTON HISTORICAL BIOMASS COMPARISON

Fortunately, the zooplankton analysis made for this report can be directly compared with the community in 1979. Bays (1983) and Beaver (1980) monitored station 3 monthly in Lake Weir during that calender year, and the methodology they employed was almost identical to that used in the present study.

The annual mean biomass values for major zooplankton components at station 3 in 1979 and 1987-1989 are presented in Table 5-6. Total zooplankton biomass was only slightly higher in 1987-1989 than in 1979. Macrozooplankton biomass, however, was 48.1% lower in the present study, while microzooplankton biomass was essentially unchanged. Cladoceran biomass was reduced by 59.0%, but since April values are missing and this season is traditionally high in Cladocera, this conclusion should be considered provisional. Calanoid copepod biomass decreased 53.7% between the two studies while cyclopoids were reduced 32.0%. Nauplii displayed a 20.3% increase. Rotifer biomass was 33.7% higher in 1987-1989, while ciliate biomass increased nearly 20%.

Table 5-5. Annual mean biomass values (ug l^{-1}) of zooplankton components in Lake Weir for the period February 1987 - February 1989.

COMPONENT	STATION 1	2	3	4	5	6	7	Lake mean	% Composition
Total zooplankton	119.9	124.6	117.6	124.7	121.2	140.5	135.4	126.3	----
Macrozooplankton	17.4	22.6	16.7	22.6	25.1	24.2	24.6	21.9	17.3
Microzooplankton	101.9	102.1	100.8	102.1	96.1	116.3	110.8	104.3	82.6
Cladocera	3.7	2.2	2.5	5.8	4.7	3.5	3.6	3.7	2.9
Calanoida	8.0	10.1	7.5	9.2	11.5	10.2	9.3	9.4	9.7
Cyclopoda	5.6	10.3	6.8	7.6	8.9	10.5	11.7	8.8	6.1
Nauplii	9.1	7.1	7.5	7.5	8.3	8.3	8.1	8.0	5.4
Rotifera	32.9	35.2	32.5	40.2	34.5	46.0	31.9	36.2	23.7
Ciliata	59.5	59.8	60.8	54.4	53.3	62.0	70.8	60.1	31.4
Oligotrichida	18.7	18.9	22.2	18.5*	20.2	22.7	29.7*	21.6	12.1
Scuticociliatida	16.3	14.5	15.7	14.1	13.6	15.8	16.1	15.2	6.7
Haptorida	6.5	13.2	7.0	6.1	6.9	6.8	8.6	7.9	3.0

* significantly different (ANOVA, $p < 0.05$)

Table 5-6. Historical comparison of the mean annual biomass of various components of the Lake Weir zooplankton community at Station 3. Data for 1979 taken from Bays (1983) and Beaver (1980). Biomass values in ug/L.

COMPONENT	1979	1987 - 1989	% CHANGE
Total zooplankton	113.1	117.6	+ 4.0
Macrozooplankton	32.2	16.7	- 48.1
Microzooplankton	88.9	100.8	+ 13.4
Cladocera	6.1	2.5	- 59.0
Calanoida	16.2	7.5	- 53.7
Cyclopoda	10.0	6.8	- 32.0
Nauplii	5.9	7.1	+ 20.3
Rotifera	24.3	32.5	+ 33.7
Ciliata Biomass	50.7	60.8	+ 19.9
Ciliata Abundance	25.3	33.8	+ 33.6
Oligotrichida	17.7	22.2	+ 25.4
Scuticociliatida	11.7	15.7	+ 34.2
Haptorida	4.7	7.0	+ 48.9

Within the Ciliata, oligotrichs increased 25.4% and the scuticociliates were elevated 34.2%. Haptorid ciliate biomass was increased by 48.9%.

Expressing these changes on a percentage basis reveals that microzooplankton (nauplii, rotfiers, ciliates) constituted 75.1% of the zooplankton community in 1979 and 85.7% of the population in 1987-1989. The major contributor to this compostional shift in biomass appears to be ciliates which increased from 39.7% to 51.7% of total zooplankton biomass. Nauplii were slightly more important as a contributor to total zooplankton biomass in 1987-1989 (7.1%) than in 1979 (5.9%).

5.4.D LAKE WEIR ZOOPLANKTON COMMUNITY STRUCTURE VERSUS COMPARABLE MESOTROPHIC FLORIDA LAKES

Seven mesotrophic lakes were selected for a detailed comparison of Lake Weir with Florida lakes of similar trophy. These lakes were chosen because of their complete data bases of all zooplankton components, as well as their similarity in sampling and analytical regimes to the present study (Bays 1983, Beaver 1980).

Comparison of the values calculated for other mesotrophic systems in Table 5-7 with Lake Weir values from Table 5-5 indicates that in general Lake Weir possesses a relatively depauperate zooplankton assemblage. The lake averages of the biomass of the major zooplankton components in Lake Weir were lower than means calculated for the other mesotrophic lakes in 11 of the 12 comparisons. Lake Weir did have substantially more scuticociliate biomass than most mesotrophic Florida systems and slightly below average rotifer compliment.

The relative absence of cladocerans, calanoid copepods, and nauplii greatly contribute to the reduced total zooplankton biomass. Expressed on a percentage composition basis, rotifers are proportionally more important to the Lake Weir zooplankton community than most mesotrophic Florida lakes.

Of the seven lakes used for comparison, Lake Weir most closely resembles Lake Placid in several respects. This Highlands County lake had similar nutrient concentrations, color, pH, and was morphometrically like Lake Weir - relatively large and deep for a Florida lake. The zooplankton populations of both systems appear to be impoverished compared to other mesotrophic lakes.

Table 5-7. Annual biomass distribution of major zooplankton components in 7 mesotrophic Florida lakes. Data calculated from Bays (1983) and Beaver (1980). Location of lakes given in Beaver & Crisman (1982).

	LAKE							
COMPONENT	A	B	C	D	E	F	G	MEAN
Total zooplankton	505.7	308.7	184.0	212.5	279.8	248.6	98.0	262.5
Macrozooplankton	269.6	157.7	64.8	89.9	62.6	23.7	17.8	98.0
Microzooplankton	236.1	151.0	119.2	122.6	217.8	225.0	80.2	164.5
Cladocera	130.6	34.0	18.3	57.3	21.9	7.6	4.5	39.2
Calanoida	74.1	108.1	31.2	17.3	18.9	4.2	65.7	45.6
Cyclopoda	64.9	15.6	15.2	15.2	21.8	11.9	9.5	22.0
Nauplii	77.5	37.5	26.6	21.0	33.0	20.8	9.8	32.3
Rotifera	56.9	45.4	31.7	27.4	56.8	59.4	6.0	40.5
Ciliata	101.7	68.1	60.9	74.2	127.5	144.8	64.4	91.7
Oligotrichida	23.8	14.1	22.4	23.8	56.8	55.7	17.8	30.6
Scuticociliatida	8.9	3.7	2.5	7.8	2.6	4.1	3.4	4.7
Haptorida	4.7	39.3	9.6	23.8	30.3	22.5	13.3	20.5

Lake code:

A = Francis
B = Ocean Pond
C = Placid
D = Sampson
E = Santa Fe
F = East Lake Tohopelagika
G = Washington

5.4.E COMPARISON OF LAKE WEIR ZOOPLANKTON BIOMASS TO PREDICTIVE ESTIMATES DERIVED FOR FLORIDA LAKES

Beaver & Crisman (1989) and Bays & Crisman (1983) have derived predictive equations for estimating ciliate, rotifer, crustacean, microzooplankton, macrozooplankton, and total zooplankton biomass. These equations, which are based on annual mean chlorophyll a concentrations, were developed from a 39 lake data base ranging from softwater oligotrophic to hypereutrophic, and allow an assessment of the response of the major zooplankton components in Lake Weir to trophic conditions relative to other Florida lakes.

The lake means for the various zooplankton components and chlorophyll a concentrations in Lake Weir were used for analysis (Table 5-8). The equation for total zooplankton biomass overpredicted the actual biomass by 51.6%. Similarly, macrozooplankton was overestimated by 170.9%, while microzooplankton was much more accurate with only an 18.6% underestimation.

All crustacean components, especially calanoid copepods, were underestimated by the equations, although predicted nauplii biomass was very close to the actual value. Rotifer biomass was underpredicted by 151.3%. As a whole, observed ciliate concentrations were reasonably close to those predicted by the equations although total ciliate abundance was underestimated by 52.2% and scuticociliate biomass were overestimated by 52.2% and 86.4%, respectively.

These results are in agreement with the trends previously established in this report - Lake Weir exhibits a low zooplankton biomass for its trophic state primarily due to a greatly reduced macrozooplankton population.

5.4.F CILIATED PROTOZOA AS INDICATOR TAXA

Beaver & Crisman (1989) developed a statistical relationship between the annual mean abundance of select ciliate species with lake trophic state. In this scheme, the average abundance of these taxa increased predictably with increasing lake productivity as measured by mean chlorophyll a concentrations. Multilinear regression analysis indicated that 92% of the variation in chlorophyll a densities in Florida lakes could be explained by the mean

Table 5-8. Comparison of the observed biomass of zooplankton components in Lake Weir with those predicted by equations empirically derived for Florida lakes.

COMPONENT	OBSERVED VALUE	PREDICTED VALUE	EQUATION SOURCE *
Total zooplankton	53.9	81.7	Bays & Crisman (1983)
Macrozooplankton	15.1	40.9	"
Microzooplankton	38.9	31.6	"
Cladocera	2.4	9.1	"
Calanoida	7.8	59.1	"
Cyclopoida	4.9	10.2	"
Nauplii	4.4	5.3	"
Rotifera	19.1	7.6	"
Ciliata Biomass	57.6	65.9	Beaver & Crisman 1989a
Ciliata Abundance	31.8	20.9	"
Oligotrichida	22.2	17.8	"
Scuticociliatida	12.3	6.6	"
Haptorida	5.5	5.8	"

* for Bays & Crisman (1983) equations express biomass in ug C l^{-1}

for Beaver & Crisman (1989a) equations express biomass in ug d.w l^{-1}

abundances of Vorticella microstoma and Mesodinium pulex.

Application of this index to the mean abundance of these species in Lake Weir indicated that this system would be characterized as mesotrophic (Table 5-9). The abundances of V. microstoma ranged from 450 cells m^{-3} at station 7 to 1090 cells m^{-3} at station 6. The lake wide average was 830 cells m^{-3}. All of the values were well within the range recommended for mesotrophic lakes.

The results produced for M. pulex were similar, with three of the stations characterized as mesotrophic and four being eutrophic. Concentrations for M. pulex ranged from 3700 cells m^{-3} at station 6 to 6860 cells m^{-3} at station 7 with a lake average of 4980 cells m^{-3}.

5.4.G ZOOPLANKTON SEASONALITY IN LAKE WEIR

Total zooplankton biomass in Lake Weir generally peaked in July 1987 and September 1988 (Figure 5-9). Values at that time ranged from 235 mg d.w. m^{-3} (station 2) to 347 mg d.w. m^{-3} (station 6). Most stations recorded their highest biomass in July with the exception of the midlake station, which had a biomass peak in March equal to that in July, and station 4 which had a higher total zooplankton biomass in May.

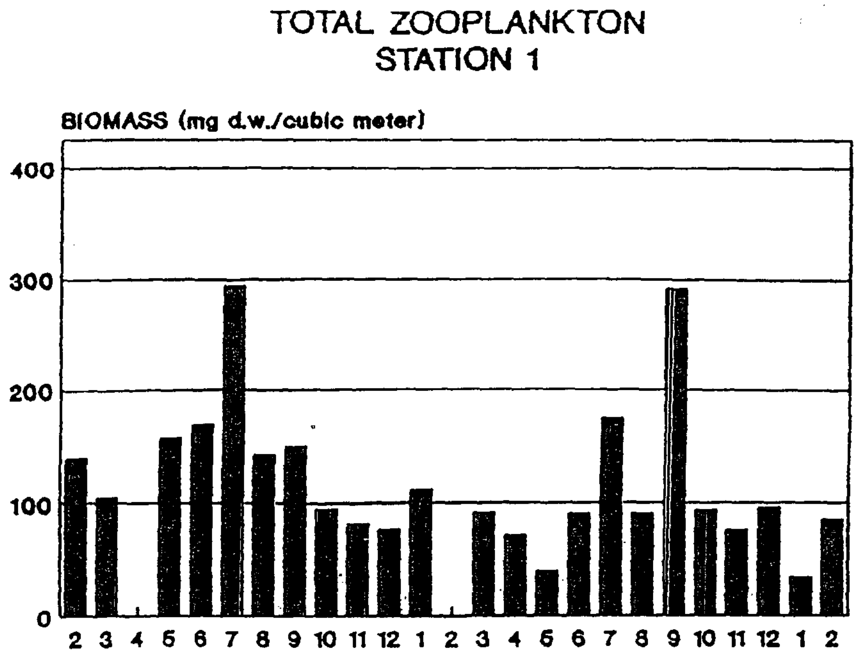
The temporal distribution of macrozooplankton biomass was extremely variable on a station to station basis, and was generally greater in the first half of the study (Figure 5-10). Most stations did have peak abundance during spring (March, May) 1987, while others recorded pulses during the fall or midsummer. The highest macrozooplankton biomass (115 mg d.w. m^{-3}) was recorded at station 2 in September 1988.

Microzooplankton biomass showed a clear seasonality when compared to macrozooplankton. Each station consistently recorded biomass peaks during the summer or early fall, usually during July (Figure 5-11). Station 3 also had a secondary microzooplankton peak in March 1987. Populations tended to be relatively depressed at other seasons. The highest microzooplankton biomass observed was 405 mg d.w. m^{-3} at station 6 in September 1988.

Cladocerans were usually the most abundant during the spring months and occasionally displayed secondary peaks during the fall (Figure 5-12). The largest cladoceran biomass encountered was 71 mg d.w. m^{-3} at station 4 in May 1987. The cladoceran community was invariably dominated by

Table 5-9. Trophic conditions associated with the mean annual abundance of select ciliate species in Lake Weir for the period February 1987 - February 1989 (M = mesotrophic, E = eutrophic). Abundances expressed as cells/L.

Station	*Vorticella microstoma*		*Mesodinium pulex*	
1	M	980	E	5280
2	M	840	M	4560
3	M	830	E	5230
4	M	1020	M	4160
5	M	610	E	5060
6	M	1090	M	3700
7	M	450	E	6860



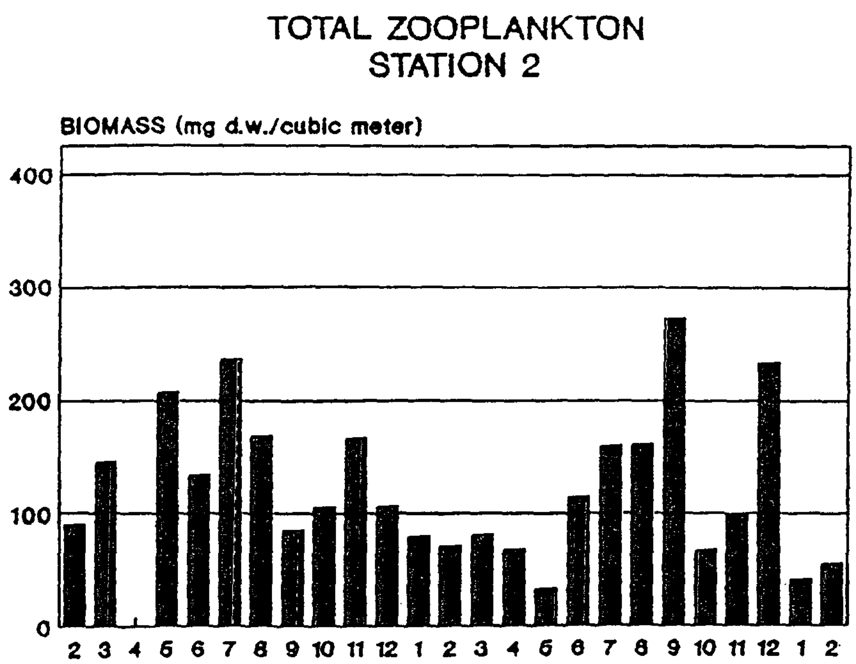
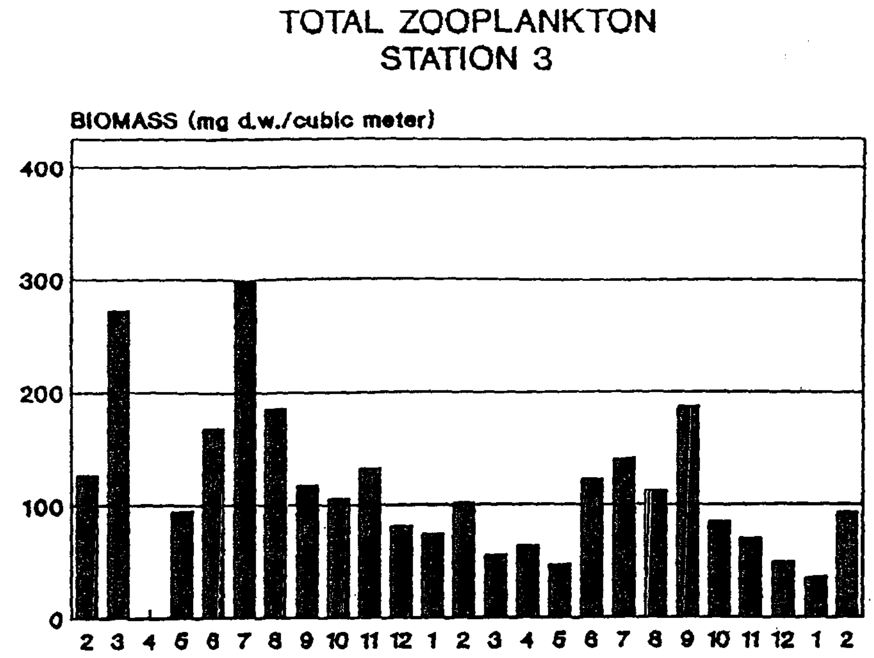
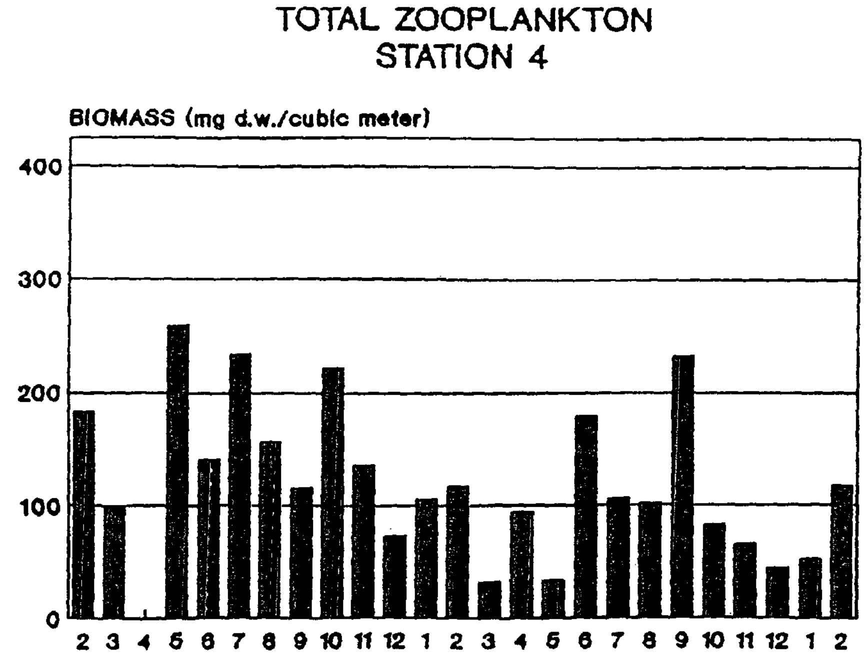


Figure 5-9. Biomass of total zooplankton at each station for individual months of 1987-1989.





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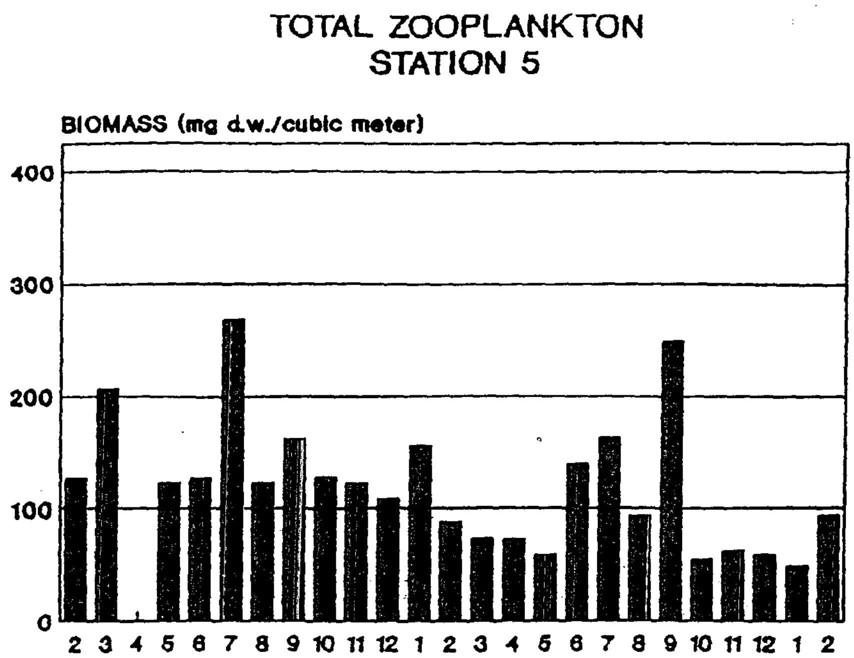

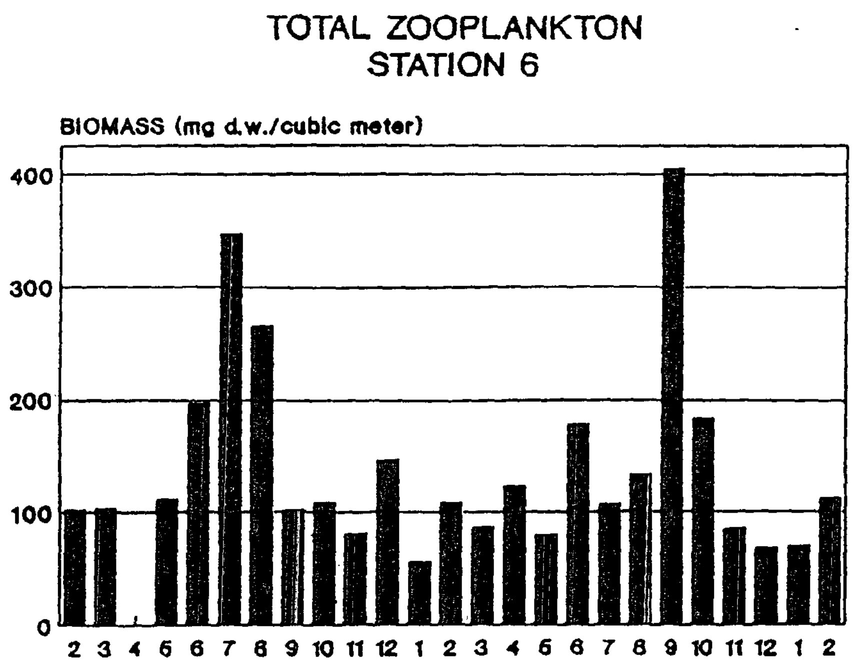

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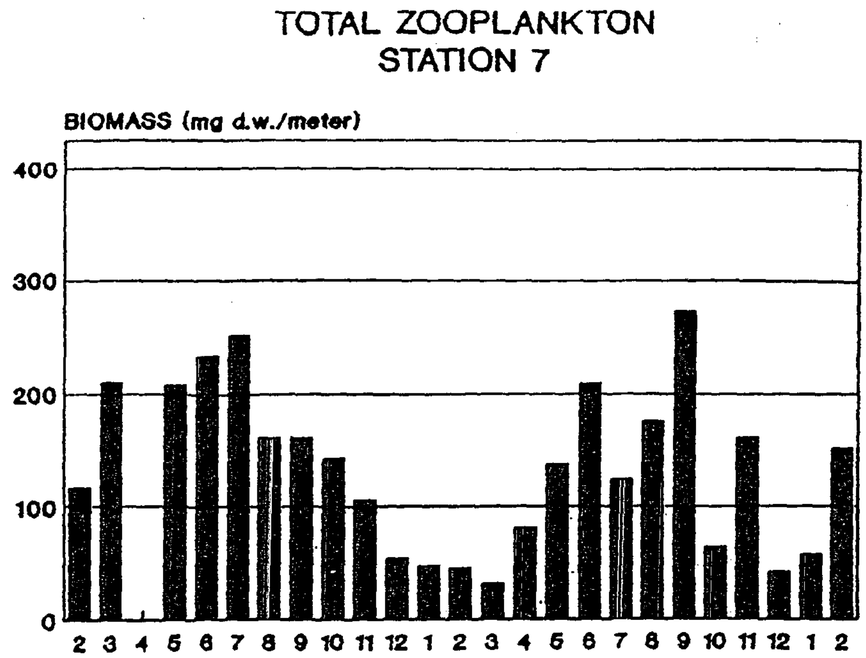

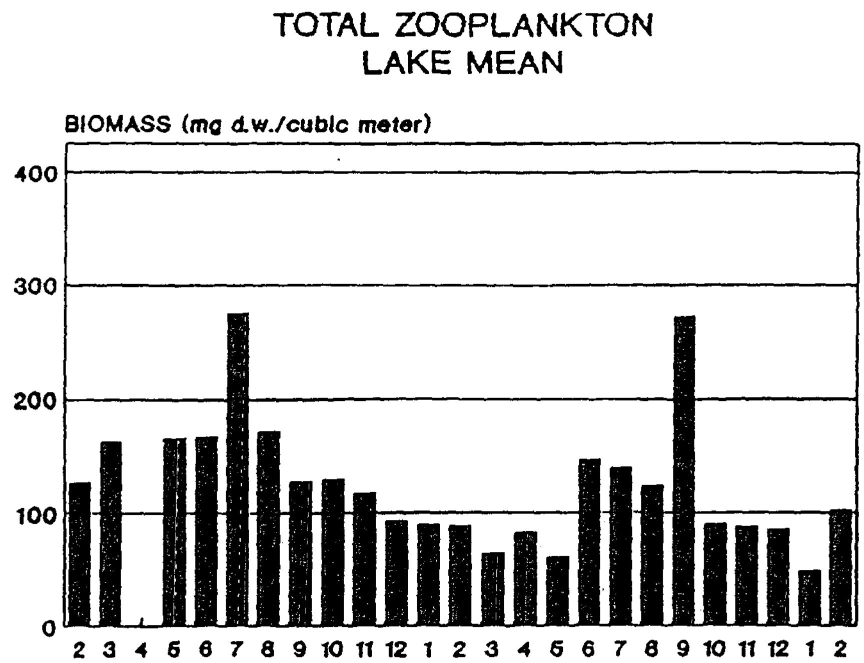

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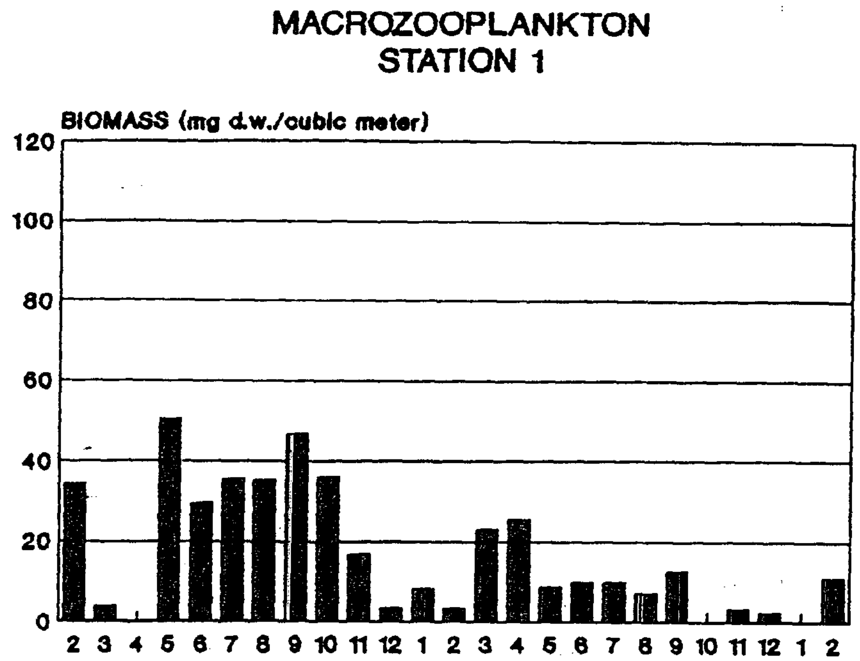


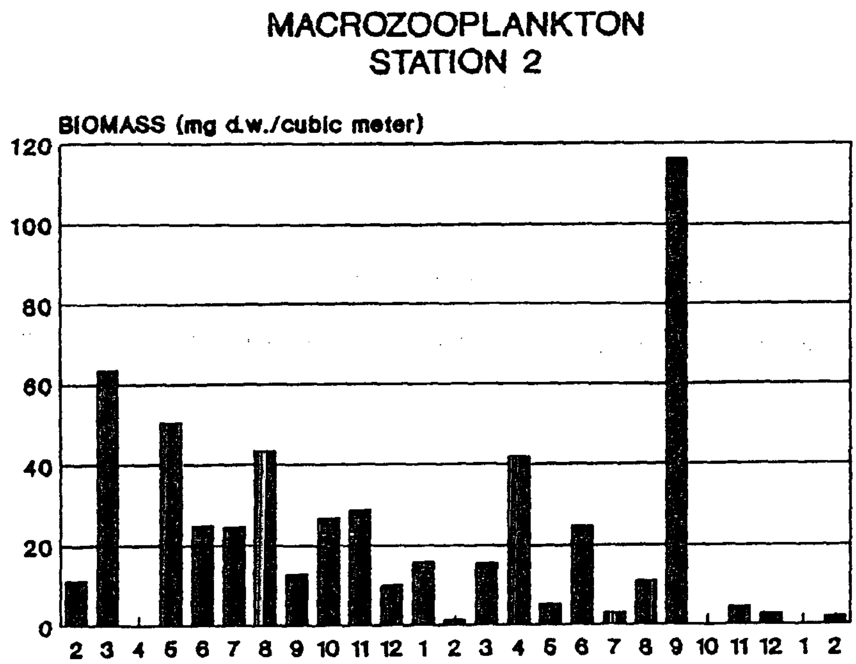
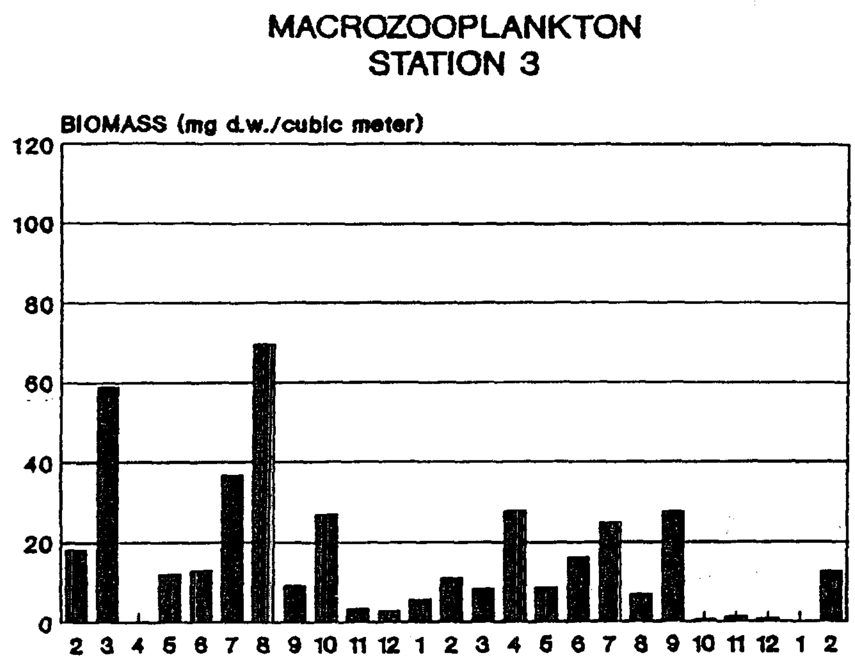
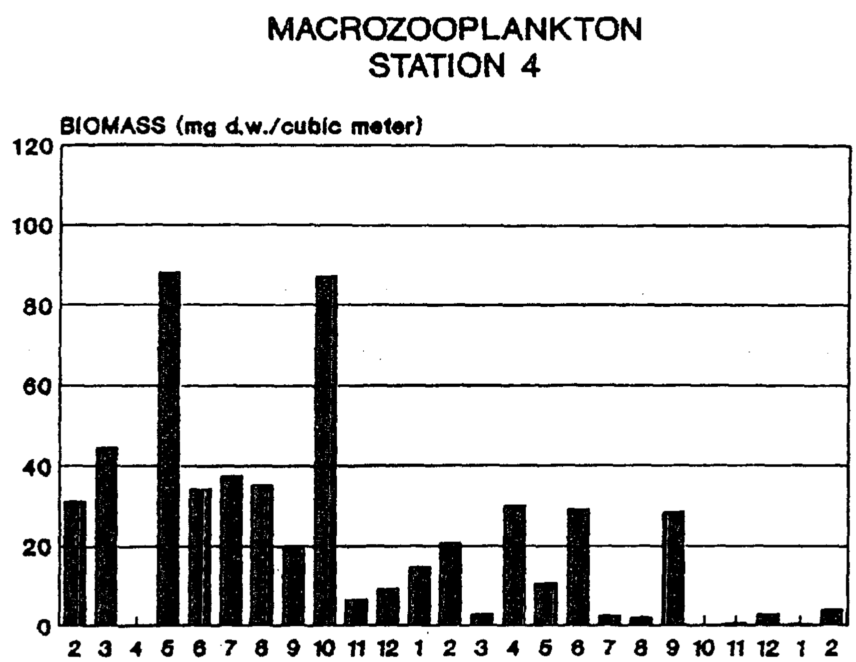


Figure 5-10. Biomass of macrozooplankton at each station for individual months of 1987-1989.





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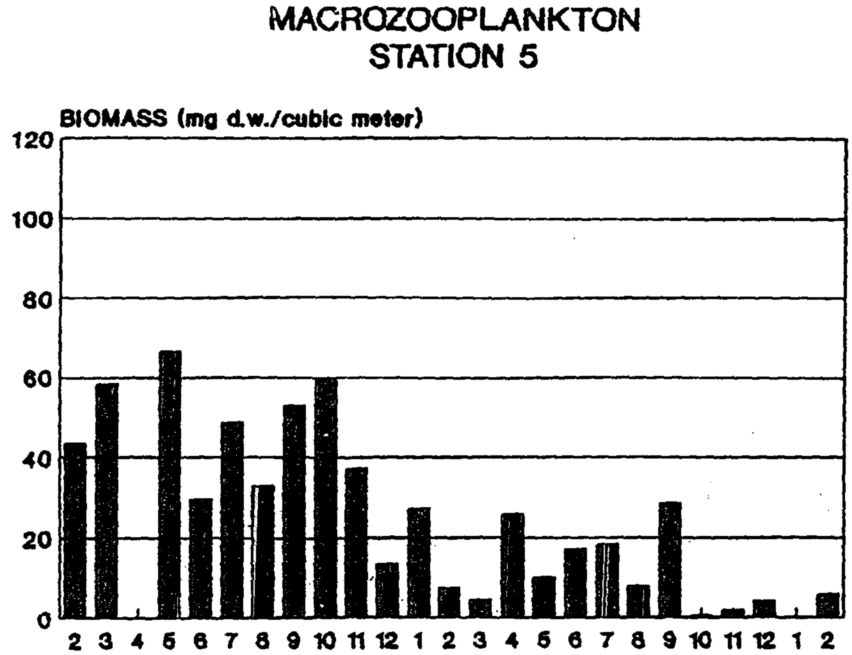

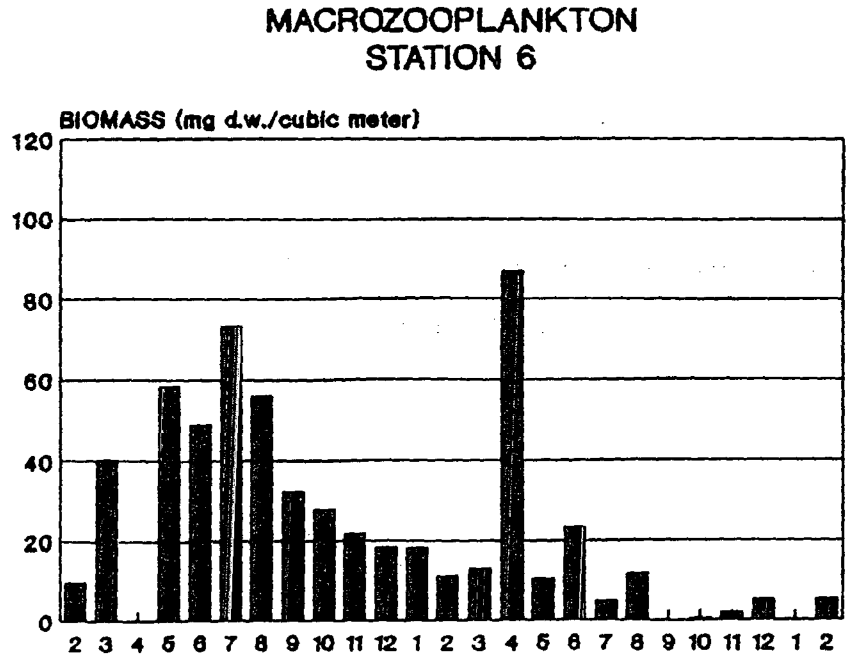

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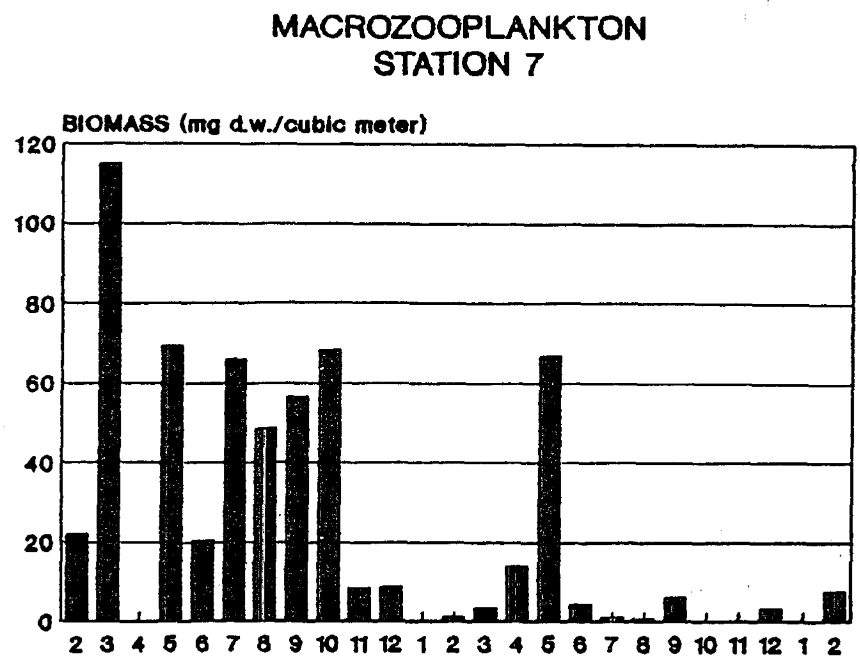

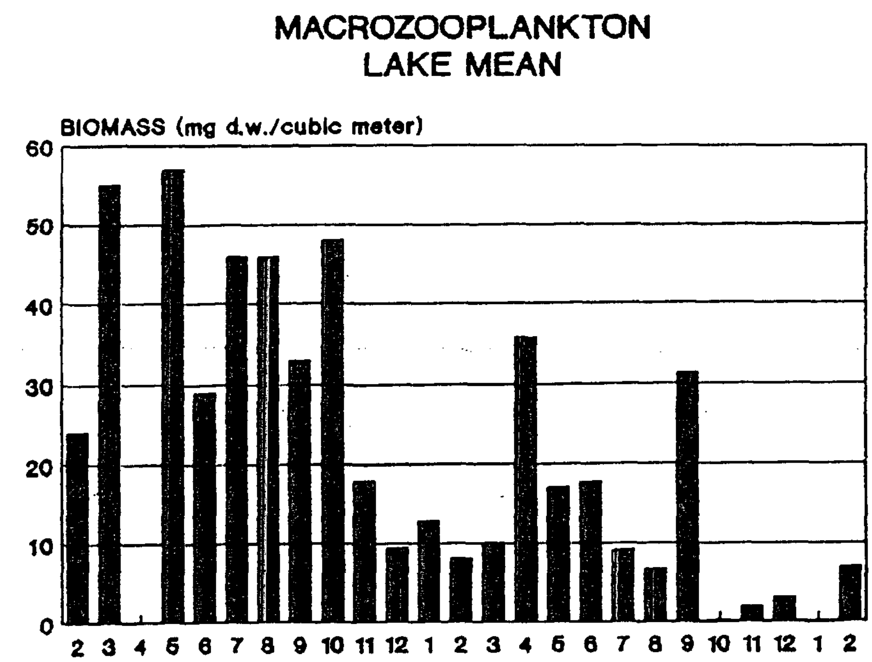

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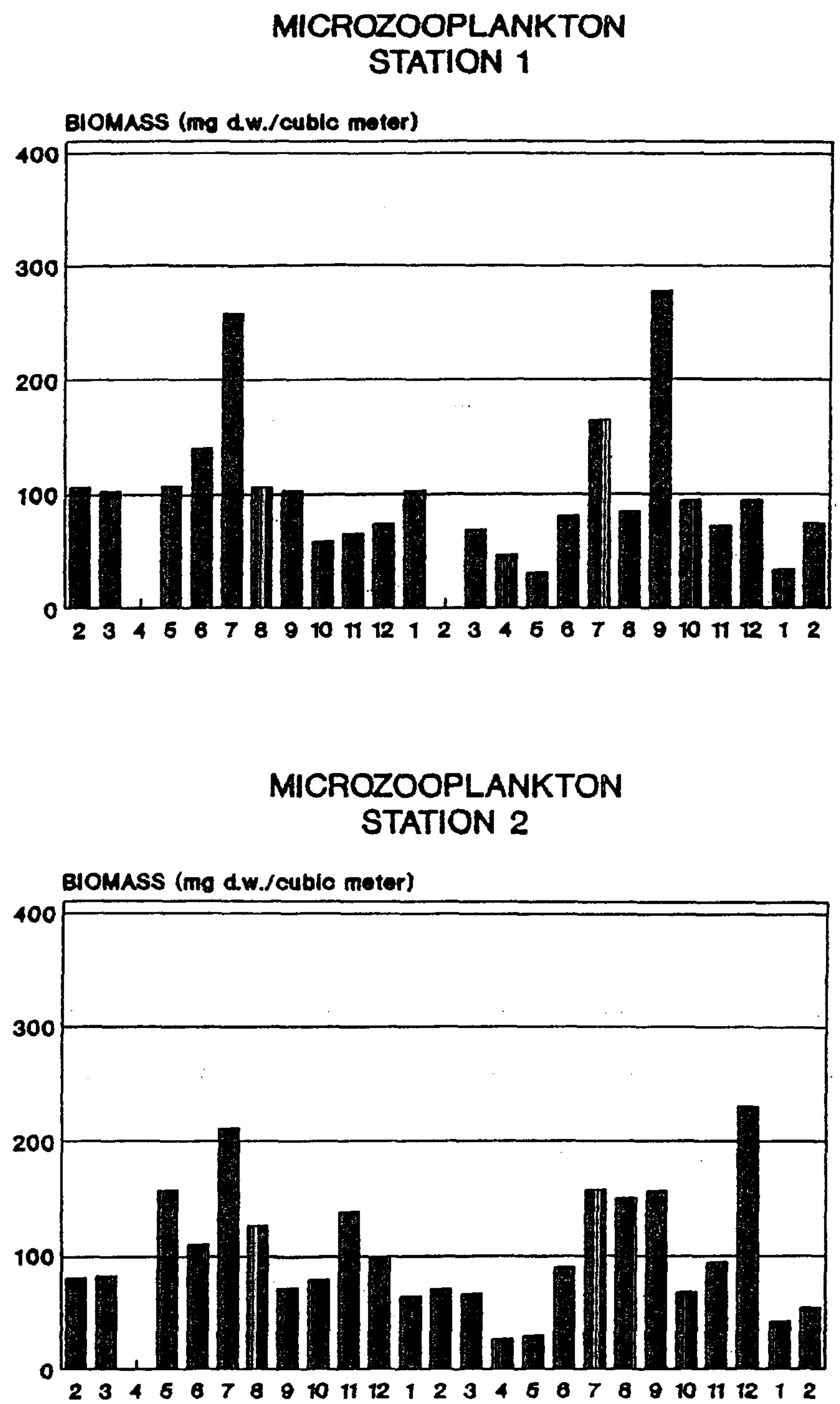
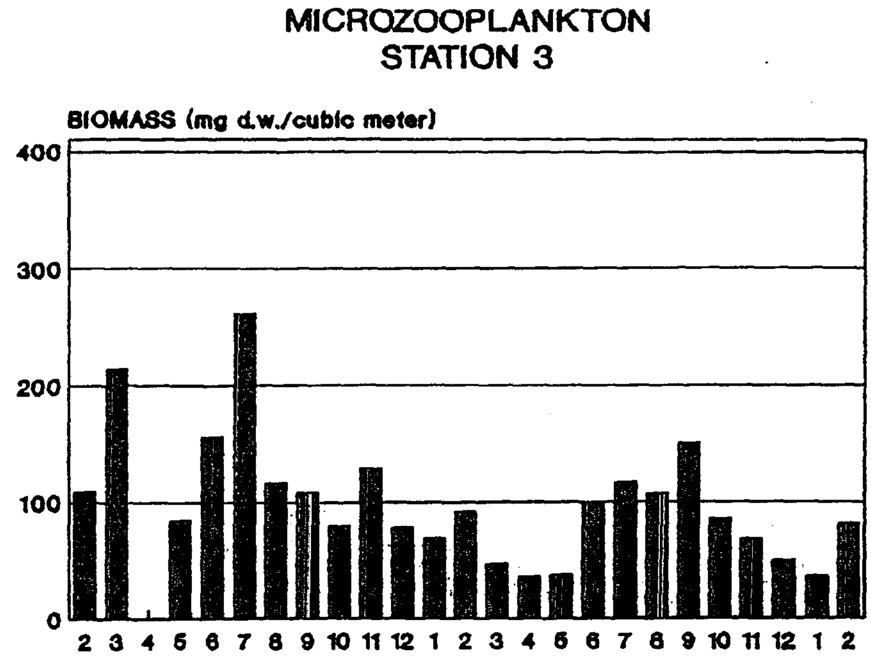
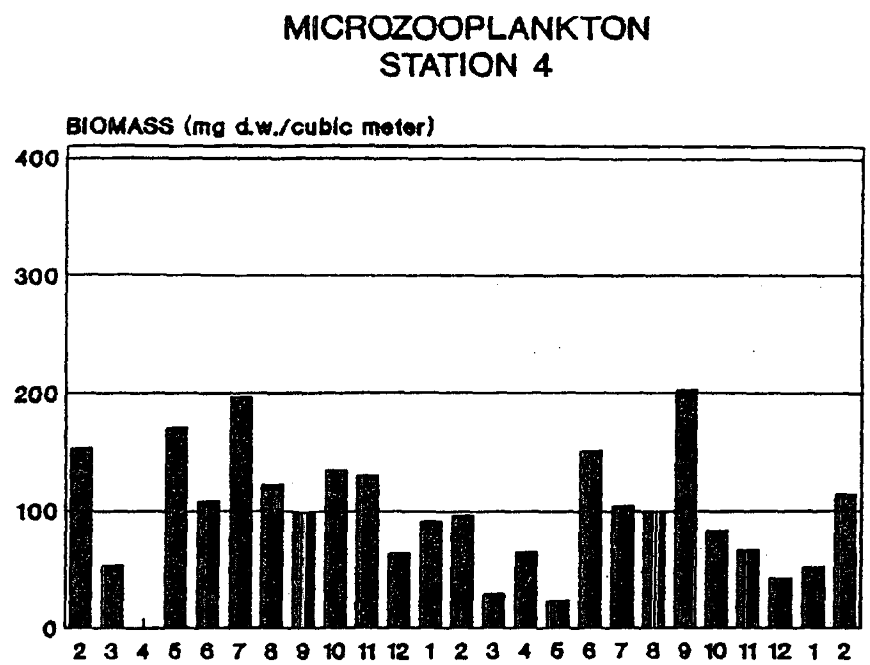


Figure 5-11. Biomass of microzooplankton at each station for individual months of 1987-1989.





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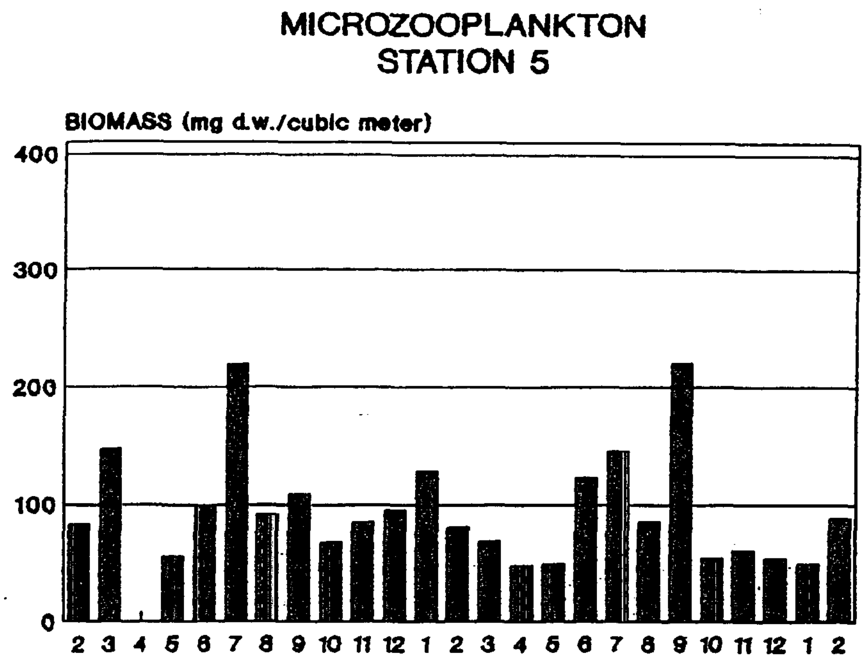

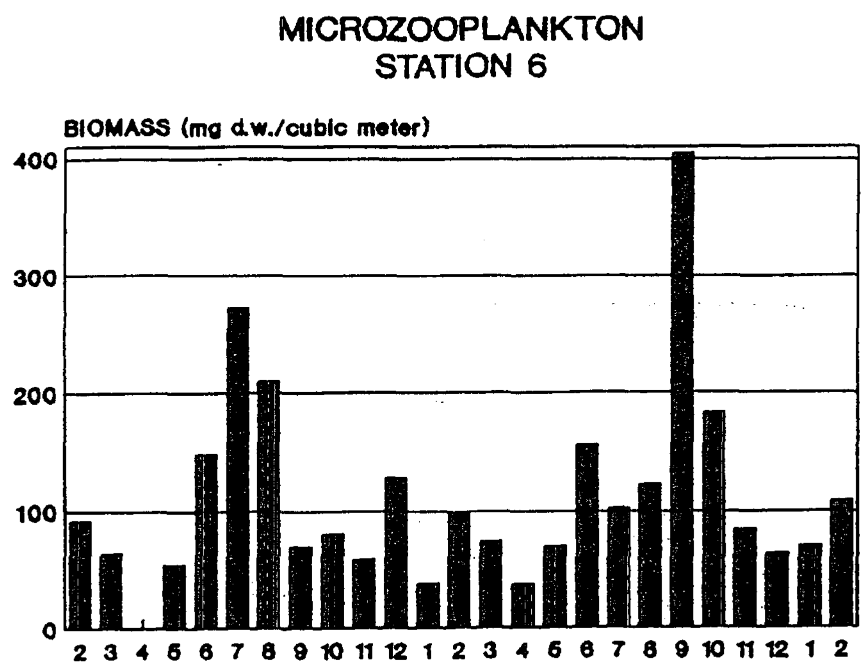

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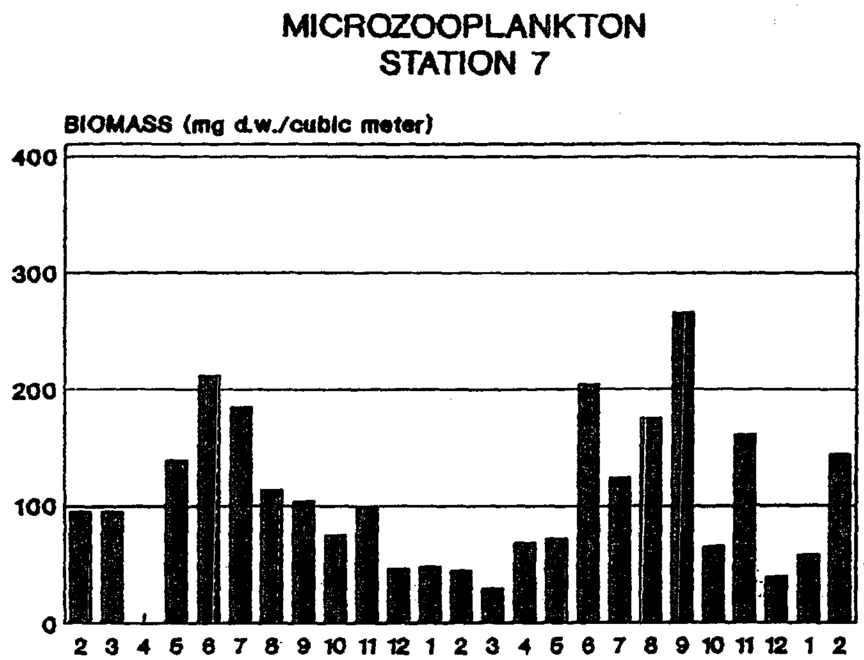

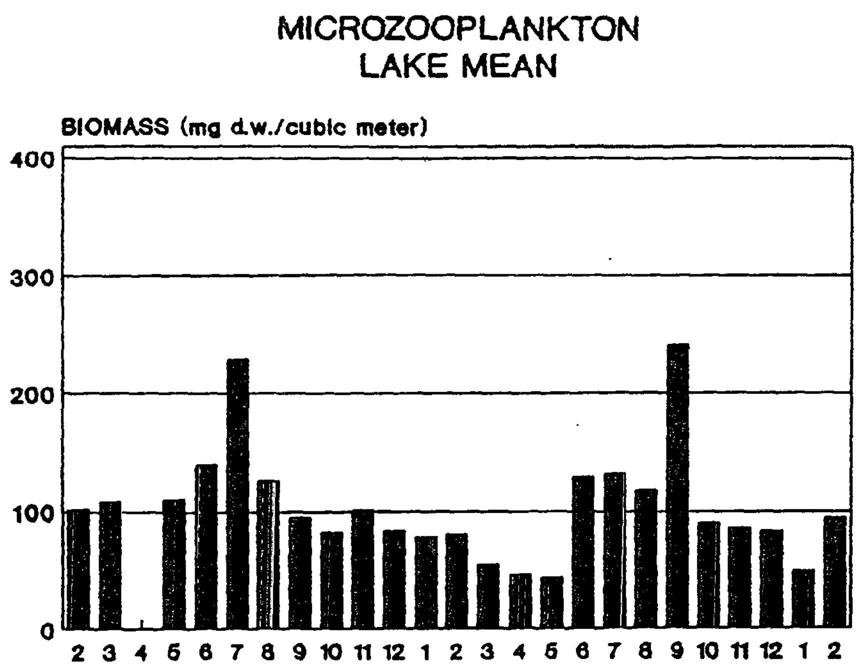

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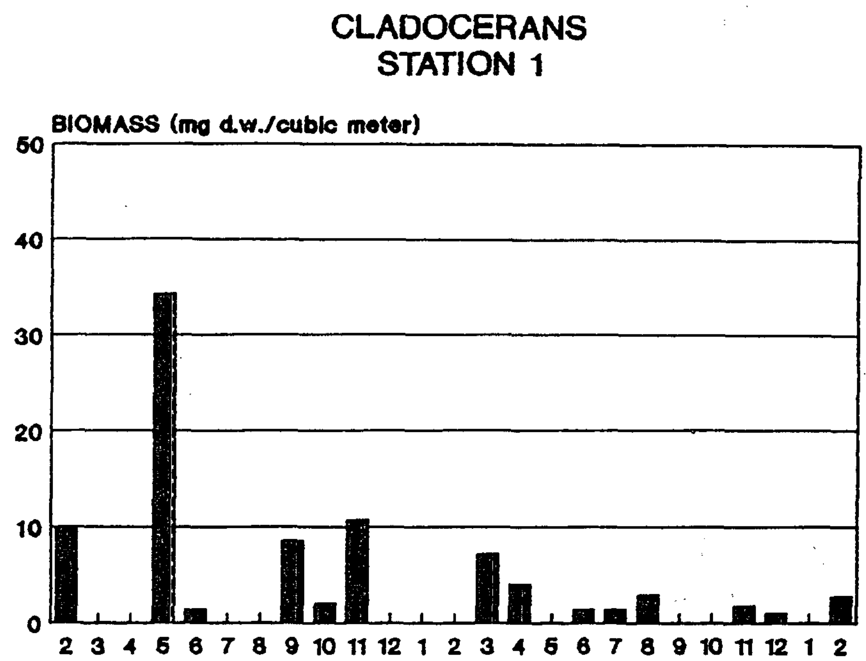


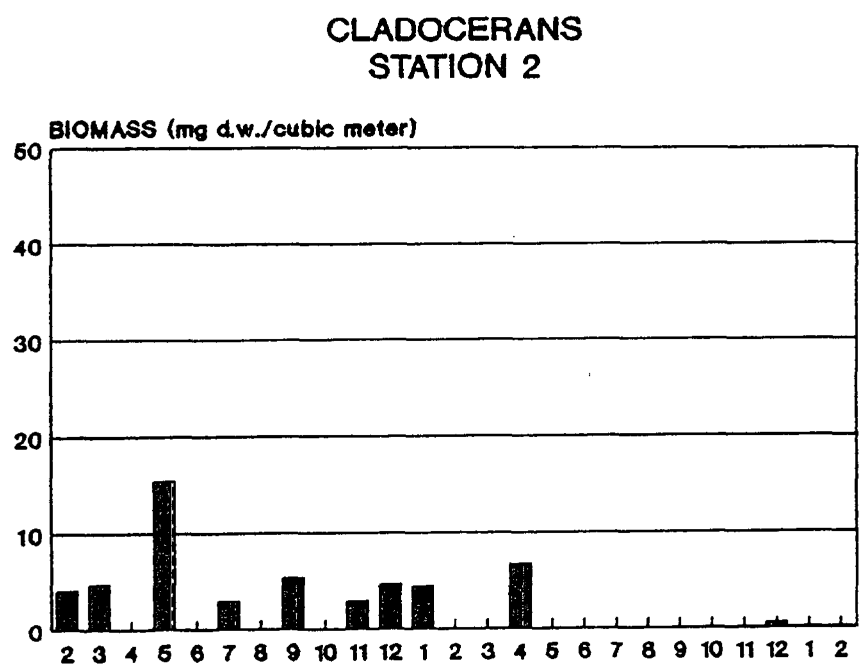
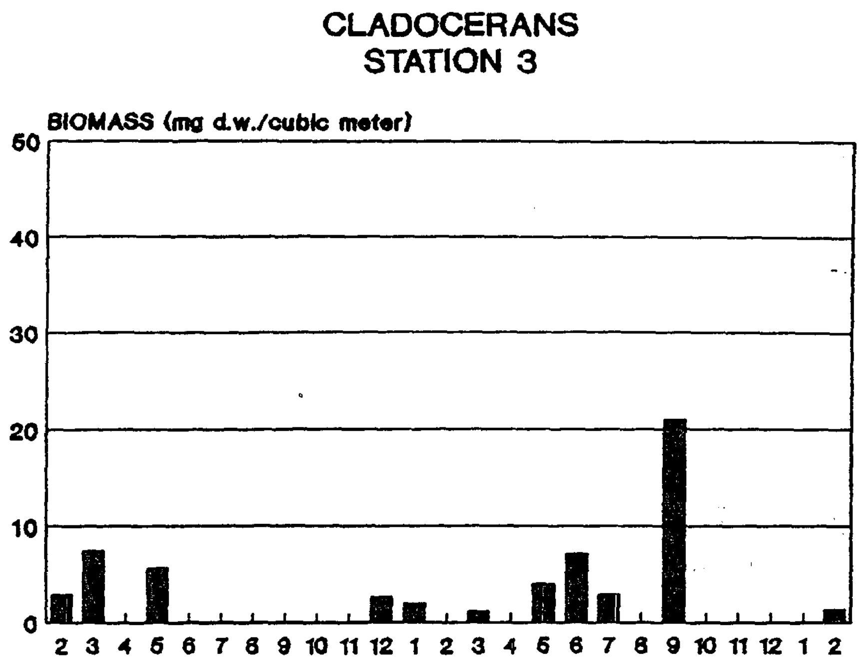
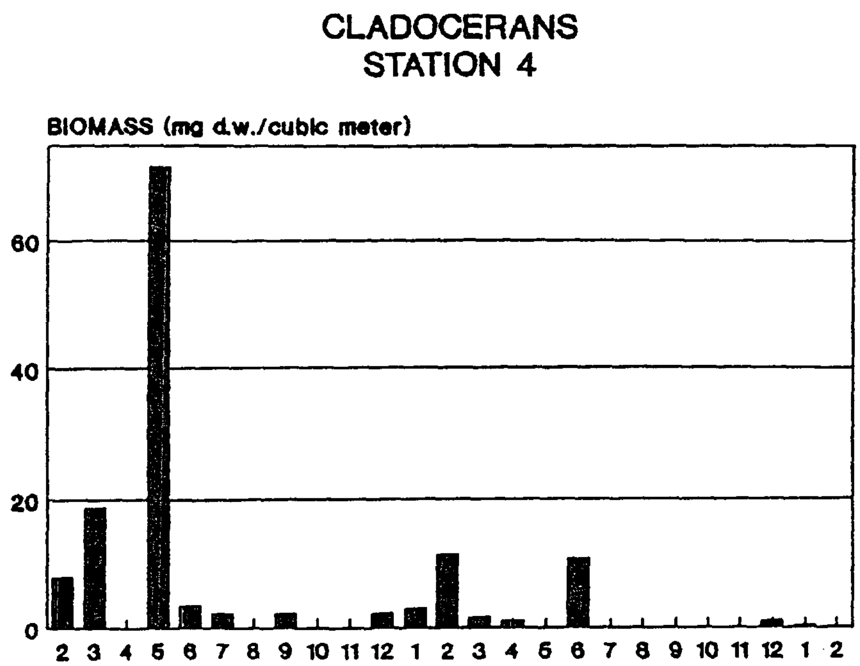


Figure 5-12. Biomass of cladocerans at each station for individual months of 1987-1989.





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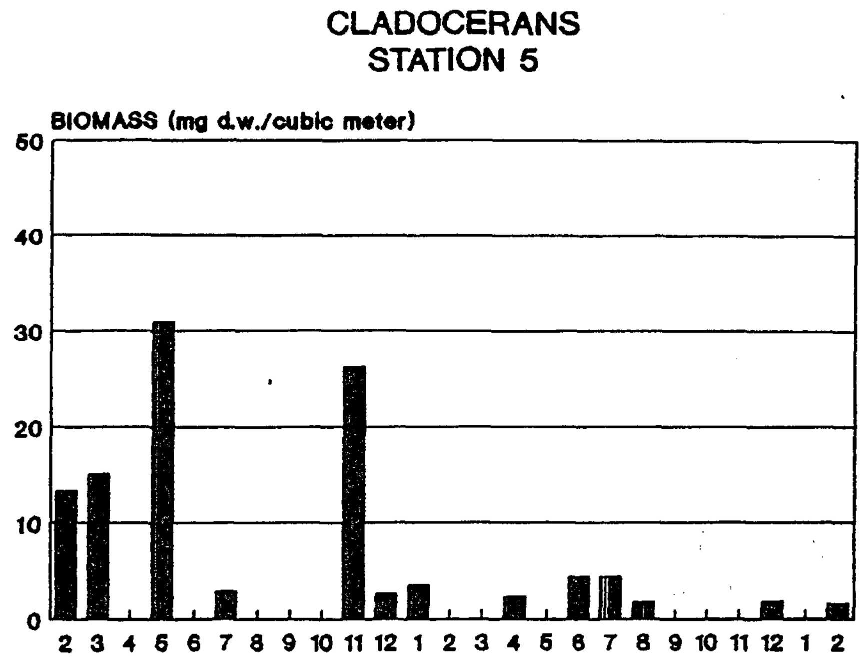

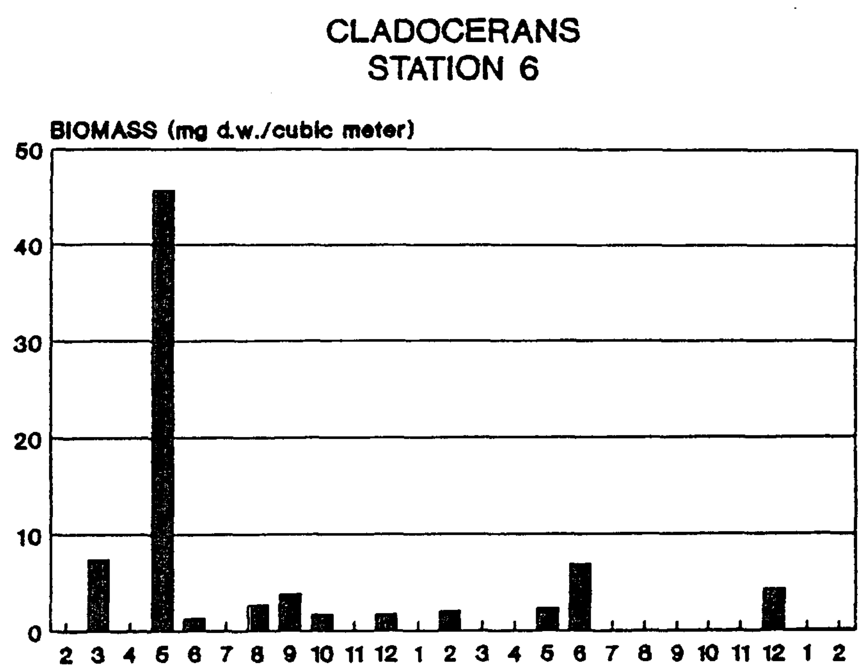

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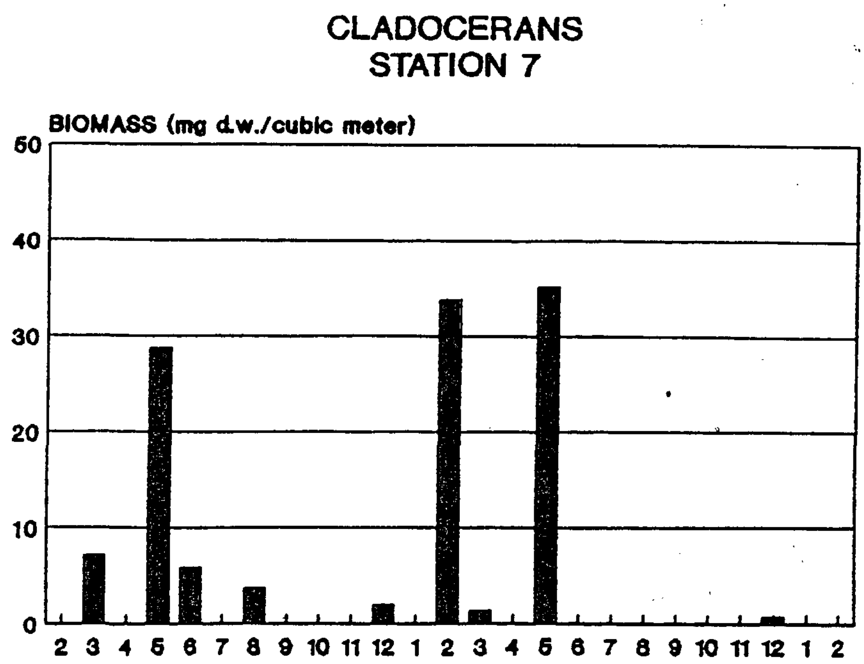


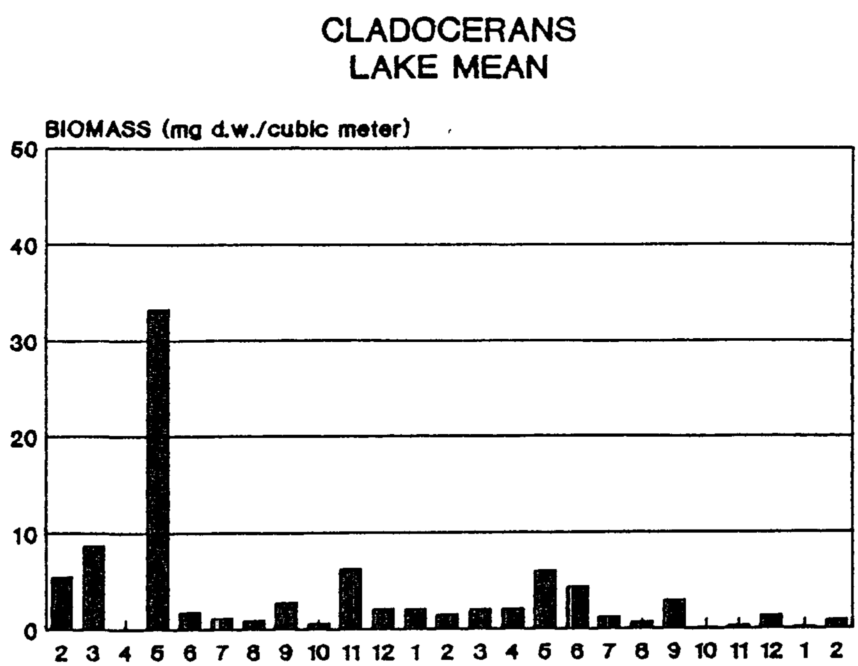


Figure 5-12. Continued.

Eubosmina tubicen.

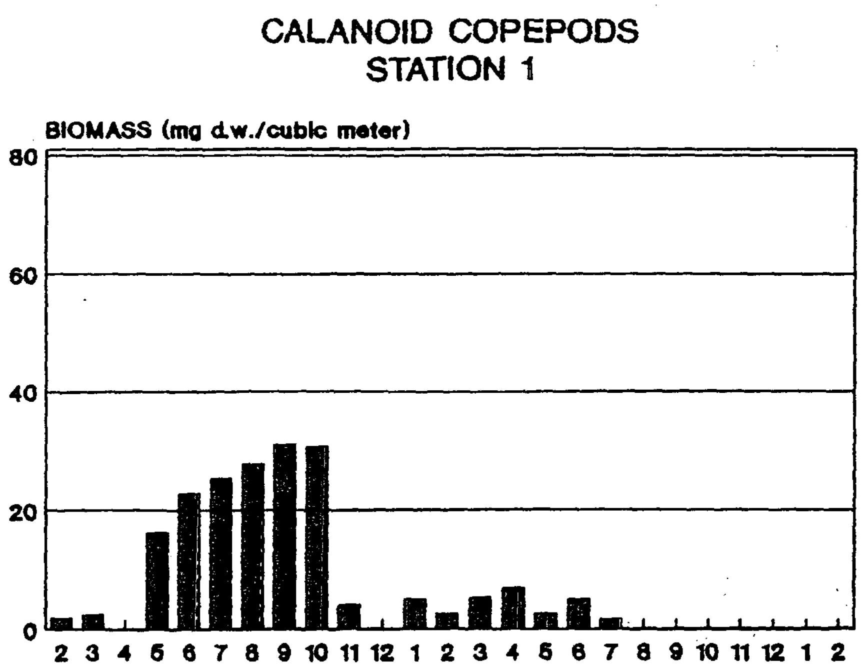
Calanoid copepods generally began to increase in spring and maintained high levels until the fall decline (Figure 5-13). The timing of the biomass peaks for this group was quite variable. The highest biomass detected for this group was 80 mg d.w. m^{-3} in October 1987 at station 4. Cyclopoid copepods usually peaked in March and sometimes late summer or early fall (Figure 5-14).

Nauplii populations displayed a consistent seasonality regardless of station (Figure 5-15). Populations increased during spring and then declined during summer. A large November 1987 and September 1988 biomass pulse was noted at most stations. The highest biomass attained by nauplii was 39 mg d.w. m^{-3} at station 6 in May 1987.

Rotifer populations displayed a clear seasonality with either midsummer (1987) or early fall (1988) pulses occurring at all stations (Figure 5-16). These periods of high rotifer biomass were characterized by surges in all rotifer species with their populations dominated by Hexarthra mira and Collotheca libera. The highest rotifer biomass (344 mg d.w.l^{-1}) recorded in Lake Weir, however, was in September 1988 at station 6 and was attributable to a bloom of H. mira.

Total ciliate biomass usually tracked rotifers with peaks recorded during July 1987 (Figure 5-17). Populations remained depressed at other times of the year. The highest ciliate biomass observed in Lake Weir was 210 mg d.w. m^{-3} in December 1988 at station 2. Midsummer ciliate communities were characterized by elevated densities of most species. Myxotrophic ciliates (those with endosymbiotic zoochlorellae) peaked in July and comprised an average of 30.0% of total ciliate biomass. Two myxotrophic ciliate species, Coleps hirtus and Strobilidium cf oculatum, were the most abundant. These ciliates are known to inhabit the metalimnion and hypolimnion, respectively. A similar midsummer maxima of myxotrophic ciliates has been noted for highly colored Florida systems, and has been ascribed to the development of thermal stratification and nutrient limiting conditions in the water column (Beaver et al. 1988).

Oligotrich ciliates were frequently abundant during the first part of the year and occasionally increased until the midsummer biomass peak (Figure 5-18). Scuticociliate populations tended to peak in June prior to total zooplankton, microzooplankton, rotifers, and total ciliate biomass (Figure 5-19). Populations of this order then declined to varying extents during summer, and often a secondary peak was noted in fall. Haptorid ciliates tended to peak in the early summer but peaks were also seen during the fall at stations 2 and 3 (Figure 5-20).



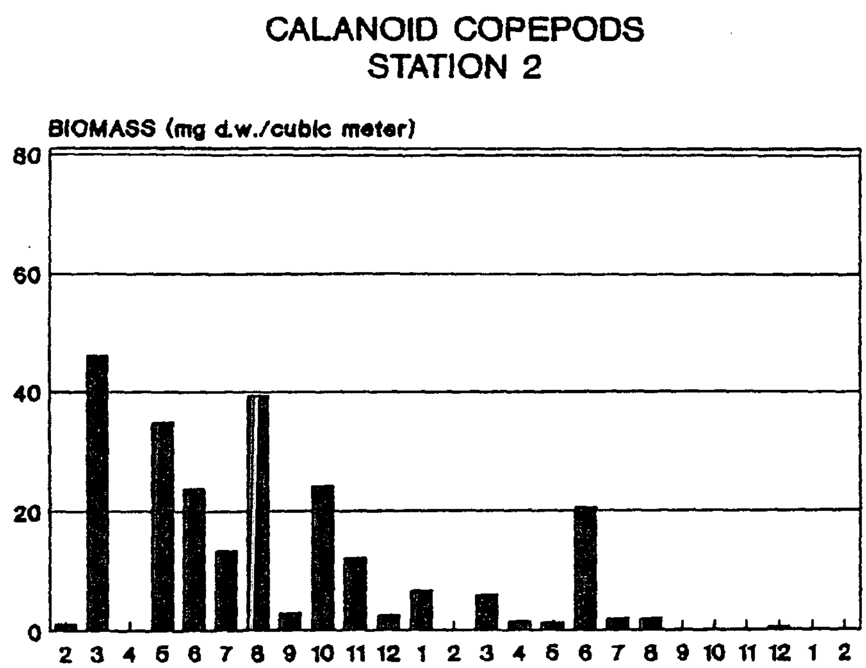
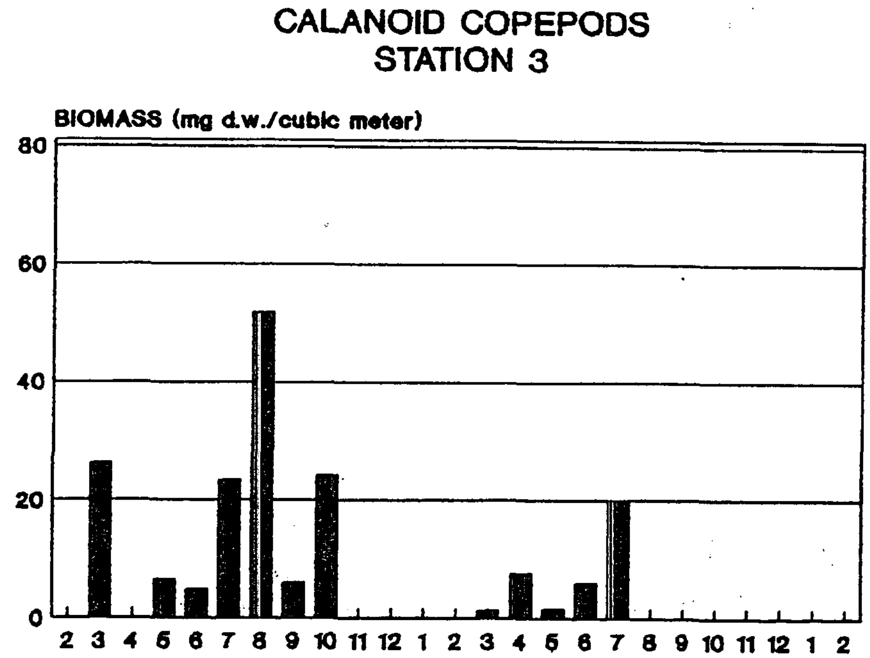
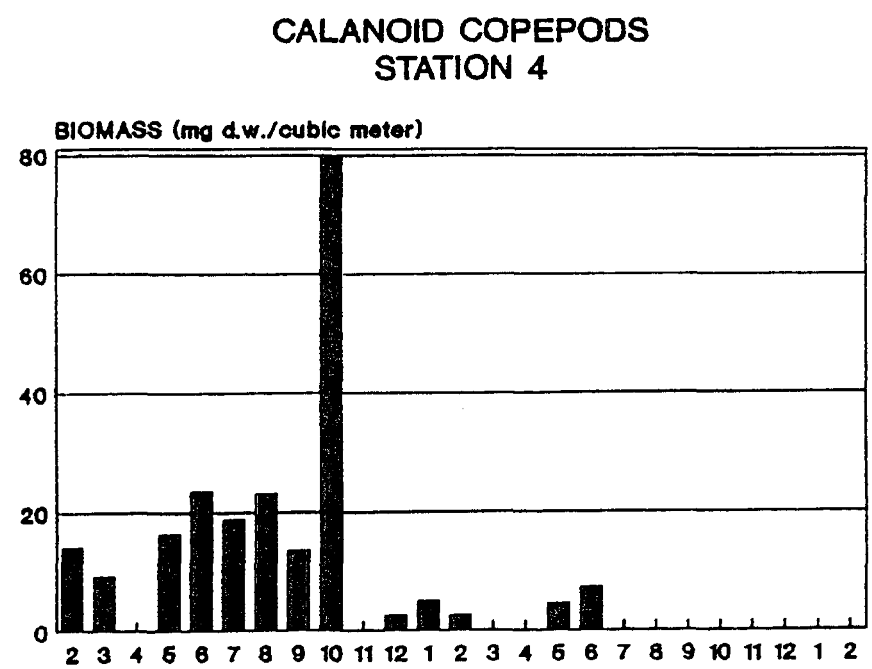


Figure 5-13. Biomass of calanoid copepods at each station for individual months of 1987-1989.





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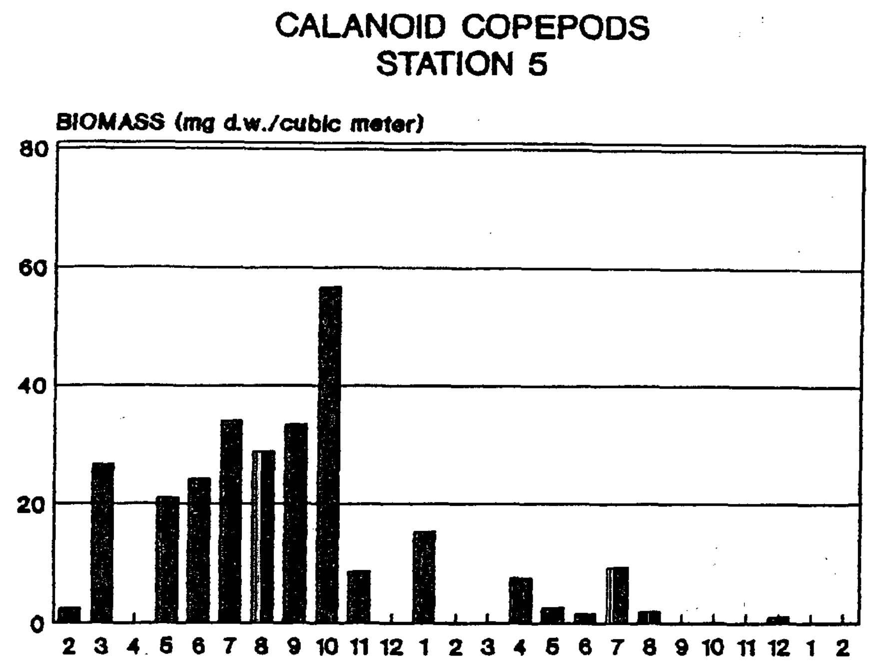

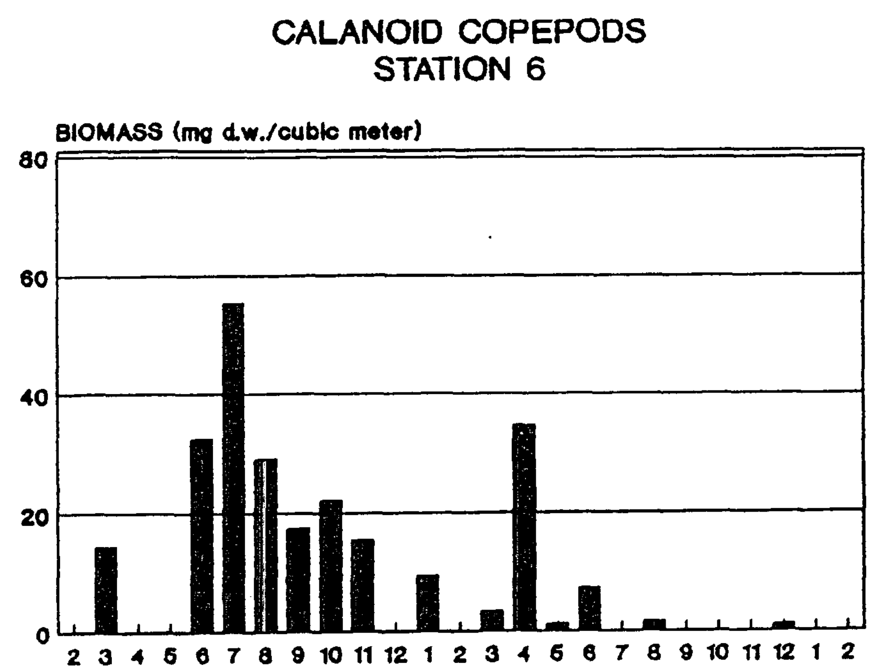

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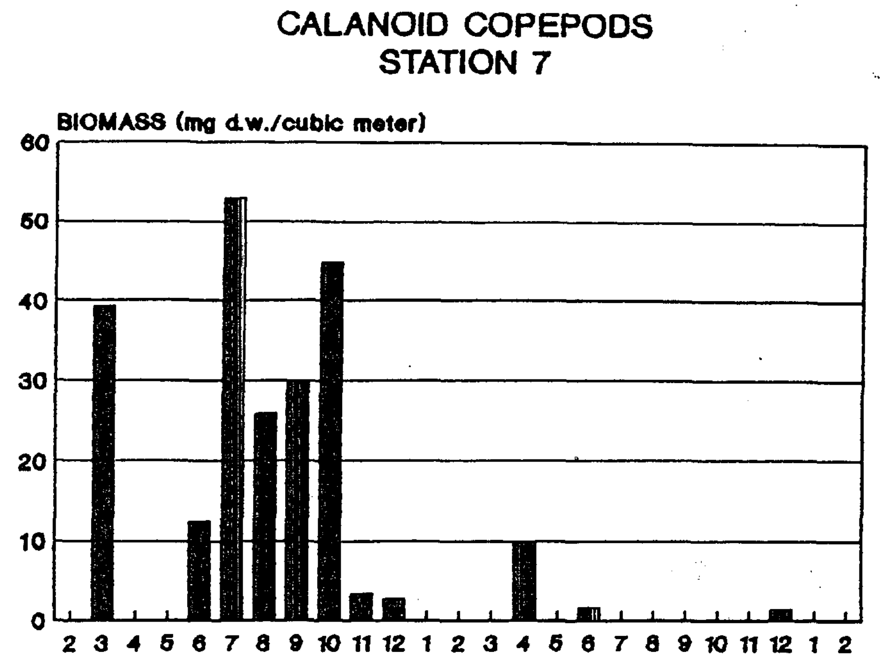

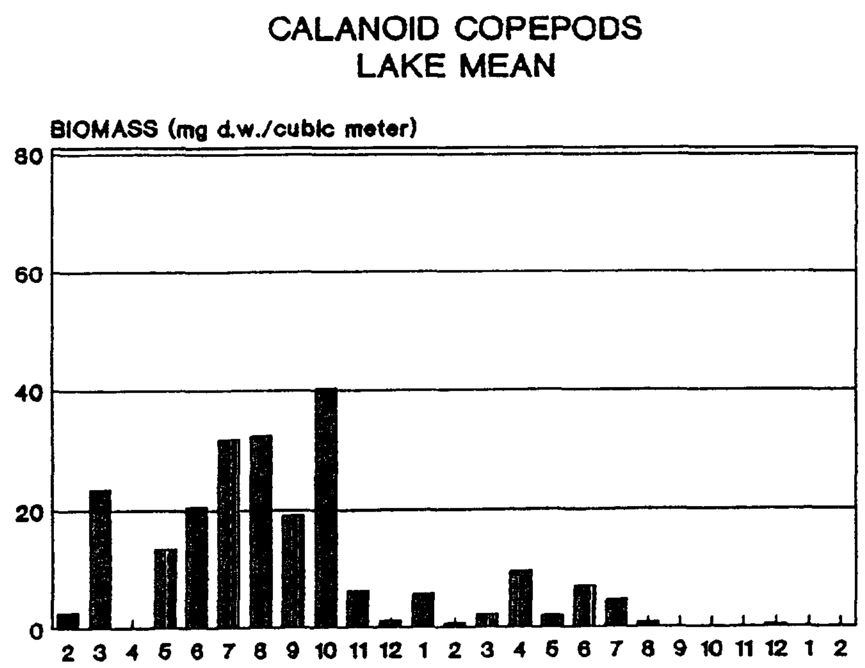

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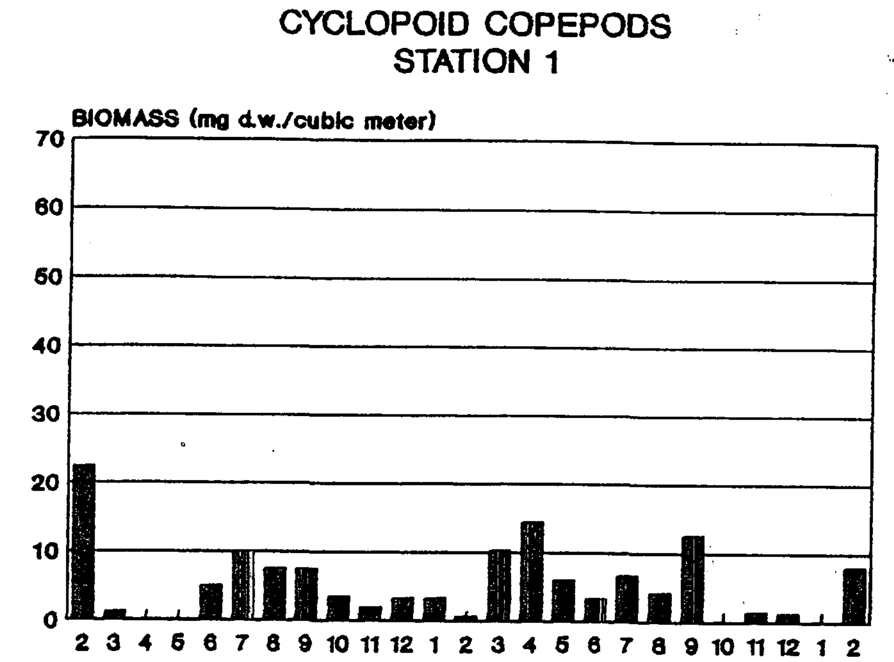


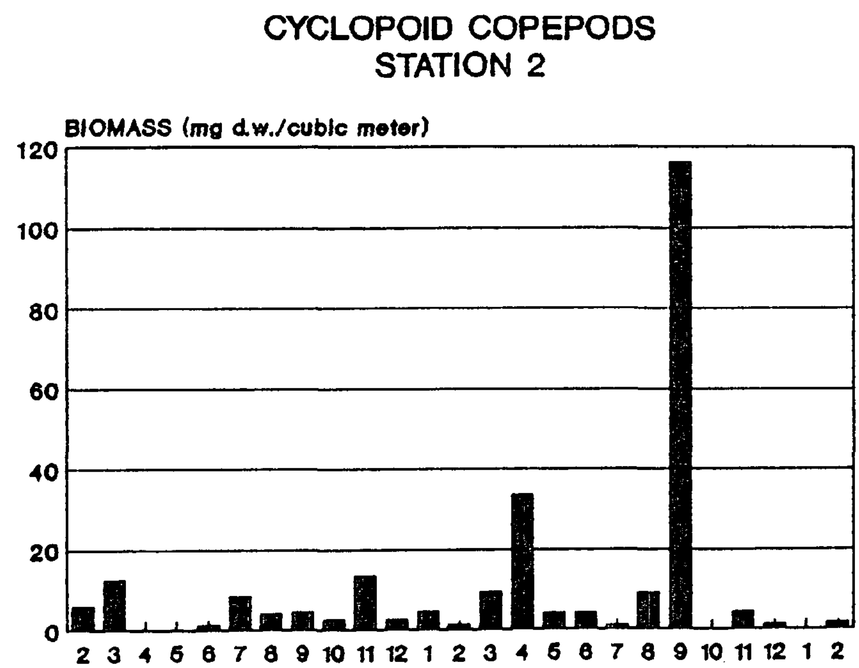
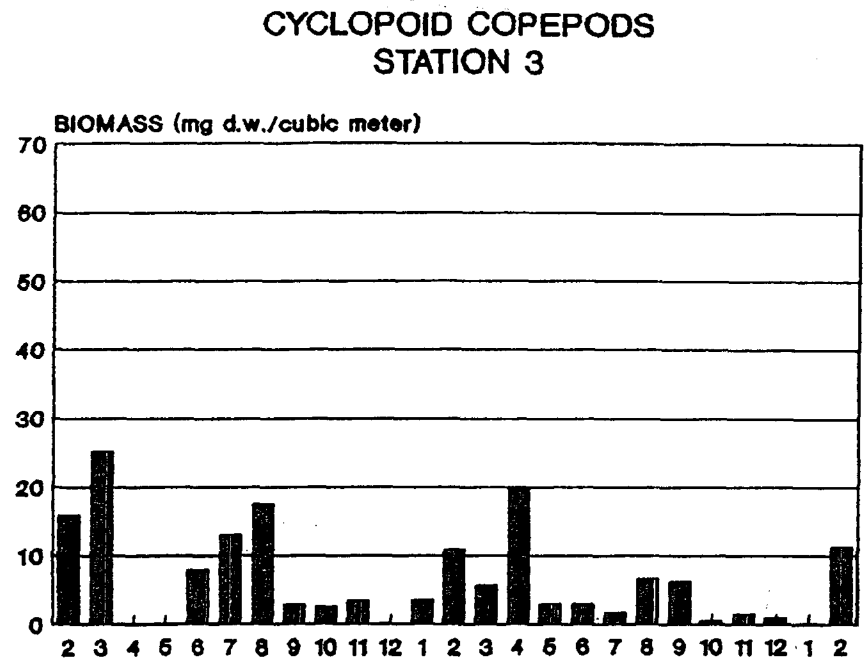


Figure 5-14. Biomass of cyclopoid copepods at each station for individual months of 1987-1989.



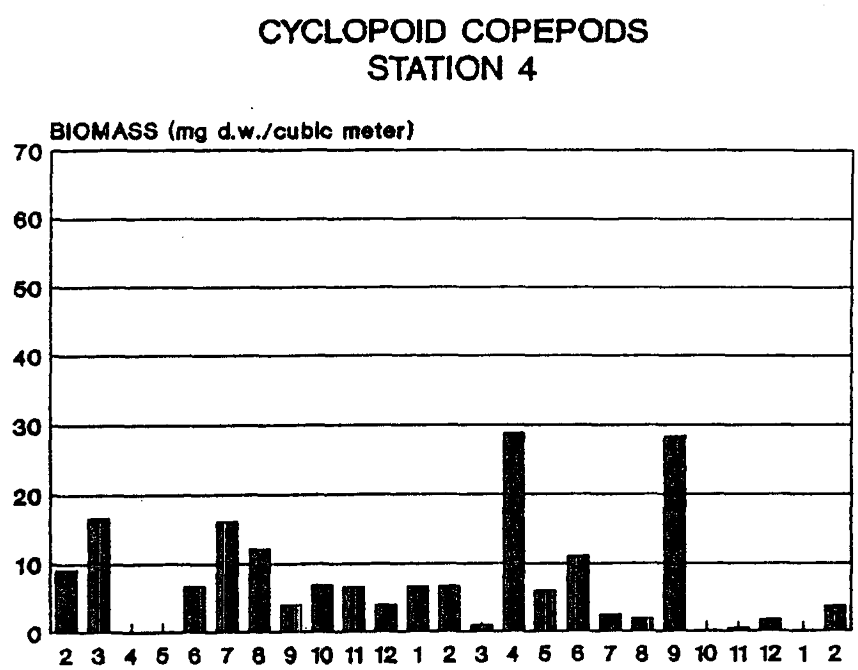
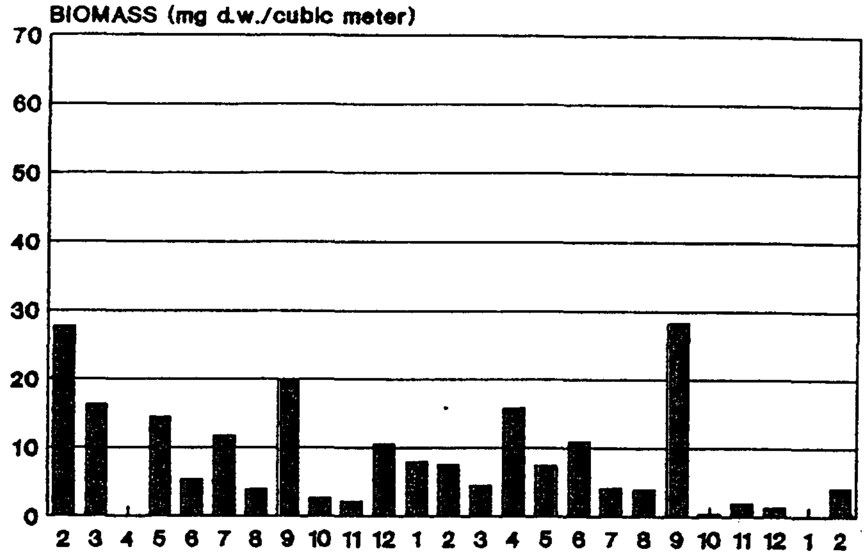
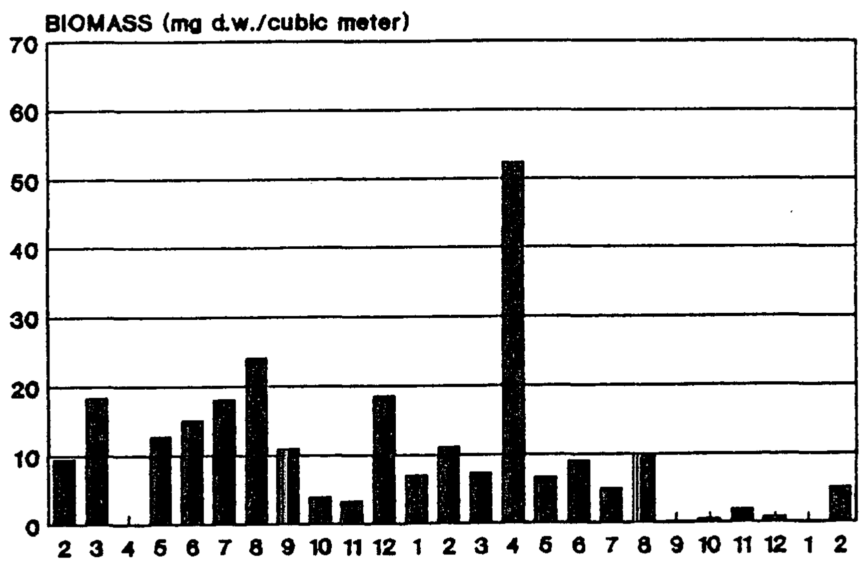


Figure 5-14. Continued.

CYCLOPOID COPEPODS
STATION 5



CYCLOPOID COPEPODS
STATION 6



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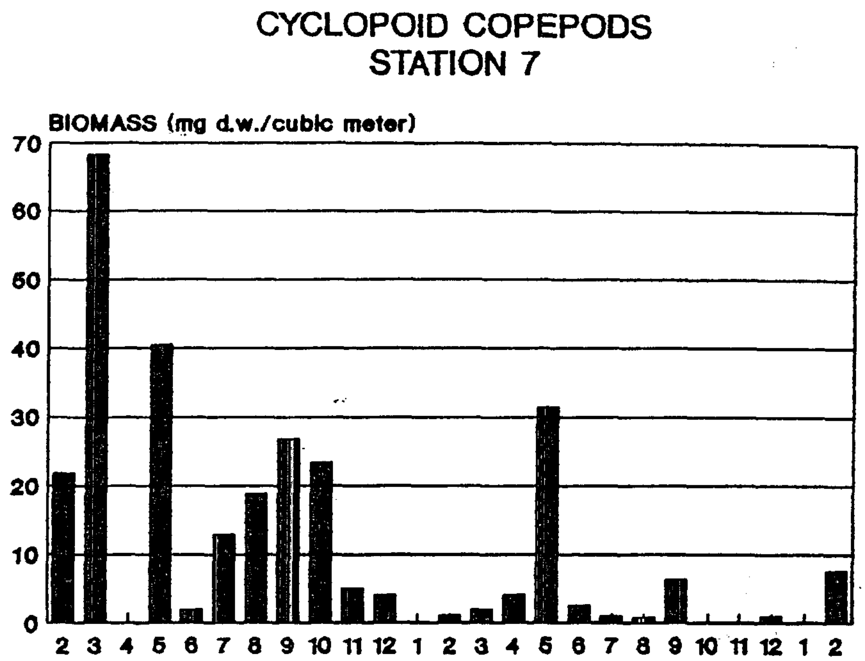

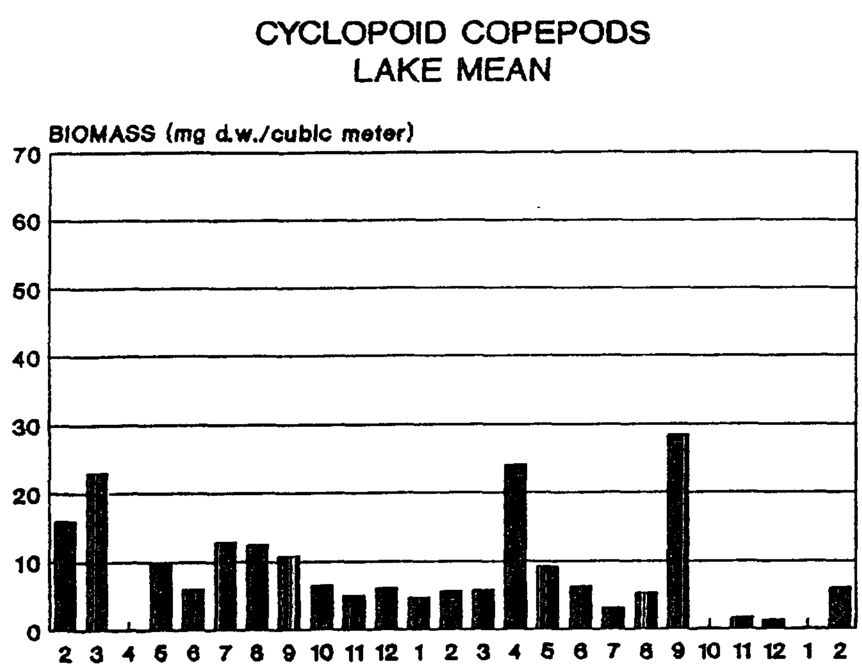

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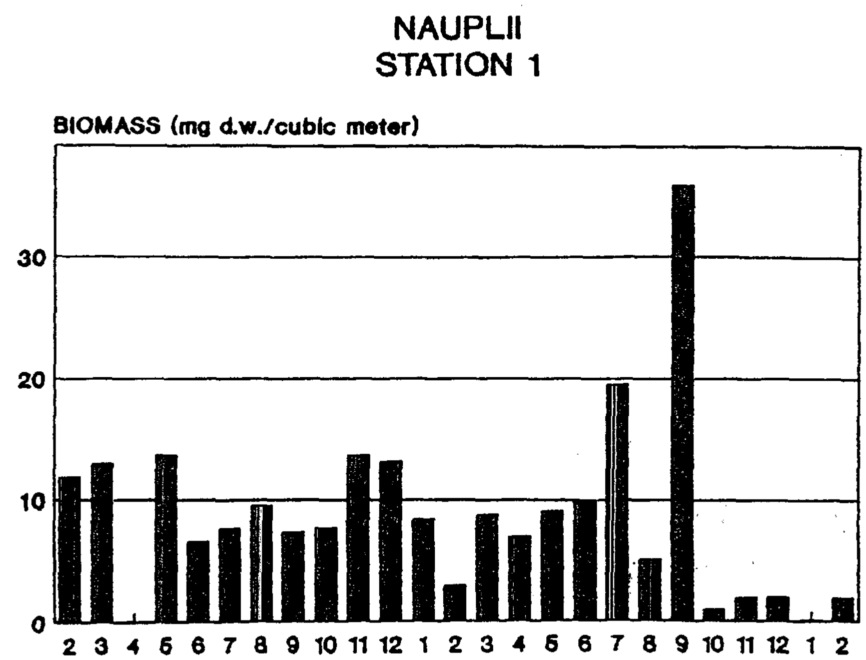


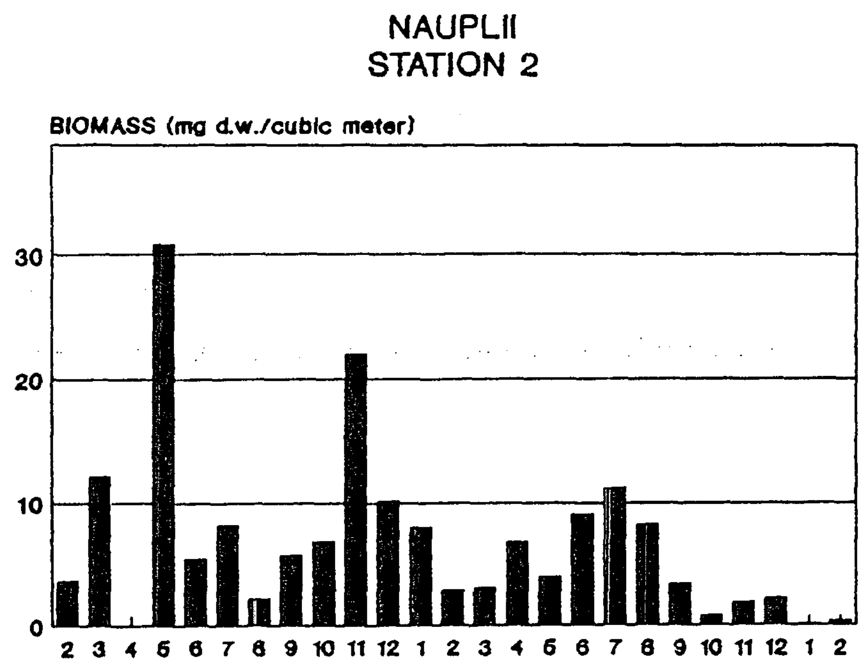
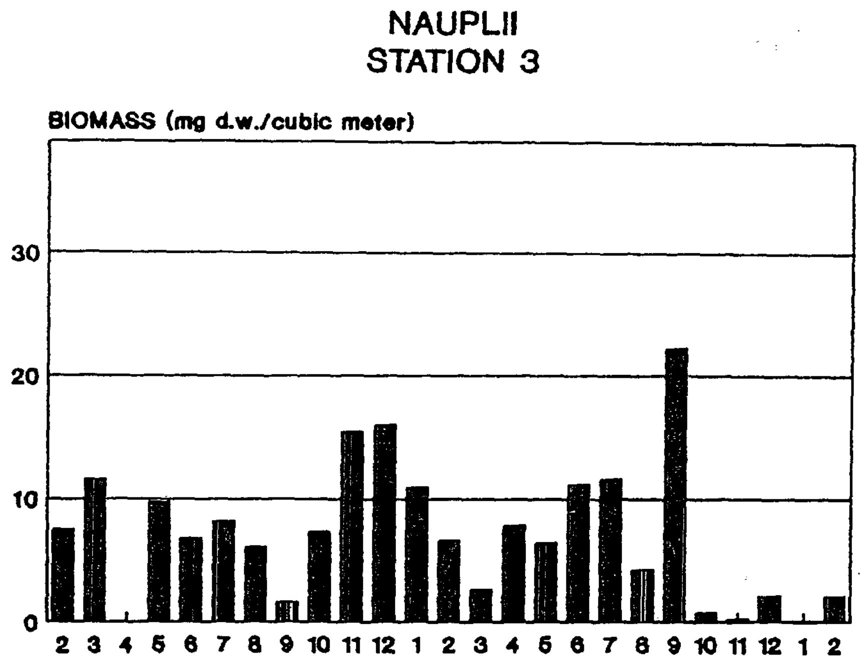
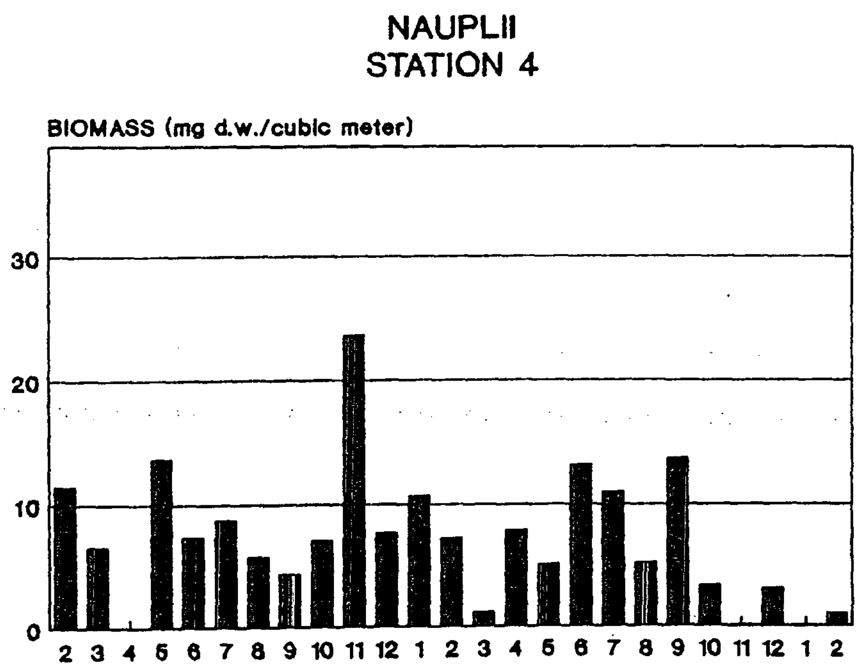


Figure 5-15. Biomass of nauplii at each station for individual months of 1987-1989.





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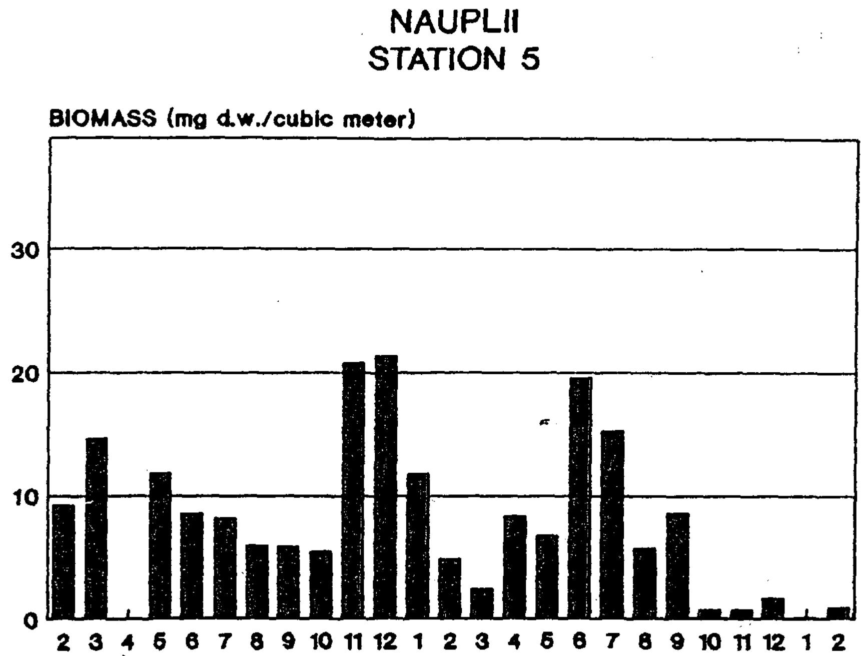

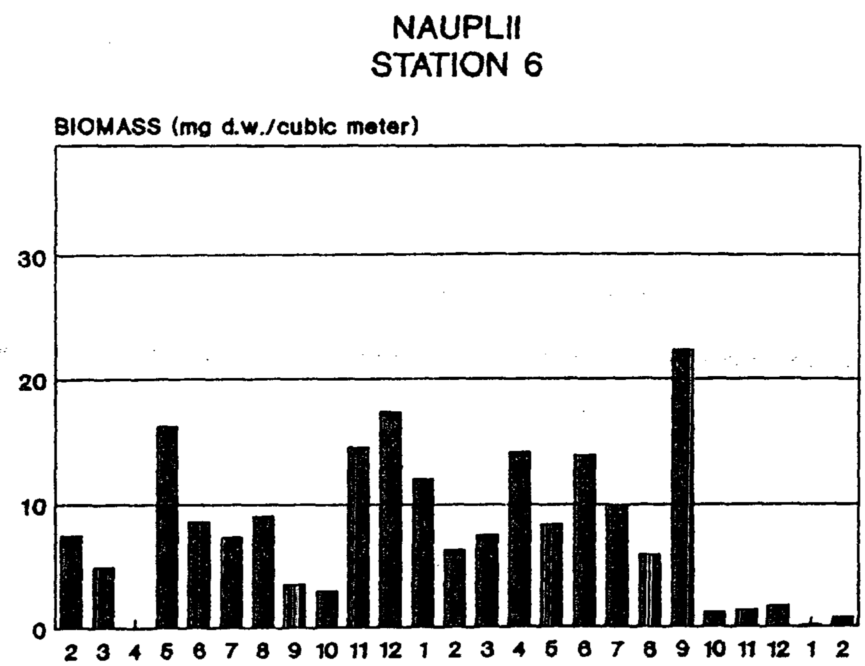

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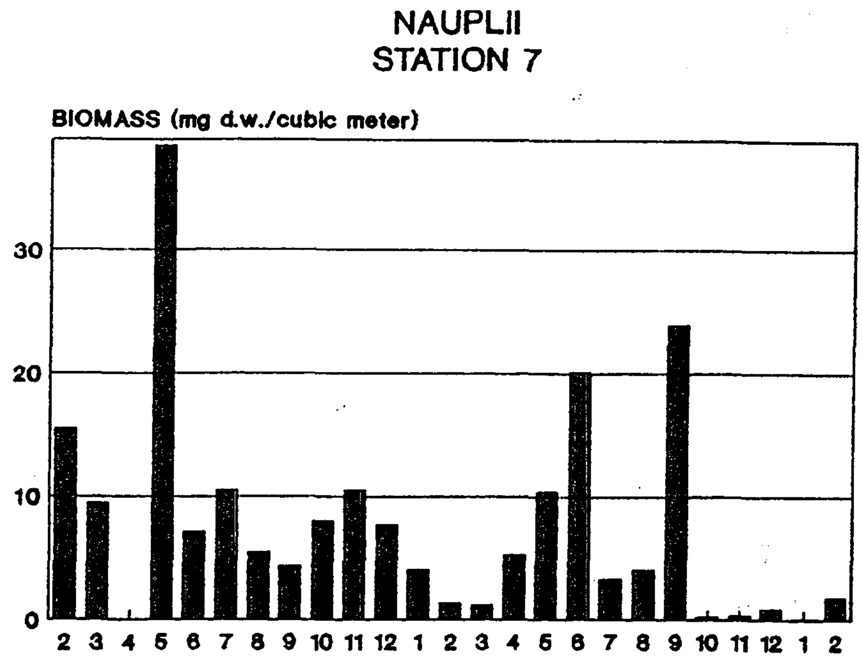

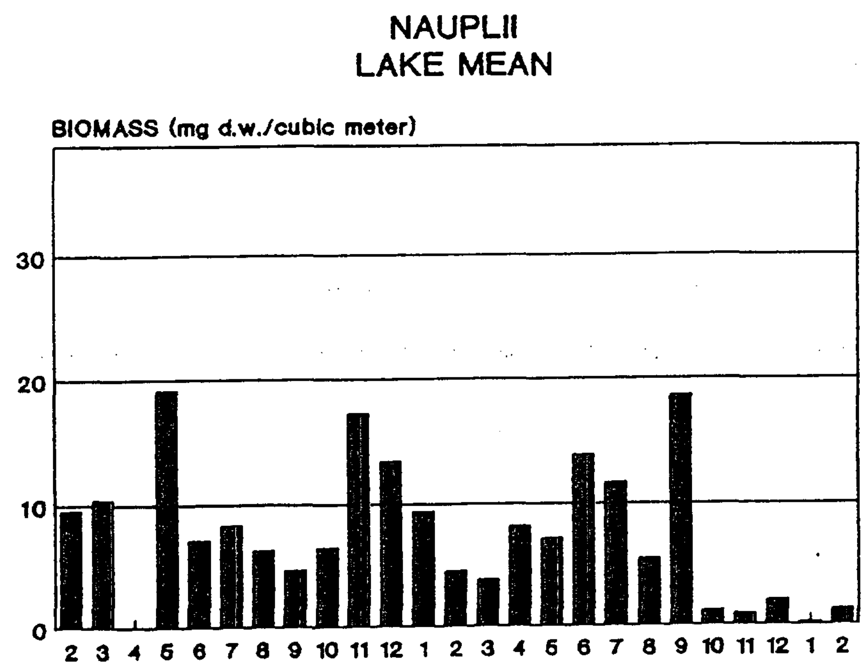

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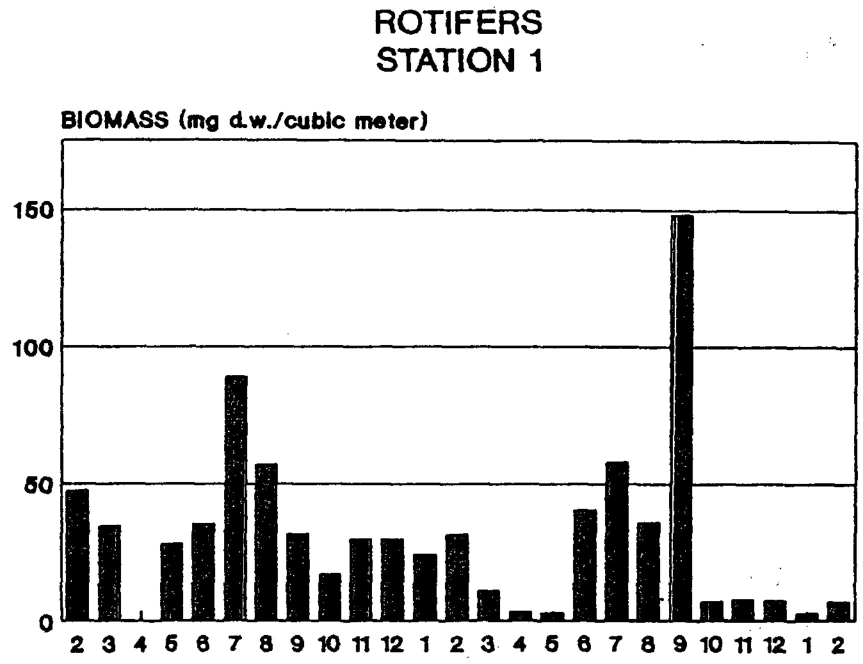


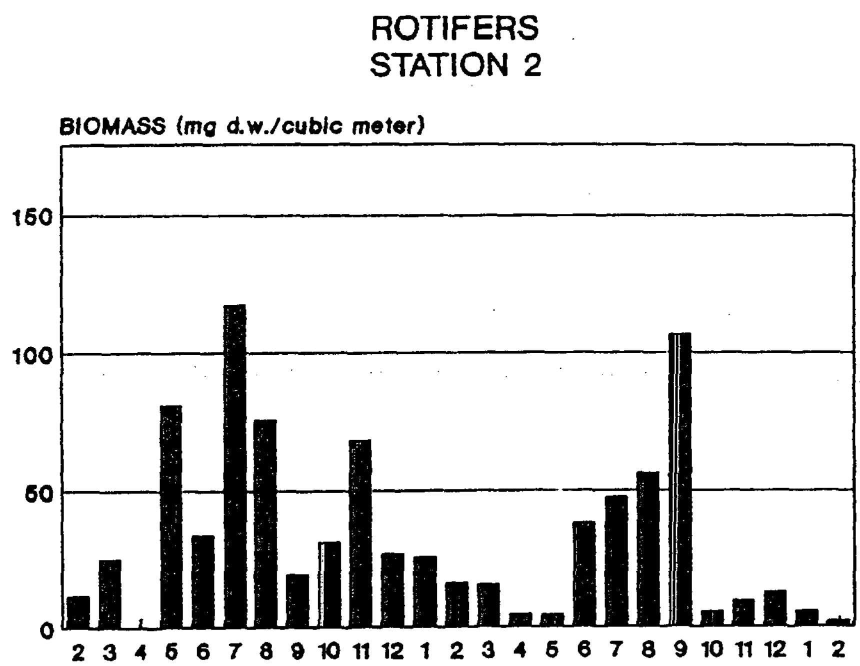
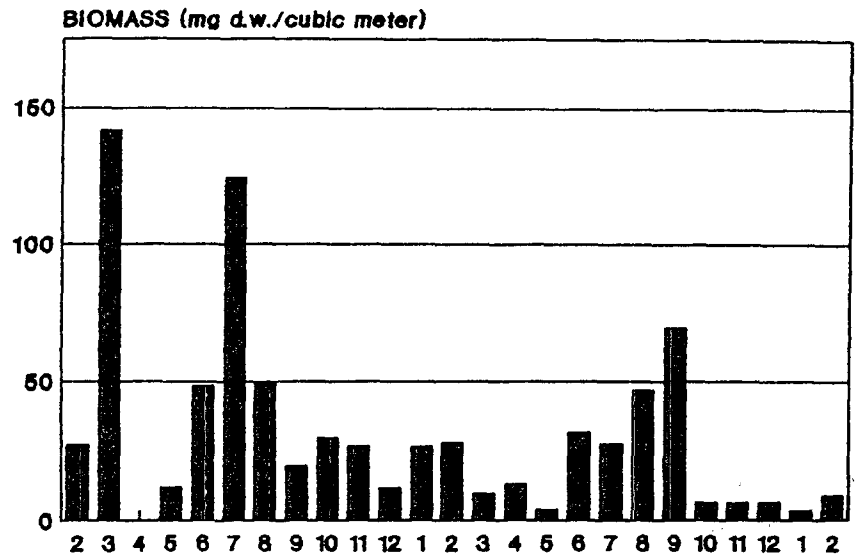


Figure 5-16. Biomass of rotifers at each station for individual months of 1987-1989.

ROTIFERS
STATION 3



ROTIFERS
STATION 4

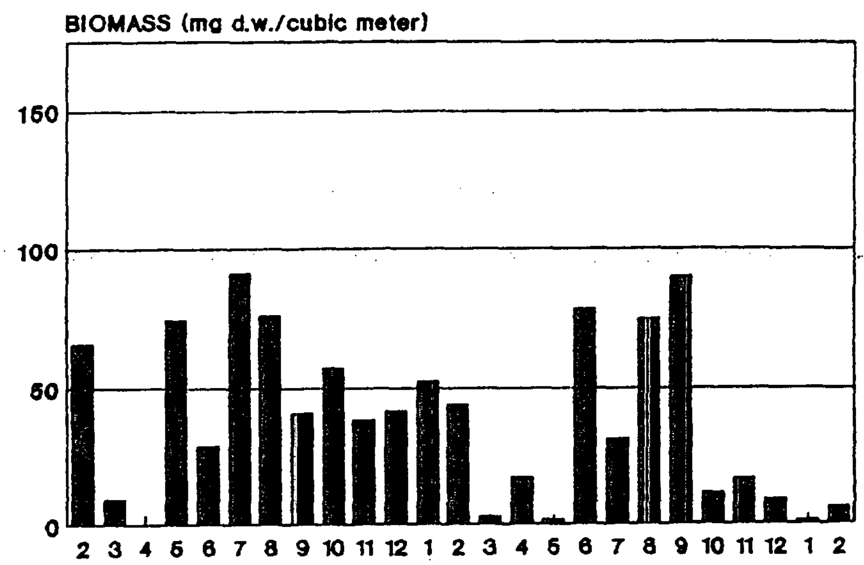
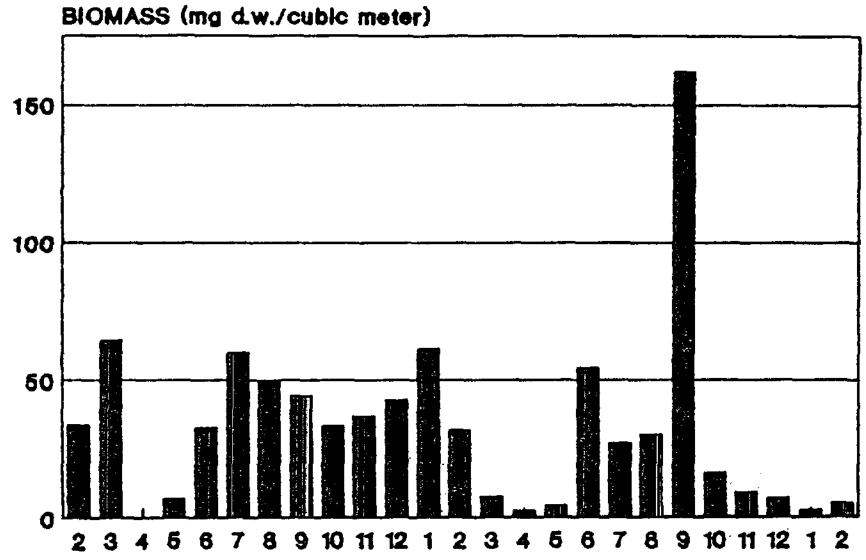
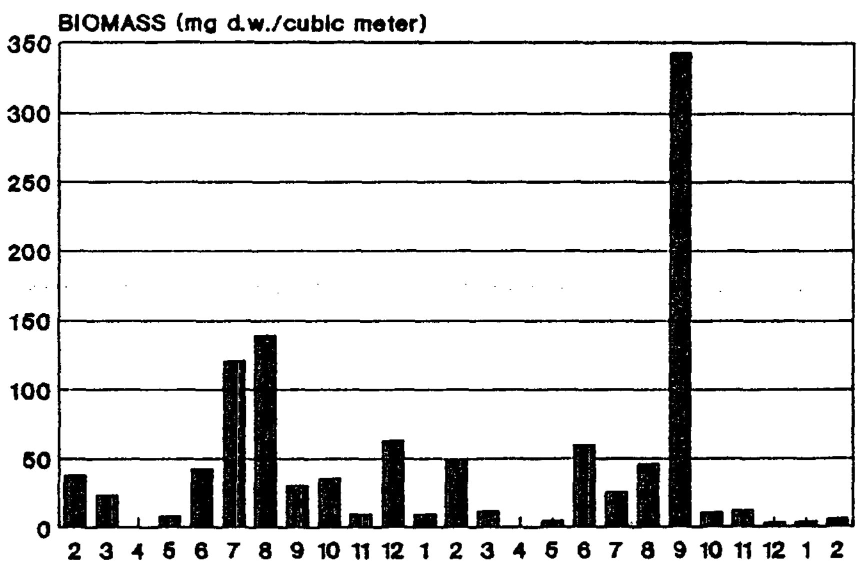


Figure 5-16. Continued.

ROTIFERS
STATION 5



ROTIFERS
STATION 6



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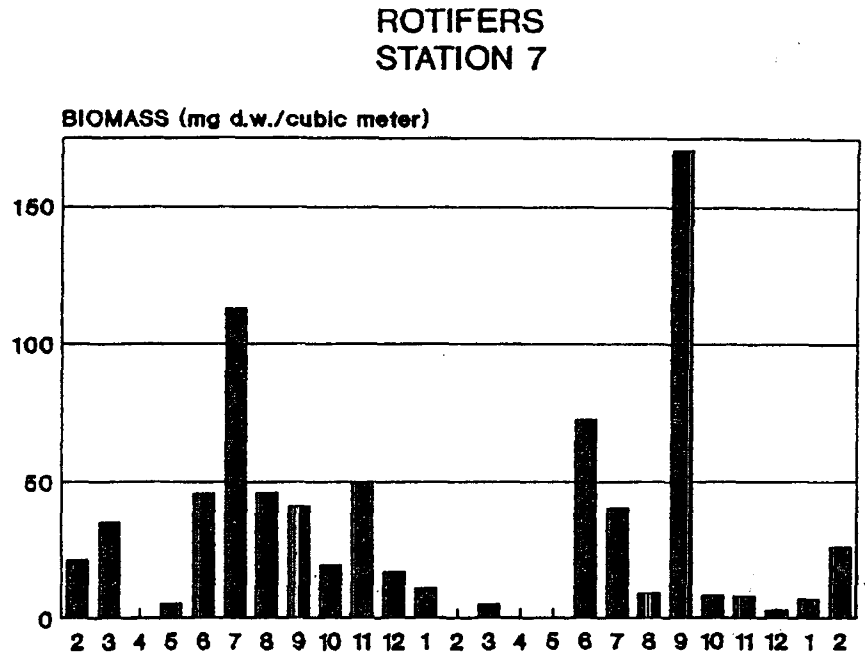

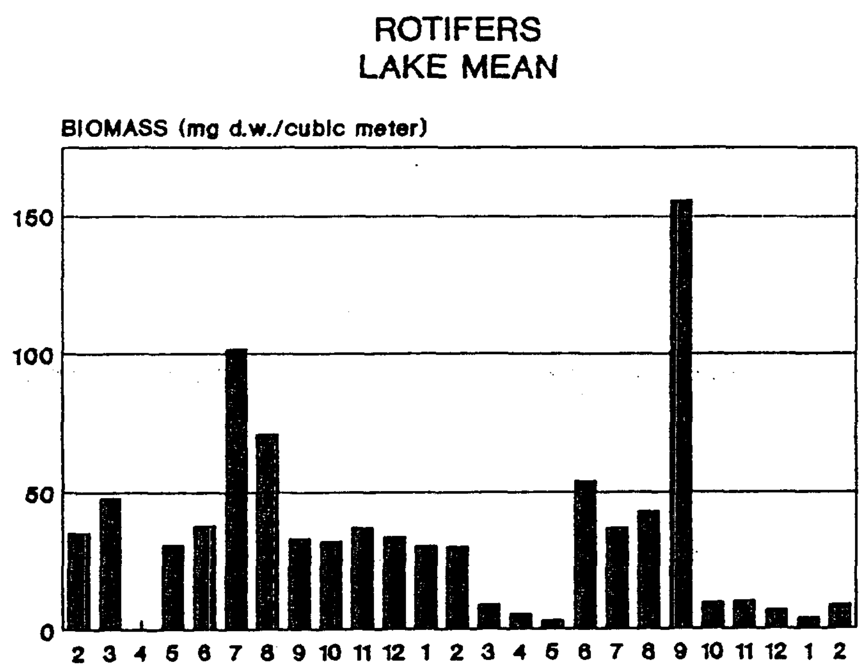

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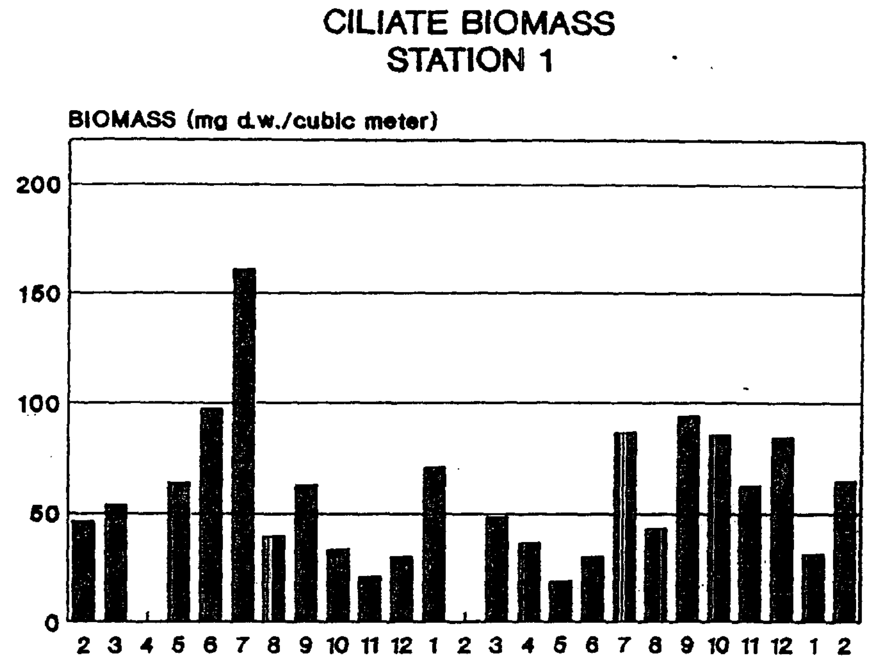


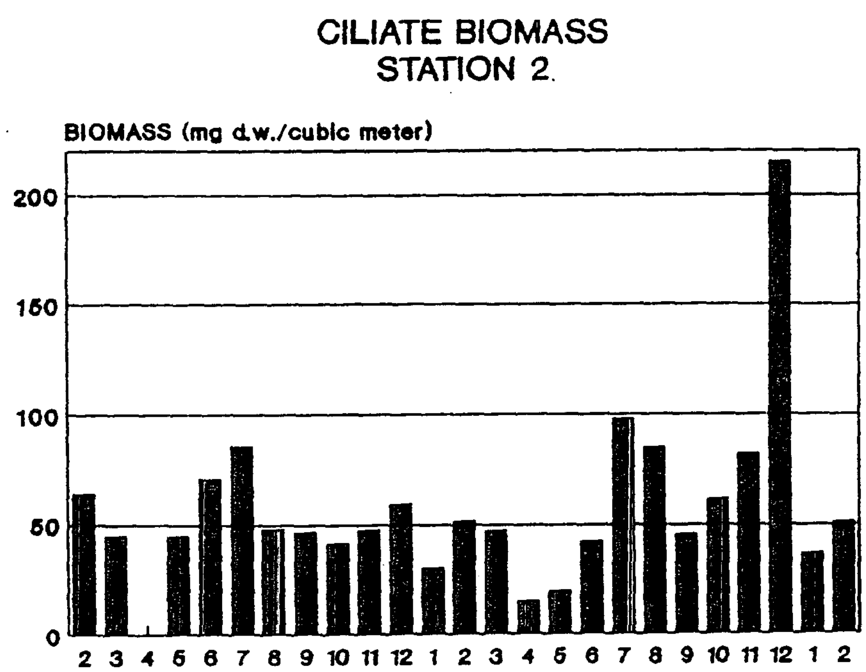
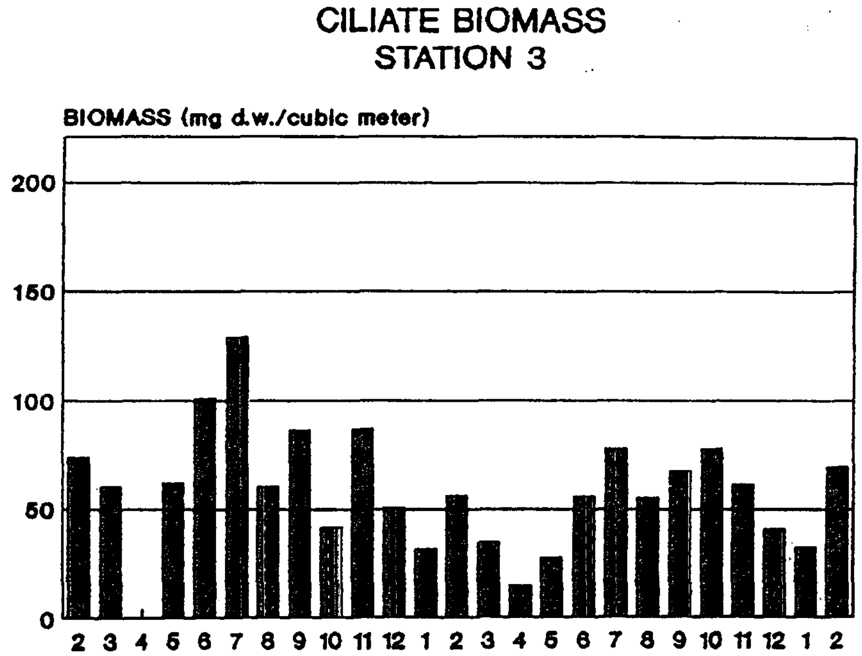
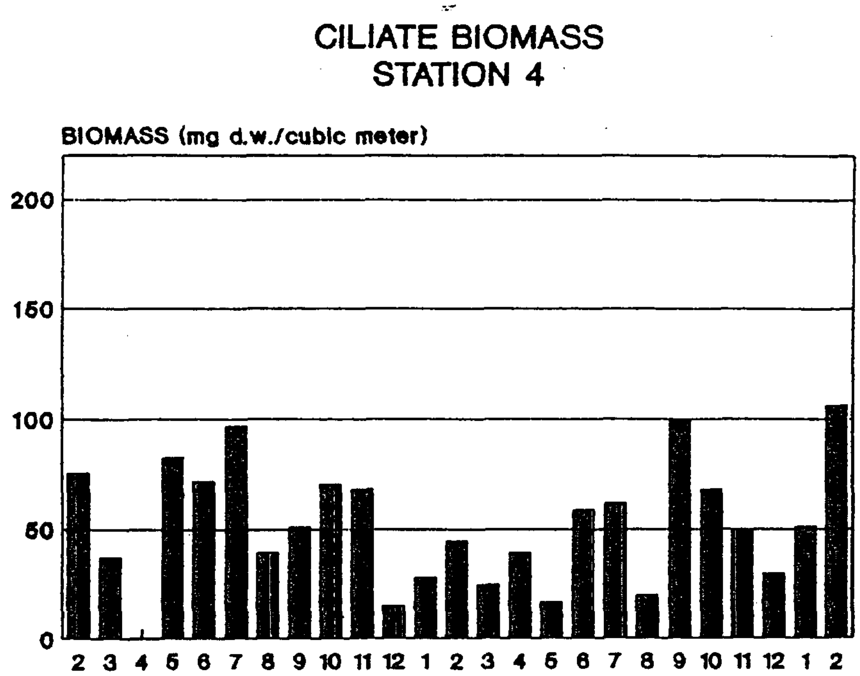


Figure 5-17. Biomass of total ciliates at each station for individual months of 1987-1989.





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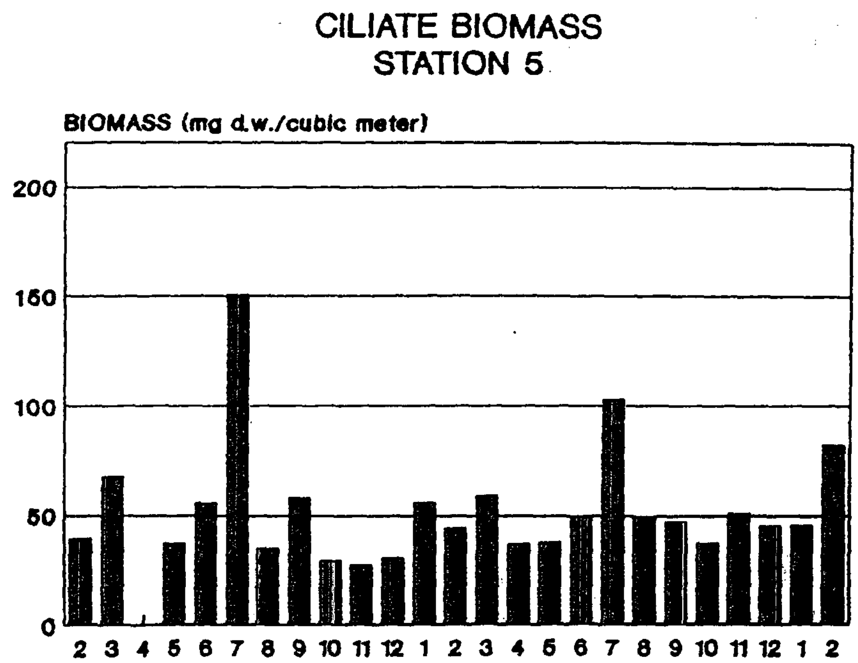

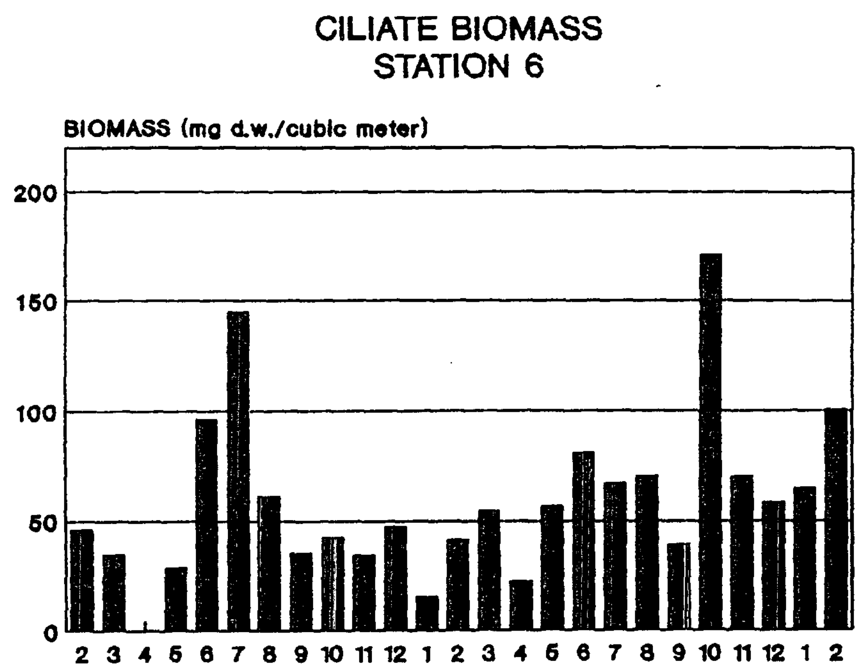

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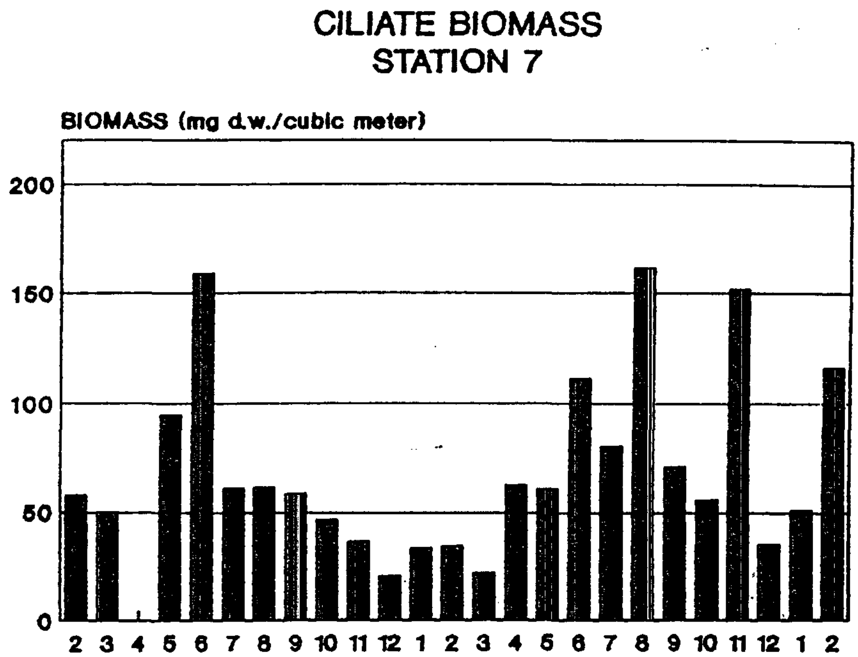

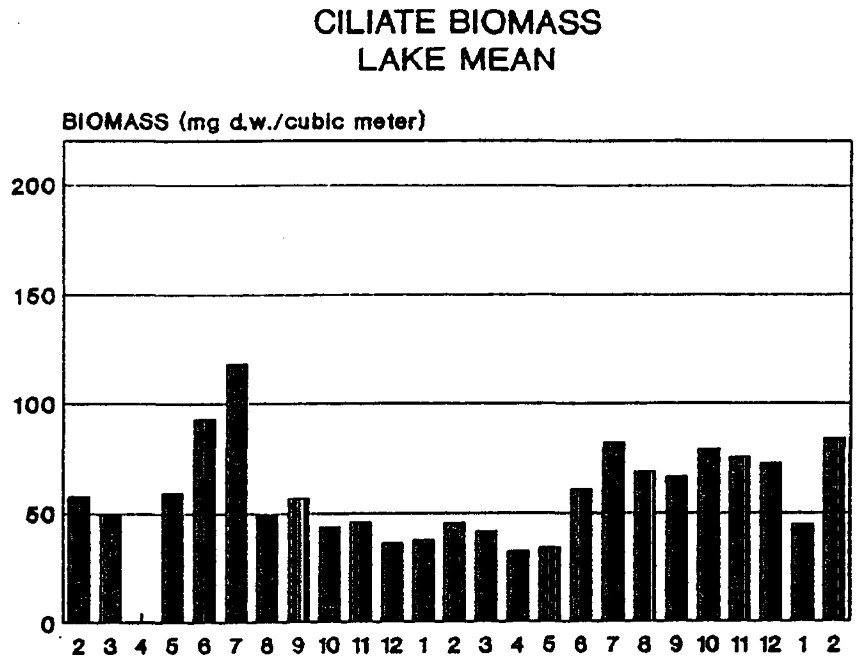

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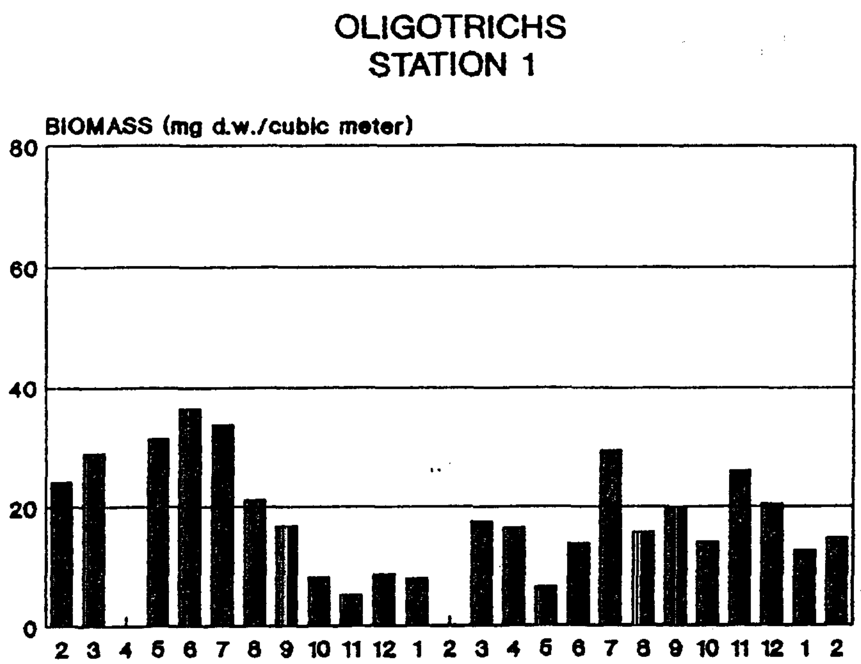


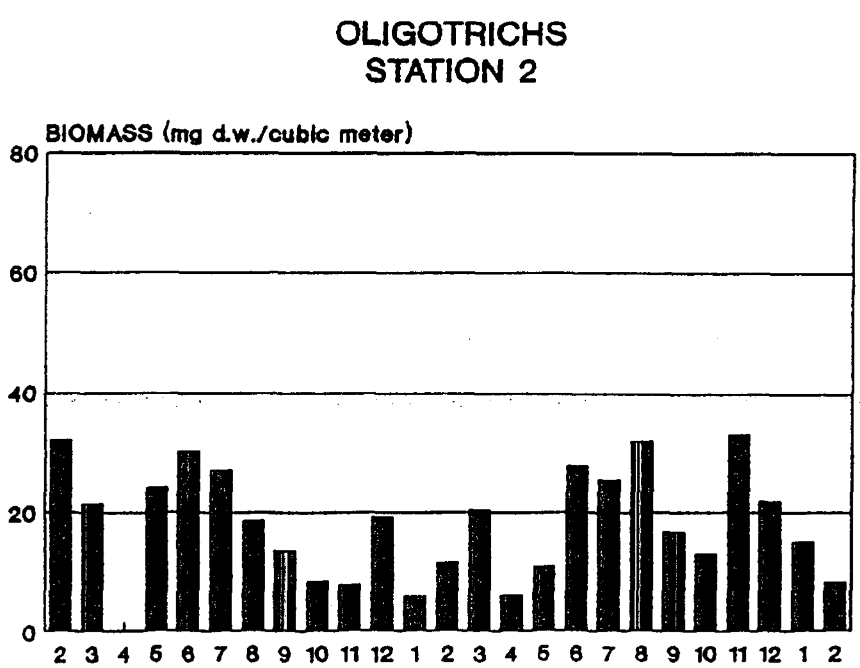
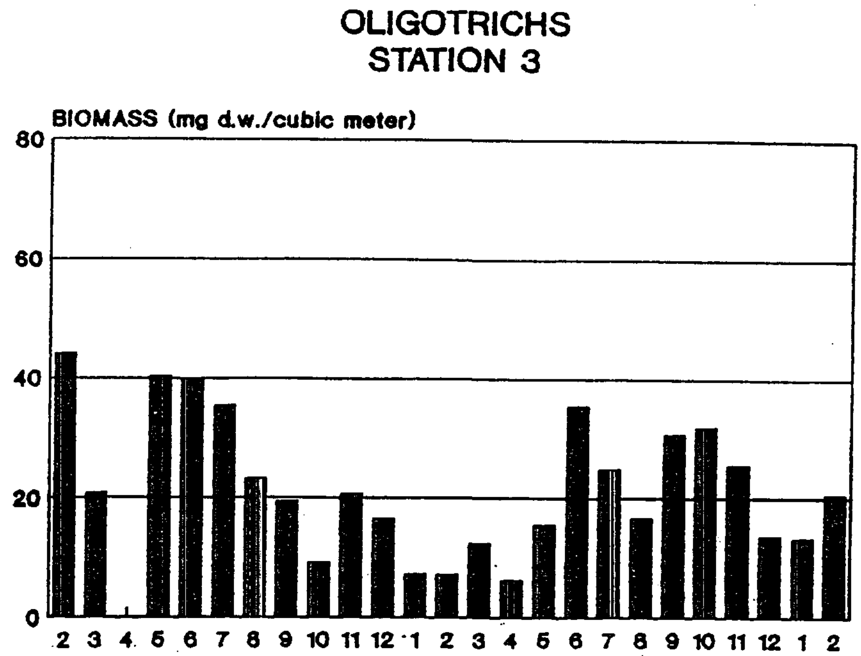


Figure 5-18. Biomass of oligotrichs at each station for individual months of 1987-1989.



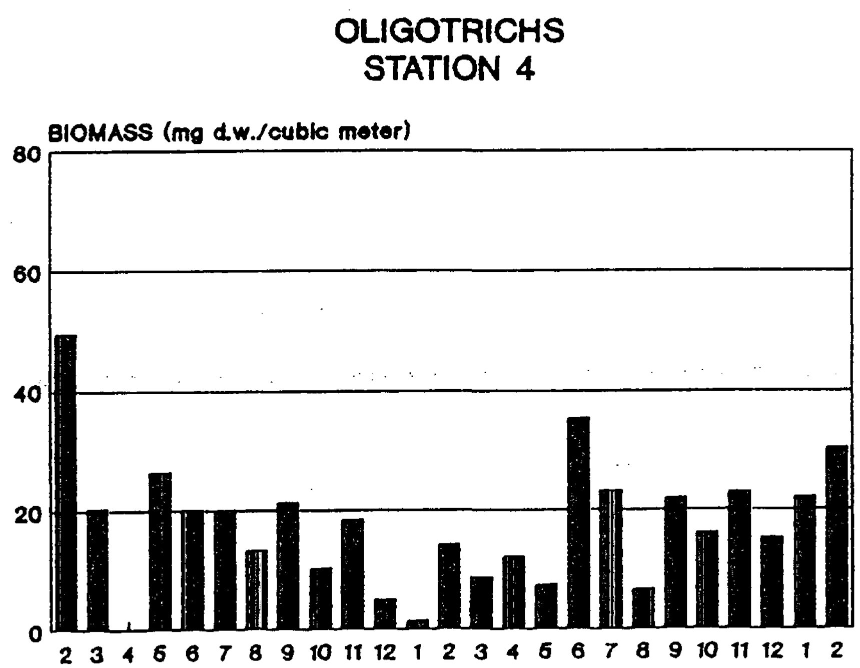
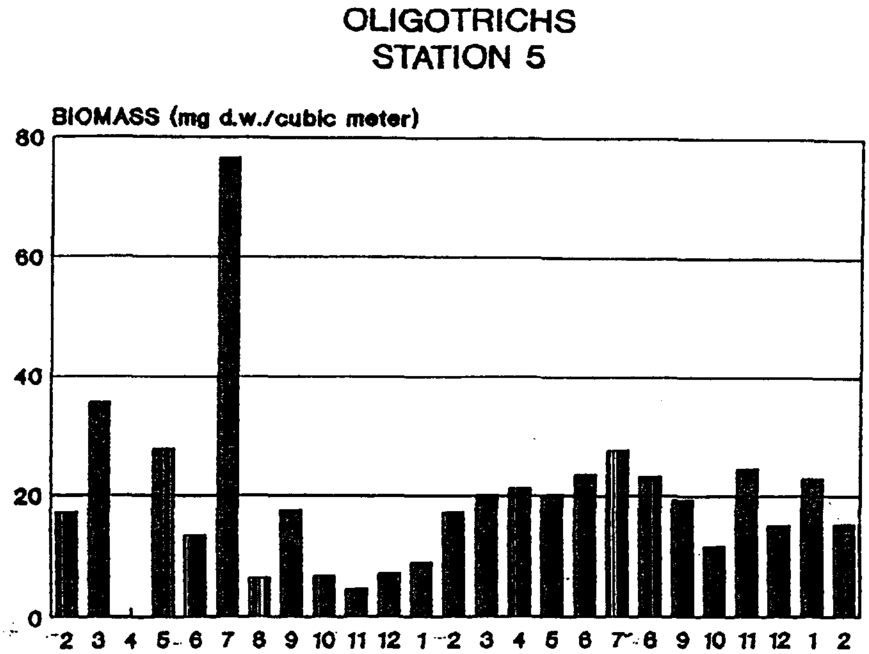
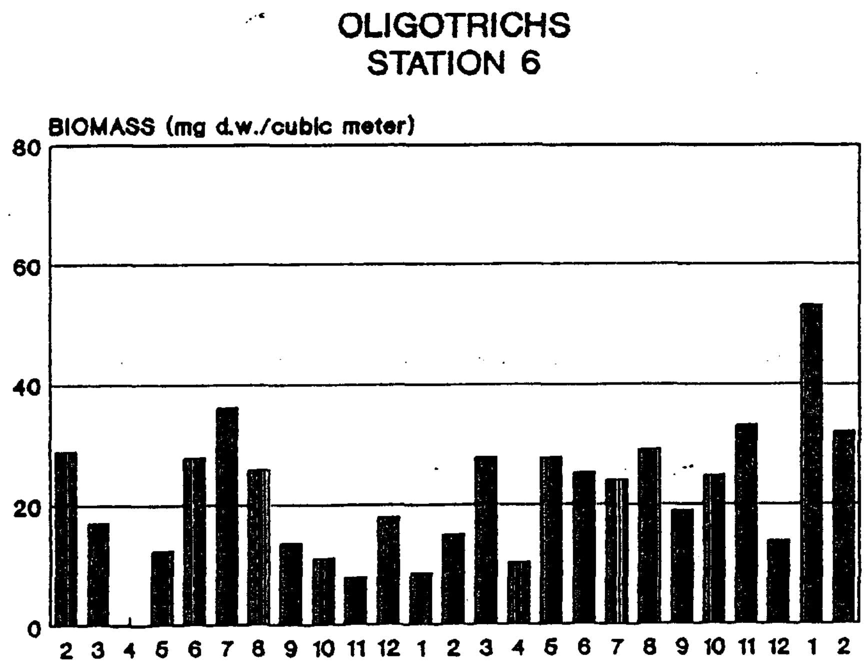


Figure 5-18. Continued.





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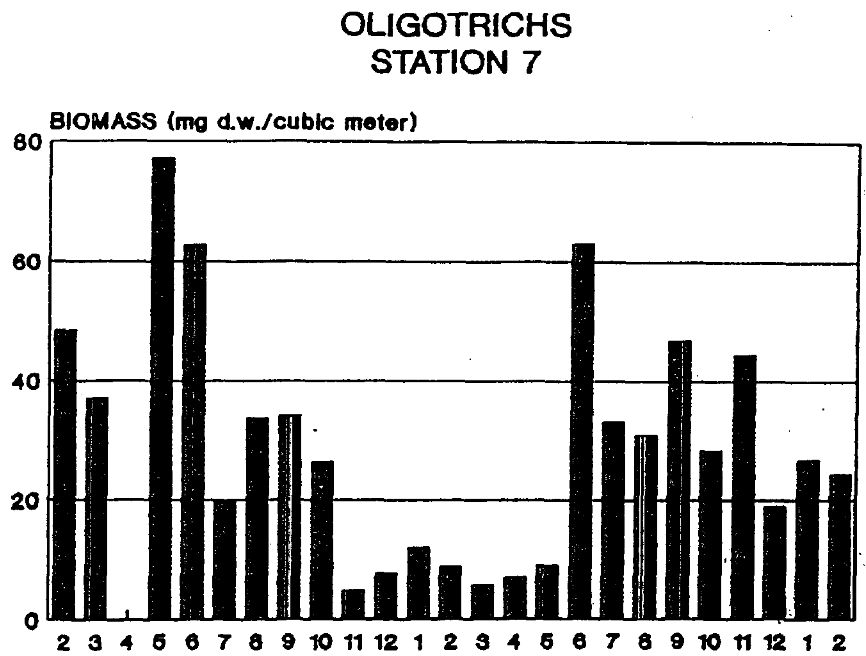

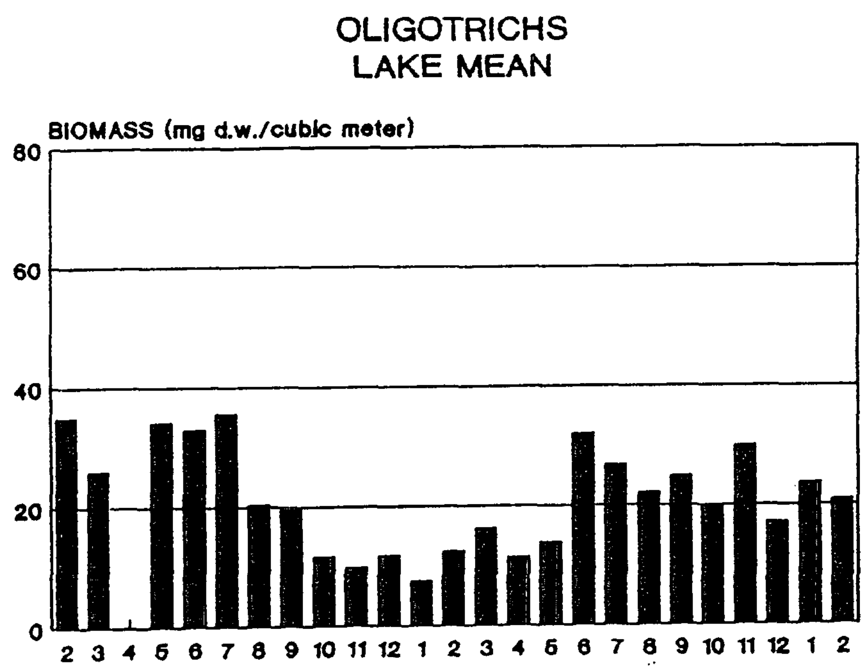

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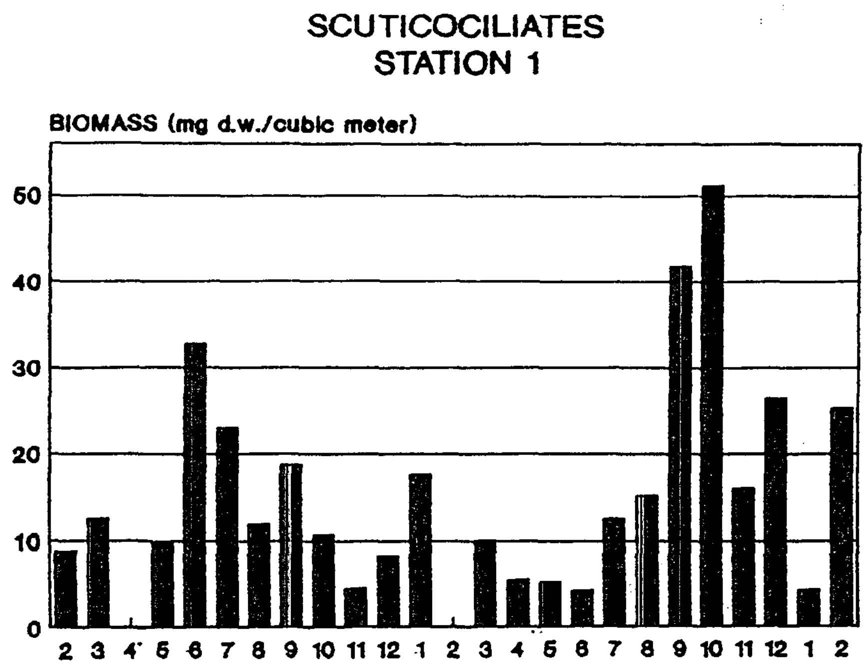


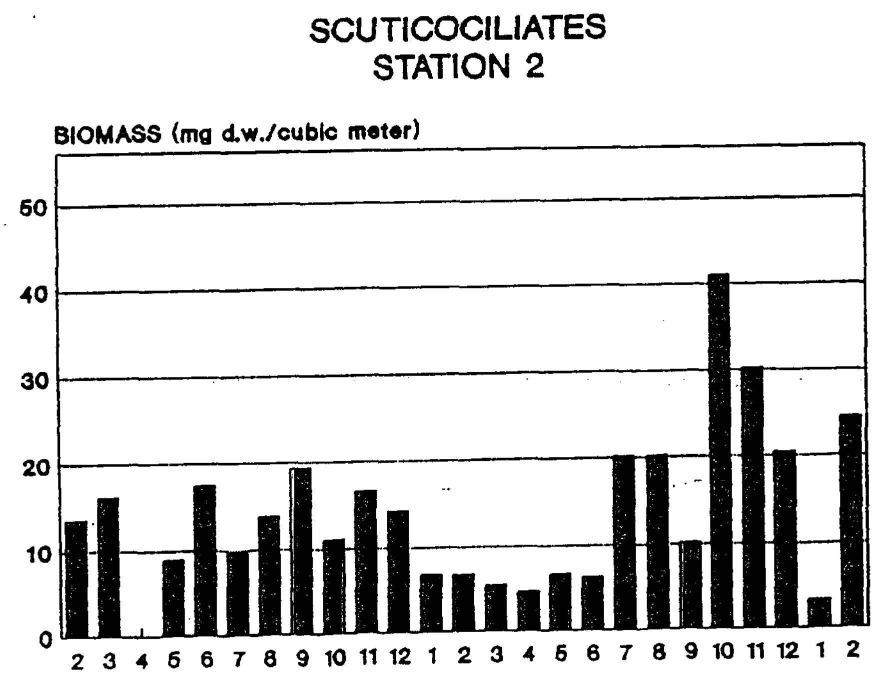
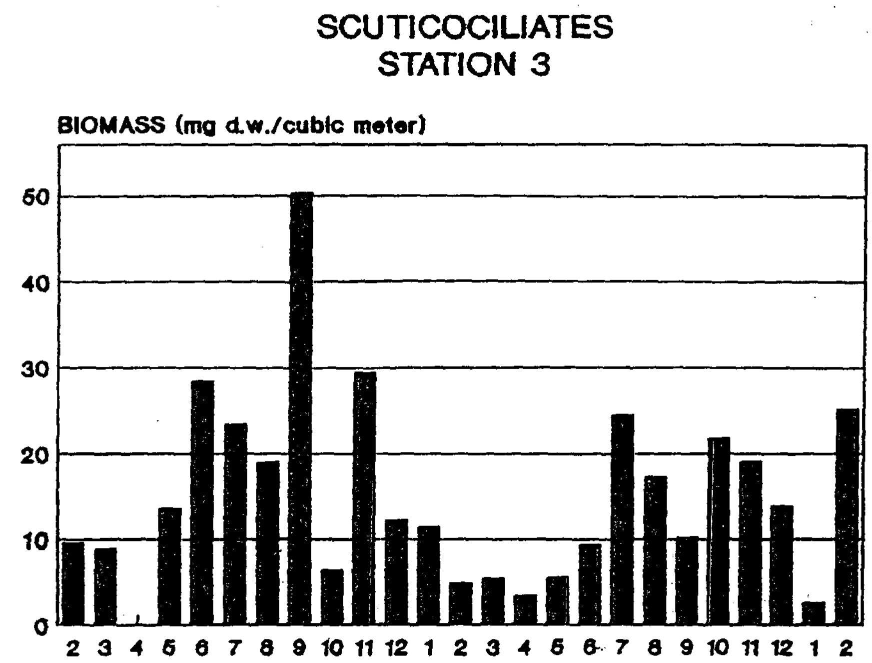
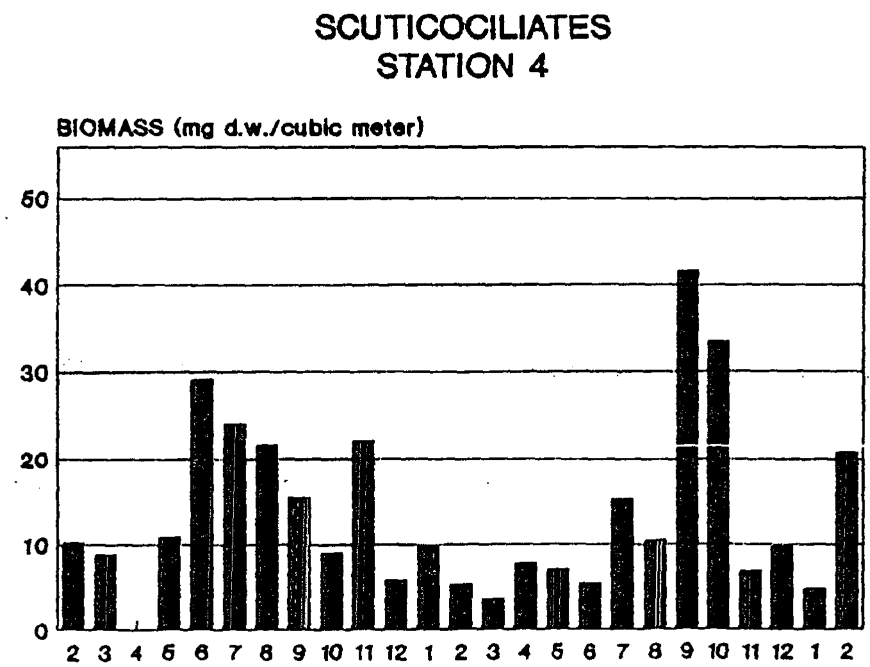


Figure 5-19. Biomass of scuticociliates at each station for individual months of 1987-1989.





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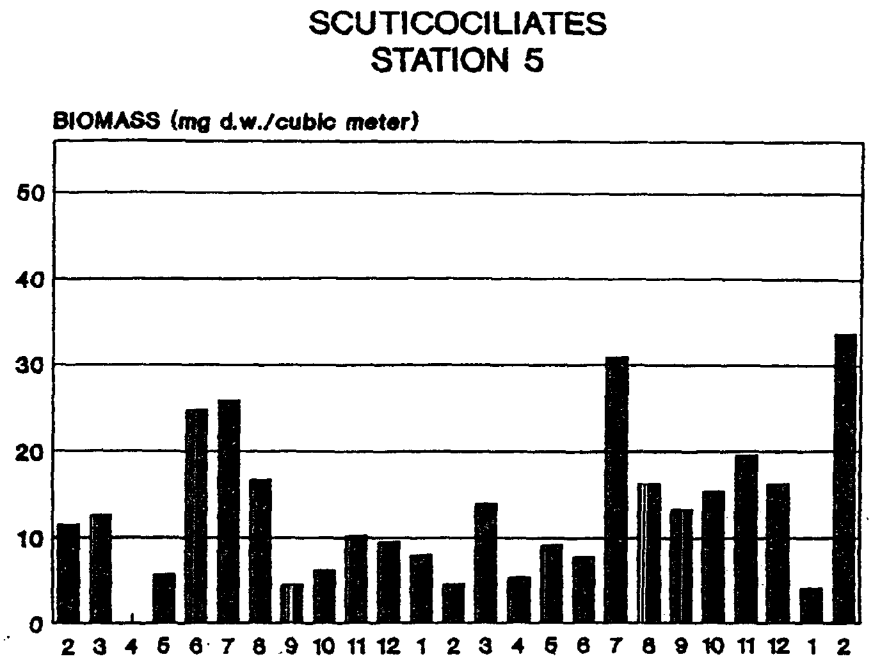

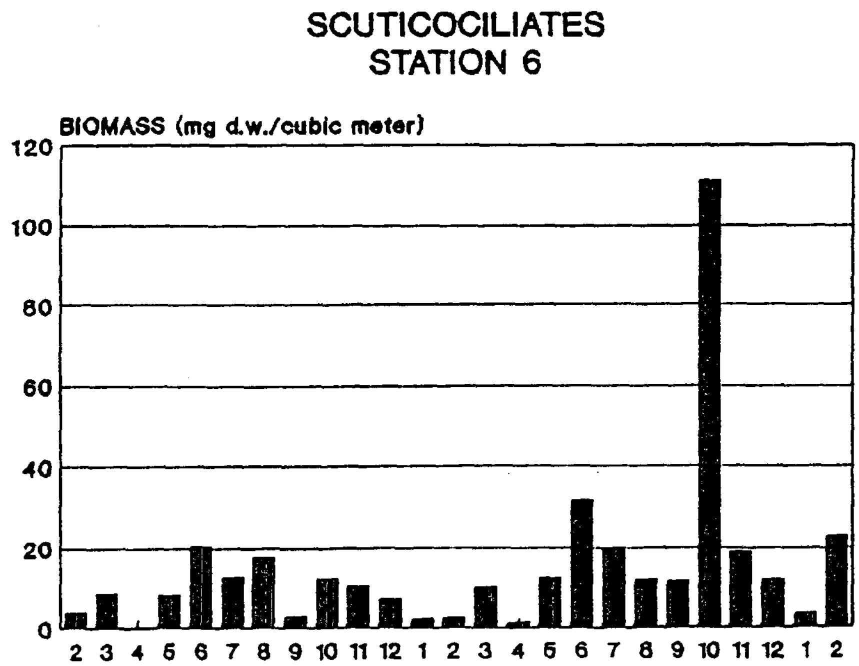

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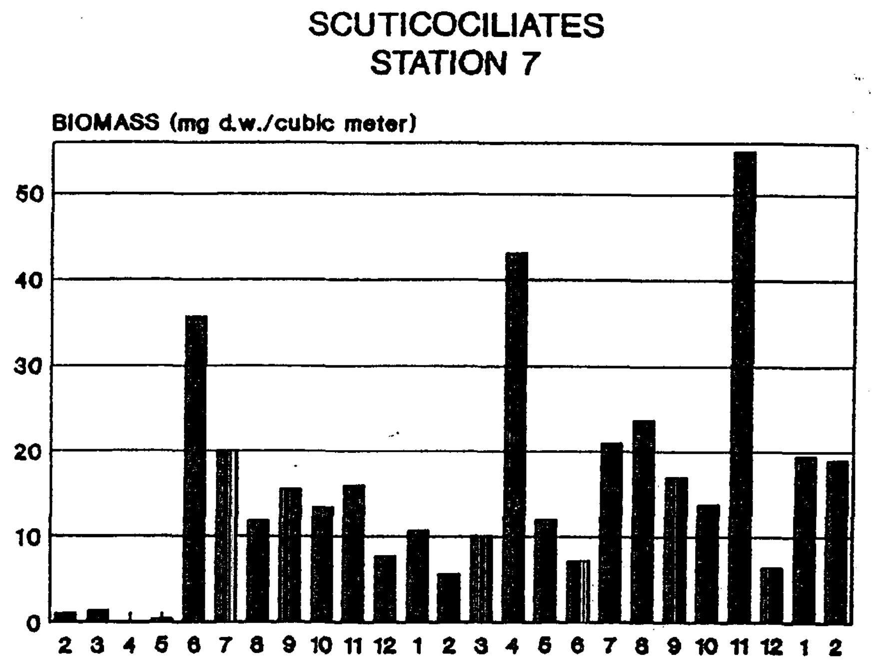

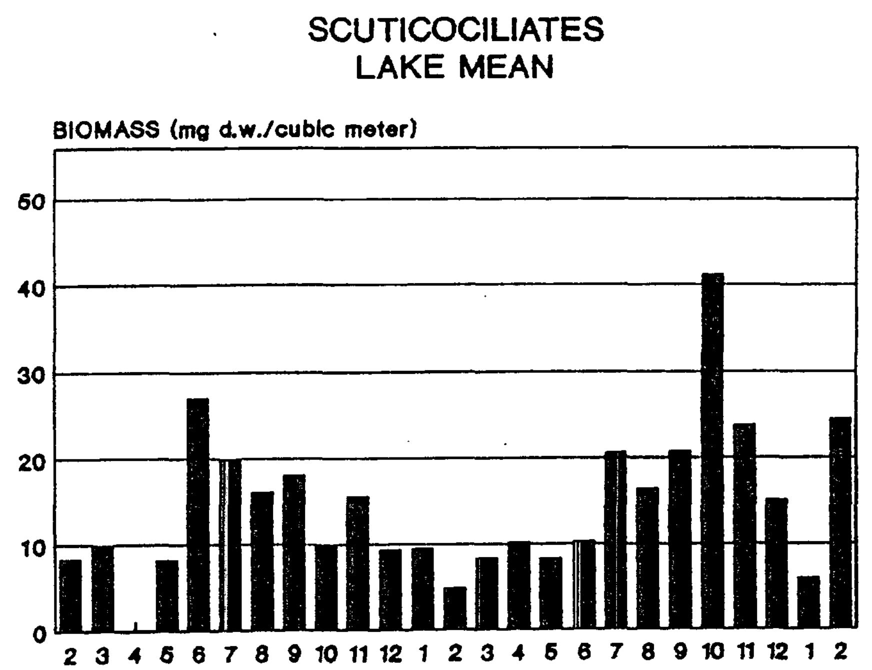

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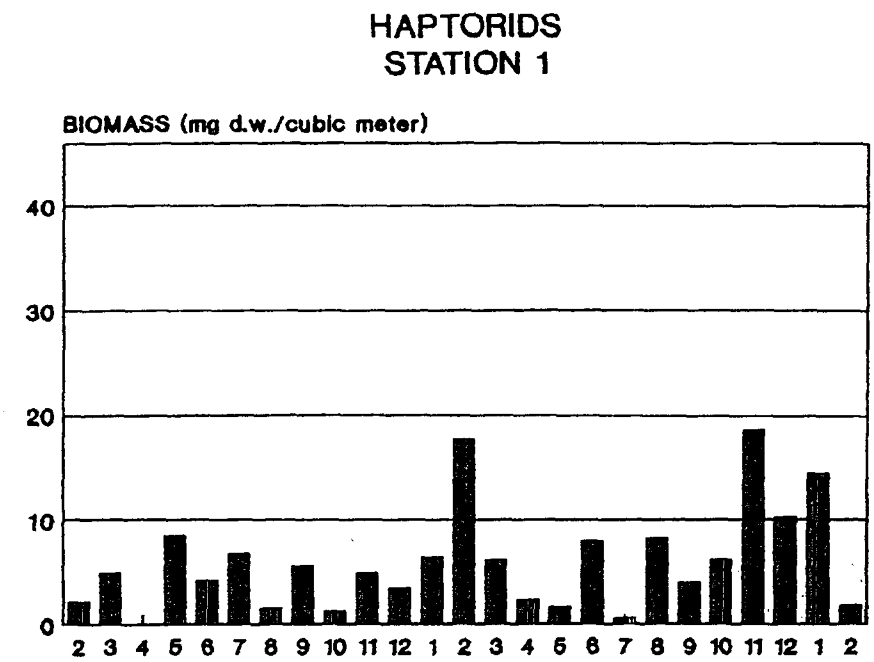


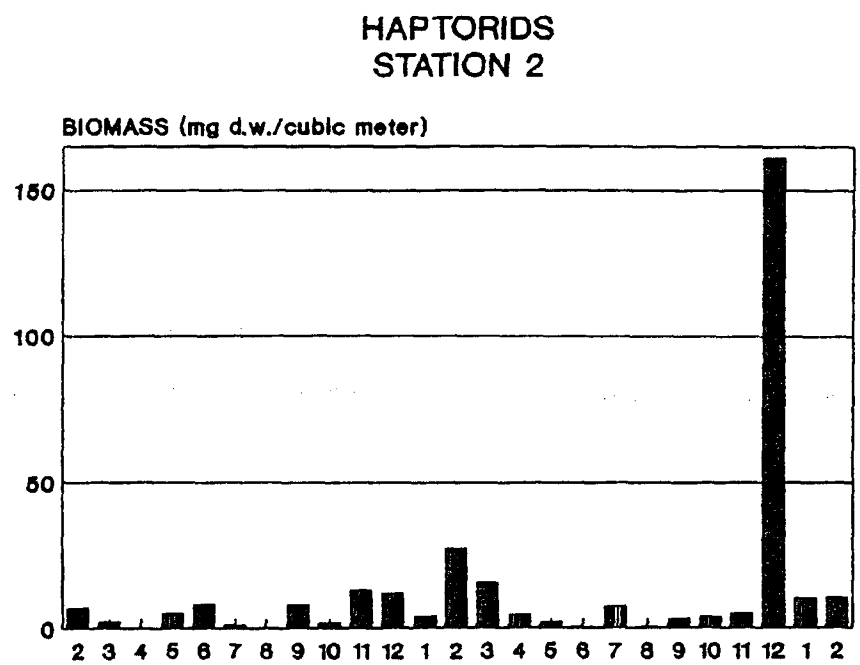
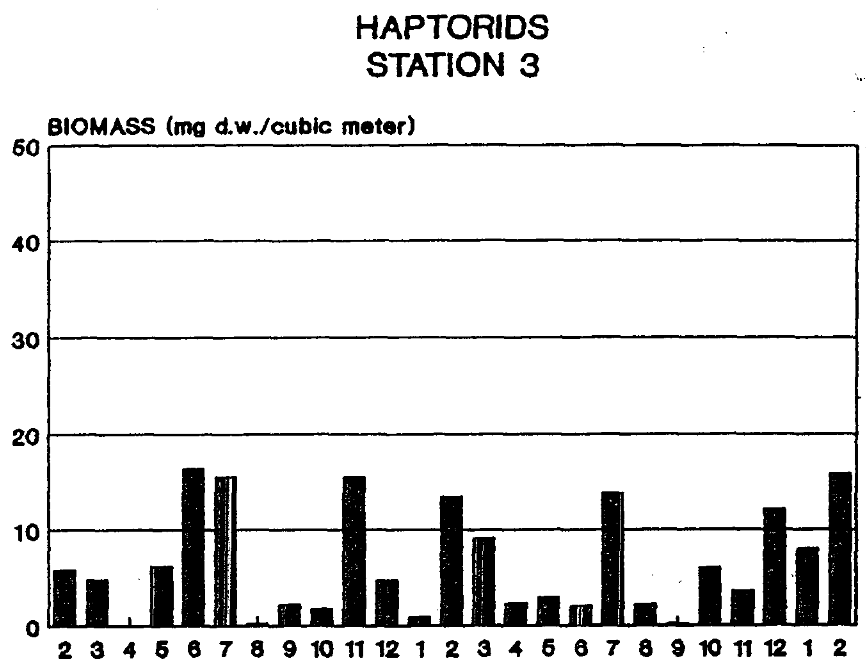
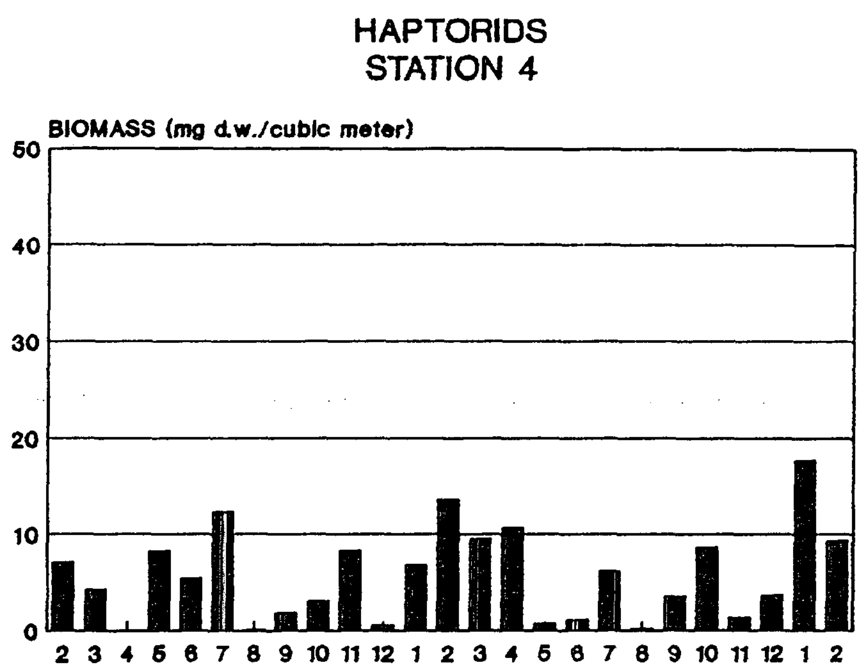


Figure 5-20. Biomass of haptorids at each station for individual months of 1987-1989.





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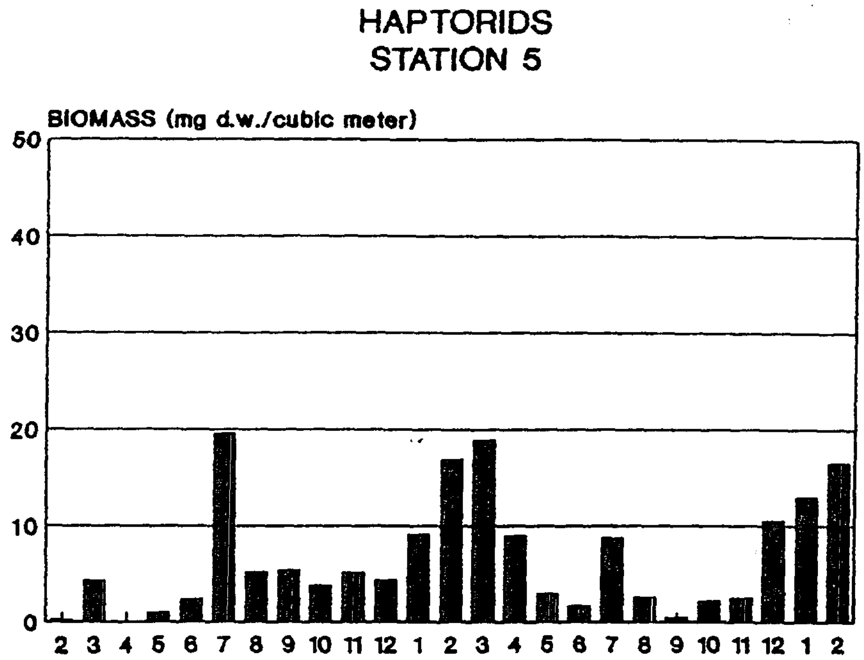


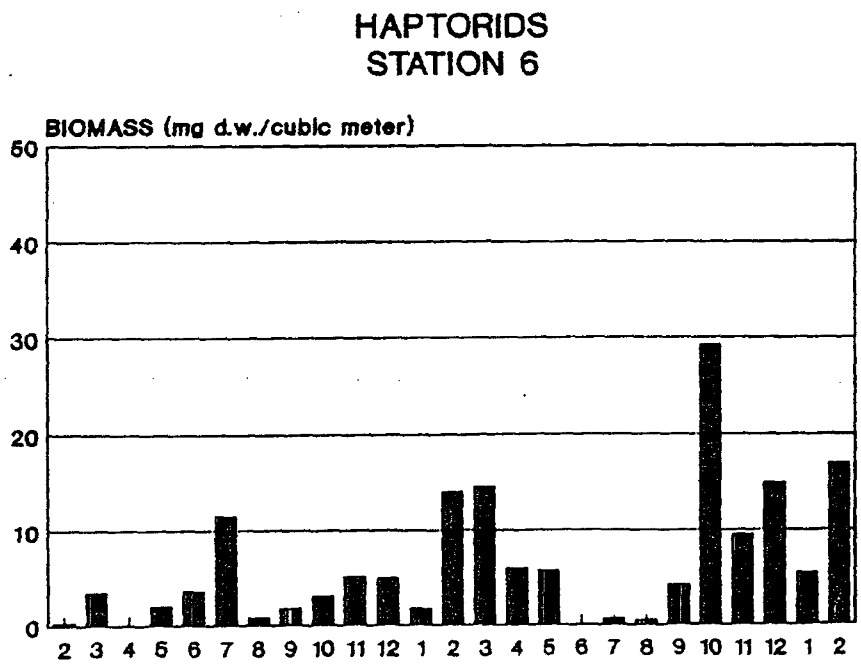
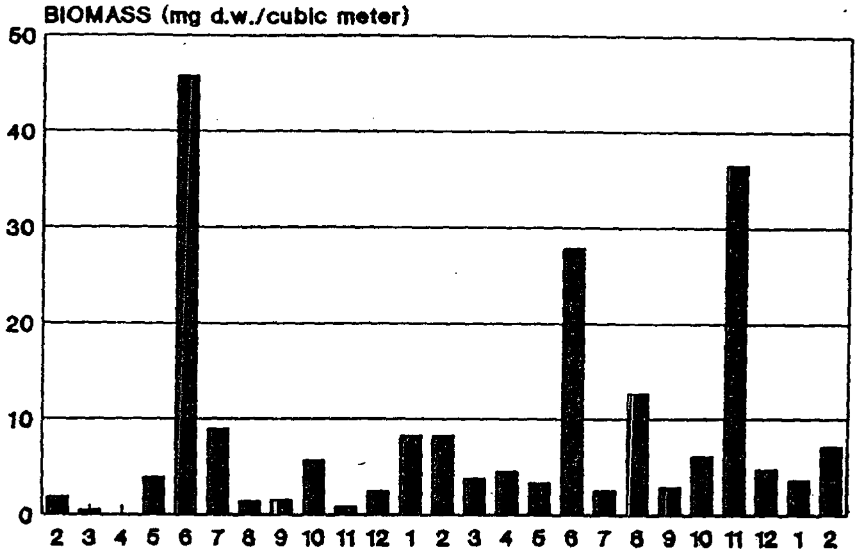


Figure 5-20. Continued.

HAPTORIDS
STATION 7



HAPTORIDS
LAKE MEAN

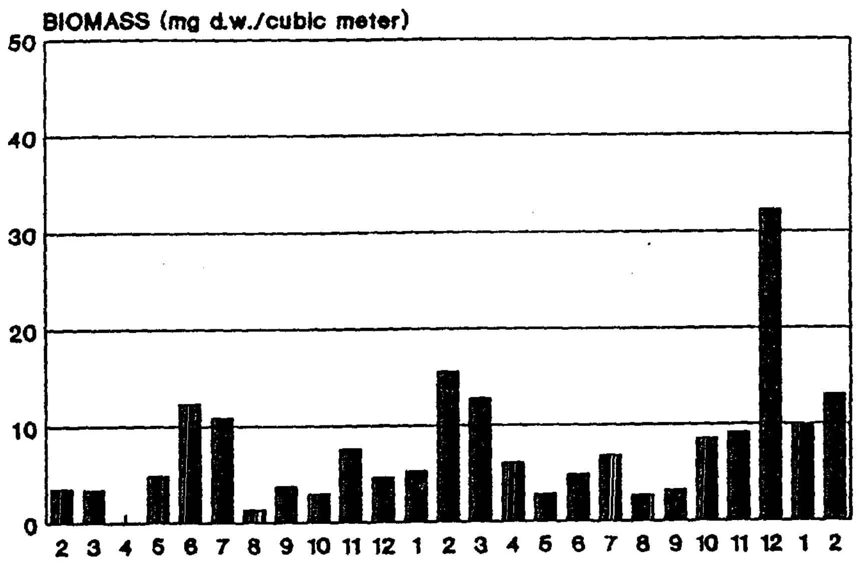


Figure 5-20. Continued.

5.4.H CORRELATIONS BETWEEN ZOOPLANKTON AND WATER QUALITY VARIABLES.

Pearson product-moment correlations of major zooplankton components with limnological variables are presented in Table 5-10. Chlorophyll a was positively correlated only with scuticociliate biomass (r=0.37) and negatively correlated with cyclopoids (r=-0.33) and oligotrichs (r=-0.21). Total phosphorus concentrations were positively related to rotifers (r=0.33) and negatively correlated with cladocerans (r=-0.35) and oligotrichs (r=-0.42).

Temperature displayed the strongest and best relationship with zooplankton components. Total zooplankton biomass (r=0.52) as well as the two major size classes, macrozooplankton (r=0.45) and microzooplankton (r=0.43), were moderately related to increasing water temperature.

Also, pH was positively related to rotifers (r=0.39) and scuticociliate biomass (r=0.41) and negatively correlated with cladocerans (r=-0.32) and nauplii (-0.34). No significant relationship was demonstrated between either Secchi disk transparency or bacterial abundances and major zooplankton components.

5.4.I HISTORICAL PATTERNS OF ZOOPLANKTON SEASONALITY IN LAKE WEIR

Total zooplankton biomass at station 3 peaked in August during 1979 whereas it peaked in March and July in 1987-1989 (Figure 5-21). Macrozooplankton biomass displayed a bimodal seasonality (Figure 5-22) during both studies with peaks occurring in March and September in 1979 and March and August in 1987-1989. Microzooplankton (Figure 5-22) also displayed a bimodal seasonality with highest values recorded at appproximately the same periods as macrozooplankton.

It appears that the major pulse in cladoceran biomass during both studies occurred during the spring and/or fall (Figure 5-23). Messer (1975) also found this bimodal pattern in cladoceran abundance in 1974 in Lake Weir.

Calanoid copepods exhibited only a fall peak in 1979

Table 5-10. *Significant correlations (p <0.05) between major zooplankton components in Lake Weir with selected limnological variables.* Coefficients are Pearson product-moment type.

COMPONENT	Chl.a (n=76)	TP (n=68)	Temperature (n=77)	Secchi disk (n=77)	pH (n=76)	Bacteria (n=77)
Total zooplankton	NS	NS	0.52	NS	NS	NS
Macrozooplankton	NS	NS	0.45	NS	NS	NS
Microzooplankton	NS	NS	0.43	NS	NS	NS
Cladocera	NS	-0.35	NS	NS	-0.32	NS
Calanioda	NS	NS	0.58	NS	NS	NS
Cyclopoda	-0.33	NS	NS	NS	NS	NS
Nauplii	NS	NS	-0.30	NS	-0.34	NS
Rotifera	NS	0.33	NS	NS	0.39	NS
Ciliata	NS	NS	0.42	NS	NS	NS
Oligotrichida	-0.21	-0.42	0.32	NS	NS	NS
Scuticociliatida	0.37	NS	0.36	NS	0.41	NS
Haptorida	NS	NS	NS	NS	NS	NS

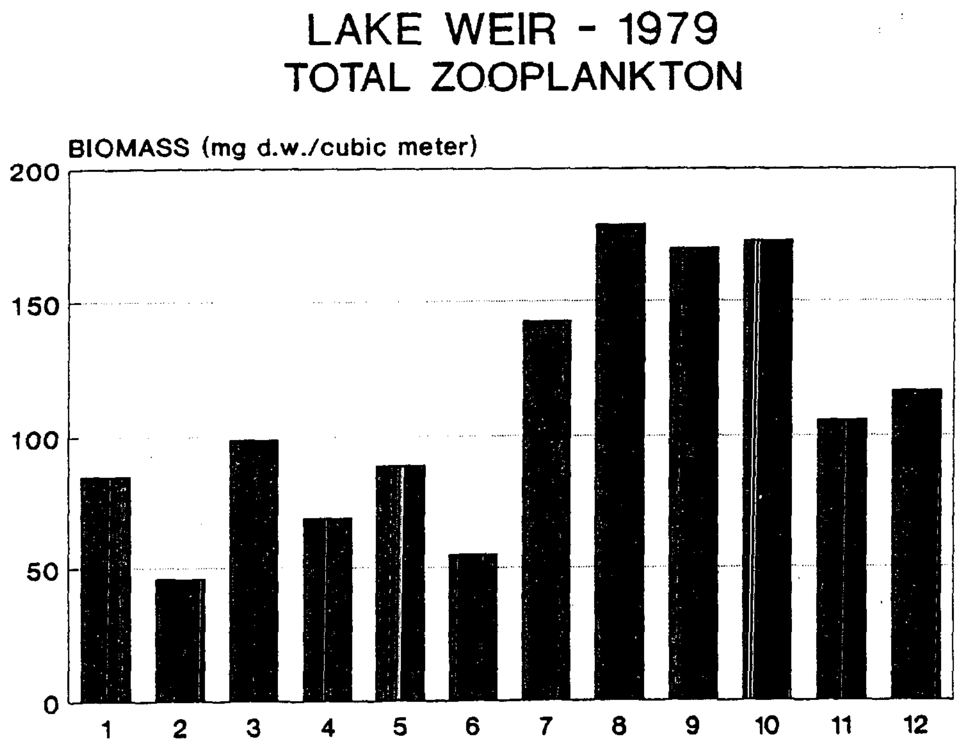
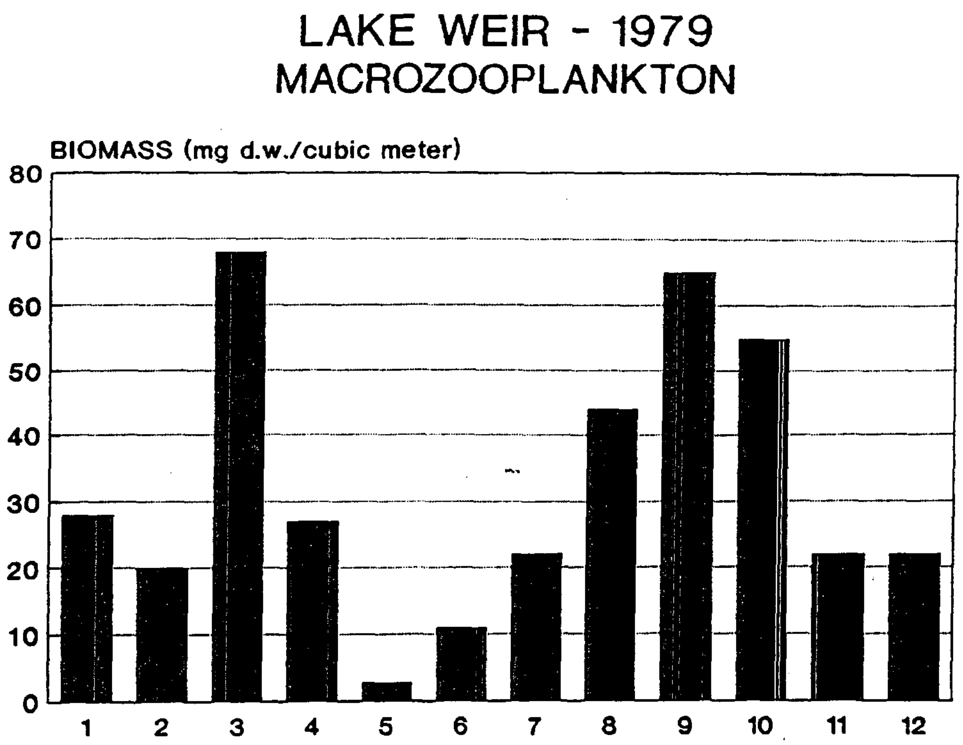


Figure 5-21. Biomass of total zooplankton in Lake Weir for individual months of 1979.



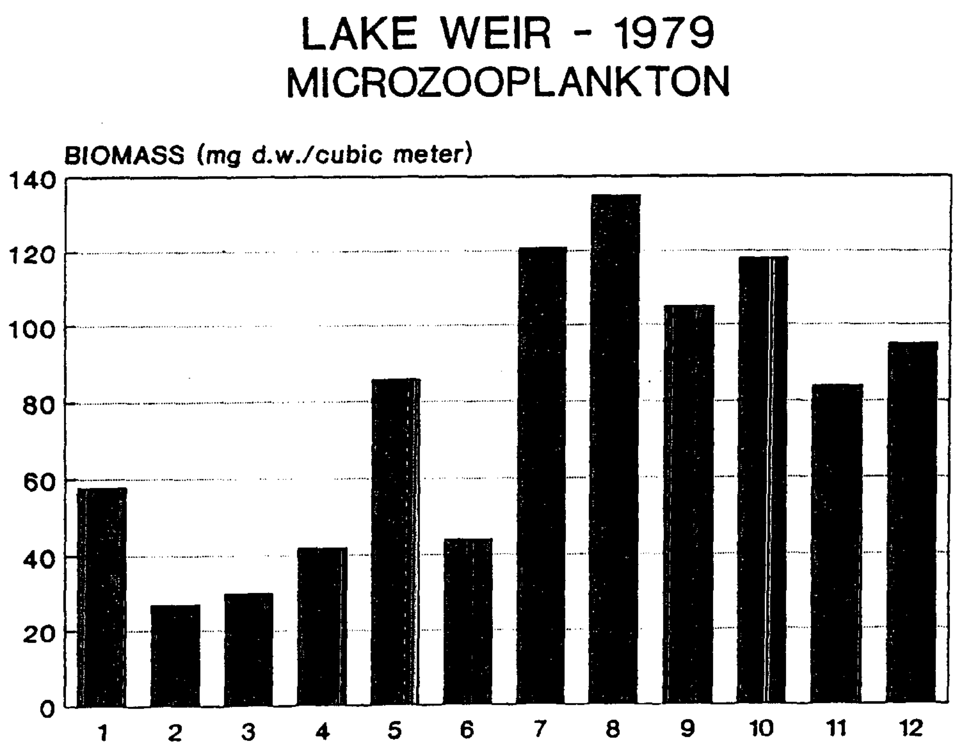


Figure 5-22. Biomass of macrozooplankton and microzooplankton in Lake Weir for individual months of 1979.

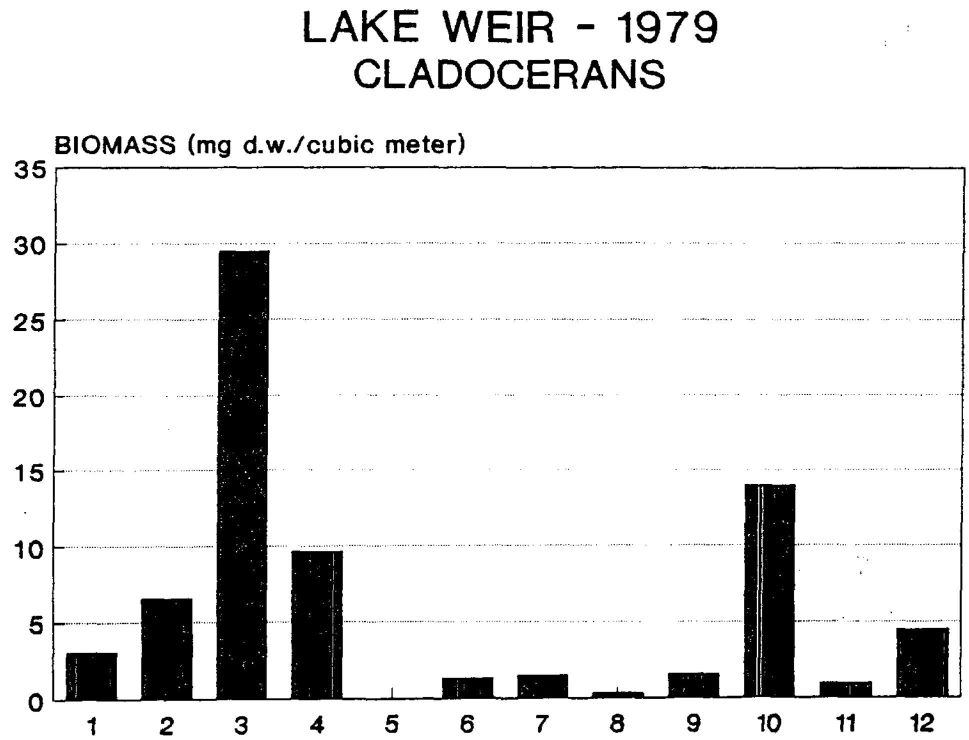


Figure 5-23. Biomass of cladocerans in Lake Weir for individual months of 1979.

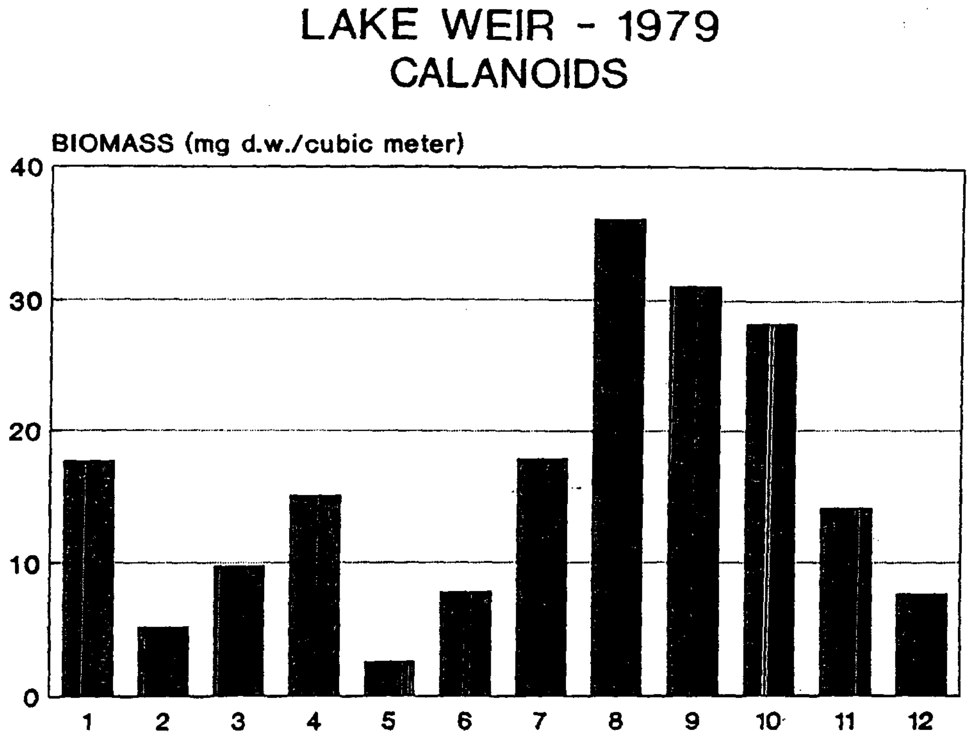
but had biomass maxima in both spring and late summer in 1987-1989 (Figure 5-24). Cyclopoid copepods displayed similar population peaks during spring and late summer and fall in both years (Figure 5-24), but the magnitude was much greater in 1987-1989. During 1974, Messer (1975) noted a similar pattern for total copepod abundance. Nauplii displayed a clear bimodality in 1979 with two major peaks in January and August (Figure 5-24). This trend was not observed during 1987-1989 with only a moderate elevation noted in fall.

Rotifers showed only one peak in July 1979 (Figure 5-25) but during 1987-1989 had major peaks during July, March and September. Similarly, Messer (1975) reported midsummer maxima in rotifer abundance during 1974 at three stations in Lake Weir. Total ciliate biomass was highest in January and September of 1979 (Figure 5-26), but the peaks occurred in July and November in 1987-1989.

Oligotrich seasonality was somewhat different between 1979 and 1987-1989. While the former year displayed peak biomass during summer (August), with secondary peaks during spring (April-May) and late fall (November-December), 1987-1989 oligotrich biomass peaked during summer (June-July) and late fall-winter (December-February) (Figure 5-26). Scuticociliate populations exhibited a major pulse in May and a smaller peak in October of 1979 (Figure 5-26). During the present study, their populations increased in spring but were maintained at higher levels during summer with other major peaks in September and November. Haptorid ciliates peaked in October and December of 1979 but peaked in June and November of 1987-1989 (Figure 5-26).

5.4.J COMPARISON OF ZOOPLANKTON SEASONALITY IN LAKE WEIR WITH OTHER MESOTROPHIC FLORIDA LAKES

Comparison of the seasonality of major zooplankton groups in Lake Weir with other Florida systems was accomplished by computing monthly mean values for each component in seven mesotrophic lakes discussed earlier. Total zooplankton biomass in mesotrophic Florida lakes usually peaked in spring, summer, and fall (Figure 5-27). In Lake Weir, however, July 1987 and September 1988 peaks were noted (Figure 5-9). Macrozooplankton biomass in mesotrophic Florida systems showed one pronounced spring maximum with populations beginning to increase during winter (Figure 5-28). Although most stations exhibited peak macrozooplankton during spring in Lake Weir for both 1987 and 1988, some stations displayed peaks during either



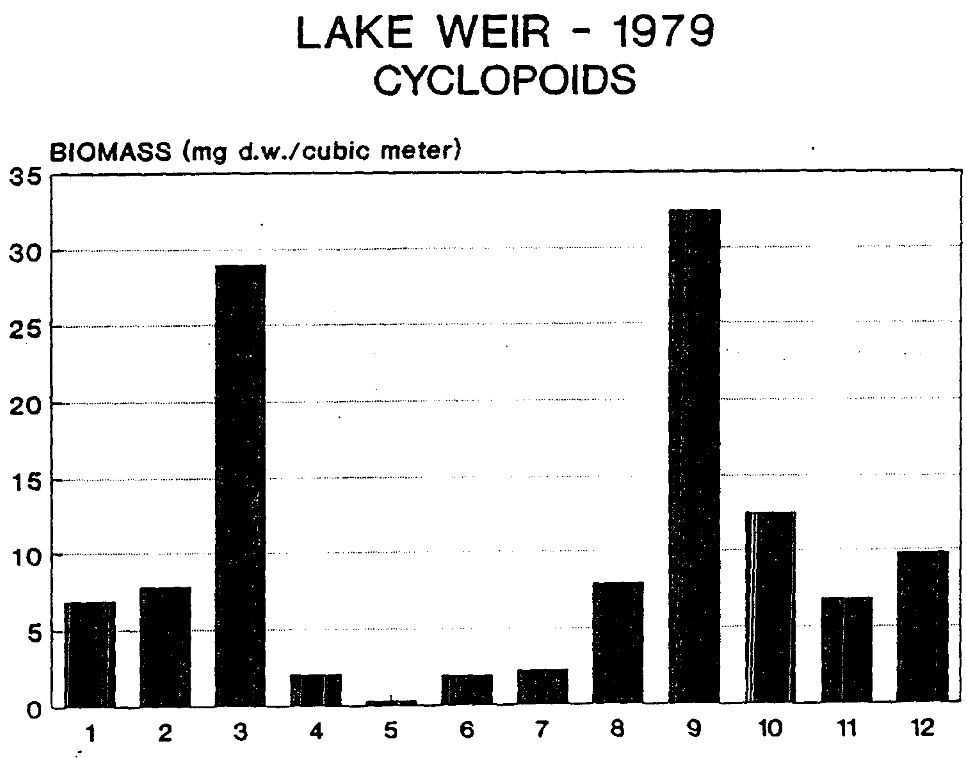


Figure 5-24. Biomass of calanoids, cyclopoids, and nauplii in Lake Weir for individual months of 1979.

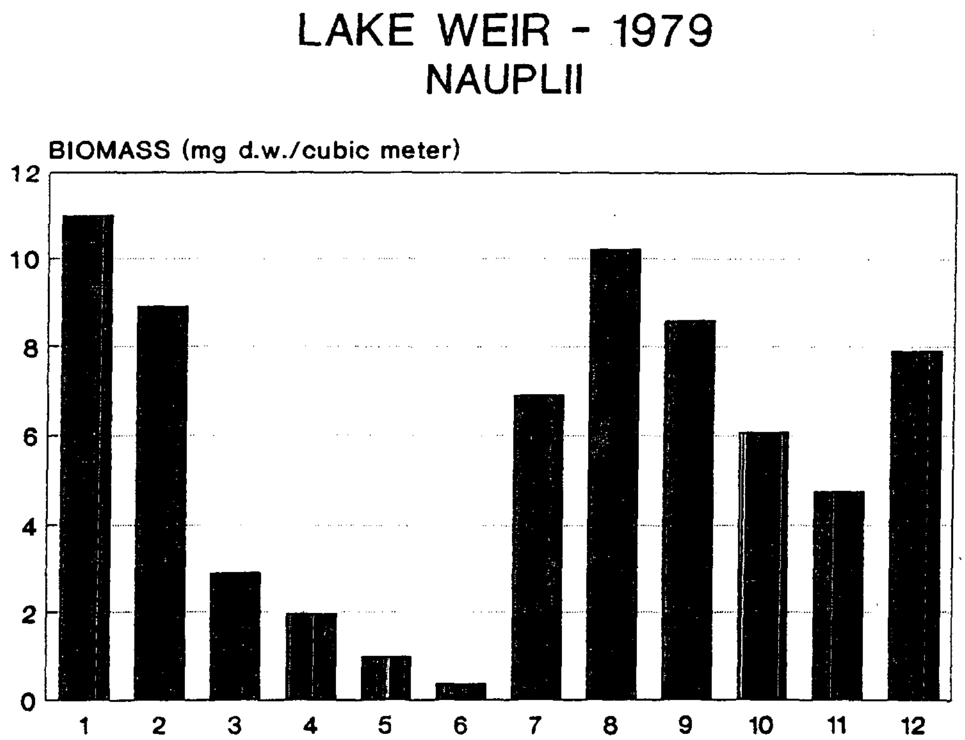


Figure 5-24. Continued.

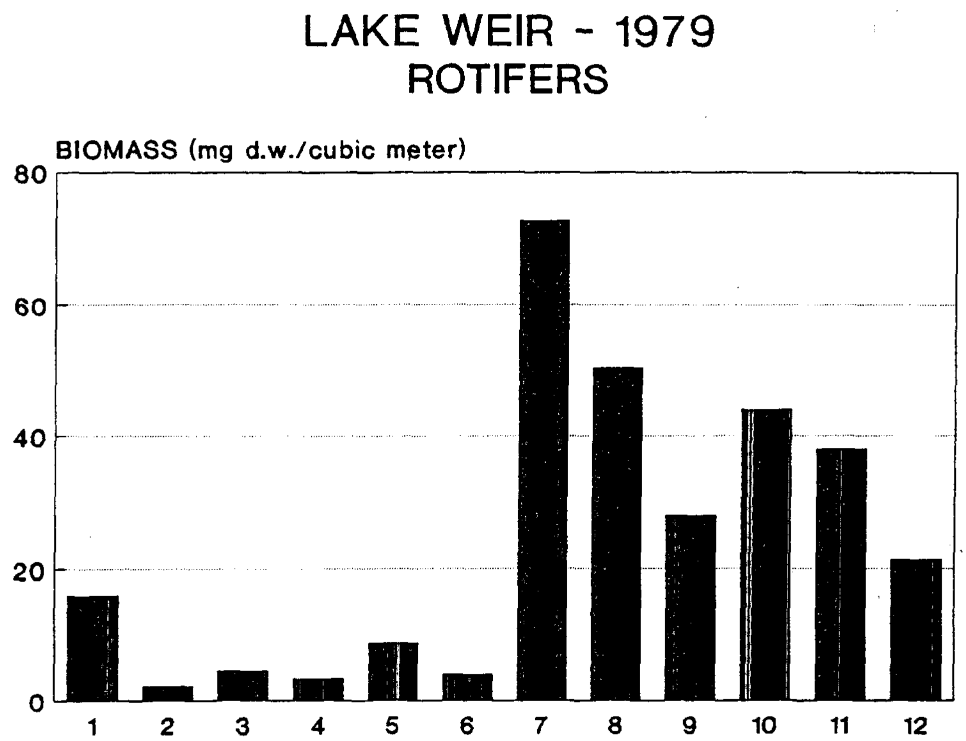
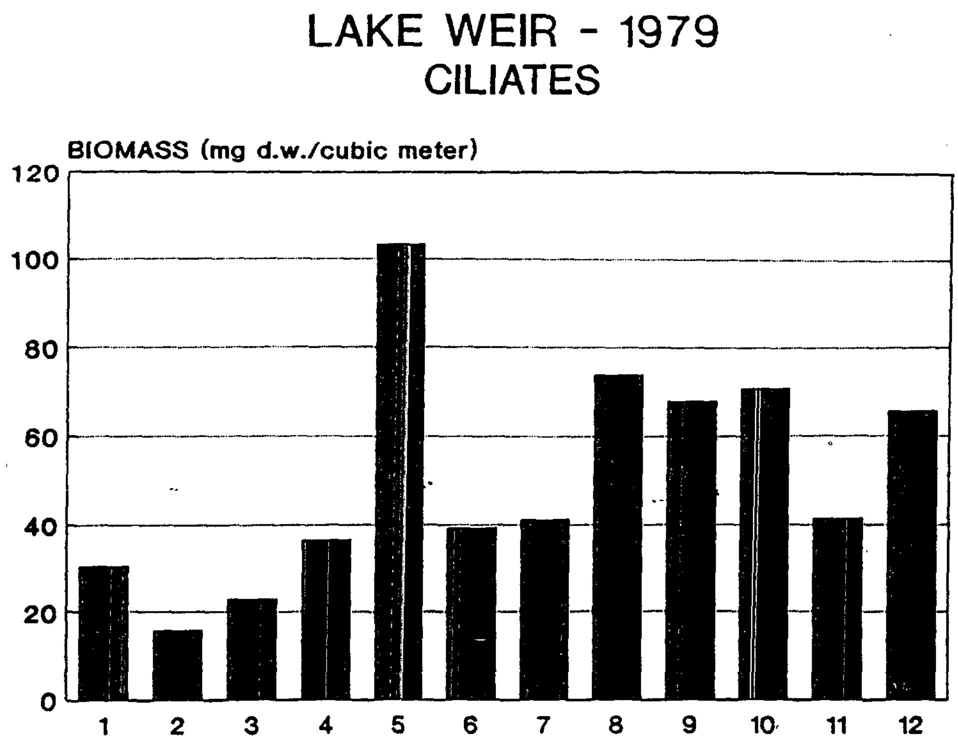


Figure 5-25. Biomass of rotifers in Lake Weir for individual months of 1979.



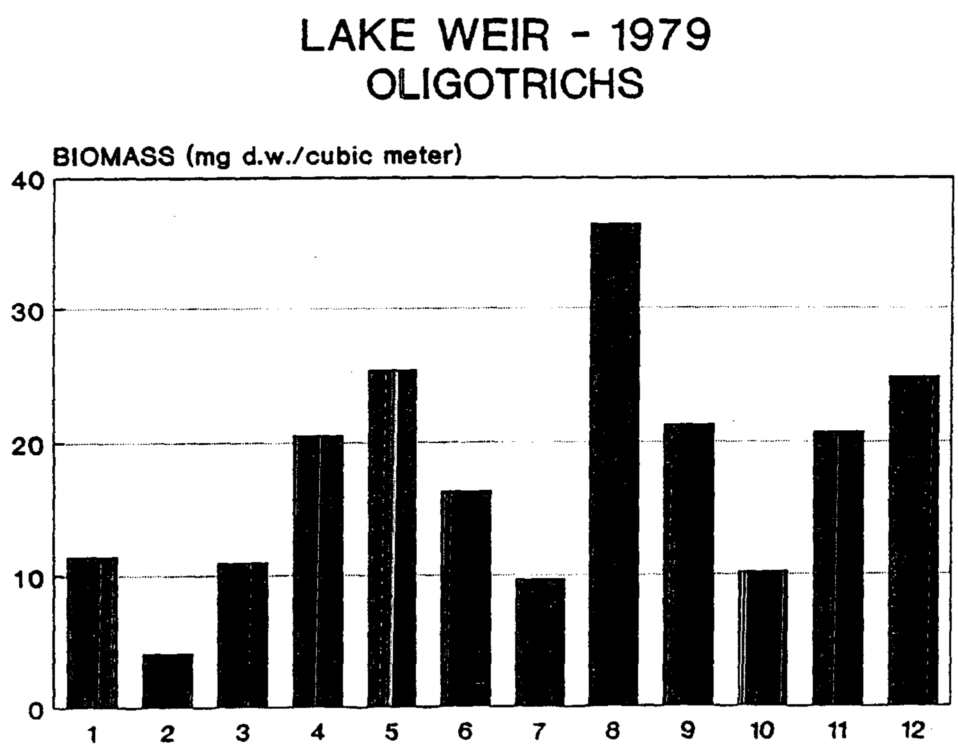
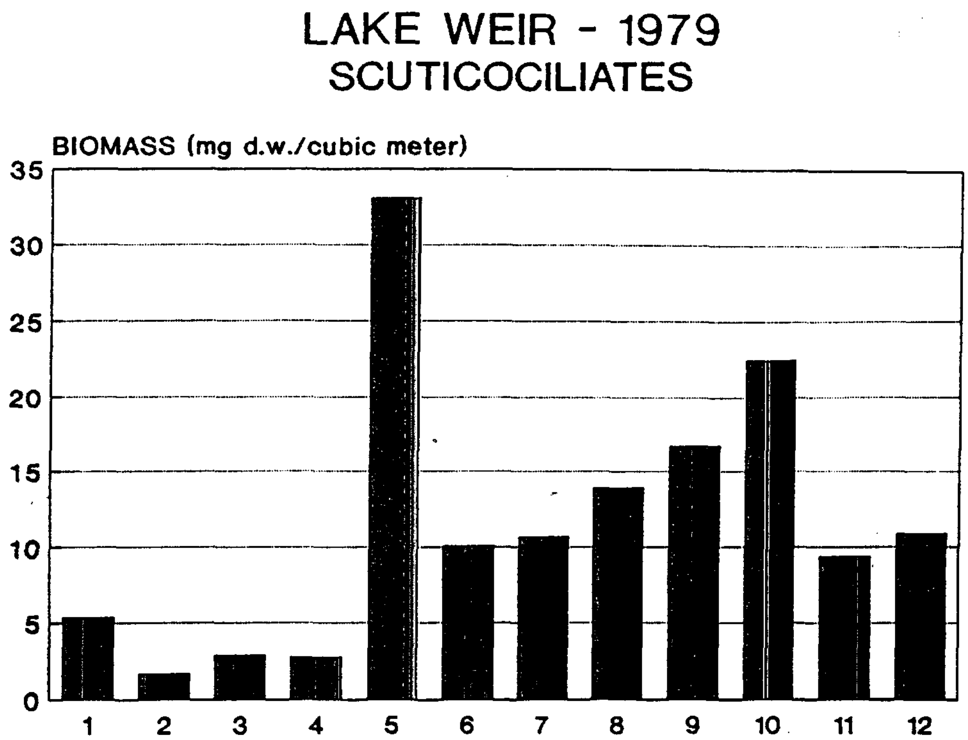
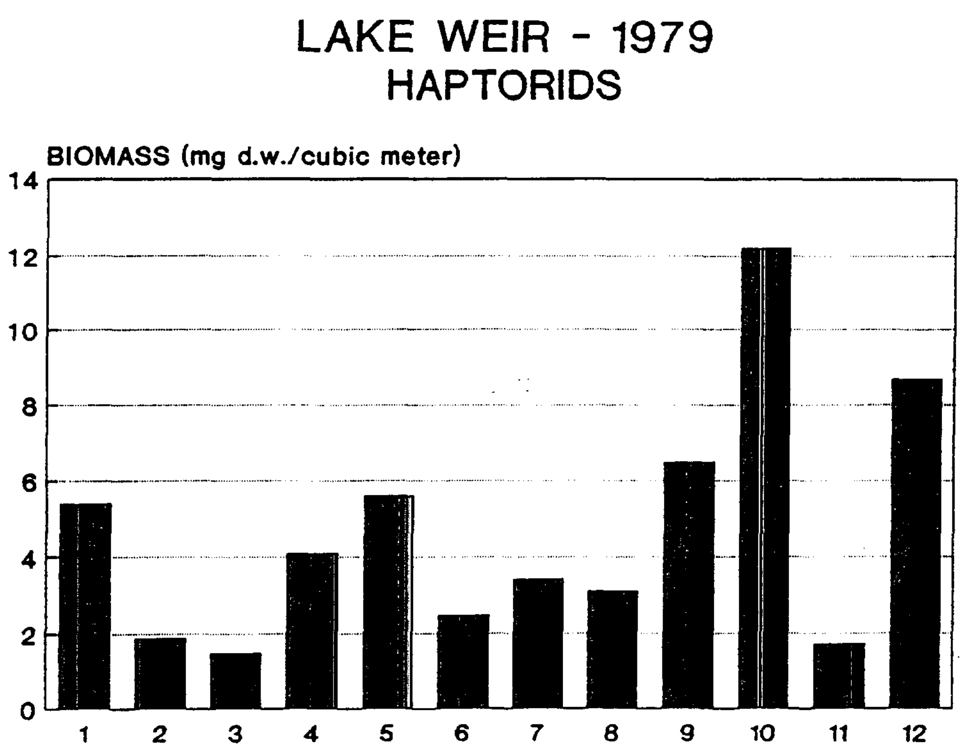


Figure 5-26. Biomass of total ciliates, oligotrichs, scuticociliates, and haptorids in Lake Weir for individual months of 1979.





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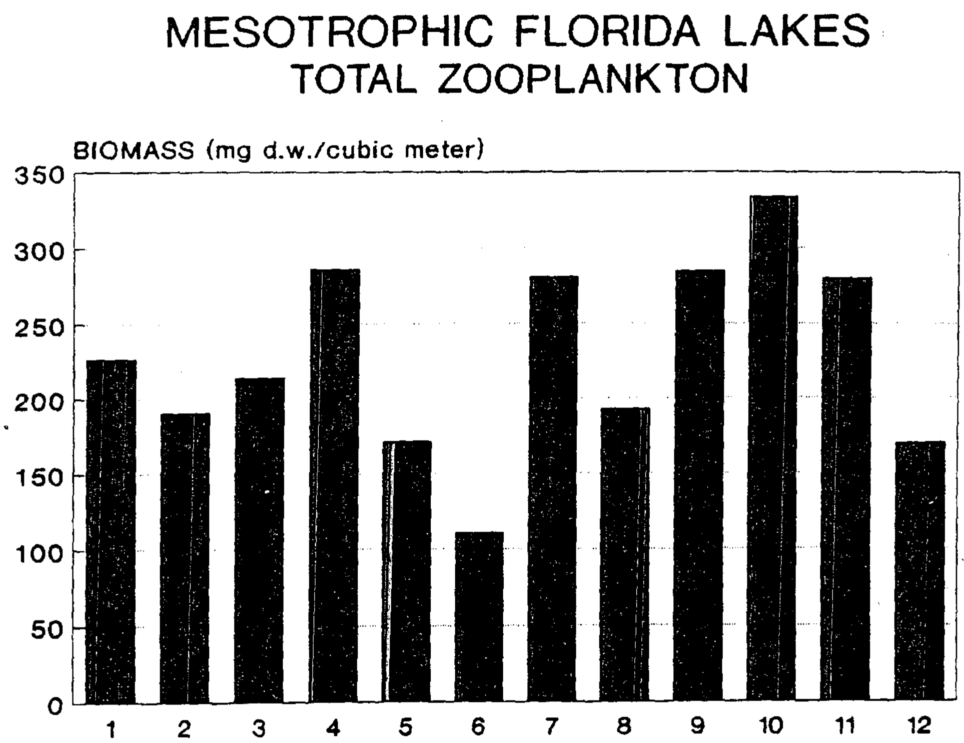
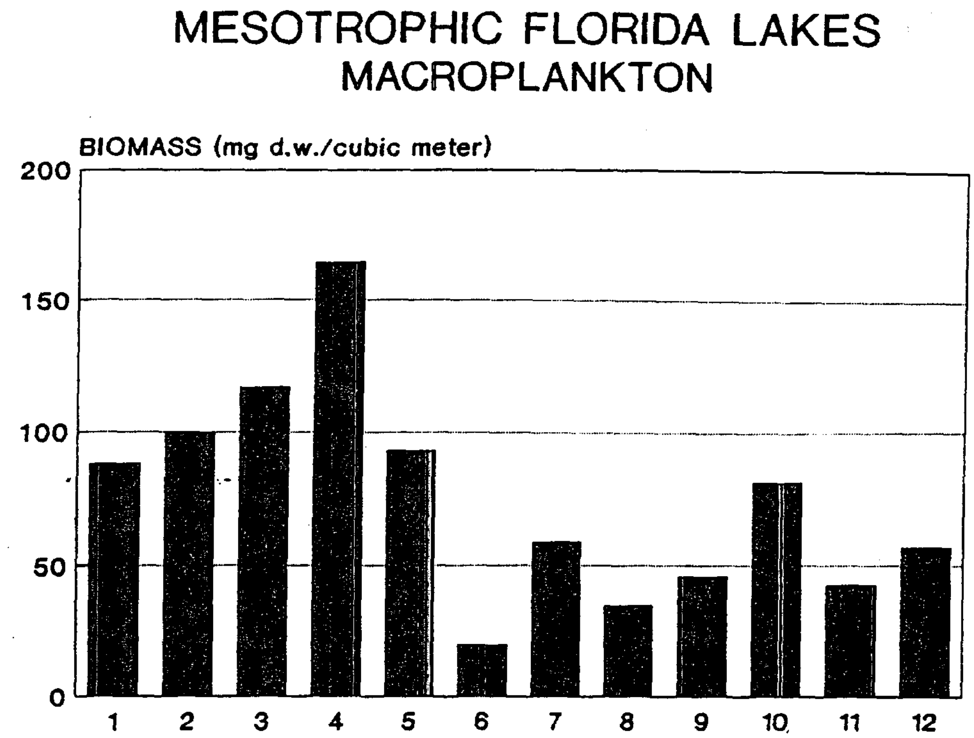


Figure 5-27. Biomass seasonality of total zooplankton in mesotrophic Florida lakes.



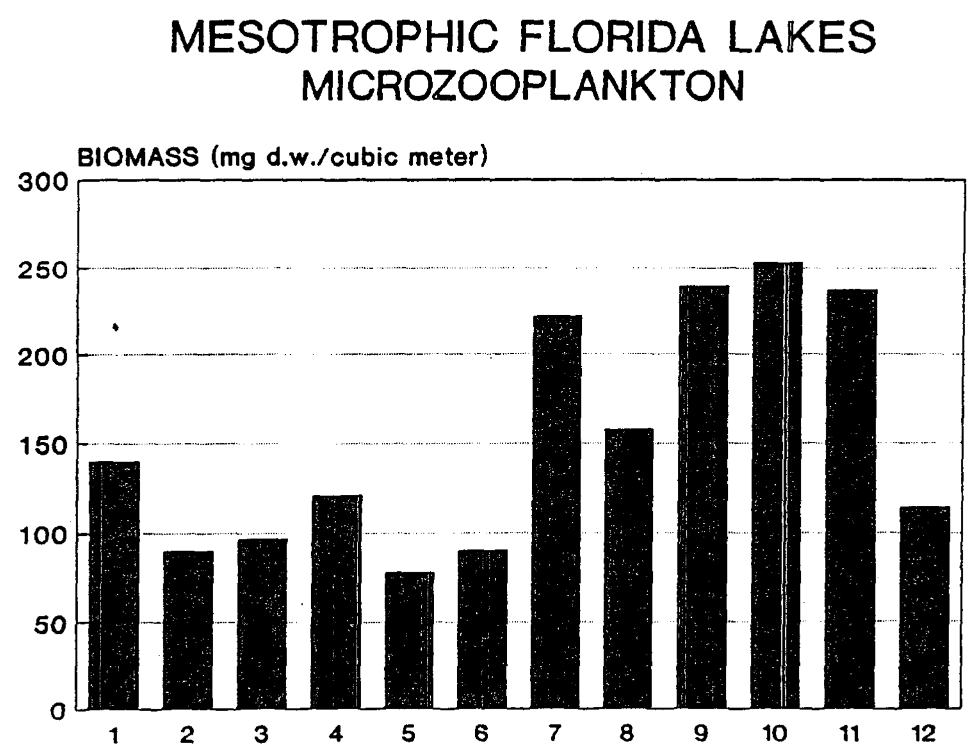


Figure 5-28. Biomass seasonality of macrozooplankton and microzooplankton in mesotrophic Florida lakes.

midsummer or fall (Figure 5-10). Microzooplankton peaked in July (1987 and 1988) in both Lake Weir (Figure 5-11) and other mesotrophic lakes (Figure 5-28), but the fall maxima observed in other mesotrophic systems was seen during one year (1988) in Lake Weir.

Cladocerans showed a clear seasonality in mesotrophic lakes with the largest biomasses encountered during spring and a small peak in fall (Figure 5-29). This pattern is consistent with those described for other mesotrophic Florida systems (Shireman & Martin 1978, Blancher 1984, Elmore et al. 1984) and was also true for Lake Weir during both 1987 and 1988 (Figure 5-12).

Calanoid copepods reached a maxima during the end of winter and spring in mesotrophic Florida lakes (Shireman & Martin 1978, Blancher 1984, Elmore et al. 1984) but no consistent pattern was evident in Lake Weir for this group (Figure 5-30). Cyclopoid copepods peaked throughout spring and again in fall in the mesotrophic subset (Figure 5-30) and other mesotrophic systems (Shireman & Martin 1978, Elmore et al. 1984). During both 1987 and 1988, cyclopoids in Lake Weir usually peaked in March and sometimes in late summer or early fall (Figure 5-14). Nauplii displayed peaks during July and October in the generalized cycle (Figure 5-30), while in Lake Weir, abundances increased during spring and then declined during summer (Figure 5-15). Large biomass pulses also were noted at most stations during November 1987 and September 1988. Other mesotrophic Florida lakes often show elevated nauplii populations in late summer or early fall (Shireman & Martin 1978, Blancher 1984, Elmore et al. 1984).

Rotifers generally peaked in both July and throughout fall in mesotrophic Florida lakes (Figure 5-31). Lake Weir experienced rotifer maxima in July 1987 but the peak was shortlived and populations quickly declined (Figure 5-16). An early fall pulse was noted at most stations during 1988. The July pulse in Lake Weir was approximately 50% higher than the average midsummer peak for the comparison systems. Rotifer maxima in other Florida systems frequently occurs during the summer months but have been noted during other seasons (Shireman & Martin 1978, Blancher 1984, Elmore et al. 1984).

The generalized pattern for total ciliate biomass indicates that these lakes experienced prolonged maxima during fall (Figure 5-32). In contrast, Lake Weir had only a single brief biomass peak during June-July of 1987, while the biomass maximum in 1988 extended uninterrupted from June through December (Figure 5-17). The generalized oligotrich cycle for mesotrophic lakes (Figure 5-32) was somewhat different than the pattern observed in Lake Weir (Figure 5-18). Most mesotrophic systems had depressed populations

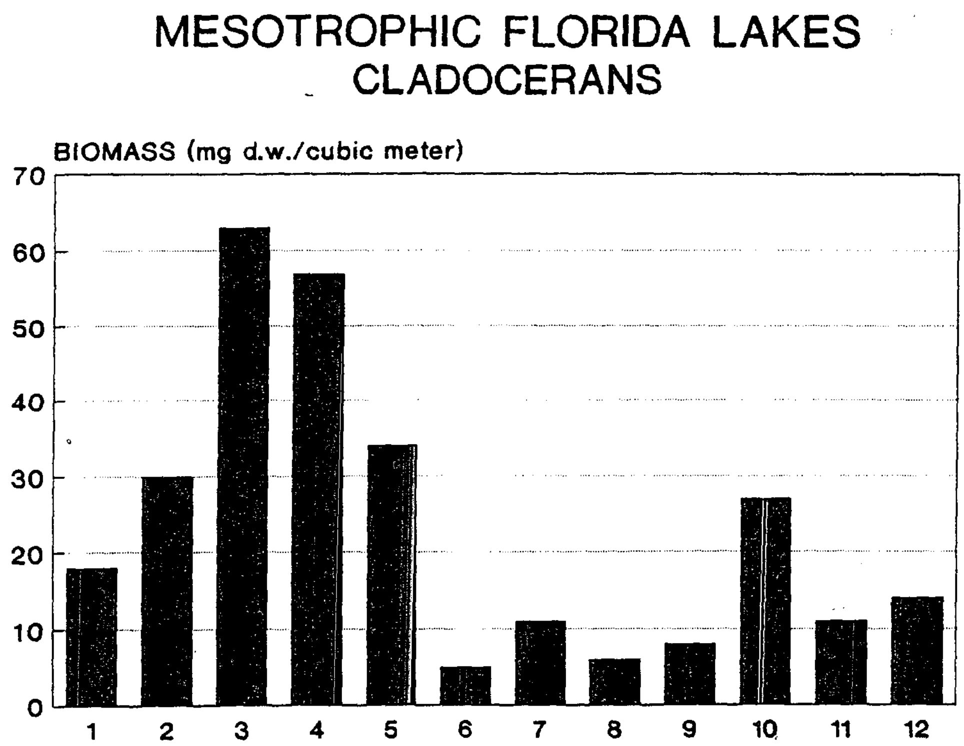


Figure 5-29. Biomass seasonality of cladocerans in mesotrophic Florida lakes.

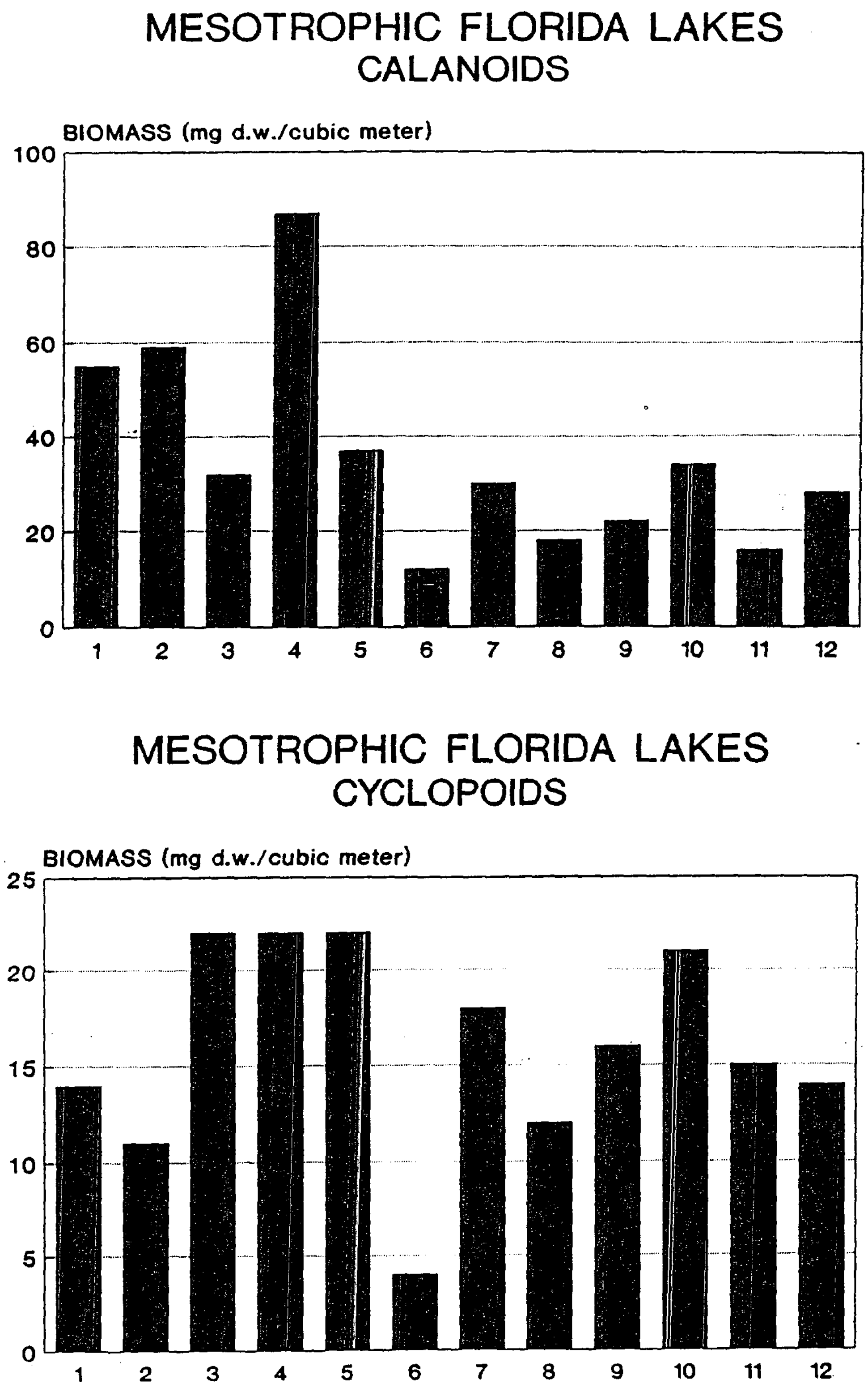
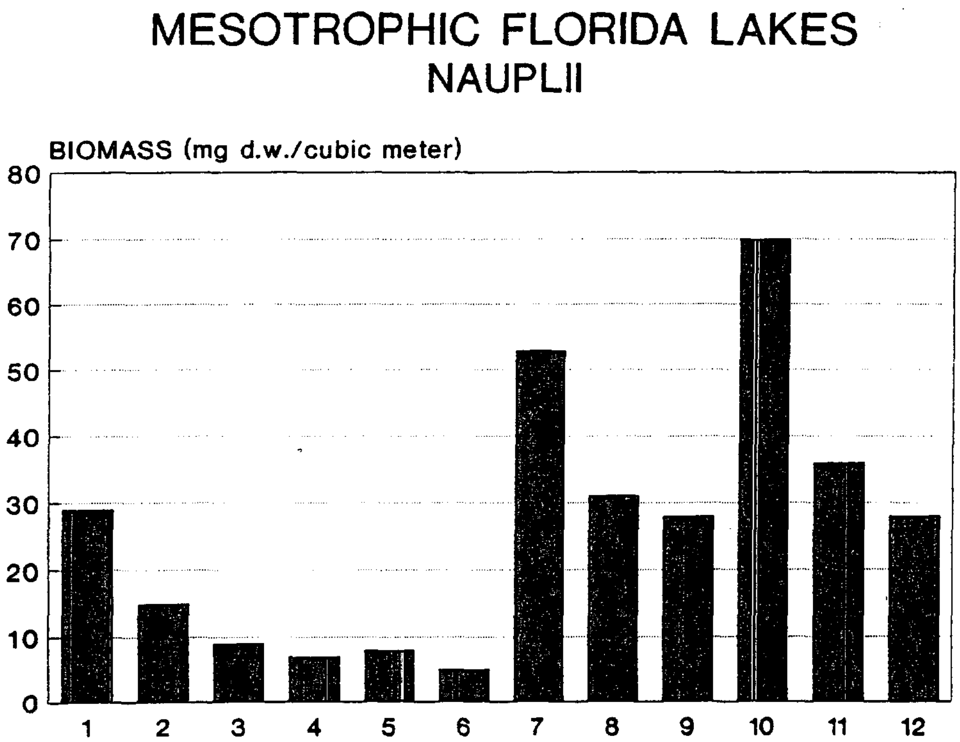


Figure 5-30. Biomass seasonality of calanoids, cyclopoids, and nauplii in mesotrophic Florida lakes.



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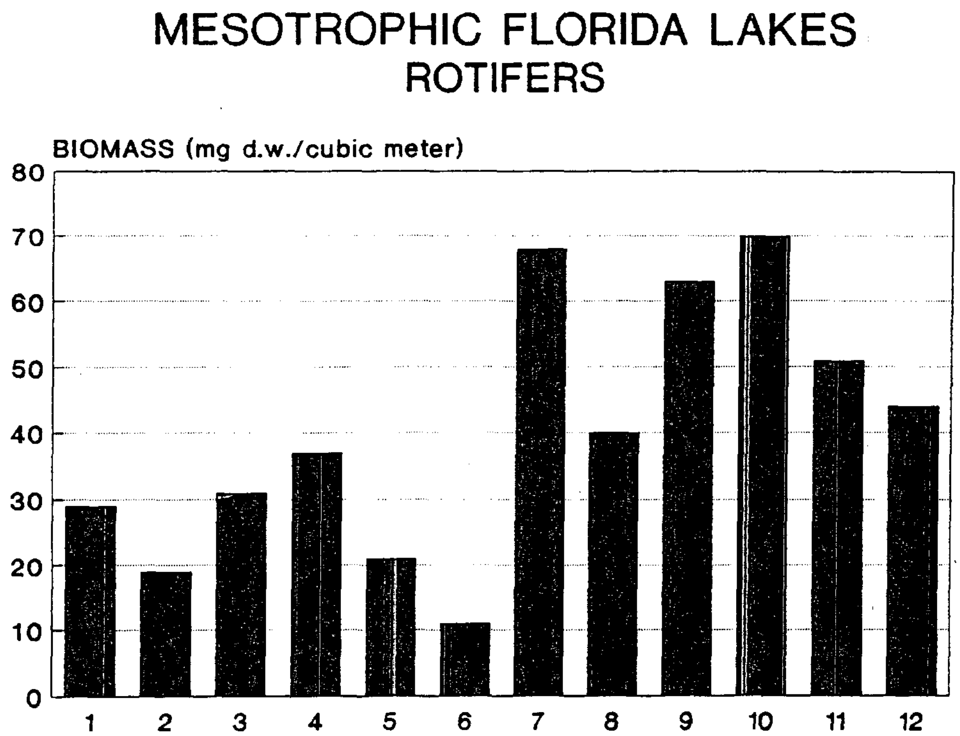
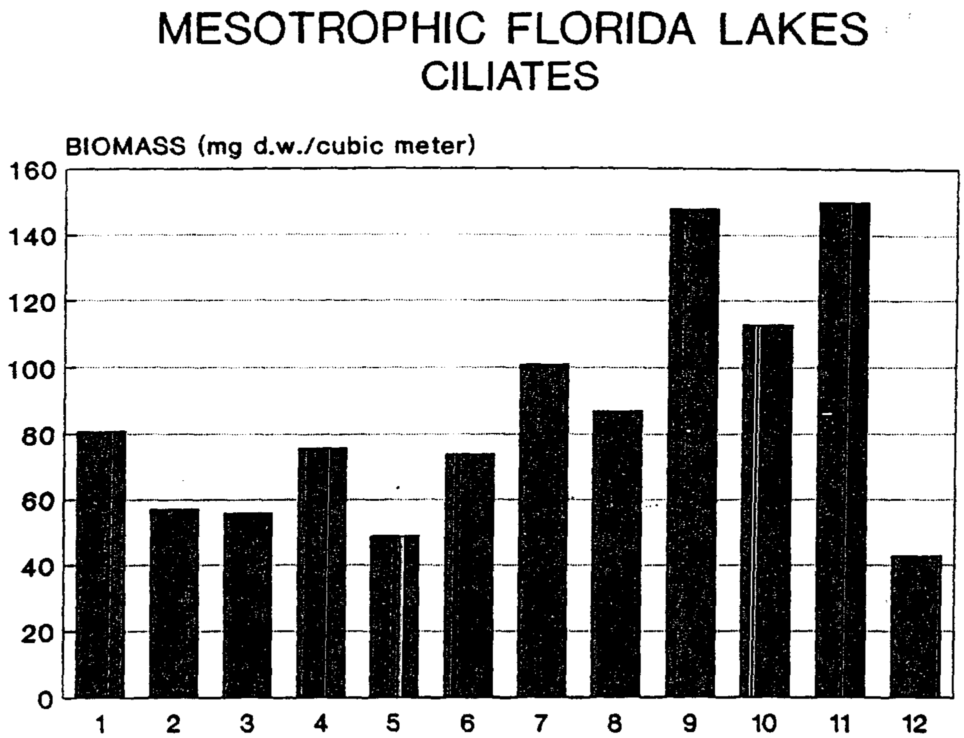


Figure 5-31. Biomass seasonality of rotifers in mesotrophic Florida lakes.



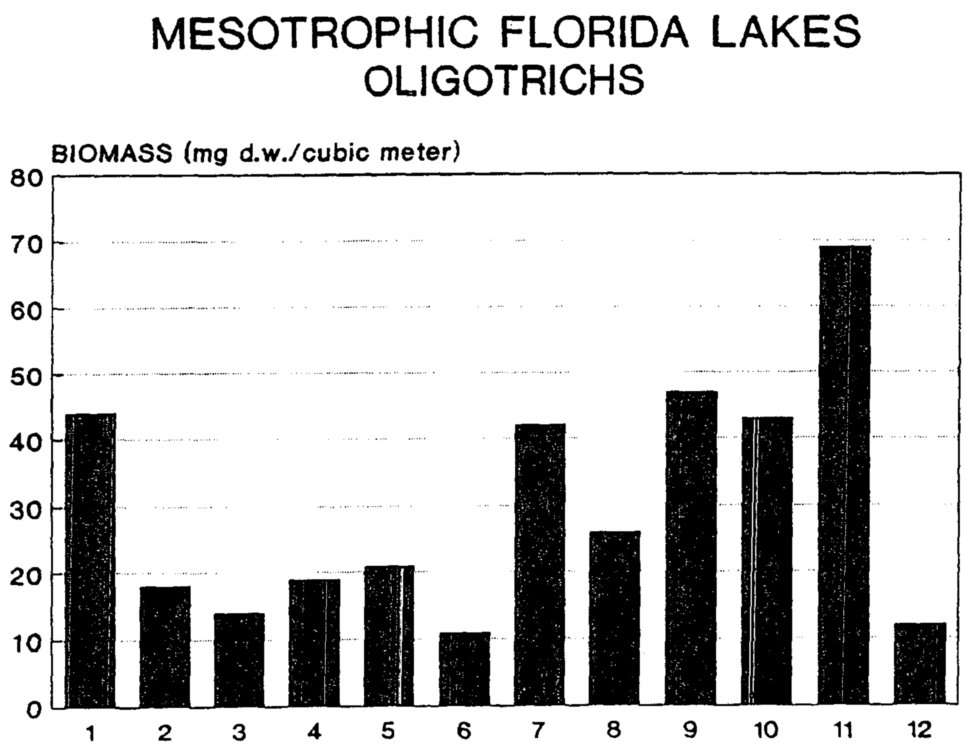
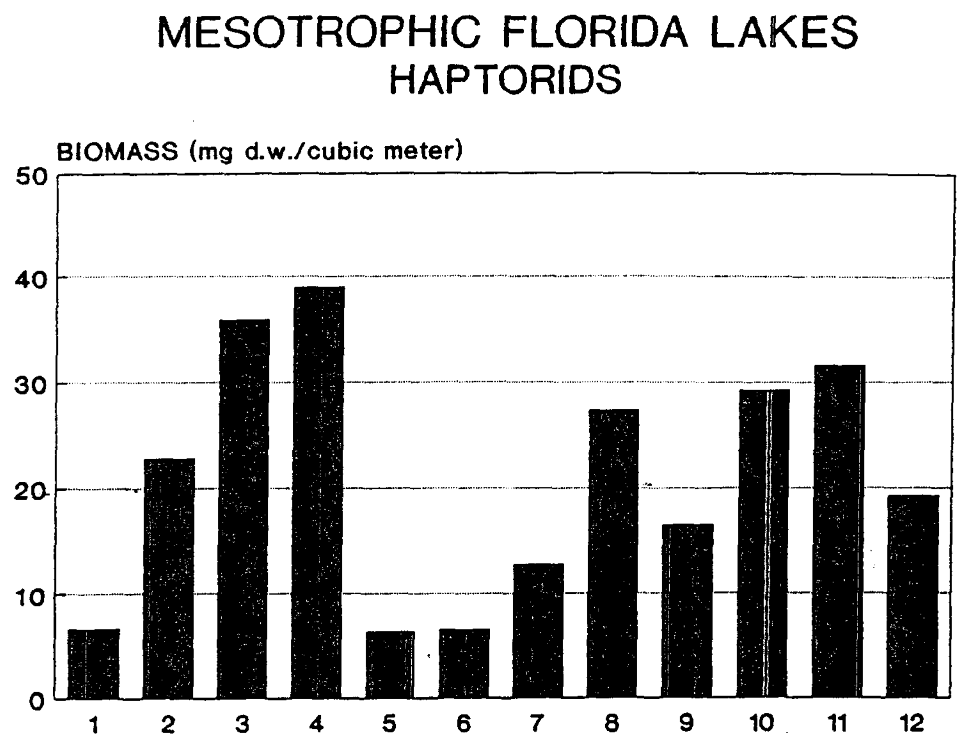


Figure 5-32. Biomass seasonality of total ciliates, oligotrichs, scuticociliates, and haptorids in mesotrophic Florida lakes.



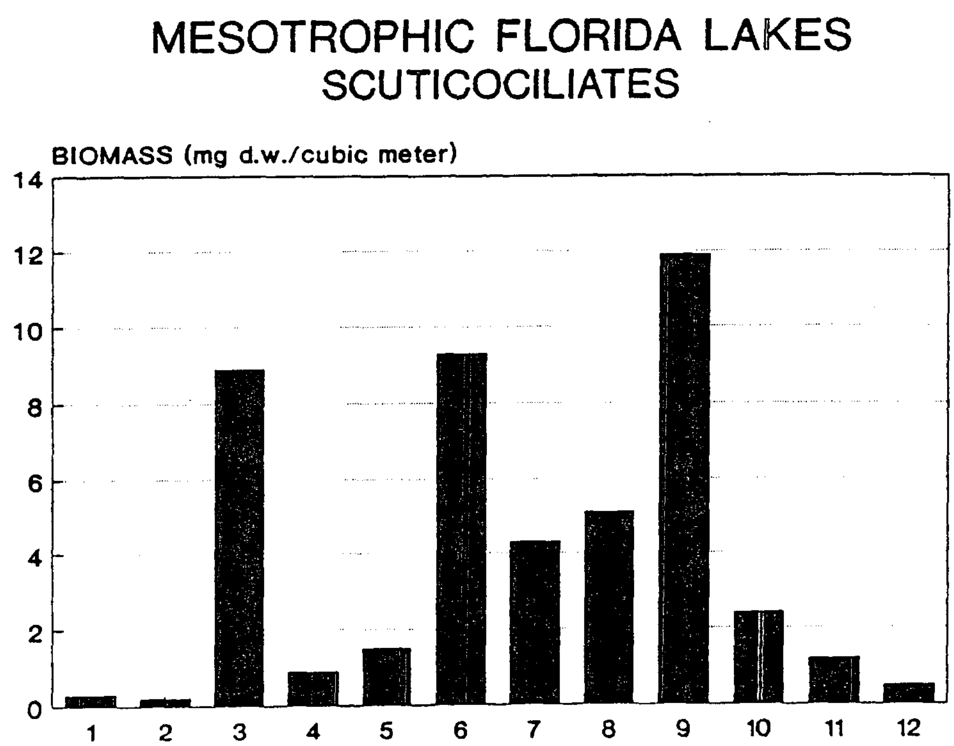


Figure 5-32. Continued.

during the first half of the year, then gradually increased from July until November. Lake Weir had maximum oligotrich densities in the first half (February-July) of 1987, but maximum biomass in 1988 was from June through December.

Scuticociliate biomass in Lake Weir peaked in June of 1987, after which it decreased progressively throughout the remainder of the year (Figure 5-19). In contrast, scuticociliate biomass in 1988 increased progressively throughout the year to a maximum in October, after which it progressively declined. In the mesotrophic lakes, scuticociliate populations peaked in March, June, and September and were usually 4 to 5 times less than the biomass maxima in Lake Weir (Figure 5-32). The pattern described for Lake Weir for scuticociliate biomass and total ciliate biomass is most similar to that described for eutrophic/hypereutrophic Florida lakes; however, in the latter lake group the biomass values were usually an order of magnitude greater than that found in Lake Weir (Beaver & Crisman 1990).

Haptorid biomass in the suite of mesotrophic Florida lakes displayed two peaks, a primary peak in lake fall following a progressive biomass increase from summer and a late winter-early spring peak in March-April (Figure 5-32). Haptorid biomass in Lake Weir during both 1987 and 1988 showed a progressive increase from summer through the end of the year, but only 1988 showed the earlier late winter-early spring peak noted for the mesotrophic Florida lake group (Figure 5-20). In contrast, the second biomass peak in Lake Weir during 1987 was during June-July.

5.4.K CORRELATIONS BETWEEN ZOOPLANKTON COMPONENTS AND LIMNOLOGICAL VARIABLES IN OTHER FLORIDA LAKES

A comparable correlation matrix developed for the seven comparision mesotrophic systems indicates that, as in Lake Weir, few strong relationships exist between environmental variables and the biomass of zooplankton groups (Table 5-11). Both correlation analyses share a weak but significant relationship between scuticociliate biomass and chlorophyll a. Total phosphorous was negatively correlated with microzooplankton, nauplii, rotifers, and oligotrichs and weakly correlated with cladocerans. Temperature was also weakly to moderately related to several zooplankton components in mesotrophic systems. In addition, pH was negatively correlated with total zooplankton, macrozooplankton, cladocerans and calanoids.

Table 5-11. Significant correlations ($p < 0.05$) between major zooplankton components in seven mesotrophic Florida lakes with selected limnological variables. Coefficients are Pearson product-moment type. Data for correlation analysis taken from Bays (1983) and Beaver (1980).

COMPONENT	Chl. a (n=84)	TP (n=80)	Temperature (n=84)	Secchi disk	pH (n=81)	Bacteria
Total zooplankton	NS	NS	NS	ND	-0.26	ND
Macrozooplankton	NS	NS	-0.25	ND	-0.40	ND
Microzooplankton	NS	-0.32	0.25	ND	NS	ND
Cladocera	NS	0.23	-0.26	ND	-0.31	ND
Calanoida	NS	NS	NS	ND	-0.42	ND
Cyclopoda	0.24	NS	NS	ND	NS	ND
Nauplii	NS	-0.45	NS	ND	NS	ND
Rotifera	NS	-0.31	NS	ND	NS	ND
Ciliata	NS	NS	0.32	ND	NS	ND
Oligotrichida	NS	-0.22	0.30	ND	NS	ND
Scuticociliatida	0.24	NS	0.54	ND	NS	ND
Haptorida	NS	NS	NS	ND	NS	ND

Table 5-12. Significant correlations (p <0.05) of major zooplankton components in Florida lakes with limnological variables. Coefficients are Pearson product-moment type (n=238).

COMPONENT	Chl. *a*	*TP*	*TN*	*Temp.*	*pH*
Total zooplankton	0.63	0.42	0.25	NS	0.28
Macrozooplankton	NS	NS	NS	-0.23	-0.12
Microzooplankton	0.70	0.44	0.35	0.17	0.35
Cladocera	-0.13	NS	-0.28	-0.35	-0.24
Calanoida	NS	NS	NS	-0.15	-0.14
Cyclopoda	0.17	0.14	NS	NS	NS
Nauplii	0.41	NS	0.20	NS	0.21
Rotifera	0.45	NS	0.21	0.15	0.13
Ciliata	0.71	0.53	0.42	0.20	0.37
Oligotrichida	0.47	0.46	0.22	0.23	0.24
Scuticociliatida	0.72	0.56	0.54	0.29	0.53
Haptorida	0.28	0.21	NS	-0.13	NS

Comparison of the above correlation matrices with one developed from a set including 20 Florida lakes and spanning the entire trophic gradient (Table 5-12), indicates that periods of high productivity (as measured by chlorophyll a, total phosphorus, total nitrogen, and pH) are frequently associated with increases in most zooplankton components. This pattern is inversely related to the size of the zooplankton group, suggesting that high productivity may have a more direct and detectable effect on small-bodied opportunistic plankters with high reproductive capacity. In contrast to the mesotrophic trend, temperature has only a weak effect when Florida systems are considered as a whole.

It has been inferred from field studies in Florida lakes that many interrelated limnological factors control the abundance and composition of zooplankton communities. Included among these factors are predation (Bays & Crisman 1983, Blancher 1984, Elmore 1983, Elmore et al. 1983), competition (Elmore 1983, Elmore et al. 1983, Foran 1986a, 1986b), food availability (Beaver & Crisman 1981, 1982, 1990, Elmore et al. 1984, Brezonik et al. 1984) and temperature (Blancher 1984, Foran 1986a, 1986b).

It is clear from this study that temperature exerts a variable but significant influence on zooplankton communities in Florida lakes. Foran (1986a, 1986b) concluded that the absence of large-bodied cladocerans in subtropical lakes is due to the competitive advantage accrued to smaller species at elevated temperatures typical of these systems. The spring cladoceran maximum observed in Lake Weir and other Florida lakes coincides with increasing water temperature and is believed to be a response to increased reproductive and growth rates, The rapid early summer decline has been ascribed to intense predation from young of the year fish (Bays & Crisman 1983).

Among the copepods, Diaptomus dorsalis usually dominates the copepod communities of eutrophic lakes due to its reduced susceptibility to vertebrate predation (Elmore et al. 1983), and is excluded from less productive systems by superior competition from D. mississippiensis and D. floridanus (Elmore 1983).

Finally, food quality and quantity likely influence the temporal and spatial distribution of zooplankton species in Florida lakes (Beaver & Crisman 1981, 1982, 1990, Bays & Crisman 1983, Brezonik et al. 1984). The results of the correlation analysis suggest that food is the primary factor regulating zooplankton populations when Florida lakes are considered as a whole.

5.4.L SUBTLE CHANGES IN ZOOPLANKTON COMPOSITION AS AN INDICATOR OF ADVANCING CULTURAL EUTROPHICATION

5.4.L.1 INTRODUCTION. Compositional shifts in zooplankton community structure associated with eutrophication are attributable in part to enhanced predation pressure (Brooks 1969). Planktivorous fish increase along with lake productivity (Larkin & Northcote 1969), decimating large-bodied zooplankton populations due to the latter's higher susceptibility to vertebrate predation. Invertebrate predators such as Chaoborus and cyclopoid copepods also increase with eutrophication and may alter zooplankton community size structure through selective predation (Zaret 1980). Finally, the temporal and spatial distribution of zooplankton species in Florida lakes, as in the temperate zone, are influenced by food quality and quantity (Beaver & Crisman 1982, 1989a, 1989b, Bays & Crisman 1983).

Previous studies have often considered compositional changes in zooplankton communities along broad trophic gradients with major emphasis on changes to the macrozooplankton community. Little emphasis has been placed on the subtle structural alterations to zooplankton populations corresponding to accelerated nutrient loading rates within a watershed. Therefore, our purpose here is to advance the idea that the microzooplankton population of a lake may display minor, but detectable, responses to increased eutrophication. We hypothesized that ciliated protozoa and rotifers, which as a group are more dependent upon bacteria as a food source than larger-bodied zooplankton (Crisman et al. 1981, Beaver & Crisman 1982, 1989b), should exhibit the first response to advancing cultural eutrophication since their primary food is tightly linked to trophy in Florida lakes (Crisman et al. 1990). In this analysis, we considered only zooplankton data computed from the first half of the current study.

5.4.L.2 METHODS. Zooplankton samples (rotifers and crustaceans) were collected 12 times between January and December 1979 by one or two vertical hauls of an 80 um mesh Wisconsin plankton net and preserved with buffered formalin. Zooplankton communities were sampled 12 times in Lake Weir between February 1987 and February 1988 from water column composites collected at 1 m intervals with 2 liter Kemmerer bottle and pooled aboard ship. Three liter subsamples of this composite were filtered through a #20 mesh (76-80um) zooplankton net aboard ship and preserved with 2mL Lugol's solution.

Samples for 1979 and 1987-1988 were analyzed by identical methodologies. In the laboratory, the concentrate was passed through a 41 um nylon mesh. The mesh was carefully rinsed with distilled water into a graduated cylinder and the volume was recorded. This procedure usually resulted in a final concentrated volume of < 10ml. The concentrate was preserved with 1 mL Lugol's solution until analysis.

Aliquots were enumerated in a Sedgwick-Rafter chamber at 100x until the total tally reached 150-200 individuals. Identification followed the keys of Ruttner-Kolisko (1974), Edmondson (1959) and Deevey & Deevey (1971). Dry weight biomass of rotifers and crustaceans were estimated by using published conversion factors (Dumont et al. 1975, Maslin 1969) as well as values empirically determined in this laboratory (Bays 1983).

Ciliate samples in 1979 and 1987-1988 were taken from water column composites taken a 1 m intervals from the surface to the bottom. Subsamples (78 mL) for ciliated protozoa were taken from the pooled composite, stained with several drops of 1.0% bromothymol blue and preserved with 2 mL saturated $HgCl^2$. Detailed enumeration, biomass estimation and taxonomic methodologies for ciliated protozoa have been previously described (Beaver and Crisman 1982, 1989a). Samples for zooplankton, ciliated protozoa, bacteria and water chemistry were all taken from the same midlake station for both the 1979 and 1987-1988 periods. Annual mean values of select limnological parameters for both 1979 and 1987-1988 are presented in Table 5-13. All statistical analyses utilized the SAS (1985) computer package available through the University of Florida.

5.4.L.3 RESULTS. Total zooplankton biomass in Lake Weir increased from 113.1 mg d.w. m^{-3} in 1979 to 146.7 mg d.w. m^{-3} during 1987-1988 (Table 5-14). Macrozooplankton (cladocerans, copepodids, copepods) decreased from 32.2 mg d.w. m^{-3} in 1979 to 22.2 mg d.w. m^{-3}, while all microzooplankton components increased between studies. The biomass of rotifers, nauplii and ciliates in 1979 (24.3 mg d.w. m^{-3}, 5.9 mg d.w. m^{-3}, 50.7 mg d.w. m^{-3}, respectively) were below comparable values for 1987-1988 (45.3 mg d.w. m^{-3}, 9.0 mg d.w. m^{-3}, 70.2 mg d.w. m^{-3}, respectively). Within the Ciliata, the biomass of oligotrichs (17.7 mg d.w. m^{-3}), scuticocciliates (11.7 mg d.w. m^{-3}) and haptorids (4.7 mg d.w. m^{-3}) in 1979 were relatively depressed when contrasted with estimates from 1987-1988 (23.7 mg d.w. m^{-3}, 18.1 mg d.w. m^{-3}, 7.4 mg d.w. m^{-3}, respectively).

When expressed on a percentage composition basis, zooplankton biomass in Lake Weir during 1979 was dominated by ciliates (44.8%), rotifers (21.5%) and calanoid copepods (14.3%) (Figure 5-33). Cladocerans (5.4%), nauplii (5.2%) and cyclopoid copepods (8.8%) constituted the remainder of

Table 5-13. Annual mean values for select trophic state parameters at Station 3 in Lake Weir in 1979 and 1987-1988.

	1979	1987-1988
Secchi disk transparency (m)	2.13	1.54
Chlorophyll a (mg m^{-3})	8.72	6.87
Total Kjeldahl nitrogen (mg m^{-3})	914	760
Total phosphorus (mg m^{-3})	50	51
Bacteria (x 10^6 cells ml^{-1})	-	1.03

Table 5-14. Historical comparison of the mean annual biomass of various components of the Lake Weir zooplankton community at Station 3 between 1979 and 1987-1988. Data for 1979 taken from Bays (1983) and Beaver (1980). Biomass values in mg d.w. per cubic meter (±SE).

COMPONENT	1979	1987-1988
Total zooplankton	113.1 ± 13.3	146.7 ± 20.9
Macrozooplankton	32.2 ± 6.1	22.2 ± 6.4
Microzooplankton	88.9 ± 10.8	124.5 ± 17.1
Cladocera	6.1 ± 2.5	1.7 ± 0.7
Calanoida	16.2 ± 3.1	11.9 ± 4.7
Cyclopoda	10.0 ± 3.0	8.5 ± 2.3
Nauplii	5.9 ± 1.1	9.0 ± 1.2
Rotifera	24.3 ± 6.5	45.3 ± 12.3
Ciliata	50.7 ± 7.4	70.2 ± 7.8
Oligotrichida	17.7 ± 2.6	23.7 ± 3.8
Scuticociliatida	11.7 ± 2.6	18.1 ± 3.8
Haptorida	4.7 ± 0.9	7.4 ± 1.8

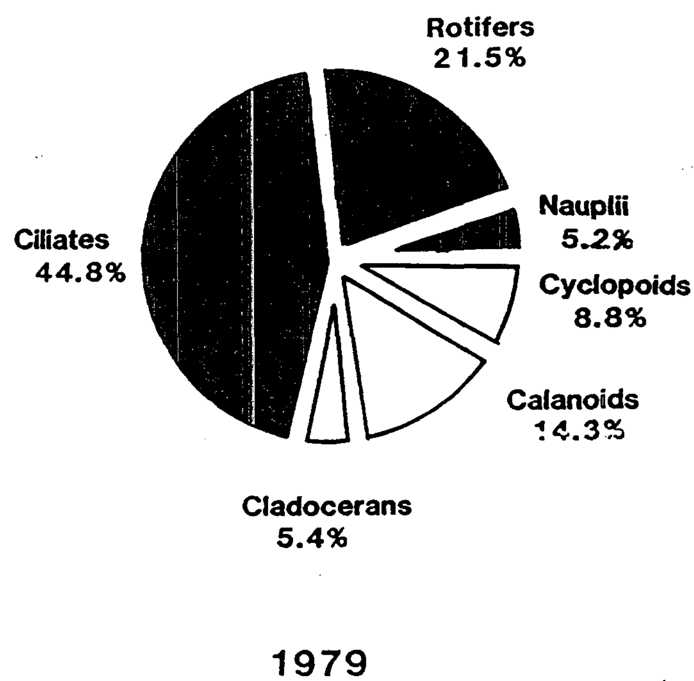


Figure 5-33. Biomass partitioning of zooplankton biomass in Lake Weir during 1979.

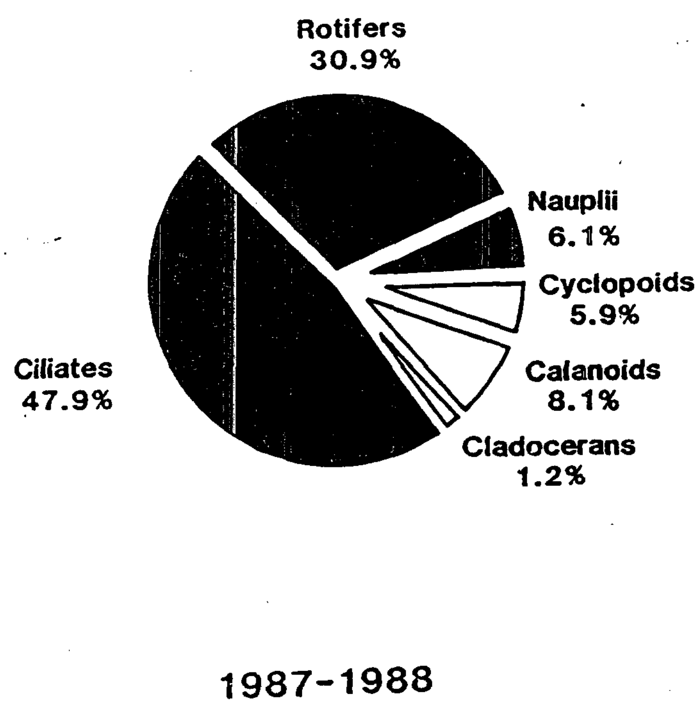


Figure 5-34. Biomass partitioning of zooplankton biomass in Lake Weir during 1987-88.

the zooplankton community. In 1987-1988, rotifers (30.9%), ciliates (47.9%) and nauplii (6.1%) were proportionally more important to zooplankton biomass, while cladocerans (1.2%), cyclopoid (5.9%) and calanoid copepods decreased (Figure 5-34). Microzooplankton (ciliated protozoa, rotifers, nauplii) composed 71.5% of the total zooplankton biomass in 1979 but increased to 84.9% of the zooplankton community by 1987-1988.

Finally, microzooplankton displayed a 53.9% increase and macrozooplankton a 31.1% decrease from 1979 to 1987-1988 (Figure 5-35). All groups of macrozooplankton decreased between studies, while all components of the microzooplankton community increased. The most prominent proportional decrease within the macrozooplankton was for cladocerans (72.1%), while rotifers nauplii, and ciliates increased 86.4%, 52.5% and 38.5%, respectively. Scuticociliates (54.7%) and haptorid (57.4%) ciliates increased by approximately the same percentage between study periods.

Like many subtropical lakes, Lake Weir has a depauperate cladoceran fauna. However, the dominant cladoceran species during both sampling periods (*Eubosmina tubicen*, *Daphnia ambigua*, *Diaphanasoma brachyurum*) were all more depressed in 1987-1988 than 1979. Predatory copepods (*Cyclops* spp.) were significantly reduced in 1987-1988, although the biomass of the scavenger copepod *Tropocyclops prasinus* was over twice as great during 1987-1988. Within the calanoid copepods, the biomass of *Diaptomus* spp. in 1987-1988 was less than half of the estimate for 1979. Although Bays (1983) reported both *D. floridanus* and *D. dorsalis* in 1979, only *D. dorsalis* was encountered in the present study.

Among the nine dominant rotifer taxa, seven (*Brachionus havanaensis*, *Hexarthra mira*, *Conochilus unicornis*, *Monostyla lunaris*, *Polyarthra vulgaris*, *Trichocerca multicrinis*, *Collotheca libera*) were higher during 1987-1988, while two taxa (*Asplanchna* spp., *Keratella cochlearis*) displayed reductions between 1979 and 1987-1988 (Table 5-15).

Of the ten dominant ciliate taxa in Lake Weir, six were more abundant during the present study (*Coleps hirtus*, *Cyclidium glaucoma*, *Mesodinium pulex*, *Strombidium viride*, *Tintinnidium semiciliatum*, *Vorticella microstoma*), and the biomass of four other common species were lower (*Cinetochilum margaritaceum*, *Holophyra simplex*, *Strobilidium humile*, *Strombidium* cf *oculatum*) (Table 5-16). Three of the latter group, however, were only slightly lower in 1987-1988. Beaver & Crisman (1989a) noted that when Florida lakes are considered as a whole, *V. microstoma* is the most sensitive indicator taxa for trophic state assessment. The biomass of this peritrich ciliate increased from 1.7 mg d.w.

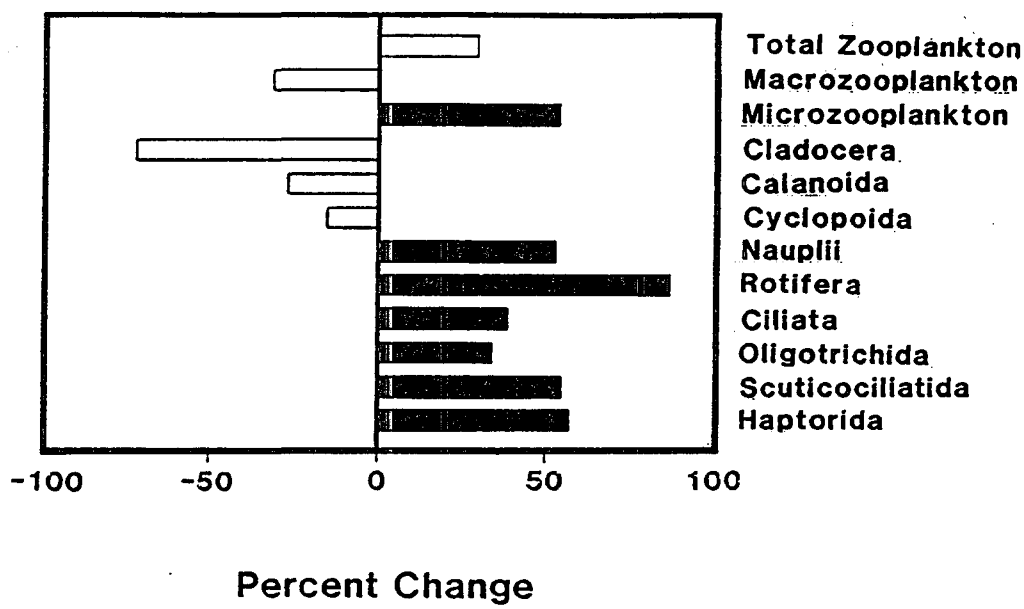


Figure 5-35. Percentage change in the contribution of individual components to total zooplankton biomass between 1979 and 1987-88.

Table 5-15. Annual mean biomass of select rotifer taxa at Station 3 in Lake Weir for 1979 and 1987-1988. All values in ug d.w. per cubic meter.

ROTIFER	1979	1987-1988
Asplanchna spp.	1.5	1.2
Brachionus havanaensis	0.4	1.6
Collotheca libera	1.2	5.0
Conochilus unicornis	0.3	4.6
Hexarthra mira	12.2	21.8
Keratella cochlearis	2.0	0.9
Monostyla lunaris	0.8	4.7
Polyarthra vulgaris	0.5	3.0
Trichocerca multicrinis	1.2	1.5

Table 5-16. Annual mean biomass of select ciliated protozoa at Station 3 for Lake Weir in 1979 and 1987-1888. All values in ug d.w. per cubic meter.

CILIATE	1979	1987-1988
Cinetochilum margaritaceum	4.5	4.3
Coleps hirtus	9.8	12.7
Cyclidium glaucoma	6.5	7.8
Holophyra simplex	2.0	1.9
Mesodinium pulex	3.5	4.5
Strobilidium humile	6.2	1.7
Strombidium viride	2.0	4.5
Strombidium cf oculatum	9.2	8.9
Tintinnidium semiciliatum	0.3	8.4
Vorticella microstoma	1.7	4.2

m^{-3} 1979 to 4.2 mg d.w. m^{-3}.

5.4.L.4 DISCUSSION. Distribution patterns in biomass and species composition for crustacean zooplankton components generally display a poor relationship with trophic state in Florida lakes. Thus, for subtropical lakes changes in macrozooplankton communities have limited predictive ability for small changes in lake trophy with the exception of calanoid copepods (Bays & Crisman 1983). *Diaptomus dorsalis* usually dominates the copepod communities of eutrophic lakes due to its reduced susceptibility to vertebrate predation (Elmore et al. 1983) and is excluded from less productive systems by superior competition from *D. mississippiensis* and *D. floridanus* (Elmore 1983). *D. dorsalis* was the only calanoid copepod encountered in Lake Weir in 1987-1988.

By most criteria, Lake Weir would be classified as mesotrophic in both 1979 and 1987-1988. Although Secchi disk transparency has decreased since 1979, chlorophyll *a* and Kjeldahl nitrogen values have not. Total phosphorus has remained unchanged despite significant increases in nutrient loading rates. Hutchinson (1969) underscored the significance of considering "lakes and their drainage basins and sediments as forming oligotrophic or eutrophic systems" rather than classifying trophy solely on the basis of water column charactersitics. Similarly, Goldman (1988) demonstrated that gradual changes in primary productivity, water transparency and nutrient dynamics are important in detecting advancing cultural eutrophication even at its earliest stages.

Most planktonic ciliates are bactivorous and have a species-specific, distinct particle size range which is retained and ingested (Fenchel 1980a). Fenchel (1986) noted that filter feeding by planktonic ciliates is the most efficient nutritional mode when the food particle spectra is skewed towards smaller particles. Thus, ciliates specialized on very small particles (0.2um - 1.0um) are dependent upon higher concentrations of food to be competitive.

Based on these observations, Fenchel (1980b) estimated that small-bodied bactivorous ciliates should be largely excluded from lakes having bacteria concentrations $< 5 \times 10^6$ cells mL^{-1}. Ciliate distribution patterns in Florida lakes have validated Fenchel's prediction since with increasing eutrophication small-bodied bactivorous taxa replace larger-bodied ciliate species less dependent on bacteria as a food source (Beaver & Crisman 1982, 1989).

The degree to which suspension-feeding rotifers utilize bacteria is highly variable (Pourriot 1977), but probably is more often a supplementary rather than a primary food source as the size of most planktonic bacteria lie below the particle range most efficiently consumed by most of these small metazoans (Gilbert 1989). The rotifers displaying the largest increases between 1979 and 1987-1988 (C. unicornis, H. mira, B. havanaensis, M. lunaris) are known to supplement their dietary regimes with free-living bacteria or those associated with detrital particles (Pourriot 1977, Pejler 1983, J. Gilbert pers. comm.).

Recently, Crisman et al. (1991) demonstrated a strong empirical relationship between bacterial abundance and lake trophic state in clearwater Florida lakes. Although bacteria were not assessed in 1979, during 1987-1988 the density of bacteria in Lake Weir averaged 1.03×10^6 cells mL^{-1} and ranged from $0.66 - 1.76 \times 10^6$ cells mL^{-1} in water column composite samples. Although our estimates of bacteria abundance are below the threshold concentration recommended by Fenchel (1980b) as necessary for populations of small-bodied ciliates to expand, it is likely that metalimnetic bacteria densities were greater during thermal stratification than the composite values we report here. Potential linkage with zones of elevated bacterioplankton abundance within the water column may account for the lack of a significant zooplankton-bacteria relationship based on mean water column values (Table 5-10).

The increase in the major bactivores of the zooplankton community of Lake Weir was likely associated with attainment of bacterial densities near the threshold level for growth of bactivorous taxa. Ciliates and rotifers have high intrinsic growth rates and should respond concurrently to environmental changes and thus are more sensitive indicators of changes in water quality. We propose that microzooplankton populations are sensitive indicators of small changes in lake trophic state due to their intimate association with phosphorus scavenging bacteria, and that an increase in these bactivores is an advanced warning of cultural eutrophication.

The zooplankton community of Lake Weir would be classified as a mesotrophic assemblage. The biomass of most major zooplankton components was relatively depressed when contrasted with lakes of similar trophy. This trend was most noticeable within the macrozooplankton since cladoceran and copepod adult biomass were very low compared to other mesotrophic Florida lakes.

Historical comparison with the zooplankton community in 1979 indicates only minor taxonomic changes have occurred. It is important to note, however, that scuticociliate ciliates and rotifers have markedly increased since 1979, and the elevated abundance of these taxa has been strongly associated with increased eutrophication in other Florida lakes (Beaver & Crisman 1982, 1989, Bays & Crisman 1983).

Our interpretation of microzooplankton data for Lake Weir was based on our fourteen years of experience with zooplankton communities in Florida lakes and published research by others on Florida and temperate zone lakes. Although we feel that our contention is valid that microzooplankton are a good early warning indicator for advancing cultural eutrophication even when more conventional trophic state parameters fail to suggest such changes, we do recognize that is it impossible with the present data base to dismiss other factors, including reduced predation and/or competition resulting from decreased abundance of macrozooplankton, as controlling variables for at least part of the recent observed change in the structure of the microzooplankton community.

5.5 BENTHIC INVERTEBRATES

5.5.A INTRODUCTION

Beginning on February 1987 and ending on February 1989, benthic macroinvertebrate communities at five stations in Lake Weir and one station each in Sunset Harbor and Little Lake Weir were sampled at approximately monthly intervals. For this two year period, 72 samples were collected at each station and a total of 504 samples were analyzed. The seven sampling stations were the same stations used to sample water quality (Figure 4-1).

Substrate types at the stations were of three basic groups. Stations 1, 2, 5, and 6 had fine sand while station 4 had a coarse sand bottom. Stations 3 and 7 had a black, organic "muck" substrate and no sand particles. This unconsolidated muck passed easily through the 600 um (standard No. 30) mesh used in the sieve bucket. The fine sand also passed through but the coarse sand was retained by the sieve bucket.

A petite ponar grab sampler was used three times at each station. The effective sampling area of the ponar was 0.023 square meters. Thus, an area of 0.07 square meters was sampled at each station every month. The rope used to lower the ponar was also used to measure the water depth. On the average, stations 2 and 4 were at three meters, stations 5 and 6 were at four meters, stations 1 and 7 were at six meters, and station 3 had a depth of about seven meters.

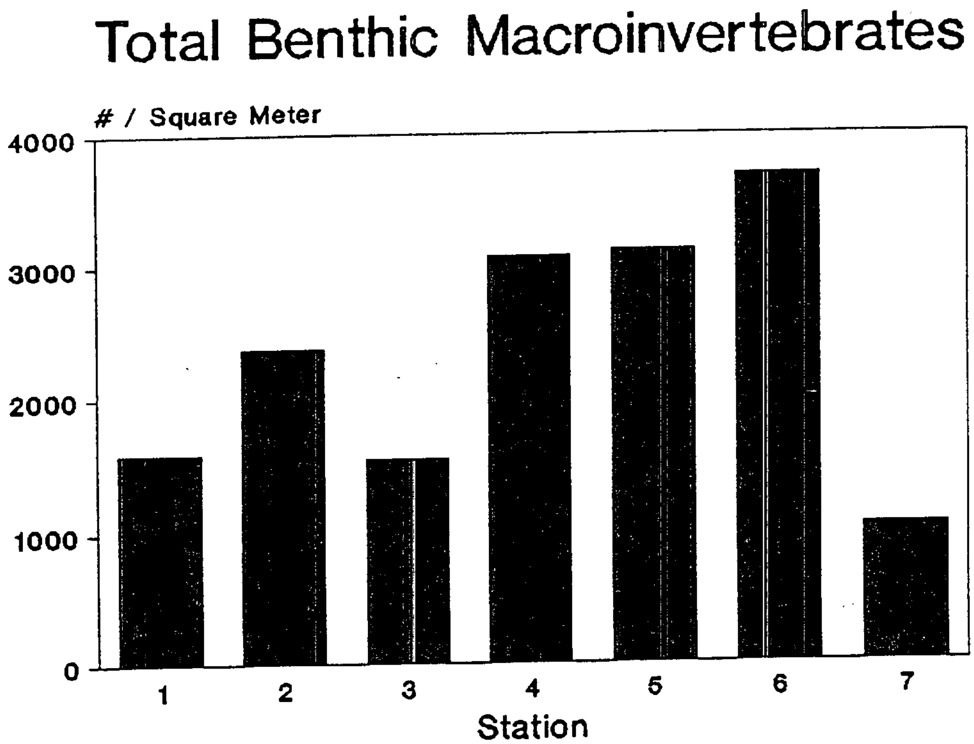


Figure 5-36. Mean biomass of total benthos at individual stations of the Lake Weir system for 1987-89.

Table 5-17. Mean benthic macroinvertebrate densities (number per square meter) in the Lake Weir system.

STATION:	1	2	3	4	5	6	7
CHIRONOMIDAE:							
Chironomus	17	22	324	67	24	480	45
Glyptotendipes	25	24	83	47	21	712	33
Polypedilum	6	5	2	14	2	22	33
Pseudochironomus	17	65	2	53	39	85	4
Cryptochironomus	14	15	7	69	38	84	15
Cladopelma	30	21	14	23	24	65	20
Tanytarsus	22	19	55	27	31	73	107
Cladotanytarsus	136	159	30	405	221	184	25
Ablabesmyia	5	21	4	64	28	32	11
Procladius	47	43	46	29	46	60	50
Coelotanypus	86	46	40	50	175	103	59
Einfeldia	0	0	1	0	0	0	1
Zavereliella	0	1	0	0	0	0	0
Epoicocladius	1	0	0	0	0	0	0
Djalmabatistia	5	28	0	4	3	1	0
Demicryptochironomus	0	1	0	0	0	0	0
Stictochironous	0	5	0	1	0	0	0
Paralauterborniela	0	1	0	0	0	0	0
Dicrotendipes	0	1	1	0	0	2	0
Cricotopus	1	3	0	4	0	0	0
Nilothauma	1	2	0	1	0	0	0
Paratendipes	0	1	0	0	0	0	0
Endochironomus	3	1	0	2	0	1	0
TOTAL CHIRONOMIDAE	416	482	607	859	652	1903	404
CHAOBORIDAE:	254	292	384	112	238	284	338
CERATOPOGONIDAE:							
Palpomyia	32	37	5	34	18	80	12
TRICHOPTERA:							
Oecetis	0	2	0	3	7	2	1
ODONATA:							
Aphylla	4	8	1	6	2	1	1
EPHEMEROPTERA:							
Hexagenia	52	17	10	18	88	195	82
MOLLUSCA:							
Physella	1	14	1	2	10	2	1
Planorbella	2	5	0	9	7	0	0
Viviparus	10	20	5	20	13	24	6
Hyalopyrgus	1	0	0	1	0	6	0
Elliptio	8	48	1	57	54	60	2
NEMATODA	86	85	38	87	146	347	26
OLIGOCHAETA	206	274	114	370	186	217	87
HIRUDINEA	12	30	18	35	47	103	10
HYALELLA	500	1059	360	1458	1646	478	73
HYDRACARINA	2	2	0	4	4	0	0
Total Organisms:	1587	2375	1543	3074	3117	3701	1044

5.5.B ABUNDANCE

The mean abundance of macroinvertebrates varied considerably among the seven stations (Figure 5-36 and Table 5-17). The two lowest abundances were found at the two deep, mid-lake stations that had a organic "muck" substrate: station 7 in Little Lake Weir ($1044/m^2$) and station 3 in Lake Weir ($1543/m^2$). The highest mean density was found at Station 6 in Sunset Harbor ($3701/m^2$). Station 6 had a hard, sandy bottom and was near Bird Island and other populated areas. With the exception of stations 1 and 2, all the sand bottom stations had significantly greater mean densities than the two stations with an organic "muck" substrate (Table 5-18).

The most abundant taxonomic groups of benthic macroinvertebrates in Lake Weir were Amphipoda, Chironomidae, Chaoboridae, and Oligochaeta (Figure 5-37). In Sunset Harbor, the most abundant groups were Chironomidae, Amphipoda, Nematoda, and Chaoboridae, while in Little Lake Weir they were Chironomidae and Chaoboridae. The rank of dominant groups in Little Lake Weir and the mid-lake station 3 in Lake Weir were similar but with lower densities in Little Lake Weir.

Stations 2, 4, and 5 were dominated by the amphipod <u>Hyalella</u>. These three stations were relatively shallow and close to shore. All the other stations were dominated by insects. In stations 1, 3, 6, and 7, chironomids were the most numerous insect on the average for the 24 months of sampling. Chaoborids were the second most populous group of Insecta.

The mean densities of chironomids at all the stations were similar except for station 6. In this sandy area of Sunset Harbor, the density of chironomids ($1903/m^2$) was more than double that of any other station (Figure 5-38). In another sandy substrate, station 4, the total Chironomidae density was higher than the remaining stations. Since chironomids were the most abundant insect, the densities of total Insecta were roughly similar and--once again--were exceedingly high in Sunset Harbor (Figure 5-39).

Another abundant insect throughout the lake system was <u>Chaoborus</u> (Figure 5-40). Its densities were highest in the two deep, mid-lake stations of Lake Weir and Little Lake Weir. The mean density of <u>Chaoborus</u> was $384/m^2$ in the middle of Lake Weir at a depth of 7 to 8 meters. The behavior and physiology of <u>Chaoborus</u> enables it to be abundant in deep, low oxygen waters. However, it was also abundant in the stations that were half as deep. Station 4 had the lowest mean density of <u>Chaoborus</u> ($112/m^2$).

Table 5-18. Mean benthic macroinvertebrate densities (number per square meter) in the Lake Weir system for February 1987 to February 1989.

STATION:	1	2	3	4	5	6	7
Mean density:	1587	2375	1543	3074	3117	3701	1044

RANKED STATION:	7	3	1	2	4	5	6
Mean density:	1044	1543	1587	2375	3074	3117	3701
	------	------	------				
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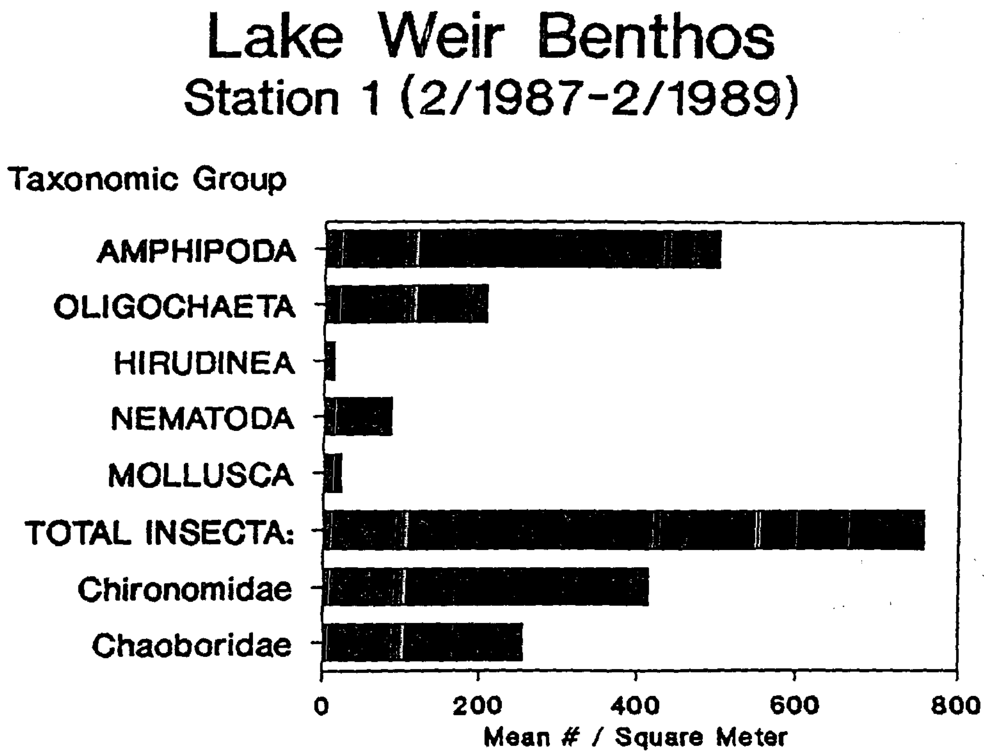
Means underscored by the same line are not significantly different using Duncan's Multiple Range Test (ANOVA; p = 0.05).



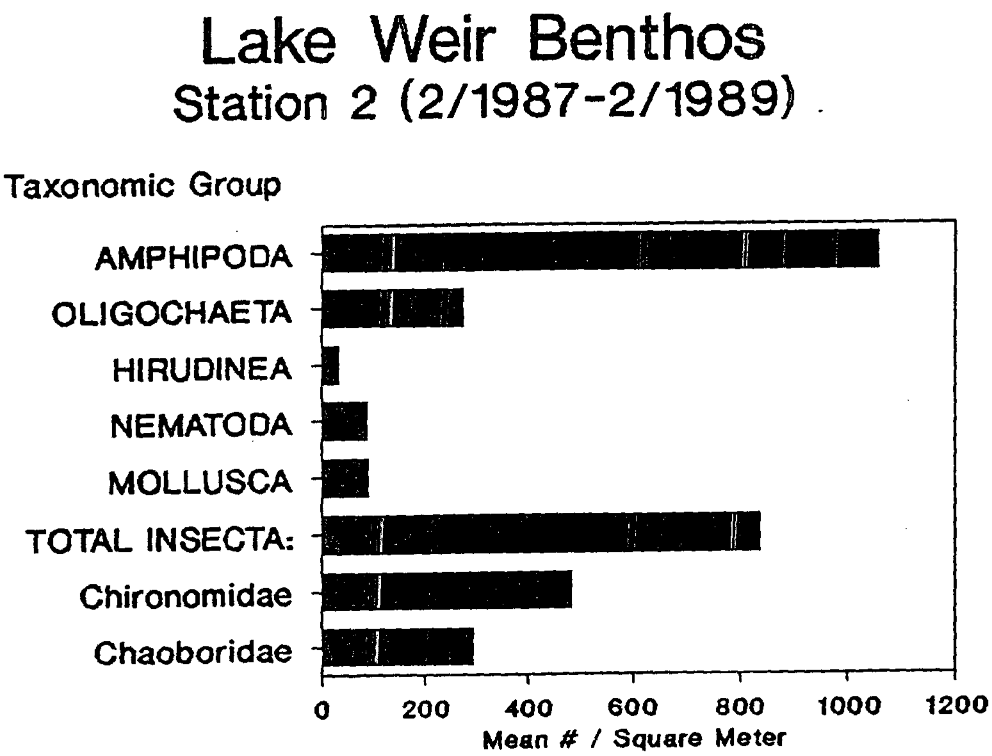
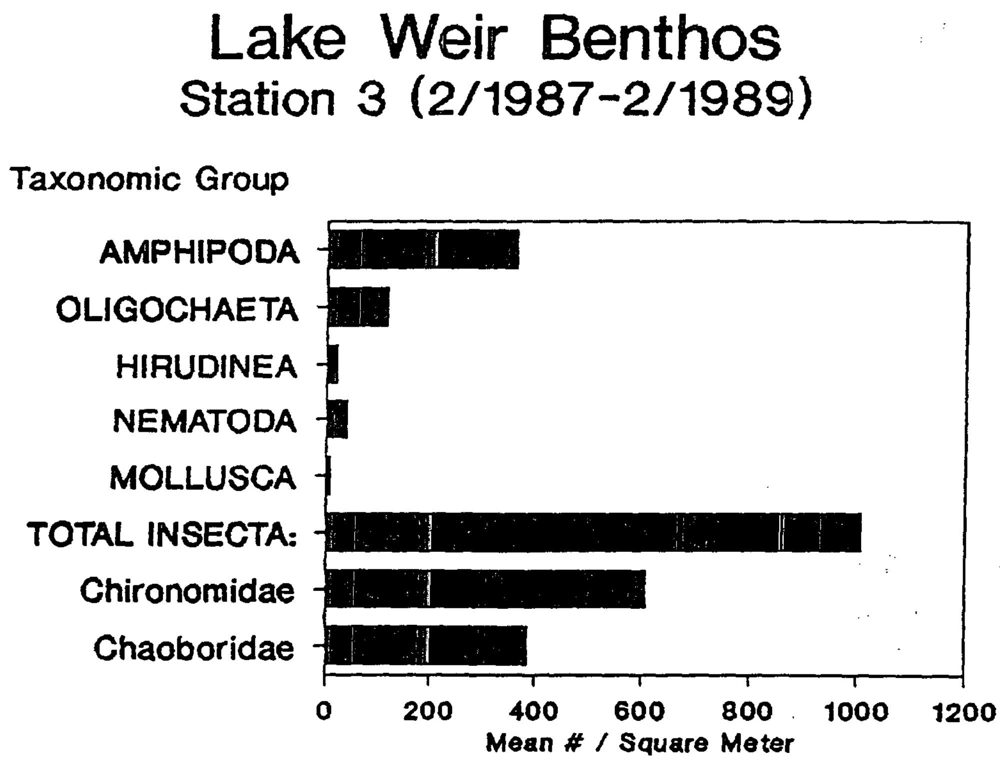


Figure 5-37. Mean biomass of individual benthic invertebrate groups at individual stations of the Lake Weir system for 1987-89.



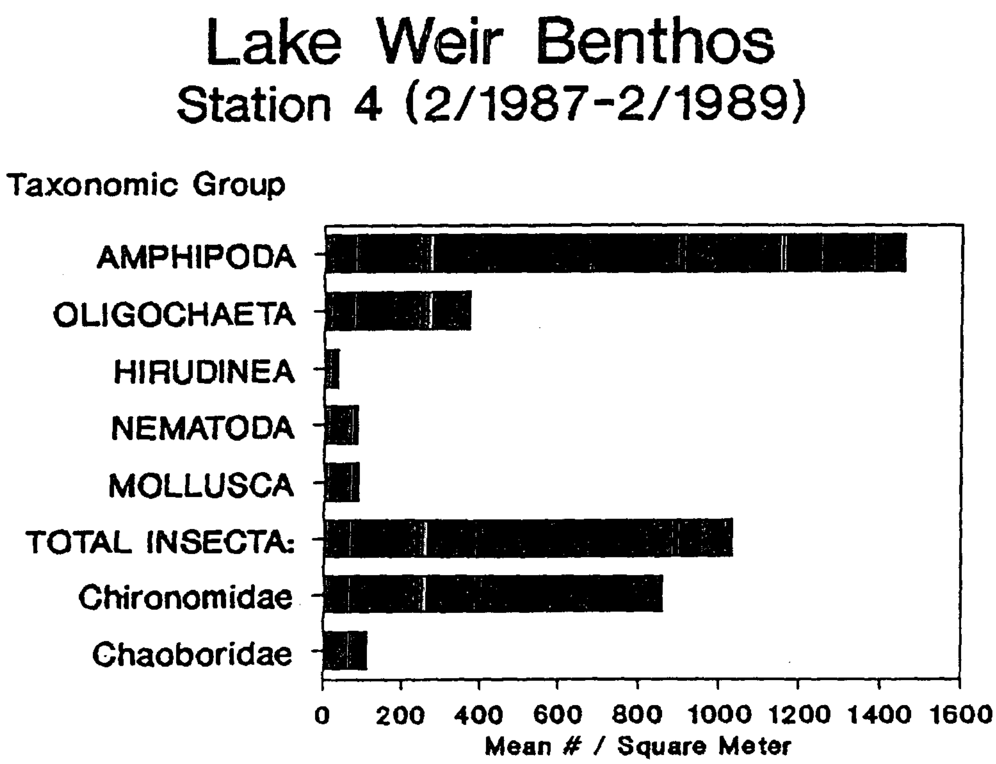
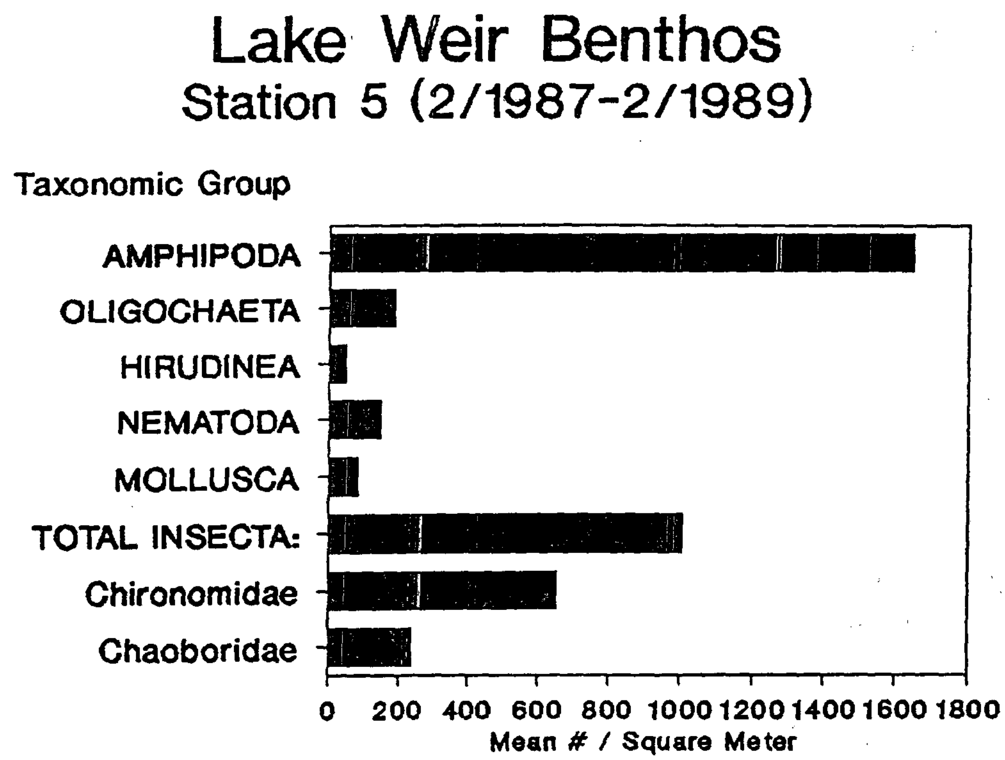


Figure 5-37. Continued.



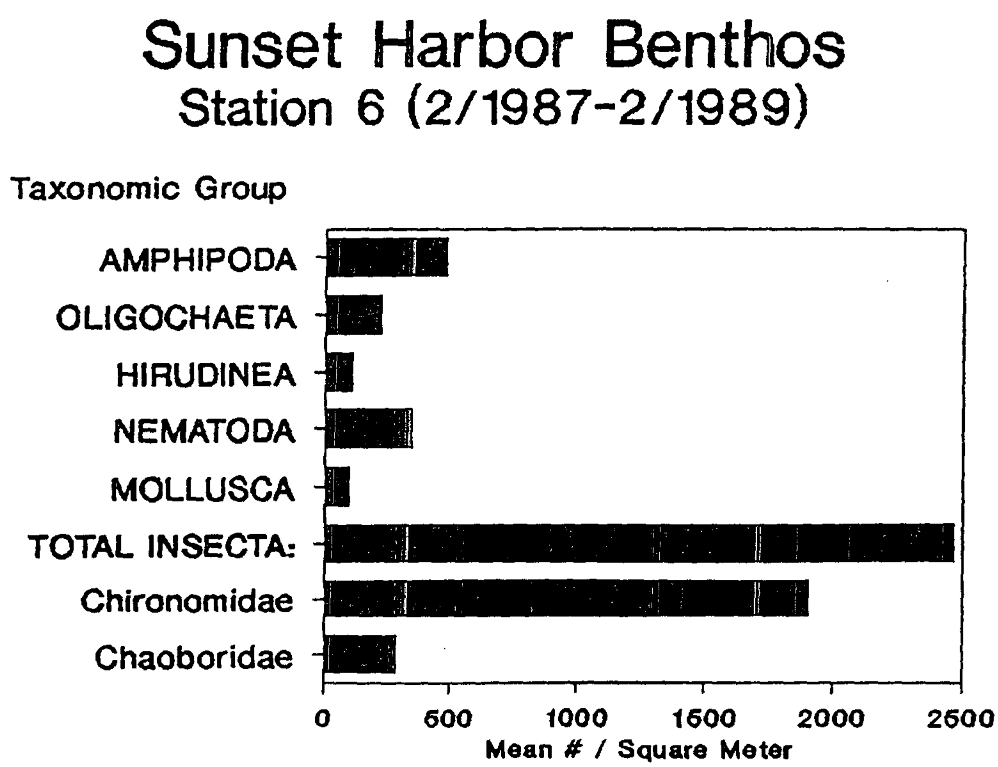


Figure 5-37. Continued.

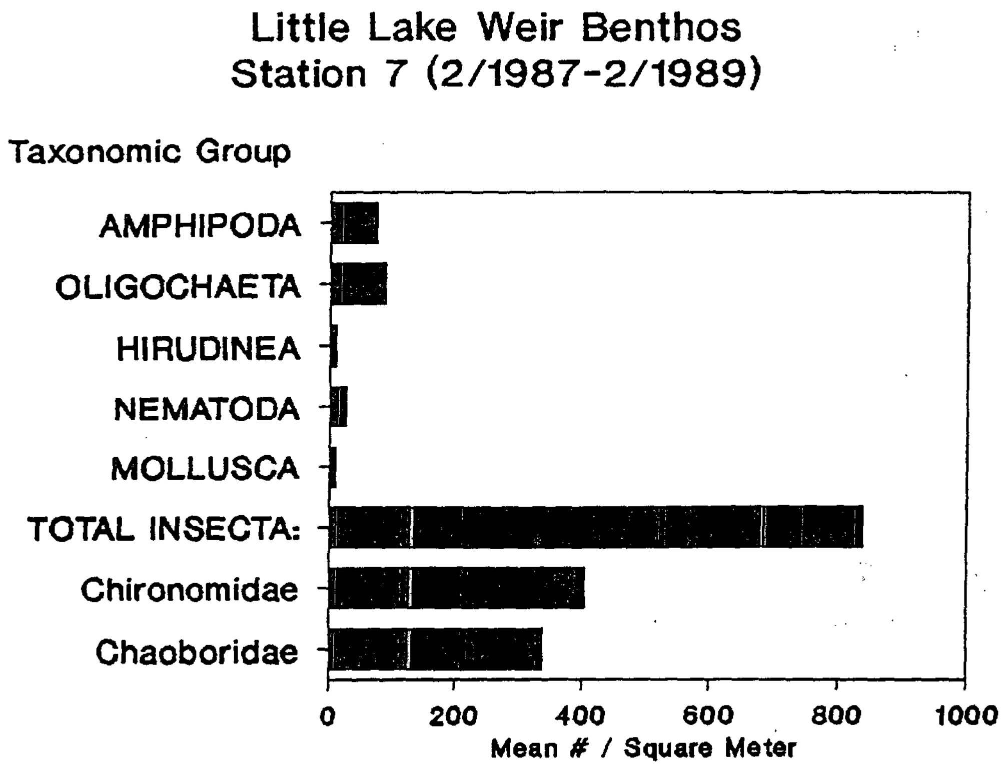


Figure 5-37. Continued.

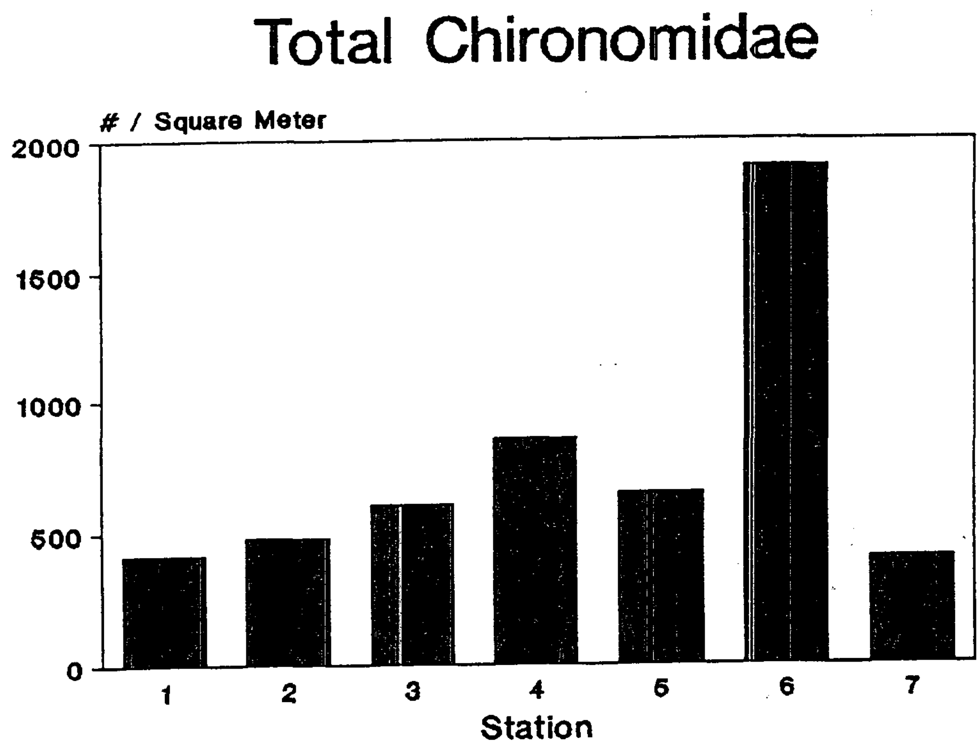


Figure 5-38. Mean biomass of Chironomidae at individual stations of the Lake Weir system for 1987-89.

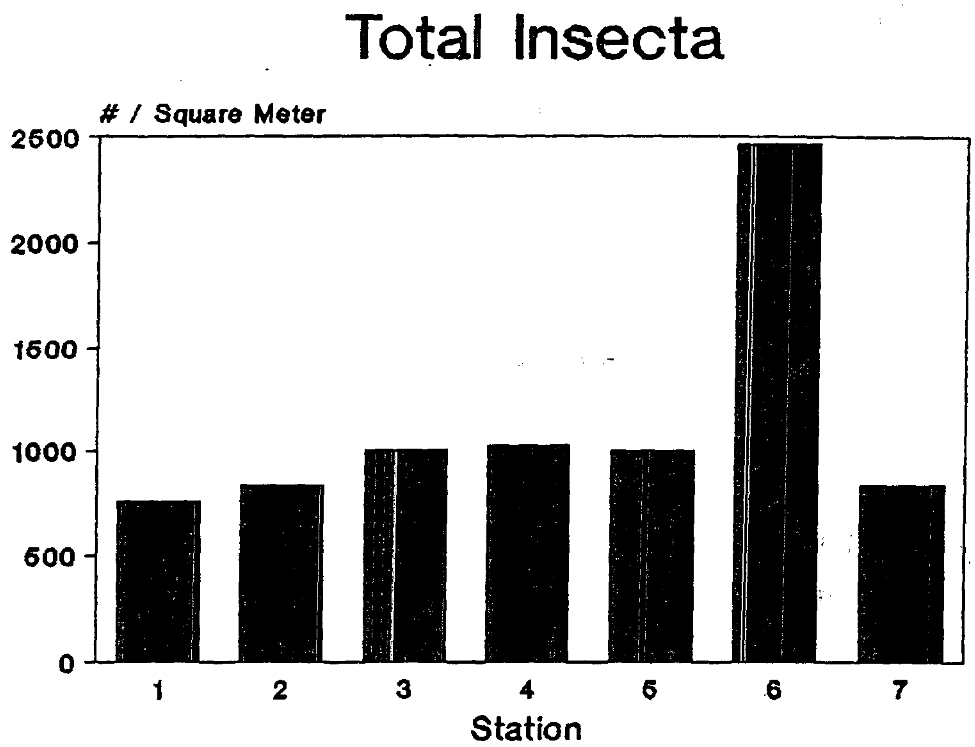


Figure 5-39. Mean biomass of total insecta at individual stations of the Lake Weir system for 1987-89.

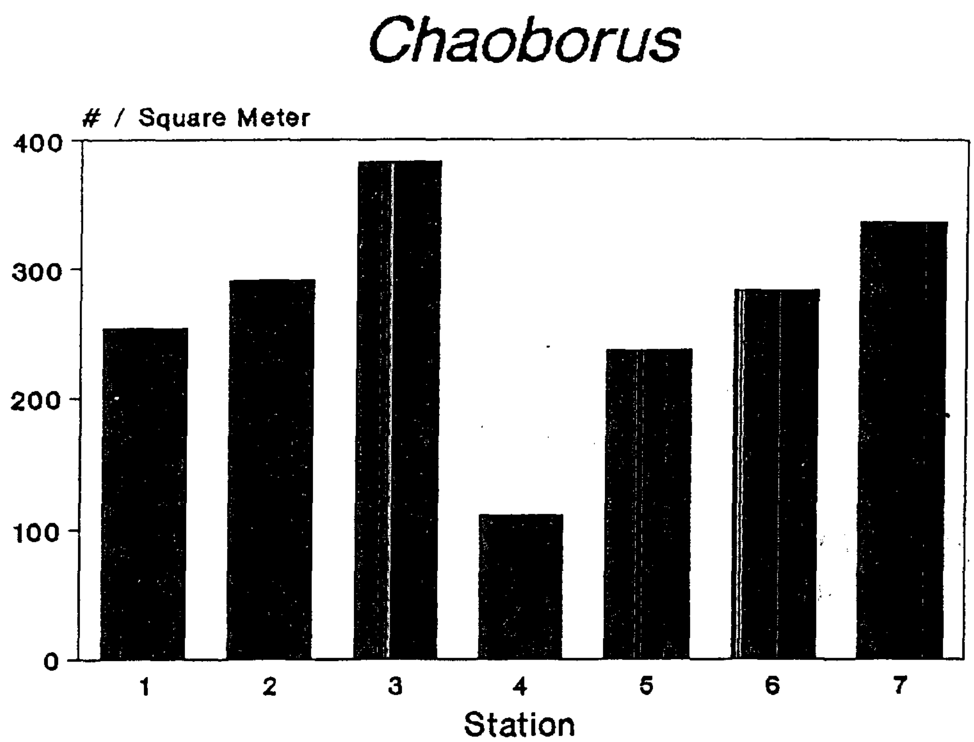


Figure 5-40. Mean biomass of Chaoborus at individual stations of the Lake Weir system for 1987-89.

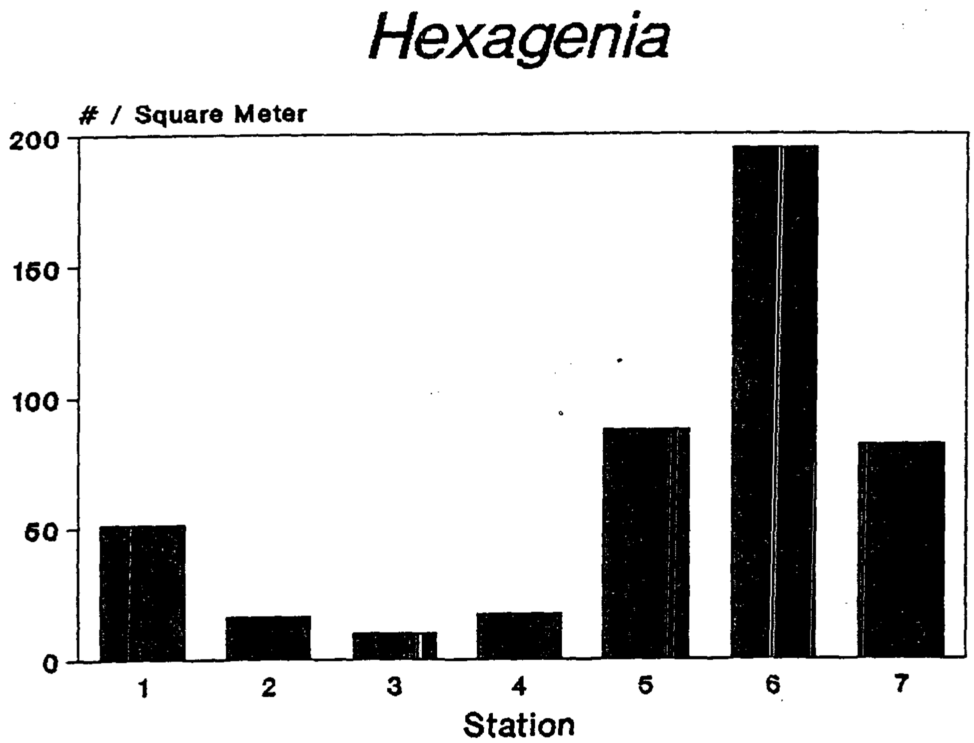


Figure 5-41. Mean biomass of <u>Hexagenia</u> at individual stations of the Lake Weir system for 1987-89.

Hexagenia was most numerous at stations 5, 6, and 7 (Figure 5-41). At station 6, the mean population density of this mayfly was almost $200/m^2$. The abundance at stations 5 and 7 was one-half that of station 6. Although stations 5 and 6 were both shallow and had sandy bottoms, station 7 was deeper and had a loose, "mucky" sediment. Stations 2, 3, and 4 had the lowest abundances of *Hexagenia*.

Amphipods, consisting of *Hyalella*, were most abundant at stations 5, 4, and 2 (Figure 5-42). These stations had the most shallow depths and were all located near littoral zones of Lake Weir. The stations with the lowest densities of amphipods, 3 and 7, were the deepest and the farthest from the shoreline.

Like the chironomids, Hirudinea and Nematoda were most abundant, by far, at station 6. The mean density of Hirudinea at station 6 ($103/m^2$) was double that of station 5 (Figure 5-43). In turn, the similar densities of leeches found at the shallow, sandy stations of Lake Weir (stations 5, 4, and 2) were about double those of the deeper stations 1, 3, and 7. The mean density of nematodes in Sunset Harbor's station 6 ($347/m^2$) was more than double that of station 5--the second highest density (Figure 5-44). Stations 1, 2, and 4 all had Nematoda densities of around $85/m^2$ and were located near the shoreline of Lake Weir. The deep, mid-lake stations 3 and 7 had the lowest densities of nematoda.

The oligochaetes were generally abundant at all stations and were most numerous at station 4 ($370/m^2$, on the average). The mean densities of oligochaetes are lowest at the mid-lake stations 3 and 7 (Figure 5-45). These are the two stations that have an organic "muck" substrate.

Densities of Mollusca--which included gastropods and pelecypods--were very similar at the sandy stations 2, 4, 5, and 6 (Figure 5-46); the mean densities ranged from 84 to $92/m^2$. The mollusc that was collected the most often at stations 2, 4, 5, and 6 was the pelecypod *Elliptio*. Station 1, about 2 meters deeper than stations 2, 4, 5, and 6, had about one-fourth as many molluscs as did those four stations. Stations 3 and 7, with "mucky" substrates, had the minimum densities and were dominated by *Viviparus*, a gastropod.

Macroinvertebrate community structure based on functional feeding groups showed that the collector-gatherer group was the most dominant followed by the predators (Figures 5-47 to 5-50). The filter feeders and the scrapers were the least numerous and comprised less than two percent of the mean total benthos. Although the mean densities of collector-gatherers varied widely among the seven stations (Figure 5-47), their proportion of the mean total benthos

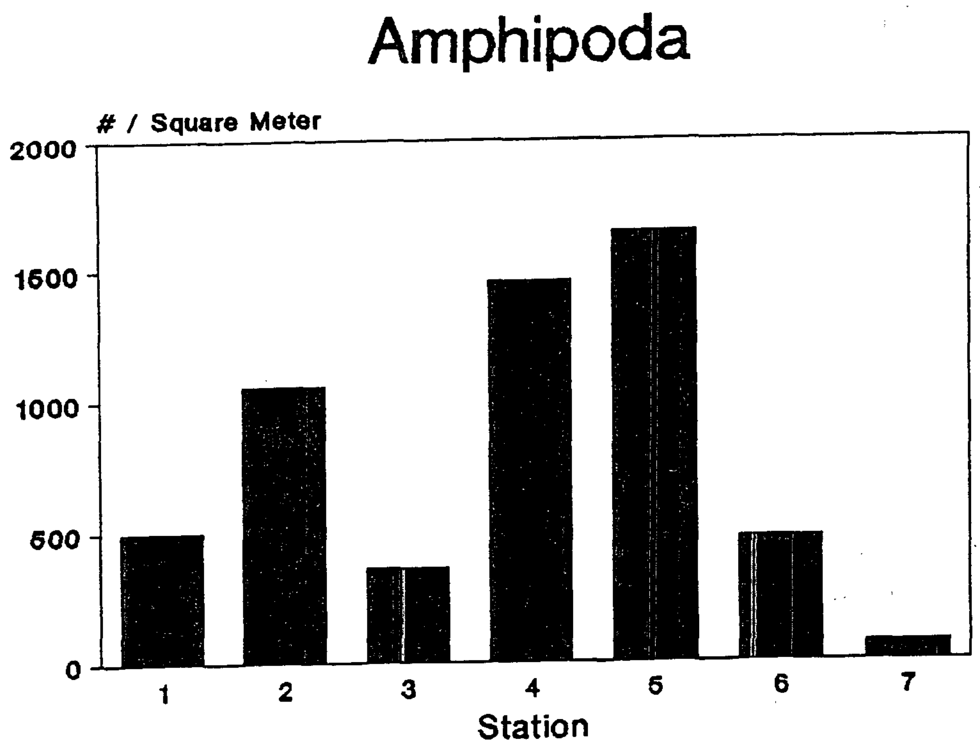


Figure 5-42. Mean biomass of Amphipods at individual stations of the Lake Weir system for 1987-89.

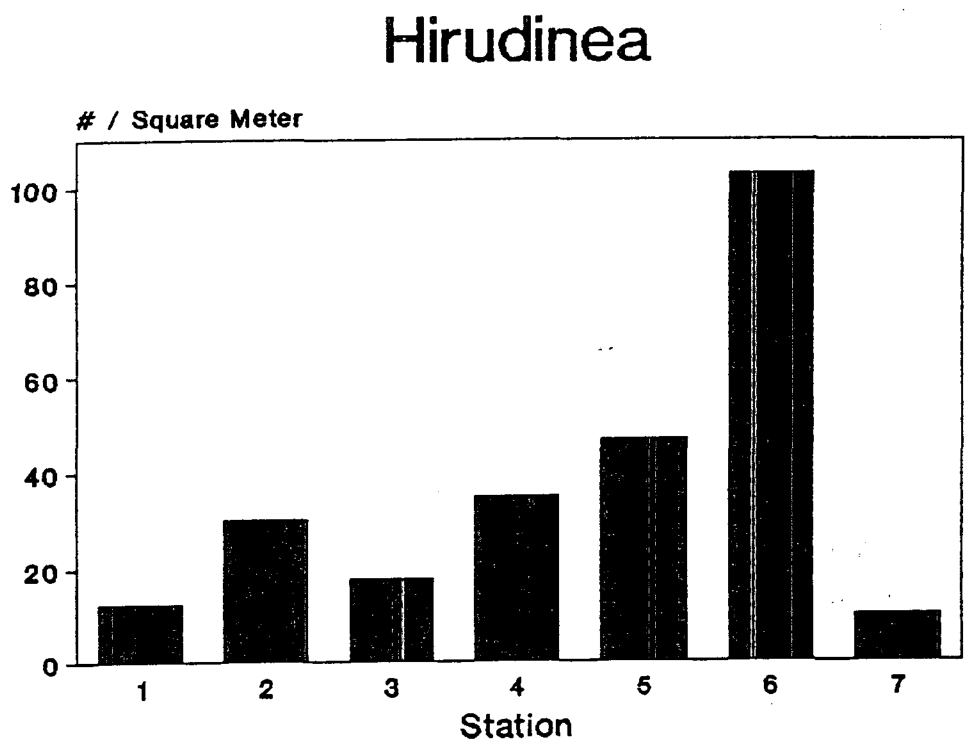


Figure 5-43. Mean biomass of Hirudinea at individual stations of the Lake Weir system for 1987-89.

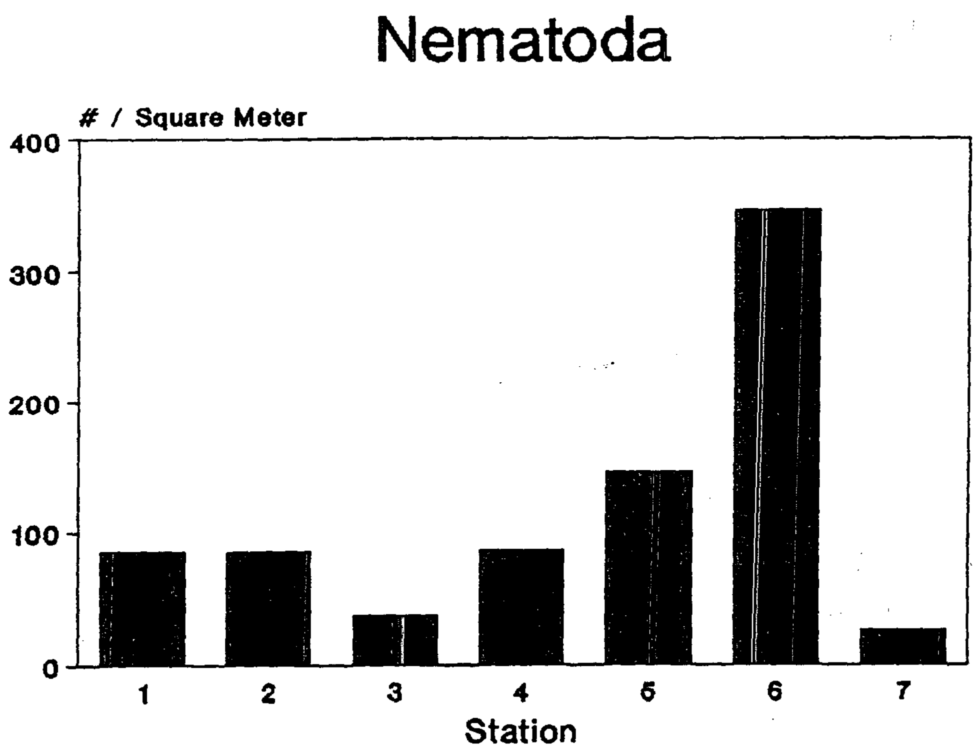


Figure 5-44. Mean biomass of Nematoda at individual stations of the Lake Weir system for 1987-89.

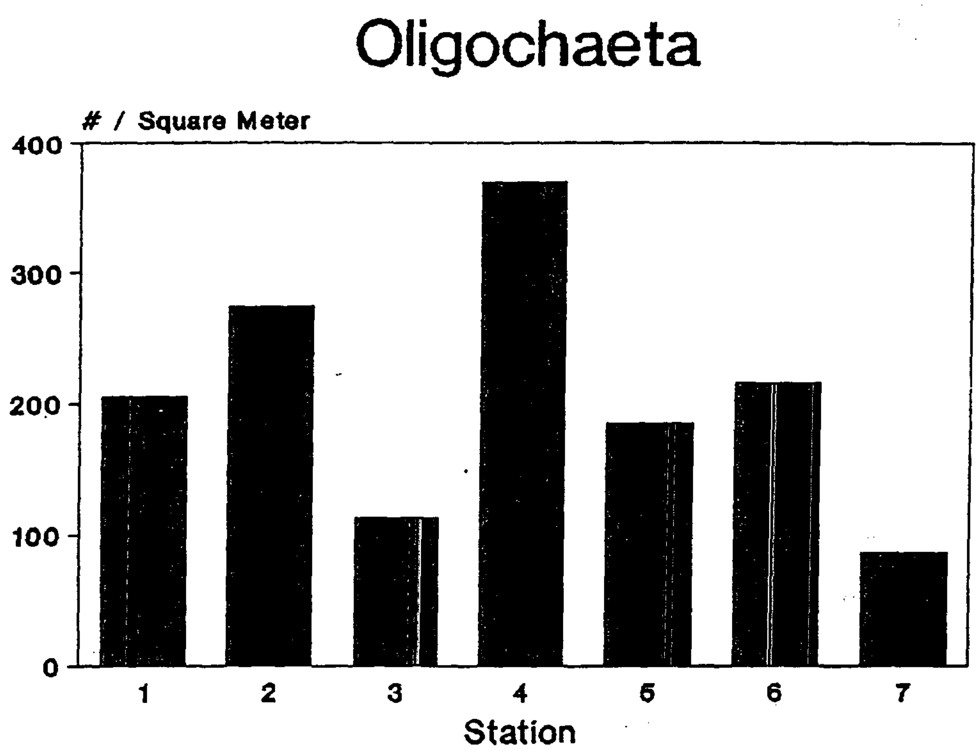


Figure 5-45. Mean biomass of Oligochaeta at individual stations of the Lake Weir system for 1987-89.

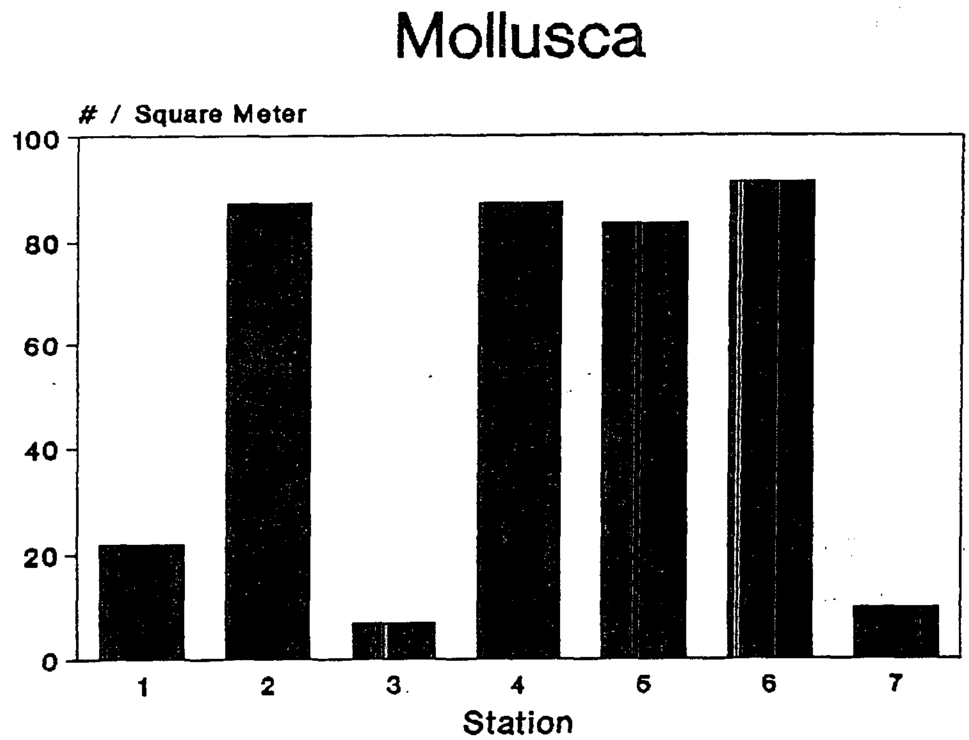


Figure 5-46. Mean biomass of Mollusca at individual stations of the Lake Weir system for 1987-89.

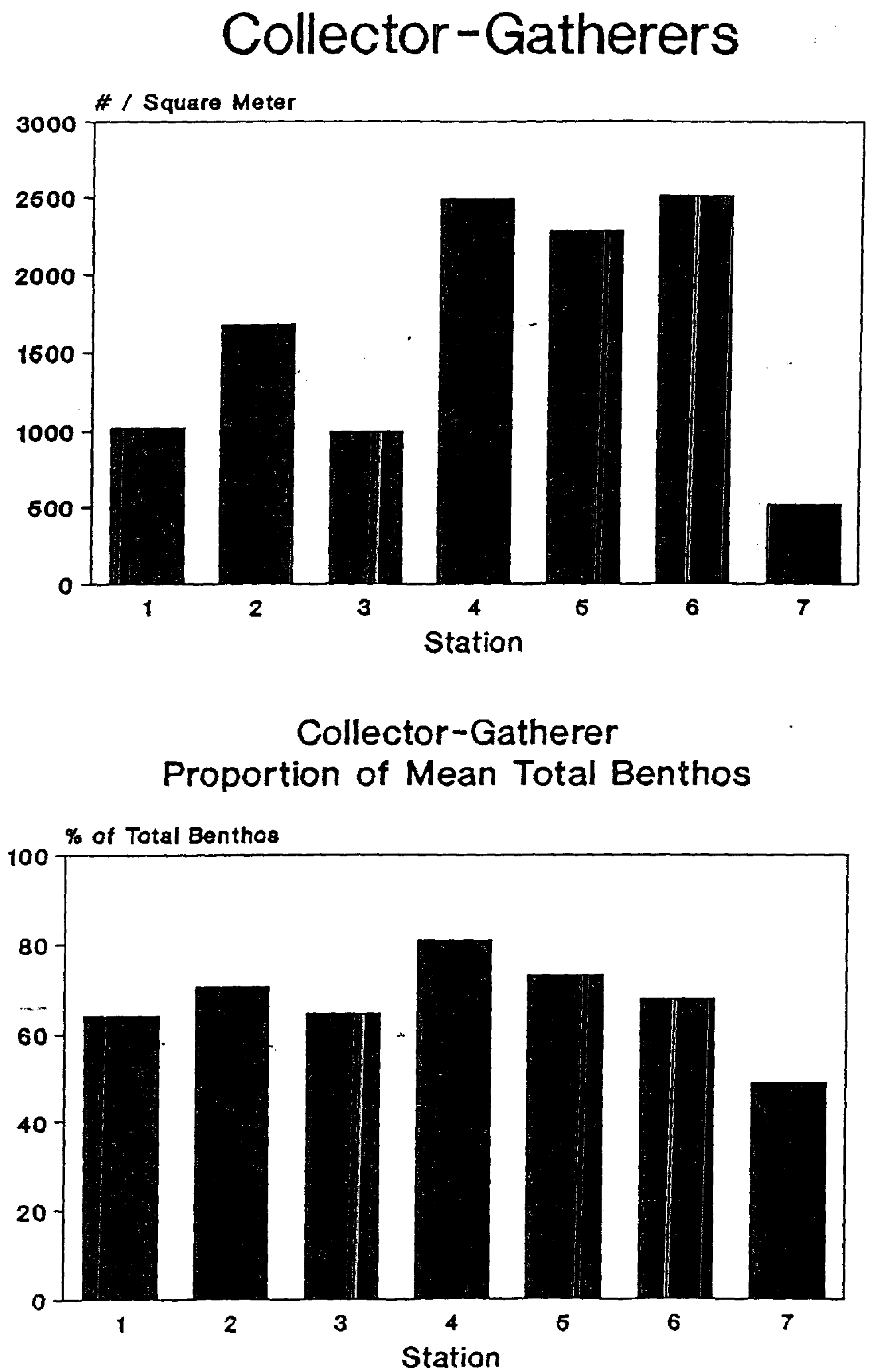


Figure 5-47. Mean biomass of collector gatherers at individual stations of the Lake Weir system for 1987-89.

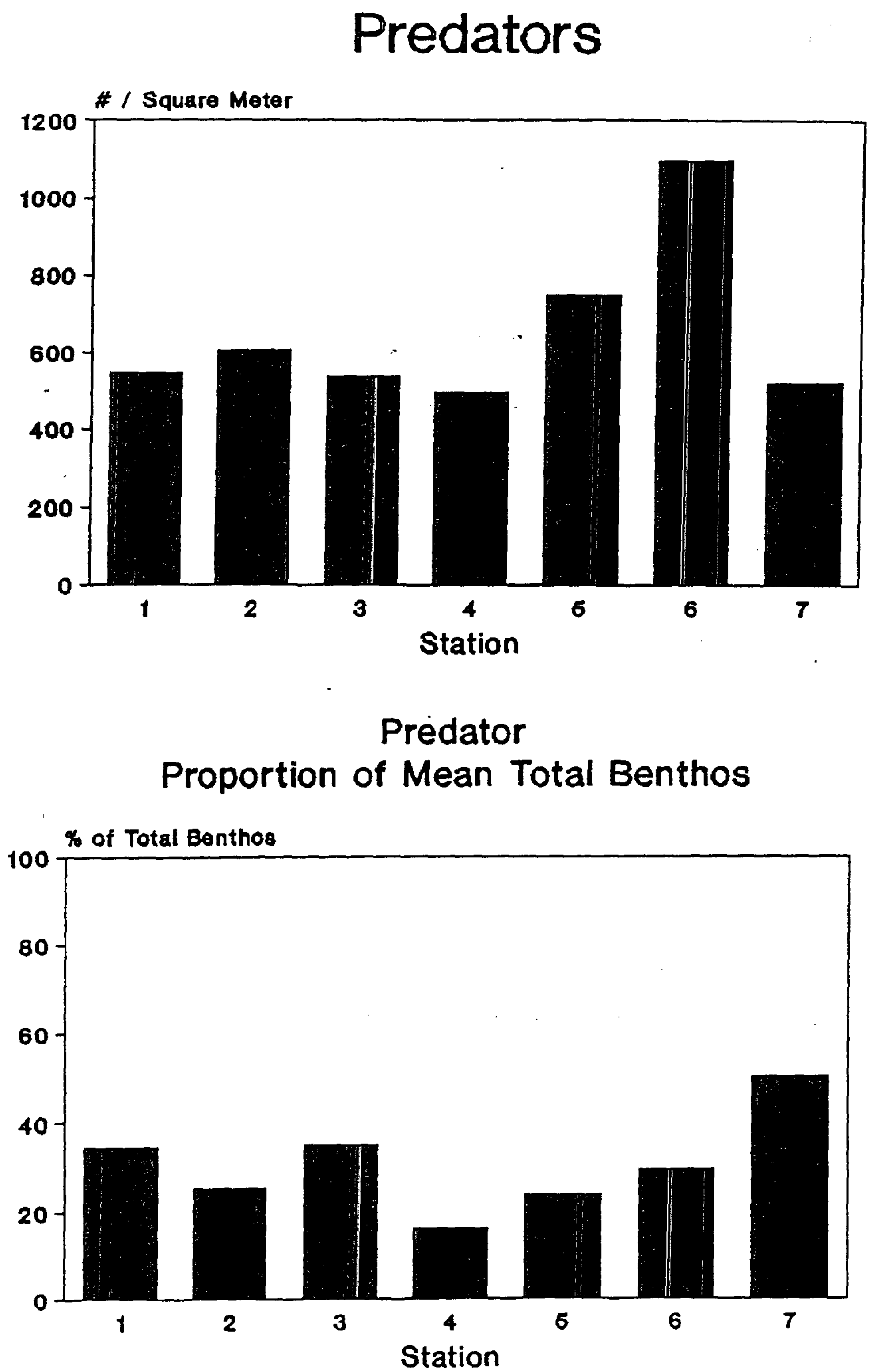


Figure 5-48. Mean biomass of predators at individual stations of the Lake Weir system for 1987-89.

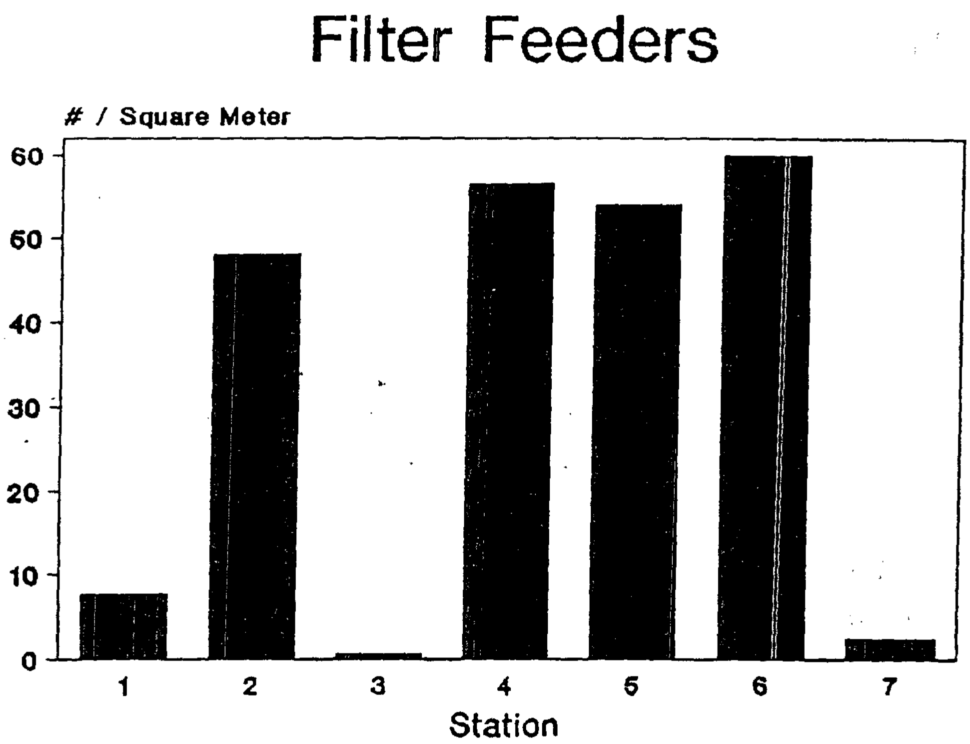


Figure 5-49. Mean biomass of filter feeders at individual stations of the Lake Weir system for 1987-89.

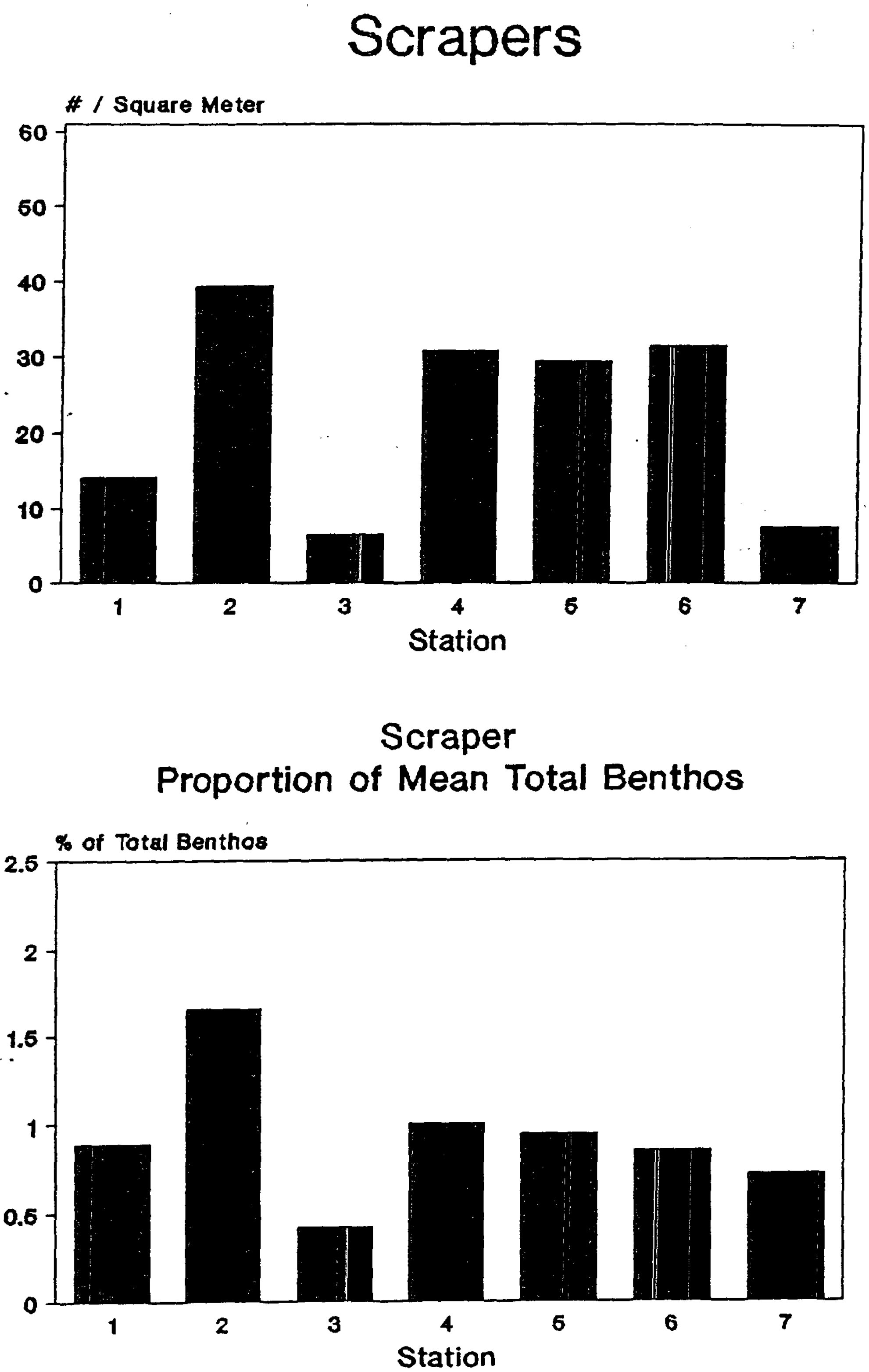


Figure 5-50. Mean biomass of scrapers at individual stations of the Lake Weir system for 1987-89.

for all stations was relatively constant. The mean density of predators at station 6 was very high (Figure 5-48), however, their ratio to the total benthos was similar to other sandy stations because the population of total macroinvertebrate benthos was extremely high in station 6. The predator proportion of total benthos was highest in station 7 (50%); as a result, the collector-gatherer proportion was lowest for station 7 (Figure 5-47).

The main filter feeder collected at the stations was the bivalve Elliptio. This mollusc was abundant only at stations 2, 4, 5, and 6 at densities of around 50 to 60/m^2 (Figure 5-49). At these stations, the proportion of filter feeders to total benthos was between 1.5 and 2%. Although these percentages were relatively low, they resulted from population densities only; the biomass of most Elliptio individuals was the largest encountered and probably dominated the benthic biomass at stations 2, 4, 5, and 6. However, being filter feeders, adult Elliptio individuals do little feeding on the other benthic organisms and should not directly affect their populations.

As with collector-gathers and filter feeders, scrapers were most abundant at stations 2, 4, 5, and 6 (Figure 5-50). These were the most shallow stations and were not deeper than 5 meters. The proportion of scrapers to total benthos was highest at station 2 (1.7%). Although the density of scrapers at station 1 was less than half that of stations 4, 5, or 6, the proportion at station 1 (0.9%) was about the same as stations 4, 5, and 6. Stations 1, 2, 4, and 5 were all near the shoreline and near extensive areas of submerged macrophytes. Scrapers need large surfaces of matter to feed upon and pieces of macrophytes would have provided this matter. The density and proportion of scrapers was lowest at station 3, about 2 kilometers from the nearest shore of Lake Weir.

5.5.C SEASONALITY

The seasonality of collector-gatherers in Lake Weir was similar to that of Sunset Harbor (Figure 5-51). Highest densities occurred about June and January, while the lowest densities were found around September. Except for the first two sampling months (February and March 1987), the densities of collector-gatherers in Little Lake Weir were low. Small increases in densities occurred during winter months in Little Lake Weir.

Predator seasonalities in Lake Weir, Sunset Harbor, and Little Lake Weir were similar (Figure 5-52). Highest

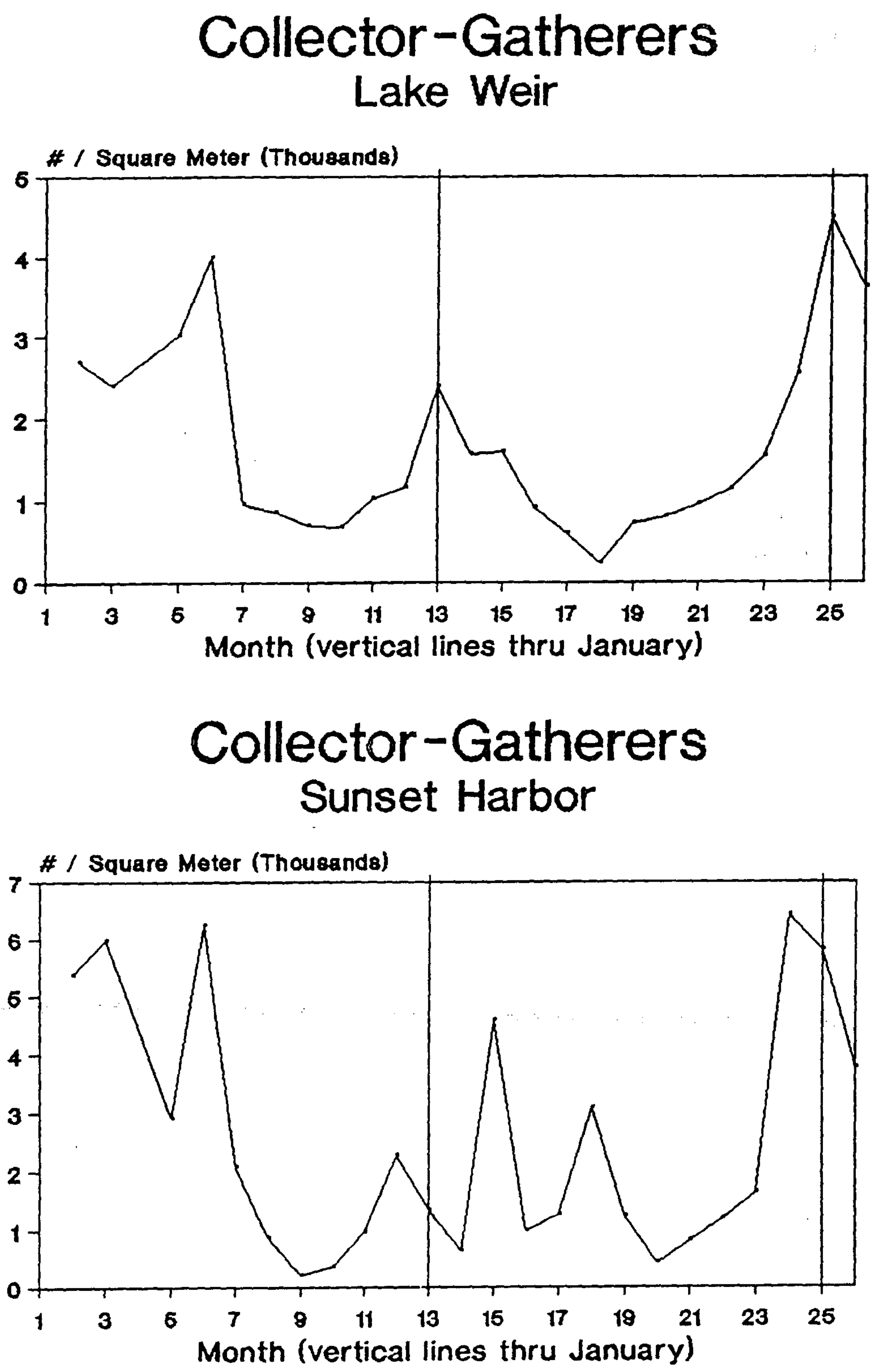


Figure 5-51. Mean biomass of collector-gatherers at three stations for individual months.

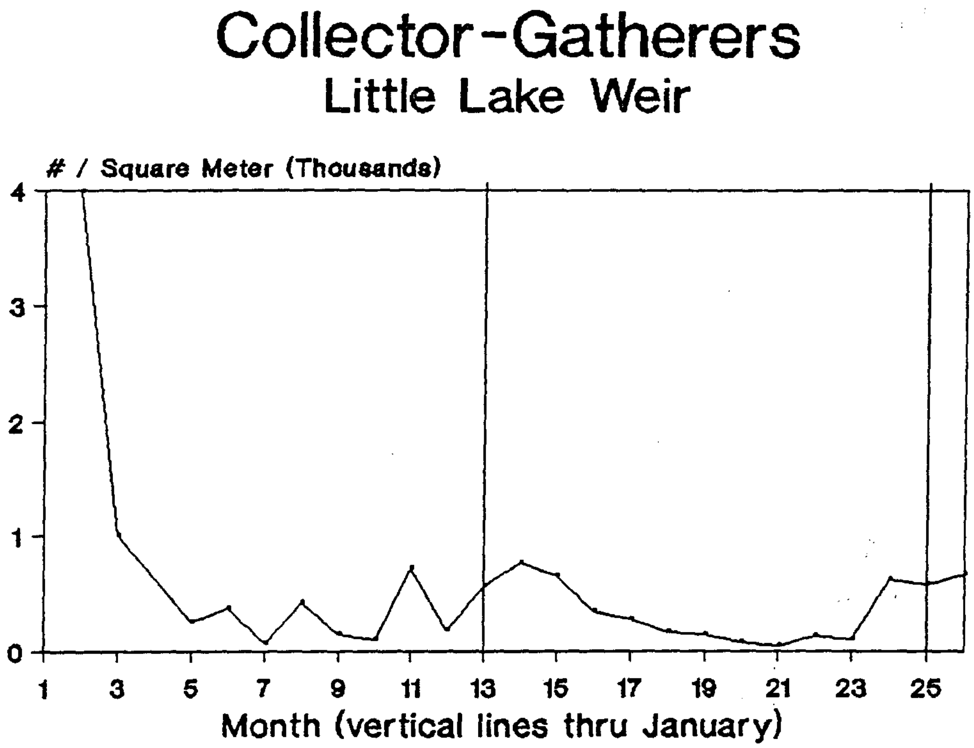
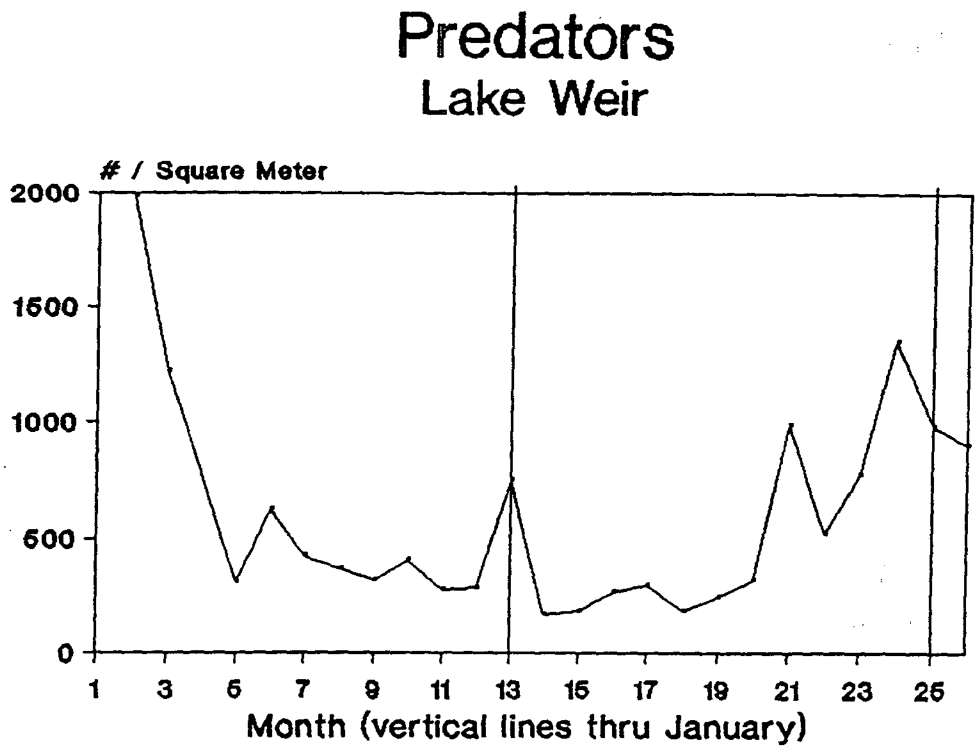


Figure 5-51. Continued.



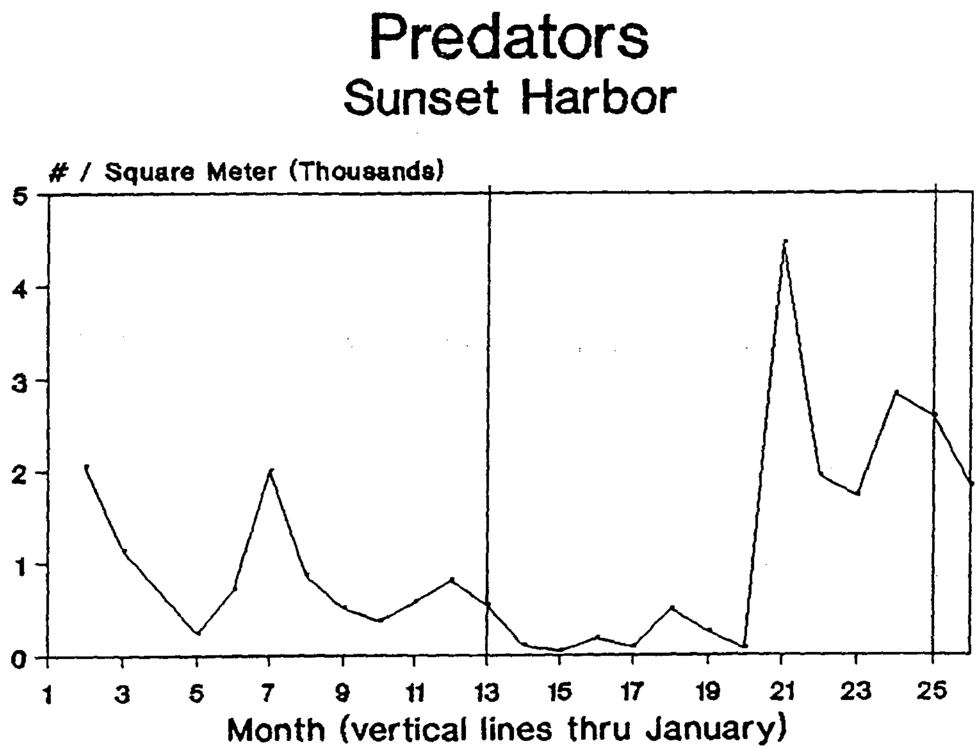


Figure 5-52. Mean biomass of predators at three stations for individual months.

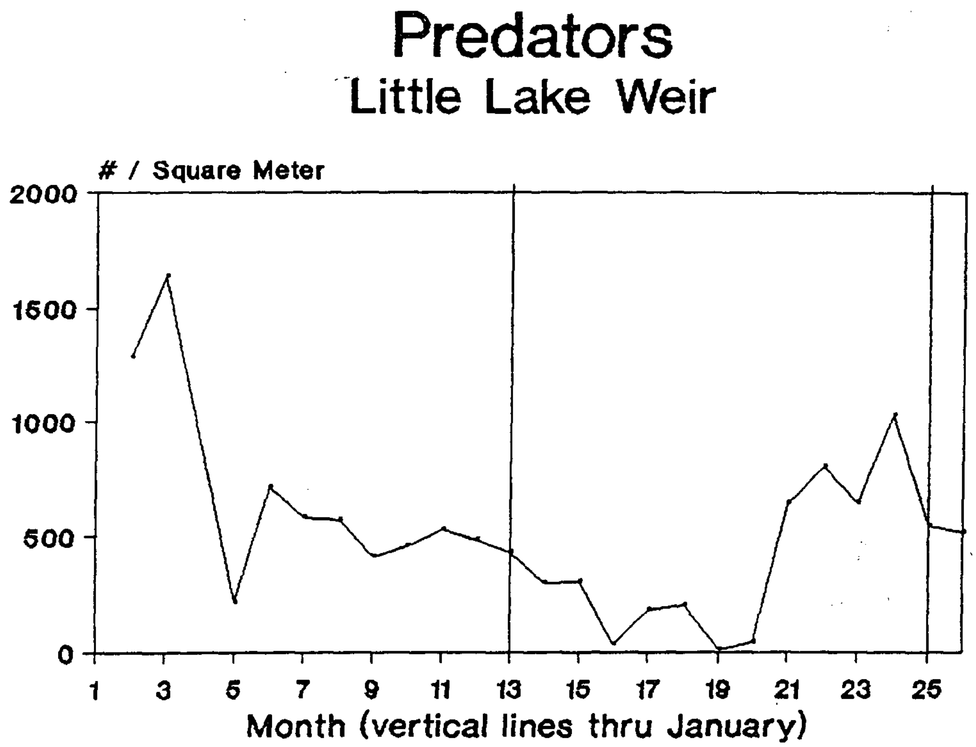
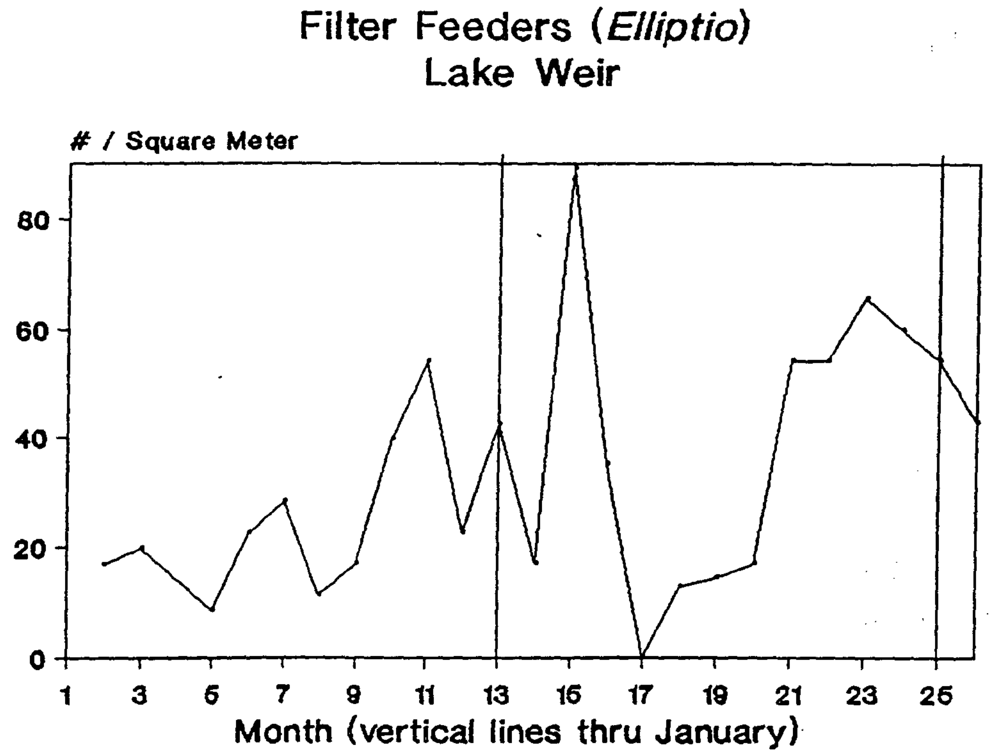


Figure 5-52. Continued.



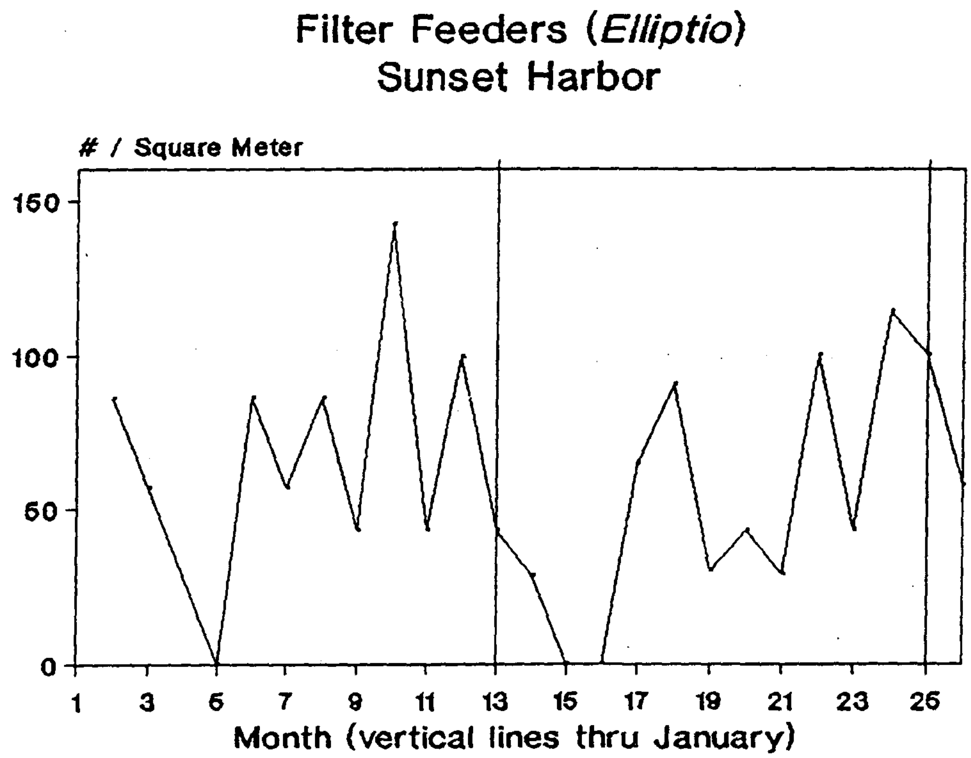


Figure 5-53. Mean biomass of filter feeders at three stations for individual months.

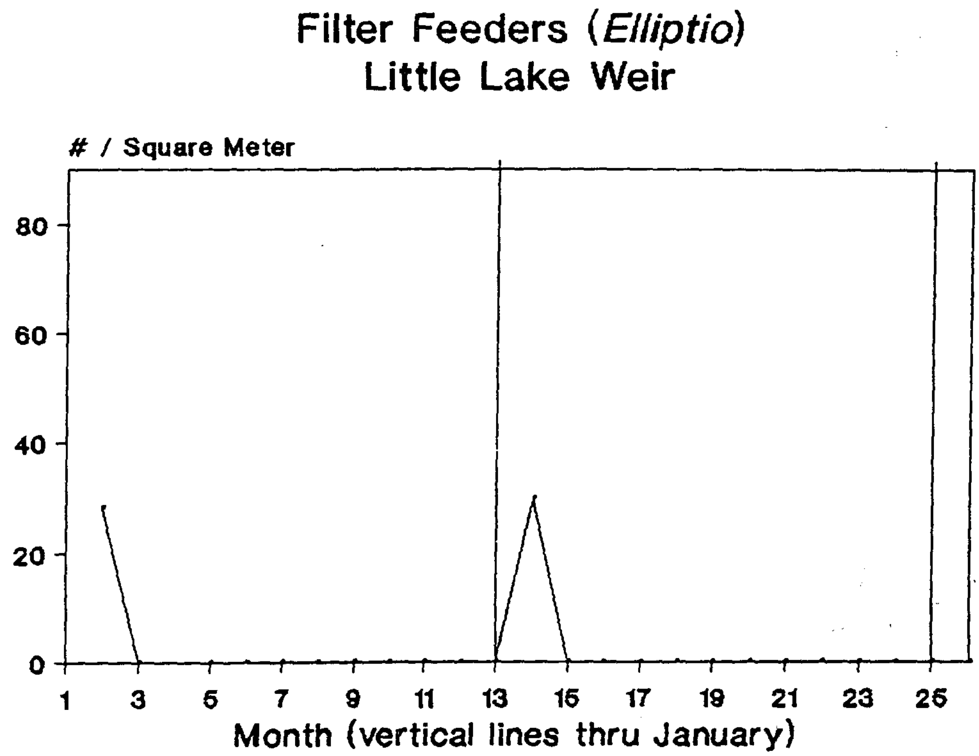


Figure 5-53. Continued.

densities occured during the spring of 1987 and the fall of 1988. Low densities of predators existed in all three bodies of water from about February to August in 1988.

The measured densities of filter feeders varied substantially month by month in Lake Weir and Sunset Harbor (Figure 5-53). Still, a general increase in densities occured around the fall in 1987 and 1988 in both basins. The only time Elliptio was encountered in Little Lake Weir was during the month of February.

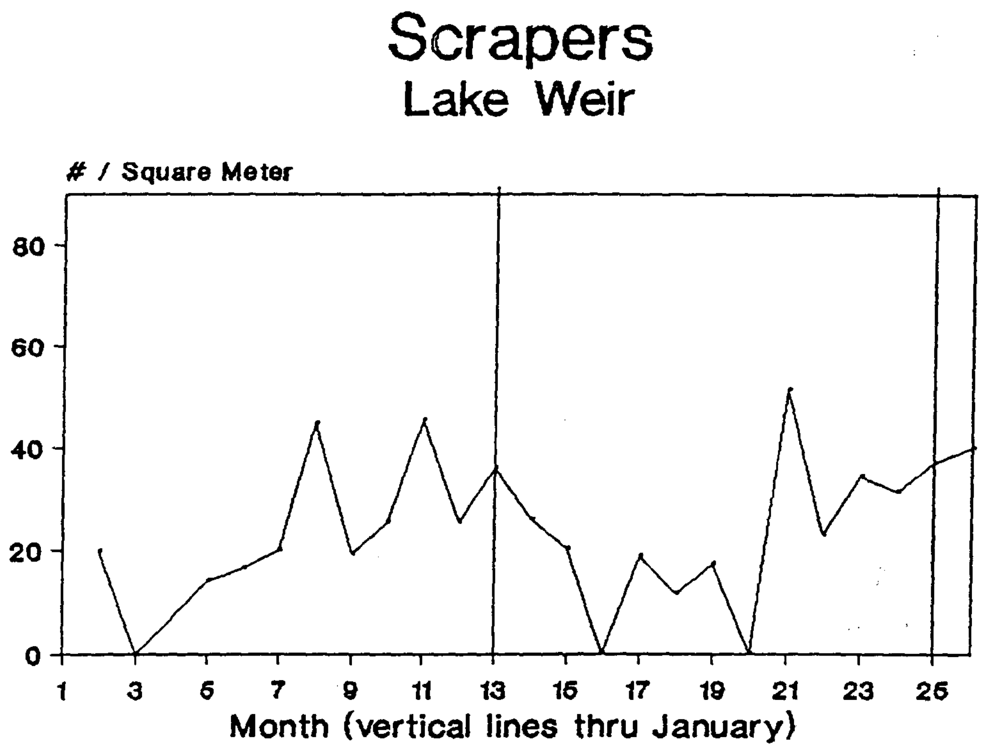
As with the filter feeders, the densities of scrapers changed greatly over four week periods (Figure 5-54). Part of this variability might have been due to the low numbers of individuals collected every month. In Lake Weir, highest densities occured during late summer and fall. Higher densities were found in Sunset Harbor during the two fall seasons. Scrapers were found in Little Lake Weir around the summer and winter but were absent during the last eight sampling months.

The seasonality of the total benthic macroinvertebrate community in Lake Weir was roughly similar to the seasonality in Sunset Harbor (Figure 5-55). In Lake Weir, high benthic populations occurred during the late fall and winter with peaks in January. After the spring, abundance declined during the summer and minima were found in June and September. After September, densities steadily increased. Like Lake Weir, benthic densities in Sunset Harbor were high during the winter and spring of 1987 and then again during the winter of 1988-89. The minimum densities in Sunset Harbor occurred in August (1988) and September (1987). Although Sunset Harbor had higher densities than Lake Weir, its population levels changed more dramatically, especially in 1988.

In Little Lake Weir, benthic densities also reached minimum levels during the summer (Figure 5-55). Densities were always relatively low and below $1,500/m^2$ except during the first two winter months of sampling. Slight increases in populations were seen during both fall seasons.

The seasonalities for Chironomidae in the three basins of the Lake Weir system were different (Figure 5-56). In Lake Weir, maximum densities about three times higher than average occurred around January. During the following winter months, the population levels of Chironomidae tapered off; a sharp drop was measured during February and March, 1988. Minimum densities occurred during the summer, particularly in July or August. During the fall of 1988, the population of midges steadily increased until it peaked in December and January.

Sunset Harbor had much denser populations of



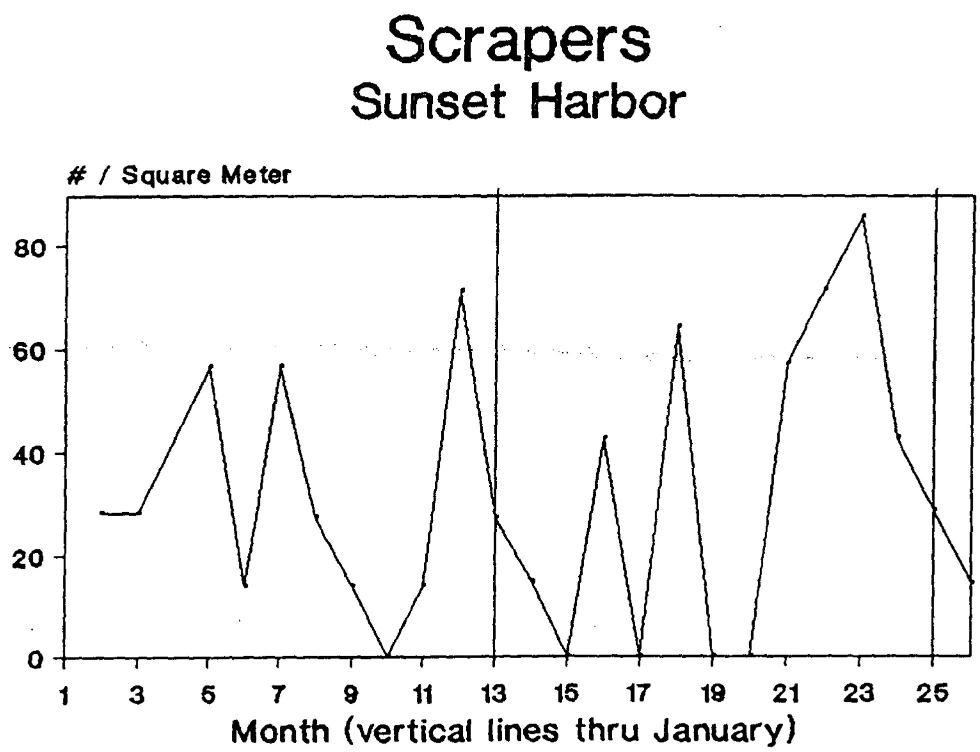
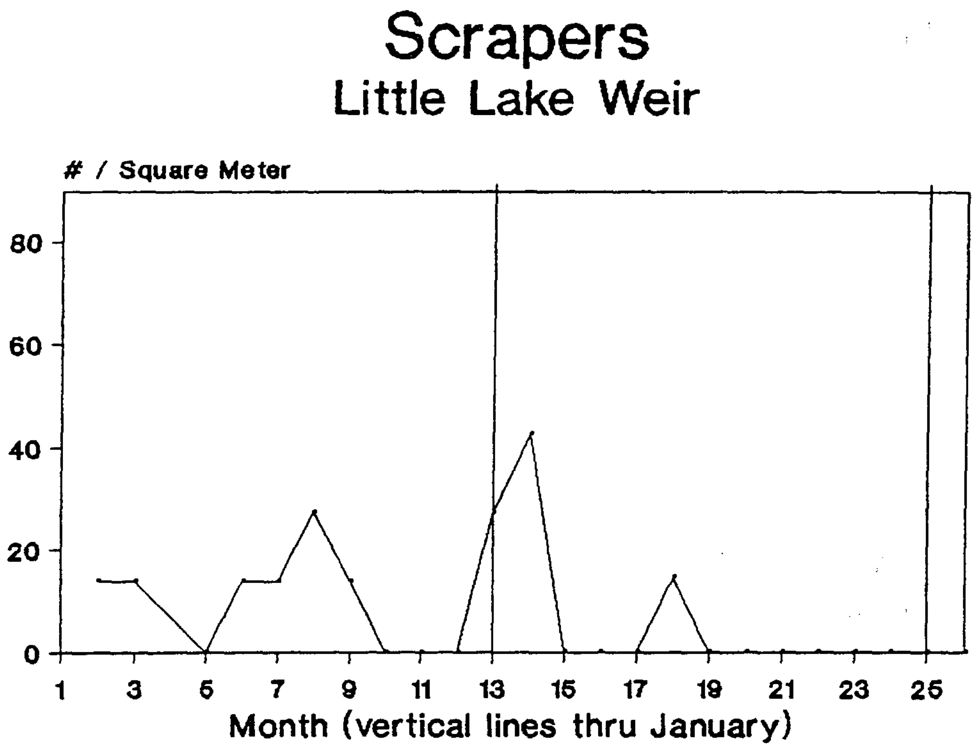


Figure 5-54. Mean biomass of scrapers at three stations for individual months.



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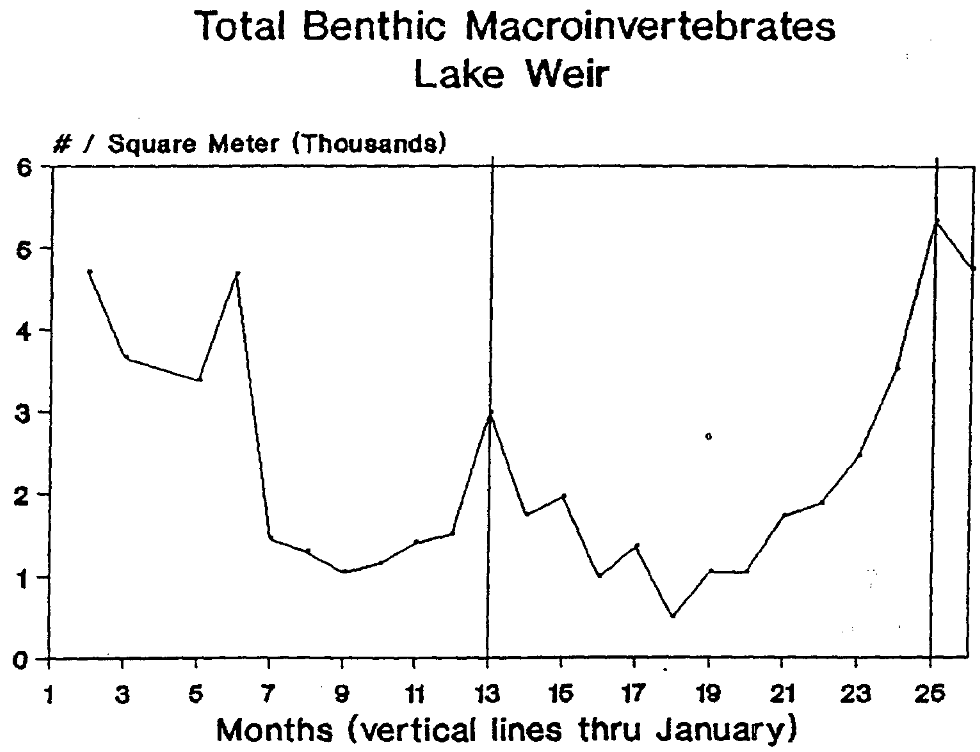


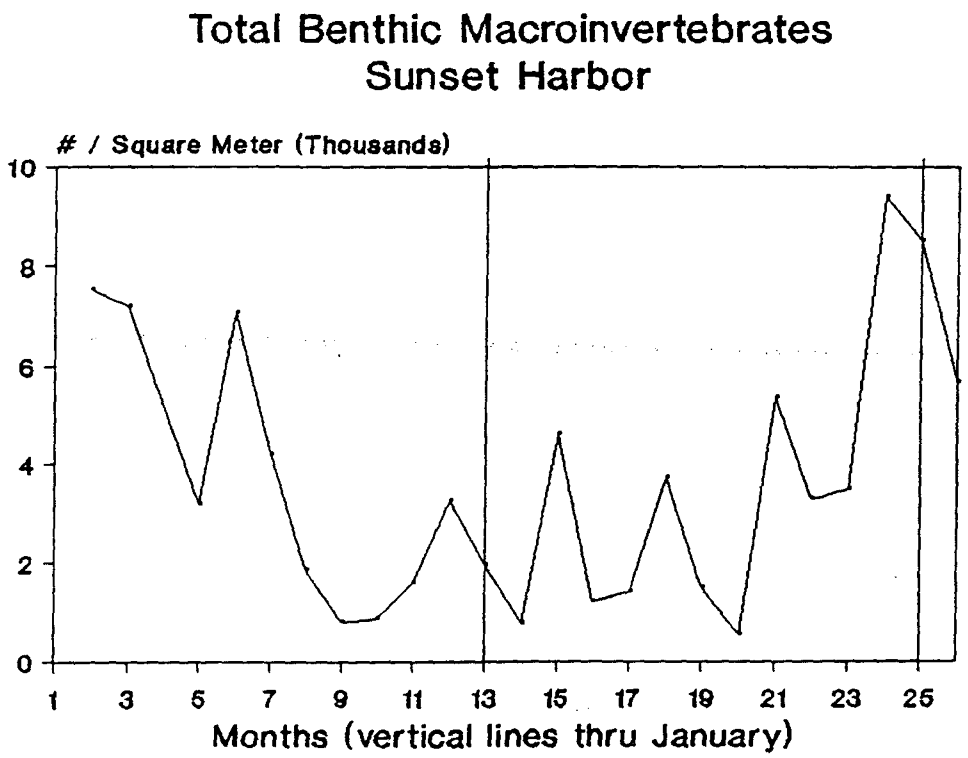
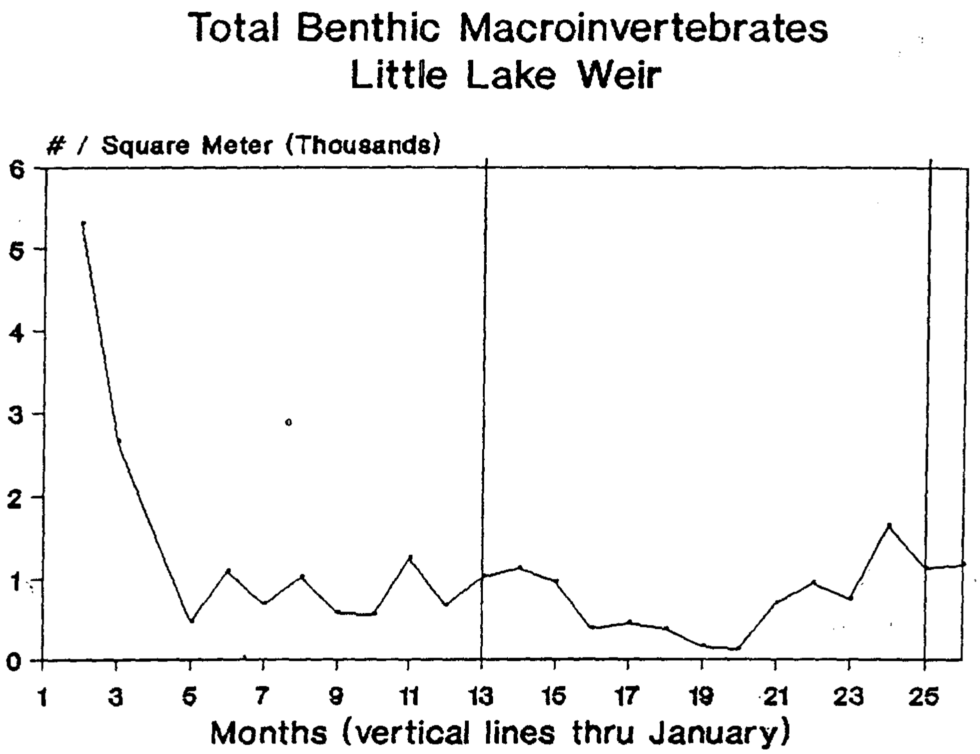


Figure 5-55. Mean biomass of total benthos at three stations for individual months.



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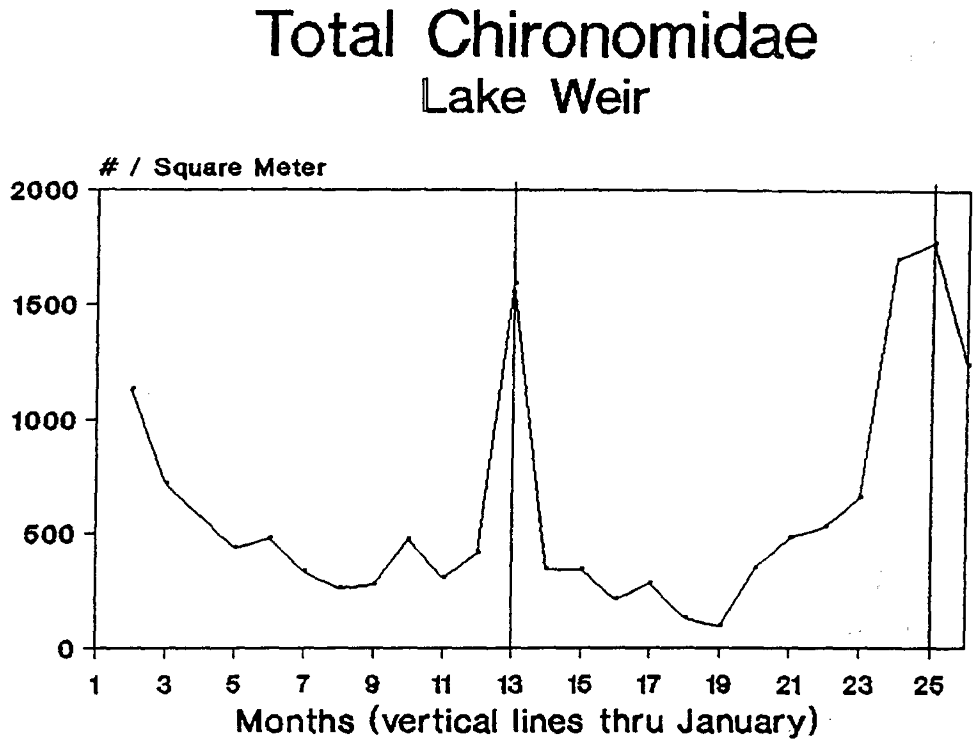


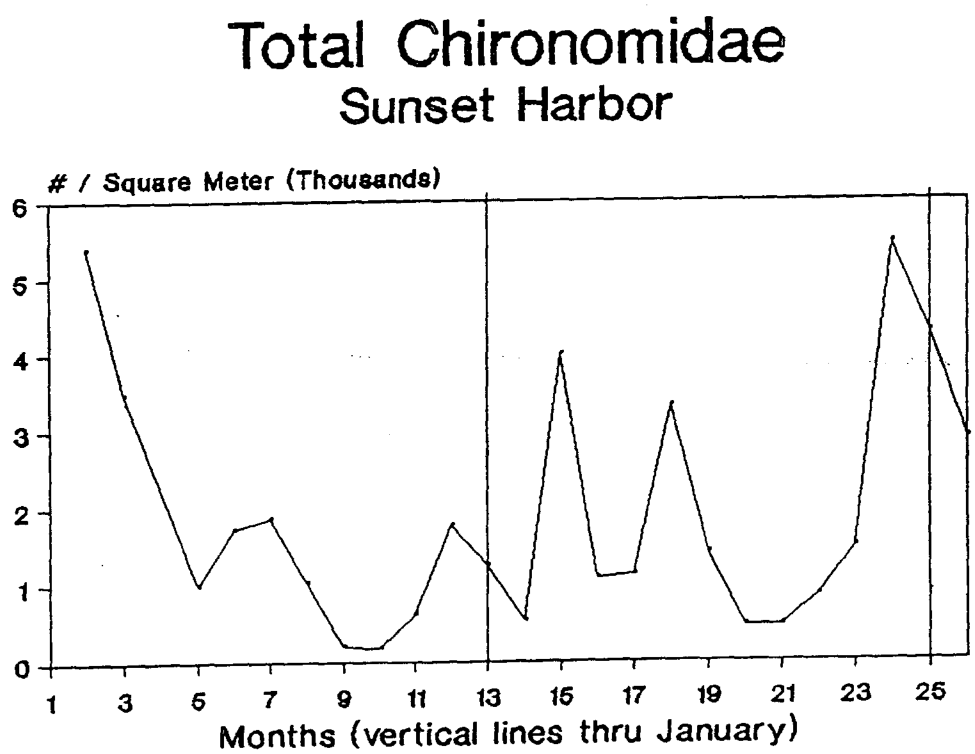


Figure 5-56. Mean biomass of Chironomidae at three stations for individual months.

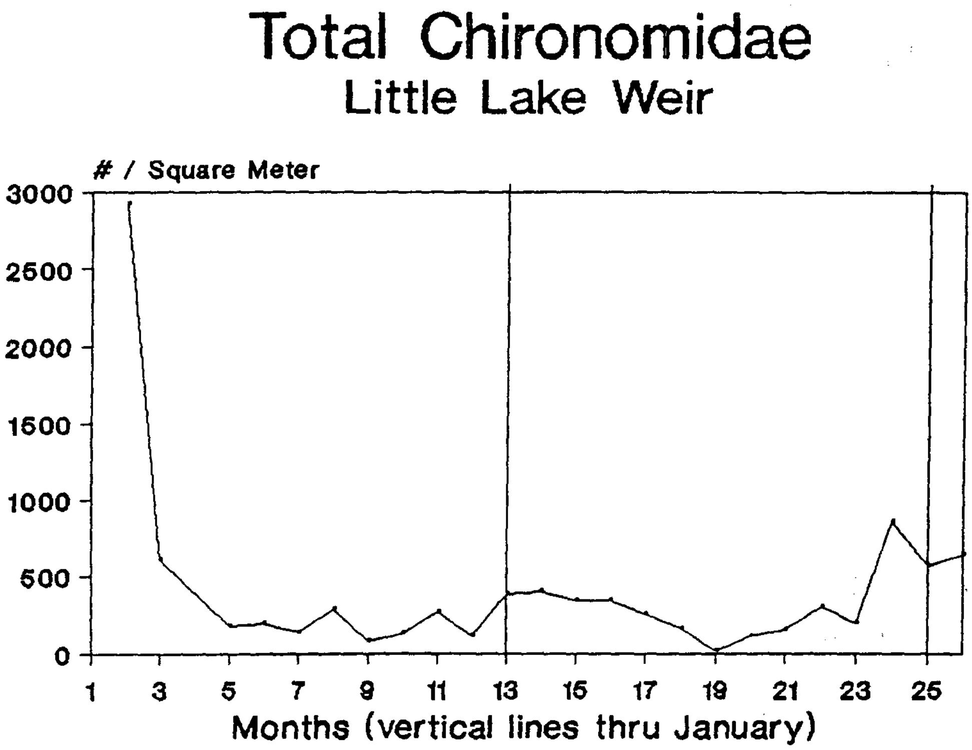


Figure 5-56. Continued.

chironomids than Lake Weir (Figure 5-56). The minimum densities in Sunset Harbor occurred a few months later than Lake Weir and were low for a distinct two month period around September. Densities increased the following months until they peaked in December. Generally, maximum populations for the year occurred during the winter. Then, by May, the Chironomidae density dropped to around $1000/m^2$ but, later, increased again to reach a temporary peak in June or July.

After the first sampling month, chironomid densities in Little Lake Weir were all below $1000/m^2$ (Figure 5-56). Minimum densities at station 7 occurred in July or September. Maximum densities of Chironomidae were found during both winters.

Members of three different Chironomidae subfamilies were found in the Lake Weir system. Only a few individuals of the subfamily Orthocladiinae were found (Figure 5-57). They were discovered only in Lake Weir and only in the fall and winter of 1988-89. Representatives of the subfamily Tanypodinae were always found in Lake Weir and were common also in Sunset Harbor and Little Lake Weir. Still, most of midge larvae belonged to the subfamily Chironominae and its two tribes, Chironomini and Tanytarsini.

The seasonality of Tanypodinae at Lake Weir's five stations was comparable to that of Little Lake Weir but not Sunset Harbor (Figure 5-58). Populations in Lake Weir and Little Lake Weir were generally high in late fall and winter but low in spring and summer. In Lake Weir, maximum densities occurred in January or February (as during 1987, 1988, and 1989). Afterwards, the level dropped tremendously in one or two months. The abundance remained low during the spring and summer until around September when a pulse occurred. Following a brief drop after the pulse, the winter maximum was quickly reached. This maximum density was more than double the yearly average and in 1989 was $500/m^2$.

The population density of Tanypodinae was high in Little Lake Weir in February 1987 but gradually declined through spring. After a low in mid-summer, a pulse occurred by October and population levels oscillated over the next six months. In the spring and mid-summer of 1988, very low densities were measured. Then, by September, the population level jumped up and a maximum was reached in December 1988.

Unlike the other two basins, spring and summer were not the seasons when minima occurred in Sunset Harbor (Figure 5-58). Extreme variablity in the population level occurred during both years. The main distinguishing feature was the low abundance that existed in the winter of 1988 for four months.

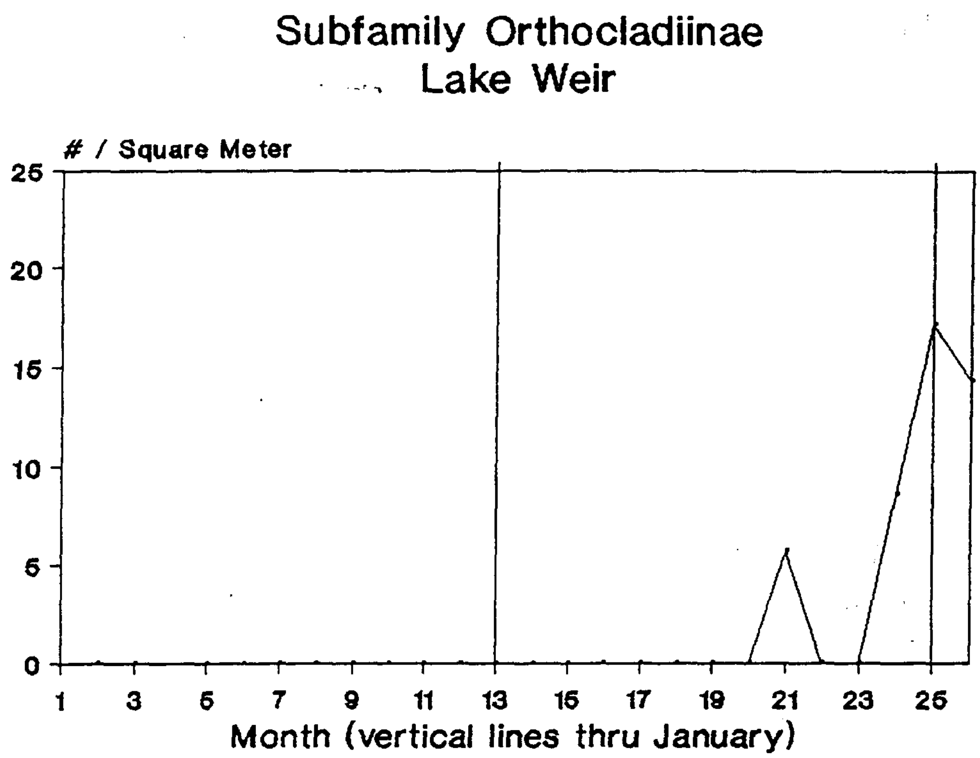
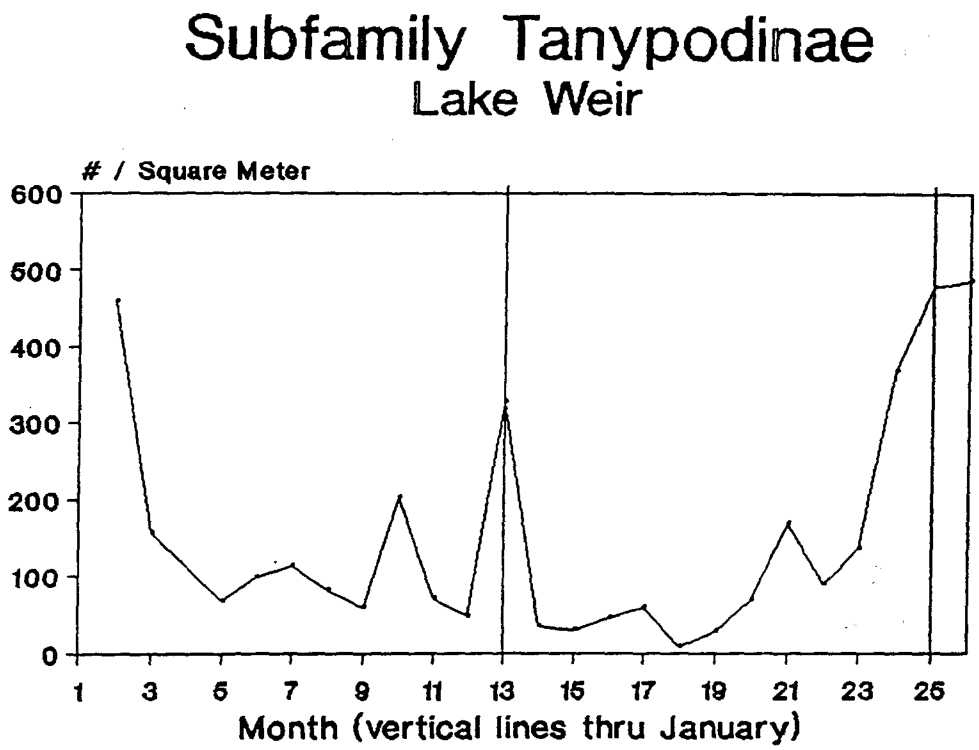


Figure 5-57. Mean biomass of Orthocladiinae in Lake Weir for individual months.



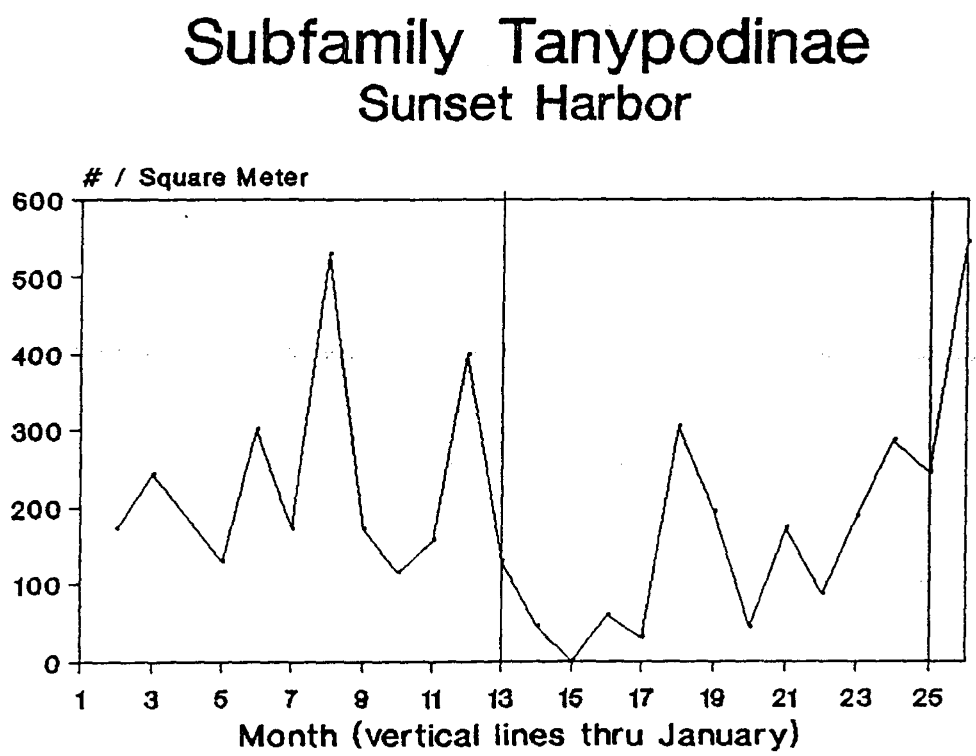
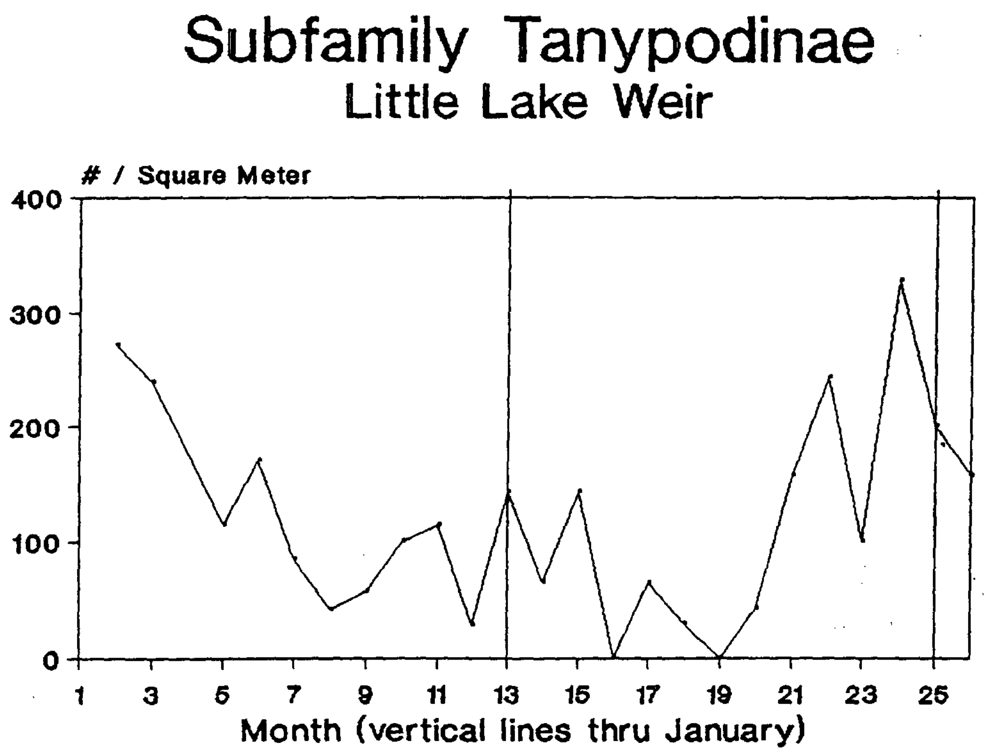


Figure 5-58. Mean biomass of Tanypodinae at three stations for individual months.



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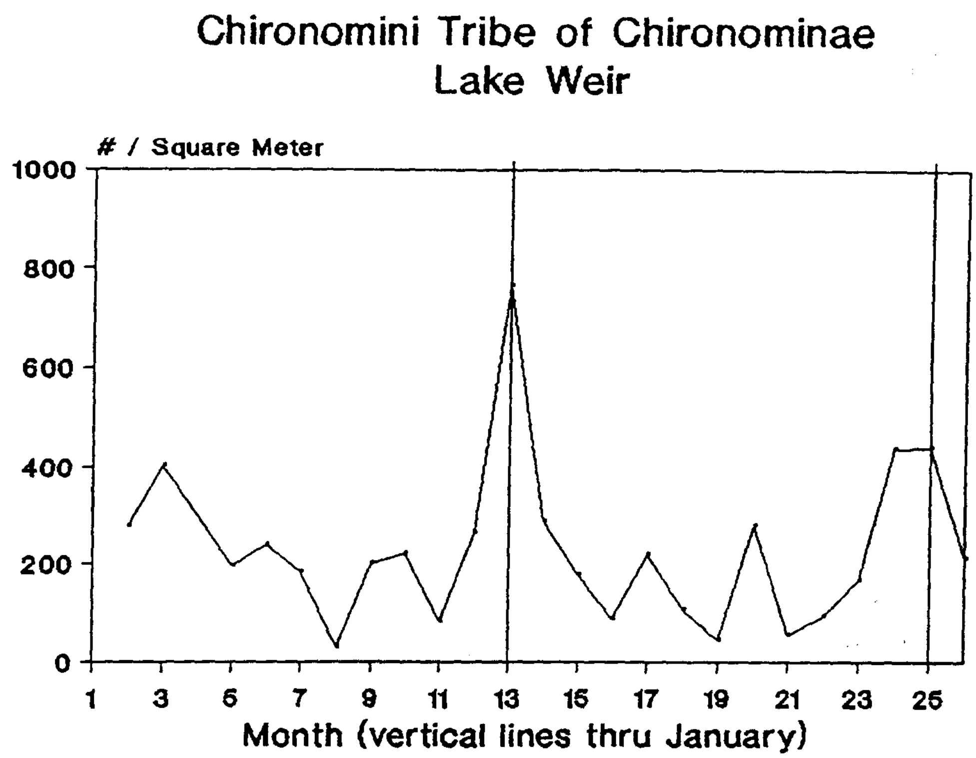


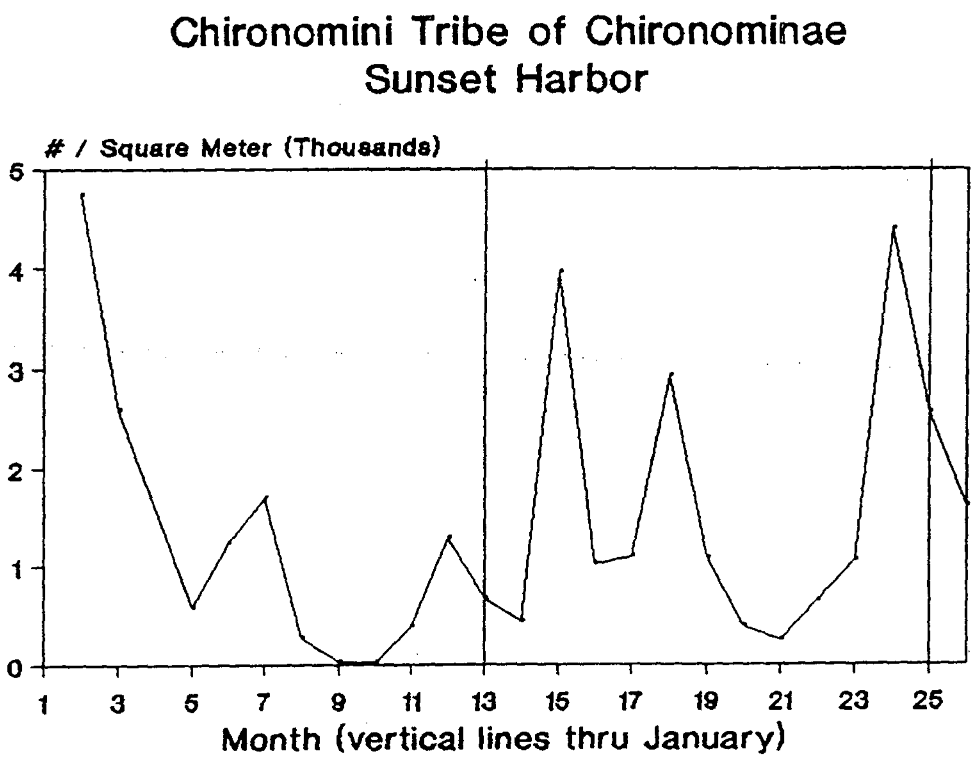


Figure 5-59. Mean biomass of Chironomini at three stations for individual months.

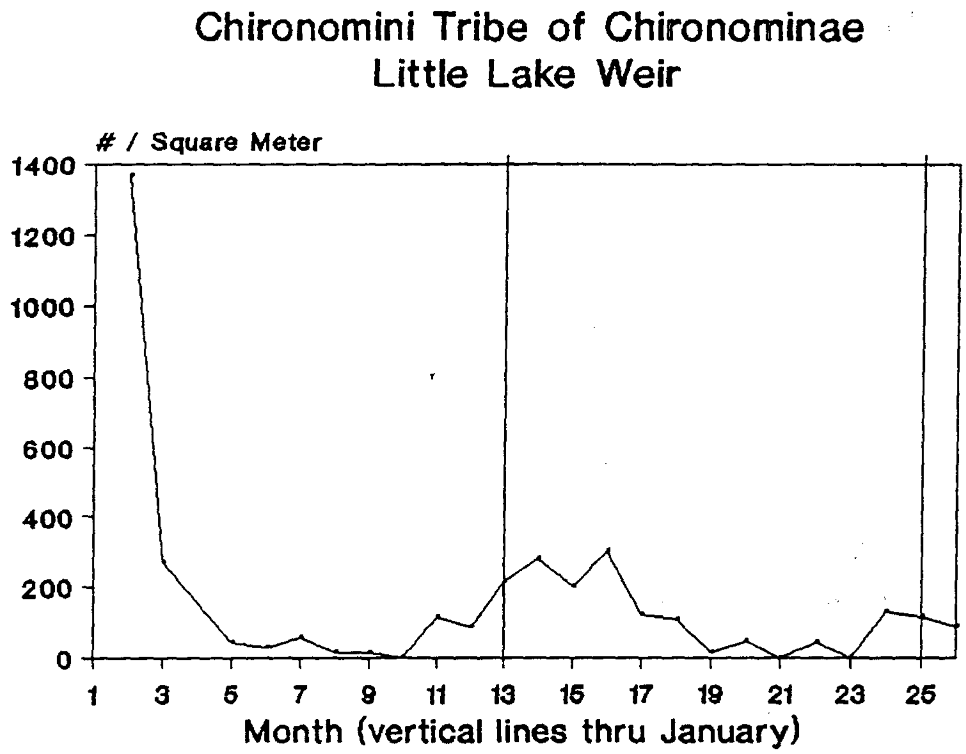


Figure 5-59. Continued.

Population levels of the Chironomini tribe in Lake Weir were highly variable (Figure 5-59). Densities were highest in the winter but only for one or two months. The lowest Chironomini densities occurred during the summer.

In Sunset Harbor, the Chironomini population levels were extremely variable (Figure 5-59). In general, high levels occurred in winter and spring. Low population densities existed during the summer and fall and even approached zero. This low occurred in 1987 and 1988 from July to November. Little Lake Weir also had higher densities in the winter and spring (Figure 5-59). Very low populations existed for several months during the summer and fall of both years. For both Sunset Harbor and Little Lake Weir, the largest population was found in February 1987.

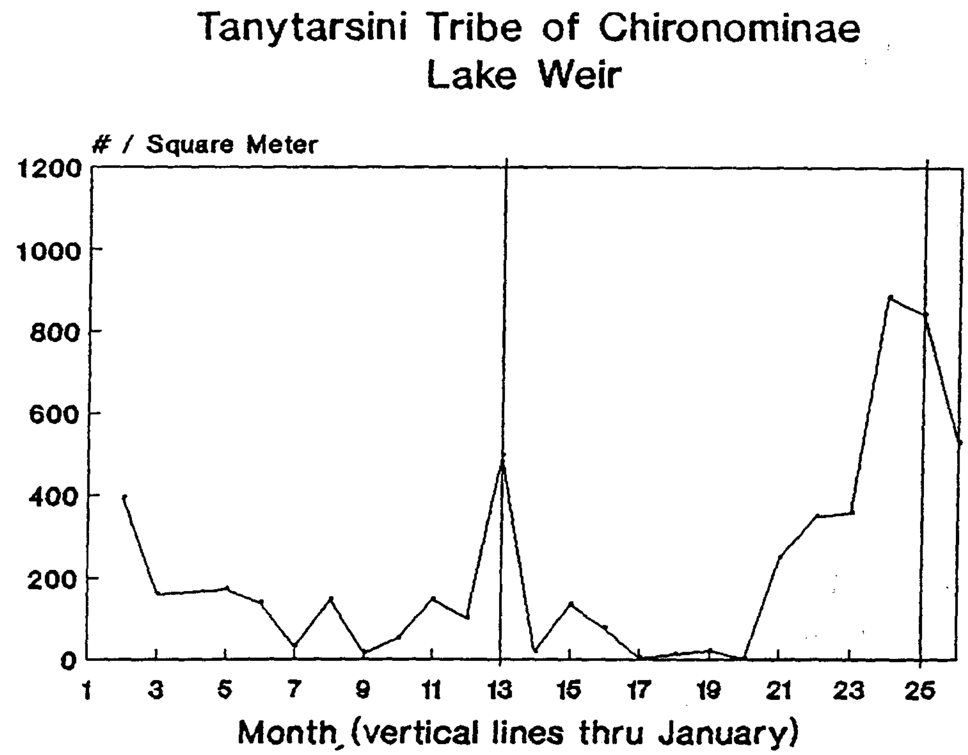
The Tanytarsini population in Lake Weir--like the Chironomini and the Tanypodinae populations--was largest during the fall and winter and smallest in the spring and summer (Figure 5-60). December and January were the months that the maximum population densities were found. From May to August 1988 the Tanytarsini density remained very close to zero.

For Sunset Harbor, the seasonality of Tanytarsini was very similar to Lake Weir's. Maximum population densities were found during January (Figure 5-60). The density was about $1500/m^2$ in January 1989; another high level was during the winter of 1987. Populations were especially low during the spring and summer of 1988.

Although it did not have a population pulse in January 1988, Little Lake Weir was similar to Sunset Harbor in regard to Tanytarsini populations (Figure 5-60). Population levels remained very low during the spring and summer of 1988 and had been low for already six months. Then in the fall and winter of 1988-89, the population density reached $400/m^2$. Two years earlier, in February 1987, the population density sampled in Little Lake Weir was over $1200/m^2$.

Mean population densities of <u>Chaoborus</u> in Lake Weir were highest during the first two sampling months but then diminished by more than 50% (Figure 5-61). From August 1987 to March 1988, the population level remained fairly steady. Afterwards, the population displayed more fluctuations. In general, the highest densities of chaoborids were found during the winter.

In Sunset Harbor, two extreme increases of chaoborid populations occurred: one in July 1987 and the other in September 1988 (Figure 5-61). In September 1988, the <u>Chaoborus</u> density was around $2000/m^2$. In both cases, the preceeding spring and summer months had <u>Chaoborus</u> densities between 0 and $100/m^2$. Also, the following months had



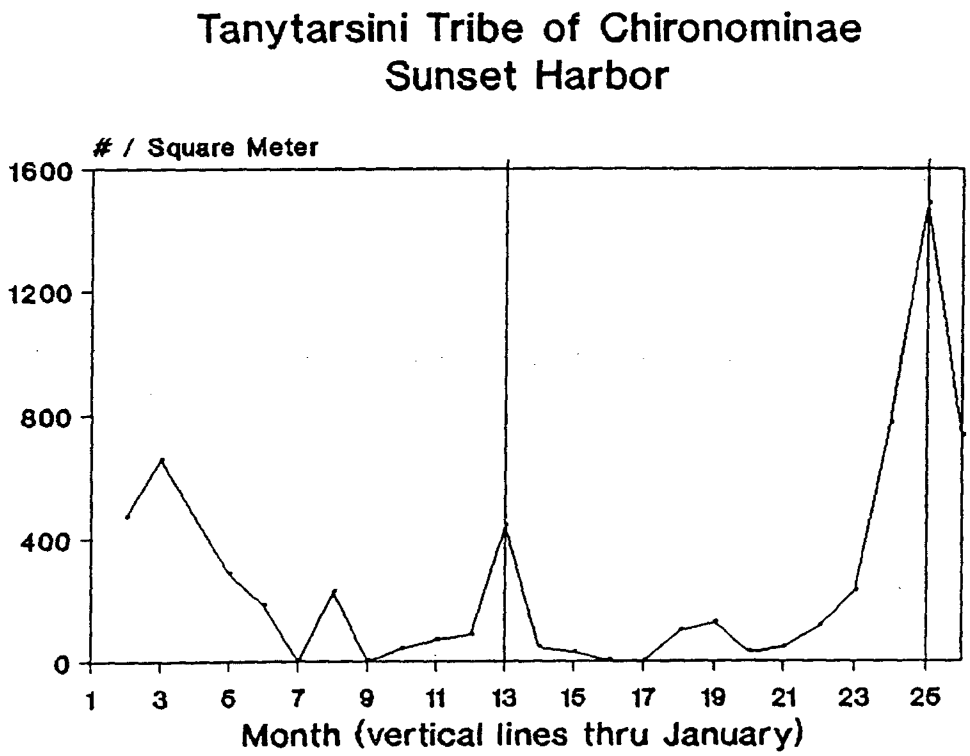
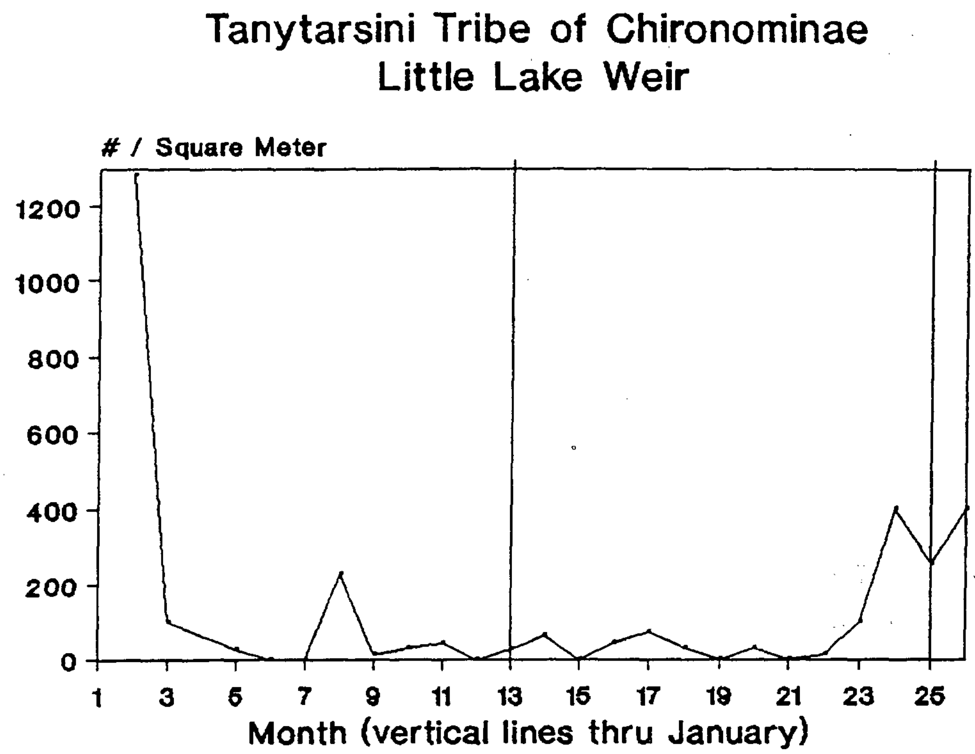


Figure 5-60. Mean biomass of Tanytarsini at three stations for individual months.



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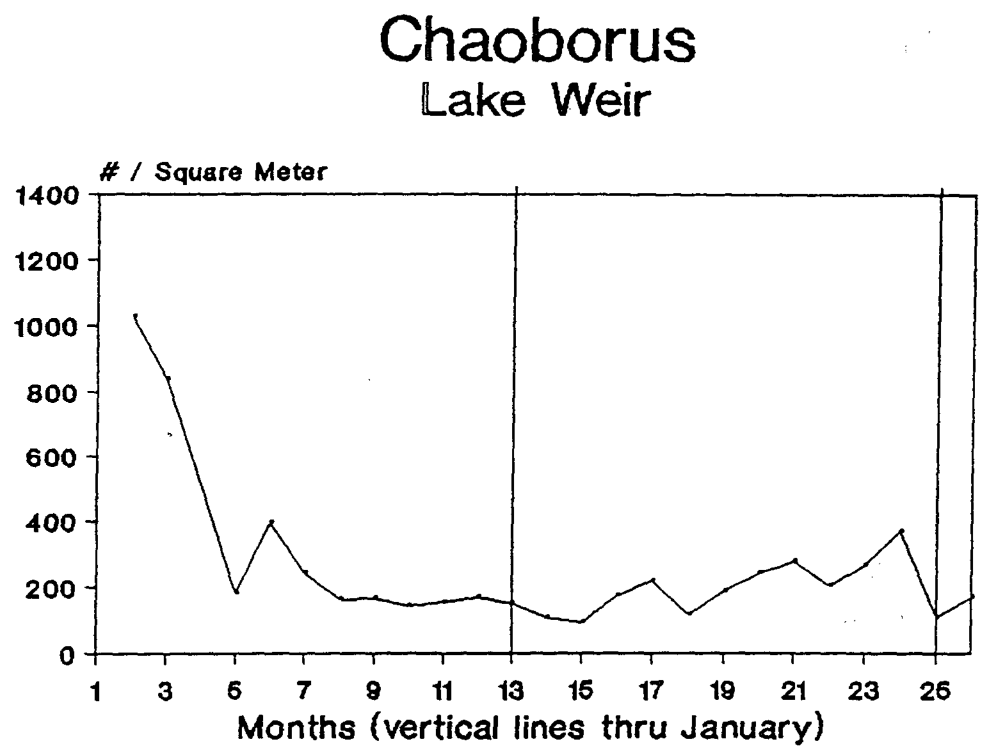


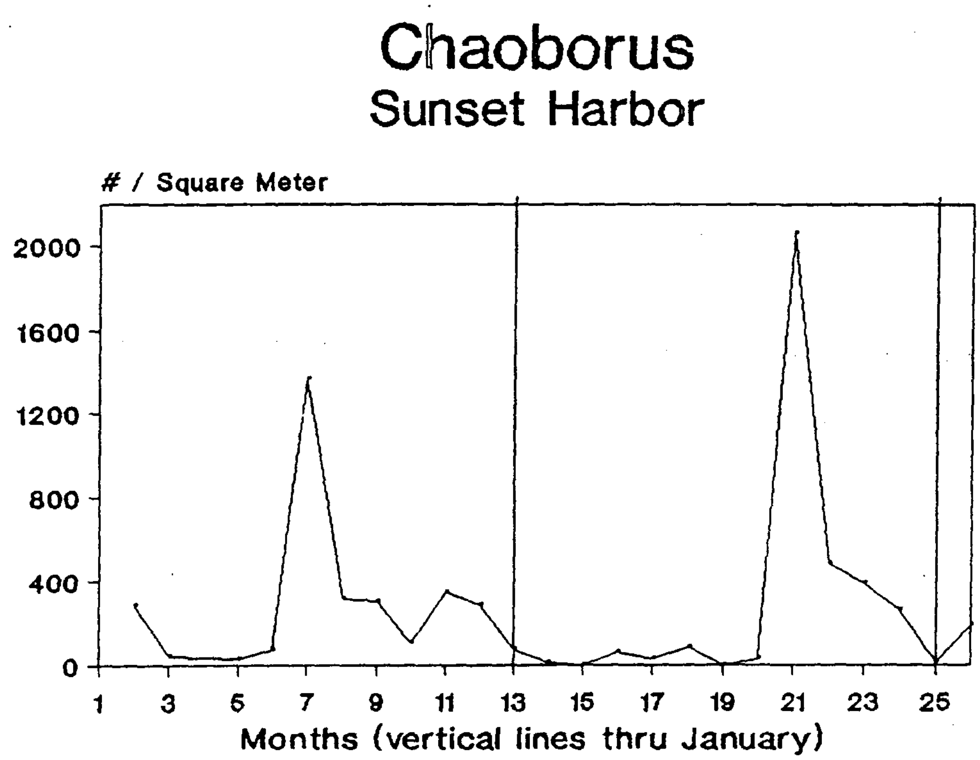


Figure 5-61. Mean biomass of *Chaoborus* at three stations for individual months.

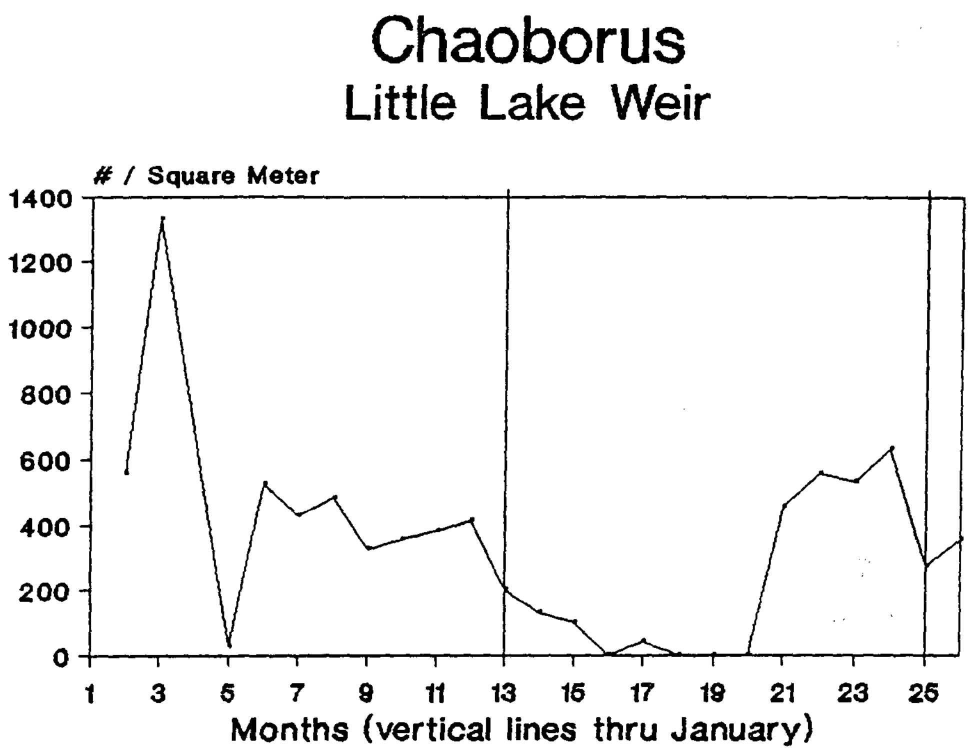


Figure 5-61. Continued.

densities around $400/m^2$. Therefore, at station 6, the highest populations occurred during summer and fall.

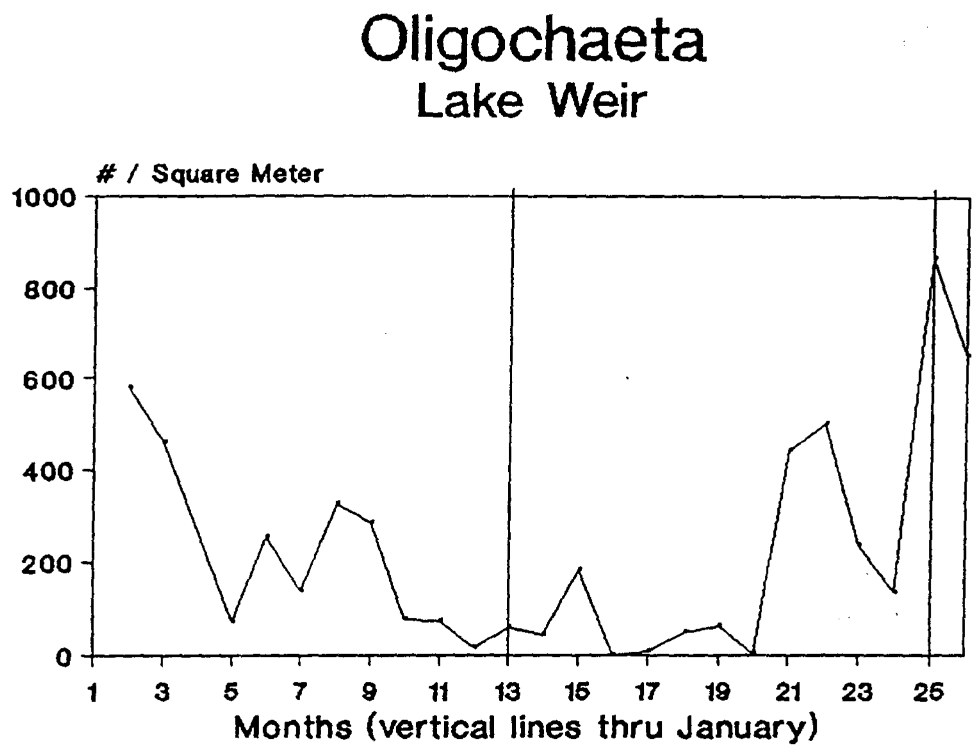
Unlike Sunset Harbor, the seasonality of Chaoborus in Little Lake Weir during 1987 was not similar to that of 1988 (Figure 5-61). The maximum chaoborid density occurred in March 1987; at no other time did the density exceed $650/m^2$. For the 15 month period from June 1987 to August 1988, the Chaoborus population decreased. For three summer months in 1988, no chaoborids were found. Then, in September 1988, almost 500 chaoborids per square meter were collected. During the fall season of both years, densities around 400 to $600/m^2$ existed.

Oligochaete population densities in Lake Weir were relatively low from October 1987 to August 1988 (Figure 5-62). Likewise, in Sunset Harbor, densities were low from July 1987 to August 1988. After August 1988, both lake basins had similar population increases in September and January with intervening lows in December and February. Lake Weir had high, but variable, Oligochaeta densities during the winter and spring of 1987 as did Sunset Harbor; however, Sunset Harbor had much denser populations. The only time Little Lake Weir had high populations was during this same time.

The seasonality of the amphipod Hyalella in Lake Weir was comparable to that of Sunset Harbor (Figure 5-63). In both lake basins, Hyalella populations increased over spring 1987 to reach a maximum density during June. Then, the populations crashed the next month (July '87) and slowly increased to a much lower density by winter. In the fall of 1988, both populations increased again around October. The main difference between the two populations was that, after the extreme decrease in July 1987, the Lake Weir population rebounded quicker and was more dense in 1988 than that of Sunset Harbor.

Compared to Lake Weir, station 7 in Little Lake Weir had very few amphipods (Figure 5-63). The seasonality of Hyalella in Little Lake Weir was very different than in either Lake Weir or Sunset Harbor. Maximum densities of Hyalella occurred during the fall and winter of 1987. Population levels were unsteady during both years. There was no major population pulse in the spring of 1987 nor in the fall of 1988.

The seasonality of Hexagenia in Lake Weir was similar to its seasonality in Little Lake Weir and, to a lesser extent, in Sunset Harbor (Figure 5-64). Although the population densities in Little Lake Weir were about double those in Lake Weir, the two populations varied at similar times in both sampling years. Both populations decreased during the spring of 1987 and nearly reached a density of



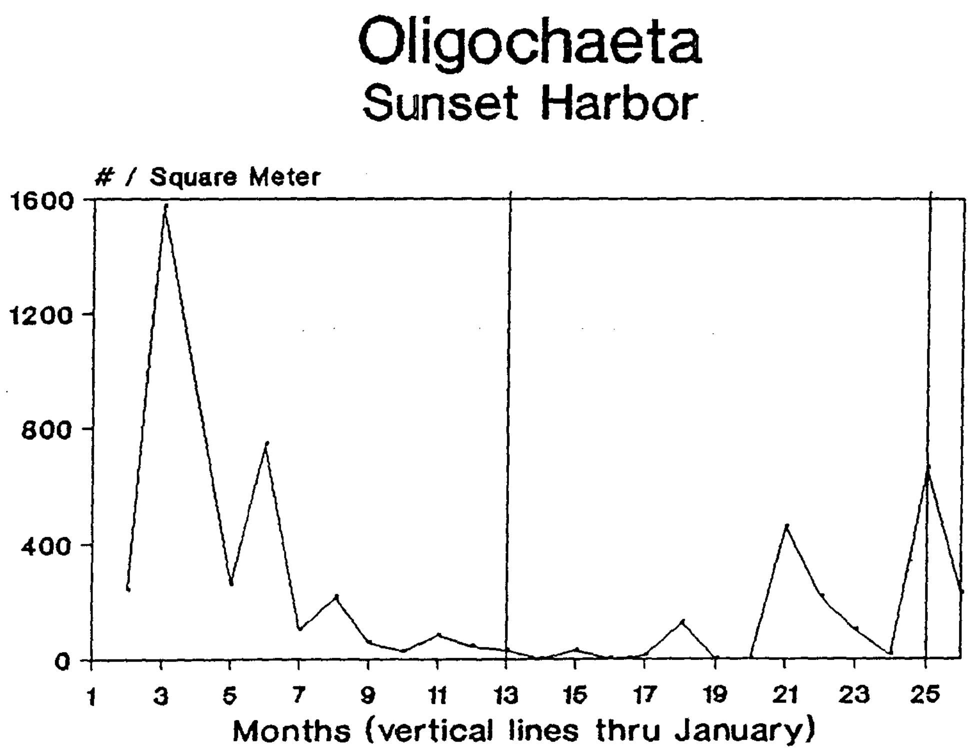
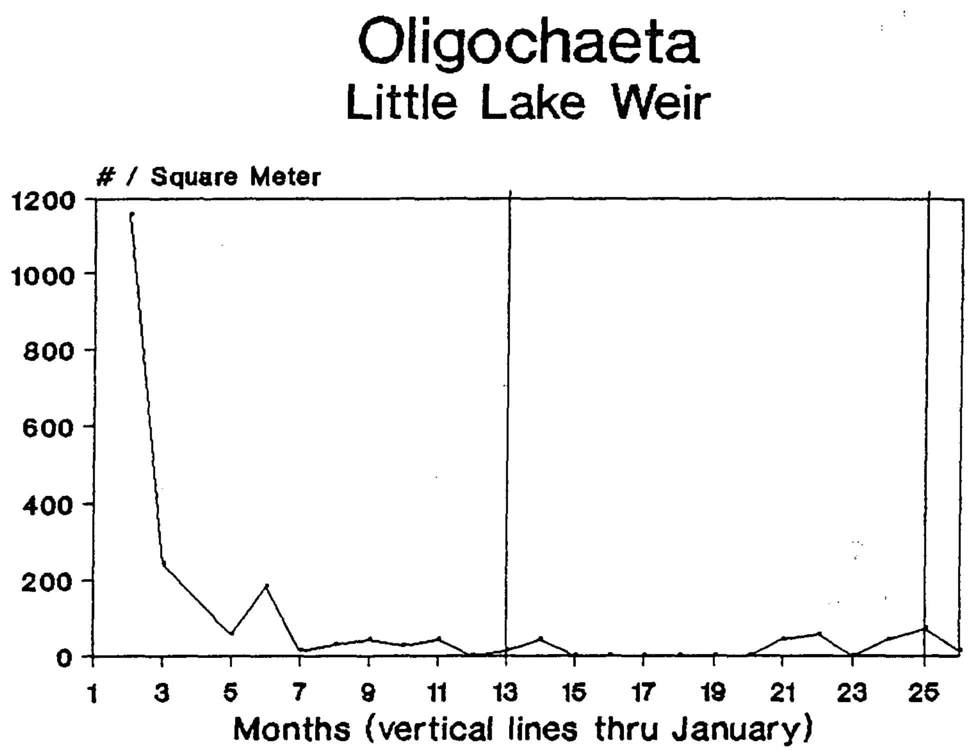


Figure 5-62. Mean biomass of Oligochaeta at three stations for individual months.



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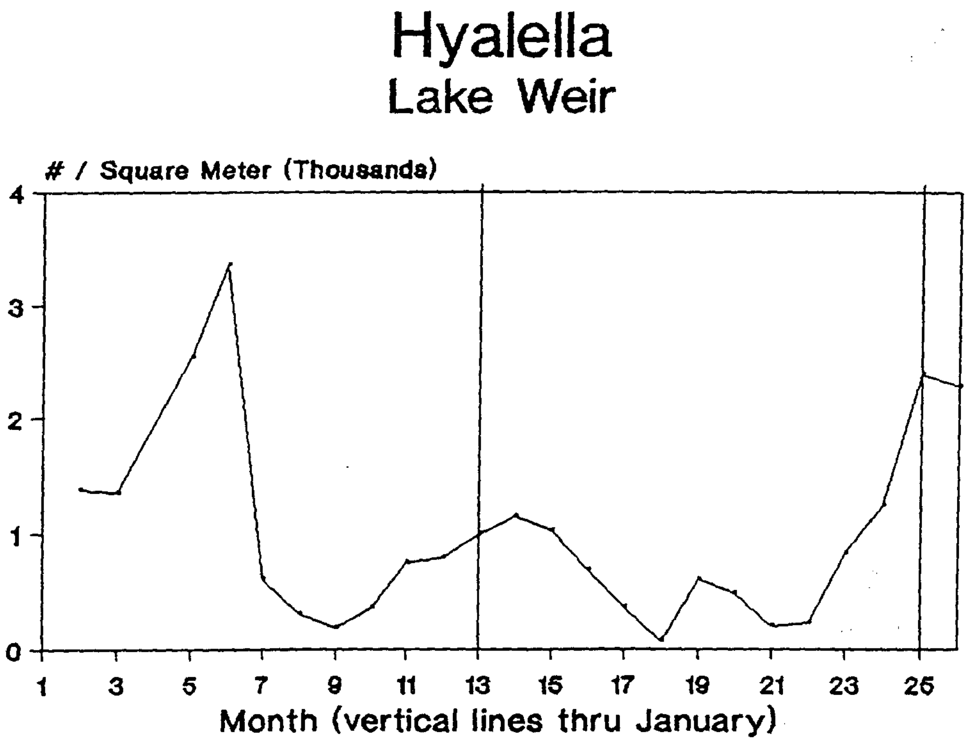


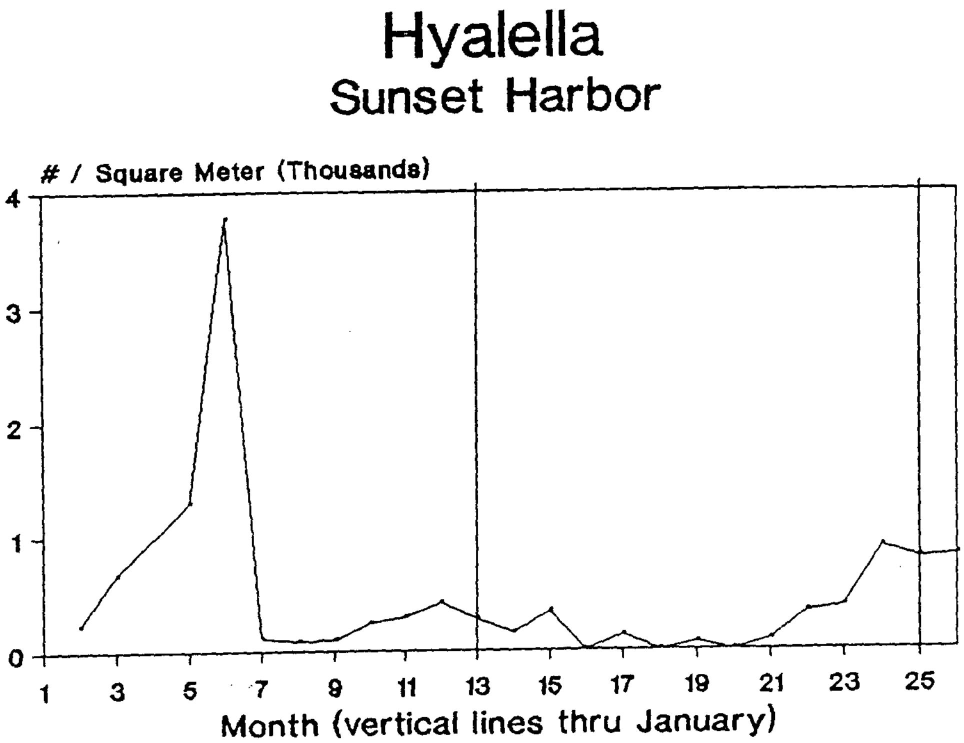
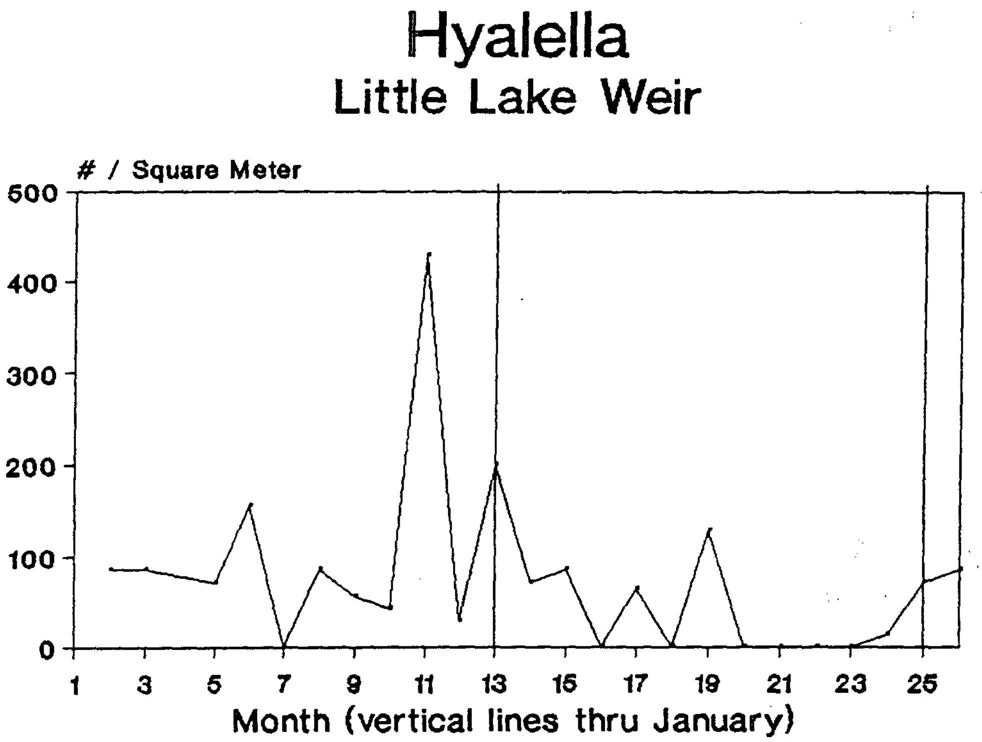


Figure 5-63. Mean biomass of Hyalella at three stations for individual months.



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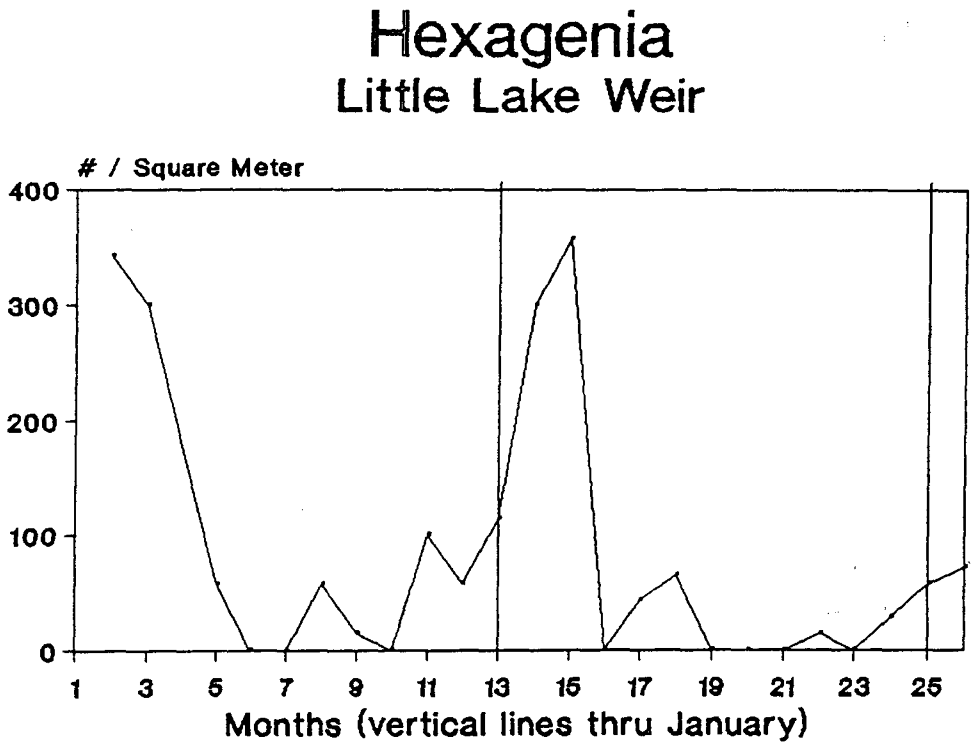

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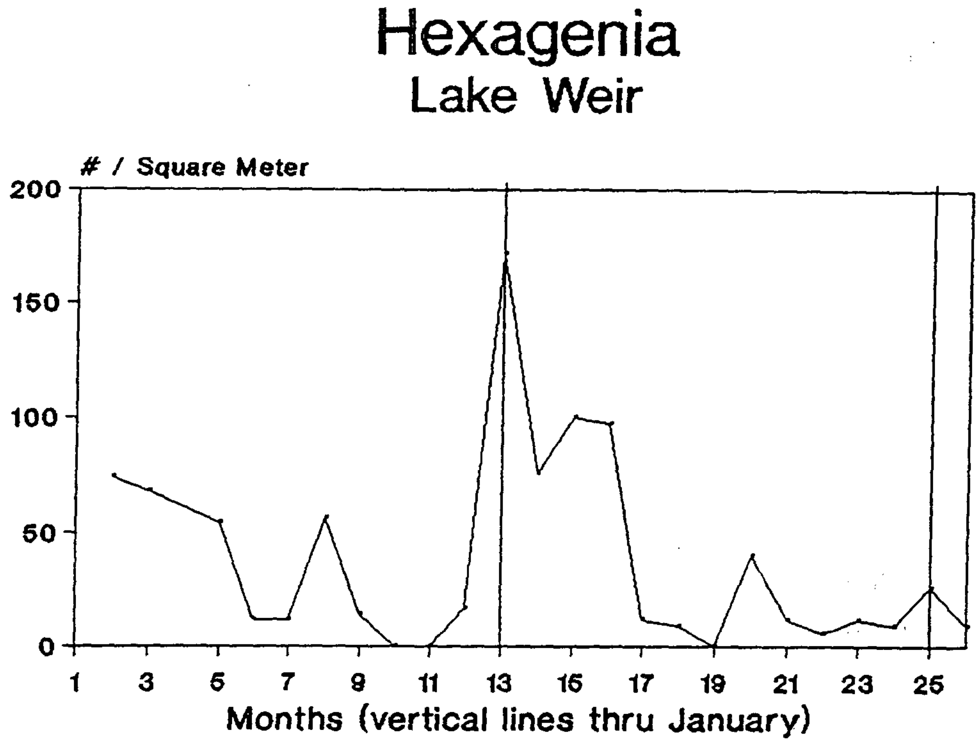


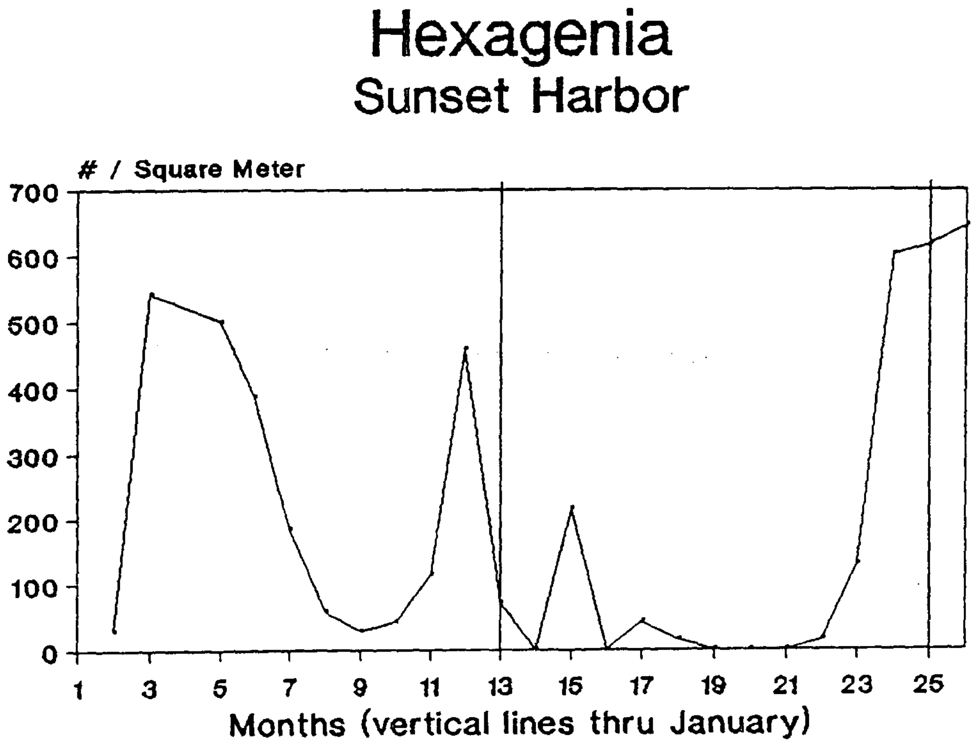


Figure 5-64. Mean biomass of <u>Hexagenia</u> at three stations for individual months.

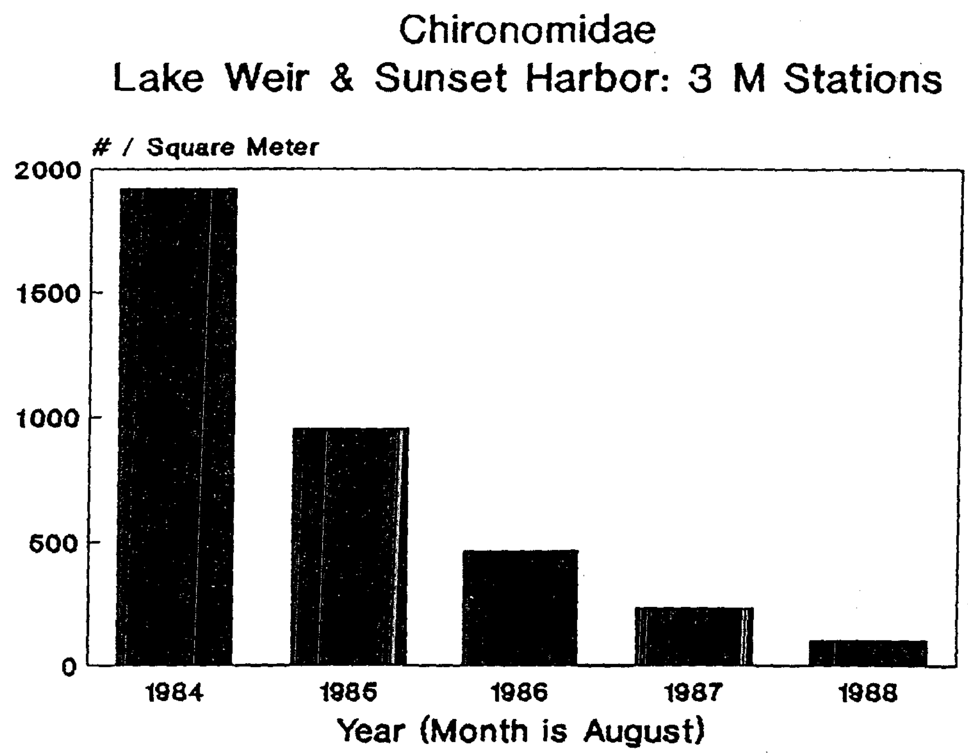
zero by July. They both pulsed during August and then decreased to near zero by October. Then Hexagenia in Lake Weir increased to a maximum density by January, while, in Little Lake Weir, it became most numerous two months later in March 1988. By May, both populations had decreased dramatically once again. Following that, each population had two more significant increases, the last occurring around January 1989. Generally, in both lakes, Hexagenia densities were highest in the winter and spring and lowest in the summer.

Like Lake Weir, Sunset Harbor had a sharp increase in Hexagenia populations during the early winter months of 1987-1988. Sunset Harbor also had a population decrease during the spring of 1987, but it extended into the summer and only one minimum was reached (September '87). The following summer, Hexagenia densities were at or near zero for a much longer time: about seven months. During November 1988, the population of Hexagenia increased about 600%. This maximum density existed through January and February 1989.

5.5.D HISTORICAL CHANGES IN THE BENTHOS OF LAKE WEIR

5.5.D.1 DATABASE. While the paleolimnological investigation of Lake Weir did provide historical data for some benthic macroinvertebrate taxa for the past 100 years (Chapter 6), benthic sampling by the Florida Game and Fresh Water Fish Commission resulted in a three year data base (1984-1986) that was more complete for recent years. The FGFWFC sampled at generally one meter depth intervals along four transects in Lake Weir and one in Sunset Harbor during the month of August in 1984, 1985, and 1986 (FGFWFC 1985, 1986, and 1987). Therefore, with the sampling done in 1987 and 1988 by the University of Florida, known depths in Lake Weir were sampled at one year intervals for five years. Only the data for August 1987 and August 1988 were compared to the that of the FGFWFC; the seasonalities of various taxa showed that annual means were very different from August values. The major differences in sampling methodolgy between the two studies were that the FGFWFC used a six-inch Eckman dredge instead of a ponar grab and that their benthic samples may have included highly vegetated areas. A number 30 sieve was used in both FGFWFC and the current studies. Nevertheless, important trends in benthic populations were distinct.

5.5.D.2 THREE METER DEPTH. At 3 meter deep stations in Lake Weir and Sunset Harbor, many taxonomic groups were decreasing in numbers from August 1984 to August 1988. For



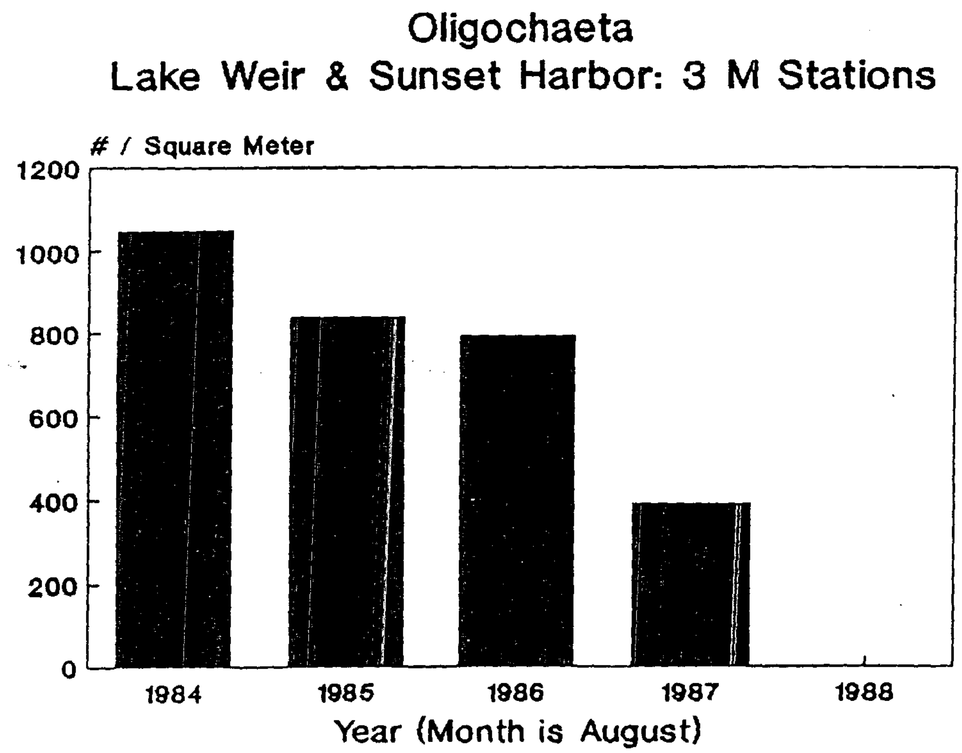


Figure 5-65. Historical changes in the mean biomass of Chironomidae and Oligochaeta at 3 meter stations in the Lake Weir system.

1987 and 1988, the sampling areas were stations 2 and 4 in Lake Weir. The population densities during August at stations 2 and 4 were averaged to obtain the 1987 and 1988 values.

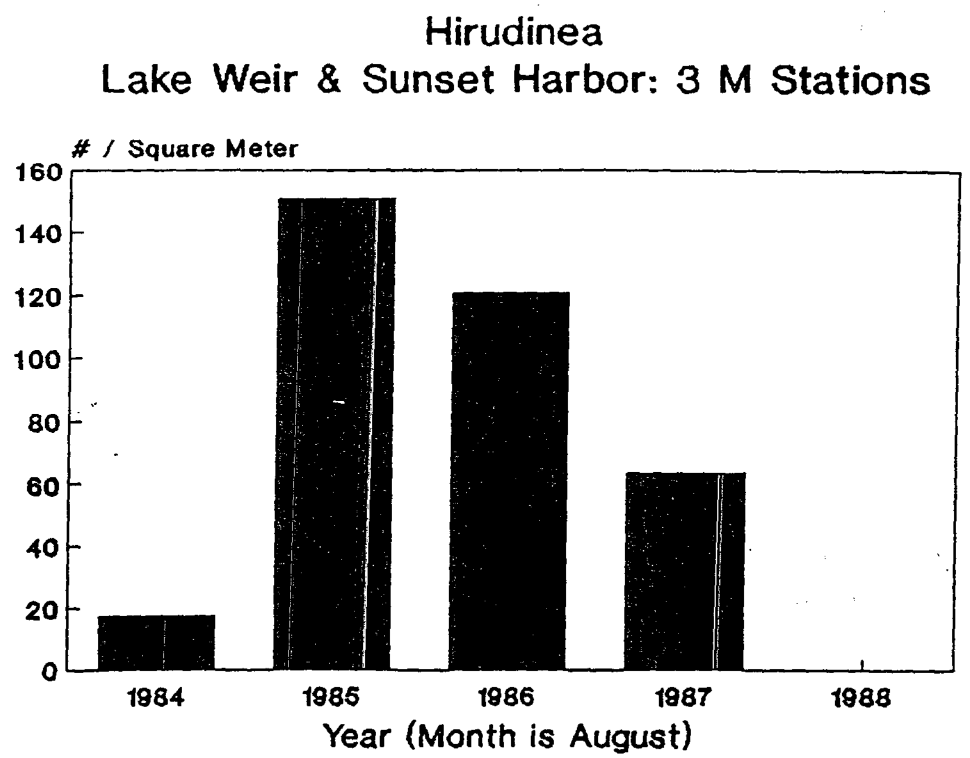
Chironomid populations showed a progressive decline of about 50% per year (Figure 5-65). Averaging almost $2000/m^2$, Chironomidae densities were very high in August 1984. Four years later, but not at the same exact stations, the chironomid density was less than $200/m^2$.

Oligochaete population levels were also dropping over the five years (Figure 5-65). There were just over 1000 oligochaetes per square meter in 1984 and about 40% of that three years later. In August 1988 no oligochaetes were found at the three meter deep stations. Hirudinea densities diminished from 1985 to 1988 (Figure 5-66); however, the mean density in 1984 was close to that of 1988.

Both Gastropoda and Pelecypoda populations changes were alike. Densities of Gastropoda were very high (above $600/m^2$) in 1984 but diminished by 50% in 1985 (Figure 5-66). The next year the population almost doubled in size. However, almost no Gastropoda were found in 1987 and 1988. The story is much the same for Pelecypoda (Figure 5-67), although the population densities of Pelecypoda were much lower than Gastropoda. Pelecypods were collected in 1987 and at levels equal to 1985 but none were collected in 1988.

Populations of Trichoptera were markedly lower in 1987 and 1988 than previously at 3 meter deep stations (Figure 5-67). Populations declined slowly from 1984 to 1986 and then almost disappeared in 1987 and 1988. Another group of insects, Ephemeroptera, did not diminish in number but densities actually increased compared to the first two years (Figure 5-68). Densities were around $20/m^2$ in 1984 and 1985 and then tripled in 1986. After that, in 1987 and 1988, densities of Ephemeroptera--which was composed of _Hexagenia_--diminished slightly. For yet another group of insects, chaoborids, the population dynamics were not clear-cut (Figure 5-68). During the years 1985, 1986, and 1987, the density of chaoborids remained fairly stable. However, in the year before and in the year after, the density was much lower. Therefore, no single pattern of decreasing or increasing populations of chaoborids occurred for the five year period.

Amphipod densities remained stable around $200/m^2$ in 1984, 1985, and 1986 (Figure 5-69). In 1987 the population increased by about 150%. This rise contrasted with the severe drop that occurred the next year. In August 1988 no amphipods were collected at three meters.



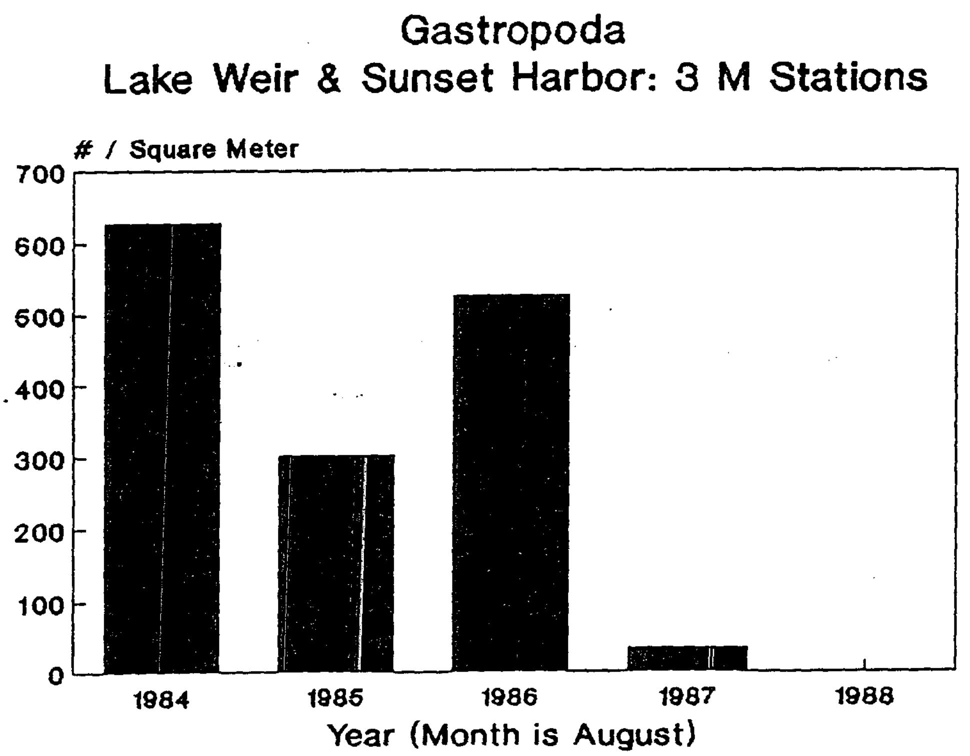
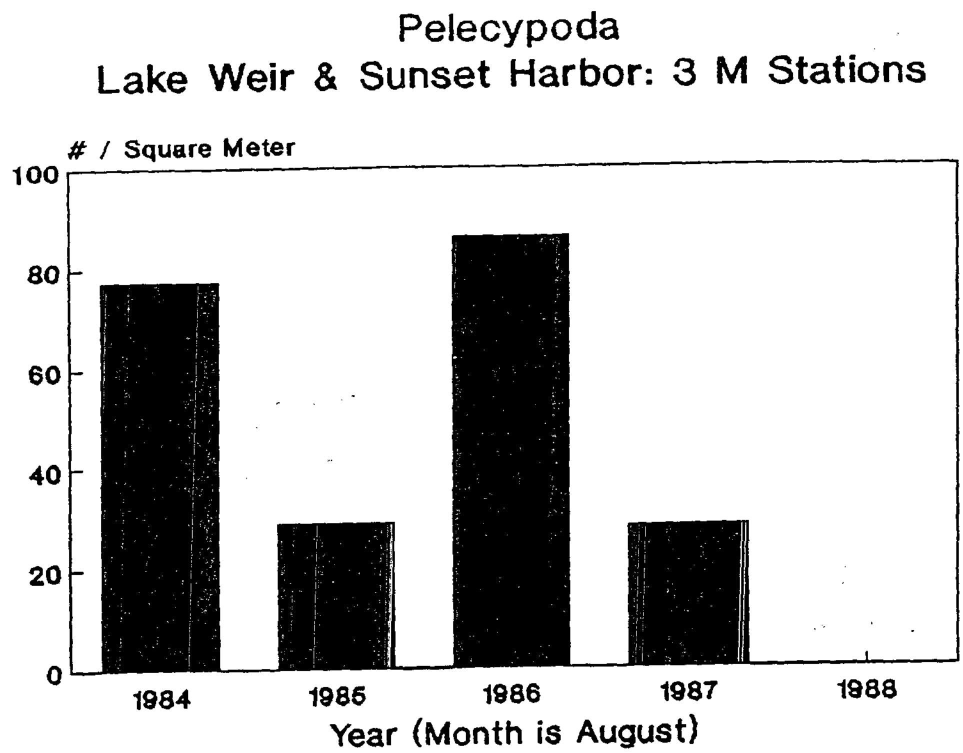


Figure 5-66. Historical changes in the mean biomass of Hirudinea and Gastropoda at 3 meter stations in the Lake Weir system.



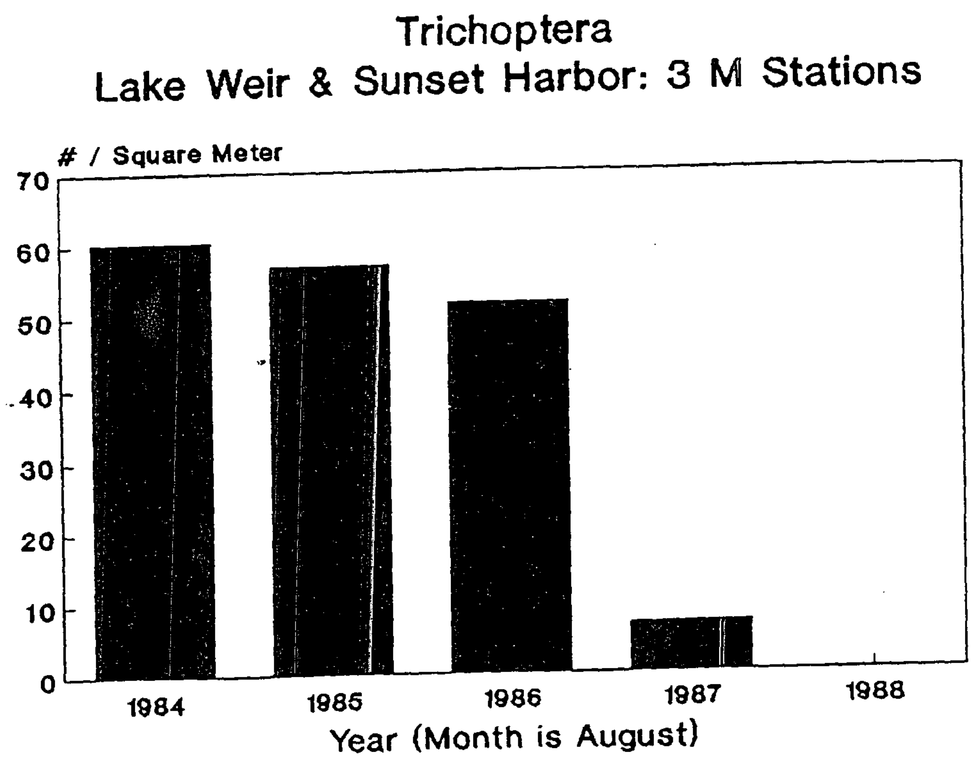
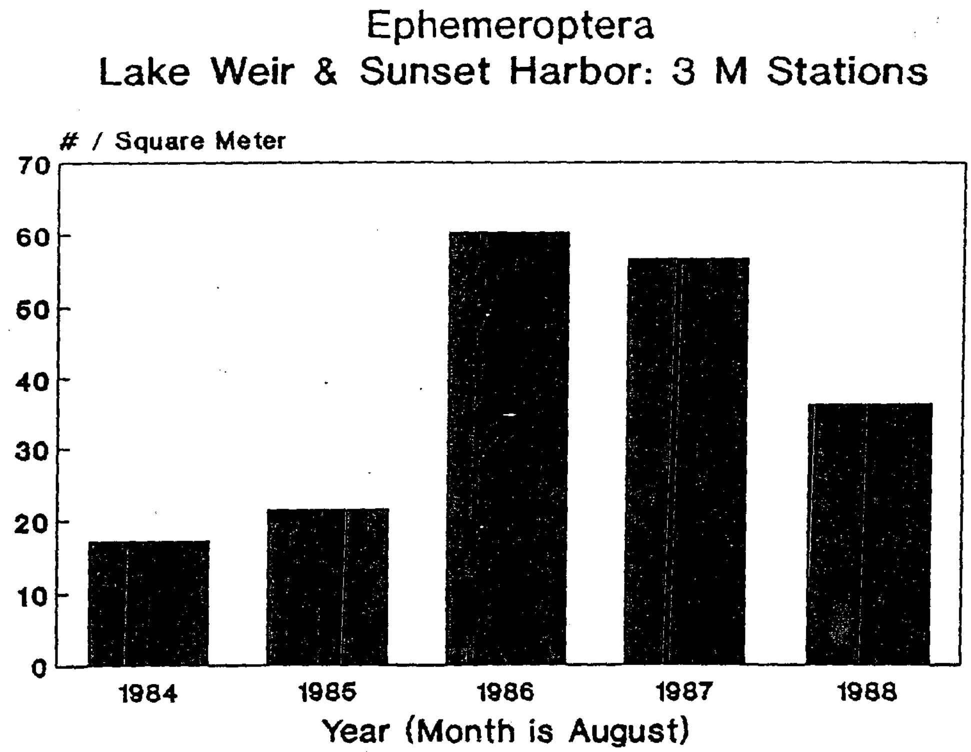


Figure 5-67. Historical changes in the mean biomass of Pelecypoda and Trichoptera at 3 meter stations in the Lake Weir system.



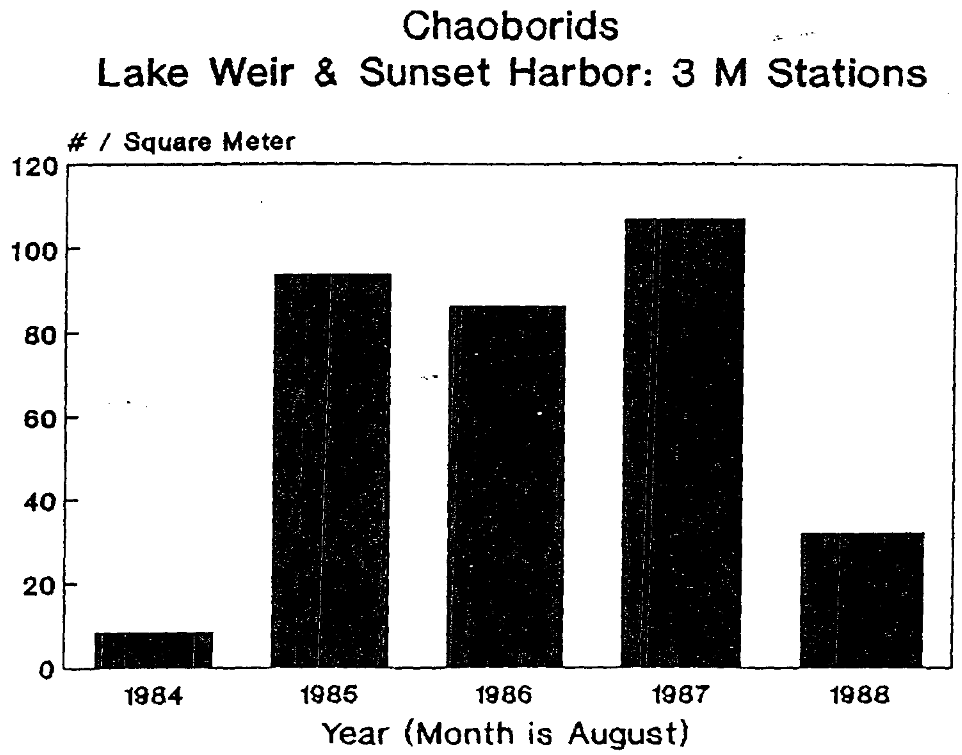


Figure 5-68. Historical changes in the mean biomass of Ephemeroptera and chaoborids at 3 meter stations in the Lake Weir system.

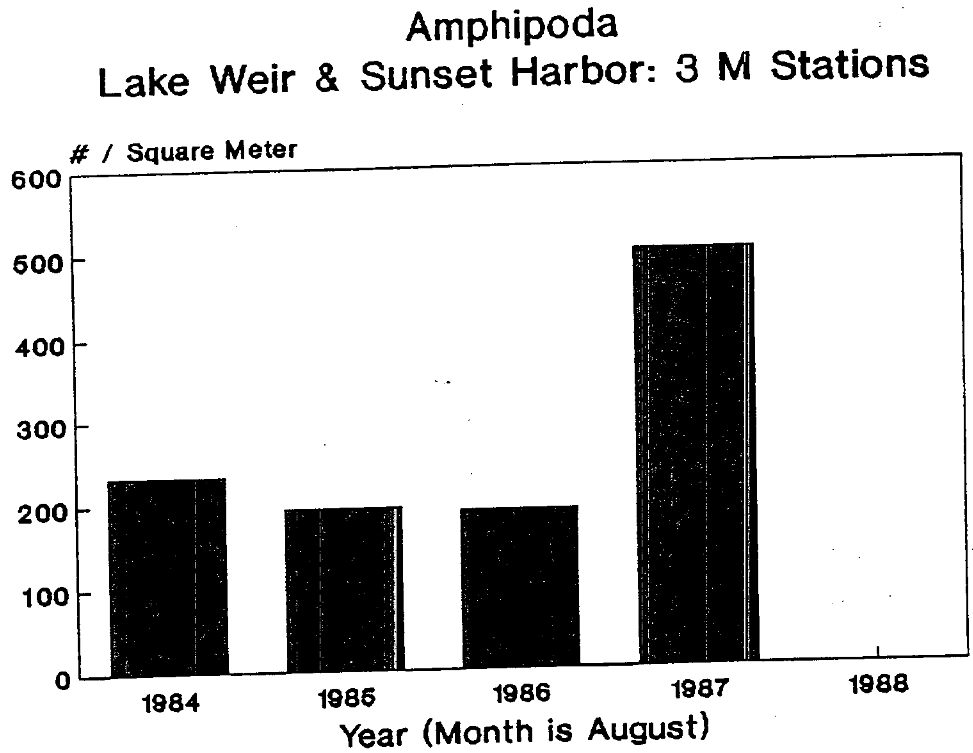
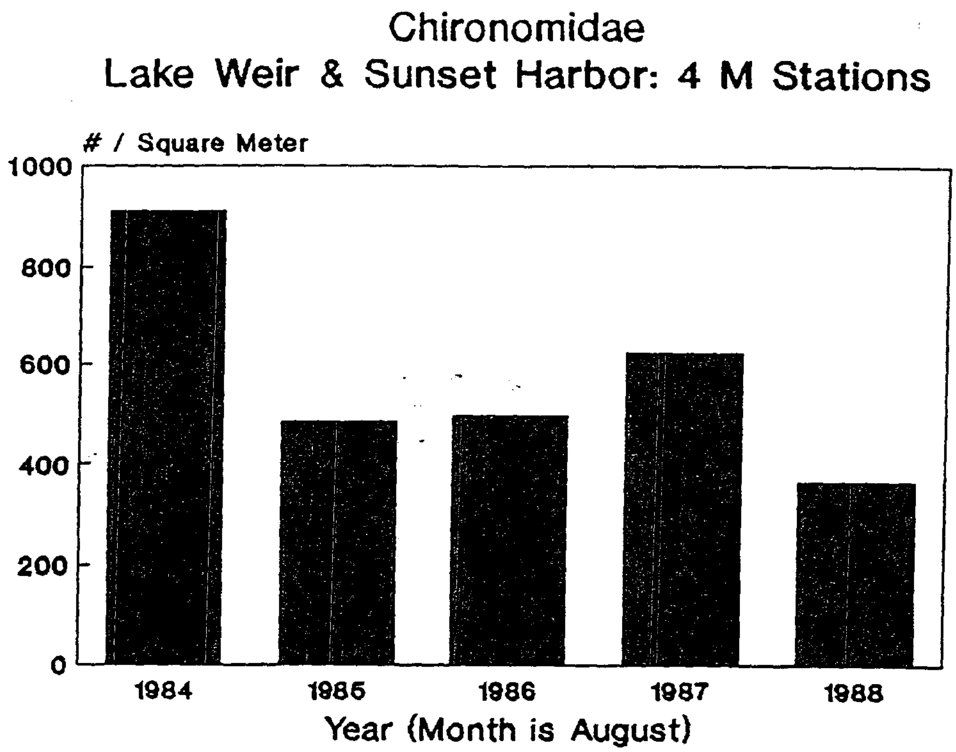


Figure 5-69. Historical changes in the mean biomass of Amphipoda at 3 meter stations in the Lake Weir system.



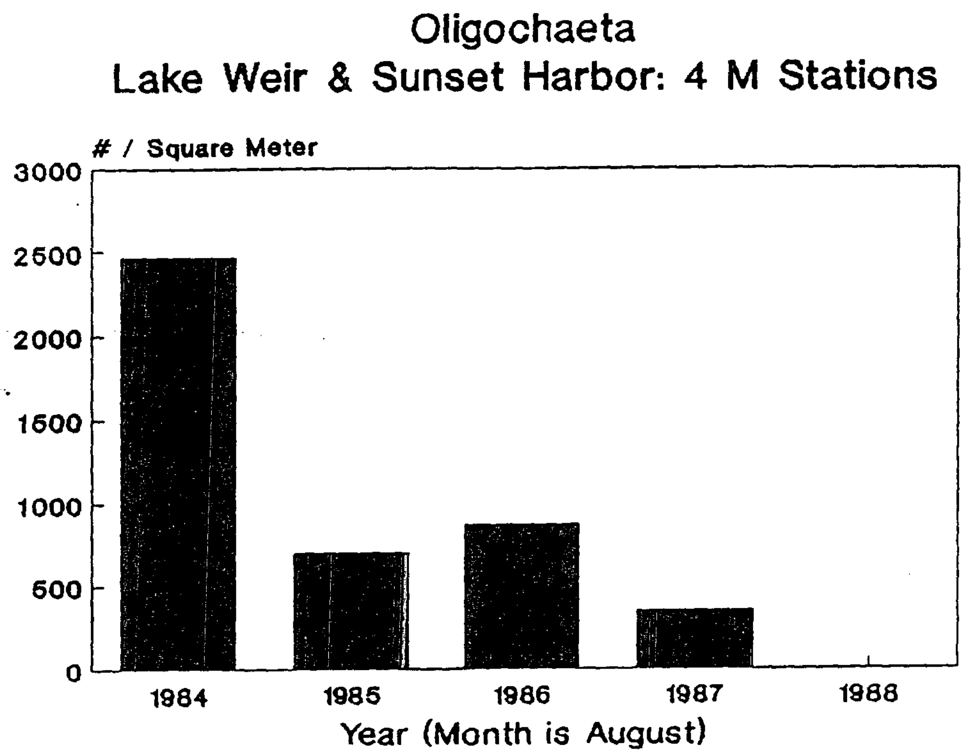


Figure 5-70. Historical changes in the mean biomass of Chironomidae and Oligochaeta at 4 meter stations in the Lake Weir system.

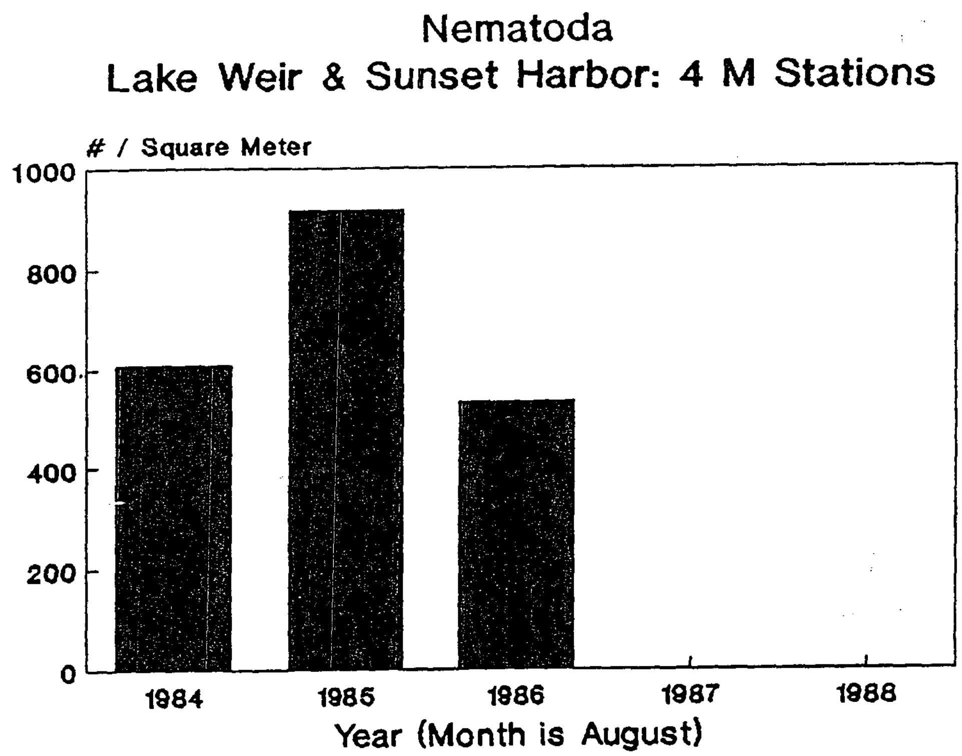
5.5.D.3 FOUR METER DEPTH. The sampling areas that were 4 meters deep in 1987 and 1988 were station 5 (near the south shore of Lake Weir) and station 6 (in the middle of Sunset Harbor). From 1984 to 1986, sampling stations were in Lake Weir and Sunset Harbor. At these 4 meter deep stations, Chironomidae populations diminished over the five years (Figure 5-70). In 1984 the chironomid density was about 900/m^2 but in subsequent years the density was about one-half. Oligochaete populations dropped even more dramatically (Figure 5-70). Densities were almost 2500/m^2 in 1984 but only about one-fifth that from 1985 to 1987. In August 1988, almost no oligochaetes were collected from the sand substrate at stations 5 and 6.

Nematodes were also rare in 1987 and 1988 (Figure 5-71). In previous years there were between 500 and 900 nematodes per square meter. Gastropoda also diminished in number during the five years (Figure 5-71). From 1985 to 1988 the population of gastropods consistently and substanially decreased. None were found in August 1988. Unlike the Gastropoda, the pelecypod population--although much lower in number--was relatively stable over the five years (Figure 5-72). The population density of Pelecypoda generally remained around 60/m^2 although a drop did occur in 1987.

Other major taxonomic groups found at 4 meters had significant population increases. Hirudinea densities rose greatly from 1984 to 1987 although no leeches were collected in August 1988 (Figure 5-72). The Hirudinea density in 1987 was almost eight times more than in 1984. Chaoborids were much more numerous in 1987 and 1988 than in previous years (Figure 5-73). The chaoborid population density did drop precipitously in 1985-86 but then it shot up by 1987 to reach 250/m^2. It rose slightly higher in 1988.

Population densites of Ephemeroptera were much higher in 1986 to 1988 than in 1984 or 1985 (Figure 5-73). Densities were equally low the first two years but increased about 700% in 1986. Population increases continued in 1987 and 1988. A maximum of 65/m^2 occurred in 1988. Densities of amphipods also jumped up quickly and reached a maximum of over 1200/m^2 in 1988 (Figure 5-74). Large population increases occurred every year except 1986.

5.5.D.4 SIX METER DEPTH. Station 1 was the 6 meter deep sampling area for 1987 and 1988. From 1984 to 1986, the sampling areas were in Lake Weir and--possibly--Sunset Harbor. At a 6 meter depth, the chironomid population diminished tremendously over the five years (Figure 5-75). There were around 1500/m^2 in 1984 but only around 150/m^2 in 1988. The largest decreases occurred in 1985 and in 1986. Oligochaeta populations diminished every year (Figure 5-75). The density was just over 600/m^2 in 1984 but was near zero



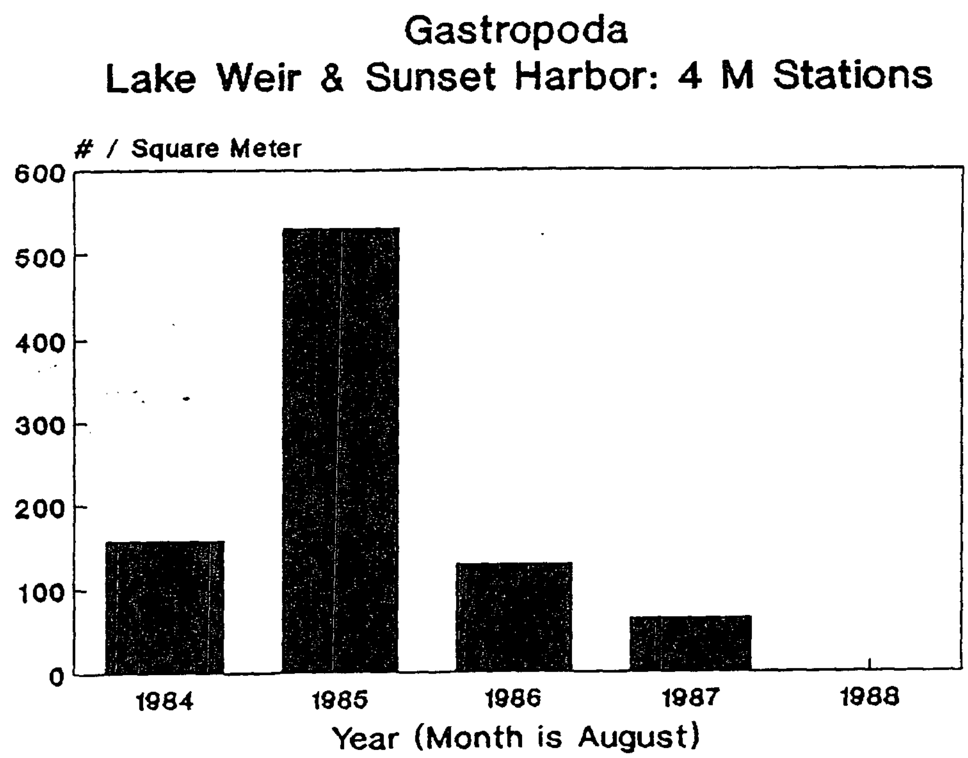
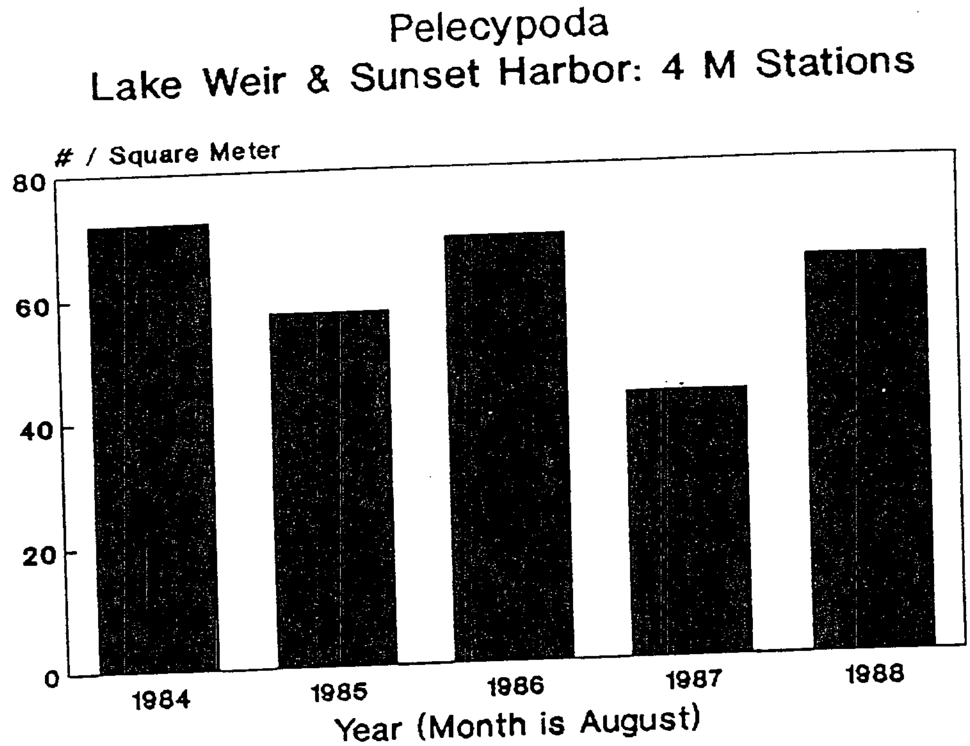


Figure 5-71. Historical changes in the mean biomass of Nematoda and Gastropods at 4 meter stations in the Lake Weir system.



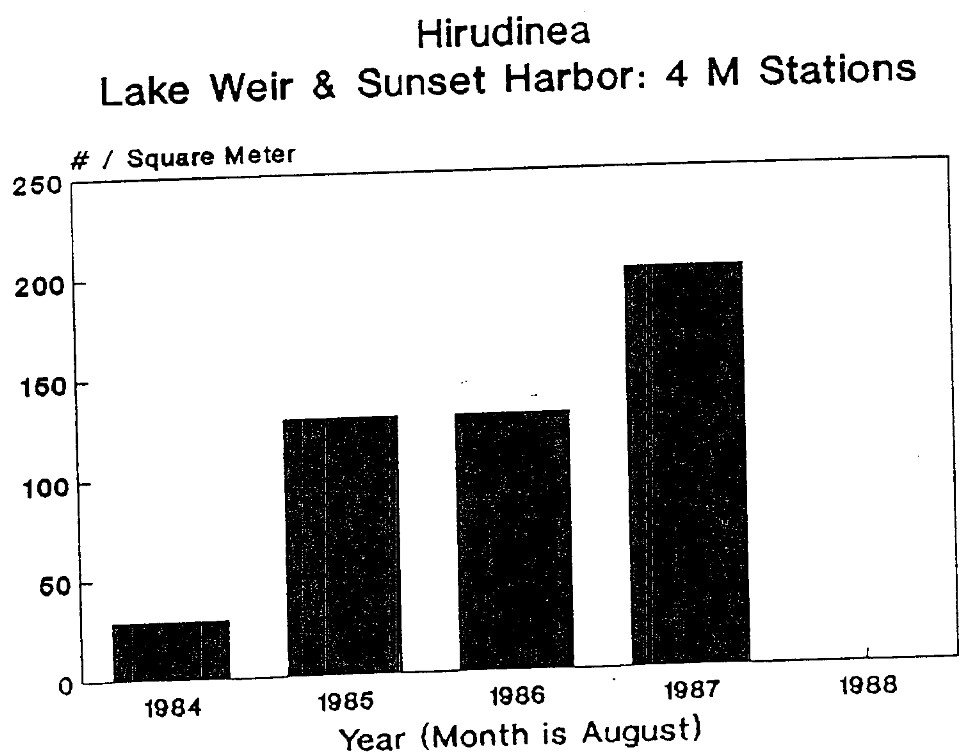
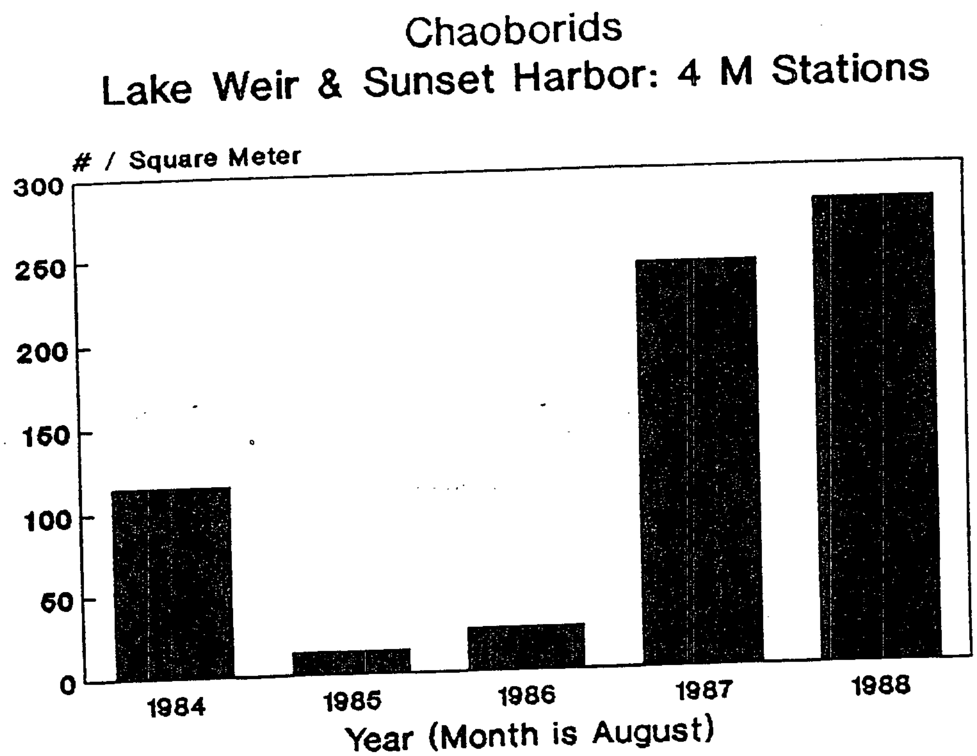


Figure 5-72. Historical changes in the mean biomass of Pelecypoda and Hirudinea at 4 meter stations in the Lake Weir system.



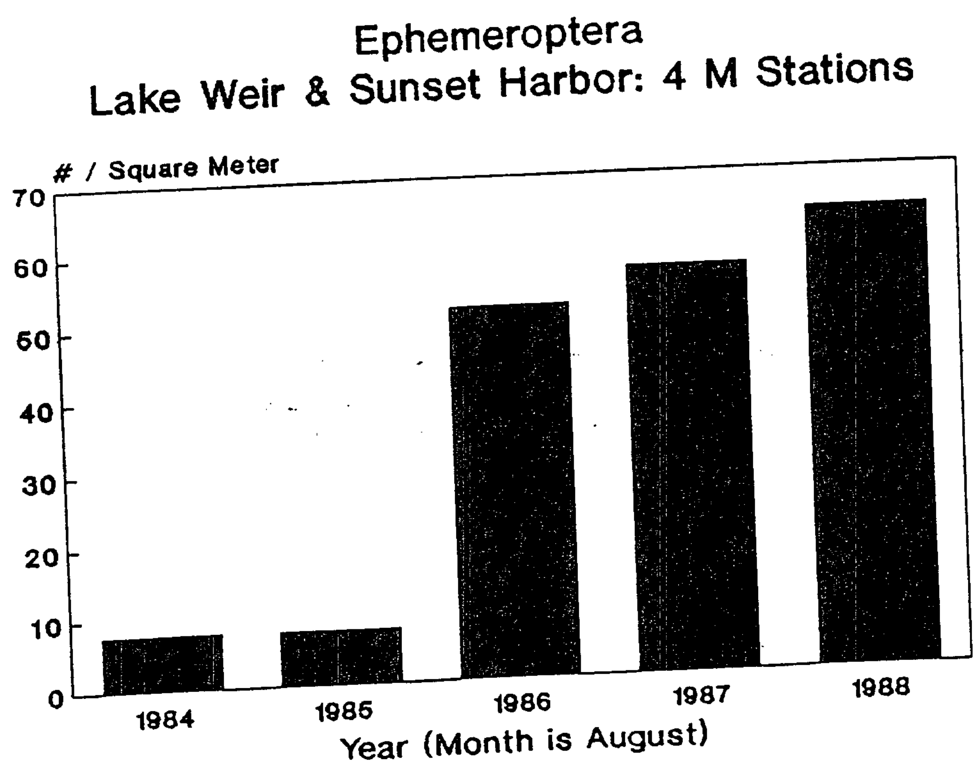


Figure 5-73. Historical changes in the mean biomass of Ephemeroptera and chaoborids at 4 meter stations in the Lake Weir system.

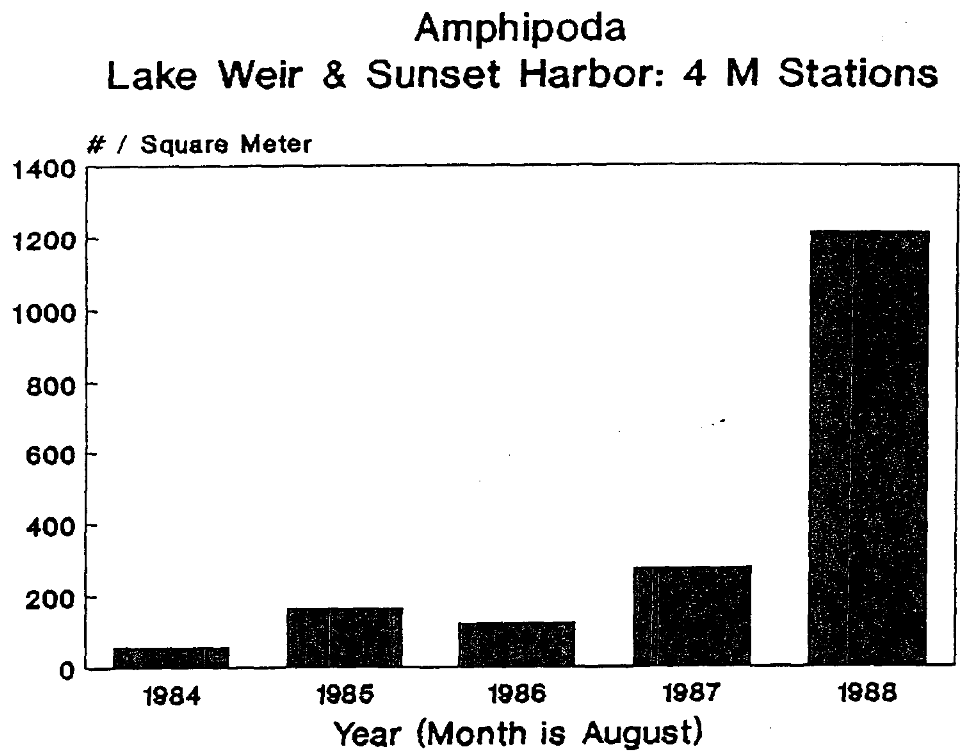
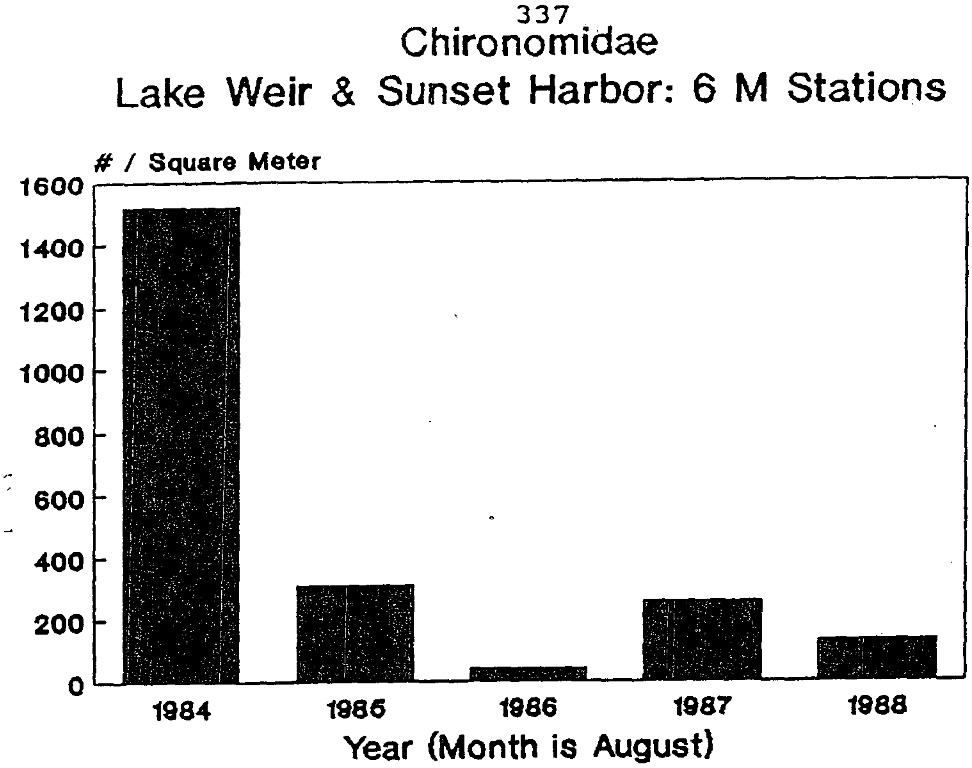


Figure 5-74. Historical changes in the mean biomass of Amphipoda at 4 meter stations in the Lake Weir sys



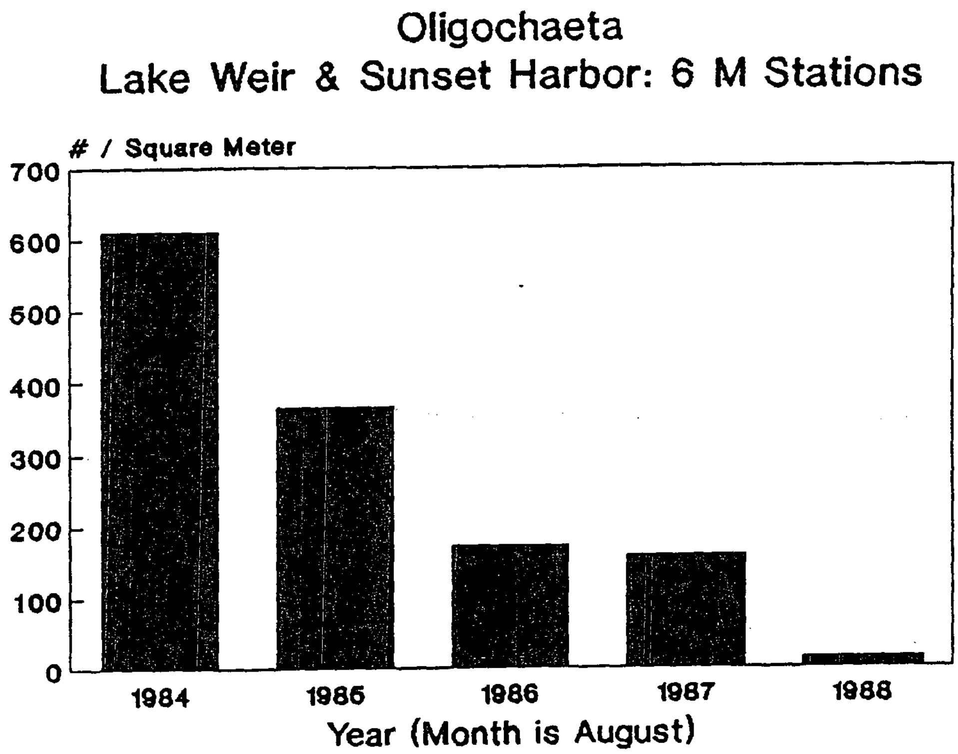
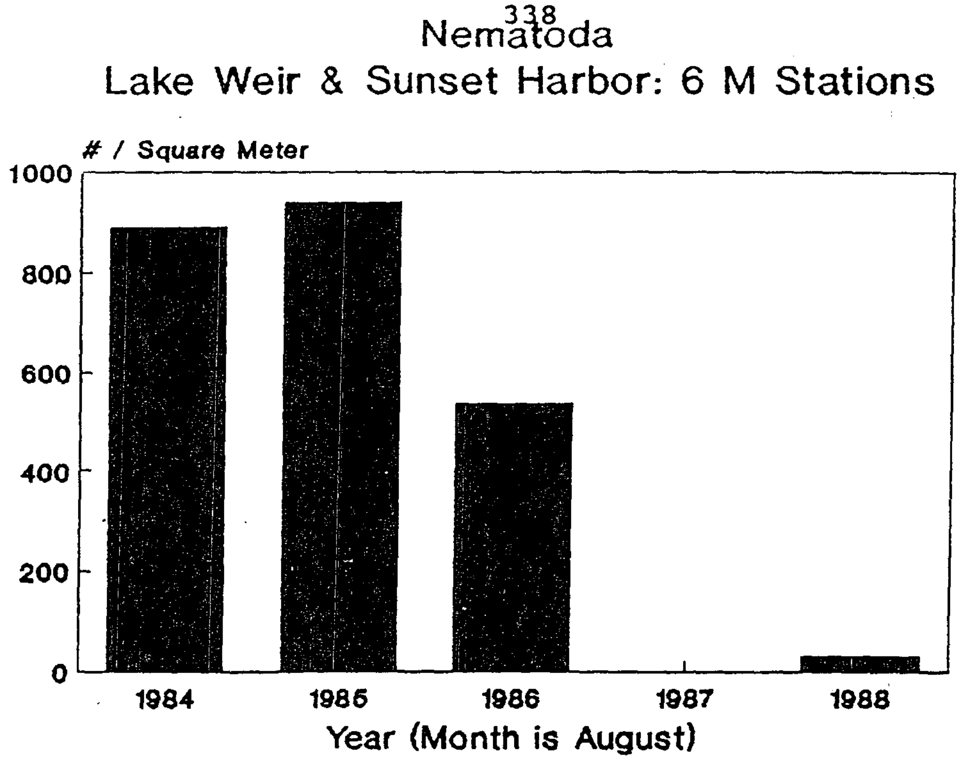


Figure 5-75. Historical changes in the mean biomass of Chironomidae and Oligochaeta at 6 meter stations in the Lake Weir system.



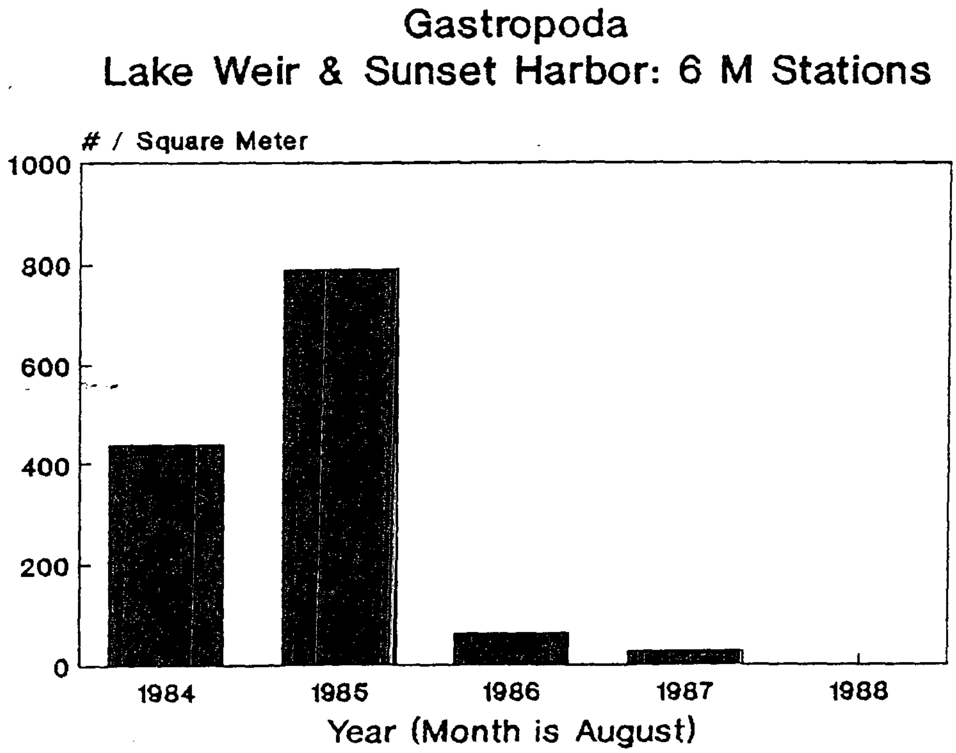


Figure 5-76. Historical changes in the mean biomass of Nematoda and Gastropoda at 6 meter stations in the Lake Weir system.

in 1988. The biggest drops occurred in 1985, 1986, and 1988 resulting in a major population crash.

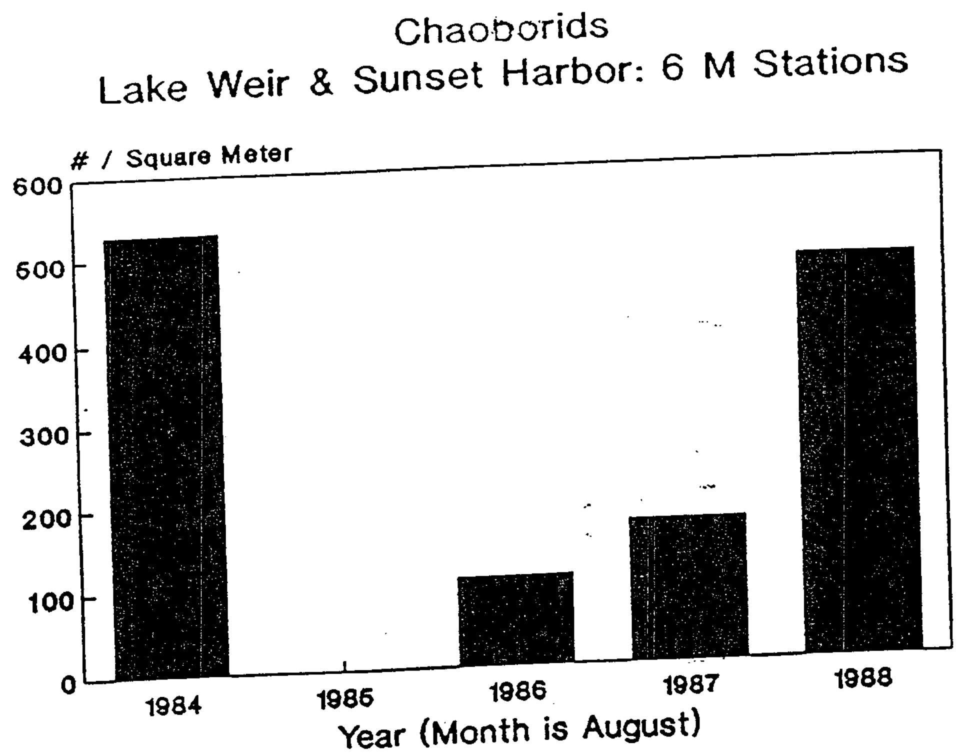
Nematode density dropped about 40% from 1985 to 1986 and 100% by 1987 (Figure 5-76). Very few nematodes were collected in August 1987 and 1988. The gastropod population decreased progressively every year after 1985 (Figure 5-76). In 1985 there were about 800 snails per square meter but, by August 1988, there were zero at station 1.

Chaoborid densities increased from zero in 1985 to about $150/m^2$ in 1987 and $500/m^2$ in 1988 (Figure 5-77). However, in 1984, the density was greater than $500/m^2$ so it took four years for the population level to recover from the crash that occurred in 1985. There was no clear trend in the population changes of amphipods (Figure 5-77). Very few were found in the alternate years of 1984, 1986, and 1988. However, a population of almost 350 amphipods per square meter existed in 1985. A population one-fourth that occurred two years later in 1987.

5.5.D.5 SEVEN METER DEPTH. Around 7 meters deep, station 3 was located in the middle of Lake Weir. No nematodes were found there in 1987 and 1988, but large populations of nematodes were found at that depth from 1984 to 1986 (Figure 5-78). These populations displayed a 50% decrease between successive years. A nematode density of about $2800/m^2$ occurred in 1984; by 1986 it was $600/m^2$ and in 1987 and 1988 it was zero.

Like nematodes, oligochaetes diminished and then disappeared three years after their maximum population level in 1985 (Figure 5-78). There were sharp population decreases from 1985 to 1988. After an increase from 1984, Oligochaeta numbered over $1000/m^2$ in 1985 and only $200/m^2$ in 1987. No oligochaetes were collected in August 1988 at 7 meters. Gastropod populations diminished significantly every year (Figure 5-79). There were about $110/m^2$ in 1984 and less than $30/m^2$ in 1987. In August 1988, no gastropods were found.

In general, very few leeches were encountered. A Hirudinea population of more than $70/m^2$ was found in August 1987 yet none were found one year before nor one year later (Figure 5-79). A density of around $10/m^2$ existed in 1984 and in 1985. Trends were more apparent with the Chironomidae. In 1985 and in 1986, the chironomid population diminished (Figure 5-80). A density of less than $100/m^2$ occurred in 1986. Reversing the trend, the population density recovered some in 1987 and increased further in 1988. The density of chironomids was greater than $1100/m^2$ in August 1988.



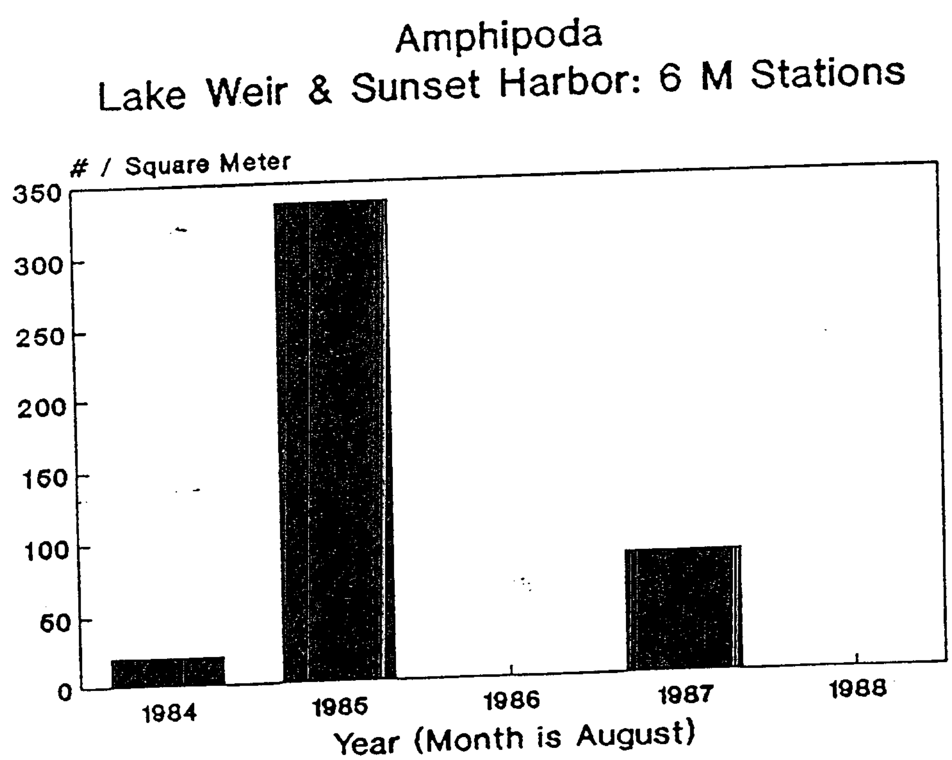
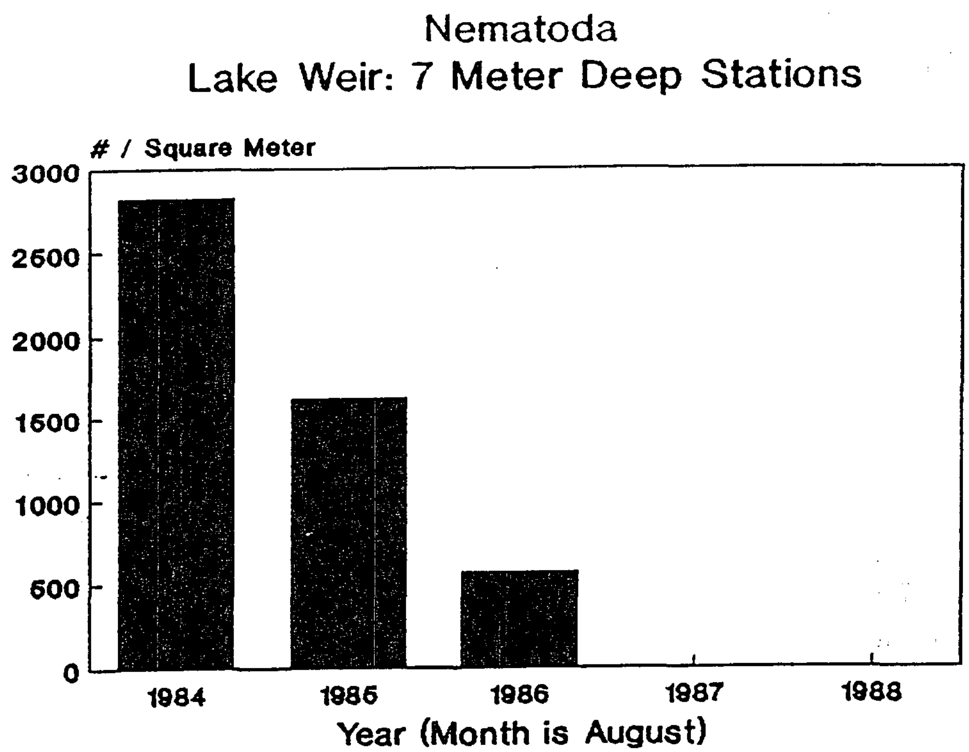


Figure 5-77. Historical changes in the mean biomass of chaoborids and Amphipoda at 6 meter stations in the Lake Weir system.



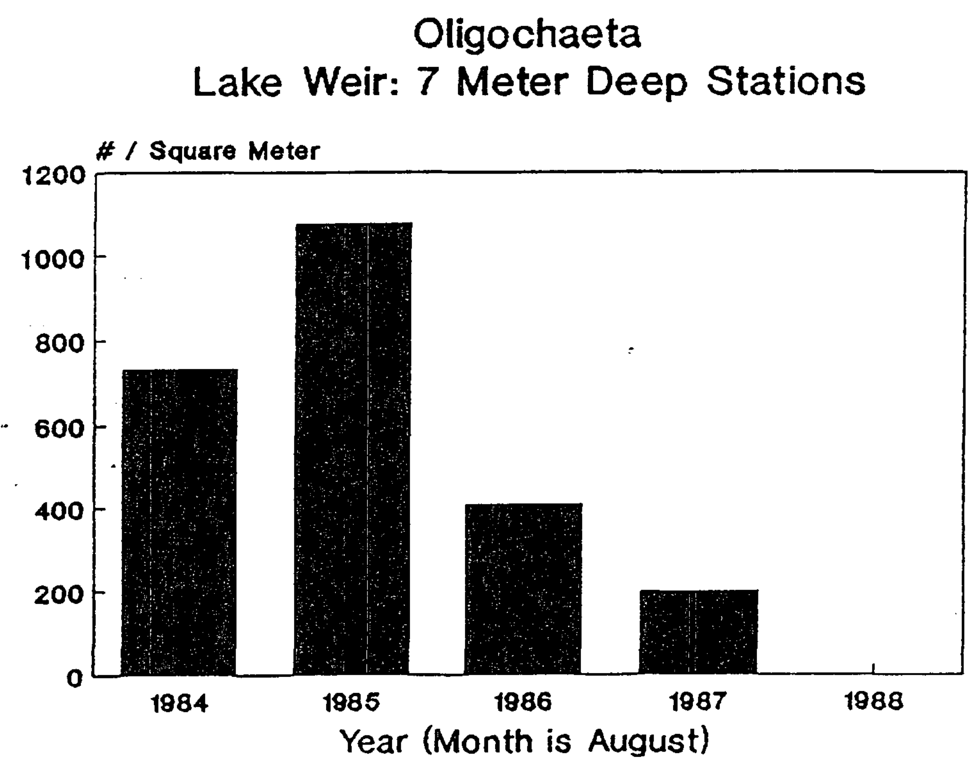
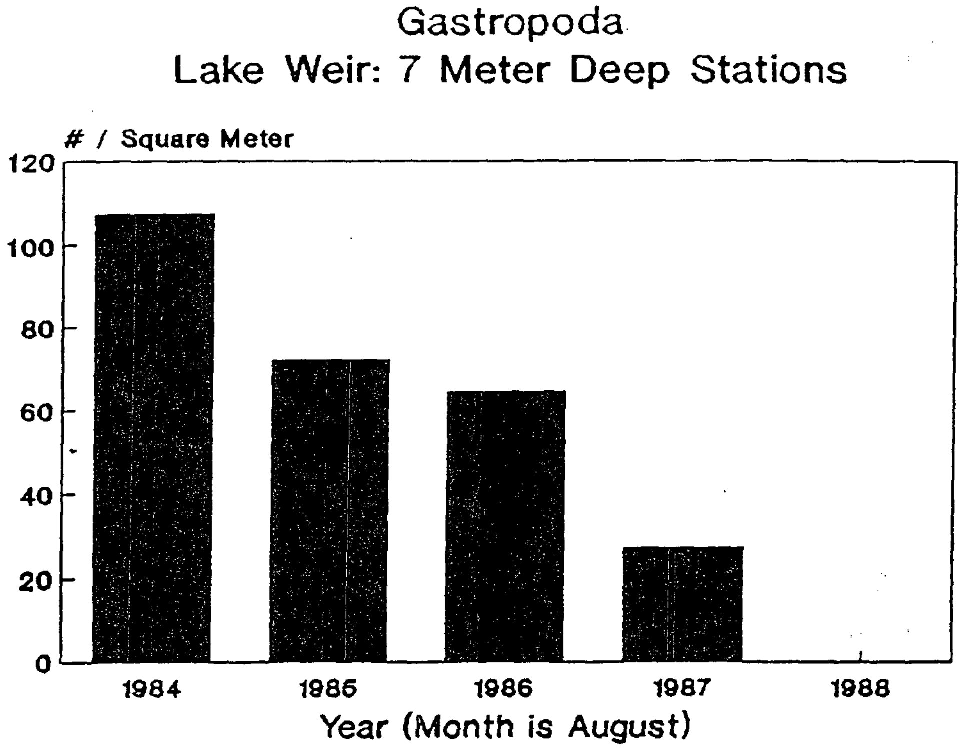


Figure 5-78. Historical changes in the mean biomass of Nematoda and Oligochaeta at 7 meter stations in the Lake Weir system.



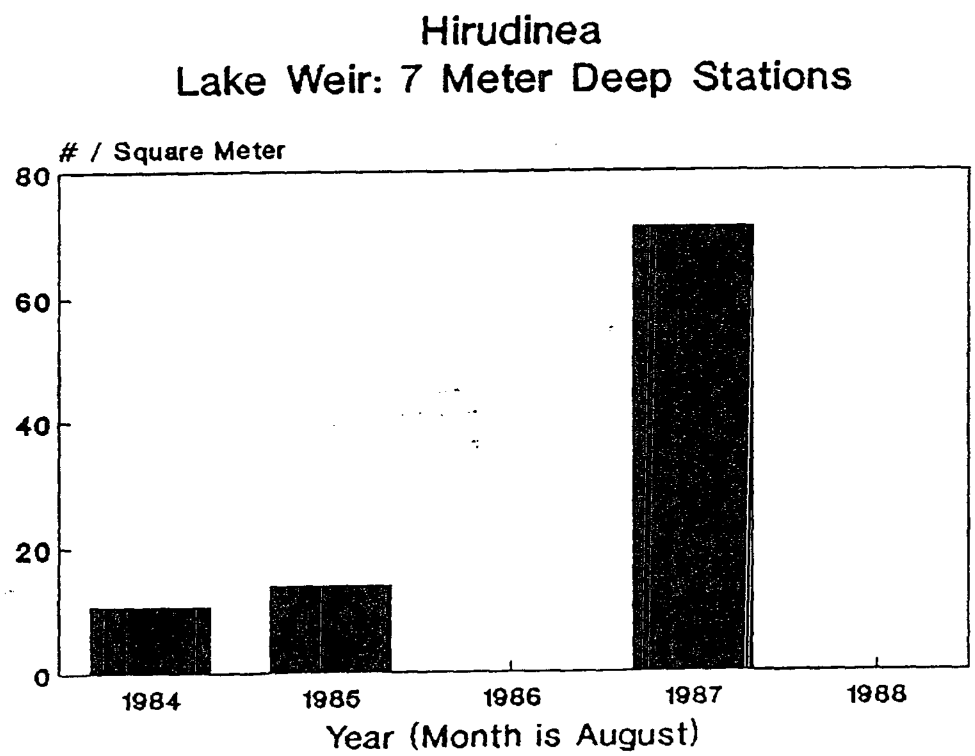


Figure 5-79. Historical changes in the mean biomass of Gastropoda and Hirudinea at 7 meter stations in the Lake Weir system.

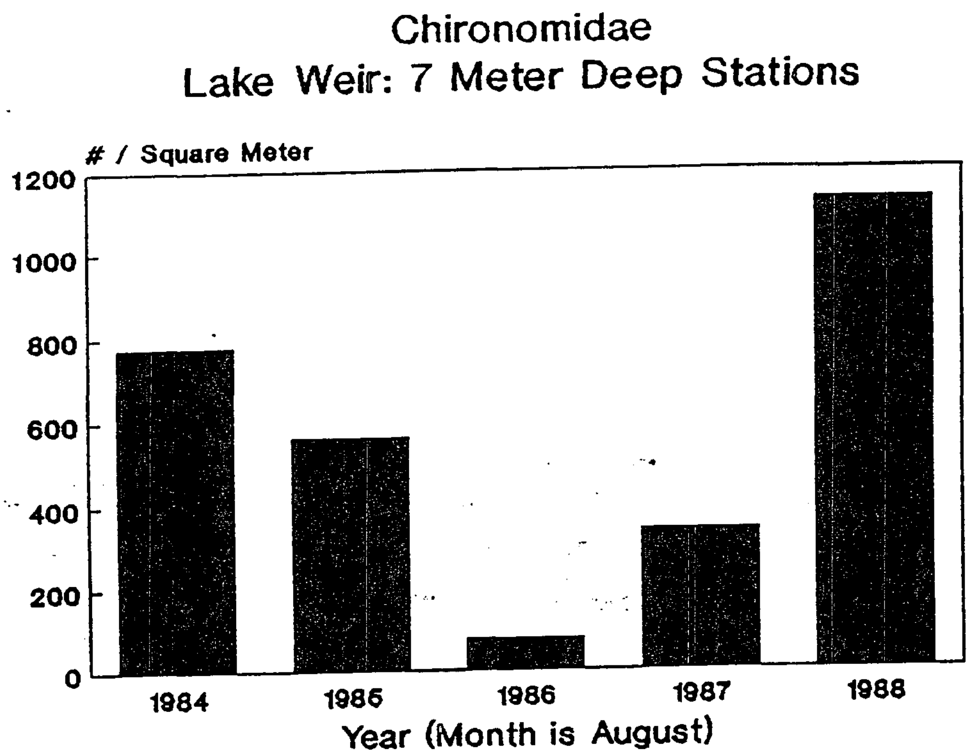


Figure 5-80. Historical changes in the mean biomass of Chironomidae at 7 meter stations in the Lake Weir system.

5.5.D.6 SUMMARY. Overall, the five year historical data indicated that the populations of many taxonomic groups were declining (at least during the mid-summer). For various depths, a total of 15 population changes for various taxonomic levels were interpreted to be major historical reductions. In comparison, only 5 changes over the five years were viewed as being conspicuous increasing trends. Various groups even appeared to be disappearing--during August if not the whole year--at all depths. The reductions at 7 meter deep stations in Lake Weir were among the most conspicuous.

Interestingly, the most populous groups were often the ones that were diminishing most rapidly. Chironomids--the most numerous group--experienced sharp drops in their populations at 3, 4, and 6 meters. Oligochaete populations declined just as quickly at 3, 4, 6, and 7 meter stations. Nematodes were rarely collected the last two years although they were numerous before 1987. Even the long-lived gastropods had major population reductions at all four depths.

On the basis of the data collected from 1984 to 1989, the benthic communities in Lake Weir appear to be becoming more impoverished. The diminishing populations of many taxonomic groups may be the indirect result of increasing nutrients or toxic compounds in the lake. Whatever the cause, the effect of the benthic impoverishment may be serious for all the lake's biota. In particular, many fish species feed directly on benthic macroinvertebrates. If the populations of benthos continue to decline, the structure of the fish community will undoubtedly change.

5.5.E. COMPARISON OF THE BENTHIC INVERTEBRATE COMMUNITY IN LAKE WEIR WITH THAT OF OTHER FLORIDA LAKES

Interpretation of benthic invertebrate data for Florida lakes is hindered by the lack of a detailed calibration model for the state. As part of an unfunded research project, we have collected all benthos data available from the files of state agencies and universities for comparison with the current data base.

The relationship between total benthos abundance (minus mollusks) and chlorophyll a in Florida lakes is not clear (Figure 5-81). We feel that the apparent lack of a clear relationship reflects the fact that extremely macrophyte-infested lakes have been included in the database, and no attempt has yet been made to account for either substrate

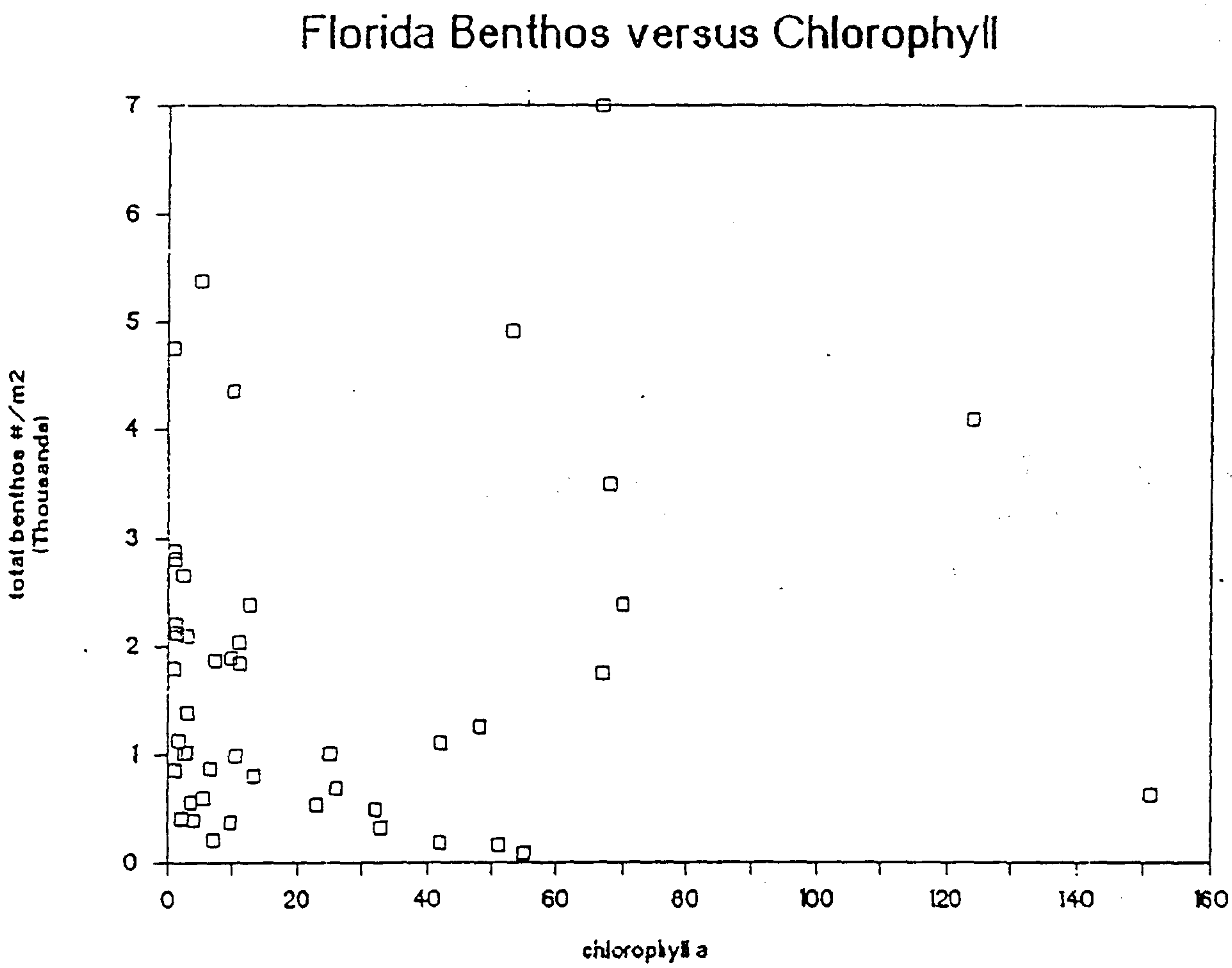


Figure 5-81. Relationship between total benthic invertebrates (minus molluscs) and chlorophyll for Florida lakes.

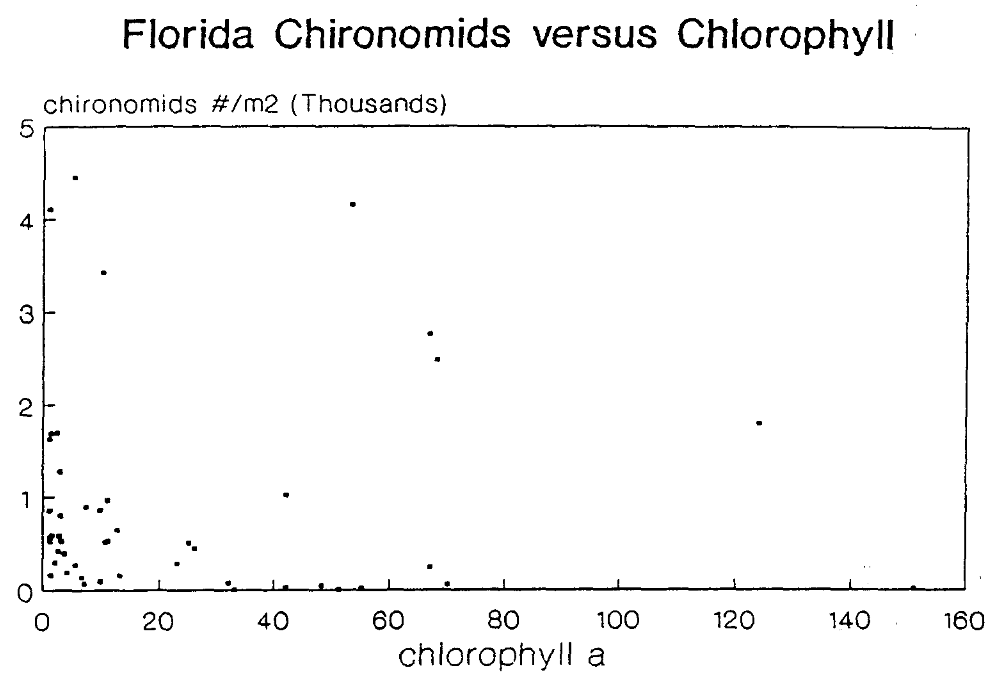


Figure 5-82. Relationship between the abundance of chironomids and chlorophyll for Florida lakes.

organic content and degree of flocculation or differences in sampling methodologies. We are now incorporating these factors into our model construction.

We have also examined the relationship between total chironomid abundance and chlorophyll a for our Florida lake database (Figure 5-82). As mentioned previously for total benthos, we are now incorporating additional environmental and substrate factors with the hope of delineating relationships that may be of value for predicting water quality in Florida lakes.

Our laboratory has collected more than four years of benthos data on the Oklawaha lakes. As sampling methodologies were similar between this study and the current investigation at Lake Weir, we can use the former database to predict how the benthic invertebrate community of the Lake Weir system may respond to further cultural eutrophication.

Total benthos abundances (minus mollusks) in the three basins of the Lake Weir system were similar to those of the more eutrophic Oklawaha lakes (Figure 5-83). The notable exceptions were Lakes Eustis and Apopka, which displayed the lowest values of both investigations. Oligochaete abundance in the Lake Weir system (Figure 5-84) was comparable to that of the three least productive Oklawaha lakes (Eustis, Griffin, Apopka) and more than five times lower than the most productive lakes (Dora and Beauclair). It appears that annual mean chlorophyll concentrations in the Lake Weir system would have to increase 500% before oligochaetes would be expected to be significantly more abundant.

Finally, chironomid abundance in the three basins of the Lake Weir system approximated that of Lakes Griffin and Dora but was higher than that of the other three lakes (Figure 5-85). Of the three latter lakes, Apopka and Beauclair displayed the most flocculent sediments.

On the basis of our preliminary analysis of benthos in Florida lakes, it appears that the abundance of total benthos, chironomids, and oligochaetes in the Lake Weir system should not change markedly if a moderate rate of cultural eutrophication continues. However, if sediments become flocculent, regardless of a change in annual mean chlorophyll, major changes in chironomid abundance could occur. These observations are considered preliminary and will be tested further as our work on analysis of the Florida benthos database continues.

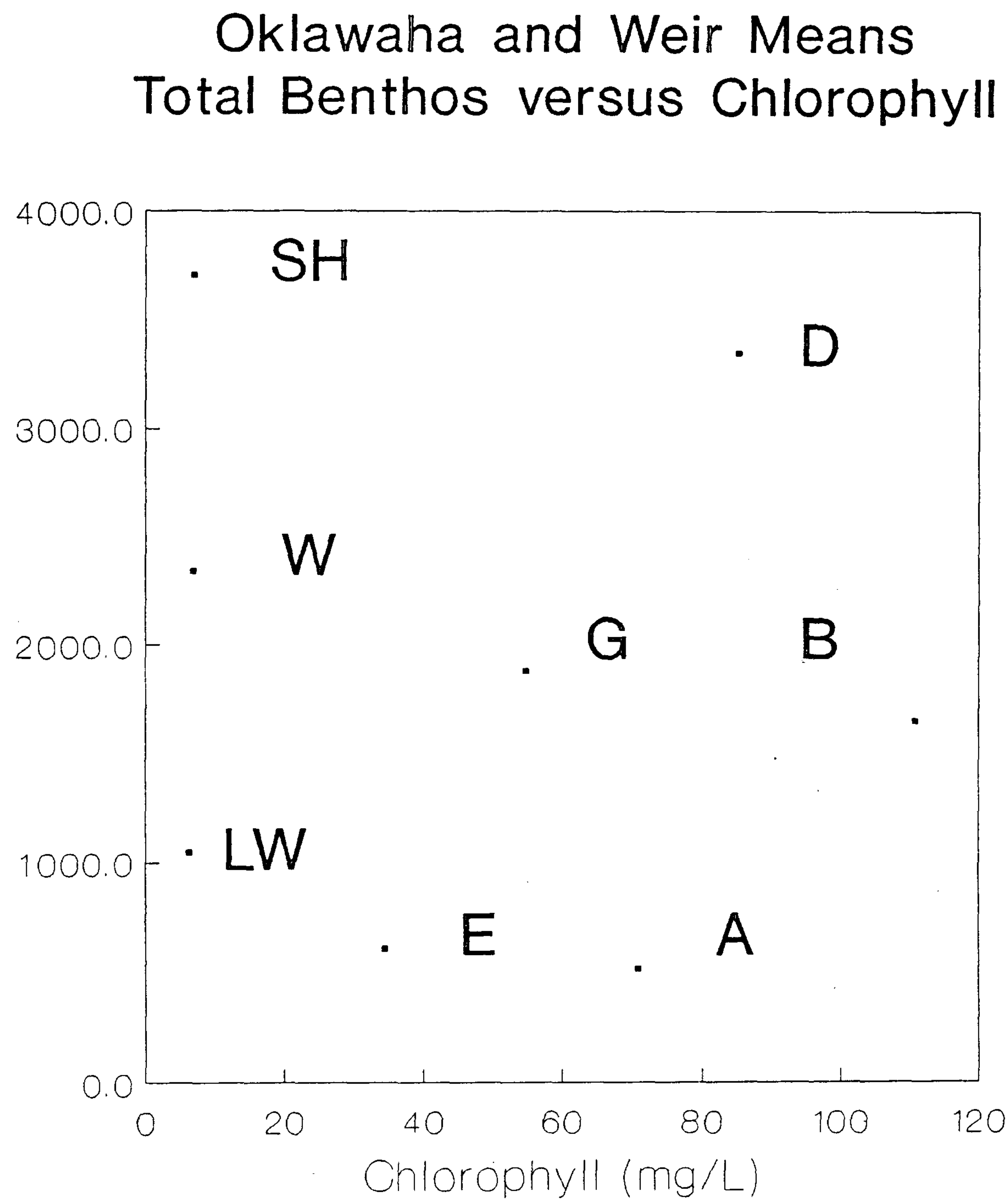


Figure 5-83. Relationship between the abundance of total benthic invertebrates and chlorophyll for Lakes Apopka, Beauclair, Dora, Eustis, Griffin, Weir, Sunset Harbor, and Little Lake Weir.

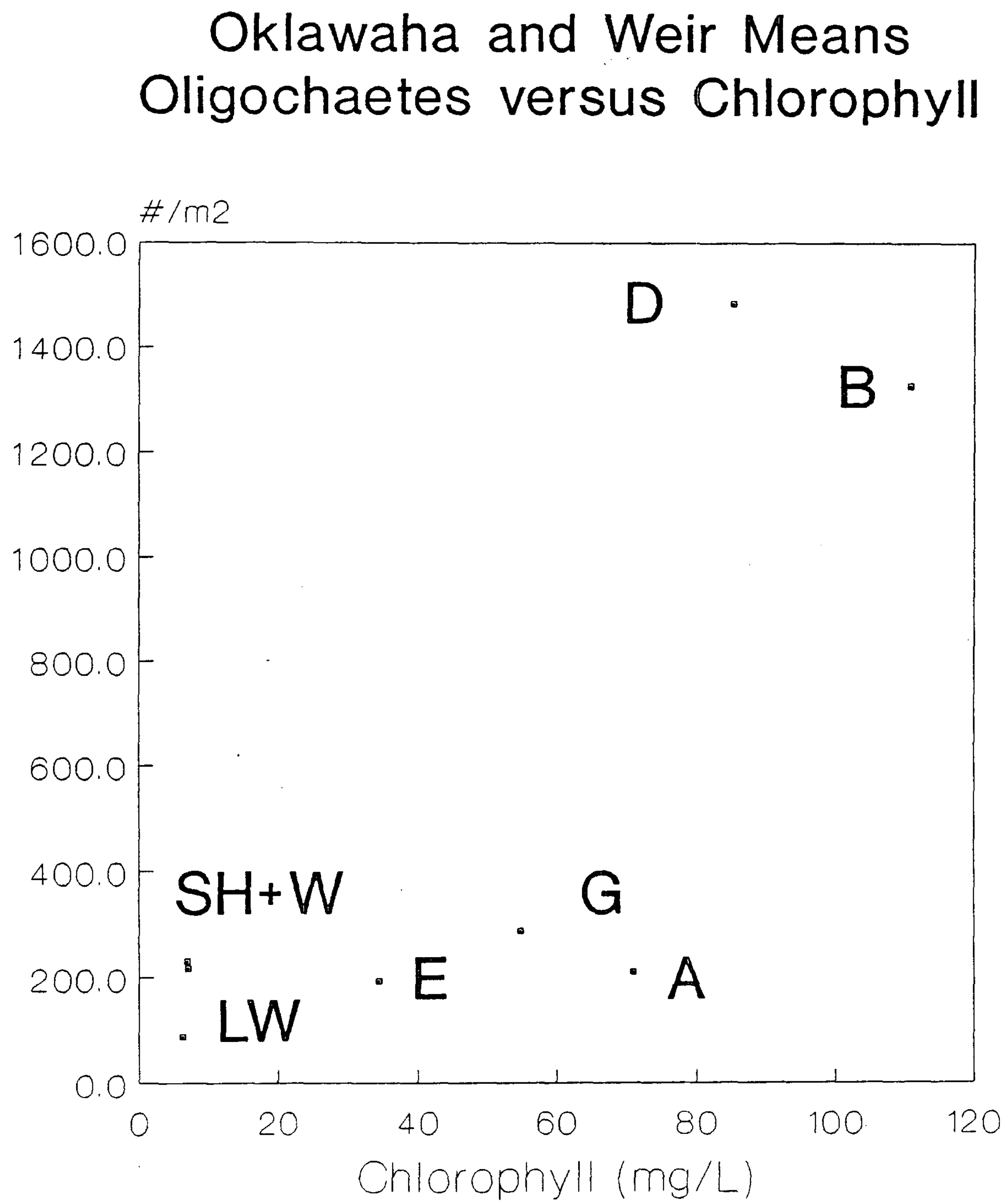


Figure 5-84. Relationship between the abundance of oligochaetes and chlorophyll for Lakes Apopka, Beauclair, Dora, Eustis, Griffin, Weir, Sunset Harbor, and Little Lake Weir.

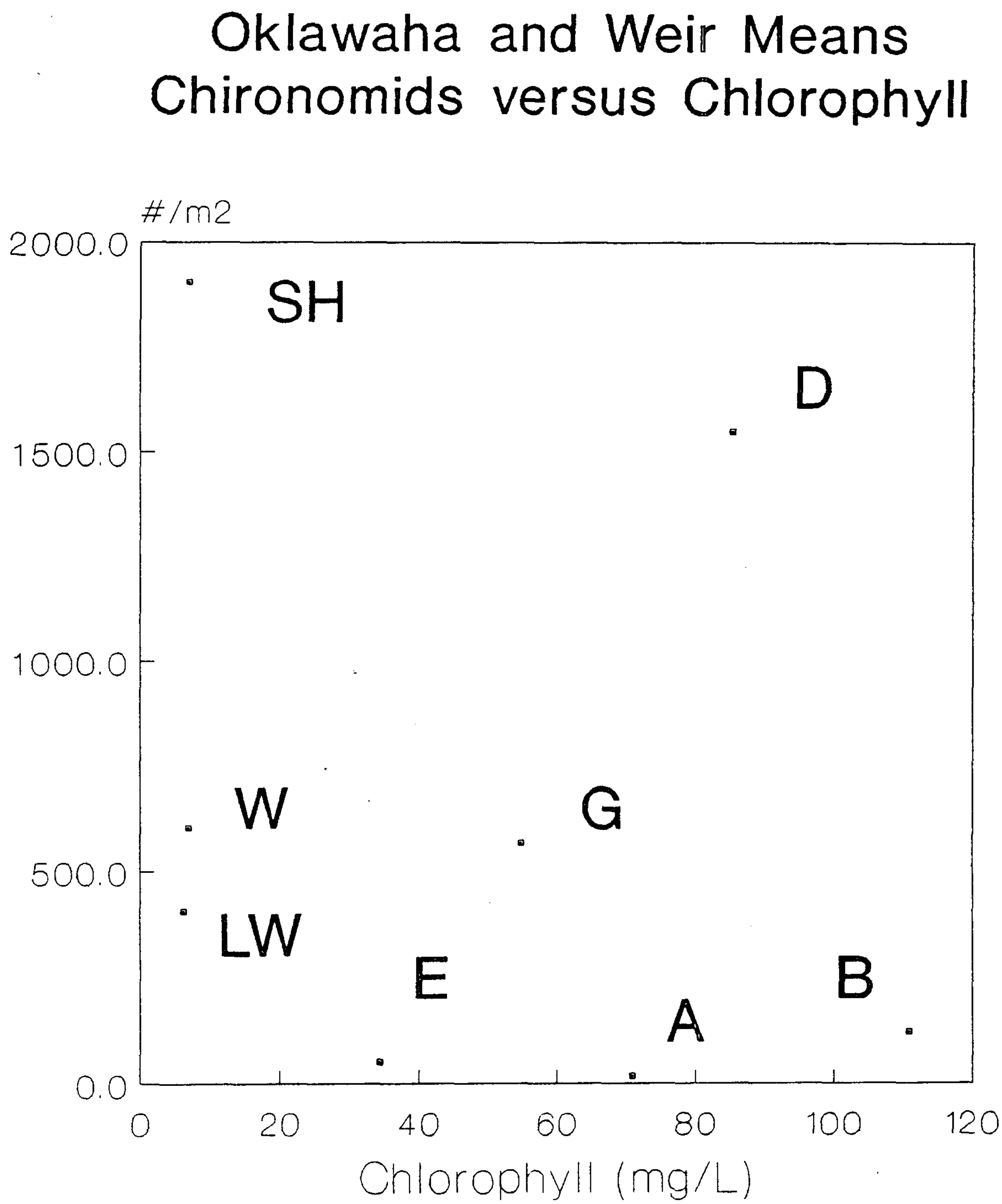


Figure 5-85. Relationship between the abundance of total chironomids and chlorophyll for Lakes Apopka, Beauclair, Dora, Eustis, Griffin, Weir, Sunset Harbor, and Little Lake Weir.

5.6 FISH

5.6.A THE FISH ASSEMBLAGE OF LAKE WEIR

Lake Weir's fish assemblage is typical of many mesotrophic Florida lakes (Keller 1984, FGFWFC 1975-1986). Centrarchids such as bluegill, redear sunfish, black crappie and largemouth bass have been the dominant gamefish species historically (Table 5-19). Forage fish include threadfin shad, brook silversides, mosquitofish, Seminole killifish and golden shiners, while rough fish are represented by gar and mudfish (FGFWFC 1985). In all, 19 species of fish have been identified in Lake Weir. This value corresponds to the predicted number of species for a lake with a pH of 7.15 and a surface area of 2,086 hectares based on regression models (Table 5-20) for Florida lakes (Keller 1984).

Historical records of year class strength and the abundance of particular species are lacking because little routine monitoring of fish occurred prior to 1983 (FGFWFC 1985). At that time, the FGFWFC initiated a fish population survey in response to public concern over the onset of algal blooms and a declining black crappie fishery. This monitoring was continued in 1985 and 1986.

Survey results (Figure 5-86) indicate that the Lake Weir (only the main basin) largemouth bass population has fluctuated somewhat (from 20,722 in 1983 to 13,493 in 1987), as have those of the bluegill and redear sunfish. Such changes are normal responses to food availability, climatic cycles and mortality due to disease or fishing pressure. However, the complete loss of black crappie between 1982 and 1984 is not so easily explained.

5.6.B LOSS OF CRAPPIE IN LAKE WEIR

Interviews with fishermen and data from creel reports indicate that in 1981-1982 almost all of the black crappie caught were large, i.e. older adults. By 1983-1984, the catch had declined dramatically and in the following year there were virtually no crappie at all. Extensive sampling by the FGFWFC with a variety of methods resulted in the capture of only eight crappie individuals between 1983 and 1988. Several hypotheses have been proposed to explain this dramatic loss. They include changes in habitat quality due to eutrophication, the colder than normal winters of 1982

Table 5-19. Lake Weir fish species list*.

SCIENTIFIC NAME	COMMON NAME
Micropterus salmoides floridanus	Largemouth bass
Lepomis macrochirus	Bluegill
Lepomis microlophus	Redear sunfish
Lepomis gulosus	Warmouth
Lepomis marginatus	Dollar sunfish
Pomoxis nigromaculatus	Black crappie
Enneacanthus gloriosus	Bluespotted sunfish
Esox niger	Chain pickerel
Erimyzon succetta	Lake chubsucker
Notemigonus crysoleucas	Golden shiner
Fundulus seminolis	Seminole killifish
Gambusia affinis	Mosquitofish
Labidesthes sicculus	Brook silverside
Amia calva	Bowfin
Etheostoma fusiforme	Swamp darter
Lepisosteus platyrhincus	Florida gar
Dorosoma petenense	Threadfin shad
Ictalurus nebulosus	Brown bullhead
Ictalurus natalis	Yellow bullhead

*FGFWFC 1985.

Table 5-20. Predicted number of fish species in Lake Weir using two regression models[a] based on lake pH and lake surface area.

Model[b]	Predicted No. Species
$Y = 0.42\ (pH) + 1.34$	18.8
$Y = 0.75\ (SA) + 3.55$	20.8

[a]From: Keller (1984). [b]Y represents the square root of the (number of fish species + 0.05).

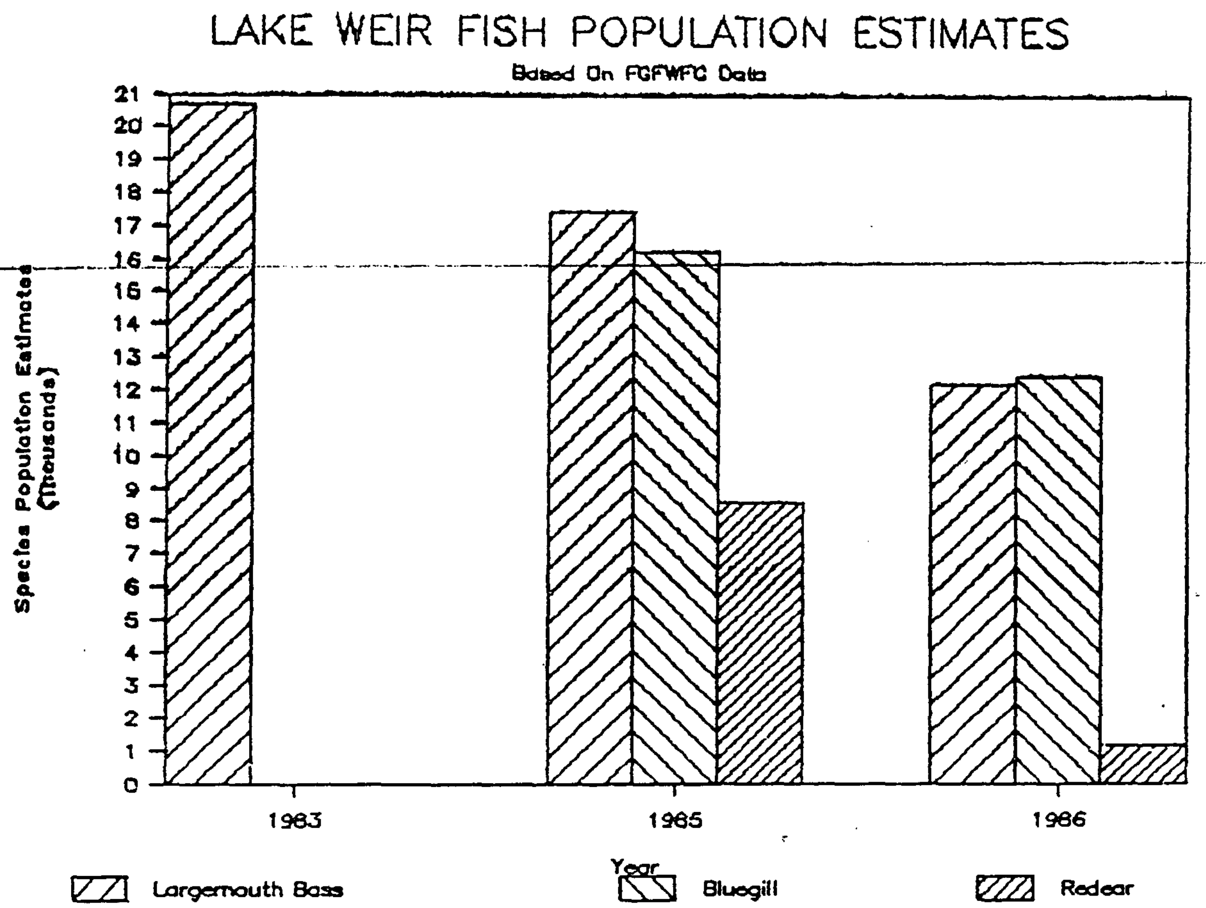


Figure 5-86. Population estimates of largemouth bass, bluegill, and redear sunfish in Lake Weir (proper) 1983-86.

Table 5-21. Some possible causes of the loss of black crappie from Lake Weir, FL and results of analyses of each parameter.

Possible Cause	Finding	Conclusions	Reference
Fish pathogens	*Aeromonas*, white grubs	Not significant	Bitton *et al*. (1982); Goldsby and Plumb (1987).
Food limitations	abundant forage, plankton, fish, macroinvertebrates	Not a factor	FGFWFC (1983-1986); Current work.
Habitat changes	Good mixture of littoral/pelagic, sandy and soft sediments	Should not affect reproductive success	Current work.
Winter temperatures	Much colder than usual (1983-84)	Did not affect other crappie populations	FGFWFC[a]
Pesticides/ heavy/metals	DDE found in several fish samples, but very low. No other pesticides identified. Metals low.	Measured levels not high, but other pesticides may be present. More work suggested.	FDER (1987)

[a] Personal communication from Sam McKinney, Ocala office of the FGFWFC.

and 1983, food limitations or losses, an influx of heavy metals or pesticides from the citrus groves killed by recent winter freezes, and a species-specific viral or bacterial agent (Table 5-21).

While each sunfish species exhibits some degree of food preference, they are all considered generalists (Werner 1977). That is, their diets overlap considerably. If one food type becomes limited, such fish can switch to another food source. Macroinvertebrates, forage fish and plankton appear to be abundant in recent Lake Weir samples (FGFWFC 1985 and 1986, current study). Thus, since only normal fluctuations in other sunfish generalists (i.e., bluegill and redear sunfish) occurred between 1983-86 in Lake Weir, it is not likely that crappie were lost because of food limitations.

The habitat requirements for successful recruitment of sunfish species commonly found in Lake Weir are similar (Carlander 1977). Sunfish build nests in sandy areas along the border between open water and vegetation. They prefer fairly compact sediments which are common along the shoreline of Lake Weir. The open water/plant interface is an important boundary for large size classes of crappie, bluegill and redear sunfish. Black crappie become more pelagic as they mature, while the bluegill and redear sunfish remain in the littoral zone. Since both pelagic and littoral zones are present in Lake Weir, loss of habitat cannot explain the extinction of crappie.

Statistical comparisons between current and historical estimates of Lake Weir's trophic state indicate that while there has been no significant change during the past 20 years (See Tables 4-5 and 4-6), recent phosphorus levels are higher and Secchi depth is lower than the annual means of past data. While Lake Weir is still mesotrophic, there may be a trend toward increasing lake productivity. Data from five Florida lakes (Apopka, Dora, Griffin, Newnan's and Ocean Pond) collected by the Florida Game and Fresh Water Fish Commission demonstrate the adaptability of black crappie to increasing trophic state (Figure 5-87). As chlorophyll a concentration increases so does the biomass of crappie. Therefore, Lake Weir crappie harvest should have increased with any increase in trophic state.

Extremely cold winters can lead to recruitment failure in fish populations for several reasons. Adults can be killed, the forage base may decline and/or eggs or fry may be adversely affected in early spawning species. Small, shallow lakes are more likely to experience fish losses due to extreme weather than are deeper lakes. In 1983 and 1984, the winters were inordinately cold. Since black crappie spawn in late winter or early spring, it is possible that their recruitment failed in those years due to the cold.

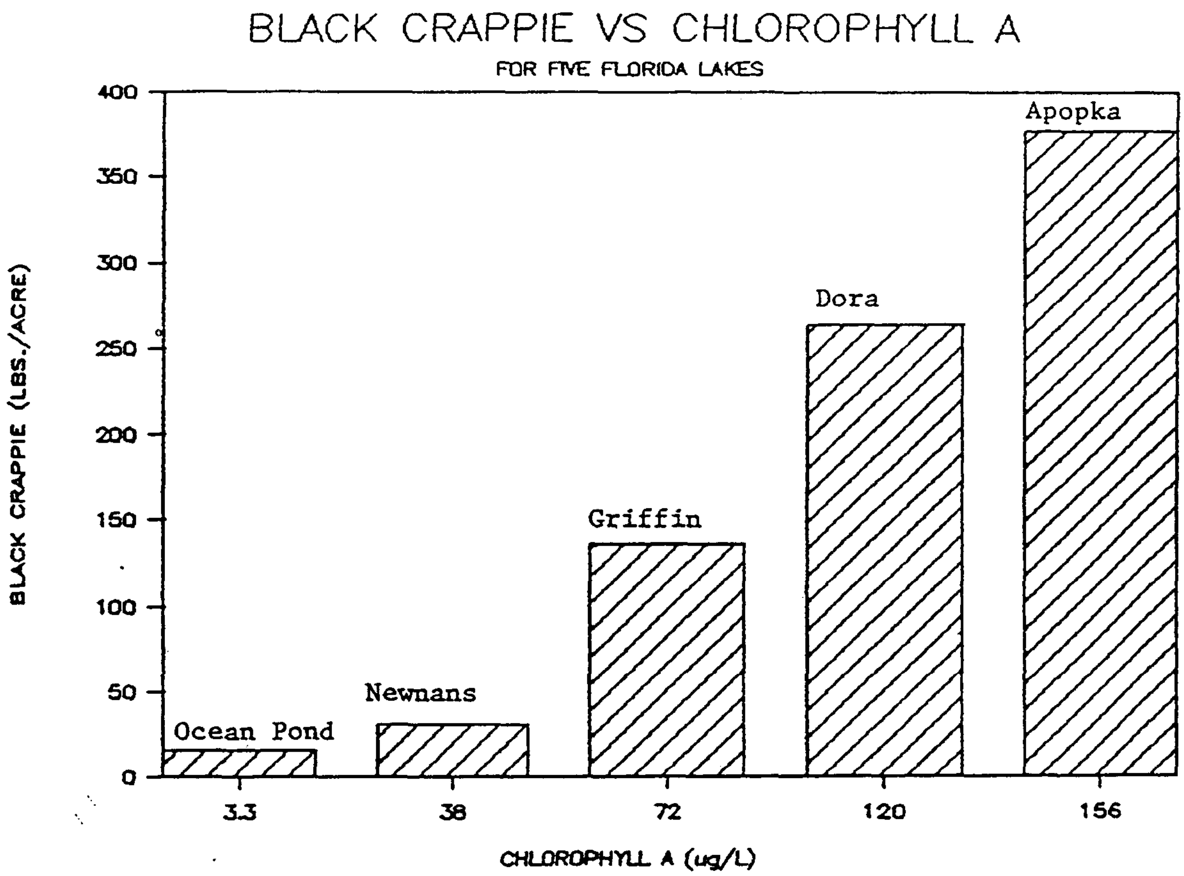


Figure 5-87. Biomass of black crappie relative to lake chlorophyll-a levels. Data from FGFWFC annual reports.

Indeed, some decline in other sunfish including largemouth bass and bluegill was detected in population surveys conducted in 1985 and 1986 (FGFWFC 1986). However, crappie populations in nearby shallower lakes were not lost (FGFWFC). It does not appear that cold weather killed the crappies.

A substantial citrus industry has flourished within the Lake Weir watershed since the late 1800's (Shackleford 1883). In the decades since World War II, the use of agricultural pesticides has increased steadily for all crops. Citrus growers have used a variety of these chemicals to boost crop production and minimize harvest effort. Pesticides have included organics such as DDT, aldrin and chlordane as well as compounds containing copper. With continual use, such chemicals accumulate in the trees and soils, and eventually they can begin to leach into lakes with runoff from rain.

Lake sediment, water and fish tissue samples were collected in 1986 by the FGFWFC for analysis of heavy metal and pesticide content. Results of analyses by the FGFWFC, Florida Department of Health and Rehabilitative Services, and Florida Department of Environmental Regulation (Table 5-22) detected virtually no heavy metals or pesticides in the samples (FGFWFC 1986). Copper ranged from 0.3-0.6 mg/kg wet weight, mercury from 0.09-0.85 mg/kg, zinc from 4.5-10.9 mg/kg and lead from 0.37-0.61 mg/kg. A few samples of largemouth bass had low but detectable amounts of DDE, a degradation product of DDT. The levels encountered, however, were not considered to be hazardous to fish (FGFWFC 1986).

There is nothing to suggest that black crappie are more vulnerable to pesticides than are largemouth bass. Consequently, it seems unlikely that influxes of pesticides from decaying citrus trees or grove soils eliminated the crappie.

Finally, Auburn University researchers Terry Goldsby and Dr. John Plumb have taken blood, muscle and organ samples from largemouth bass and bluegills to screen for pathological agents. Their findings through their 1989 field data suggest that parasite burdens may be a factor in the fish deaths occurring in Lake Weir. However, there is no indication of an unusual disease vector, and there was no largescale die-off of crappie.

Both white grubs and bacterial pathogens are common among natural fish populations (Hoffman 1967). It still remains unknown whether a species-specific agent killed the crappie population, but ongoing analysis of the Auburn University data is increasingly pointing to white grub as an important factor (S. McKinney, personal communication).

Table 5-22. Heavy metal concentrations in fish and hydrosoil samples from Lake Weir (1986).*

Fish Species	Total Length (mm)	Cd	Cu	Hg	Pb	Zn
		(mg/kg wet weight)				
Largemouth bass	538	0.05	0.6	0.45	0.46	5.4
Largemouth bass	463	BDL[a]	0.4	0.62	0.46	6.1
Largemouth bass	1320	BDL	0.5	0.85	0.61	4.5
Bluegill	91	BDL	0.4	0.10	0.37	9.5
Bluegill	66	BDL	0.3	0.10	0.40	10.9
Bluegill	79	BDL	0.6	0.09	0.40	9.1
				(MDL = 0.03)		

Soil	Cd	Cu	Hg	Pb	Zn
	(mg/kg dry weight)				
#1	0.07	3.4	0.04	2.31	11.7
#2	0.05	2.2	0.04	2.31	9.0
#3	0.03	1.1	BDL	1.59	3.7
			(MDL = 0.04)		

* Analyses performed by FGFWFC.
[a] BDL = Below Detection Limits; MDL = Minimum Detection Limits.

Researchers from the College of Veterinary Medicine, University of Florida, have also been collecting blood from crappies periodically. Their ongoing analyses are pointing to anemia as a factor in the crappie loss, but they have not been able, as yet, to separate nutrition versus pollution as the root cause for the anemia (S. McKinney, personal communication). Hopefully, continued analysis of data from these two investigations will better elucidate the root cause for the crappie decline in Lake Weir.

Black crappie were stocked (450,000 fingerlings, 600 adults) in Lake Weir in 1986 and 1987 (FGFWFC) but have not been detected to date after extensive population sampling efforts. No further stocking has taken place.

After examining the possible causes for the dramatic loss of the black crappie fishery, no obvious explanation exists. Extreme fishing pressure, inappropriate use of herbicides or other factors can contribute to fish population changes. But even these suggestions can be ruled out for Lake Weir since neither has occurred (FDNR and FGFWFC, personal communication). Perhaps a combination of factors led to the loss. If crappie can be re-established by stocking, the problem will be solved although an explanation for their current demise may be lacking. If not, further efforts to identify the factor or factors that killed the crappie will probably continue.

CHAPTER SIX:

PALEOLIMNOLOGY OF LAKE WEIR

6.1 INTRODUCTION

This project employs paleolimnology, the reconstruction of past water quality from lake sediment cores. By correlating historical trends in water quality to concomitant development within the watershed, we have been able to pinpoint the activities which have contributed most heavily to observed changes in past water quality.

Other paleolimnological work has been conducted at Lake Weir, chiefly by Thompson (1981), Flannery (1982) and Deevey et al (1986). Additional unpublished data exist in Deevey's laboratory. In addition to estimating accumulation rates of organic and inorganic sediment, chlorophyll a, nutrients and metals, these studies also examined diatom and pollen stratigraphies. The current investigation examines stratigraphic changes in water, organic, and inorganic content of sediment, phosphorus concentrations, and subfossil remains of chydorids, chironomids, and select green algae. Core intervals were dated by measuring lead-210 isotopic decay in order to estimate annual accumulation rates of each of the above parameters.

6.2 PALEOLIMNOLOGICAL METHODS

6.2.A CORE COLLECTION

Sediment cores for paleolimnological analyses were collected from six sites in Lake Weir, Sunset Harbor and Little Lake Weir in 1987 and 1988 (Figure 6-1, Table 6-1). Cores were collected using a modified Livingstone piston coring apparatus equipped with 4.1 cm ID cellulose buterate tubes. Appropriate caution was exercised to ensure preservation of the sediment-water interface. Visual observations of the cores were made in the field and again during sectioning in the lab in order to detect changes in sediment color or texture which might provide insight on the depositional environment.

All analyses were run on the primary core from northern

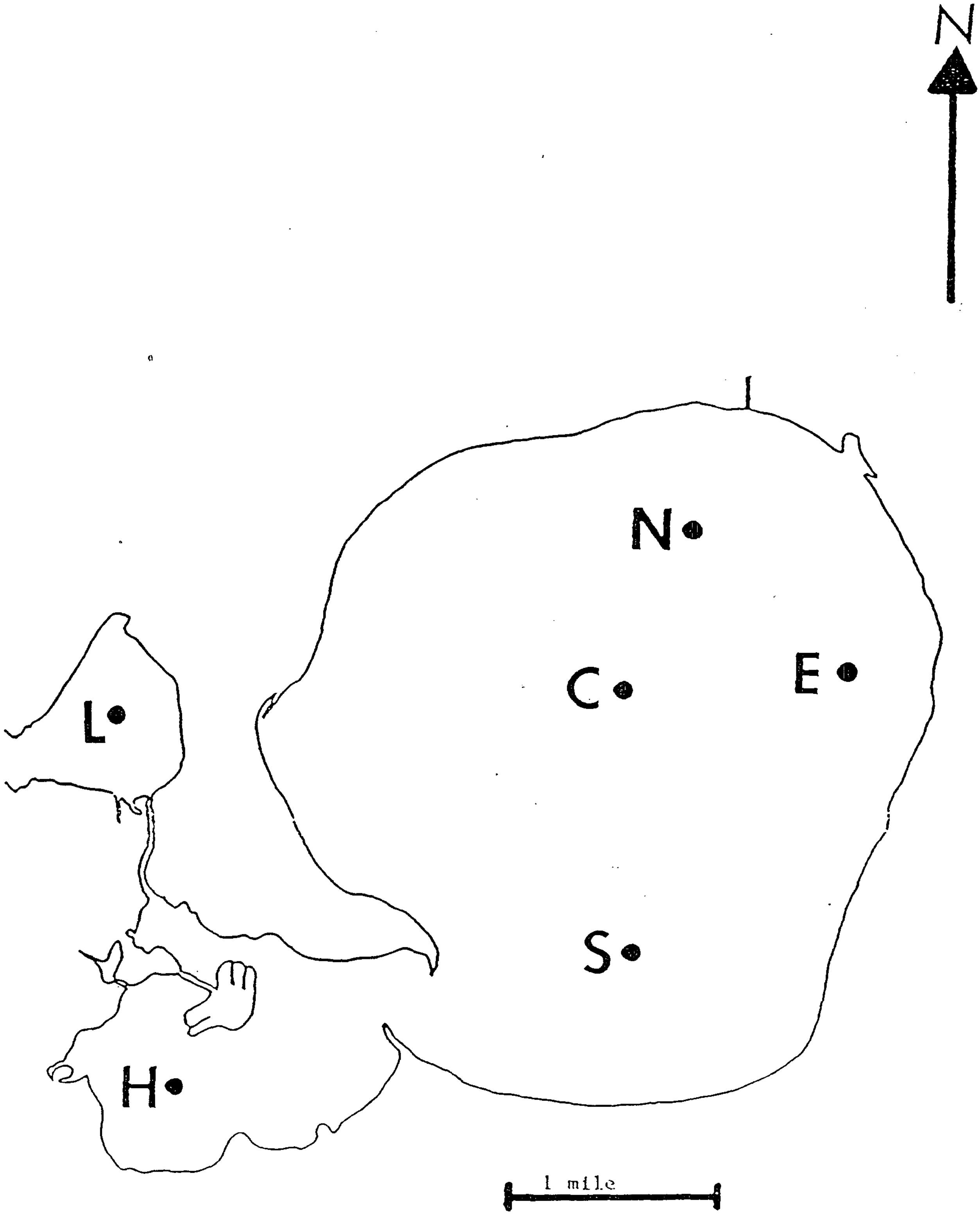


Figure 6-1. Coring sites in the Lake Weir system.

Table 6-1. Sediment core collection data for Lake Weir, FL.

Core Name	Location	Date	Number of Cores	Lengths(cm)
E	East Lake Weir	26 Feb 87	1	109
C	Center Lake Weir	26 Feb 87	1	120
N	North Lake Weir	14 Dec 87	2	111, 162
S	South Lake Weir	14 Dec 87	1	119
H	Sunset Harbor	14 Dec 87	2	110, 117
L	Little Lake Weir	6 Mar 88	2	132, 124

Lake Weir. This area of the lake was identified as one of the "hot spots" of algal growth during the Secchi disk survey (Crisman et al. 1990). Additionally, it was felt that the North core would most closely reflect watershed activities around the town of Oklawaha, including lake impoundment and associated dredging in 1938. Other core samples were retained for possible analysis if the North core results were non-conclusive.

The core was sectioned into 0.5 cm intervals to a depth of 30 cm, and into 1.0 cm intervals below that. The upper intervals contained roughly 6 cc, while the lower intervals had over 12 cc of sediment. Samples were sealed in plastic zip-lock bags and stored in a refrigerator. Because the amount of sediment was limited, small portions of alternating intervals were allotted for each analysis in order to conserve material for lead-210 dating. The core was carefully mapped out for this purpose.

6.2.B LEAD-210 DATING OF THE SEDIMENT CORE

Isotopic dating via lead-210 was performed in order to provide a chronology of the core's paleolimnological profiles. This would allow direct comparison between these parameters and concomitant developmental events in the watershed's history.

Lead-210 is a member of the uranium-238 radioactive decay series and is derived from radon-226 gas, a component of the atmosphere. Lead-210 falls out of the atmosphere and is deposited ubiquitously in natural sedimentary systems. It is not hazardous to work with, and its half-life of 22.26 years makes it ideal for precise dating up to 150 years.

Lead-210 in lake sediment comes from atmospheric fallout (unsupported) and from the underlying rocks (supported). Supported lead-210 exists as a uniform baseline concentration throughout the sediment, whereas unsupported lead-210 decays rapidly downward in the core (Rama and Goldberg 1961).

Concentrations of lead-210 and three short-lived daughter isotopes were measured on a low-energy, high-purity Germanium gamma-ray spectroscope. This unit permitted simultaneous determination of supported and unsupported lead-210 in lake-bottom sediments (Nagy 1988).

6.2.C SEDIMENT PREPARATION FOR DATING

Nine horizons of the core were selected for lead-210 dating. After sediment samples had been extracted for the other four paleolimnological analyses, all of the remaining sediment from the selected intervals was used for lead-210 dating. The uppermost sediment sample (0-4 cm) was taken from the backup north core from Lake Weir.

Each of the nine horizons spanned 4.0 cm of the core, with an equal amount of sediment from each of its intervals, so as not to bias the age determination. Each sample consisted of 40 to 50 cc of sediment (wet volume).

After weighing the wet samples, they were dried at 100°C for 24 hours, broken apart, and dried for 24 additional hours. The dried sediment was carefully hammered, pulverized by mortar and pestle, weighed, and placed in small plastic petri dishes. Most of the lower samples contained 2-4 g of dried material, but the top two intervals contained less than 1.0 g dried sediment.

In order to reduce air which could introduce additional radon daughter isotopes, sugar was added to fill the extra space in the sample dishes. Table sugar was ground with mortar and pestle until it no longer shined, and was mixed with the sediment samples. The petri dishes were filled with the sediment and sugar mixture and sealed with Duco (TM) cement. A blank containing only ground sugar was treated similarly.

Core samples were prepared on 2 September 1988 and were sealed for two weeks to allow equilibration of the radon daughter isotopes. Radiometric counting required fourteen to twenty hours per sample.

6.2.D CALCULATION OF SEDIMENT DATES

Dates were determined according to the assumptions of the constant rate of supply (CRS) model (Appleby and Oldfield 1983). First, influx of lead-210 into the lake was assumed to be constant. This is a valid assumption for most subtropical lakes, which are not subject to winter freezing and subsequent snow melts. Secondly, the residence time of the lead-210 in the water column must be constant. Because lead-210 is rapidly adsorbed onto fine particles, it is presumed to be deposited at the same rate as its atmospheric fallout (Binford and Brenner 1986). Finally, lead-210 must not migrate within the sediment after deposition.

The top 39 cm of the core had sufficient concentrations of unsupported lead-210 to allow dating, but deeper intervals were below detectable limits (Table 6-2). Total lead-210 levels reached almost 28 pCi/g in the surface sediment and stabilized below 3.0 pCi/g beneath 40 cm depth (Figure 6-2). Supported lead-210 levels were calculated by weighted average concentrations of the daughter isotopes. Unsupported lead-210, deposited in the lake from atmospheric fallout, was determined by simply subtracting the supported levels from the total lead-210 (Figure 6-2).

Dates were calculated using average concentrations for the sediment intervals (Figure 6-3). Interpolation of this curve provided approximate dates for the uppermost 40 cm (Table 6-2). Below this level the concentration of unsupported lead-210 was below detection limits. After dates were assigned to the intervals of interest, the rest of the core was dated by interpolation.

Binford (1990) performed an interlab comparison of lead-210 measurements between our Florida lab and the University of Maine, and evaluated the uncertainty of assigning lead-210 based dates to sediment profiles. His investigation suggests that ninety-five percent confidence intervals range from approximately 1-2 years for 10 year old deposits, 10-20 years for 100 year old deposits, and 8-90 years for 150 year old deposits. The current study stresses only that section of the core profile less than 100 years old, with major interpretational comments limited to the past 50 years. Dates assigned to profile levels in the current study are <u>not</u> considered absolute, but in all cases, are approximations. The reader should be aware of the constraints of the lead-210 method and not overinterprete our results.

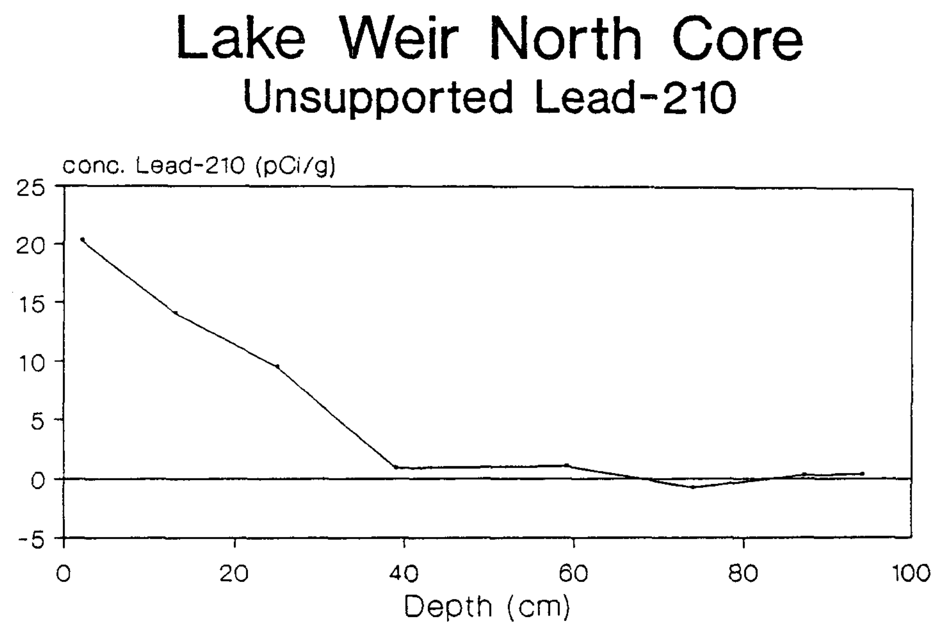
6.2.E SEDIMENT WATER, ORGANIC AND INORGANIC CONTENT

Thirty-one samples consisting of 1.0 cc of sediment were removed at 2 cm intervals down to a core depth of 30 cm, and at 5 cm intervals below that. Thirty additional samples were run from alternating intervals throughout the core for weight loss on ignition (LOI) and subsequent total phosphorus analysis. Nine additional samples were run at lower intervals to delineate further two inorganic peaks which were identified in the preliminary analysis. In all, 70 samples were included in the core's physical profile.

Samples were placed in small porcelain crucibles of

Table 6-2. Counting data for the Lake Weir core.

LAKE WEIR NORTH CORE (avg depth)	SAMPLE WEIGHT (g)	COUNT TIME (s)	Pb-210 46.52 keV Net	Pb-210 46.52 keV C/s	Pb-214 295.2 keV Net	Pb-214 295.2 keV C/s	Pb-214 351.9 keV Net	Pb-214 351.9 keV C/s
2 cm	0.8755	72000	1487	0.0207	411	0.0057	634	0.0088
13 cm	0.9532	72000	1338	0.0186	268	0.0037	472	0.0066
25 cm	1.537	50400	909	0.0180	58	0.0012	117	0.0023
39 cm	2.517	72000	1088	0.0151	225	0.0031	548	0.0076
59 cm	3.345	72000	1124	0.0156	318	0.0044	575	0.0080
74 cm	3.559	72000	967	0.0134	208	0.0029	429	0.0060
87 cm	3.509	72000	1049	0.0146	194	0.0027	567	0.0079
94 cm	2.658	72000	1022	0.0142	155	0.0022	362	0.0050
104 cm	2.939							



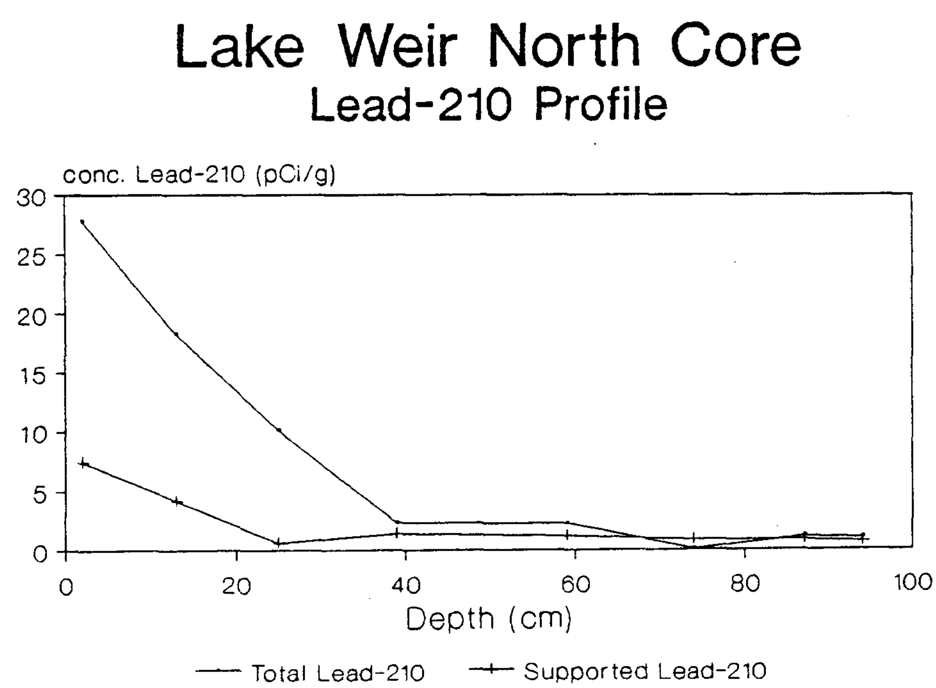


Figure 6-2. Profiles for total, supported and unsupported Lead-210 in the Lake Weir core.

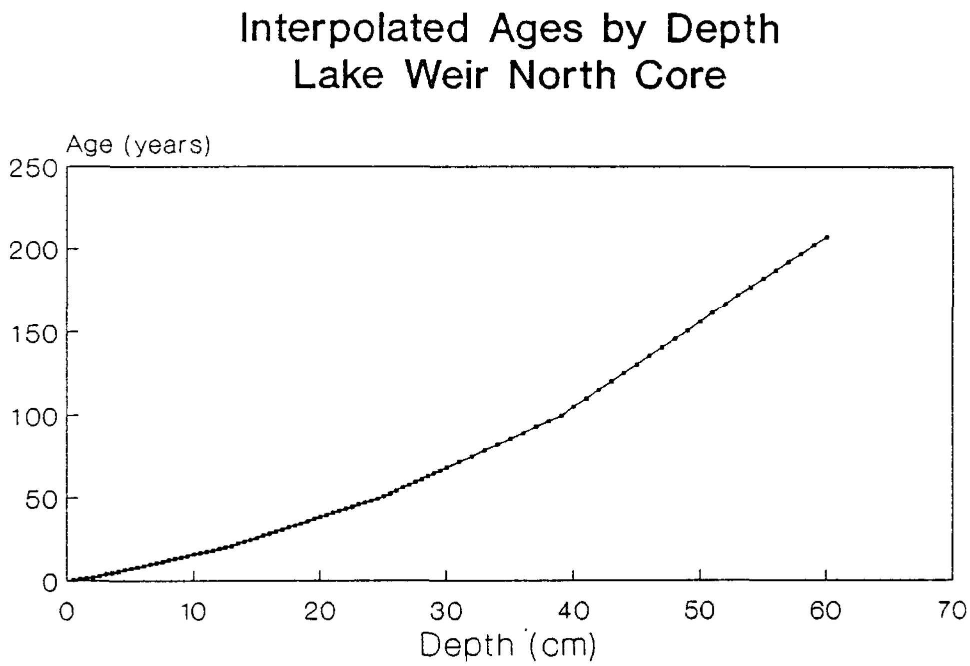


Figure 6-3. Interpolated ages by depth in the Lake Weir core.

known dry weight, and wet weight was measured using a Mettler analytical balance. Water loss was measured after drying the samples at 100°C for 24 hours. The inorganic and organic fractions were determined by weight loss following ignition at 550°C for one hour. Samples were allowed to cool to room temperature in a dessicator before weighing. Replicate samples were run on three select levels, and several samples were reweighed in each step to ensure precision.

6.2.F SEDIMENT ACCUMULATION RATES

Sediment accumulation rates (r) were calculated by:

$$r = kA/c$$

where k is the radioactive decay constant, A is the cumulative residual lead-210 below a given interval, and c represents the lead-210 concentration in the sediment layer. Accumulation rates remained fairly uniform at 0.017 $g/cm^2/yr$ from 1890 to 1938, when they rapidly increased to over 0.022 $g/cm^2/yr$ (Figure 6-4).

Interestingly, this transition occurred approximately when the weir structure was established in 1938. Accumulation rates varied rather dramatically after that, showing a general increase until 1946 then a sweeping decline until 1980. This trend was punctuated by one period of low accumulation in the mid 1960's. Rates increased from 1980 to the present, discounting the uppermost point which appears to be anomalous due to difficulty in defining the exact sediment-water interface.

6.2.G SEDIMENT TOTAL PHOSPHORUS

Determination of total phosphorus for the core intervals was determined using Anderson's (1976) ignition method. Inorganic residue from the LOI analysis was washed into a 200 ml beaker using 25 ml of 1N HCl and boiled for 15 minutes on a hot plate. Each sample was diluted to exactly 100 ml, and orthophosphate was measured by the perchloric acid method (APHA 1971).

In order to allow direct comparison of sediment TP concentrations in the sediment, it was necessary to factor out changes in sedimentation rates. Total phosphorus concentrations were divided by the specific dry sediment accumulation rates for each core interval to determine TP accumulation rates. Intervals

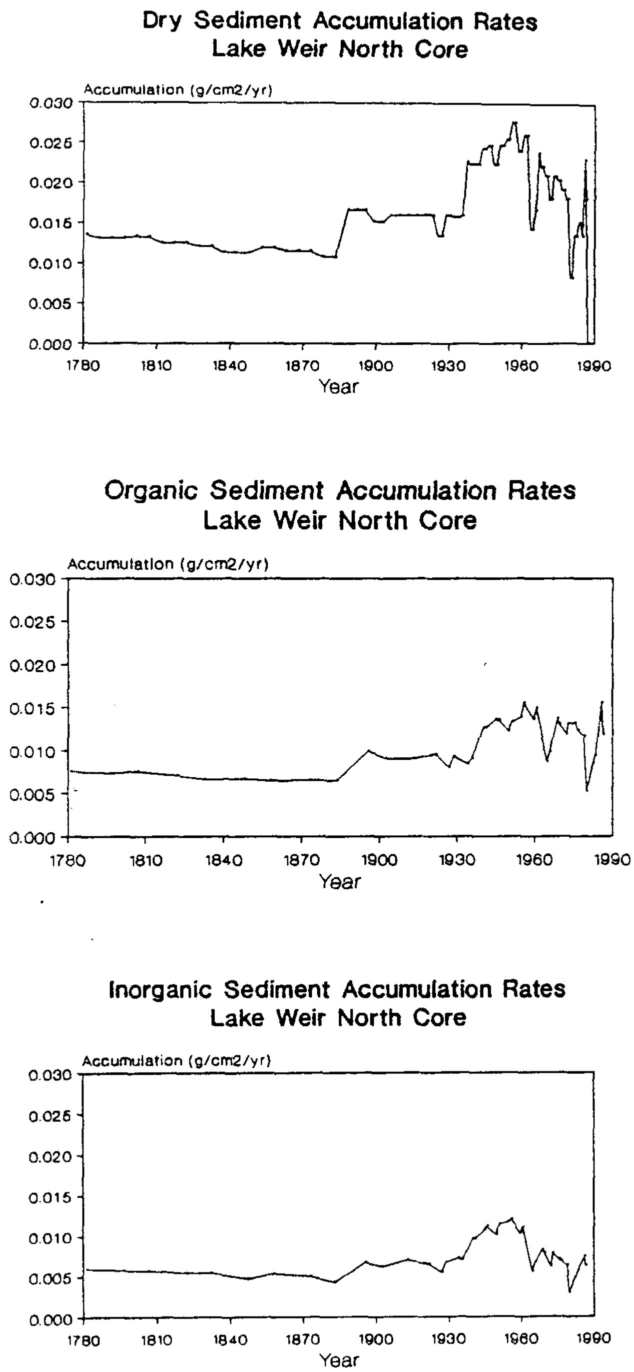


Figure 6-4. Accumulation rates of dry sediment, organic sediment and inorganic sediment in the Lake Weir core.

of significant change in TP accumulation were correlated to concomitant watershed activities, human population, rainfall and lake water level to determine their relative impacts on the lake trophic status.

6.2.H SUBFOSSIL ASSEMBLAGES

For subfossil analyses, 1.0 cc of sediment was extracted from the specified core intervals. This sediment was boiled gently in 30-40 ml of 10% KOH for 30 minutes, while agitating the clumps of material with a glass stirring rod. The sample was then diluted to over 100 ml with distilled water and poured through a 40 um sieve. Water was flushed through the mesh for nearly a minute. The residue was rinsed with tertiary butyl alcohol (TBA) then was carefully concentrated and backwashed with TBA into a small beaker, and final volume was measured (generally 3-4 ml).

Glass microscope slides were placed on a warm hotplate and a drop of silicon oil (Dow-Corning 200 fluid) was added. A 100 um Eppendorf pipette with a wide aperture disposable tip was used to extract a random sample from the TBA slurry. This was slowly added to the silicon oil, drop by drop as the TBA volatilized.

Generally two aliquots (0.2 ml) were added to the slide, but occasionally one was sufficient to achieve the desired density of at least 100 subfossil cladoceran remains per slide. For most intervals, the entire 1.0 cc of sediment in TBA was spotted evenly across five glass slides. Dilution factor (percent of total sample) was recorded on the slide to allow quantification of results. Slides were removed from the hotplate, allowed to cool, and coverslips were added. After several hours, clear fingernail polish was used to seal the coverslip.

Subfossil algae, pine pollen, cladocera, chironomids, chaoborids, and rotifer and neorhabdocoel egg cases were enumerated for each interval. Typically, one slide was adequate to yield a statistically significant taxonomic sample of all groups except for the midges. Chironomids and chaoborids were counted on all five slides.

Cladoceran remains were identified by taxon (generally to species) and by element (e.g. body shell, headshield or post-abdomen) using Pennak (1978). Elements were recorded as being complete, half, or fragmental and were tabulated by adding their respective fractional parts (with fragments equalling 1/4 shell or headshield).

The number of reconstructed individuals of a given taxon was defined as the minimum number of specimens represented by the most abundant element. For instance:

Leydigia leydigi subfossil remains at interval x cm

	Complete	Half	Fragment	Total
Headshield	2	4	1	4.25
Body Shell *	1	8	9	7.25
Post-abdomen	3	7	0	6.50

* Based on remains of body shells, at least eight (8) reconstructed individuals were present.

Chironomid head capsules and chaoborid mandibles were generally identified to genus using Merritt and Cummins (1984). For the lower intervals where less than the entire 1.0 cc was spotted on the slides, midges were picked from the remaining sample on a counting wheel under a dissecting scope with an Eppendorf pipette. Occasionally it was necessary to concentrate the remains by filtering the sample through 80 um mesh as above.

Subfossil concentrations were converted to accumulation rates by dividing by the dry sedimentation rates for each core interval. This allowed for direct comparison of how many individuals were deposited in the sediment at a given time, independent of dilution by increased sedimentation rates.

Interpretations of Lake Weir's historical water quality were based on the presence, absence or relative abundance of ecologically specific taxa. Changes in water quality over time were used to assess the impacts of changing water level, lake impoundment, and watershed development.

6.3 PHYSICAL STRATIGRAPHY OF LAKE WEIR CORE

6.3.A INTRODUCTION

The core from northwest Lake Weir was examined to determine the historical impact of development on lake water quality.

Because much of Lake Weir's urbanization has been concentrated in the vicinity of the town of Oklawaha on the lake's northern shore, this core should exhibit the clearest effects of development.

6.3.B VISUAL APPEARANCE OF CORE

The north core was different in appearance from sediment cores collected elsewhere in the Lake Weir system (Figure 6-1). The 120 cm primary core lacked visible stratigraphy and was composed of dark brown, presumably highly organic, mud throughout. The mud was highly flocculent above 28 cm and was more congealed below that. Small sand lenses at 90 and 100 cm were visible upon sectioning the core. The secondary core taken at the north site was 167 cm long and had dark brown bands at 140 and 146 cm.

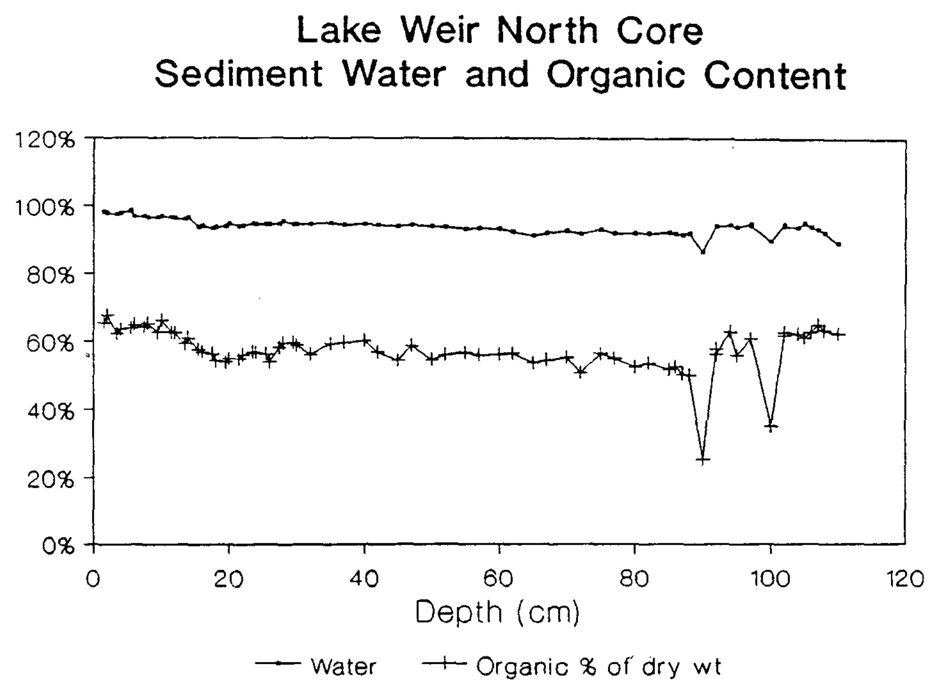
Cores from other areas of the lake displayed more pronounced stratigraphic changes below a similarly flocculent surface. Interbedded bands of grey clay became increasingly dominant deeper in the core, with fibrous root hairs appearing generally below 100 cm. Additionally, cores from Sunset Harbor had sand lenses at approximately 63 and 94 cm depths. The core from south Lake Weir was also sandy at 94 cm.

Overall, the north core appeared to be more organic, possibly the result of generally higher productivity historically. Cores from Sunset Harbor and south Lake Weir showed more episodic variation throughout time, apparently being more subject to erosional events.

6.3.C WATER, ORGANIC AND INORGANIC CONTENT OF SEDIMENT

Sediment water content of the north core confirmed the field observation of increased flocculence near the top of the core (Figure 6-5). Water comprised over 96% of the sediment by weight down to 14 cm where it dropped to 94%. Water content remained fairly constant at 94% down to 60 cm then edged lower to 92% by 88 cm. Distinct periods of lower water content occurred at 90 and 100 cm, yet intervals surrounding these points showed elevated water content.

Organic composition of the dry sediment was determined by loss on ignition at 550^{o}C. The core's organic fraction generally ranged from 50% to 67% (Figure 6-5). A transition similar to the one observed in the water profile occurred at 14 cm, possibly



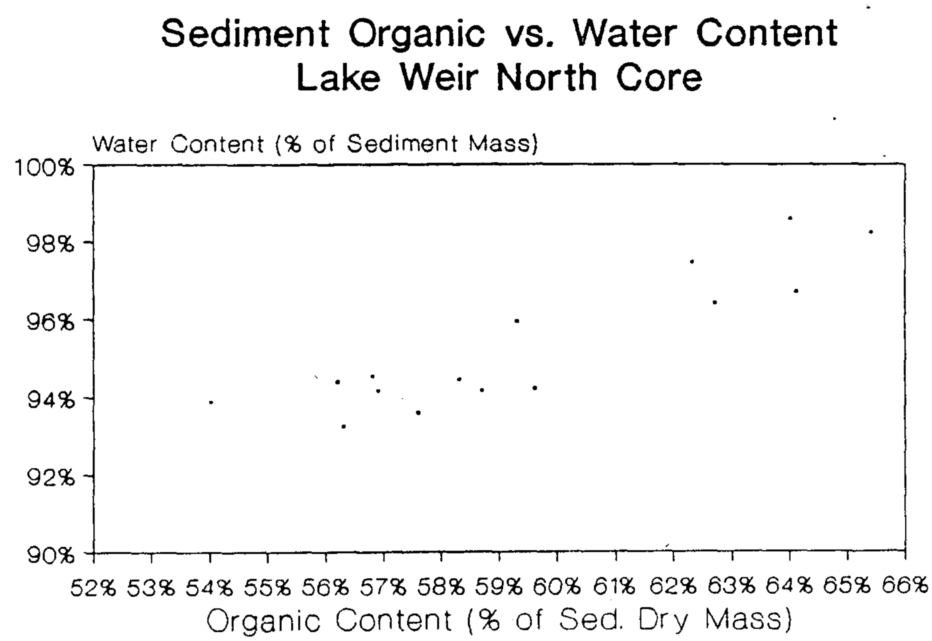


Figure 6-5. Percent water and organic matter and sediment organic matter versus water content in the Lake Weir core.

marking a shift to higher productivity in the upper core. Organic content varied from 50% to 55% between 15 and 88 cm. Two sharp spikes of inorganic sediment occurred at 90 and 100 cm, corresponding to the previously mentioned reduction in water content at these levels.

The apparent association between increased organic matter and higher water content was found to be significant with R^2 = 0.81 for the upper 40 cm of the core (Figure 6-5). Organic content closely reflected sediment flocculance, suggesting that algae were the dominant primary producer. Highly flocculent intervals above the apparent transition at 14 cm could indicate increased primary production by algae.

In the deepest core intervals, increased organic content was associated with lower water content. This reduced flocculance may be due simply to sediment compaction, or may indicate that the system was not algae-driven. Root fibers observed at this depth suggest that primary production within the lake was dominated by aquatic macrophytes.

6.4 SEDIMENT PHOSPHORUS

6.4.A SEDIMENT CORE PROFILE FOR TOTAL PHOSPHORUS

Primary production in Lake Weir is algal dominated and limited by availability of phosphorus (Messer 1975). Although aquatic macrophytes fringe the lake, there is no evidence that they have expanded beyond the narrow littoral zone in recent history. Therefore, the lake's productivity is only limited by the amount of phosphorus reaching the open water. Algal utilization of increased phosphorus loading in recent years has largely contributed to the perceived cultural eutrophication of the lake.

Total phosphorus (TP) at select levels of the sediment core was measured using the Anderson Method (APHA 1971). A standard phosphorus curve at 735 nm was established. Total phosphorus concentrations in the sediment intervals (Figure 6-6) were divided by their dry sedimentation rates to yield TP accumulation rates (Figure 6-6). Sediment TP accumulation remained under 10.0 ug/cm^2/yr from 1848 through 1929. By 1941, the next interval, TP jumped to 18.4 ug/cm^2/yr. Sediment TP remained in the range of 15 to 24 ug/cm^2/yr until 1980, when it dropped to 8.5 ug/cm^2/yr. It rebounded to 23.4 in 1983 and reached an all time high of 26.2 ug/cm^2/yr in 1987.

Interpretation of historical phosphorus levels is based on

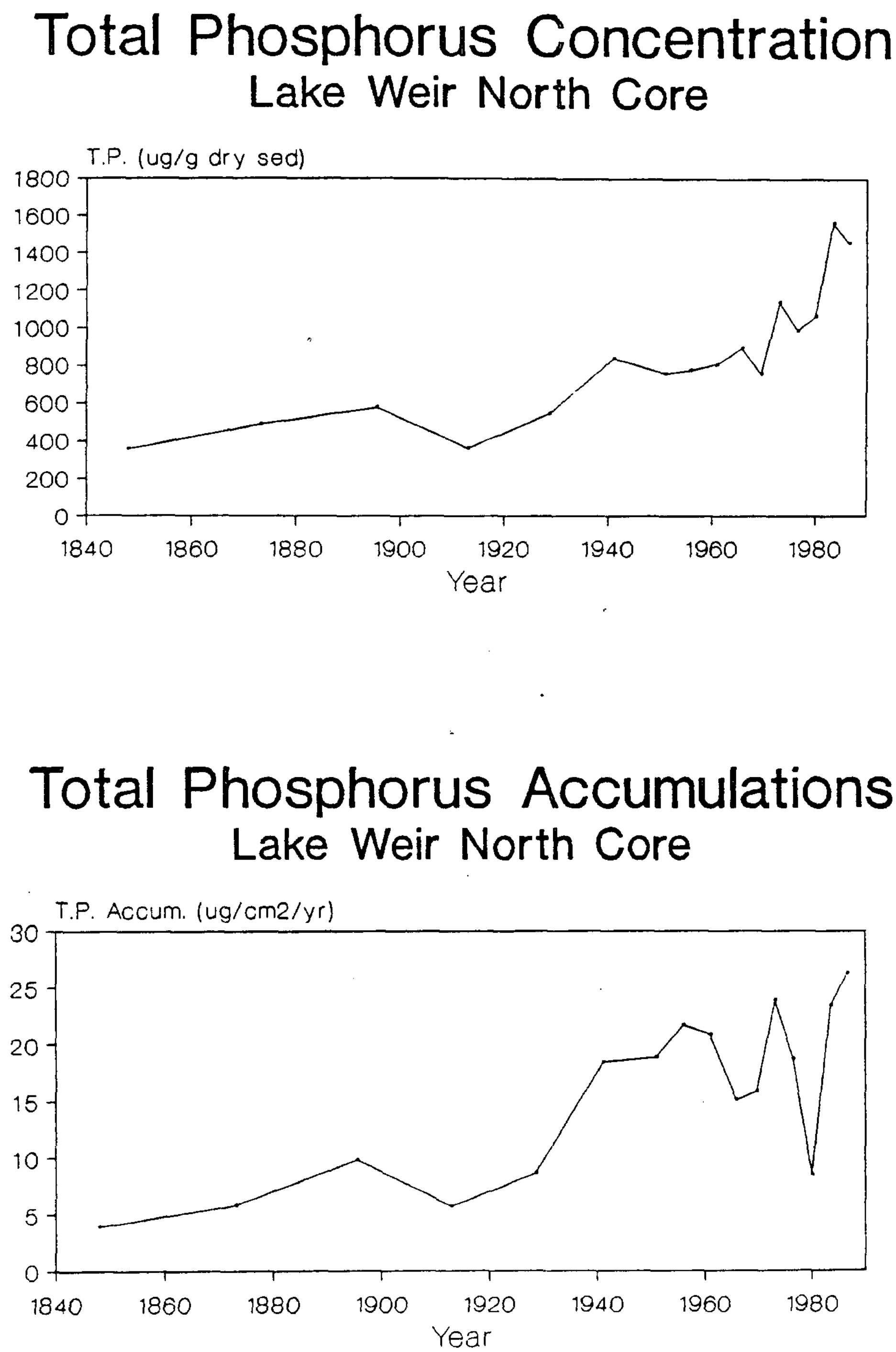
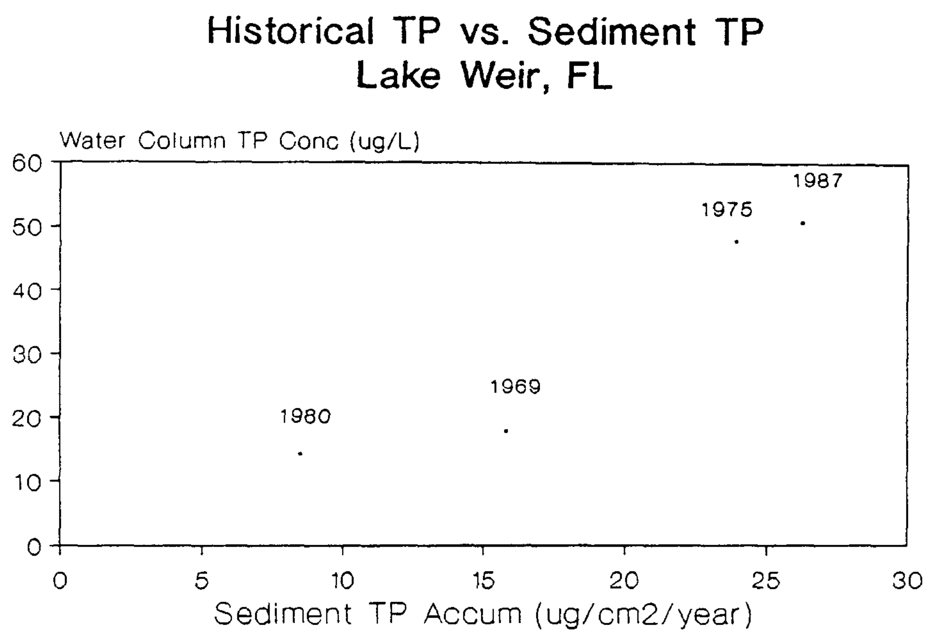


Figure 6-6. Total phosphorus concentrations and accumulation rates in the Lake Weir core.



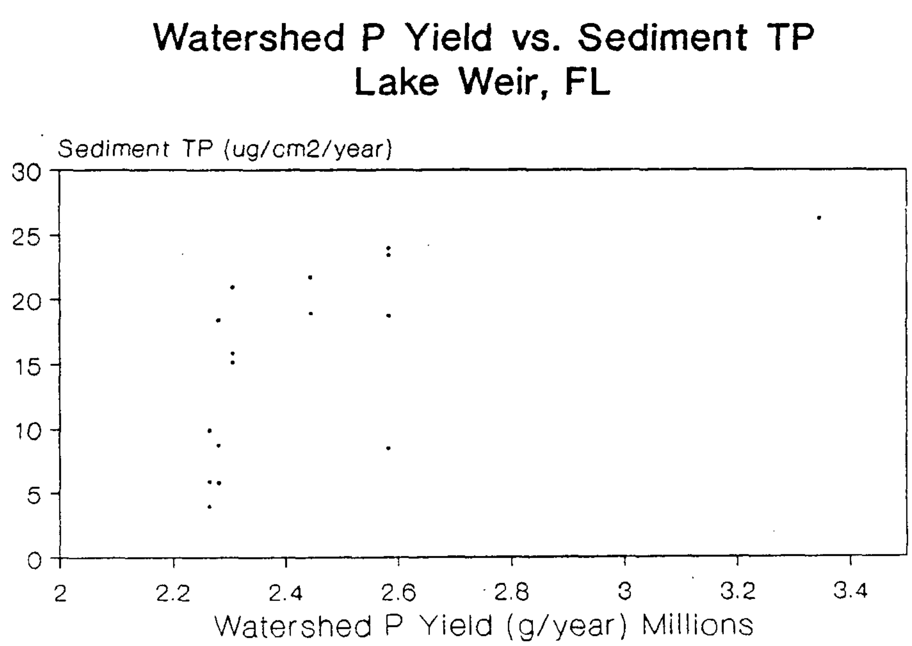


Figure 6-7. Relationships between historical and sediment total phosphorus and watershed export and sediment total phosphorus in the Lake Weir core.

the implicit premise that TP levels in the core reflect the water column TP during the period of deposition. As a check of this assumption's validity, water column phosphorus levels from previous investigations were compared to sediment TP (Figure 6-7). Because of the paucity of historical water chemistry data for Lake Weir, only four years were available for direct comparison: 1969, 1975, 1980, and 1987. The historical water column TP levels were expressed as the annual mean values of all surveys in a given year.

Although there were not enough data points to draw statistical conclusions about their correlation, it appears evident that sediment TP accumulation is a direct reflection of water column TP levels for a given year. Of particular note, 1980 showed a sharp reduction in both sediment and water column TP levels to the modern low for both sets of data. On the other hand, 1987 represented the all time high (to that date) for both data sets.

One concern for interpretation of sediment phosphorus profiles is the possibility that this element may migrate upward in the profile from deeper reduced sediments to oxidized surface sediments. Shapiro et al. (1971) addressed this potential problem by comparing phosphorus profiles from cores collected in Lake Washington in 1958-1958 with those collected at the same locations in 1968 and 1970. During the time interval, there had been a major reduction in the phosphorus levels in the lake. This investigation suggested that the record of the higher phosphorus period was likely to remain identifiable in the historical record and that upward migration of phosphorus did not appear to obscure the sediment record.

The amount of phosphorus in a lake can be defined as the sum of all phosphorus inputs minus all phosphorus sinks (Vollenweider 1971). Potential phosphorus sources for Lake Weir include watershed land use practices, human population, and airborne dust which is introduced by rainfall. Mechanisms of phosphorus removal include hydrologic flushing, macrophyte uptake and deposition in the sediment. Other factors such as low water level and resolubilization from sediment can serve to increase phosphorus levels in the open water. These variables, viewed in concert, may account for the highs and lows observed in the core's TP profile.

6.4.B WATERSHED LAND USE AND HUMAN POPULATION

Specific events in the watershed's development appear to account for many of the highs and lows observed in the core's TP profile (Table 2-2). The earliest perturbation by Europeans occurred between 1890 and 1910 when indigenous forest was cleared for citrus. TP returned to lower levels by 1920, a period of relative dormancy within the watershed. TP rose dramatically between 1929 and 1941, corresponding to the installation of the weir structure and related dredging. Phosphorus levels declined from 1966 to 1970, but increased again by 1973 during the period of road construction north of the lake. TP accumulation rates sharply increased after 1980, perhaps in response to the soaring population.

Because much of Lake Weir's urbanization has been concentrated near Oklawaha, the nutrient impacts of watershed development should have been reflected in the north core. The north shore has been the site of dredging and impoundment (1938), road construction (1972), and a rapid population growth (1980-1988). Therefore, these factors should have a more pronounced impact on the Northern core than for the lake as a whole.

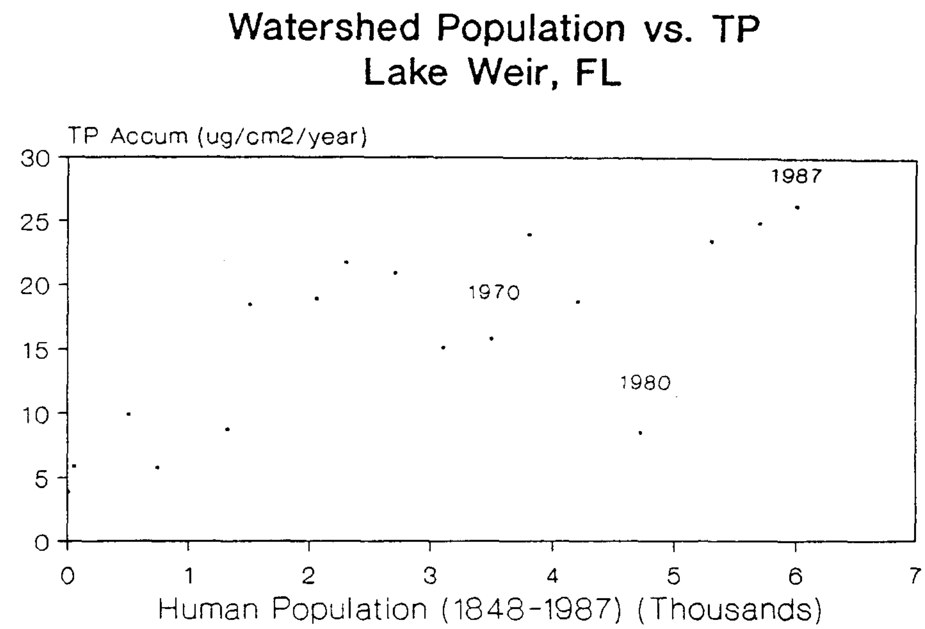
The sediment TP accumulation rates were compared to the predicted nutrient loadings based on historical watershed land use for individual years (Figure 6-7). As predicted, TP was low for 1883 and high for 1985, but no correlation was evident for the years in between. Sediment TP was far lower than the prediction based on watershed nutrient yields for 1980. Thus, it appears that factors other than watershed land use have influenced sediment TP accumulation.

Lake Weir's watershed has experienced tremendous population growth since 1970. There are no central sewage treatment facilities in the watershed, so the entire human population contributes phosphorus through septic tank effluent. Sediment TP accumulation rates were compared to concomitant human population figures (Figure 6-8).

Human watershed population corresponded to sediment TP accumulation with an R^2 value of 0.55. Once again, the 1980 point appeared to be anomalously low. Removing this sole outlier strengthened this association to an R^2 value of 0.74. Clearly, human population affects sediment TP accumulation, but there seems to be some other factor influencing 1980.

6.4.C EFFECTS OF LAKE LEVEL

Water level governs the degree of hydrologic flushing and may play an important role in regulating water column phosphorus concentrations. Primarily, higher water levels lead to increased overflow from the lake, which removes phosphorus. Also, higher lake levels increase the amount of flushing by groundwater, because most interchange occurs around the littoral zone of perched lakes. For both of these reasons, higher water reduces residence time of phosphorus in the lake.



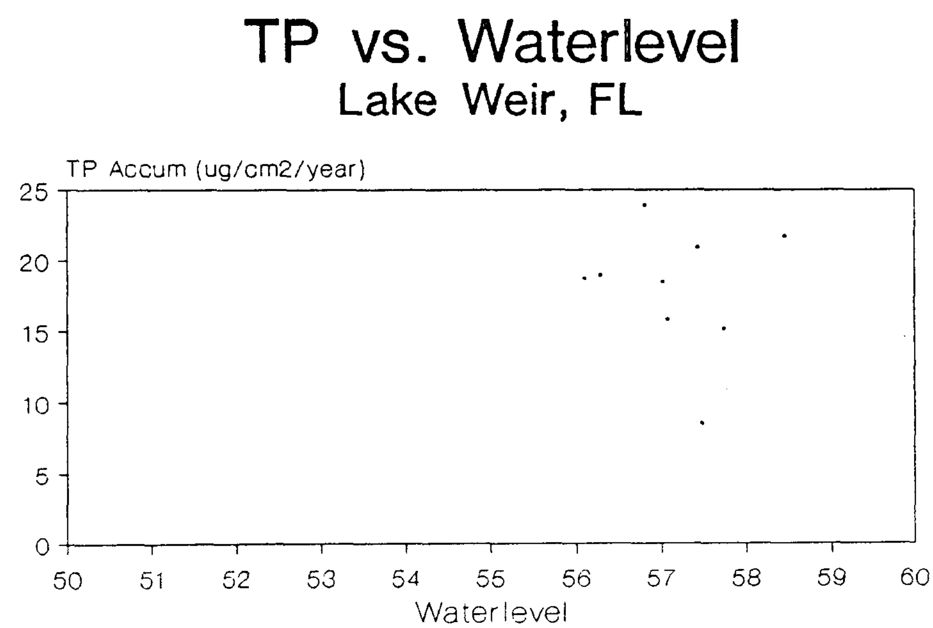


Figure 6-8. Relationships between watershed population and total phosphorus and water level and total phosphorus for the Lake Weir core.

Conversely, low water level can increase water column phosphorus levels by reduced flushing and increased mixing of sediment by wind and boating activities. There are also a few beneficial long term effects of low water episodes. Periods of low lake level can consolidate and oxidize the littoral sediment (reducing future phosphorus release) and allow some expansion of the rooted aquatic macrophyte community.

Total phosphorus levels peaked around 1956 which was a period of extremely low lake water level. Phosphorus accumulation rates dropped in the 1960's, when water levels were higher than their historical mean. TP levels dropped sharply in 1980, a period of very high water level. This may explain why the sediment TP accumulation was lower than predictions based on land use and human population. However, annual mean lake level by itself does not account for sediment TP accumulation rates (Figure 6-8).

6.4.D LAKE IMPOUNDMENT

Installation of the weir structure and canal in 1938 may have extensively changed Lake Weir's hydrologic regime. The weir was designed to minimize fluctuations in lake water level. The weir serves as a dam throughout most of the year, restricting overland discharge. But during high water episodes, the notched weir structure and spillway permit rapid outflow. Thus, overland discharge from Lake Weir has become a hit-or-miss proposition.

Sediment TP accumulation more than doubled from 1929 to 1941, over the period of impoundment. In addition to the hydrologic reasons for phosphorus loading, dredging of the canal could have released phosphorus from the sediment into the water column.

6.4.E PHOSPHORUS:SEDIMENT RELATIONSHIPS

Several factors influence the removal of phosphorus by deposition in the sediment. Its chemical form affects its solubility from the sediment back into the water column. In the presence of oxygen, phosphorus is assimilated into phosphate. This ortho-phosphorus is not as readily resolubilized as elemental phosphorus, the dominant species under anoxic, reducing conditions. Levels of dissolved oxygen in Lake Weir were generally measured above 8.0 mg/l, and were never below 4.0 mg/l. Therefore, the sediment is potentially an effective agent in trapping phosphorus from the water column.

Physical mixing of the sediment by wind fetch and by boating activity can also result in phosphorus being recycled into the water column. Lake Weir's narrow littoral zone and pan-shaped morphometry helped to minimize the areal extent of sediment exposed to these processes. Dredging activities pose a potential threat of phosphorus release by sediment mixing.

6.4.F PHOSPHORUS:AQUATIC MACROPHYTE RELATIONSHIPS

One other factor which could remove phosphorus from the open water column is uptake by aquatic macrophytes in the littoral zone. There is no evidence that aquatic macrophytes have achieved significantly greater abundance in modern history. Aerial photographs taken in 1940, 1957, and 1964 showed the extent of weeds to be comparable to modern levels. Lake impoundment could have further limited the extent of rooted aquatic macrophytes by reducing the number and magnitude of lower water episodes which allow some encroachment into deeper waters.

Whereas the morphometry of Lake Weir proper is not conducive to dominance by aquatic macrophytes, the potential for macrophyte expansion in the two ancillary lakes is significant. Therefore, these lakes may respond differently to increased nutrient loading.

Root fibers observed deep in many of the cores may attest to the historical importance of macrophytes in the Lake Weir system. These were observed at over a meter depth in the cores; far below levels datable by lead-210.

6.4.G CONCLUSIONS

Phosphorus levels in Lake Weir are the sum result of all watershed activity sources minus the amount removed by flushing, deposition and macrophyte uptake. Accumulation of TP in the sediment core was more closely related to human population than to watershed land use.

Fluctuations in lake water level may have had some affect the phosphorus removal processes. Lake impoundment in 1938 was marked by a doubling of sediment TP accumulation and an apparent shift to a higher nutrient regime. High water level in 1980 may account for lower than predicted phosphorus levels for the given watershed population.

6.5 POLLEN

6.5.A OVERVIEW

The native forests of the Lake Weir region were dominated by pine (Shackleford 1883). Because pine is wind pollinated it may be over-represented relative to other pollen in the sediment. Nevertheless, changes in pine pollen accumulation rates in the sediment core should reflect the extent of native forest surrounding the lake. Any land clearance in the watershed would be accompanied by a reduction in pine pollen accumulation.

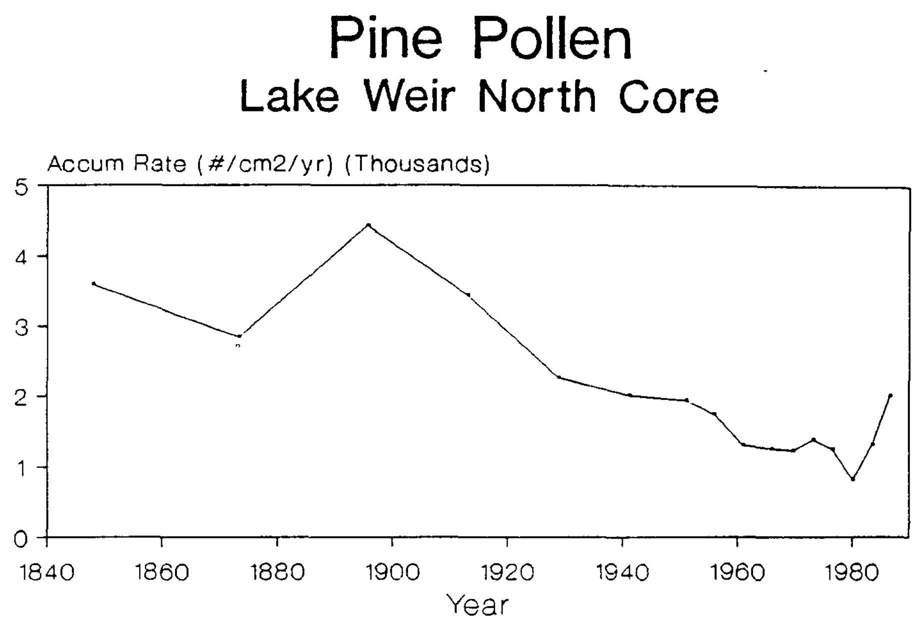
The accumulation rate of pine pollen in Lake Weir's sediment peaked at over 4400 grains/cm^2/year in 1896 and steadily declined to 800 units in 1980 (Figure 6-9). Historical watershed land use data indicate continuous deforestation around Lake Weir throughout most of this time (Figure 6-9). Pine pollen rebounded to 2000 grains/cm^2/year by 1988, reflecting recent commercial planting of pine. Pine pollen accumulation throughout the core correlated to the areal extent of native forest within the watershed with an R^2 value of 0.89 (Figure 6-10).

As discussed earlier, sediment TP accumulation was found to be proportional to the amount of phosphorus in the water column at the time of deposition. Hence, a comparison of pine pollen to TP accumulation in the core might reveal an association between deforestation and lake trophic state. However, this relationship revealed a correlation coefficient (R^2) of 0.35 (Figure 6-10).

Once again, 1980 appeared as an outlier due to the lower than expected TP accumulation, probably associated with high lake stage. Omitting this point strengthened the correlation to an R^2 value of 0.54. Although this relationship was still not strong enough to connote a direct influence of pine forests on Lake Weir's TP levels, there was probably some indirect association. For instance, native forests were cleared to accommodate a greater human population or other developmental activities that may have influenced TP levels.

6.5.B CONCLUSIONS

Pine pollen accumulation rates in the core closely



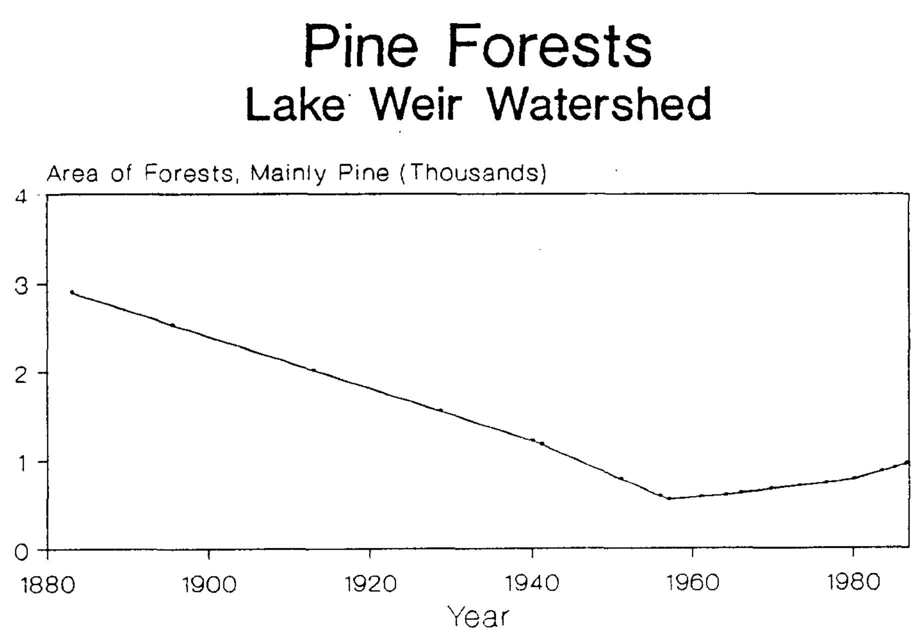
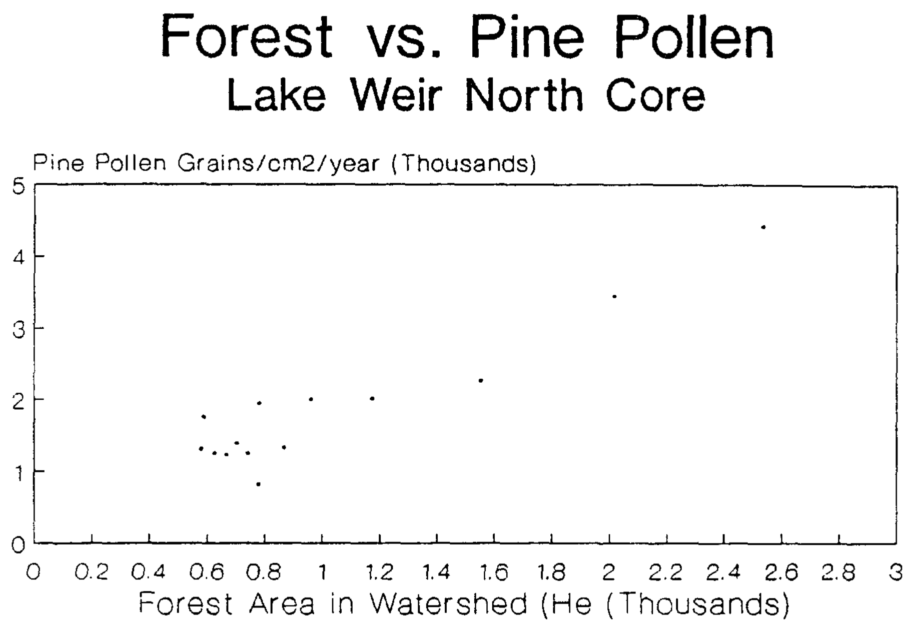


Figure 6-9. Pine pollen accumulation rates in the Lake Weir core and historical record of pine forest area in the Lake Weir watershed.



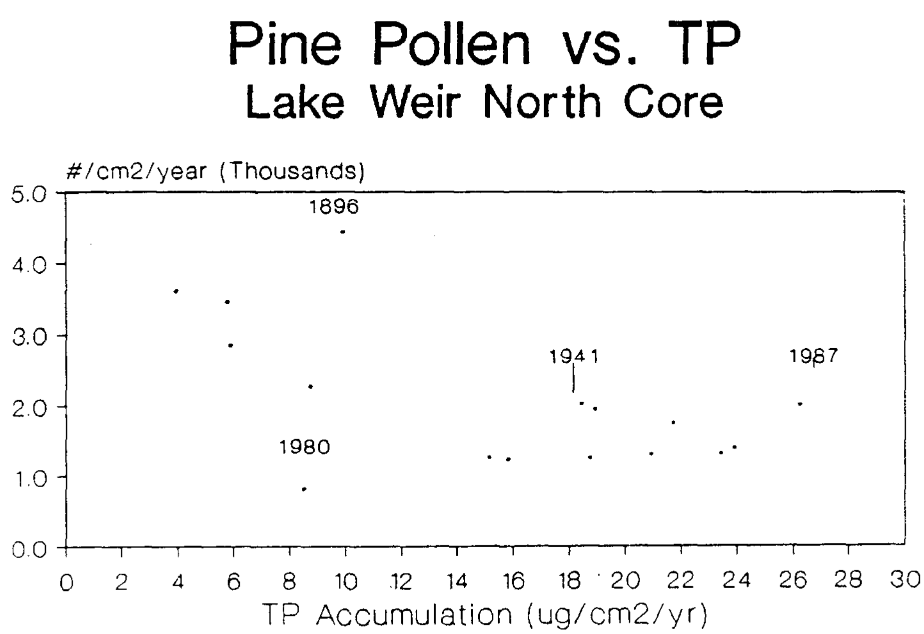


Figure 6-10. Relationships between forest area and pine pollen accumulation and pine pollen accumulation and total phosphorus in the Lake Weir core.

reflected the clearance of pine forests in the watershed. Pine generally decreased with increasing TP, but the correlation ($R^2 = 0.54$) was not strong enough to suggest that land clearance directly influenced lake phosphorus levels. Rather, the observed increases in TP were probably caused by watershed activities which replaced the native pine forests.

6.6 SUBFOSSIL ALGAE

6.6.A OVERVIEW

Four algal genera comprised over 98% of subfossil algae found throughout the core (Figure 6-11). Botryococcus sp. was the dominant species, generally comprising over 80% of total individuals. Three species of Pediastrum together accounted for roughly 10% of the population. Peridinium was historically the third most abundant genus, and was gradually replaced by Staurastrum in the upper core intervals.

Total algal accumulation rates increased sharply at several intervals within core profile (Figure 6-12). Prior to 1930, algal accumulation varied between 500 and 800 individuals/cm^2/year (ICY), except for 1896 which had nearly 1000 ICY. This may be an indication of slightly elevated lake productivity associated with extensive land clearance which was occurring throughout the watershed in that era. Accumulation rates nearly doubled between 1929 and 1941, perhaps signaling the installation of the weir structure and associated dredging. Algal accumulation fluctuated between 700 and 1200 ICY from 1941 to 1983, and markedly increased to 1900 ICY after 1983. This recent pulse of productivity is consistent with the perceived eutrophication of the lake in recent years, but it must be recognized that at least part of the apparent increase in the surface sediments may be attributed to the fact that time has not been sufficient for disappearance of the more readily decomposable matter.

No clear relationship existed between total algae and TP throughout the core (Figure 6-12). Subfossil algal accumulation sharply increased in 1987, when TP accumulation was at its highest. It is not clear why such an incremental increase in TP accumulation would result in such a marked algal response. Perhaps a greater percentage of water column phosphorus was made available to the algae by some change in the aquatic macrophyte community. In order to better understand the association between algae and TP in

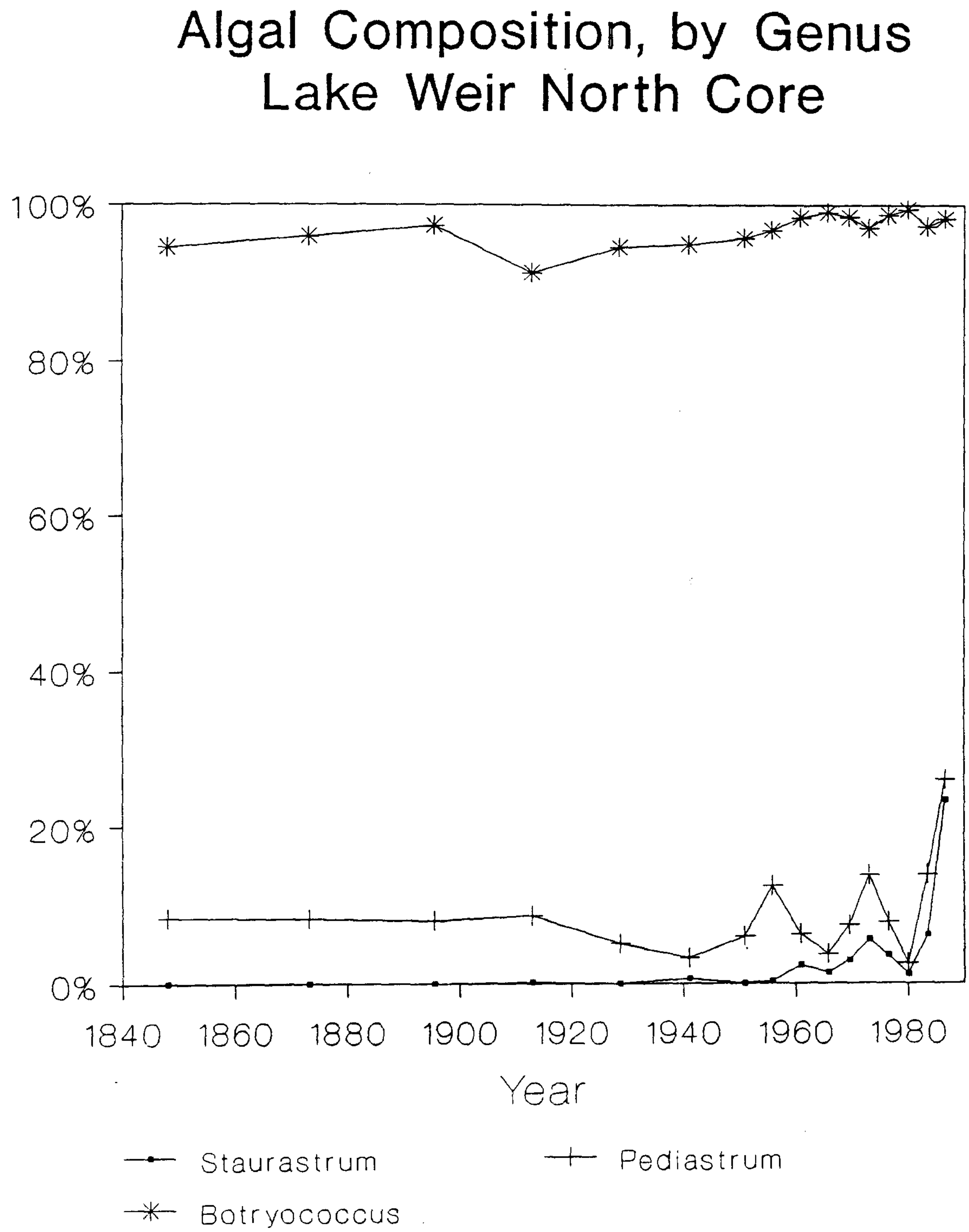
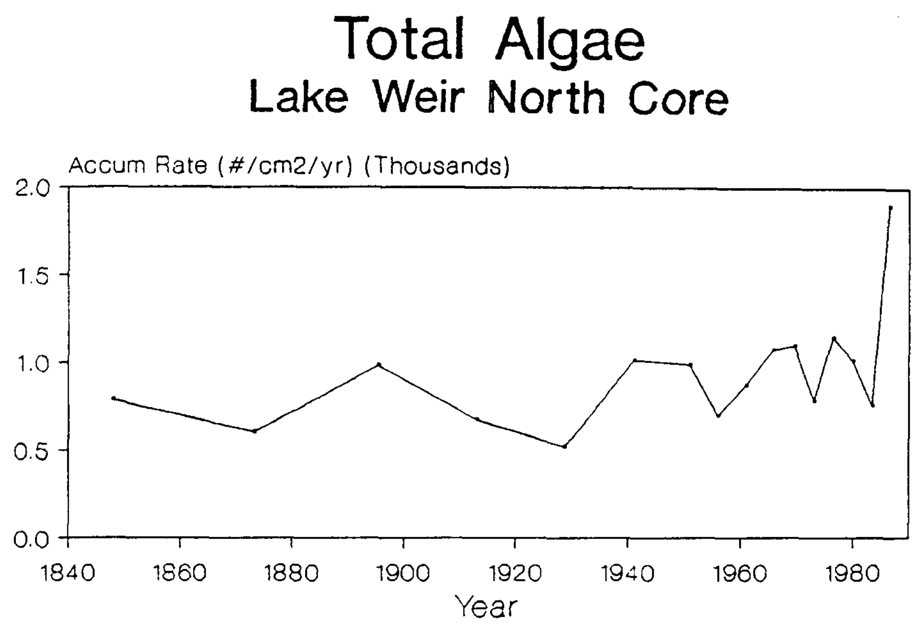


Figure 6-11. Percentage contribution of individual taxa to the subfossil algal assemblage in the Lake Weir core.



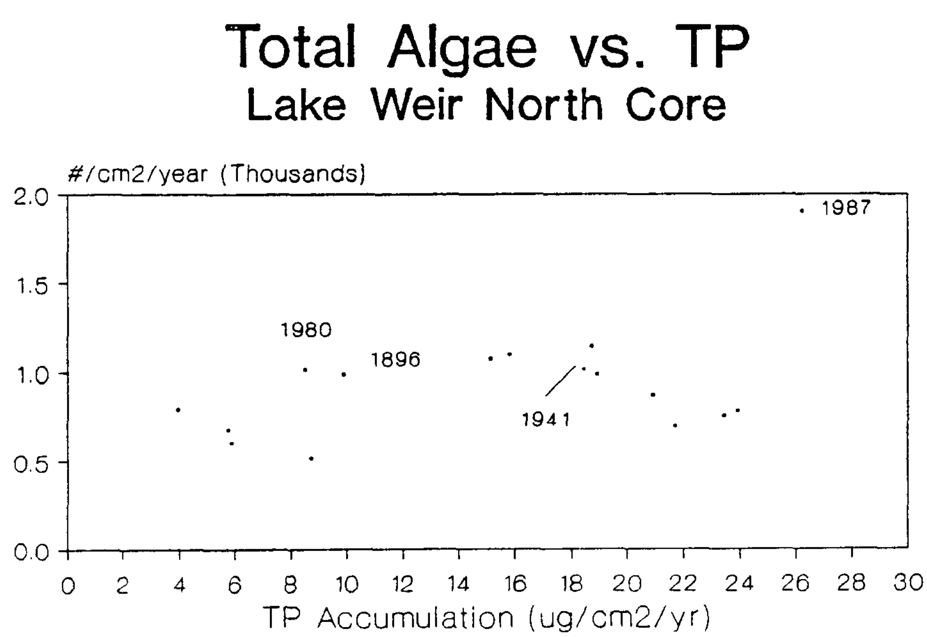


Figure 6-12. Accumulation rates for total algae and the relationship between total algae and total phosphorus in the Lake Weir core.

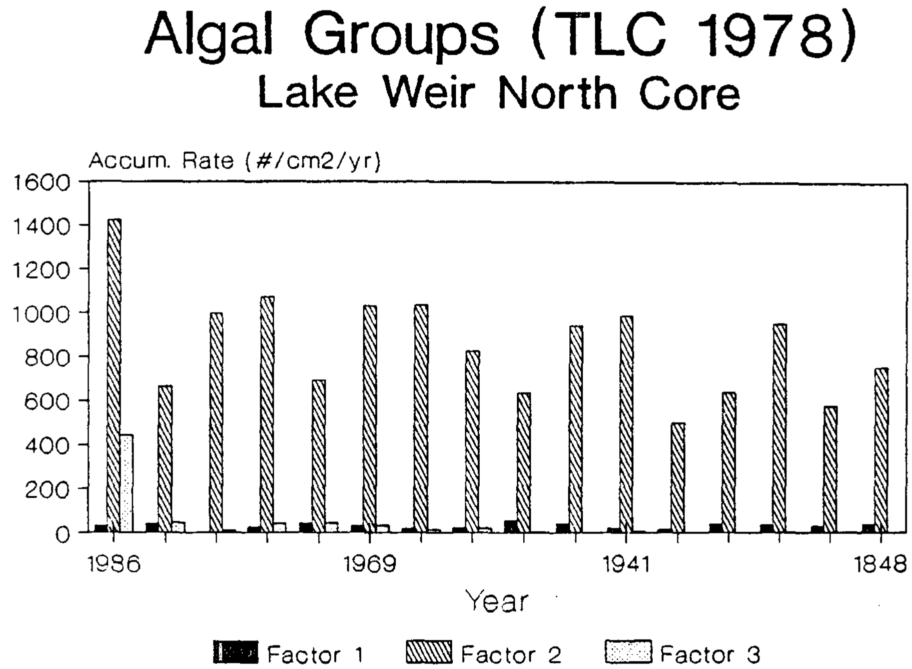
Lake Weir, it was necessary to examine the algal groups separately.

Crisman (1978) used principal component analysis to divide eleven subfossil algal taxa into three groups of association and found that distribution was governed more by water chemistry and productivity than by water depth. Algal species grouped into factor 1 were indicative of hardwater eutrophic systems. These systems were dominated by *Pediastrum boryanum*, *P. duplex*, and *P. simplex* which positively correlated with increased productivity and conductivity. Factor 2 species included *Peridinium* sp., *Botryococcus* sp., and *Pediastrum araneosum*, all typical of softwater oligotrophic systems. *Staurastrum* spp. (factor 3) showed no significant correlation to water chemistry or productivity.

Algal taxa from the Lake Weir core were separated according to Crisman's factor groups (Figure 6-13). Factor 2 species, indicative of softwater lakes, dominated the algal taxa of Lake Weir during the past 100 years. Factor 1, hardwater species, comprised less than ten percent of subfossil algae. Both Factors 1 and 2 increased in 1896 and decreased in 1929. Softwater (Factor 2) species also displayed increased accumulation rates in 1941, 1977 and 1987.

Factor 3 was absent from the Lake Weir subfossil algae prior to impoundment in 1938. It first appeared in 1941 and was sporadically present until 1970, at which time it had become consistently established at greater than one percent of total subfossil algae. In 1987 Factor 3 algae increased tenfold to over 400 individuals/cm^2/year, possibly reflecting some ecological shift in Lake Weir.

The ratio of softwater to hardwater species may provide a valuable index of historical water hardness in Lake Weir. This ratio showed no distinct linear trend throughout time, but oscillated between 10:1 and 50:1 (Figure 6-13). The 1980 interval was marked by a sharp increase in Factor 2 to Factor 1 species, due largely to the virtual absence of hardwater species at that level. This softwater spike diminished by 1985, and algal species composition returned to its baseline range. It seems that the perceived recent changes in the lake's trophic state were not accompanied by any particular shift in water hardness.



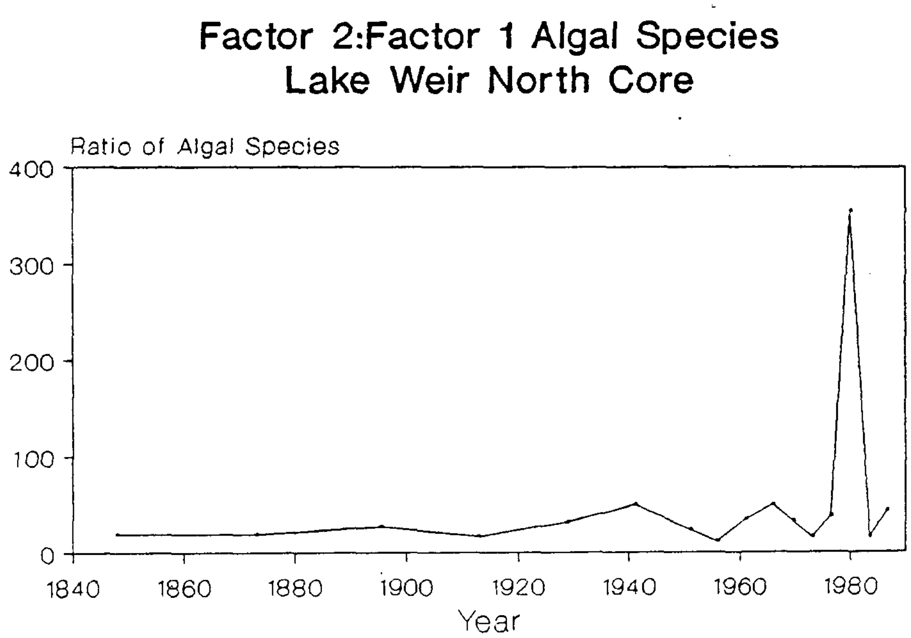


Figure 6-13. Accumulation rates for individual algal groups and the ratio of factor 2 to factor 1 algal species in the Lake Weir core.

6.6.B BOTRYOCOCCUS

Botryococcus sp., the dominant Factor 2 (softwater) species, comprised over 80 percent of the total subfossil algae (Figure 6-11), generally accumulating between 500 and 1000 individuals/cm^2/year. This species increased about 1900, declined through 1929, then peaked again in 1941, 1966, 1977, and 1987 (Figure 6-14). In 1987, *Botryococcus* accumulation rates reached almost 1400 ICY, the highest historical level.

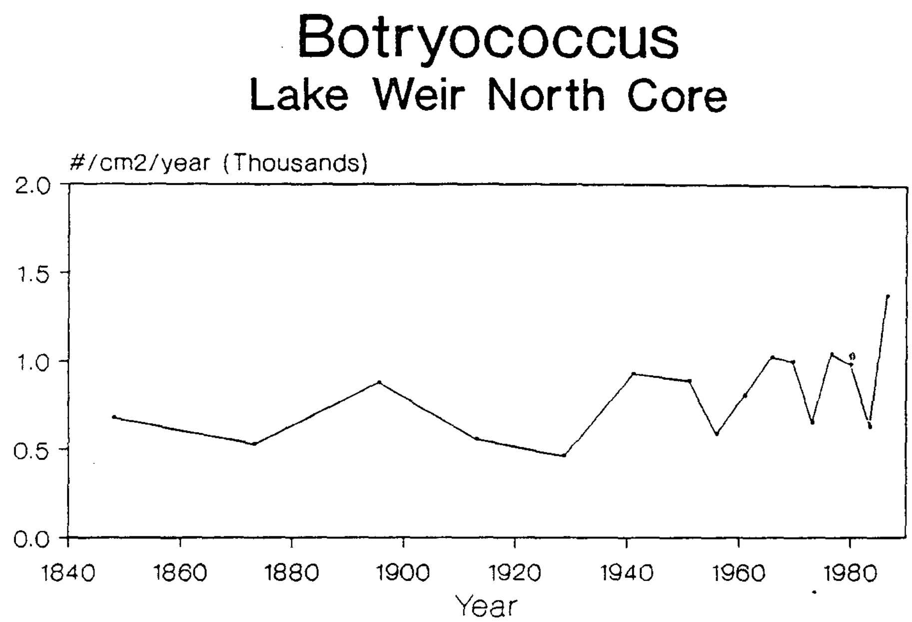
Comparison of *Botryococcus* sp. to TP accumulation revealed no distinct trends (Figure 6-14). The apparent decline of *Botryococcus* in the upper TP range supported the documented association between *Botryococcus* and lower trophic state (Crisman 1978). The 1987 data point was an apparent outlier to this generalization, having the highest *Botryococcus* levels coinciding to the highest TP accumulation. However, other algal genera were also more abundant in 1987, and *Botryococcus* actually declined relative to other subfossil algae (Figure 6-13).

In addition to TP levels, lake impoundment may possibly have affected the percentage of *Botryococcus* in the algal community. The five pre-weir points are scattered, showing no apparent trend with TP (Figure 6-14). The eleven data points following the lake's impoundment in 1938 displayed a strong negative correlation, (R^2 = 0.80). The 1980 point was omitted for reasons discussed earlier. However, there were not enough points to draw conclusions based on this association.

6.6.C STAURASTRUM

Staurastrum spp. was the sole representative of Crisman's (1978) Factor 3 species discussed earlier. This species was present in Lake Weir after impoundment in 1938, and became established at around 40 individuals/cm^2/year (ICY) by 1977 (Figure 6-15). Its accumulation rates dipped in 1980, the year marked by lower TP and softwater algal dominance. *Staurastrum* accumulation increased tenfold between 1983 and 1987, reaching 443 ICY and comprising nearly 24% of the preserved algal taxa (Figure 6-11).

Staurastrum has been known to occur in lakes spanning a broad spectrum of water chemistry, including TKN, P, N:P ratio, Chlorophyll a, and other parameters of productivity (EPA, 1979). Accordingly, *Staurastrum* did not correlate



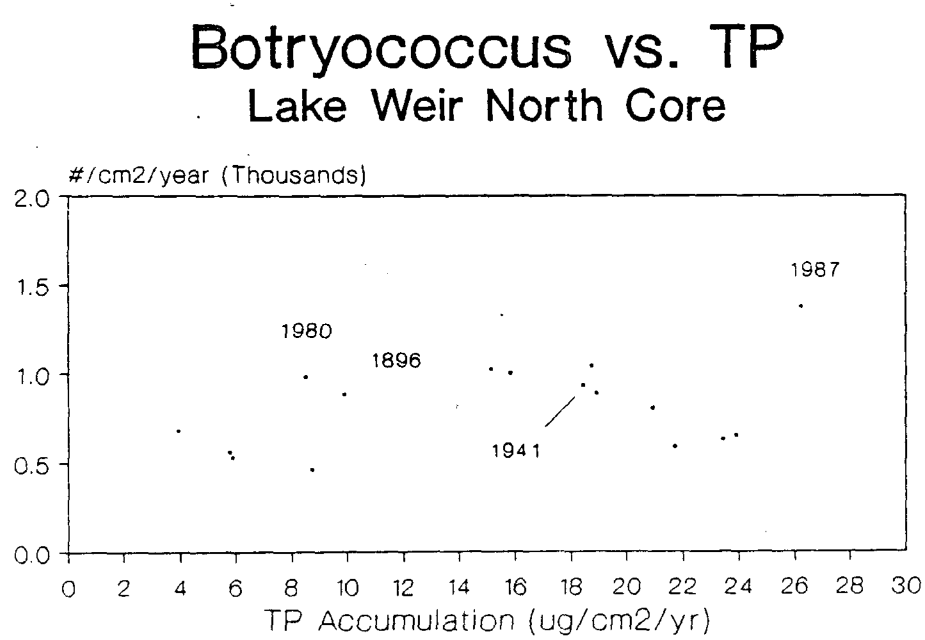
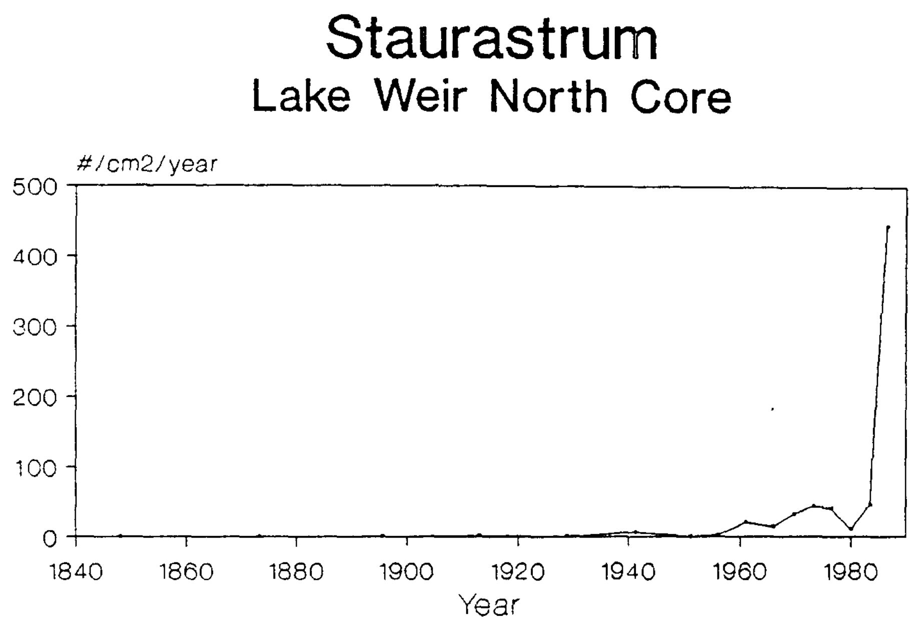


Figure 6-14. Botryococcus accumulation rates and the relationship between Botryococcus and total phosphorus in the Lake Weir core.



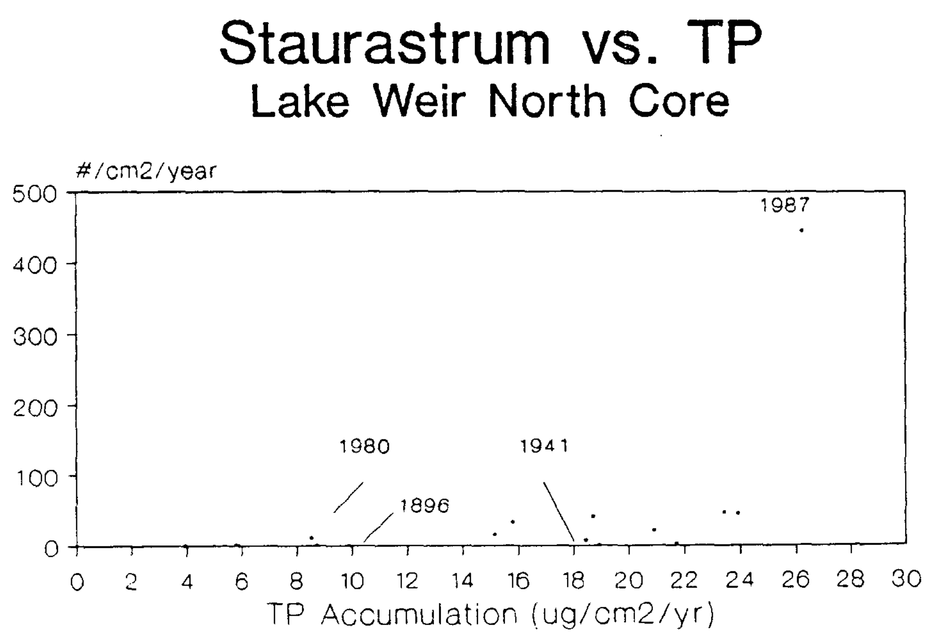


Figure 6-15. Staurastrum accumulation rates and the relationship between Staurastrum and total phosphorus in the Lake Weir core.

with TP accumulation (Figure 6-15). The sharp increase of Staurastrum in 1987 was probably a response to some variable other than TP.

6.6.D PERIDINIUM

Peridinium is a classic clean-water genus. This indicator of low trophic state was more abundant prior to 1951, having accumulation rates between 30 and 60 individuals/cm^2/year (Figure 6-16). Peridinium accumulation peaked at 60 ICY in 1913, a period of relative tranquility within the watershed. Accumulation of this genus decreased by 1956, and remained below 24 ICY until 1987. Once again, 1980 stands out as an unusual year. Peridinium reached its lowest level in 1980, yet its abundance relative to other algal genera increased.

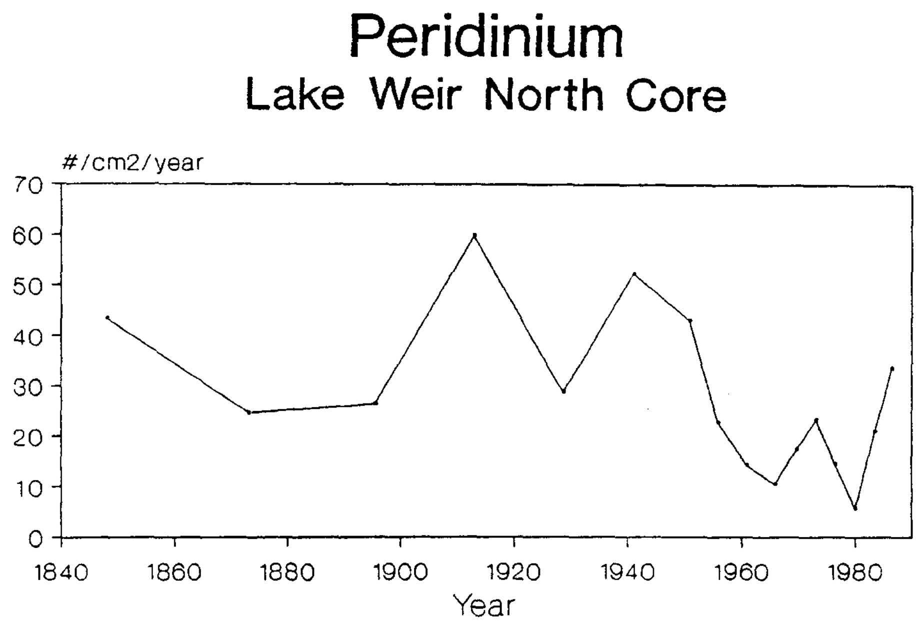
Peridinium did not show any significant correlation to TP accumulation (Figure 6-16). Like Botryococcus, this genus seems to have responded to variables other than TP levels.

6.6.E PEDIASTRUM

Pediastrum was the second most abundant algal genus in the Lake Weir core. The accumulation rate of Pediastrum varied between 20 and 90 individuals/cm^2/year throughout the core profile, peaking at 79 ICY in 1896 and again in 1956 with 85 ICY (Figure 6-17). No changes in accumulation were evident over the interval of impoundment, and this genus remained in its historical range of abundance following 1938. Pediastrum did not increase in 1987 with Botryococcus and Staurastrum.

Three species of Pediastrum were identified: P. araneosum, P. duplex, and P. boryanum. Crisman (1978) listed P. araneosum as a factor 2 (soft-water, lower trophic state) species, and P. duplex and P. boryanum as factor 1 (indicative of hard water, higher trophic state) taxa. Therefore, shifts in the relative abundance of P. araneosum to the other species could represent changing environmental conditions.

The three species in the Lake Weir core were expressed as a percentage of total Pediastrum (Figure 6-17). In the oldest sediment (pre-1900), P. araneosum comprised roughly



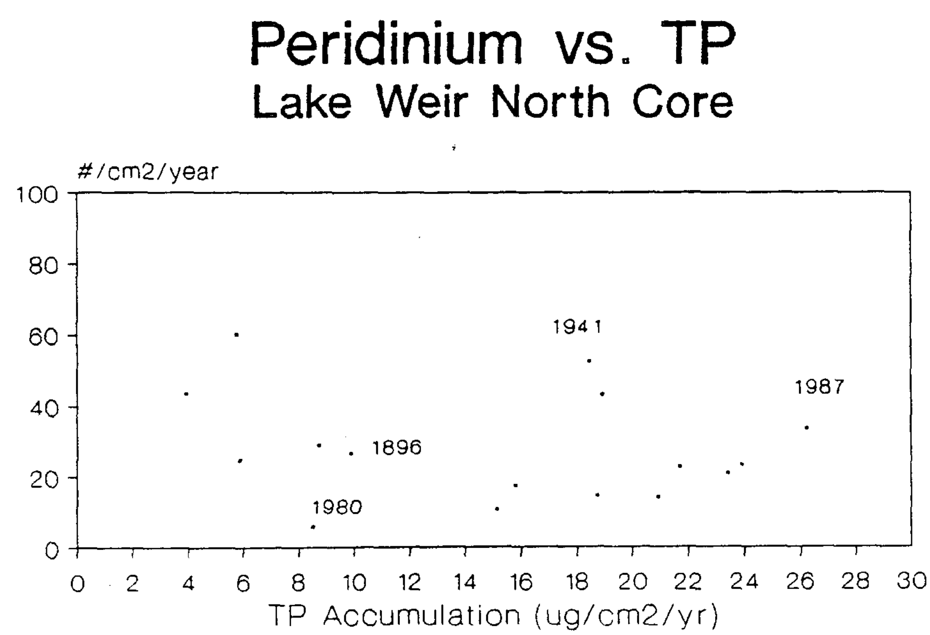


Figure 6-16. Peridinium accumulation rates and the relationship between Peridinium and total phosphorus in the Lake Weir core.

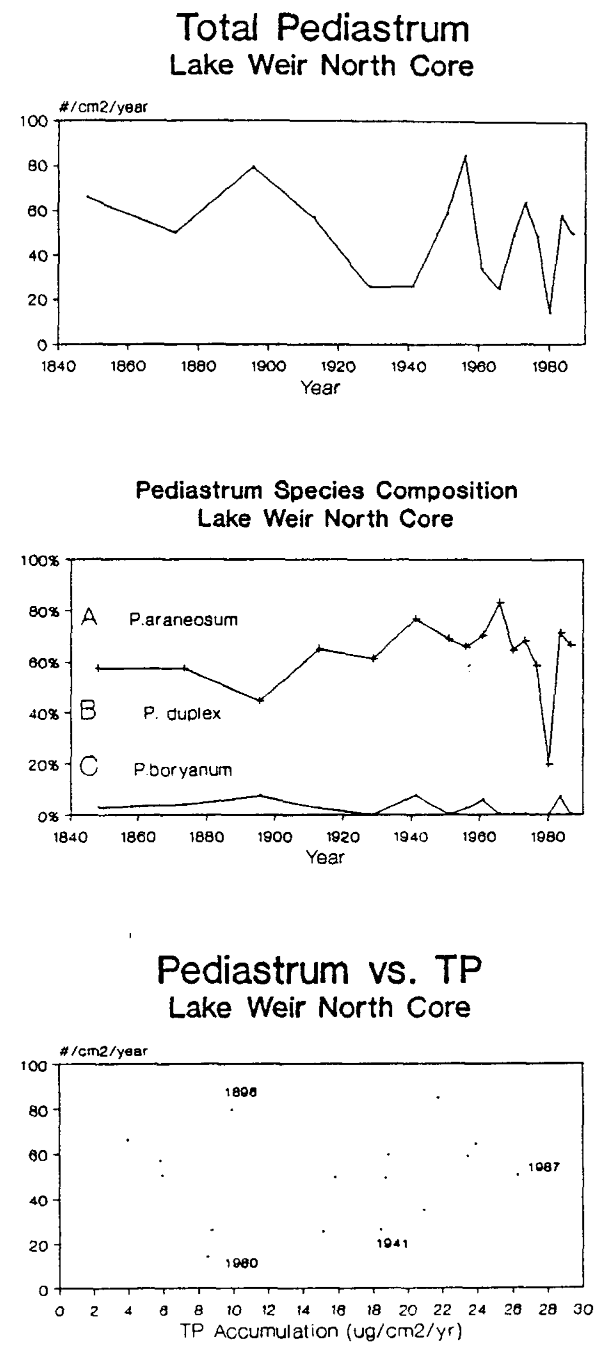


Figure 6-17. _Pediastrum_ accumulation rates, percentage contribution of individual species of _Pediastrum_, and the relationship between _Pediastrum_ and total phosphorus in the Lake Weir core.

half of total Pediastrum abundance. After 1896, Pediastrum araneosum was steadily replaced by P. duplex, suggesting a trend toward higher productivity. This trend peaked in 1966 when P. duplex represented 83% of all Pediastrum. Pediastrum duplex crashed to 20% in 1980, suggesting a pulse of low productivity in the lake, but it quickly rebounded to over 70% by 1983. Pediastrum boryanum historically comprised between three and ten percent of this genus, but it was noticeably absent after 1961, except for a brief occurrence in 1983.

Total Pediastrum accumulation showed no relationship to TP levels (R^2 = 0.02) (Figure 6-17). However, some weak trends emerged when each species, expressed as a percentage of the entire genus, was plotted against TP (Figures 6-18). Percentage of Pediastrum araneosum gradually declined with increasing TP, but this relationship was weak (R^2 = 0.24) (Figure 6-18). Similarly, the fraction of P. duplex generally increased with higher TP (R^2 = 0.24) (Figure 6-18). Pediastrum boryanum showed no relationship to TP whatsoever (R^2 = 0.00) (Figure 6-18). These weak correlations suggest that elevations in Lake Weir's nutrient regime were not accompanied by increased water hardness.

6.6.F CONCLUSIONS

Four distinct periods of change within Lake Weir's autotrophic community over recent history were identified in the sediment core. Changes in subfossil algal species composition were assumed to represent ecological shifts in the lake system. Each of these intervals was associated with anthropogenic activities within the watershed.

Land clearance around 1900 was associated with a moderate elevation in total algal abundance and TP accumulation. Both Botryococcus sp. and total Pediastrum peaked in 1896, but Peridinium (an indicator of lower productivity) did not reflect this increase. The algal community resumed its baseline composition by approximately 1913. This may suggest that Lake Weir has the innate capacity to revert back to lower trophic state once extraordinary nutrient inputs have been removed.

Installation of the weir structure in 1938 may have been responsible for a number of changes observed in the core. Sediment TP accumulation more than doubled and total algal abundance increased roughly forty percent from its baseline level. Staurastrum first appeared immediately following impoundment, and Peridinium declined after 1951. It is possible that changes in Lake Weir's flushing regime

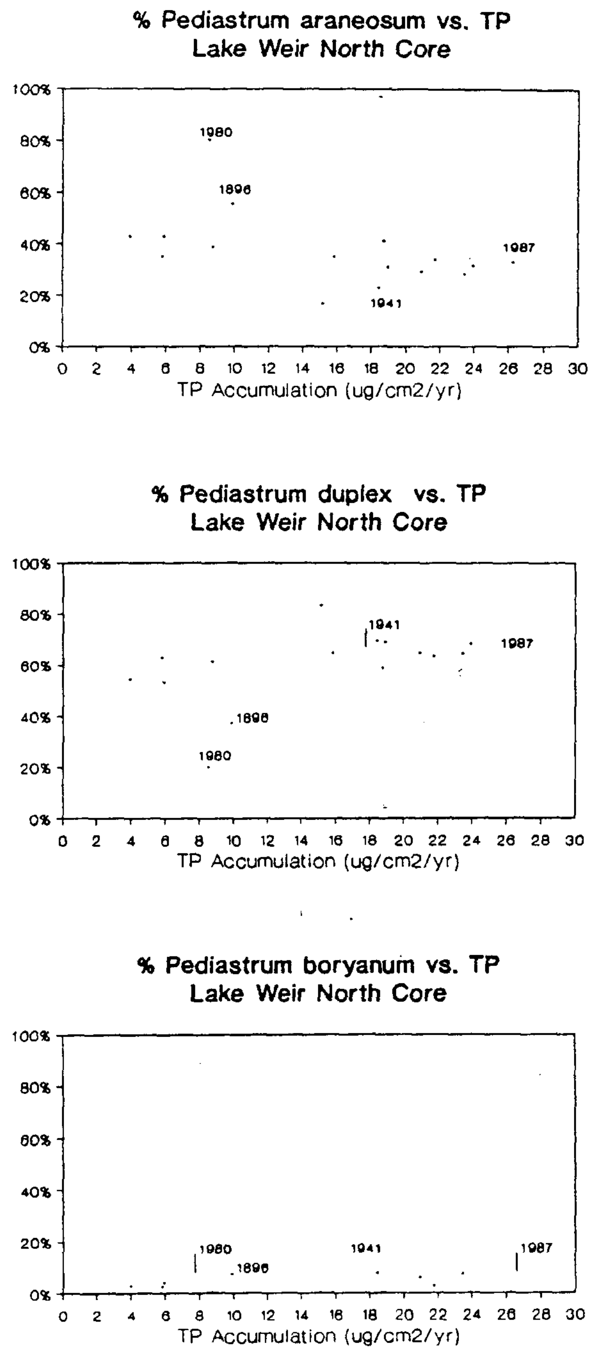


Figure 6-18. Relationship between the percentage abundance of individual species of <u>Pediastrum</u> and total phosphorus in the Lake Weir core.

caused by the weir structure were responsible for these observed shifts, and that the lake now has less capacity to cleanse itself than before impoundment.

A brief episode of lower productivity was observed about 1980. This interval was marked by sharply diminished TP levels and a sharp pulse in the ratio of softwater (lower trophic state) to hardwater algal species. Accumulation rates of Staurastrum and total Pediastrum decreased, while Peridinium became relatively more abundant. It is possible that this unusually clean-water episode is associated with extremely high water levels during April through July of that year caused sufficient flushing to purge the lake of much of its water column phosphorus.

Finally, 1987 was associated with signs of higher productivity. All algal taxa except Pediastrum displayed sharply increased accumulation. Staurastrum represented the most evident change, increasing abundance tenfold. While Peridinium increased in number, its relative percentage among total algal species decreased.

The year 1987 was also marked by the highest TP levels in the core. These indicators of higher productivity probably corresponded to the rapid growth in watershed population at that time. Lower water levels during this period could have contributed to higher water column TP concentrations and related biological parameters.

6.7 SUBFOSSIL CLADOCERANS

6.7.A OVERVIEW

Cladocera (Crustacea) are valuable indicators of lake trophic state because they are fairly ubiquitous and abundant in lake systems, have specific ecological tolerances, and are easy to identify to species. They also have been used extensively for paleolimnological interpretations. In particular, the chydorid cladocerans have many valuable attributes for paleoecological evaluations: they are abundant subfossils in all kinds of lacustrine sediments, are well-correlated to ecological conditions, and can be easily identified to species by many body parts (e.g. head shield, body shell, postabdomen and claw) (Frey 1960a, 1960b, 1967). Cladoceran species have been correlated to trophic state, water chemistry, community structure, size-selective predation, oxygen concentration, sediment composition, water depth, seasonality, and environmental fluctuation (Crisman 1978).

Six species of chydorid cladocera were identified from the Lake Weir core: Chydorus sphaericus, Alona affinis, Leydigia leydigi, L. acanthocercoides, Rhynchotalona falcata, and Eurycercus sp. Chydorids are generally benthic, with the notable exception of Chydorus sphaericus, which can become planktonic by means of rafting on blue-green algae. Because blue-green algae have not been historically dominant in Lake Weir (Messer 1975), all chydorids were considered to be indicators of littoral productivity.

Additionally, three species of planktonic cladocera were identified and enumerated. Eubosmina tubicen was by far the dominant planktonic species, generally comprising over 95% of the cladoceran assemblage. Daphnia ambigua, and Diaphanosoma brachyurum were present sporadically from 1966 to the present, but never in adequate abundance to warrant further discussion.

6.7.B CLADOCERAN ACCUMULATION RATES

The accumulation rate of total cladocera (planktonic and littoral) was determined for the Lake Weir core (Figure 6-19). The intervals prior to the weir structure ranged from 150 to 200 individuals/cm^2/year (ICY), except for 1896 which had 315 ICY. This peak coincided with elevated levels in sediment TP, total algae, neorhabdocoels, and rotifers and represented a time when much of the native forest in Lake Weir's watershed was being cleared for pastures and citrus groves.

Cladocera accumulation dropped to 95 ICY in 1941. This may have been a short term response to either installation of the weir structure or associated dredging in 1938. Cladocera levels quickly rebounded to the 300 ICY range, where they remained from 1951 until 1970 when they increased to the 400 ICY range.

In 1980, total cladocera accumulation dropped to 270 ICY. This was an interval also characterized by reduced sediment TP and algal accumulations, and dominance by softwater algal species. Water column TP in 1980 also was the lowest recorded for the historical data base of water quality monitoring (1969-1989). Cladocera rebounded by 1987, reaching nearly 600 ICY, their highest historical level. It must be noted, however, that accumulation rates of subfossils in the most recently deposited sediments may

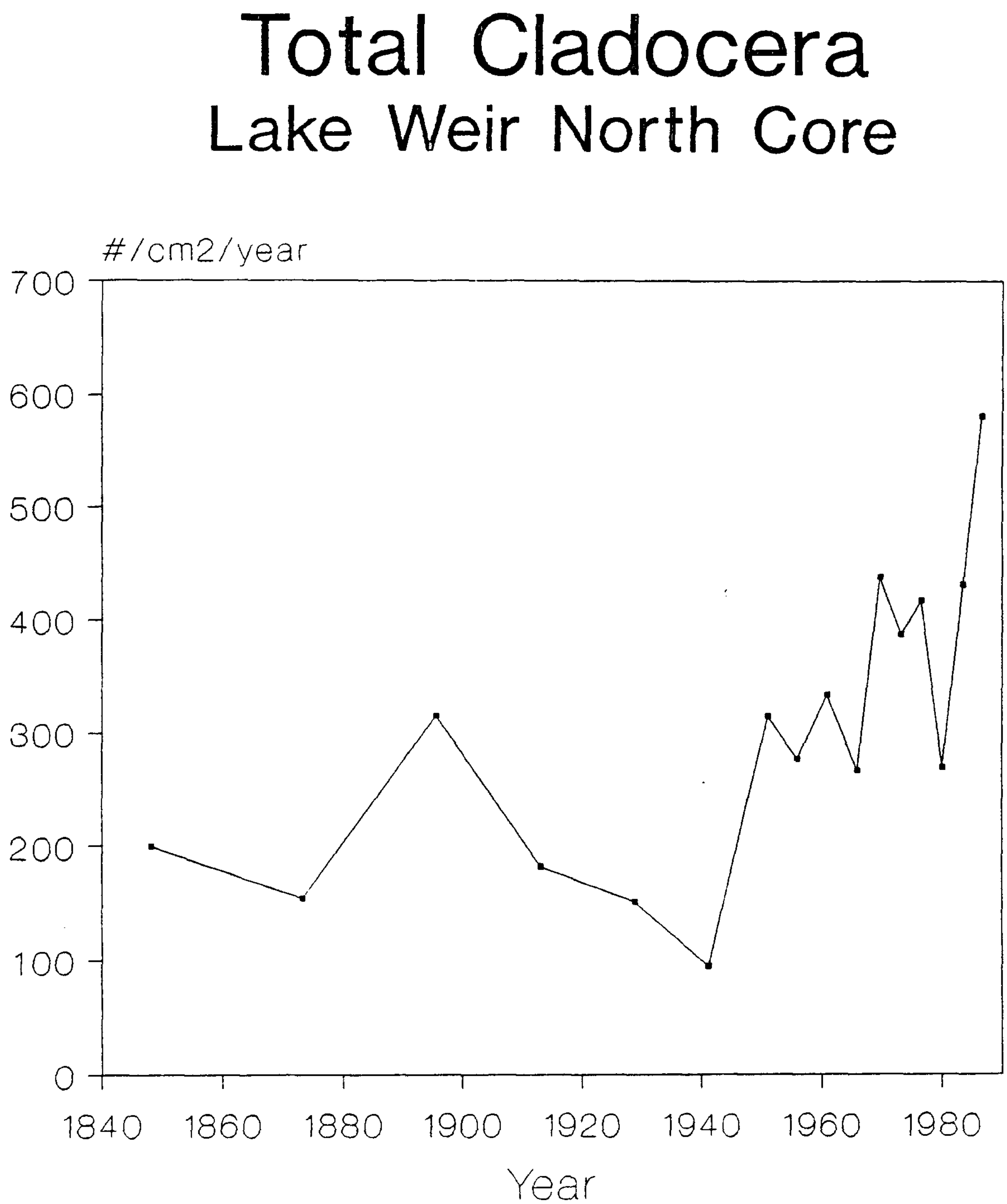


Figure 6-19. Accumulation rates of total cladocerans in the Lake Weir core.

be affected by differential preservation, in that there has not been sufficient time since deposition for readily decomposable matter to disappear.

6.7.C PLANKTONIC VERSUS LITTORAL CLADOCERANS

The trophic behavior of a lake is a function of the littoral contribution to its total productivity. For instance, increased nutrient loading could result in littoral zone expansion or in increased dominance by phytoplankton. Knowing how a lake has responded to nutrient additions in the past is the key to predicting future trophic changes. Historical changes in a lake's littoral productivity are recorded by the relative abundance of littoral subfossils in its sediment.

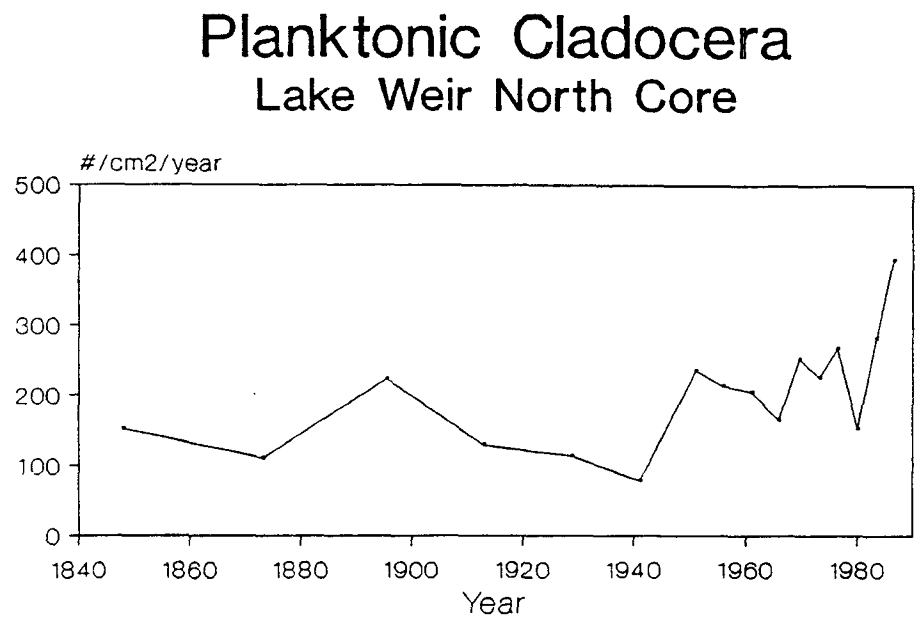
Littoral zone expansions can also result from changes in lake level which increase the areal extent of shallow water. Water level fluctuations should not dramatically alter the littoral area of Lake Weir, due to its steep-sided morphometry. Therefore, any observed amplification in Lake Weir's littoral productivity probably resulted from increased nutrient loading.

Subfossil cladocera in Lake Weir were used to identify any historical littoral expansions. Trends in planktonic (Figure 6-20) and littoral cladocera (Figure 6-20) accumulation rates were similar to the pattern described for total cladocera. The proportion of littoral cladocera remained fairly costant throughout the core (Figure 6-21). In fact, direct comparison of the two cladoceran communities throughout the core revealed a close correlation ($R^2 = 0.68$) (Figure 6-21).

This relationship implies that Lake Weir's littoral zone has not been significantly altered by changes in nutrient loading or lake level. Further, increased productivity seems to have been more or less evenly distributed between the littoral and planktonic communities.

6.7.D ClADOCERANS VERSUS TOTAL PHOSPHORUS

Total cladocera were moderately correlated with TP accumulation throughout the core ($R^2 = 0.46$) (Figure 6-22). This correlation became stronger ($R^2 = 0.65$) by omitting the 1941 point. This apparent outlier, as mentioned earlier,



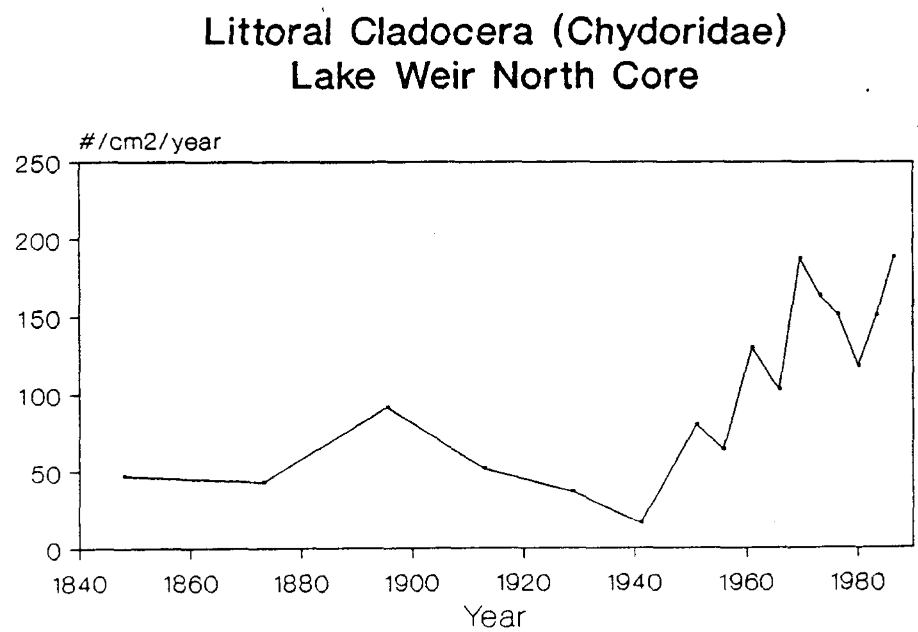
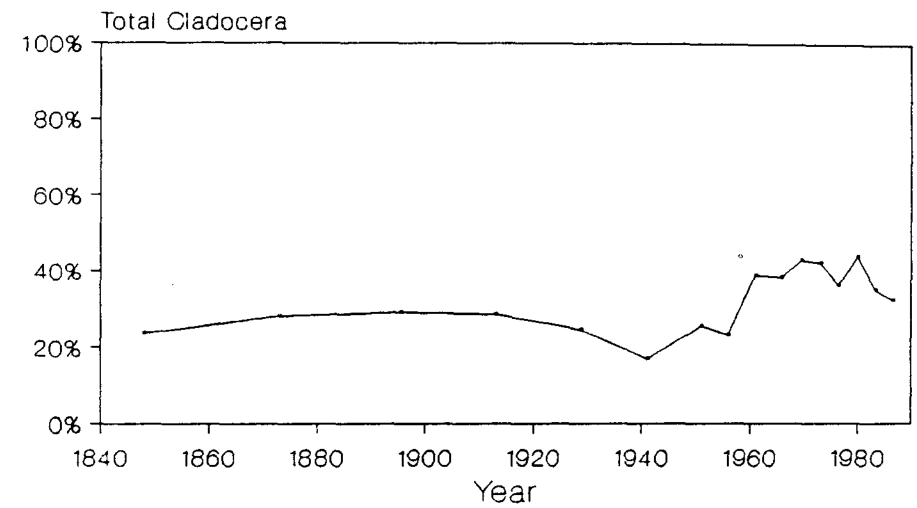


Figure 6-20. Accumulation rates of planktonic and littoral cladocerans in the Lake Weir core.

% Littoral Cladocera (Chydoridae)
Lake Weir North Core



Littoral vs. Planktonic Cladocera
Lake Weir North Core

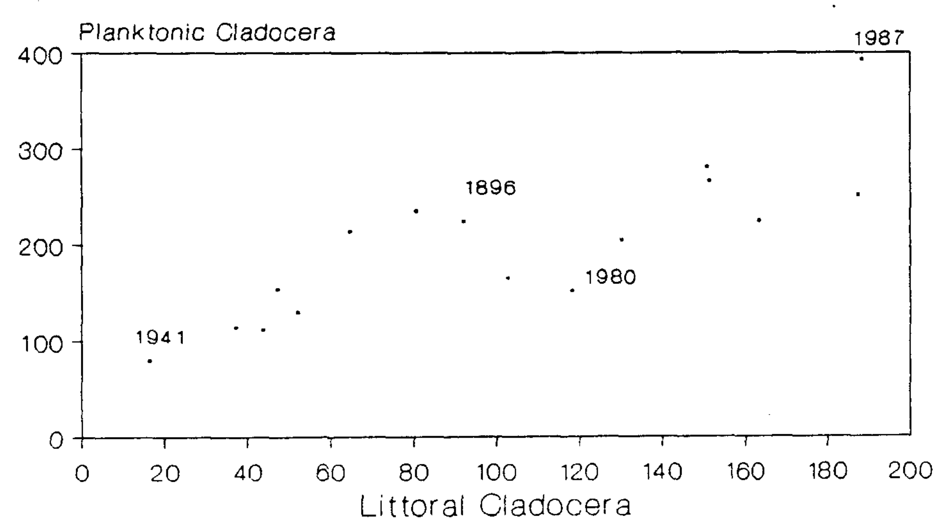


Figure 6-21. Percentage contribution of littoral cladocerans and the relationship between littoral and planktonic cladocerans in the Lake Weir core.

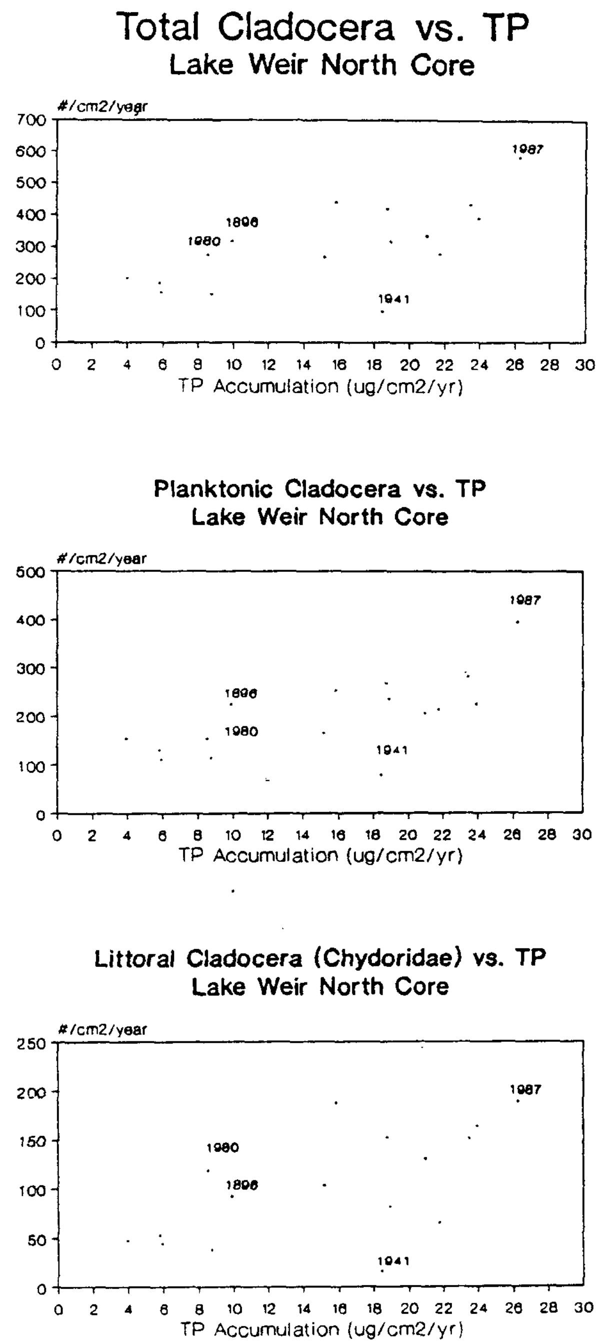


Figure 6-22. Relationship between total, planktonic, and littoral cladocerans and total phosphorus in the Lake Weir core.

may have been related to the impoundment activities of 1938.

Planktonic cladocera were even more closely correlated to TP accumulation ($R^2 = 0.64$), omitting the 1941 interval (Figure 6-22). Inclusion of 1941 in the data set would reduce this relationship. Littoral cladocera showed slightly less relationship to TP ($R^2 = 0.51$) (Figure 6-22). Of the individual chydorid species, *Leydigia leydigi* showed the closest correlation to TP ($R^2 = 0.53$) (Figure 6-23). *Leydigia leydigi* has frequently been found in polluted lakes (Whiteside 1969).

While there seemed to be some association between TP and cladocera accumulations, these relationships were not strong enough to fully account for cladoceran abundance. Planktonic cladocera appeared to be more sensitive to changes in TP than the littoral chydorids.

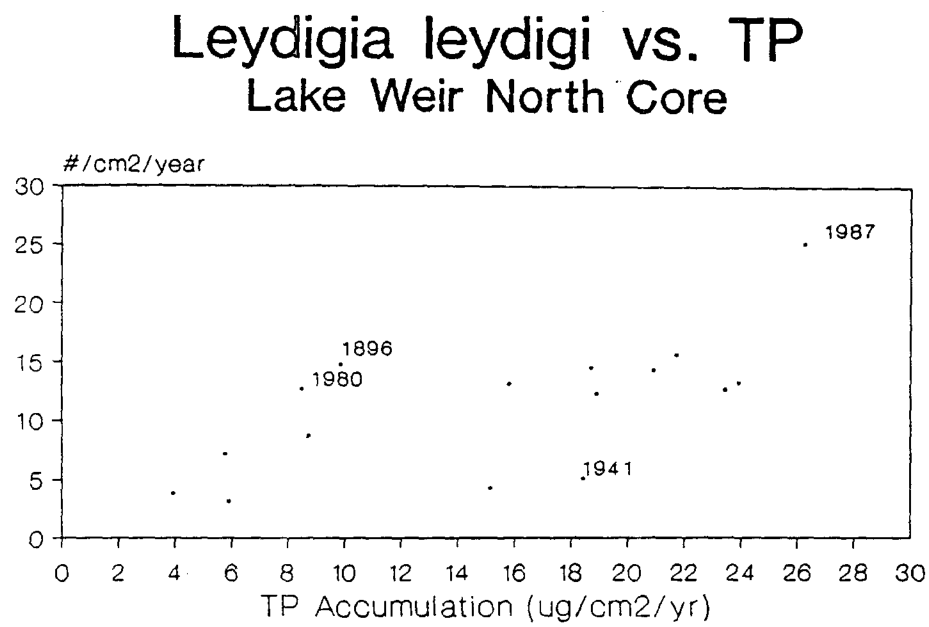
6.7.E CHYDORID ECOLOGY

Chydorus sphaericus, the dominant chydorid throughout the core, is a well known indicator of higher productivity. It was found in all lakes sampled by Whiteside (1969), and was most abundant in highly polluted lakes. The historical abundance of *C. sphaericus* in Lake Weir suggests that the lake has not been oligotrophic over the past century (Figure 6-23).

Rhynchotalona falcata, a classic indicator of lower trophic state (Crisman 1980) was the second most abundant chydorid species present. This species seemed to prefer acidic lakes and was rarely found in polluted systems (Whiteside 1969). In Lake Weir, *R. falcata* was proportionately more abundant (relative to *Chydorus sphaericus*) prior to 1956 (Figure 6-24). At that point, *C. sphaericus* appeared to replace it, possibly indicating a transition toward higher productivity. However, *R. falcata* made a strong comeback in 1987, the period of highest TP elevation.

Leydigia leydigi was the third most abundant chydorid species in the Lake Weir core (Figure 6-24). It has been identified as a bottom dweller frequently found in polluted lakes. Changes in its accumulation rates resembled those of *Rhynchotalona falcata*. Both exhibited peaks in 1896, lows in 1941, sharp increases by 1951, and reductions in 1956.

Alona affinis was the fourth most common chydorid. This cosmopolitan species showed no significant correlations to lake trophic parameters (Whiteside 1969). *Leydigia*



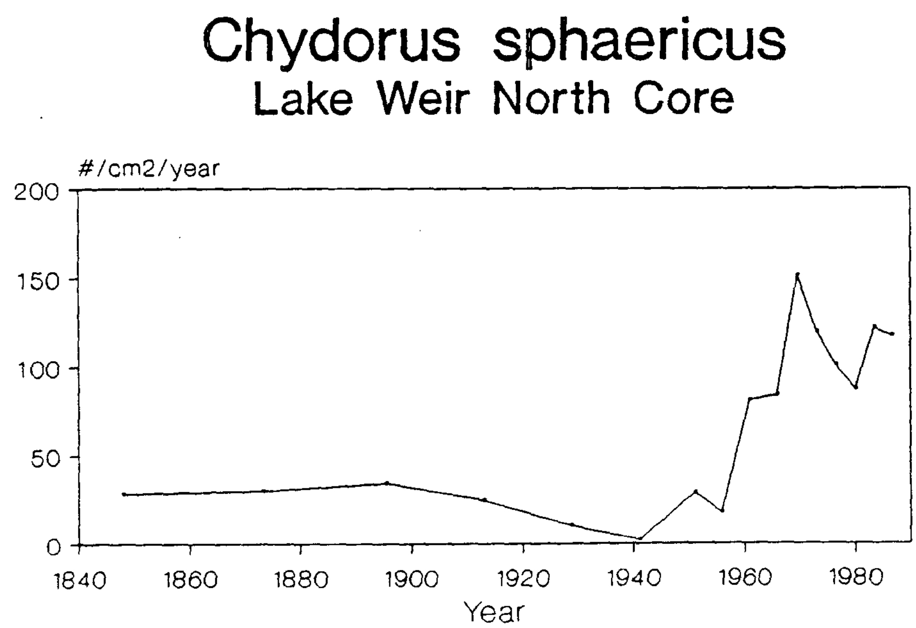
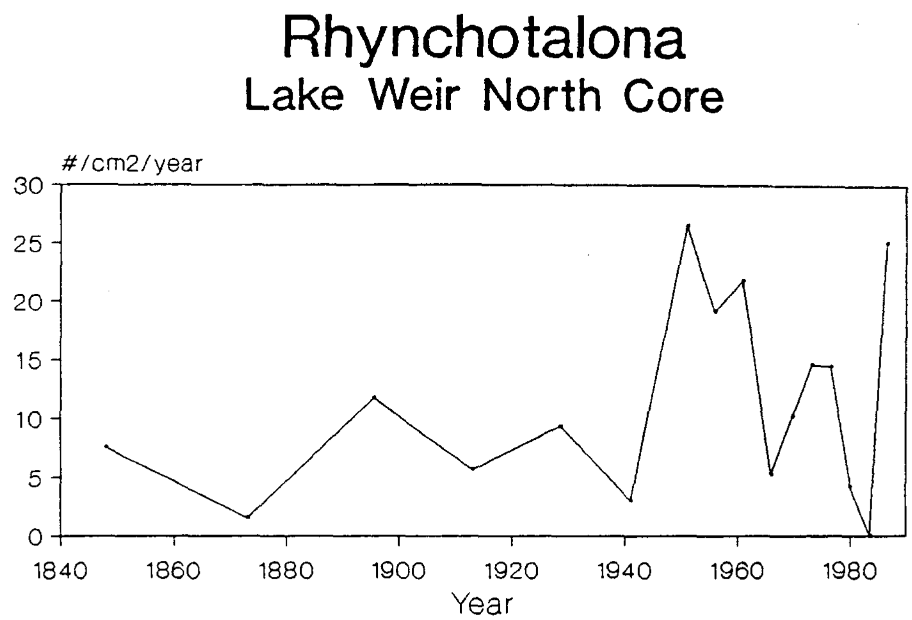


Figure 6-23. Relationship between Leydigia leydigi and total phosphorus and accumulation rates of Chydorus sphaericus in the Lake Weir core.



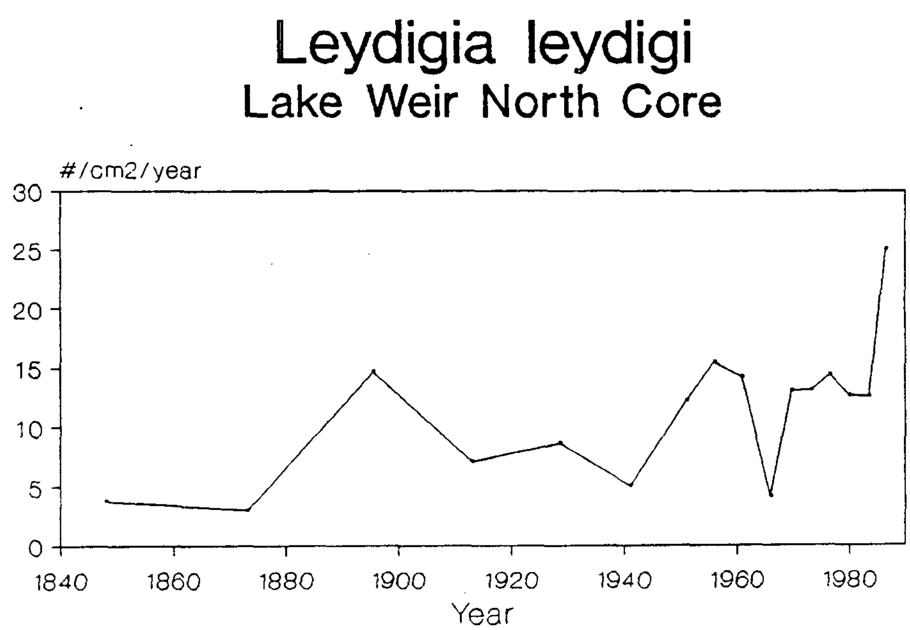


Figure 6-24. Accumulation rates of *Rhynchotalona falcata* and *Leydigia leydigi* in the Lake Weir core.

acanthocercoides, the next most common, has shown a high preference for polluted sites (Whiteside 1969). Finally, *Eurycercus lamellatus* was sporadically present, first appearing in 1961. This species was negatively correlated with depth, conductivity, and alkalitity; having an affinity for non-polluted sites (Whiteside 1969).

Rhynchotalona falcata and *Leydigia leydigi* both demonstrated elevated accumulation rates in 1896, a period associated with considerable land clearance within the watershed. While all chydorid species were less abundant in 1941, *Rhynchotalona falcata* and *Leydigia leydigi* rebounded more rapidly than did *Chydorus sphaericus*. When water column TP increased in 1970 (Messer, 1975), *C. sphaericus* reached its greatest historical abundance, and *L. leydigi* and *R. falcata* both declined sharply. In 1987 these two increased sharply while *Chydorus sphaericus* remained fairly constant.

6.7.F CLADOCERANS VERSUS SUBSTRATE

One important factor which could influence the cladoceran community is lake substrate. The organic composition of the sediment or the abundance of aquatic macrophytes could affect the number of claocera and the species composition. Chydorid cladocera, being littoral in nature, should be the most sensitive to changes in the lake bottom.

Cladocera accumulation was compared to percent organic content of the sediment. Total cladocera accumulation rates were moderately correlated to sediment organic content (R^2 = 0.49). However, the littoral (i.e. chydorid) cladocera were more strongly associated with percent organics (R^2 = 0.63) (Figure 6-25) than the planktonic cladocera (R^2 = 0.35). The strongest correlation to organics among the chydorid species was by *Chydorus sphaericus* (R^2 = 0.66) (Figure 6-25).

These results indicate that cladocera were more abundant during periods of increased organic sediment composition. However, it was not clear whether the cladocera were responding to changes in the sediment, or whether both were the result of some covariable such as TP. The chydorid family, and particularly *Chydorus sphaericus*, was the most sensitive to whichever factor was responsible.

No exclusive weed dwelling chydorid species were found in the core. Obligatory weed dwellers such as *Graptoleberis testudinaria* were noticeably absent from the entire core.

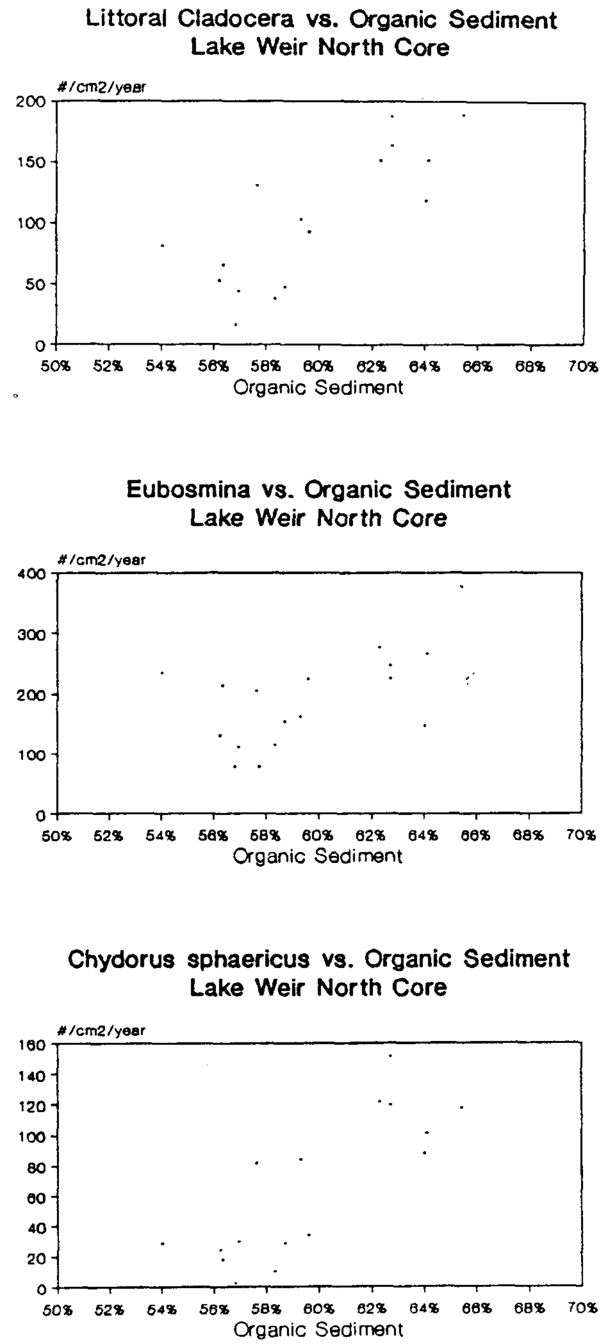


Figure 6-25. Relationship between littoral cladocerans, <u>Eubosmina</u>, and <u>Chydorus sphaericus</u> and total phosphorus in the Lake Weir core.

This suggests that Lake Weir has not been dominated by aquatic macrophytes over the past century.

6.7.G CLADOCERANS VERSUS TOTAL ALGAE

Another factor controlling cladoceran populations is algal composition and abundance. Botryococcus, the dominant subfossil algal species, is a fairly palatable form of green algae, lacking a protective sheath or mucilage. Because this species was always dominant, shifts in algal composition would not have strong bearing on the cladoceran community.

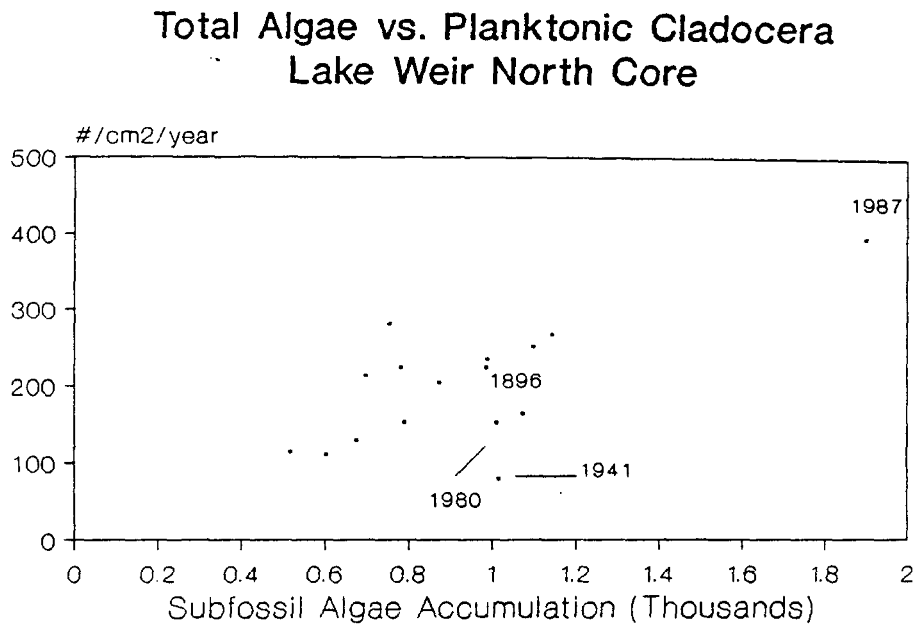
Rather, changes in total algal abundance could have governed cladoceran populations. Total algae versus total cladocera had an R^2 value of 0.61, omitting the 1941 interval. Planktonic cladocera showed a slightly higher level of significance ($R^2 = 0.62$) (Figure 6-26). Littoral cladocera showed only an R^2 value of 0.45 (Figure 6-26). Therefore, planktonic cladocera were more sensitive to total algal abundance than the littoral (chydorid) cladocera.

6.7.H CONCLUSIONS

Cladoceran accumulation rates showed several peaks and dips at various intervals throughout the core, probably in response to changes in TP, percent of organic sediment, and algal abundance. It is interesting to note that planktonic cladocera were correlated more closely to TP levels and total algal abundance, while littoral cladocera were more closely linked with substrate (percent organics). There appeared to be some degree of covariance between these factors.

The continuous presence of Chydorus sphaericus throughout the past 140 years suggests that the lake has maintained at least a low mesotrophic state over that time. Rhynchotalona falcata, a classic cladoceran indicator of lower productivity, was proportionately more abundant in the lower core intervals.

Of the chydorids, Leydigia leydigi was the most sensitive to changes in TP levels, but this was not a strong enough relationship to account for chydorid abundance. Absence of weed dwelling cladocerans downplays the historical significance of aquatic macrophytes in Lake Weir.



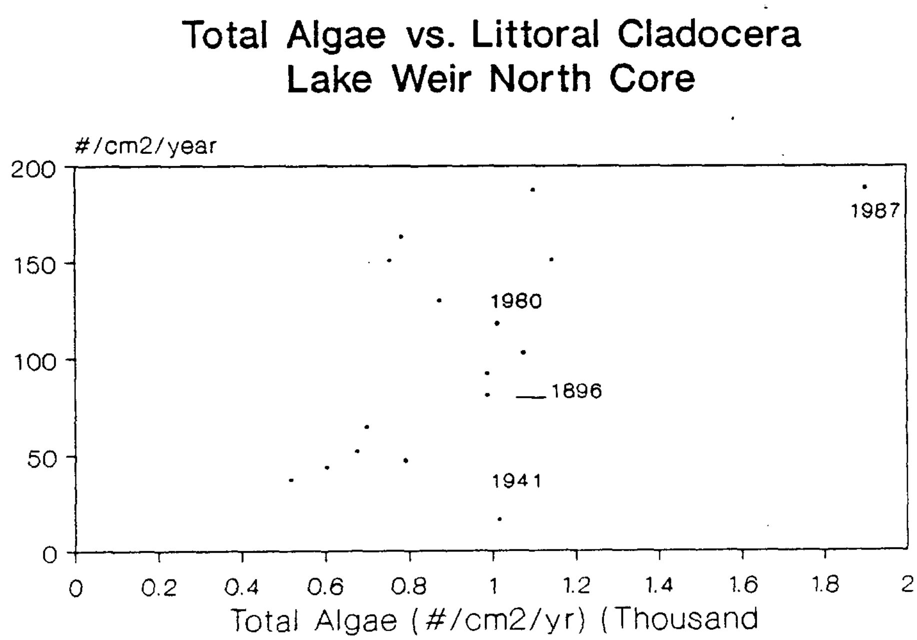


Figure 6-26. Relationship between total algae and planktoni‹
and littoral cladocerans in the Lake Weir core

6.8 SUBFOSSIL ROTIFERS AND NEORHABDOCOELS

6.8.A ROTIFERS

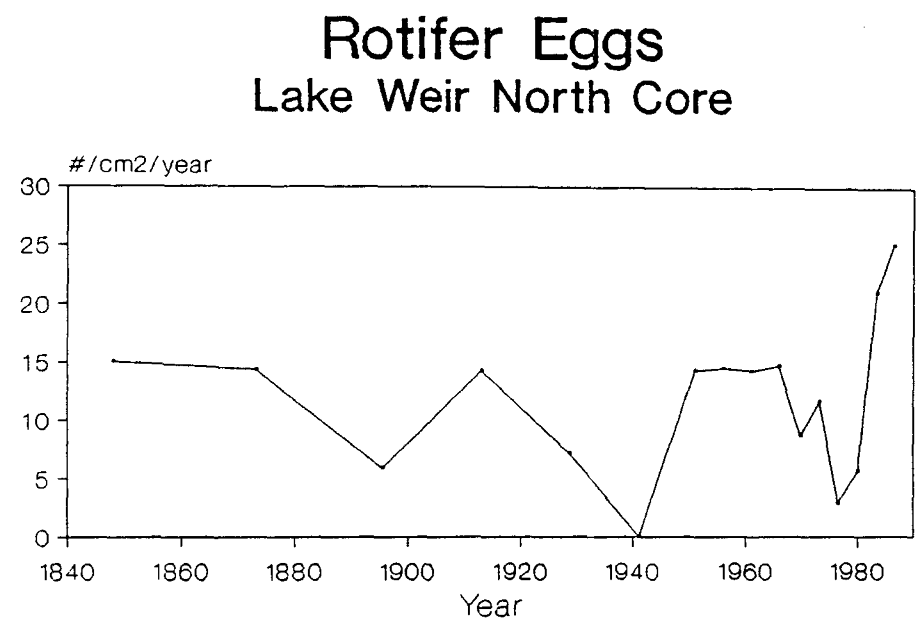
Rotifers are an important component of Lake Weir's zooplankton community, comprising over 30% of the total current zooplankton biomass (cf. Chapter 5). They are an important indicator of planktonic productivity, and increased rotifer biomass has been related to higher trophic state in Florida lakes (Bays and Crisman 1983). Further, they have been shown to foreshadow eutrophication (Beaver and Crisman 1988).

Rotifers are represented in the sediment record by their egg capsules. Although both littoral and planktonic assemblages can be represented in the sediment record, clearly, differential preservation of taxa plagues interpretation. We have not been able to separate the contribution of littoral and planktonic assemblages but have assumed that accumulation rates of preserved egg capsules in the core profile are roughly proportional to the contemporaneous rotifer populations.

Prior to 1896 rotifers varied between 14 and 15 individuals/cm^2/year (ICY) (Figure 6-27). Accumulation rates dropped to 6 ICY in 1896, a period of presumably higher productivity associated with land clearance. Rotifers were completely absent in 1941, following installation of the weir structure, but rebounded to around 14 ICY by 1951. Rotifers declined again about 1980, further evidencing some dramatic but short-lived shift to lower productivity in that year. Finally, rotifer populations sharply increased in approximately 1983 and 1988.

This recent increase to the highest recorded level corresponds to the recorded increase of rotifer biomass from 1969 to 1988 (Beaver and Crisman 1988). This is reason for concern, as rotifers and scuticociliates were demonstrated to be early indicators of a shift to higher trophic state.

Interestingly, rotifer accumulation showed a different relationship to TP levels pre- and post-impoundment (Figure 6-27). Prior to the weir structure rotifer accumulation decreased with higher TP ($R^2 = 0.93$). However, rotifer accumulation increased with increasing TP ($R^2 = 0.36$) following lake impoundment. Overall correlation to TP was



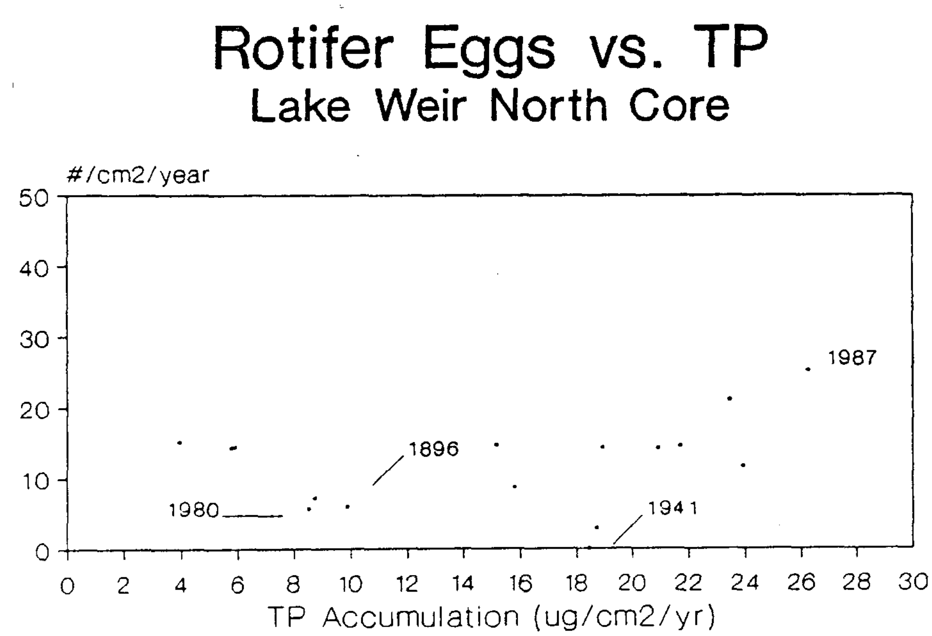


Figure 6-27. Accumulation rates of rotifer eggs and the relationship between rotifer eggs and total phosphorus in the Lake Weir core.

weak (R^2 = 0.09). This may attest to a basic difference in biotic or abiotic conditions operating within the lake system caused by impoundment.

6.8.B NEORHABDOCOELS

Neorhabdocoels have not received much attention in previous paleolimnological studies. Although their ecological significance in sediment cores has not been studied as thoroughly as that of the cladocerans or chironomids, their presence and abundance are generally associated with increased benthic productivity.

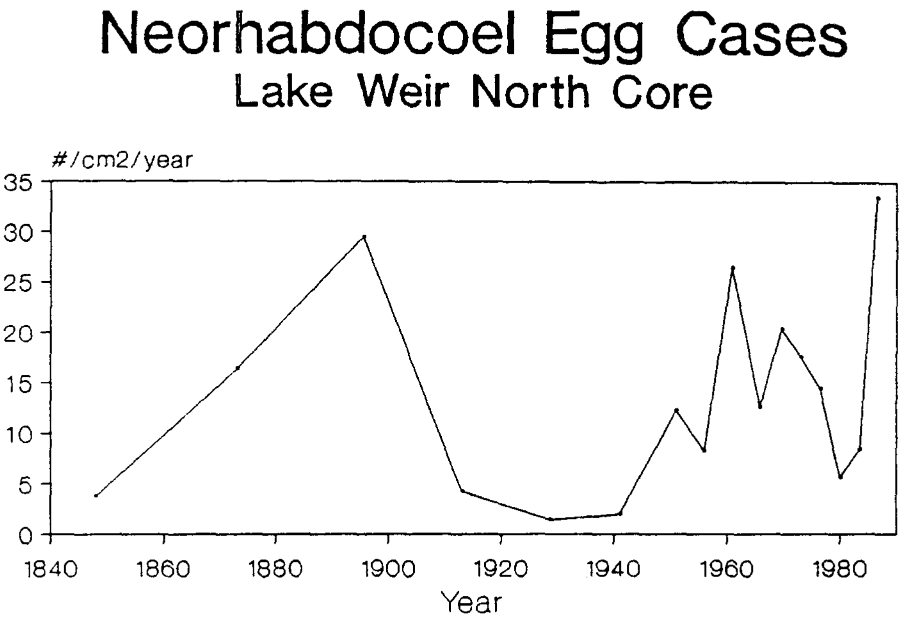
Accumulation rates of neorhabdocoel egg cases peaked at 29 individuals/cm^2/year around the turn of the century, possibly reflecting the pulse of productivity caused by widespread land clearance in the watershed at that time (Figure 6-28). Their accumulation rate decreased to 1 ICY by 1929, then moderately increased between 1941 and 1951.

Neorhabdocoels peaked at 26 ICY in 1961, a year marked by the highest historical water levels. After 1961, their accumulation varied between 12 and 20 ICY, then decreased to 6 ICY in 1980. This interval was marked by lower TP, proportionately more soft-water algal species, and fewer total cladocera. Finally, they abruptly jumped to 33 ICY in 1988, suggesting a recent increase in benthic productivity.

Even though neorhabdocoel accumulation tracked the periods of highest and lowest productivity, they were only weakly related to TP over the entire core (R^2 = 0.16) (Figure 6-28) possibly related to their benthic habitat preference. At least in 1961, they appear to have been influenced by lake level.

6.9.A CHIRONOMIDS

Chironomidae, the non-biting midge family, is ecologically diverse and highly ubiquitous, having species in many freshwater habitats, spanning a broad range of productivity. However, many of the species are restricted to specific ecological conditions. Due to their winged adult forms, midges are often one of the earliest pioneers to inhabit newly created or disturbed aquatic habitats. These characteristics make the group one of the fastest, most sensitive biological indicators of ecological



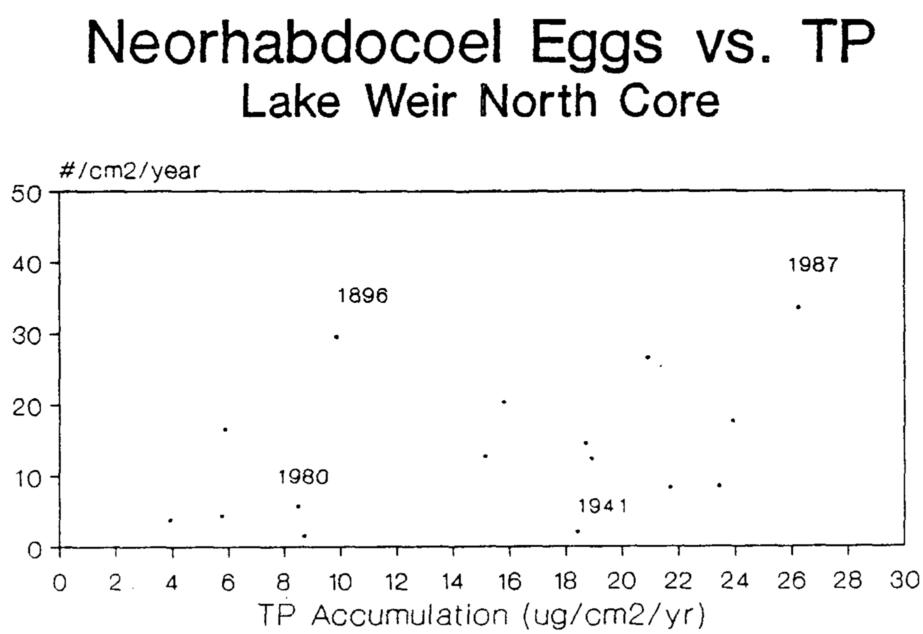


Figure 6-28. Accumulation rates of neorhabdocoel eggs and the relationship between neorhabdocoel eggs and total phosphorus in the Lake Weir core.

perturbations.

Chironomidae is also a highly diverse group in terms of material cycling and energy flow. Different chironomid species are shredders, collectors (sediment and filter feeders), mineral and organic scrapers, and predators (Cummins 1973). Chironomids are a common component of Florida's freshwater ecosystems, occupying many different habitats in lakes or along stream gradients (Beck 1954).

Lake Weir's total chironomid profile showed a baseline accumulation rate of under three midge individuals/cm^2/year (ICY) through 1941 (Figure 6-29). Midge accumulation rates reached five ICY by 1951, and the historical high of eleven ICY by 1961. The midge community subsided by 1966 and fluctuated between five and ten ICY until 1980 when it dropped to under two ICY, their lowest modern level. Midges increased again to five ICY by 1987.

Several intervals punctuate the historical midge accumulation rates. As observed in the TP, algae and cladocera profiles, 1896 was associatied with a moderate pulse of productivity. The next period of expansion occurred between 1941 and 1951, later than in the TP, algae and cladocera. Once again, 1980 stands out as a period of lower productivity.

Total chironomids showed some correlation to sediment TP accumulation (R^2 = 0.39) (Figure 6-29). While this does not appear to be highly significant, it is interesting to note that the five pre-weir points correlated closely (R^2 = 0.61) and that post-impoundment data showed no association (R^2 = 0.02). This may indicate that lake impoundment changed the way in which midge populations responded to TP or other variables.

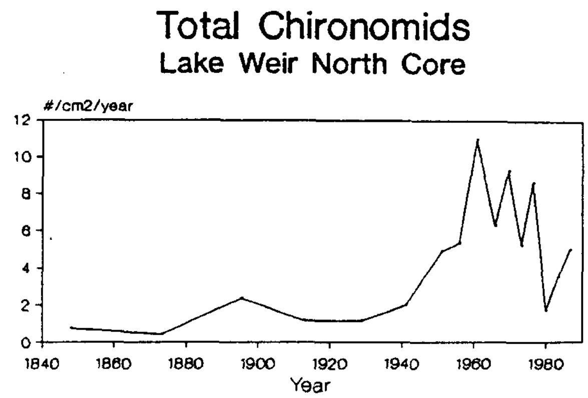
At least six chironomid genera were identified from the Lake Weir sediment. The taxonomic relationships are as follows:

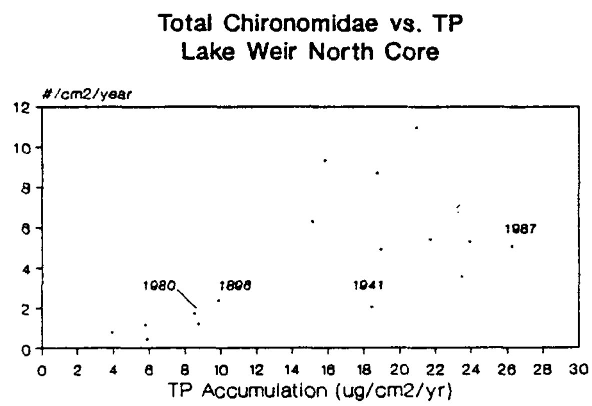
Family Chironomidae

Subfamily Chirinominae

Tribe Chironomini
Genus <u>Lauterborniella</u>
Genus <u>Chironomus</u>

Tribe Tanytarsini
Genus <u>Tanytarsus</u>





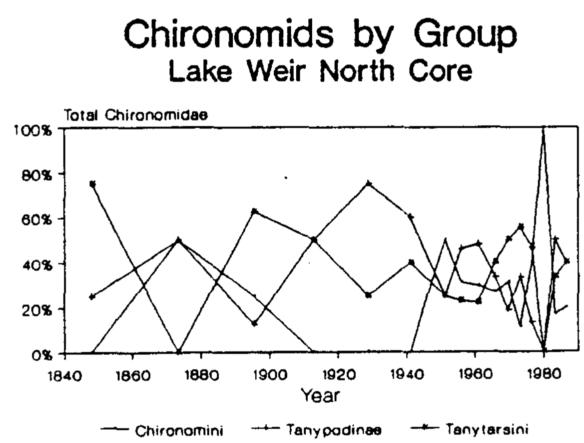


Figure 6-29. Total chironomid accumulation rates, the relationship between total chironomids and total phosphorus, and the percentage contribution of individual chironomid groups the Lake Weir core.

Subfamily Tanypodinae
Genus <u>Ablabesmyia</u>
Genus <u>Coelotanypus</u>
Genus <u>Procladius</u>

Examination of the three groups of chironomids revealed several compositional shifts (Figure 6-29). Tanypodinae were present throughout the entire core, but achieved their greatest percentage of abundance between 1913 and 1941, representing over 50% of all midges during this period. Tanytarsini were dominant in the deepest core interval, and became progressively less dominant over time, with the exception of a brief resurgence in 1973. Chironomini were present briefly from 1873 to 1896, but did not become a major component of the community until 1951.

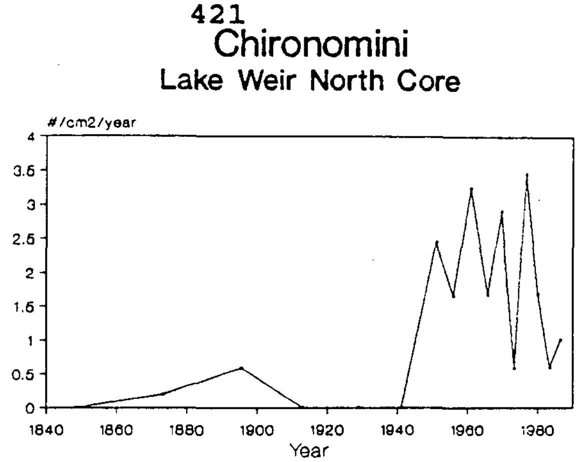
Chironomini are generally considered to be indicative of higher trophic state. This group was absent in the oldest levels of the core, and appeared for the first time in 1873, having an accumulation rate of under 0.6 ICY (Figure 6-30). They were completely absent from 1913 to 1941, and increased sharply to almost 2.5 ICY by 1951. Following that interval, Chironomini numbers fluctuated between 0.5 and 3.5 ICY.

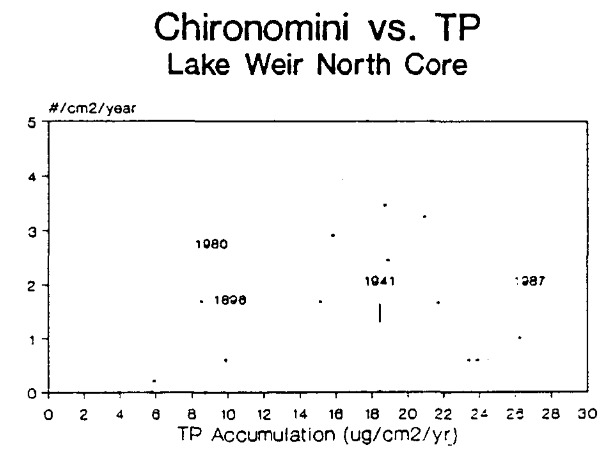
Chironomini showed little correlation to TP (R^2 = 0.16) (Figure 6-30). When compared to total algae, the 1987 point appeared to be anomalous (Figure 6-30). The relationship was strengthened significantly (from R^2 = 0.11 to R^2 = 0.39) by removal of this one outlier. An association with total algae is reasonable considering that the Chironomini are largely (>80%) algivorous (Cummins 1973).

Accumulation of Tanytarsini in the core showed a baseline level of under 0.5 ICY (Figure 6-31). They moderately increased in 1896, corresponding to elevated levels of productivity indicated by TP and multiple biological parameters. Tanytarsini became progressively more dominant from 1929 to 1970, when they reached their historical high of over 4.5 ICY. This group dropped out of the core profile in 1980, a period marked by lower trophic parameters, then rebounded slightly by 1987.

Many species of the genus <u>Tanytarsus</u> are associated with lower productivity. However, within the Lake Weir core this genus increased during periods of higher productivity. This implies that Lake Weir has historically been of low to moderate trophic state, and that <u>Tanytarsus</u> populations have been limited by food availability.

Accordingly, Tanytarsini accumulation was loosely correlated with TP (R^2 = 0.26), generally increasing in number at times of higher productivity (Figure 6-31).





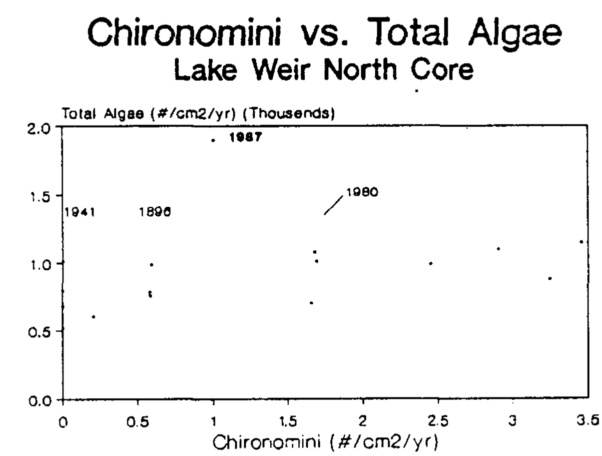
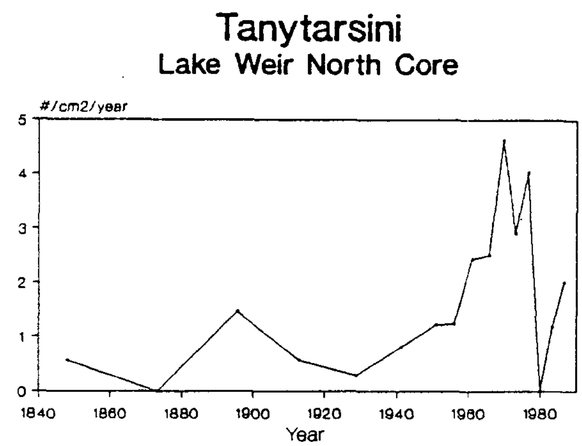
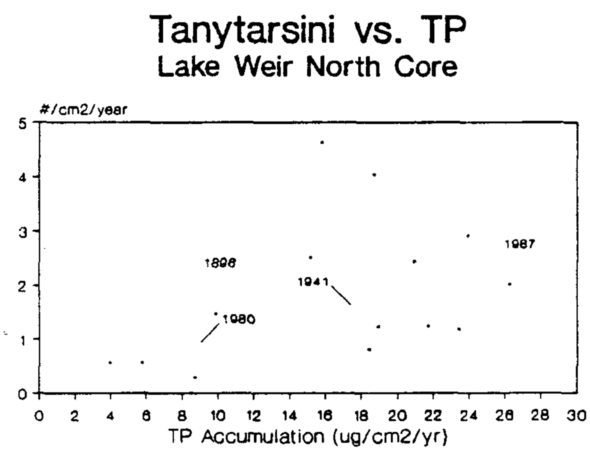


Figure 6-30. Accumulation rates of chironomini, the relationship between chironomini and total phosphorus and total algae in the Lake Weir core.





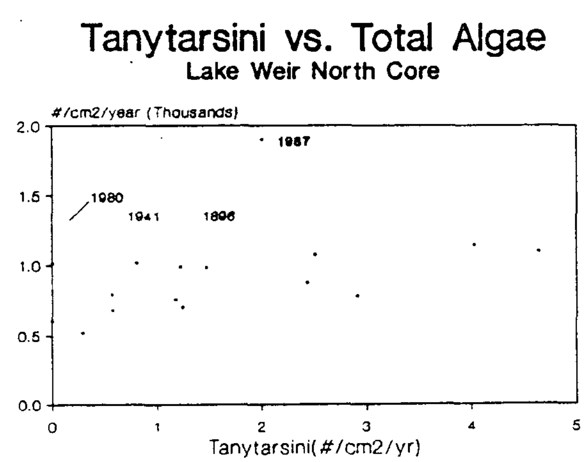


Figure 6-31. Accumulation rates of tanytarsini, the relationship between tanytarsini and total phosphorus and total algae in the Lake Weir core.

However, this association was not strong enough to connote a direct relationship. Other food-related factors which may have affected Tanytarsini levels include algal abundance, sediment organic composition, and cladoceran communities.

Algal accumulation was slightly correlated to Tanytarsini (Figure 6-31) throughout the core ($R^2 = 0.17$). This relationship was improved ($R^2 = 0.36$) by removing the 1987 outlier. Sediment organic content showed a similarly weak association to this genus ($R^2 = 0.21$). Clearly, none of these factors can reasonably account for historical Tanytarsini populations in Lake Weir.

Some interesting associations arose in comparison of Tanytarsini populations to the chydorid community. Tanytarsini displayed a much higher correlation to total cladocera ($R^2 = 0.42$) than to any of the above parameters. The littoral cladocera (i.e. Chydoridae) were more closely correlated ($R^2 = 0.54$) to Tanytarsini midges than were planktonic cladocera ($R^2 = 0.30$).

Tanytarsini midges appeared to respond more to chydorid cladoceran levels than to any other parameter investigated. If the midges were indeed food-limited, it would appear that Lake Weir's Tanytarsini population preferred a carnivorous diet to algal or detrital grazing. This contradicted Cummins' (1973) food habits for Rheotanytarsus exigua, which was 66% algivorous and only 6.9% carnivorous.

Subfamily Tanypodinae, which is almost purely carivorous in habit, maintained a small but continuous presence in the deeper core (Figure 6-32). Their number gradually increased from a baseline accumulation of 0.25 ICY to just over 1.0 ICY in 1951. Tanypods dramatically increased over the next two intervals, reaching their all-time high of over 5.0 ICY in 1961. They dropped down to around 2.0 ICY as quickly as they had increased, and were absent during the celebrated clean water episode of 1980.

Two tanypod genera were introduced to Lake Weir following installation of the weir structure. Procladius debuted in 1941, the interval immediately following impoundment (Figure 6-32). This genus reached its highest level in 1961, at over 1.6 ICY. Procladius has been documented as an indicator of sediment organic content (Merritt and Cummins 1984), but there were not enough occurrances to adequately document this relationship in the Lake Weir core.

Coelotanypus, the second tanypod genus to enter the system after impoundment, came in slightly later than Procladius (Figure 6-32). From 1951 to date Coelotanypus was sporadically present, peaking in 1966 at over 1.2 ICY. The absence of these predatory midges prior to impoundment

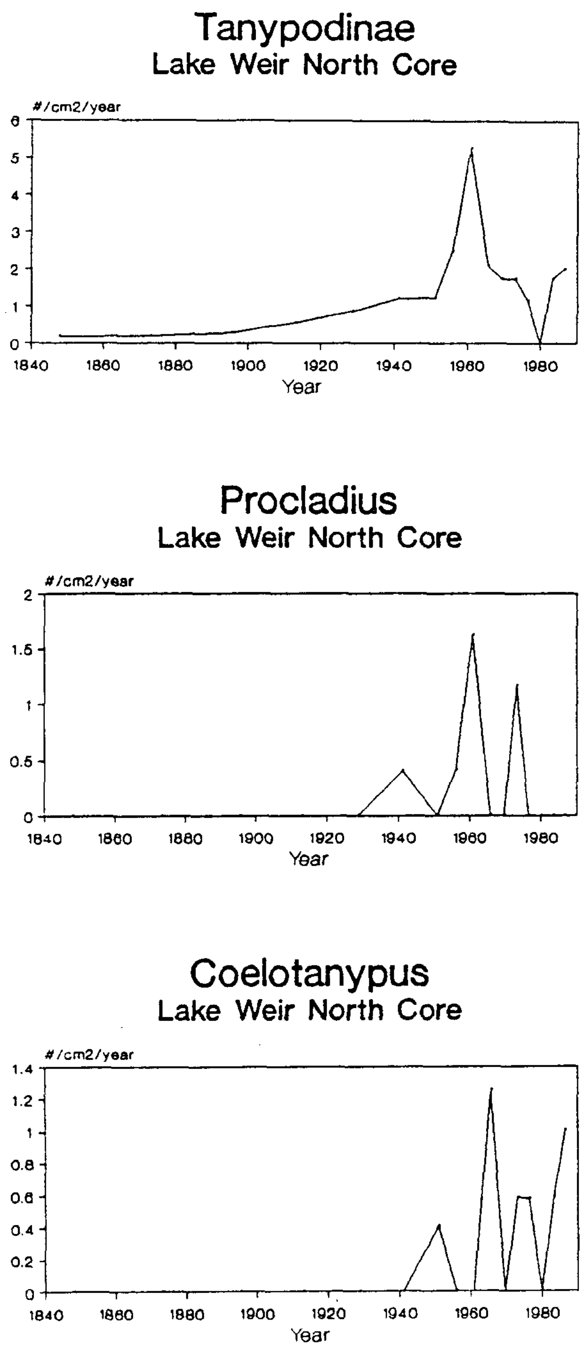


Figure 6-32. Accumulation rates of total tanypodinae, Procladius, and Coelotanypus in the Lake Weir core.

and their sudden occurrance thereafter suggests the introduction of some prey species to the lake. This explanation would fit well with the food-limited scenario for Lake Weir.

6.9.B CHAOBORIDAE

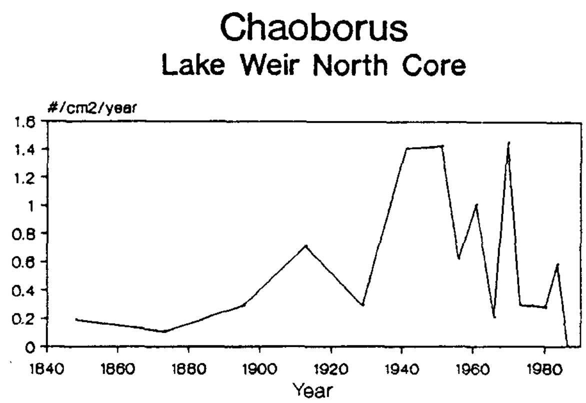
Chaoborids, the phantom midges, are a major component of Lake Weir's benthic community. Their life cycle includes four larval stages and a short-lived winged adult form. The instar stages are progressively more benthic in habit due to increased sight selective grazing pressure by fish. They are predatory upon zooplankton and certain benthic organisms, particularly oligochaetes.

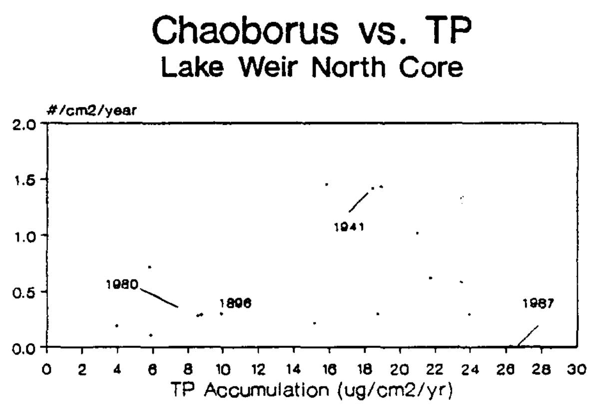
Chaoborus, the principal genus, is tolerant of anaerobic bottom conditions due to its ability to migrate vertically in the water column. Migration activity is increased by oxygen stress and reduced by cold (<5^{o} C) temperatures, and has been measured at up to 4-6 meters per hour. As hypolimnetic anoxia prevails, *Chaoborus* replaces chironomid genera and some other benthic dwellers. Therefore, the degree of *Chaoborus* dominance in a sediment core interval may be indicative of water quality.

The historical accumulation rate of *Chaoborus* was measured by the abundance of its preserved mandibles in the Lake Weir sediment core (Figure 6-33). Its accumulation in and before 1896 was under 0.3 individuals/cm^2/year (ICY). The *Chaoborus* population doubled in 1913, a period marked by unexceptional levels of TP, algae, chydorids, rotifers, neorhadocoels, and chironomids. Most of these parameters had returned to baseline levels after experiencing elevated productivity in 1896. The relative increase of *Chaoborus* at this level may signal some reduction in mixing, but does not necessarily connote a significant decline in water quality.

A dramatic change in the *Chaoborus* population occurred between 1929 and 1941, the interval of lake impoundment. *Chaoborus* accumulation increased four-fold (from 0.3 to 1.4 ICY), providing even more evidence of the weir structure's adverse impact on Lake Weir. *Chaoborus* remained at this level through 1951, then declined to 0.6 ICY.

By 1966, *Chaoborus* had resumed its baseline concentration of around 0.3 ICY, possibly due to increased competition for food as the slower adapting members of the benthic community became established. The brief spike of over 1.4 ICY in 1970 may have been in response to some temporary disturbance, but is unsupported by the other





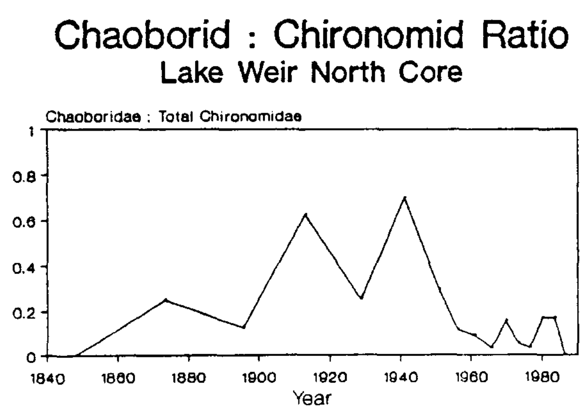


Figure 6-33. Accumulation rates of <u>Chaoborus</u>, and the relationships between <u>Chaoborus</u> and total phosphorus and total chironomids in the Lake Weir core.

parameters.

Although _Chaoborus_ was a major component of the current benthic community (often exceeding 200 individuals per square meter per year), it was not found in the uppermost (1988) core interval. This could be a result of its burrowing habit or of the sampling size (1.0 cc; 98% water), which was small relative to the size of the animal.

Chaoborus showed no significant correlation to TP (R^2 = 0.05) (Figure 6-33). This is reasonable, considering that _Chaoborus_ populations behave differently from other biotic communities which have shown association to TP levels in the Lake Weir core. The Chaoborid to Chironomid ratio shows two fairly distinct peaks (Figure 6-33). These correspond to the 1913 and 1941 intervals, described earlier.

CHAPTER SEVEN:

CONCLUSIONS AND RECOMMENDATIONS

The watershed of Lake Weir has undergone substantial changes since land clearance by European settlers in the late 1800's. Although no direct evidence is available, the lake may have been oligotrophic or oligotrophic-mesotrophic prior to settlement of the watershed. Since the beginning of water quality·monitoring in the 1970's, the lake has been in a mesotrophic state. Although conventional chemical indicators of trophic state do not indicate an acceleration of cultural eutrophication since the mid 1970's, biological parameters, especially those of the microbial loop, suggest that while the trophic state changes may be subtle, they are nevertheless occuring.

A paleolimnological assessment of lake sediments suggests that three watershed events have had the greatest impact on the trophic state of Lake Weir: land clearance in the late 1800's, installation of the weir in 1938, and a progressive expansion in human population following WW II. The initial land clearance by Europeans increased trophic state in the lake, but the impact was short lived and the lake returned to its baseline condition within 20-30 years. Unfortunately, the impact of the other two events have not shown such a trend.

The ecosystem response to the installation of the weir in 1938 was immediate. Within a short time, accumulation rates of organic and inorganic matter as well as total phosphorus in Lake Weir increased markedly, and biological parameters indicated a clear increase in cultural eutrophication. This single event resulted in the greatest proportional increase in trophic state at Lake Weir for at least the past 100 years.

Since the Second World War, human population has increased progressively at Lake Weir. Both our paleolimnological and Secchi disk investigations indicated that nutrient loading to the lake and associated cultural eutrophication are directly related to human population levels. Such a relationship reflects the fact that the entire watershed residential population is on septic systems.

Citrus agriculture appears to be only a minor nutrient loader to Lake Weir since the citrus killing freezes of the early 1980's, but our Secchi disk study suggested that runoff from new residential developments should be monitored closely and may soon be a major nutrient contributor to the lake. Agriculture in general, however, including vacant land, is still a major nutrient source for the lake. Future management plans should examine best management practices including vegetated swales, retention ponds for intercepting agricultural runoff before it enters the lake.

The cultural eutrophication of Lake Weir can not be stabilized and/or reversed without sound watershed management practices. Of prime concern is the nutrient contribution from an ever expanding human population. It is recommended that measures be taken to maximize minimum lot size requirements for near shore areas. Our Secchi disk survey indicated that water clarity is inversely proportional to the density of residences immediately onshore. Multiple family residences should be discouraged.

The most heavily populated segments of the Lake Weir watershed are in immediate need of centralized sewer facilities. In particular, the town of Oklawaha and shoreline residences of Little Lake Weir and Sunset Harbor.

While it can be argued that the entire lake system should eventually be ringed with a sewer system, such action should be approached cautiously. As commonly seen elsewhere, laxation of rules on population/housing densities often follow installation of sewer facilities. Given the fragile nature of the vegetated littoral zone in Lake Weir, increased boating activities associated with expanded population could have a marked negative impact on the lake.

It appears that residential development also contributes to nutrient loading to the lake via stormwater runoff. It is recommended that stormwater treatment systems be implemented both for existing and future development areas within the watershed. Even if such systems are constructed, ways must be found for insuring that they be properly maintained for effective water and nutrient interception.

In-lake management practices should concentrate on ways to protect the vegetated nearshore fringe. Such areas are essential for fish reproduction and serve as "kidneys" to trap nutrients leaching into the lake from septic systems. Destruction of macrophytes will likely lead to further increases in trophic state.

Residences should be encouraged to observe no wake zones and should be required to leave shorelines vegetated as a buffer from the erosive action of waves. Equally threatening to the littoral zone is construction of boat docks and boat houses. It is important that both the size and number of such structures be minimized to have the least negative impact on aquatic plants.

Finally, our field observations as well as those of several residents suggest that sea gulls may be an important nutrient loader to Lake Weir, especially during winter. Gulls commonly migrate inland during winter and congregate in large numbers on lakes. Such is the case at Lake Weir. Unfortunately, Lake Weir gulls appear to feed during the day at a nearby landfill and return to the lake during the evening. In the process, nutrient loading to the lake is increased via feces. It is recommended that the gull problem be examined as part of any comprehensive lake management plan.

BIBLIOGRAPHY

Anderson, G. and W. Faulkner. 1973. Water resourses of Marion County, Florida. FL. Bur. of Geol. Map Ser. No. 55 (Map).

APHA. 1980. Standard Methods for the Examination of Water and Wastewater. 15th ed. Washington, D.C.

Baker, L.A., P.L. Brezonik, and C.R. Kratzer. 1981. Nutrient loading-trophic state relationships in Florida lakes. FL. Wat. Res. Res. Cen. Pub. 56. University of Florida, Gainesville, FL.

Bays, J.S. 1983. Zooplankton and trophic state relationships in Florida lakes. M.S. Thesis. University of Florida, Gainesville, FL.

Bays, J.S. and T.L. Crisman. 1983. Zooplankton and trophic state relationships in Florida lakes. Can. J. Fish. Aquat. Sci. 40:1813-1819.

Beaver, J.R. 1980. The distribution of planktonic ciliated protozoans in 30 Florida lakes of varying trophic state. M.S. Thesis. University of Florida, Gainesville, FL.

Beaver, J.R. and T.L. Crisman. 1981. Acid precipitation and the response of ciliated protozoans in Florida lakes. Verh. Int. Verein. Limnol. 21:353-358.

Beaver, J.R. and T.L. Crisman. 1982. The trophic response of ciliated protozoans in freshwater lakes. Limnol. Oceanogr. 27:246-253.

Beaver, J.R. and T.L. Crisman. 1988a. Analysis of the community structure of planktonic ciliated protozoa relative to trophic state in Florida lakes. Hydrobiologia: in press.

Beaver, J.R. and T.L. Crisman. 1988b. Seasonality of planktonic ciliated protozoa in 20 subtropical Florida lakes of varying trophic state. Hydrobiologia: in press.

Beaver, J.R., T.L. Crisman, and J.S. Bays. 1981. Thermal regimes of Florida lakes: a comparison with biotic and climatic transitions. Hydrobiologia 83:267-273.

Beaver, J.R., T.L. Crisman, and R.W. Bienert. 1988. Distribution of planktonic ciliates in highly coloured subtropical lakes: comparison with clearwater ciliate communities and the contribution of myxotrophic taxa to total autotrophic biomass. Freshwat. Biol. 20:51-60.

Belanger, T.V., D.F. Mikutel, and P.A. Churchill. 1985. Groundwater seepage nutrient loading in a Florida lake. Water Res. 19:773-781.

Biggar, J. and R. Corey. 1969. Agricultural drainage and eutrophication. Pp. 405-445. In G. Rohlich [ed], Eutrophication: Causes, Consequences, Correctives. N.A.S.: Washington, D.C.

Binford, M.W. 1990. Calculation and uncetainty analysis of ^{210}Pb dates for PIRLA project lake sediment cores. J. Paleolimn. 3:253-267.

Binford, M.W. and M. Brenner. 1986. Dilution of ^{210}Pb by organic sedimentation in lakes of different trophic states, and application to studies of sediment-water interactions. Limnol. Oceanogr. 31:584-595.

Binford, M.W., E.S. Deevey, and T.L. Crisman. 1983. Paleolimnology: an historical perspective on lacustrine ecosystems. Ann. Rev. Ecol. Syst. 14:255-286.

Bitton, G.B., T.L. Crisman, S.R. Farrah, and J. Bossart. 1982. Aeromonas hydrophila as an indicator of trophic state of Florida lakes. Final Report to the Engineering and Industrial Experimental Station, University of Florida, Gainesville, FL.

Blancher, E.C. 1984. Zooplankton-trophic state relationships in some North and Central Florida lakes. Hydrobiologia 109:251-263.

Brezonik, P.L. 1969. Eutrophication: the process and its modeling potential. Pp. 68-110. In Modeling the Eutrophication Process. Workshop proceedings, University of Florida Dept. of Env. Engr. and Federal Water Quality Admin., U.S. Dept. of Interior.

Brezonik, P.L. 1972. Nitrogen: sources and transformations. pp. 1-50. In H.E. Allen and J.R. Kramer [eds], Nutrients in Natural Waters. John Wiley and Sons, New York.

Brezonik, P.L. and J.J. Messer. 1975. Analysis of trophic conditions and eutrophication factors in Lake Weir, Florida. In D.E.C.C.- North American Eutrophication Study. EPA Ecological Res. Ser.

Brezonik, P.L. and R.L. Shannon. 1971. Trophic state of lakes in N. Central Florida. Water Resources Research Center, #13. Gainesville, FL.

Brezonik, P.L., T.L. Crisman, and R.L. Schulze. 1984. Planktonic communities in Florida softwater lakes of varying pH. Can. J. Fish. Aquat. Sci. 41:46-56.

Brezonik, P.L., W.H. Morgan, E.E. Shannon, and H.D. Putnam. 1969. Eutrophication factors in North Central Florida lakes. Florida Engineering and Industrial Research Station, Gainesville, FL.

Brigham, A.R., W.U. Brigham, and A. Grilka, eds. 1982. Aquatic Insects and Oligochaetes and North and South Carolina. Midwest Aquatic Enterprises. Mahomet, IL. 837 pp.

Brooks, J.L. 1969. Eutrophication and changes in the composition of zooplankton. Pp. 236-255. In G.A. Rohlich [ed], Eutrophication: Causes, Consequences, Correctives. N.A.S., Washington, D.C.

Brooks, J.L. and S.I. Dodson. 1965. Predation, body size, and composition of plankton. Science 150:28-35.

Brylinsky, M. and K.H. Mann. 1973. An analysis of factors governing productivity in lakes and reservoirs. Limnol. Oceanogr. 18:1-14.

Canfield, D.E. Jr. 1981. Chemical and trophic state charact-eristics of Florida lakes in relation to regional geology. Final report to the Cooperative Fish and Wild-life Unit, University of Florida, Gainesville, FL. 444 pp.

Canfield, D.E. Jr. 1983. Prediction of chlorophyll a concentrations in Florida lakes: the importance of phosphorus and nitrogen. Water Res. Bull. 19:255-262.

Canfield, D.E. Jr. and C.E. Watkins, II. 1984. Relationships between zooplankton abundance and chlorophyll a concentrations in Florida lakes. Journal of Freshwater Ecology 2:335-344.

Canfield, D.E. Jr., J.V. Shireman, et al. 1984. Prediction of chlorophyll a concentrations in Florida lakes: the importance of aquatic macrophytes. Can. J. Fish. Aquat. Sci. 41:497-501.

Canfield, D.E. Jr., K.A. Langeland, et al. 1983. Trophic state classification of lakes with aquatic macrophytes. Can. J. Fish. Aquat. Sci. 40:1713-1718.

Carlander, K.D. 1977. Handbook of Freshwater Fishery Biology. Volume 2. Iowa State University Press, Ames, IA.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Ocean. 22:361-369.

Chestnut, T.L. and E.H. Barman, Jr. 1974. Aquatic vascular plants of Lake Apopka, Florida. Fl. Sci. 37:60-64.

Cook, D.G., and M.G. Johynson. 1974. Benthic macro-invertebrates of the St. Lawrence Great Lakes. J. Fish. Res. Bd. Canada. 31:763-782.

Cowell, B.C. and D.S. Vodopich. 1981. Distribution and seasonal abundance of benthic macroinvertebrates in a subtropical Florida lake. Hydrobiologia. 78:97-105.

Crisman, T.L. 1978. Reconstruction of past lacustrine environments based on the remains of aquatic invertebrates. Pp. 69-101. In D. Walker and J.C. Guppy [eds], Biology and Quaternary Environments. Canberra, Aust. Acad. Sci.

Crisman, T.L. 1980. Chydorid cladoceran assemblages from subtropical Florida. Pp. 657-668. In W.C. Kerfoot [ed], Evolution and Ecology of Zooplankton Communities, University Press of New England, Hanover, N.H.

Crisman, T.L. 1981. Algal control through trophic-level interactions: a subtropical perspective. Pp. 131-145. In Proceedings of a workshop on algal management and control. Tech. Rpt. E-81-7, U.S. E.P.A.

Crisman, T.L. 1986a. Eutrophication control with an emphasis on macrophytes and algae. Ecosystem Theory and Application. John Wiley and Sons, New York.

Crisman, T.L. 1986b. Historical analysis of the cultural eutrophication of Lake Maxinkuckee, Indiana. Report submitted to the Lake Maxinkuckee Association.

Crisman, T.L. 1986c. The use of subfossil benthic invertebrates in aquatic resource management. Presented at the Tenth ASTM Aquatic Toxicology and Hazard Assessment Symposium, New Orleans, LA, 4-6 May 1986.

Crisman, T.L. 1991. Natural lakes of the southeastern United States: origin, structure, and function. IN: C. Hackney, M. Adams, and B. Martin (eds.). Biotic Diversity of the Southeastern United States: Aquatic Communities. Wiley Press. (In Press).

Crisman, T.L., J.R. Beaver, and J.S. Bays. 1981. Examination of the relative impact of microzooplankton and macrozooplankton on bacteria in Florida lakes. Verh. Internat. Verein. Limnol. 21:359-362.

Crisman, T.L., J.R. Beaver, and A.E. Keller. 1991. Bacterioplankton abundance in subtropical lakes relative to trophic state and humic color: comparison with temperate systems. Freshwater Biology (Accepted pending revision).

Crisman, T.L., P. Scheuerman, R.W. Bienert, J.R. Beaver, and J.S. Bays. 1984. A preliminary characterization of bacterioplankton seasonality in subtropical Florida lakes. Verh. Internat. Verein. Limnol. 22:620-626.

Crisman, T.L., J.A. Foran, J.R. Beaver, A.E. Keller, P.D. Sacco, R.W. Bienert, R.W. Ruble and J.S. Bays. 1986. Algal Control through trophic-level interactions: Investigations at Lakes Wauberg and Newnans, Florida. Report submitted to the Florida Department of Natural Resources.

Deevey, E.S. 1972. Biogeochemistry of lakes: major substances. Pp. 14-20. In G.E. Likens [ed], Nutrients and eutrophication. Limnol. Oceanogr. Spec. Symposia 1.

Deevey, E.S. and G.B. Deevey. 1971. The American species of Eubosmina Seligo (Crustacea, Cladocera). Limnol. Oceanogr. 16:201-218.

Deevey, E.S., M.W. Binford, M. Brenner and T.J. Whitmore. 1986. Sedimentary records of accelerated nutrient loading in Florida lakes. Hydrobiologia 143:49-53.

Dumont, H.J., I. Vand deVelde and S. Dumont. 1975. The dry weight estimates of biomass in a selection of Cladocera, Copepods and Rotifera from the plankton, periphyton and benthos of continental waters. Oecologia 19:75-97.

Edmiston, H.L. and V.B. Myers. 1983. Florida Lakes: A description of lakes, their processes, and means of protection. D.E.R., Tallahassee, FL.

Edmondson, W.T. 1959. Freshwater Biology. 2nd ed. Wiley-Interscience. London.

Elmore, J.L. 1983. Factors influencing Diaptomus distributions: an experimental study in subtropical Florida. Limnol. Oceanogr. 28:522-532.

Elmore, J.L., B.C. Cowell, and D.S. Vodopich. 1984. Biological communities of three subtropical Florida lakes of different trophic character. Arch. Hydrobiol. 100:455-478.

Elmore, J.L., D.S. Vodopich and J.J. Hoover. 1983. Selective predation by bluegill sunfish (Lepomis macrochirus) on three species of Diaptomus (Copepoda) from subtropical Florida. J. Freshwater Ecol. 2:183-192.

Engstrom, D.R., E.B. Swain and J.C. Kingston. 1985. A palaeolimnological record of human disturbance from Harvey's Lake, Vermont: geochemistry, pigments and diatoms. Freshwater Biology. 15:261-288.

Engstrom, D.R. and E.B. Swain. 1986. The chemistry of lake sediments in time and space. Hydrobiologia. 143:37-44.

Fellows, C.R. and P.L. Brezonik. 1980. Seepage flow into Florida lakes. Water Res. Bull. 16:635-641.

Flannery, M.S. 1984. Seasonal variations in water chemistry and zooplankton communities in four macrophyte infested central Florida lakes. M.S. thesis, University of Florida, Gainesville, FL.

Flannery, M.S., R.D. Snodgrass and T.J. Whitmore. 1982. Deepwater sediments and trophic conditions in Florida lakes. Hydrobiologia 92:597-602.

Florida Department of Environmental Regulation. Field monitoring of Lake Weir 1975-1980. Database printout.

Florida Game and Fresh Water Fish Commission. 1968. Annual report for water quality study. Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1969. Annual report for water quality study. Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1973. Final completion report on water quality investigations. Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1985. Central Region. Fish management annual progress report. Ocala, FL.

Florida Game and Fresh Water Fish Commission. 1986. Central Region. Fish management annual progress report.

Florida Lakes, Part III. 1969. Gazetteer, Division of Water Resources and Board of Conservation, Tallahassee, FL.

Foran, J.A. 1986a. A comparison of the life history features of a temperate and subtropical Daphnia species. Oikos 46:185-193.

Foran, J.A. 1986b. The relationship between temperature, competition and the potential for colonization of a subtropical pond by Daphnia magna. Hydrobiologia. 134:103-112.

Frey, D.G. 1969. The rationale of paleolimnology. Mitt. Intern. Verein. Limnol. 17:7.

Fruh, E., K. Stewart, G.F. Lee, and G. Rohlich. 1966. Measurement of eutrophication and trends. Jour. Wat. Poll. Contr. Fed. 38:1237-1258.

Fuller, A. and B.C. Cowell. 1985. Seasonal variation in benthic invertebrate recolonization of small-scale disturbances in a subtropical Florida lake. Hydrobiologia 124:211-221.

Gannon, J.E. and R.S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Amer. Microsc. Soc. 97:16-35.

Garren, R.A. 1982. Macrophyte species composition-trophic state relationships in fourteen north and north-central Florida lakes. M.S. thesis, University of Florida, Gainesville, FL.

Gates, M.A., A. Rogerson and J. Berger. 1982. Dry to wet weight biomass conversion constant for Tetrahymena elliotti (Ciliophora, Protozoa). Oecologia 55:145-148.

Gilbert, J.J. 1989. The effect of Daphnia interference on a natural rotifer and ciliate community: short-term bottle experiments. Limnol. Oceanogr. 34:606-617.

Gliwicz, Z.M. 1969. Studies on the feeding of pelagic zooplankton in lakes with varying trophy. Ekol. Pol. 17(A):663-708.

Hall, D.J., W.E. Cooper and E.E. Werner. 1970. An experimental approach to the productive dynamics and structure of freshwater animal communities. Limnol. Oceanogr. 15:839-928.

Hasler, A.D. 1947. Eutrophication of lakes by domestic drainage. Ecology 28:383-395.

Healy, H.G. 1972. Water levels in artesian and non-artesian aquifers in Florida. 1969-1970. USGS Information Circ. No. 73. Tallahassee, FL.

Hobbie, J. E., R.J. Daley and S. Jasper. 1977. Use of nucleopore filters for counting bacteria by fluorescence microscopy. Appl. Environ. Microbiol. 33:1225-1228.

Hoffman, G.L. 1967. Parasites of North American Freshwater Fishes. University of California Press, Los Angeles.

Huber, W.C., P.L. Brezonik, J.P. Heaney, R.E. Dickinson, S.D. Preston, D.S. Dwornik, and D.A. DeMaio. 1982. A classification of Florida lakes. Florida Water Resources Research Center. Publication No. 72.

Hunt, B.P. 1953. The life history and economic importance of a burrowing mayfly, Hexagenia limbata, in southern Michigan lakes. Mich. Cons. Dept. Bull. Inst. Fish. Res. No. 4. 151 pp.

Kahl, A. 1930-1935. Wimpertiere oder Ciliata (Infusoria), Tierwelt Deutschlands 26:18, 21, 25, 30, 886pp. Fischer.

Keller, A.E. 1984. Fish communities in Florida lakes: relationship to physico-chemical parameters. M.S. Thesis. University of Florida, Gainesville, FL. 107 pp.

Kenner, W.E. 1964. Maps showing depths of selected lakes in Florida. FL. Geol. Surv. Info. Circ. 40. Tallahassee, FL.

Kratzer, C.R. and Brezonik, P.L. 1984. Application of nutrient loading models to the analysis of trophic conditions in Lake Okeechobee, Florida. Env. Management 8:109-120.

Larkin, P.A. and T.L. Northcote. 1969. Fish as indices of eutrophication. In: G.A. Rohlich (ed.) Eutrophication: causes, consequences, correctives. National Academy of Sciences, Washington, DC.

Lean, D.R.S. 1973. Phosphorus dynamics in lake water. Science 179:567-680.

Loehr, R.C. 1974. Characteristics and comparative magnitude of non-point sources. Jour. Wat. Poll. Contr. Fed. 46:1849-1872.

Macek, K.J., K.S. Buxton, S.K. Derr, J.W. Dean, and S. Sauter. 1976. Chronic toxicity of Atraxine to selected aquatic invertebrates and fishes. EPA-600/3-76-047. U.S. EPA.

Maeda, M. 1986. An illustrated guide to the species of the families Halteriidae and Strobilidiidae (Oligotrichida, Ciliophora), free swimming protozoa common in the aquatic environment. Bull. Ocean Res. Inst. Tokyo 21:1-67.

Maeda, M. and P.G. Carey. 1985. An illustrated guide to the species of the family Strombididae (Oligotrichida, Ciliophora), free swimming protozoa common in the aquatic environment. Bull. Ocean Res. Inst. Tokyo 19:1-68.

Maslin, P.E. 1969. Population dynamics and productivity of zooplankton in two sandhill lakes. Ph.D. dissertation. University of Florida, Gainesville, FL.

McNaught, D.C. 1975. A hypothesis to explain the succession from calanoids to cladocerans during eutrophication. Verh. Int. Ver. Limnol. 19:724-781.

Merritt, R.W. and K.W. Cummins. 1984. An Introduction to the Aquatic Insects of North America. Kendall-Hunt Publ. Dubuque, IA. 722 pp.

Messer, J.J. 1975. An analysis of nutrient loading and trophic conditions in Lake Weir, Florida. Ph.D. Dissertation, University of Florida, Gainesville, FL.

Nagy, J.W. 1988. Simultaneous determination of supported and unsupported Pb-210 concentrations in lake-bottom sediments using low-energy, high purity Germanium gamma-ray spectroscopy. M.S. Thesis. University of Florida, Gainesville, FL. 51 pp.

O'Brien, W.J. and F. de Noyelles, Jr. 1974. Relationship between nutrient concentration, phytoplankton density and zooplankton density in nutrient enriched experimental ponds. Hydrobiologia 44:105-125.

O.E.C.D. 1971. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication.

Osborne, J.A., M.P. Wanielista, and Y.A. Yousef. 1976. Benthic fauna species diversity in six central Florida lakes in summer. Hydrobiologia 48:125-129.

Parrish, F.K. [ed]. 1968. Keys to water quality indicative organisms of the South Eastern United States. U.S. EPA Office of Research and Development. Environmental Monitoring and Support Laboratory. Cincinnati, OH.

Pennak, R.W. 1978. Fresh Water Invertebrates of the United States. Ronald Press. New York, NY. 769 pp.

Proc. Eutrophication Workshop Southeast, St. Petersburg, FL. 1969. University of Florida Water Resources Publication.

Richman, S. and S.I. Dodson. 1983. The effect of food quality on feeding and respiration by Daphnia and Diaptomus. Limnol. Oceanogr. 28:948-956.

Rohlich, G.A. [ed]. 1969. Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences. Washington, D.C. 661 pp.

Ruttner-Kolisko, A. 1974. Plankton rotifers, biology and taxonomy. Die Binnengewassen. 26(suppl):1-146.

Saether, O.A. 1975. Neartic chironomids as indicators of lake typology. Verh. Internat. Verein. Limnol. 19:3127-3133.

SAS. 1986. SAS User's Guide. SAS Institute, Inc. Cary, NC.

Schneider, R.F. and Little, J.A. 1968. Characterization of bottom sediments and selected nitrogen and phosphorus sources in Lake Apopka, Florida. U.S. Dept. of Interior, Fed. Wat. Poll. Contr. Admin., Southeast Water Lab.

Serruya, C. and Pollingher, U. 1983. Lakes of the Warm Belt. Cambridge University Press, London.

Shackleford, T.M. 1883. Lake Weir, Florida. History and description. Reprinted in Southern Progress, Vol. 1&2, 1886-1887, pp 9-93.

Shannon, E.E. 1970. Eutrophication-trophic state relationships in north and central Florida lakes. Ph D. Dissertation, University of Florida, Gainesville, FL. 257 pp.

Shannon, E.E. and P.L. Brezonik. 1972a. Eutrophication analysis: a multivariate approach. Jour. San. Engr. Div., ASCE.

Shannon, E.E. and P.L. Brezonik. 1972b. Limnological characteristics of north and central Florida lakes. Limnol. Oceanogr. 17:97-110.

Shannon, E.E. and P.L. Brezonik. 1972c. Relationships between lake trophic state and nitrogen and phosphorus loading rates. Env. Sci. Tech. 6:719-725.

Shapiro, J., W.T. Edmondson, and D.E. Allison. 1971. Changes in the chemical composition of sediments of Lake Washington. Limnol. Oceanogr. 16:437-452.

Shapiro, J., J.B. Lundquist, and R.E. Carlson. 1975. Involving the public in limnology--an approach to communication. Verh. Internat. Verein. Limnol. 19:866-874.

Shireman, J.L. and R.G. Martin. 1978. Seasonal and diurnal zooplankton investigations of a south-central Florida lake. Fla. Sci. 41:193-200.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry. W.H. Freeman. San Francisco, CA. 766 pp.

St. Johns River Water Management District. Field monitoring of Lake Weir 1984-1987. Database printout.

Swain, E.B. 1985. Measurement and interpretation of sedimentary pigments. Freshwater Biology. 15:53-75.

United States Geological Survey. Field monitoring of Lake Weir 1956-1983. Database printout.

USEPA. 1983. Methods for Chemical Analysis of Water and Wastes. EMSL, Cincinnati. EPA-600/4-79-020.

Vodopich, D.A. 1980. The influence of sediment type and food availability on the distribution of Procladius culiformis (Linnaeus) (Diptera: Chironomidae) in a subtropical Florida lake. Ph.D. Dissertation, University of South Florida, Tampa, FL.

Warwick, W.F. 1980. Chironomidae (Diptera) responses to 2800 years of cultural influence: a paleoecological study with special reference to sedimentation, eutrophication, and contamination process. Can. Ent. 112:1193-1238.

Werner, E.E. 1977. Species packing and niche complimentarity in three sunfishes. Am. Naturalist 3:553-578.

Westlake, D.F. 1965. Some basic data for the investigations of the productivity of aquatic macrophytes. Memorie 1st. Ital. Idrobiol. 18:229-248.

Wiederholm. 1980. Use of benthos in lake monitoring. J.W.P.C.F. 52:337-347.

Winer, B.J., D.R. Brown, and K.M. Michels. 1991. Statistical principles in experimental design. McGraw-Hill Inc. New York.

Wood, K.G. 1973. Decline of Hexagenia (Ephemeroptera) nymphs in Western Lake Erie, pp. 26-32. IN: W.L. Peters and J.G. Peters (eds.). Proceedings of the First International Conference on Ephemeroptera. E.J. Brill, Leiden. The Netherlands. 312 pp.

Zaret, T.M. 1980. Predation and freshwater communities. Yale University Press, New Haven, CT.