LIMNOLOGY OF
LAKES LACAWAC, GILES, AND WAYNEWOOD 1989-93:

AN INTRODUCTION TO THE CORE LAKES
OF THE POCONO COMPARATIVE LAKES PROGRAM

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INTRODUCTION

This report is a collection of information on three lakes in the Pocono region of northeastern Pennsylvania that have been studied since 1988 as part of the ***Pocono Comparative Lakes Program***. The information should be useful to investigators working on the lakes, or considering inclusion of the lakes in future investigations. The aim of the Pocono Comparative Lakes Program is to foster collaborative research among investigators from regional institutions, to develop field research facilities through support of the Lacawac Sanctuary and through research agreements with other lake owners, and to enrich the educational experience of students from Lehigh and other institutions by expanding the availability and quality of summer research opportunities in environmental science.

Major funding from the Andrew W. Mellon Foundation to Lehigh University (1989-1994) permitted development of the Pocono Comparative Lakes Program ("PCLP"). An important component of this initiative was establishing a long-term database on three lakes of contrasting trophic conditions. Results of the Mellon-funded baseline sampling period are summarized here.

The Pocono region was subjected to late Wisconsin age glaciation; the terminal moraine lies across the southern Poconos. Small natural lakes are common within the glaciated region. Most of these are currently impacted by human activities within their watersheds, notably farming (a decreasing trend) and vacation homes (a sharply increasing trend). All are potentially affected by atmospheric inputs of various pollutants from large up-wind industrial and metropolitan areas of northeastern North America. ***Lake Lacawac*** is one of the few remaining lakes without intensive watershed disturbance and residential development. This mesotrophic lake can serve as a reference site for long-term trends. It is privately owned by the Lacawac Sanctuary Foundation, a non-profit organization dedicated to conservation of Lake Lacawac and its watershed, and to ecological research and public education. ***Lake Waynewood*** is a culturally eutrophied lake owned by the Lake Waynewood Association of permanent and summer-time residents. Its large watershed includes secondary roads and active dairy farms as well as lake-shore cottages. ***Lake Giles*** is an oligotrophic, very clear lake owned by the Blooming Grove Hunting and Fishing Club. The lake is managed for fishing and recreation, and may have been affected by acidic precipitation. Through the interest and generous cooperation of these lake owners, scientists from Lehigh and other institutions are obtaining basic information that provides objective documentation of current lake conditions and a context for more intensive limnological studies.

BASELINE STUDY 1989-93.

Data presented in this report were mostly collected from June 1989 through December 1993 as part of the collaborative research initiative funded by the Andrew W. Mellon Foundation and directed by Dr. Craig Williamson. Some additional data were collected in summer 1988 (notably zooplankton), and most of the measurements have been continued through December 1994. The three lakes were sampled monthly (missing a few winter months), or twice monthly from May through August or September. The routine sampling included depth-profiles of temperature, dissolved oxygen, and light (PAR) penetration. Samples for chlorophyll, pH, alkalinity, and phytoplankton were collected at three discrete depths, corresponding in summer to the middle of the epilimnion (EPI), metalimnion (META) or hypolimnion (HYPO). In winter the "EPI" sample was 0.5 m; during overturn periods the samples were equally spaced within the water column. Secchi depth was measured. Zooplankton were collected with closing nets from the three depth-zones, usually both during the day and again after dark. More extensive chemical analyses were performed on samples collected at 4-6 depths on several dates in 1989 and 1991-92. Morphometric maps were prepared in 1992 from new or existing surveys. Fish were sampled once in July 1990. Regional long-term precipitation and air temperature data were summarized from a NOAA cooperator's station at Hawley, PA. Detailed methods of sampling or analysis are presented in the various **Annual Reports** or (excluding the extra chemical sampling) in a document entitled **Sampling Protocols (1989-1993)** that was distributed with the 1992 Annual Reports.

The ***primary database*** consists of electronic files maintained on microcomputer hard-drives using the DOS program Reflex^{TM} (version 2, Borland International, copyright 1989). Other data exist as DOS spreadsheets (Quattro Pro, Lotus 123). ***Original field sampling sheets*** (temperature, oxygen, light 1989-1993, Secchi depth, pH, alkalinity) and ***zooplankton counting sheets*** are stored at Lehigh with a copy deposited at the Lacawac Sanctuary. Summary reports that include all the physical-chemical data, plus graphs of whole water-column zooplankton concentrations for all common taxa, have been distributed as ***Annual Reports*** to the lake owners and to members of the PCLP steering committee. Additional copies have been deposited at the Lacawac Sanctuary, and a combined report for all three lakes has been deposited in the ***Lehigh University library system*** for distribution through interlibrary loan (Moeller, R.E. and C.E. Williamson, catalog number 551.482 P741 plus year of report -- e.g. 1993 for 1992 data).

PCLP DATABASE.

Data included in this summary were extracted from the electronic database maintained at Lehigh University by the authors in the Department of Earth and Environmental Sciences. Although efforts have been made to assure the accuracy of data included in the database, and compiled in this report, we cannot guarantee complete accuracy and do not claim specific levels of accuracy or precision. The data have been collected as part of a lake characterization program and may not be suitable for uses not envisioned by the investigators.

Information acquired through the Pocono Comparative Lakes Program is to be shared among scientists desiring to make broad limnological comparisons or considering research projects in these lakes. Inquiries to examine or use the data are invited. Of course, the primary right to publish extensive extracts from the database, or analyses based mainly on PCLP data, resides with the PCLP cooperating investigators who generated the data. We hope to build the database through continuing inclusion of basic limnological measurements as they can be acquired through available funding. Investigators are urged to consider depositing past or future datasets, with brief documentation, to help turn the 5-year baseline study funded by the A.W. Mellon Foundation into a long-term scientific resource for Lake Lacawac and other Pocono area lakes.

ACKNOWLEDGEMENTS.

Lehigh University has supported the program at all levels, including important financial support to the Lacawac Sanctuary for activities of researchers and students. A major grant from the Andrew W. Mellon Foundation enabled organization of the Pocono Comparative Lakes Program and funded most of the data collection and database development summarized here. Research projects funded by the National Science Foundation (especially DEB-9014414 and DEB-9306978) have generated some of the routine data incorporated into the database and into this report.

For access to facilities at the Lacawac Sanctuary, we are grateful to its Director, Sally Jones, as well as to Arthur Watres and other Lacawac Board members. We thank the staff -- in particular Ken Ersbak and Bob Kobler -- and membership at the Blooming Grove Hunting and Fishing Club for their interest in including Lake Giles in this comparative study. Sampling at Lake Waynewood has been greatly facilitated by the friendly cooperation of Dave Westpfahl and his neighbors, as well as other members of the Lake Waynewood Association.

The authors of this report have received important help in collecting the data and maintaining the database. Gina Brockway and Scott Carpenter, in particular, have assisted Bruce Hargreaves with the database. John Aufderheide worked with Craig Williamson on zooplankton species identifications. For field sampling, zooplankton counting, and other laboratory analyses, we acknowledge the capable efforts of John Aufderheide, Karen Basehore, Gina Brockway, Scott Carpenter, Gaby Grad, Lauren Graves, Brian Sharer, Paul Stutzman, Natasha Vinogradova, Tim Vail, and Yin Zhong, plus many undergraduate helpers and summer interns.

LAKE GEOGRAPHY

The general characterization of these three lakes includes (1) regional climatic trends of air temperature and precipitation (**Figure 1**), (2) summary of geographic location and morphometric features (**Table 1**), (3) bathymetric maps (**Figures 2,4,6**) and tabulated bathymetric data (**Figure 8**), (4) topographic maps of the lake watersheds (**Figures 3,5,7**), and (5) major chemical features of the water (**Table 2**).

REGIONAL CLIMATIC TRENDS.

Long-term records of precipitation and air temperature are available from a NOAA cooperator's station in Hawley, PA, since 1962. Mean monthly precipitation (rainfall plus melted snow) and mean monthly temperature (mean of daily means) are presented in **Figure 1** for 1962-1992 and for the study period 1989-93. Annual precipitation for the 1962-1992 period was 98 ±19 cm/yr (mean ± SD).

The Hawley station is located ca. 10 km north of the study lakes (at Lat. 41°29' N, Long. 75°10'W, elevation 271 metres asl). Some bias in temperature and precipitation relative to the study lakes can be expected because of small latitudinal and elevational differences (see **Table 1**), and eventually can be established from our ongoing meteorological monitoring at Lake Lacawac.

Meteorological information monitored at Lacawac since 1992 includes air temperature, rainfall, wind direction and velocity, relative humidity, solar radiation, and lake surface temperature. The Campbell weather station is mounted on a raft anchored in mid-lake during the ice-free period, but moved to the dock for late autumn through mid-spring. In 1993 continuous monitoring of ultraviolet radiation was initiated, using a Biospherical Instruments GUV-521. This instrument measures UV radiation in four wavebands, centered on 305, 320, 340, and 380 nm, plus total PAR (400-700 nm). Data from all meteorological instruments are logged electronically for periodic downloads via cellular phone to our computer network at Lehigh.

GEOGRAPHIC LOCATION AND MORPHOMETRIC FEATURES.

Basic information derived from topographic maps as well as our bathymetric maps of the lakes is summarized in **Table 1**. Included are latitude, longitude, elevation, lake area, total drainage basin area (including lake), lake volume, maximum and mean depths, and hydraulic detention time.

Hydraulic detention times were calculated as lake volume divided by annual water inflow, which in turn was estimated by assuming 107 cm of precipitation a year (104 cm/yr at Lake Giles), evapotranspiration of 51 cm/yr from the terrestrial watershed, and evaporation of 72 cm/yr from the lakes (R. Schultz, 1990 unpubl. report). Unlike Lake Lacawac and Lake Giles, which have comparatively small watersheds and lack channelized inflows, Lake Waynewood has a large watershed draining via a perennial stream and at least one intermittent stream. Corresponding detention time for Lake Waynewood is only 0.42 yr compared to 3.3 yr for Lake Lacawac and 5.6 yr for Lake Giles.

MAPS OF LAKE MORPHOMETRY AND WATERSHED TOPOGRAPHY.

Morphometric maps (**Figures 2,4,6**) were drawn in 1992-93 from bathymetric surveys of R. Schultz and R. Weisman (Giles and Waynewood in July 1990) and A. Tessier (Lacawac in winter 1987). More details are presented in the **1992 Annual Reports**. Hypsographic and bathymetric curves are plotted in **Figure 8**.

Water level can vary within ca. 0.5 m range, with low levels occurring in August-October of relatively dry summers. High levels can occur at any time of year, and are constrained by channelized outlets at all three lakes. A concrete dam regulates the level of Lake Waynewood at roughly 1-2 m above the natural channel. Beaver are active on Lake Lacawac, but recent policy has been to breach their dam when water level rises. Unfortunately, there are no absolute water level references for the lakes or for the bathymetric maps, and water levels are not monitored.

Lake watersheds have been traced out on enlarged photocopies of topographic maps (**Figures 3,5,7**). These maps also display buildings and roads in the lake environs, circa 1983. Lake Giles and Lake Waynewood have numerous houses within their watersheds, which are potential sources of nutrient inflow to the lakes. Most of these houses are summer vacation residences, only sporadically occupied. At Lake Waynewood, houses ring the lakeshore, and septic leachate has only a short flow path to the lake. At Lake Giles, most homes are set well back from the shore. Septic tanks at about a third of them, including the clubhouse, drain through a common line that exits the watershed (R. Kobler, pers. comm.). At Lake Lacawac, the lodge and ice house have been used as summer residences in recent years, but outflow from the septic tank has been diverted out of the watershed.

The watersheds and lakeshore at Lake Lacawac and Lake Giles are nearly completely forested. These secondary forests have regrown following extensive late 19th century cutting. The proximal watershed at Lake Waynewood is forested also, except for small clearings adjacent to the summer houses. The more distal watershed includes active dairy farms, however. These lakes lie within a transition zone from northern hardwood forest to the mixed oak forests more typical of Pennsylvania. Northern hardwoods, locally with lots of hemlock or oak, predominate at Lake Lacawac and Lake Waynewood, but Lake Giles lies more clearly within the mixed oak forest. The northern and northwestern shores of Lake Lacawac are formed by the encroaching margin of a peat bog, which is thickly vegetated with typical bog shrubs and trees (including tamarack and some spruce).

CHEMICAL CHARACTERIZATION OF THE LAKES.

Chemistry of major elements is presented in **Table 2**. For cations and anions, data are averages from multiple depths on 10 sampling dates scattered throughout summer-fall of 1989 (4 dates) and spring 1991 through spring 1992 (6 dates). Data from anoxic hypolimnia of Lake Lacawac and Lake Waynewood were excluded, however. Analyses were performed at the Institute of Ecosystem Studies, Millbrook, New York (J. Cole and N. Caraco, unpubl.). Results are presented in more detail in the **1990** and **1993 Annual Reports**.

Total phosphorus data originate from 8 of the 10 ion sampling dates, again excluding P-enriched samples from anoxic hypolimnia. Conductivity was measured along with the 1989 samples, and alkalinity (acid-neutralizing capacity by Gran titration) and dissolved inorganic carbon (by head-space gas chromatography of acidified samples) along with the 1991-92 samples. Dissolved organic carbon was measured on 9 dates in 1993 (June-November, 3 depths).

More intensive nutrient sampling was initiated in 1993 and continued through 1994. Parameters measured include soluble reactive phosphate, total dissolved phosphorus, total particulate phosphorus, ammonium, nitrate, dissolved organic carbon, and particulate carbon and nitrogen. These analyses are not yet complete.

The main differences among the lakes reflect alkalinity and trophic gradients. Lake Lacawac is a softwater, slightly acidic lake with moderate dissolved organic carbon. Lake Giles is more strongly acidic, has no bicarbonate buffering capacity, and has relatively low dissolved organic carbon. Lake Waynewood has substantially more bicarbonate and higher alkalinity than Lake Lacawac, though it is not really a hardwater lake. Total phosphorus reflects the trophic gradient, but the range is only 4-fold (less than the range in summer epilimnetic chlorophyll concentrations--see **Figure 15**). Concentrations of Na and Cl are several times higher in both Lake Giles and Lake Waynewood than in Lake Lacawac, possibly because of road salting or other human activities within their watersheds.

One idea behind the selection of these three lakes for comparative studies was that the present day differences among the lakes stem from, or have been heightened by, human activities. Indeed, paleoecological study of scaled chrysophytes in Lake Waynewood sediment (**Lott et al. 1994**) has suggested that specific conductance (a non-specific correlate of many water chemistry and nutrient gradients) has increased from about 20 (like Lacawac today) to about 70 (Waynewood's actual conductivity today). The increase began with settlement and forest clearance, but has not reversed with forest regrowth, probably because of continuing pockets of intensive dairy farming and other soil-disturbing or human waste-generating activities within the watershed. High phosphorus concentrations in Lake Waynewood's inlets in August and September 1990 (see **1992 Annual Report**), as well as high alkalinities and specific conductance (**Gould 1991**), demonstrate that lake conditions are strongly influenced by processes in the distal watershed. In Lake Giles, in contrast, the small watershed and lack of agricultural activities, combined with apparent lack of inflow from deeper, regionally bicarbonate-rich groundwater (see chemical data of **Gould 1991** for Lacawac watershed), may have exposed the lake to acidification during the mid-20th century. Changes in diatom remains in Lake Giles sediment are being analyzed to determine if the lake was formerly less acidic, and more like Lake Lacawac (J. Huvane and J. Sherman, unpubl.).

ROUTINE PHYSICAL-CHEMICAL MEASUREMENTS

Data presented here include: (1) temperature and dissolved oxygen trends at three fixed depths (**Figure 9**), (2) mean monthly depth profiles of temperature (**Figure 10**), (3) mean June-August light (PAR) penetration (**Figure 11**), (4) mean monthly Secchi depths compared to depths of 10% and 1% PAR penetration (**Figure 12**), (5) attenuation coefficients for UV at 320 nm compared to PAR (**Figure 13**: April-November 1993-94), (6) mean monthly epilimnial pH and alkalinity (**Figure 14**), and (7) mean monthly chlorophyll-a at three depths (**Figure 15**).

TEMPERATURE AND DISSOLVED OXYGEN.

Temperature and oxygen have been measured with YSI electrodes. Monthly temperature trends at a depth of 2m are very similar in the three lakes (**Figure 9**). Lake Giles' epilimnion warms up and cools down a little more slowly than those of the other lakes, basically because the epilimnion is thicker. It is thicker because of the larger size of the lake (greater exposure to wind) and greater water clarity (greater thickness of solar heating).

Oxygen trends in the surface waters of the three lakes are similar, dissolved oxygen being maintained near its temperature-dependent atmospheric saturation. Oxygen becomes strongly depleted in deep waters of Lake Lacawac and Lake Waynewood during summer stratification of the water column. This is a direct consequence of reduced light penetration, and of presumably higher microbial oxygen consumption during mineralization of greater amounts of organic detritus in the more productive lakes. Lake Lacawac's hypolimnion gradually becomes anoxic during the summer. In Lake Waynewood, anoxia is rapidly established in early summer. But in Lake Giles, the water column remains oxygenated.

Depth profiles of temperature (**Figure 10**) show the typical patterns of thermal stratification and vertical mixing. Reverse stratification in the winter (especially under the ice in January-March) creates a stable environment for phytoplankton development, light permitting. The lakes are typically ice-covered for 2-4 months. Under long-term "normal" climatic conditions, they would probably freeze-over in mid-December, and thaw in early April. Ice thickness would reach ca. 0.5 m in mid-March. During our 1989-93 study period, however, ice cover was generally shorter, thinner, and sometimes interrupted during warmer than normal weather. January temperature in 1989-93 has averaged 2.5°C warmer than "normal" (**Figure 1**). There is little oxygen depletion during the winter ice cover, even in eutrophic Lake Waynewood.

LIGHT PENETRATION.

Light penetration has been measured with cosine-corrected sensors (Licor submersible sensors) calibrated to give a quantum (as opposed to energy) response to photosynthetically active radiation (PAR, 400-700 nm). Resulting measures of downwelling radiation are expressed as percentage of the PAR that enters the lake. The differing trophic and water clarity conditions of the three lakes are reflected in the average summer light conditions (**Figure 11**). The 1% level is reached within the metalimnion of Lake Lacawac and Lake Waynewood, but extends virtually to the bottom of Lake Giles, the deepest lake. Monthly trends of Secchi disk transparency reflect this difference, with Secchi depth (a visual measure of transparency) lying roughly midway between the 10% and 1% PAR penetration depths (**Figure 12**).

Starting in 1993, we have been measuring penetration of ultraviolet radiation in parallel with PAR, using a submersible instrument with cosine-corrected sensors that measures PAR as well as UV in ca. 10-nm bands around 305, 320, 340, and 380 nm (Biospherical Instruments PUV-500; see **Kirk et al. 1994**). Epilimnetic monthly mean attenuation coefficients calculated from 1993-94 data for the 320-nm band illustrate the greater attenuation of UV compared with PAR (**Figure 13**). UV-320 penetrates fairly well into Lake Giles, but is very rapidly attenuated in Lake Lacawac and Lake Waynewood. Ultraviolet radiation may play significant ecological roles in Lake Giles, as well as the other Pocono lakes and lakes in general (**Williamson et al. 1995**, **Zagarese and Williamson 1994**).

ALKALINITY AND pH.

Monthly mean trends of alkalinity and pH are presented for the "EPI" samples from the routine sampling (**Figure 14**). Alkalinity was measured using Gran titration with dilute acid; it is thus the same as acid-neutralizing capacity (ANC). Good quality Orion Ross™ combination electrodes, which have high electrolyte flow, were used to measure pH. [Note that plotted pH values are mean (pH) not p(mean H).]

All three lakes have pH < 7 in late autumn and winter -- all are basically relatively softwater lakes. Increases in pH to ca. 6.5 (Lacawac) or to ca. 8.5 (Waynewood) during the summer reflect cumulative phytoplanktonic uptake of inorganic carbon. *In situ* pH in Waynewood probably reaches 9.5-10 on some calm, sunny August days when algae are especially abundant. In Lake Giles, epilimnetic pH varies only slightly within the range 5.2-5.4. Alkalinities of the lakes differ sharply. Lake Giles shows no seasonal pattern around its ca. -4 μeq/L epilimnetic mean. Autumn increases in Lake Lacawac and Lake Waynewood reflect gradual advection of high-alkalinity anoxic bottom water (see **Annual Reports**) as the epilimnion cooled and mixed deeper. This alkalinity was soon destroyed through oxidation reactions.

ALGAL CHLOROPHYLL-a.

Chlorophyll was determined fluorimetrically in 90% acetone extracts (June 1989-May 1990) or in 90% acetone/methanol (5:1 vol/vol) extracts (June 1990-May 1993), and more recently spectrophotometrically in 90% ethanol extracts (starting June 1993). The monthly mean chlorophyll concentrations in the three lakes (**Figure 15**) display lake-to-lake, among-depth, and seasonal patterns that are key limnological features of these lakes and the main justification for classifying Lake Giles, Lake Lacawac, and Lake Waynewood as oligotrophic, mesotrophic, and eutrophic, respectively.

Epilimnetic chlorophyll is occasionally very high under the ice in all three lakes ("EPI" under the ice was 0.5 m depth), reflecting physical stability of the water column and good light penetration through ice free of deep snow. Lowest levels in April-June are likely caused by heavy grazing pressure. Marked late summer-autumn increases in Lake Giles and Lake Waynewood may reflect different processes. In Lake Waynewood, the late summer increase involves grazing-resistant cyanobacteria (bluegreen algae) typical of eutrophic lakes.

During spring through early autumn, thermal stratification interacts with light penetration to create contrasting depth-distributions of algae in the three lakes (**Figure 15**). In Lake Giles, algae peak first within the hypolimnion, then shift to the metalimnion as water transparency decreases in late summer. In Lake Lacawac and Lake Waynewood, the hypolimnia are too dark to sustain most algae, but peak populations develop in the metalimnia. These tend to be gradually pinched out by thickening epilimnia and decreasing light penetration during late summer and early autumn. Only in Lake Waynewood does a late summer epilimnetic "bloom" of algae develop. In late spring and early summer, algae are hardly more abundant in Lake Waynewood's epilimnion than in Lake Lacawac, but dense algal populations eventually develop, first in the metalimnion but then throughout the epilimnion, giving the lake water a muddy greenish coloration reflective of its rich nutrient conditions. Lake Giles, at the other extreme, has crystal clear water and a distinctive bluish luminance imparted by scattering of deeply penetrating blue light.

BIOLOGY

Zooplankton have been studied in great detail throughout the study period; monthly mean water column concentrations of major synthetic groups (rotifers, cladocerans, calanoid copepods, cyclopoid copepods, copepod nauplii, and *Chaoborus*) are plotted in **Figures 16-21**. Separate graphs are presented for nighttime and daytime sampling. All species identified in the course of this study are listed in **Table 7**. Phytoplankton have been collected and preserved, but not counted, except for a series of composite seasonal samples spanning three years (summer 1989 through spring 1992). To give an idea of algae in each lake, the mean composite biovolumes are given, by species, for each season (**Tables 4-6**). These data are also summarized by taxonomic group (**Table 3**). Fish populations were sampled with gill and trap nets over a 24-hr period in July 1990. Data are summarized in **Table 8**.

PHYTOPLANKTON.

Phytoplankton abundances in composited samples (all three depths, all dates) are presented for each season of each year that was analyzed in the **1993 Annual Reports**. These counts were performed by PhycoTech, Inc. under the direction of Ann St Amand, who has suggested the species identifications listed. Cell counts were converted to biovolumes. Many uncommon species are not included. The 3-year means are given by species in **Tables 4-6**, and further condensed into seasonal means of major taxonomic groups in **Table 3**.

The eutrophic nature of Lake Waynewood is dramatically illustrated by the abundance of such colonial cyanobacteria (blue-green algae) as *Aphanizomenon flos-aquae*, *Anabaena macrospora*, *Oscillatoria limnetica*, and *Coelosphaerium naegelianum* in summer. *Aphanizomenon* was also abundant in autumn. Lake Waynewood is the only lake of the three with cyanobacterial dominance. More surprisingly, Lake Waynewood also was the only lake with important planktonic diatom populations, which appeared in the autumn.

Chrysophytes are important in all three lakes. They are the most important algal group in the winter and spring, but also are well represented throughout the year in Lake Lacawac and Lake Giles, especially in the metalimnion and deeper. They virtually disappear during the period of cyanobacterial and/or diatom dominance in summer and autumn in Lake Waynewood. The most important taxa are *Synura* (all three lakes) and *Mallomonas* (especially Giles and Lacawac). Because scales from these genera are preserved in the sediment and can be identified to species, they are important guides to past ecological conditions in the lakes (**Lott et al. 1994**). Cryptophytes and chlorophytes are important summer components of the phytoplankton community, especially in Lake Lacawac and Lake Giles.

An earlier study by **Siver and Chock (1985)** describes the phytoplankton community in Lake Lacawac for 1980-81, emphasizing depth-distributions and seasonal patterns. One dramatic difference from their study has been the minor role of the non-scaled chrysophyte *Stichogloea* in the 1989-92 summer plankton -- it was the summer dominant in 1980-81, and was still fairly common in 1985-86 (R. Moeller, unpubl.). **Moeller (1994)** reports sensitivity of summer epilimnial phytoplankton from the three lakes to ultraviolet radiation (species were not differentiated).

ZOOPLANKTON.

Zooplankton were collected on each sampling date, usually during the day and again after dark. Two 30-cm diameter conical nets 1.2 m long were used: a 202-μm mesh net with 60 cm tubular collar and 30 cm diameter mouth, and a 48-μm mesh net with 60 cm long collar tapering to a 15 cm mouth -- ie. Wisconsin-style [see **Sampling Protocols (1988-1993)**]. They were mounted in tandem and operated as closing nets, allowing separate sampling of the "EPI", "META", and "HYPO" layers. Samples were concentrated to ca. 90 ml, narcotized with soda water (202-μm samples only), and preserved by adding chilled sucrose formalin (1:9 vol/vol). Large Cladocera (all except *Bosmina* and *Chydorus*) and adult female cyclopoid copepods (except *Tropocyclops*) were counted from the 202-μm net samples; all others were counted from the 48-μm samples. Comparison with integrated Schindler trap depth-series on one date in all three lakes indicated good sampling efficiency of both nets (see **1993 Annual Reports**).

Figures 16-21 present water-column mean monthly concentrations (number per litre) for major taxonomic groupings of zooplankton. Since Lake Giles is twice as deep as the other lakes, comparable population data for the lakes on a per m^2 basis entails a doubling of Lake Giles' concentrations relative to those of the other lakes. The **Annual Reports** present nighttime concentrations for all of the main taxa, at their level of identification, for each sampling date. The electronic database includes separate data for the 3 layers, the day vs night comparison, and the two replicates of each sample. A complete species list (**Table 7**) attempts to identify the most important taxa and their seasons of abundance. Year-to-year variability makes the latter information unreliable, however. Further notes on species identifications are given in **Sampling Protocols (1988-1993)**.

The abundance of rotifers is related to the trophic status of the lakes: concentrations are usually highest in Lake Waynewood (or in Lacawac, April-June), intermediate in Lake Lacawac, and lowest throughout the year in Lake Giles (**Figure 16**). Day and night concentrations are the same. The early stages of cyanobacterial build-up in Lake Waynewood in July and August are associated with especially high concentrations of rotifers. The taxonomic diversity of rotifers also is in general highest in Lake Waynewood and least in Lake Giles. This can be better appreciated from the counts of common species (**Annual Reports**) than from the list of all species encountered during the five-year study(**Table 7**).

Cladocerans are common in all three lakes (**Figure 17**). Except for times of conspicuous spring and fall cladoceran peaks in Lake Waynewood, there is no relationship between lake trophic status and cladoceran concentration. On a per m^2 basis, Lake Giles actually has the highest cladoceran density except during early spring. *Daphnia* spp make up a large part of total cladocerans in all three lakes, though *Holopedium* is a major summer component in Lake Lacawac, and *Diaphanosoma* in Lake Giles.

Calanoid copepods are most common in Lake Giles, and least abundant in Lake Waynewood (**Figure 18**), so an inverse relationship exists with trophic status. There was little difference in daytime vs nighttime collections. Though the copepods often change position within the water column during day vs night, apparently few go all the way to the bottom of the lake (though this conclusion might be less true of adults than for the adults plus copepodids plotted in **Figure 18**). Only three species are involved: *Diaptomus minutus* in Lake Lacawac and Lake Giles, *D. spatulocrenatus* in Lake Giles, and *D. oregonensis* in Lake Waynewood.

Cyclopoid copepods are generally least abundant in Lake Giles, and often most abundant in Lake Waynewood (**Figure 19**). This pattern is consistent with general trophic differences among the lakes, and also with the abundance pattern of rotifers (**Figure 16**), an important food of many cyclopoids. For the year as a whole, there is roughly a 50:1 ratio between rotifers and cyclopoids in each lake, although the ratio varies substantially from month-to-month, and this variation is not the same in each lake. Several species are involved: *Cyclops scutifer* (especially Lacawac and Giles), *Mesocyclops edax* and *Orthocyclops modestus* (Lacawac and Waynewood), *Tropocyclops prasinus* (especially Waynewood), and *Diacyclops thomasi* (Waynewood). Unlike the other lakes, Lake Giles has only one routinely encountered cyclopoid. Densities of total cyclopoids are usually the same in day vs night sampling.

Two species of *Chaoborus* are present in the lakes: *Chaoborus punctipennis* (all three lakes) and *C. flavicans* (Lacawac and Waynewood). They have not been separated in the routine counts. In winter and spring the concentration (and density per m^2) of these dipteran larvae is consistent with the lake trophic status, with lowest concentrations in Lake Giles and highest in Lake Waynewood (**Figure 21**). After spring-summer recruitment of new individuals, however, the concentrations become similar, giving Lake Giles the densest population per m^2 in July-September. Daytime sampling is generally inefficient. When Lake Lacawac and Lake Waynewood are anoxic through the hypolimnia, however, sampling efficiency is similar in daytime and nighttime. This is presumably because the animals do not migrate all the way to the sediments during the day.

The ecology of Lake Lacawac's *Holopedium gibberum* and *Daphnia catawba* was intensively studied by Alan Tessier (**Tessier 1981, 1986a**). Tessier measured population dynamics in 1979-80 and 1983 by multi-station sampling and addressed issues of food limitation, competition, and differential susceptibility to fish predation. Separate experimental investigations of food-limitation, reproduction, and life history characteristics of Cladocera utilized organisms from Lake Lacawac and other lakes (**Tessier 1984, 1986b, Tessier and Goulden 1982**). The stable epilimnial patches of *Holopedium* and reverse diurnal migrations of this cladoceran that Tessier described (**Tessier 1983**) have been general features of the Lacawac summer zooplankton during the PCLP study. Scott Carpenter's subsequent multi-station sampling of *Holopedium* and other macrozooplankton in Lake Lacawac during May-September 1990 was complemented by information on their diurnal vertical migrations and relative susceptibility to predation by young-of-the-year fish (**Carpenter 1992**). The acute effects of ultraviolet radiation on different zooplankton species, and on populations of single species from different lakes, are a current topic of investigation (**Williamson et al. 1994**, **Zagarese et al. 1994**).

FISH SURVEY.

Kenneth Ersbak and Aquatic Resource Consulting surveyed fish populations in the three lakes in July 1990 (data are summarized in **Table 8**). Trap and gill nets were deployed at several locations in the nearshore zone of each lake for two consecutive 12-hr (day and night) periods. Sampling effort (number of nets) was the same in Lake Giles and Lake Lacawac, but was one-fourth less in Lake Waynewood. In Lake Lacawac an additional hook-and-line survey was carried out. Full details and data are included in the unpublished report of the survey (**Aquatic Resource Consulting 1990**), in the **1990 Annual Reports**, and in electronic files maintained as part of the PCLP database.

Two dissertations present information on predator-prey relations of icthyoplankton (larval and young-of-the-year fish) in Lake Lacawac (**Phoenix 1976, Carpenter 1992**).

All three lakes have populations of numerous native warm-water species (perch, bass, sunfish, bullheads, etc.). Many of these species were presumably introduced long ago from other North American populations. In addition to the netted fish, Lake Giles has populations of yellow perch, lake trout, and American eel (Ken Ersbak, pers. comm.). Lake Giles is stocked annually with hatchery raised trout, which are not thought to reproduce in the lake (an exception may be the small population of lake trout that has persisted without recent stocking). The low pH in Lake Giles (ca. 5.3) may make the lake marginal for some of its fish populations. Chemical sampling in 1983-85 showed that total aluminum levels were not especially elevated, however (ca. 2 μM total Al: **Sherman and Fairchild 1994**).

Lake Waynewood is distinctive in having a large population of golden shiners. These presumably exert heavy predation pressure on large zooplankton such as *Daphnia*, potentially facilitating development of large cyanobacteria populations in late summer. In September 1991, 2500 fingerlings of walleye, a large predator, were stocked in an attempt to establish more effective control of small fish such as the shiners (David Westpfahl, pers. comm.).

LITTORAL COMMUNITIES.

Currently the Pocono Comparative Lakes Program emphasizes studies of the water column and plankton communities. Several notable studies have been published on littoral communities of the core lakes, however.

Nutrient limitations of periphyton were studied by Win Fairchild and colleagues in Lake Lacawac (**Fairchild and Everett 1988**, **Fairchild et al. 1989a**) and Lake Giles (**Fairchild et al. 1989b**). In a comparative study of 12 softwater lakes in the Poconos -- including Lacawac, Giles and Waynewood -- the nutrients nitrogen and/or phosphorus were found to limit periphyton accumulation rates on artificial substrates when the water column alkalinity was greater than 100 ueq/L; at lower alkalinities (lower total dissolved inorganic carbon) inorganic carbon became a limiting or co-limiting factor (**Fairchild and Sherman 1992**). Annette Heist found that the submersed macrophyte *Myriophyllum humile* was not limited by nitrogen or phosphorus when grown *in situ* in its natural Lacawac or Giles sediment (**Heist 1992**).

Goulden (1971) described the littoral and benthic chydorid cladoceran assemblage from Lake Lacawac. The lake sediments record change in this community through post-glacial time, which **Goulden (1969)** has interpreted as an example of the long-term development of biotic diversity within a lake ecosystem. **Fairchild et al. (1989a)** showed that density of littoral invertebrates in Lake Lacawac responded positively to nutrient-stimulation of their algal foods. **Fairchild and Sherman (1992)** presented circumstantial evidence that invertebrate grazers might be a more important control on periphyton in the more eutrophic lakes, where snails were an important component of the invertebrate community, than in the more oligotrophic, especially acidic lakes, where snails were absent.

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Table 1. Geographic and Morphometric Fact Sheet on the Three Lakes.

Parameter	(units)	GILES	LACAWAC	WAYNEWOOD
Drainage Area [1]	miles^2	0.705	0.270	2.812
(including lake)	feet^2	$1.97x10^{7}$	$7.53x10^{6}$	$7.84x10^{7}$
	km^2	1.83	0.70	7.28
	hectares	183	70	728
Lake Area [2]	miles^2	0.186	0.082	0.108
	feet^2	$5.18x10^{6}$	$2.30x10^{6}$	$3.01x10^{6}$
	km^2	0.481	0.214	0.280
	hectares	48.1	21.4	28.0
Lake Volume [2]	feet^3	$17.2\ x10^{7}$	$3.96x10^{7}$	$5.90x10^{7}$
	m^3	$4.88x10^{6}$	$1.12x10^{6}$	$1.67x10^{6}$
Max. Depth	feet	79	43	41
	m	24.1	13.0	12.5
Mean Depth	feet	33	17	20
	m	10.1	5.2	6.0
Hydraulic Detention [1]	year	5.6	3.3	0.42
Elevation	feet asl	1404	1439	1381
(lake surface)	metres asl	428	439	421
Latitude	North	41°22'34"	41°22'57"	41°23'42"
Longitude	West	75°05'33"	75°17'35"	75°21'50"
Quadrangle Map *(USGS 7.5' series)*		Rowland & Peck's Pond	Lakeville	Lakeville & Lake Ariel
Map Date/Photorevision		1966/1983	1966/1983	1966/1983
County (PA)		Pike	Wayne	Wayne

[1] R. Schultz and R. Weisman (1990, unpublished)

[2] Lake bathymetry from maps drawn by R. Moeller (Oct. 1992) based on bathymetric survey of A. Tessier (Lacawac) or R. Schultz and R. Weisman (Giles and Waynewood, 1990 unpubl.)

Table 2. Chemical Characterization of the Lakes.

LAKE GILES		micromoles/L	microequivalents/L
Anions			
Sulfate	SO_4^{-2}	94. μM	188. μeq/L
Chloride	Cl^{-1}	160.	160.
Bicarbonate	HCO_3^{-1}	3.3	3.3
Nitrate	NO_3^{-1}	0.5	0.5
Cations			
Sodium	Na^{+1}	163. μM	163. μeq/L
Calcium	Ca^{+2}	52.0	104.
Magnesium	Mg^{+2}	31.6	63.2
Potassium	K^{+1}	12.1	12.1
Hydrogen ion	H^+	4.4	4.4
Ammonium	NH_4^{+1}	2.5	2.5

Other Chemical Parameters		
pH	5.35	
Alkalinity	-4.1	μeq/L
Conductivity (1989 data)	42.	μmho/cm
Dissolved Inorganic Carbon (DIC)[1]	33.	μM
Dissolved Organic Carbon (DOC)	91.	μM
Total Phosphorus (totP)	0.23	μM

[1] includes mid-depths; epilimnetic DIC in summer is ca. 25 μM

LAKE LACAWAC		micromoles/L	microequivalents/L
Anions			
Sulfate	SO_4^{-2}	76. μM	143. μeq/L
Chloride	Cl^{-1}	23.5	23.5
Bicarbonate	HCO_3^{-1}	43.	43.
Nitrate	NO_3^{-1}	0.5	0.5
Cations			
Sodium	Na^{+1}	31.8 μM	31.8 μeq/L
Calcium	Ca^{+2}	74.	147.
Magnesium	Mg^{+2}	21.1	42.2
Potassium	K^{+1}	9.7	9.7
Hydrogen ion	H^+	0.01	0.01
Ammonium	NH_4^{+1}	3.9	3.9

Other Chemical Parameters		
pH	6.03	
Alkalinity	30.	μeq/L
Conductivity (1989 data)	27.	μmho/cm
Dissolved Inorganic Carbon (DIC)[1]	130.	μM
Dissolved Organic Carbon (DOC)	400.	μM
Total Phosphorus (totP)	0.46	μM

[1] includes mid-depths; epilimnetic DIC in summer is ca. 40 μM

LAKE WAYNEWOOD		micromoles/L		microequivalents/L	
Anions					
Sulfate	SO_4^{-2}	122.	μM	244.	μeq/L
Chloride	Cl^{-1}	180.		180.	
Bicarbonate	HCO_3^{-1}	295.		295.	
Nitrate	NO_3^{-1}	4.		4.	
Cations					
Sodium	Na^{+1}	166.	μM	166.	μeq/L
Calcium	Ca^{+2}	207.		414.	
Magnesium	Mg^{+2}	54.7		109.	
Potassium	K^{+1}	34.0		34.0	
Hydrogen ion	H^+	<0.01		<0.01	
Ammonium	NH_4^{+1}	7.		7.	

Other Chemical Parameters		
pH	7.27	
Alkalinity	303.	μeq/L
Conductivity (1989 data)	72.	μmho/cm
Dissolved Inorganic Carbon (DIC)	327.	μM
Dissolved Organic Carbon (DOC)	440.	μM
Total Phosphorus (totP)	0.78	μM

Table 3. Summary of Phytoplankton Biovolumes by Type of Algae.

Samples are composites of all dates and depths sampled within 4 seasons over 3 years. Units are $10^3 \mu m^3$ of algal biovolume per mL of lakewater.

Lake Giles Algal Biovolumes (1989-92).

Type	spring		summer		fall		winter	
	volume	%	volume	%	volume	%	volume	%
Diatoms	0.3	*0.5*	0.6	*0.6*	0.0	*0.0*	0.0	*0.0*
Chrysophytes	49.3	*76.8*	27.5	*29.7*	28.5	*42.4*	151.	*85.1*
Cryptophytes	6.3	*9.8*	19.3	*20.8*	17.9	*26.6*	11.7	*6.6*
Chlorophytes	1.8	*2.8*	41.7	*45.0*	17.5	*26.0*	10.5	*5.9*
Dinoflagellates	0.0	*0.0*	0.3	*0.3*	0.0	*0.0*	0.0	*0.0*
Cyanobacteria	0.5	*0.8*	0.0	*0.0*	0.1	*0.1*	0.0	*0.0*
Microflagellates	6.0	*9.4*	3.3	*3.6*	3.2	*4.8*	4.3	*2.4*
Other	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
TOTAL	64.		93.		67.		177.	

Lake Lacawac Algal Biovolumes (1989-92).

Type	spring		summer		fall		winter	
	volume	%	volume	%	volume	%	volume	%
Diatoms	11.5	*0.7*	1.0	*0.4*	8.8	*1.9*	6.8	*0.6*
Chrysophytes	928.	*56.2*	110.	*41.5*	112.	*23.6*	1060.	*90.3*
Cryptophytes	92.5	*5.6*	37.7	*14.2*	71.2	*15.0*	97.8	*8.3*
Chlorophytes	143.	*8.6*	65.9	*24.8*	175.	*36.9*	6.7	*0.6*
Dinoflagellates	463.	*28.1*	6.5	*2.4*	56.0	*11.8*	0.0	*0.0*
Cyanobacteria	0.1	*0.0*	5.3	*2.0*	1.8	*0.4*	0.2	*0.0*
Microflagellates	12.0	*0.7*	7.8	*2.9*	22.0	*4.6*	2.7	*0.2*
Other	0.0	*0.0*	30.9	*11.6*	27.5	*5.8*	0.0	*0.0*
TOTAL	1650.		265.		474.		1180.	

Lake Waynewood Algal Biovolumes (1989-92).

Type	spring		summer		fall		winter	
	volume	%	volume	%	volume	%	volume	%
Diatoms	86.8	*4.5*	111.	*8.2*	627.	*57.1*	37.2	*5.4*
Chrysophytes	1520.	*78.1*	7.9	*0.6*	4.2	*0.4*	360.	*51.9*
Cryptophytes	173.	*8.9*	54.4	*4.0*	76.0	*6.9*	127.	*18.3*
Chlorophytes	103.	*5.3*	28.5	*2.1*	30.9	*2.8*	116.	*16.6*
Dinoflagellates	26.8	*1.4*	45.0	*3.3*	2.6	*0.2*	2.1	*0.3*
Cyanobacteria	29.9	*1.5*	1080.	*79.4*	349.	*31.7*	38.4	*5.5*
Microflagellates	5.7	*0.3*	7.4	*0.5*	9.5	*0.9*	14.0	*2.0*
Other	0.0	*0.0*	27.0	*2.0*	0.0	*0.0*	0.1	*0.0*
TOTAL	1950.		1360.		1100.		694.	

Table 4. Phytoplankton from Lake Giles, 1989-1992. Major species with their abundance as biovolume.

Values are means of three years, where a single sample was counted from each season each year, representing a composite of all dates and sampling depths during the periods January--February (winter), March--May (spring), June--September (summer) and October--December (autumn).
[Corrected version of 1/27/95]

Alga	Biovolume of species ($10^3 \mu m^3$/mL)			
	winter	spring	summer	autumn
Diatoms				
Asterionella formosa			0.3	
Navicula sp.			0.3	
Nitzschia acicularis		0.3		
Chrysophytes				
Chrysosphaerella longispina		8.1		
Diceras sp.	0.9		0.5	1.0
Dinobryon cylindricum	0.6			0.6
Dinobryon spp. (monads)		1.0		
Epipyxis utriculus v. acuta			0.1	0.3
Mallomonas caudata	56.			16.
Mallomonas spp.	7.5	10.	1.7	
Ochromonas sp.	0.9	3.2	1.0	
Synura uvella/sphagnicola	68.	17.	18.	4.7
Uroglena sp.	17.	10.	6.2	5.9
Cryptophytes				
Cryptomonas sp.		0.3	1.8	0.1
Cryptomonas erosa	5.3	3.7	12.	12.
Cryptomonas ovata	6.3	2.3	5.0	5.3
Rhodomonas minuta	0.1		0.5	0.5
Chlorophytes				
Ankistrodesmus falcatus	0.1			0.1
Botryococcus braunii			32.	5.0
Closterium moniliferum				1.0
Elakatothrix gelatinosa			0.1	
Kirchneriella contorta			2.5	0.4
Monomastix astigmata	2.1	0.8	0.1	2.8
Oocystis parva			1.2	
Schroederia judayi	8.3	0.9	5.2	8.1
Selenastrum minutum			0.1	0.1
Sphaerocystis schroeteri			0.4	
colonial Chlorophyte			0.1	
misc. Chlorococcales		0.1		
Dinoflagellates				
Gymnodinium spp.			0.3	
Cyanobacteria				
coccoid Cyanobacteria		0.5		0.1
Other				
microflagellates (misc.)	4.3	6.0	3.3	3.2
Total Biovolume ($10^3 \mu m^3$/mL):	177.	64.	93.	67.

Table 5. Phytoplankton from Lake Lacawac, 1989-1992. Major species with their abundance as biovolume.

Values are means of three years, where a single sample was counted from each season of each year, representing a composite of all dates and sampling depths during the periods January--February (winter), March--May (spring), June--September (summer) and October--December (autumn).
[Corrected version of 1/27/95]

Alga	Biovolume of species ($10^3 \mu m^3$/mL)			
	winter	spring	summer	autumn
Diatoms				
Asterionella formosa	4.9	1.0	0.1	1.7
Cyclotella spp.		0.1	0.8	
Meridion sp.		5.2		
Navicula sp.				0.4
Nitzschia sp.			0.1	
Tabellaria fenestrata	1.9	5.2		6.7
Chrysophytes				
Chrysosphaerella longispina			0.2	
Diceras sp.	0.4	0.4		0.7
Dinobryon bavaricum				2.8
Dinobryon cylindricum				0.3
Dinobryon divergens	0.3	1.8		3.9
Dinobryon sertularia	5.6	13.	3.0	10.
Dinobryon cysts		0.5		
Dinobryon spp. (monads)	2.7	28.		24.
Kephyrion sp.				0.5
Mallomonas akrokomos			23.	
Mallomonas caudata			7.8	57.
Mallomonas spp.	150.	56.	33.	12.
Psephonema aenigmaticum			0.2	
Ochromonas sp.	0.4			0.4
Stichogloea olivaceae		0.7	3.0	
Synura uvella/sphagnicola	880.	810.	40.	
Uroglena sp.	22.	13.		
misc. Chrysophyta		4.1		0.1
Cryptophytes				
Cryptomonas sp.	0.4	0.4	1.9	2.1
Cryptomonas erosa	4.3	27.	12.	9.5
Cryptomonas ovata	90.	60.	20.	51.
Rhodomonas minuta	3.1	5.1	3.8	8.6
Chlorophytes				
Ankistrodesmus falcatus		1.0		0.2
Arthrodesmus incus			6.8	
Botryococcus braunii			0.6	
Cosmarium sp.			5.6	150.
Crucigenia rectangularis			3.2	0.4
Crucigenia tetrapedia			0.1	0.2
Crucigenia sp.			1.1	
Dictyosphaerium pulchellum		130.		
Dispora crucigenioides				0.7
Elakatothrix gelatinosa	0.1		0.1	
Kirchneriella lunaris			0.5	
Monomastix astigmata	0.2	0.8	0.8	0.2
Nephrocytium lunatum			0.1	
Oocystis borgei/lacustris			0.1	
Oocystis parva		9.0	7.4	3.6
Quadrigula chodatti			0.3	0.1
Quadrigula lacustris			0.3	

continued

Table 5. Phytoplankton from Lake Lacawac, 1989-1992. Major species with their abundance as biovolume. (continued)

Alga	Biovolume of species ($10^3 \mu m^3$/mL)			
	winter	spring	summer	autumn
Chlorophytes (continued)				
Schroederia judayi	0.8	0.1		0.4
Schroederia setigera		0.2	0.1	
Selenastrum minutum			0.1	
Sphaerocystis schroeteri			0.8	
Staurastrum paradoxum	5.5		0.5	
Tetraedron caudatum			0.1	
Tetrastrum staurogeniaeforme			2.2	
Ulothrix sp.				0.3
colonial Chlorophyte		0.5	21.	13.
filamentous Chlorophyte			0.1	
misc. Chlorococcales	0.1	1.0	14.	5.9
Dinoflagellates				
Glenodinium sp.			0.7	
Gymnodinium spp.		10.	0.6	23.
Peridinium inconspicuum			1.4	
Peridinium umbonatum			3.4	
Peridinium wisconsinense			0.4	
Peridinium sp.		450.		33.
dinoflagellate cyst		3.2		
Cyanobacteria				
Anabaena sp.			0.1	
Aphanizomenon flos-aquae			1.2	
Aphanothece sp.			0.2	
Coelosphaerium naegelianum	0.1		0.5	0.9
Merismopedia tenuissima			3.2	
Oscillatoria limnetica		0.1		0.7
Oscillatoria sp.			0.1	
coccoid Cyanobacteria	0.1			0.2
Other				
Euglena acus			0.5	
Euglena gracilis			7.6	24.
Gonyostomum sp.			20.	
Phacus sp.			0.1	
Trachelomonas sp.			2.7	
microflagellates (misc.)	2.7	12.	7.8	22.
unidentifiable cyst				3.5
Total Biovolume ($10^3 \mu m^3$/mL):	1176.	1649.	265.	474.

Table 6. Phytoplankton from Lake Waynewood, 1989-1992. Major species with their abundance as biovolume.

Values are means of three years, where a single sample was counted from each season of each year, representing a composite of all dates and sampling depths during the periods January--February (winter), March--May (spring), June--September (summer) and October--December (autumn).

Alga	Biovolume of species ($10^3 \mu m^3$/mL)			
	winter	spring	summer	autumn
Diatoms				
Asterionella formosa	17.	83.		1.0
Cyclotella spp.		1.2	3.2	0.2
Fragilaria capucina			7.4	162.
Melosira varians				320.
Melosira sp.	2.2		5.3	13.
Synedra sp.			35.	35.
Tabellaria fenestrata	18.	2.6	60.	96.
Chrysophytes				
Chrysococcus sp.	0.1			
Diceras sp.		0.2		
Dinobryon cylindricum		3.3		0.3
Dinobryon sertularia			0.6	0.6
Dinobryon cysts		1.0		
Epipyxis utriculus	0.1	12.		0.1
Mallomonas sp.	19.	1.2		0.3
Ochromonas sp.	1.0	4.9	1.7	
Synura uvella/sphagnicola	340.	1490.	5.9	2.9
Uroglena sp.		9.0		
Cryptophytes				
Cryptomonas sp.	1.2	0.6	1.1	
Cryptomonas erosa	3.1	28.	19.	24.
Cryptomonas ovata	120.	135.	31.	50.
Cryptomonas pyredinosa			0.6	
Rhodomonas minuta	2.5	9.5	2.7	2.0
Chlorophytes				
Ankistrodesmus falcatus	0.1	3.2	0.3	0.4
Chlamydomonas sp.		15.		
Closterium moniliferum			2.6	0.5
Eudorina sp.	95.	25.		8.4
Monomastix astigmata	0.9	1.5	0.2	0.7
Oocystis parva			23.	
Oocystis sp.			0.1	
Quadrigula lacustris	0.1			
Scenedesmus longus				2.2
Schroederia judayi	0.3		0.2	
Schroederia setigera	13.			
Sphaerocystis schroeteri	4.5	39.	1.6	
colonial Chlorophyte	1.5	14.		
misc. Chlorococcales	0.1	5.7	0.5	18.7
Dinoflagellates				
Ceratium hirundinella			43.	
Gymnodinium spp.	2.1	5.8	2.0	1.3
dinoflagellate cyst		21.		1.3

continued

Table 6. Phytoplankton from Lake Waynewood, 1989-1992. Major species with their abundance as biovolume. (continued)

Alga	Biovolume of species ($10^3 \mu m^3$/mL)			
	winter	spring	summer	autumn
Cyanobacteria				
Anabaena affinis			1.6	
Anabaena macrospora			130.	2.2
Aphanizomenon flos-aquae	37.	29.	860.	300.
Coelosphaerium naegelianum	0.2	0.2	5.6	4.7
Gloeothece rupestris			24.	
Merismopedia sp.		0.1	0.1	
Oscillatoria limnetica	0.3	0.5	38.	39.
Oscillatoria sp.			21.	
coccoid Cyanobacteria	0.9	0.1	0.1	3.1
Other				
Lepocinclis fusiformis			7.0	
Phacus sp.			20.	
microflagellates (misc.)	14.	5.7	7.4	9.5
unidentifiable cyst	0.1			
Total Biovolume ($10^3 \mu m^3$/mL):	694.	1947.	1362.	1099.

Table. 7. Zooplankton Taxa Recorded from the Three Lakes (1988-93).

Seasons of especially high abundance are indicated for the more important taxa: W (winter), Sp (spring), Su (summer), F (fall). **Bold font** indicates dominance of the taxon in its group. Other codes: "**x**" often present but rarely if ever abundant or dominant in its group, "**g**" positively recorded but tallied only at the genus level, "**r**" rare.

Taxon	Occurrence by Lake		
	WAYNEWOOD	LACAWAC	GILES
Diptera			
Chaoborus spp.	***Sp,Su,F***	***Sp,Su,F***	***Sp,Su***
C. flavicans	g	g	
C. punctipennis	g	g	g
Cyclopoid Copepoda			
Cyclops scutifer	r	***W,Sp***,F	W,***Sp***,Su,F
Diacyclops thomasi	W,F		
Eucyclops agilis		r	
Macrocyclops albidus	r		
Mesocyclops edax	Su	Sp,***Su***,F	
Microcyclops varicans		r	
Orthocyclops modestus	Su	W,F	r
Tropocyclops prasinus	***W,F***	x	
Calanoid Copepoda			
Diaptomus minutus		***W,Sp***,Su,***F***	***W,Sp,Su,F***
D. oregonensis	***W,Sp,Su,F***		
D. spatulocrenatus			***W***,Sp,***Su,F***
Cladocera			
Bosmina spp.	W,Sp,Su,F	x	
B. longirostris	g		
Ceriodaphnia spp.	x		
Chydorus spp.	x	x	r
Daphnia spp.	W,***Sp***,Su,***F***	W,***Sp***,Su,F	***W,Sp,Su,F***
D. ambigua		g	
D. catawba		g	g
D. pulicaria	g		
D. laevis	g		
Diaphanosoma spp.	x	x	***Su***
Holopedium gibberum	r	***Sp,Su,F***	
Leptodora kindtii	x	Su	x
Polyphemus pediculis			x
Rotifera			
Anuraeopsis spp.	x		
Ascomorpha spp.	Su	Sp	Su
A. ovalis	g	g	g
Asplanchna spp.	Su,F	x	
Collotheca spp.	Su	Sp,F	r
C. mutabilis	g	g	
Conochilus spp.	Su	Sp,Su,F	Sp,Su
Euchlanis parva			r
Filinia longiseta	Su		
F. terminalis	r		
Gastropus spp.			
G. hyptopus	Sp,F	***Sp***,F	***Su***
G. stylifer	F	***Sp***,F	Sp,***Su***

continued next page

Table. 7. Zooplankton Taxa Recorded from the Three Lakes (1988-93).
(continued)

Taxon	Occurrence by Lake		
	WAYNEWOOD	**LACAWAC**	**GILES**
Rotifera (continued)			
Kellicottia spp.			r
K. bostoniensis	F	F	
K. longispina	Sp,F	***Sp***	
Keratella spp.			
K. cochlearis	***Su***,F	W,Sp,Su,F	x
K. crassa	x	Sp,Su	r
K. earlinae	Su,F		r
K. gracilenta		x	r
K. hiemalis	Sp	Sp	r
K. serrulata	x	x	
K. taurocephala	x	Sp,Su,F	x
Lecane spp.	x	x	r
L. flexilis		g	g
L. ligona			g
L. luna	g		g
L. mira			g
L. signifera		g	
L. tenuiseta		g	g
Monommata spp.			r
Monostyla spp.	x	x	r
M. closterocerca		g	
M. copeis		g	g
M. lunaris		g	
Notholca spp.	x	x	
N. acuminata	g		
N. squamula		g	
Notommata spp.	x		
Ploesoma spp.			r
P. truncatum	Su	Sp,Su	
Polyarthra spp.	W,Sp,***Su***,F	***W,Sp,Su,F***	W,Sp,***Su***,F
P. dolichoptera	g		
P. euryptera	g		
P. remata	g		
P. vulgaris	g		
Pompholyx spp.	x		
Synchaeta spp.	Sp,Su,F	x	Su
Testudinella spp.			r
T. parva			g
Trichocerca spp.			r
T. cyclindrica	Su,F	x	
T. lophoessa	x		
T. multicrinus	Su	x	g
T. porcellus		r	
T. pusilla			g
T. rousseleti	Su	x	
T. similis	Su	Su	g
Trichotria spp.	x		
Wolga spp.	x		

Table. 8. Fish Collected From the Three Lakes (July 1990).

Values are means ±SD for length and fresh weight of fish netted at several sites in day and night deployments. Percentage of total fish mass (fresh weight) is also given. The sampling effort is described as a footnote.

LAKE GILES (Total Mass: 42.1 kg wet wt)

Species	Number	Length (mm)	Mass (g wet)	%
Brook Trout	38	381 ± 27	595 ± 129	*54*
Bluegill	30	178 56	127 93	*9*
Smallmouth Bass	19	251 66	233 254	*11*
Pumpkinseed	12	149 31	70 49	*2*
Brown Bullhead	5	357 11	668 97	*8*
Brown Trout	4	358 22	392 59	*4*
Rainbow Trout	4	333 31	389 211	*4*
Largemouth Bass	2	452 80	1386 767	*7*
Chain Pickerel	1	433	540	*1*
Tiger Trout	1	420	678	*2*

Effort: 12 12-hr gill nets and 4 12-hr trap nets

LAKE LACAWAC (Total Mass: 24.3 kg wet wt)

Species	Number	Length (mm)	Mass (g wet)	%
Pumpkinseed	36	200 ± 29	165 ± 56	*24*
Smallmouth Bass	21	250 82	261 169	*22*
Yellow Perch	16	302 26	316 67	*21*
Bluegill	15	179 45	130 77	*8*
Chain Pickerel	8	430 22	395 80	*13*
Largemouth Bass	6	219 86	204 163	*5*
Golden Shiner	6	131 14	22 8	*1*
Rock Bass	3	194 41	167 12	*2*
Brown Bullhead	2	297 90	463 375	*4*

Effort: 12 12-hr gill nets and 4 12-hr trap nets

LAKE WAYNEWOOD (Total Mass: 72.9 kg wet wt)

Species	Number	Length (mm)	Mass (g wet)	%
Yellow Perch	145	256 ± 28	236 ± 84	*49*
Golden Shiner	136	199 38	114 71	*21*
Pumpkinseed	42	162 28	94 42	*5*
Bluegill	28	159 50	112 102	*4*
Rock Bass	25	161 29	83 45	*3*
Redbreasted Sunfish	12	154 11	73 17	*1*
Brown Bullhead	10	318 70	583 272	*8*
White Sucker	8	345 66	512 265	*6*
Largemouth Bass	6	213 25	130 50	*1*
Brook Trout	1	300	298	*<1*
Brown Trout	1	325	409	*<1*

Effort: 9 12-hr gill nets and 3 12-hr trap nets

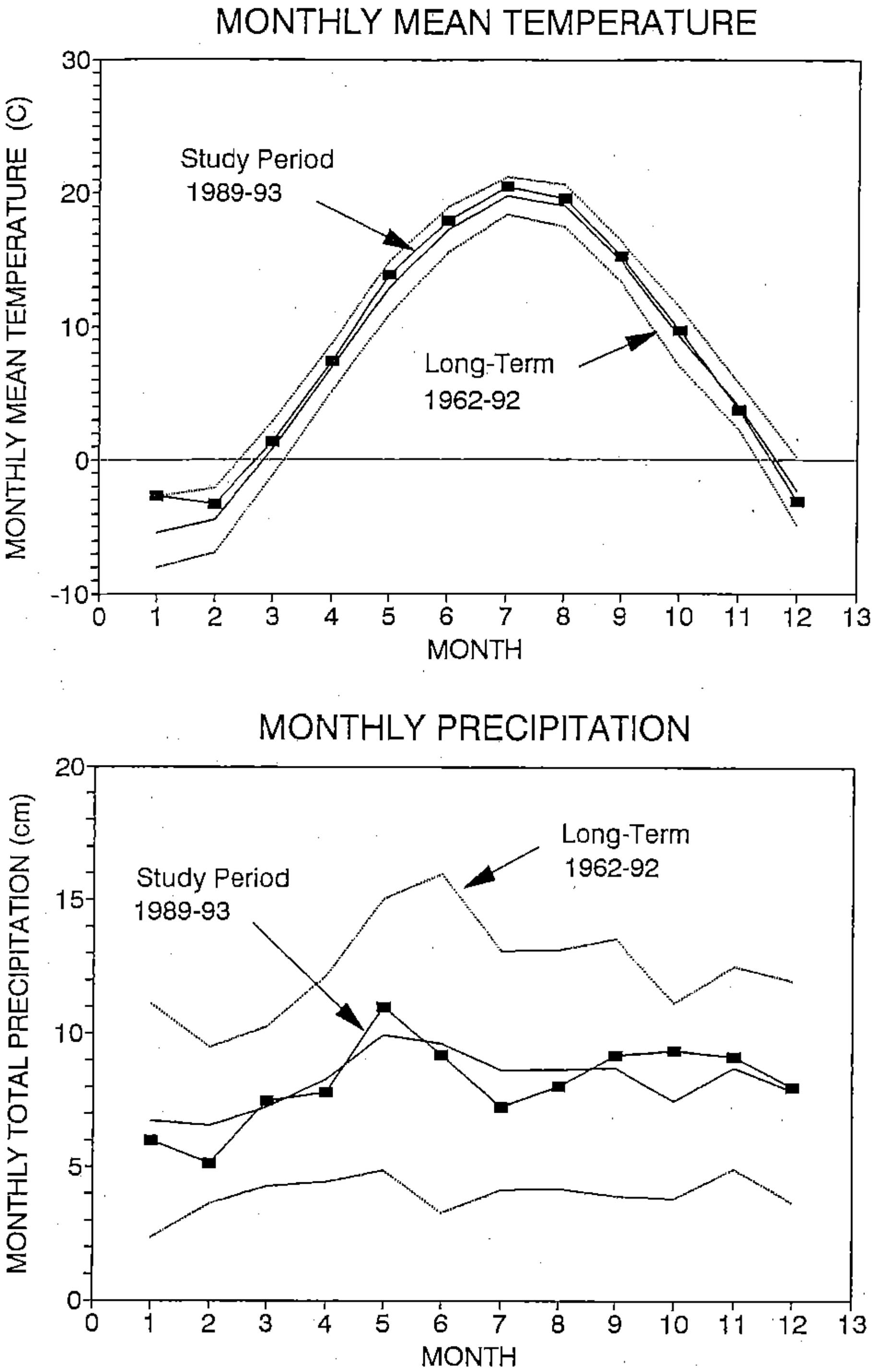
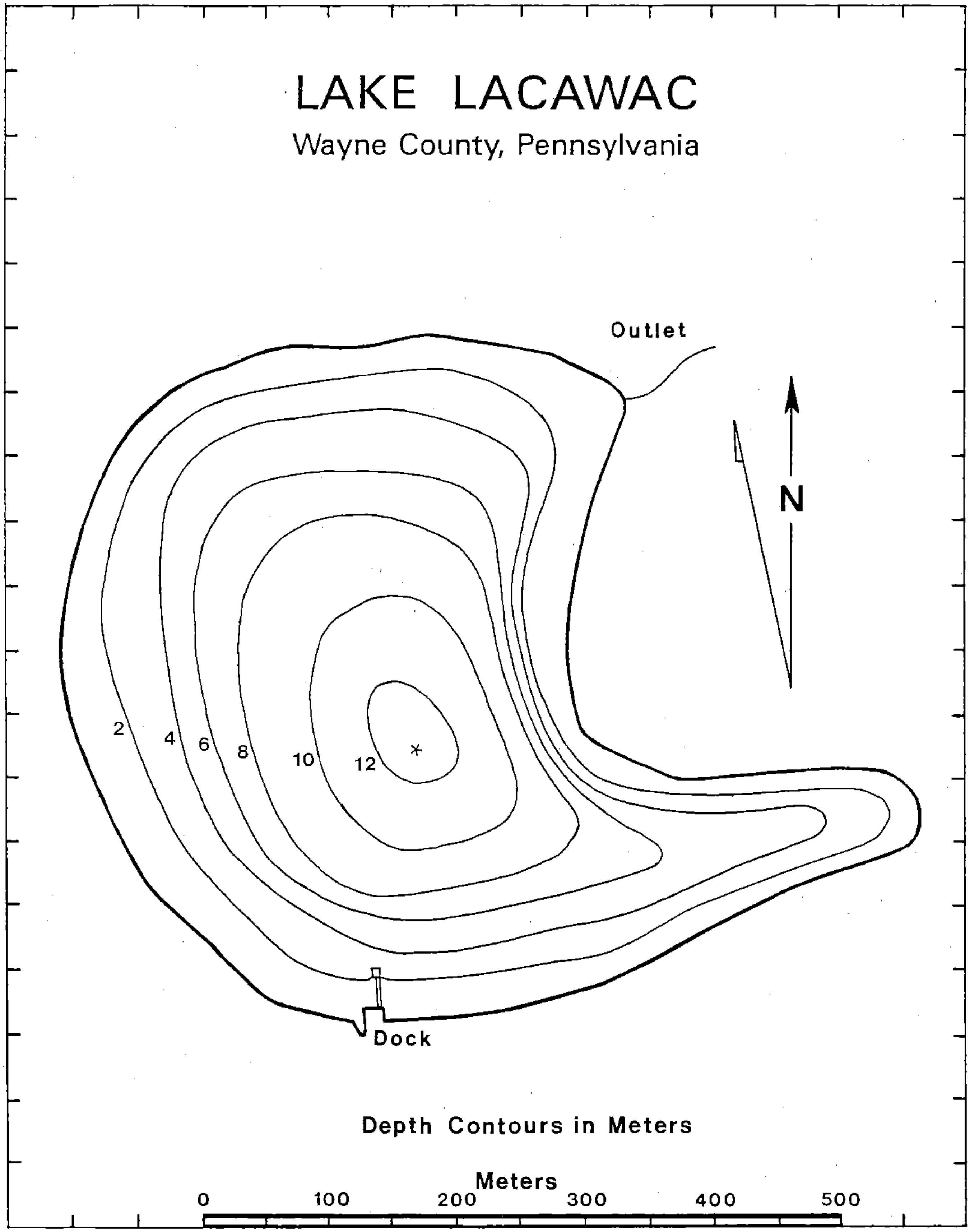


Figure. 1. Monthly climate trends at Hawley, Pennsylvania.
(Top) Temperature (degrees Celsius). **(Bottom)** Monthly precipitation (cm rain or thawed snow). Values are means (solid line) with standard deviation (dotted lines) of 1962-1992 records compared to 5-yr average from the 1989-93 study period (connected points).



POCONO COMPARATIVE LAKES PROGRAM - - - - - - - - - - - - LEHIGH UNIVERSITY - - - - - - - - - - - - 1992
Map drawn by R. Moeller from survey data of A. Tessier

Figure 2. Morphometry of Lake Lacawac.

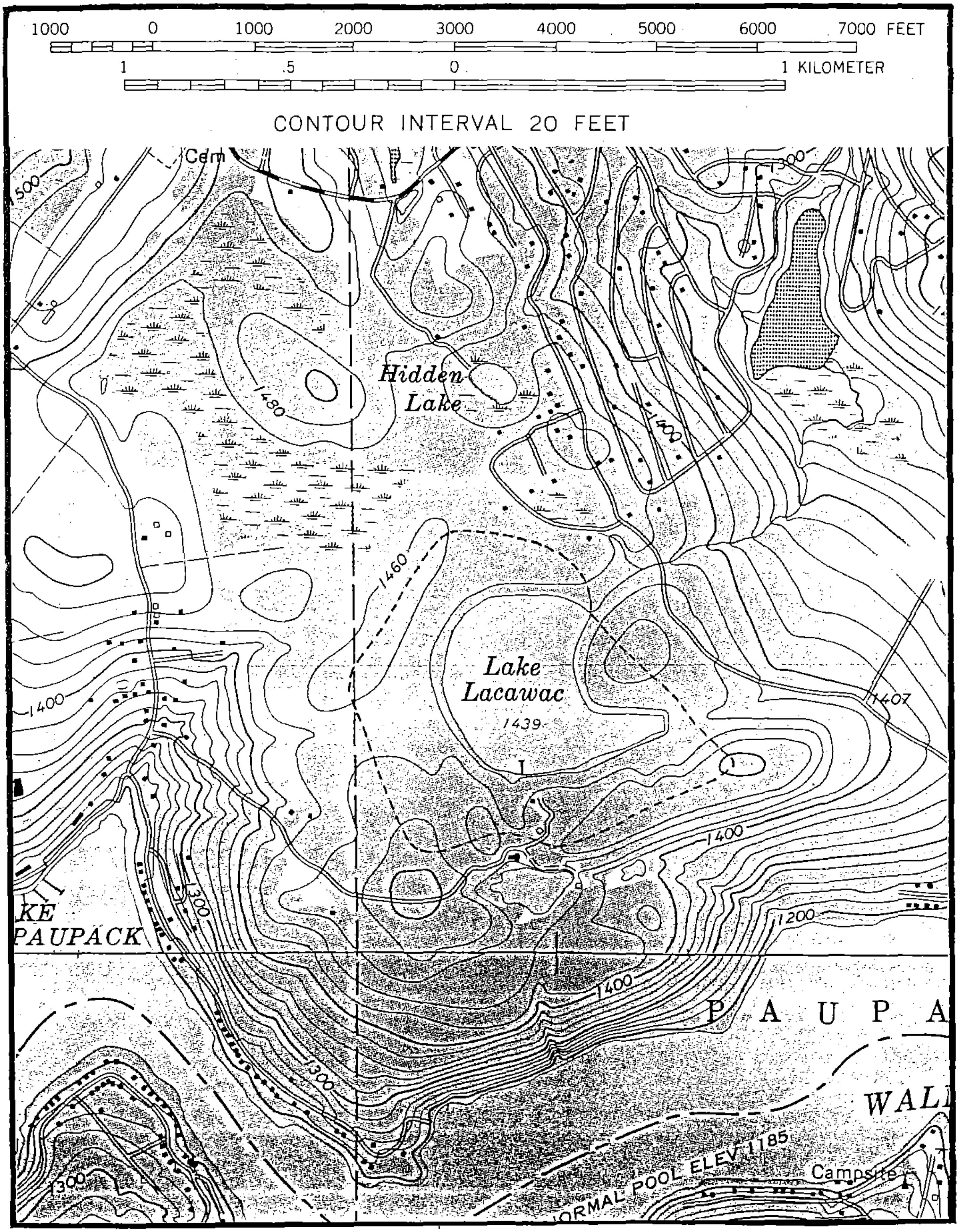
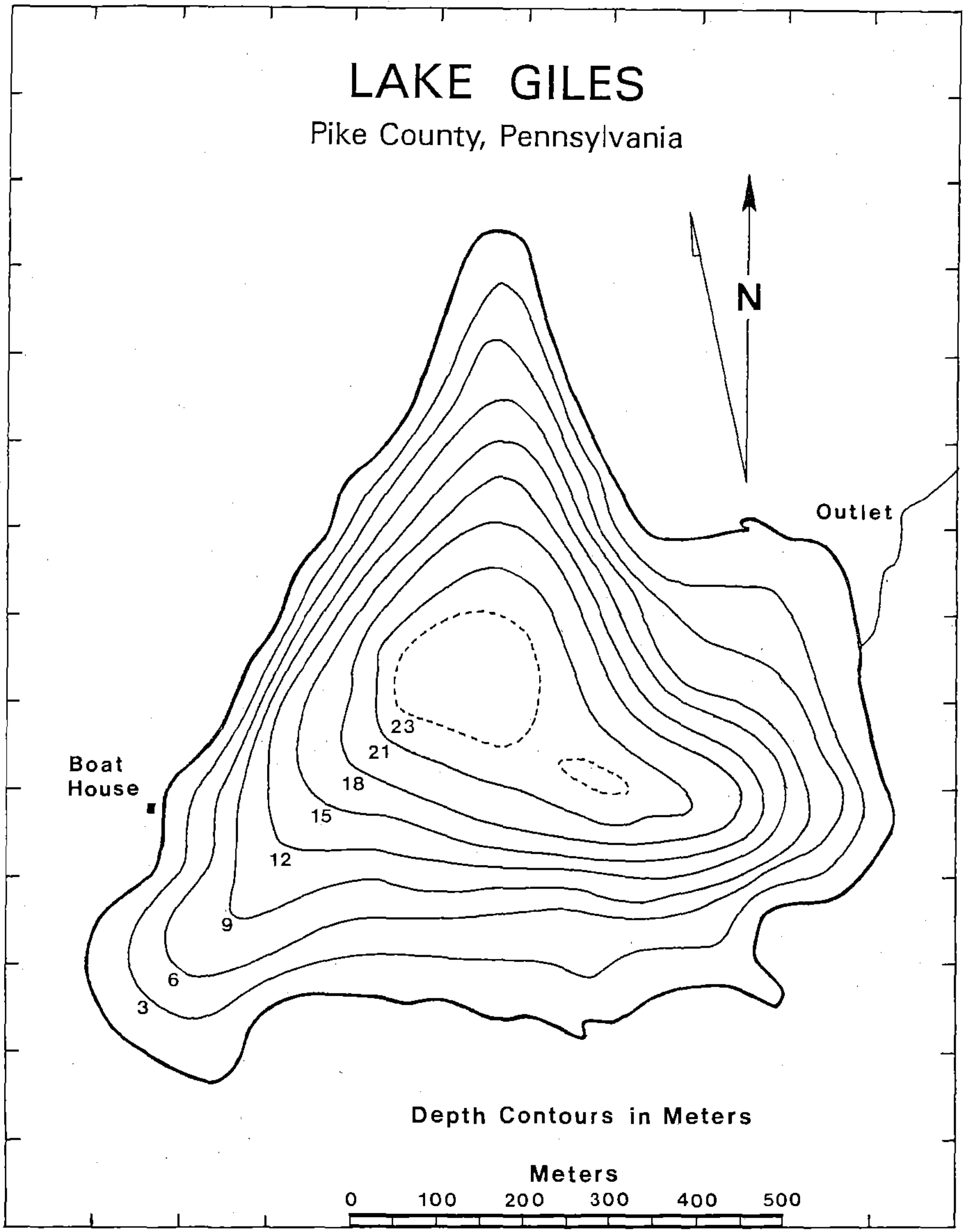


Figure 3. Lake Lacawac in its topographic setting.
The dotted line delimits the watershed. (From Lakeville 1966 7.5' series map, photorevised 1983 to update roads and structures)



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Map drawn by R. Moeller from survey data of R. Weisman and R. Schultz

Figure. 4. Morphometry of Lake Giles.

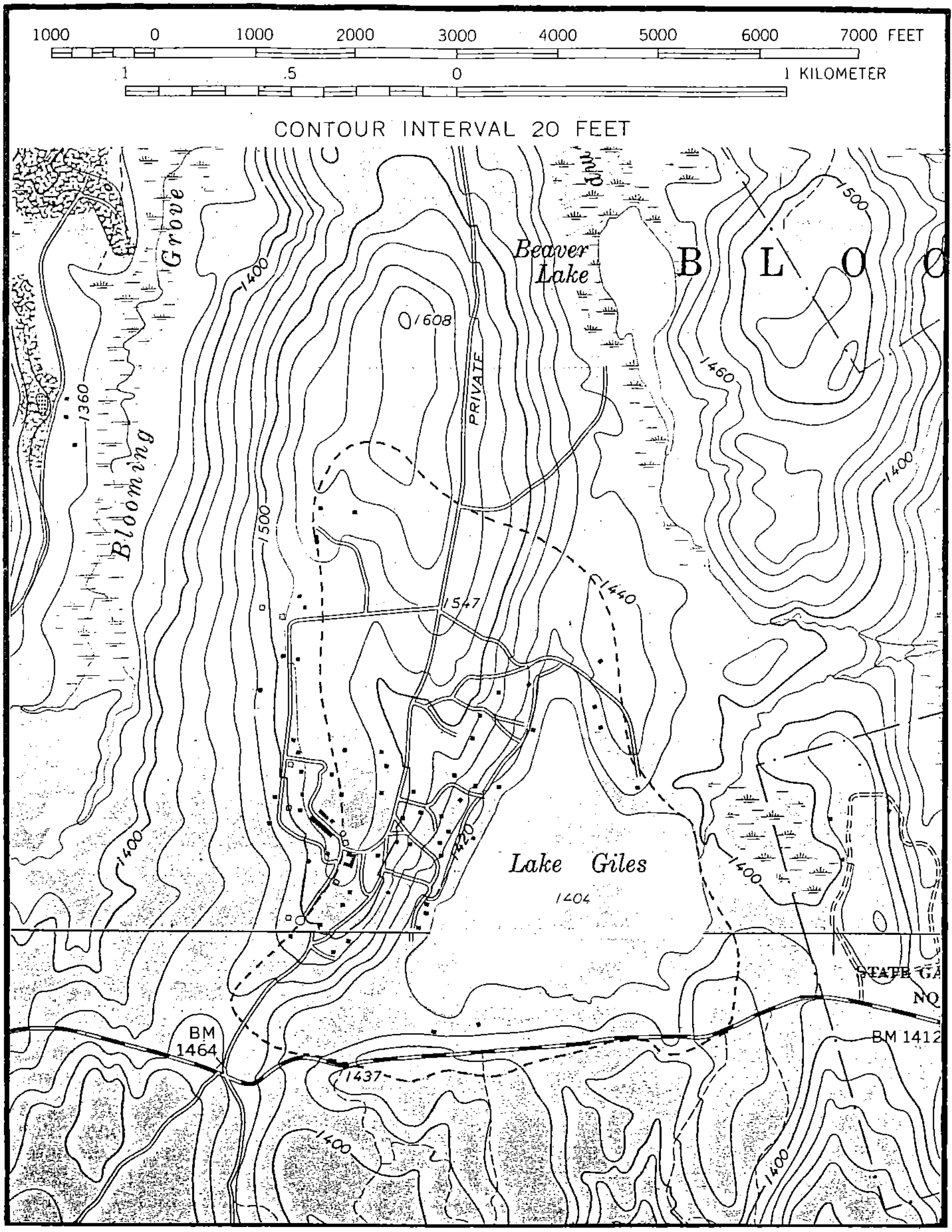
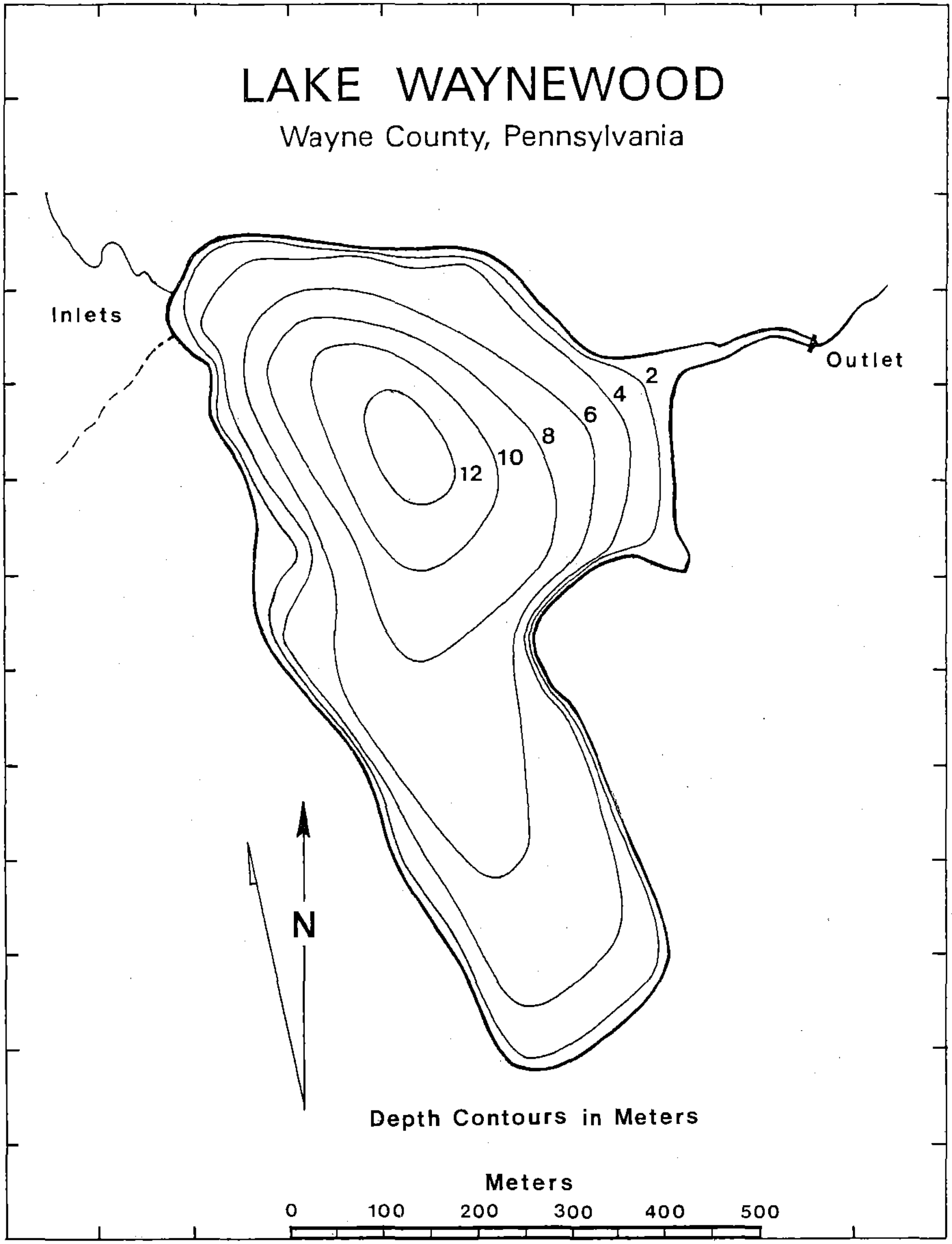


Figure 5. Lake Giles in its topographic setting.
The dotted line delimits the watershed. (From Rowland and Pecks Pond 1966 7.5' series maps, photorevised 1983 to update roads and structures)



POCONO COMPARATIVE LAKES PROGRAM - - - - - - - - - - - - LEHIGH UNIVERSITY - - - - - - - - - - - 1993
Map drawn by R. Moeller from survey data of R. Weisman and R. Schultz

Figure 6. Morphometry of Lake Waynewood.

Figure 7. Lake Waynewood in its topographic setting.
The dotted line delimits the watershed. (From Lakeville and Lake Ariel 1966 7.5' series maps, photorevised 1983 to update roads and structures)

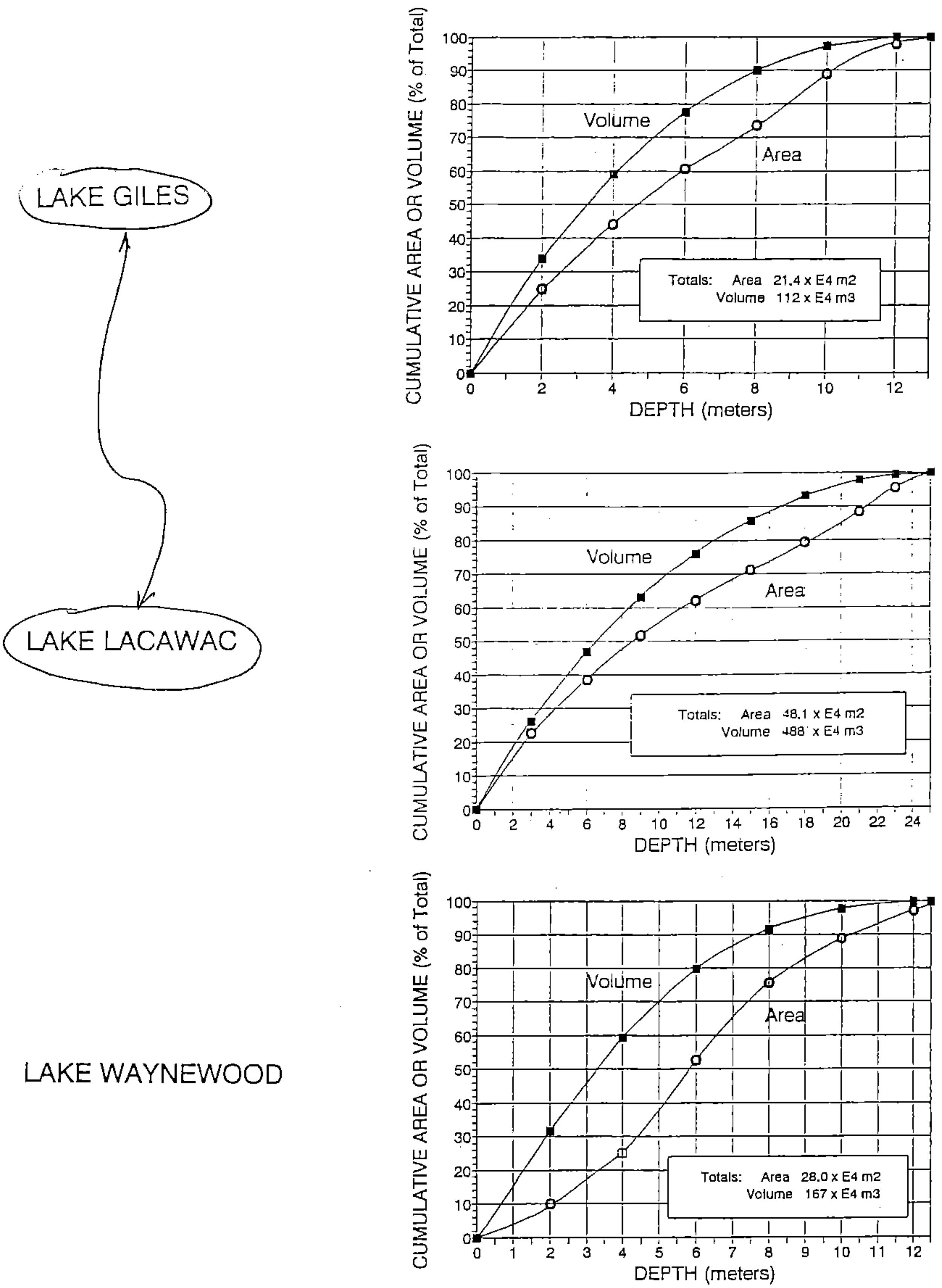


Figure 8. Hypsographic and bathymetric curves for the three lakes.

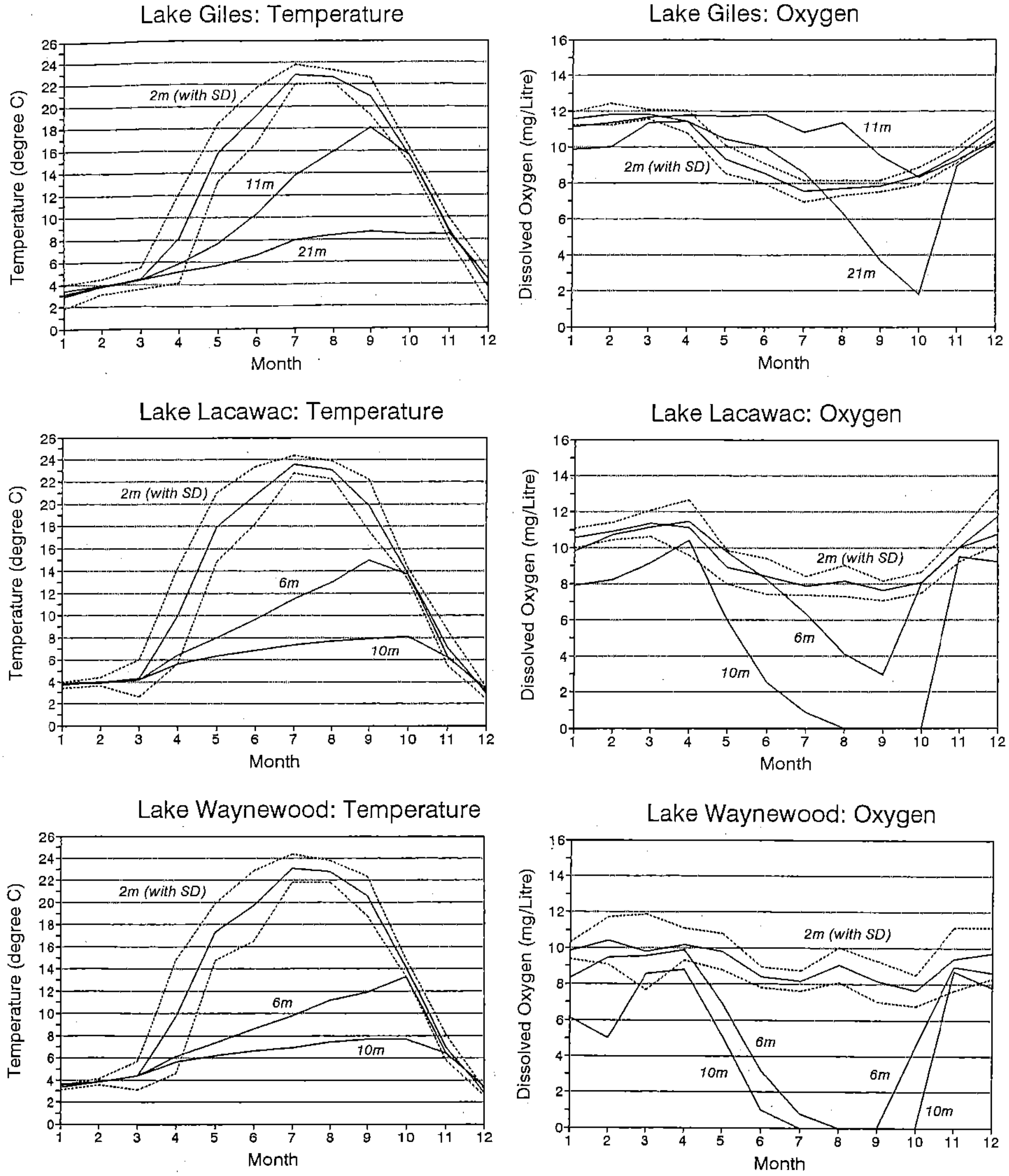


Figure 9. Monthly trends of temperature (left) and dissolved oxygen (right).
Values are plotted for three depths: 2m, 2m above the bottom, and an intermediate depth. The 2m mean is plotted with a standard deviation (dotted line). Oxygen is corrected for lake elevation.

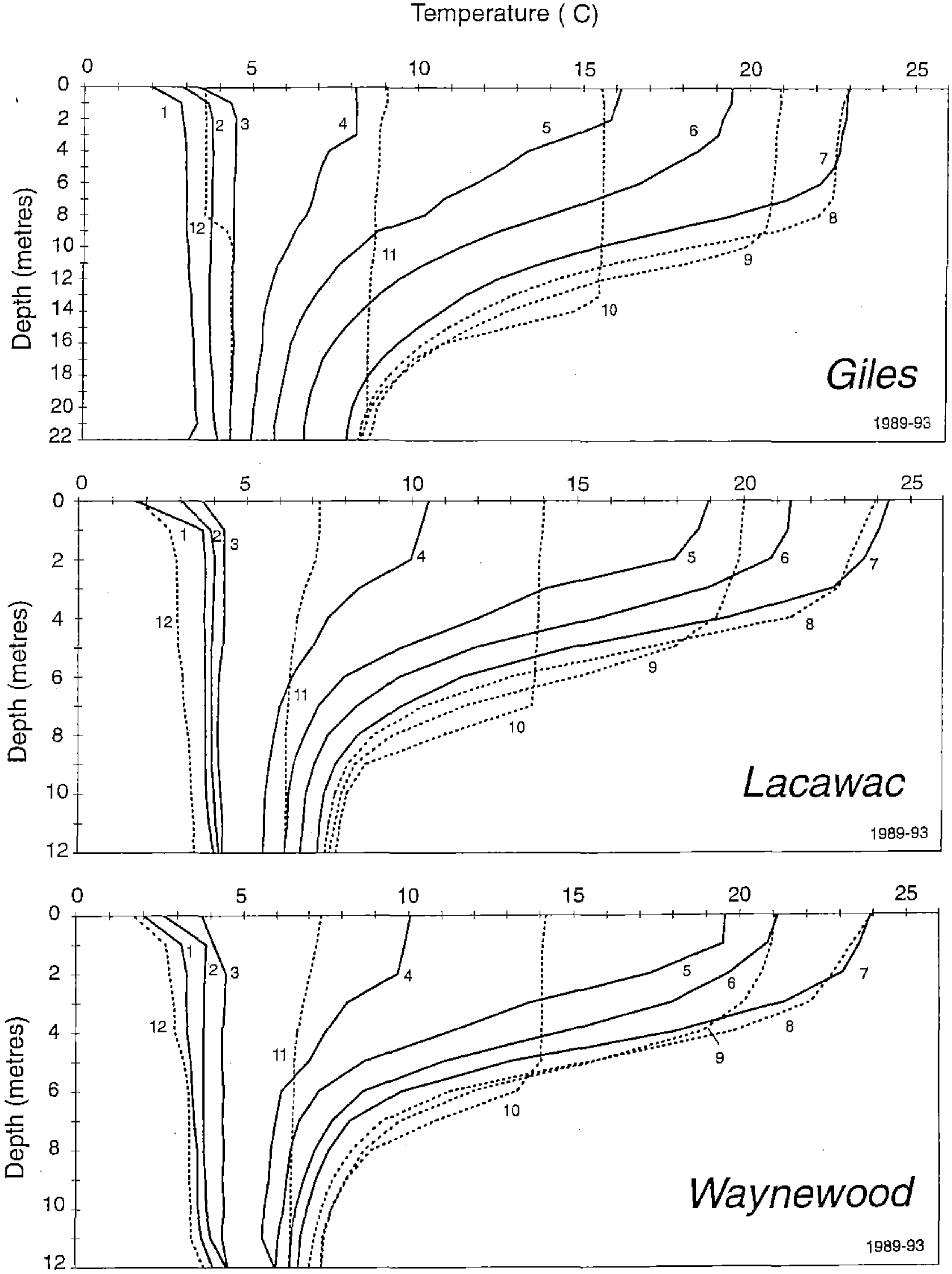


Figure 10. Monthly mean temperature profiles (1989-93).
Month is indicated by the numeral.

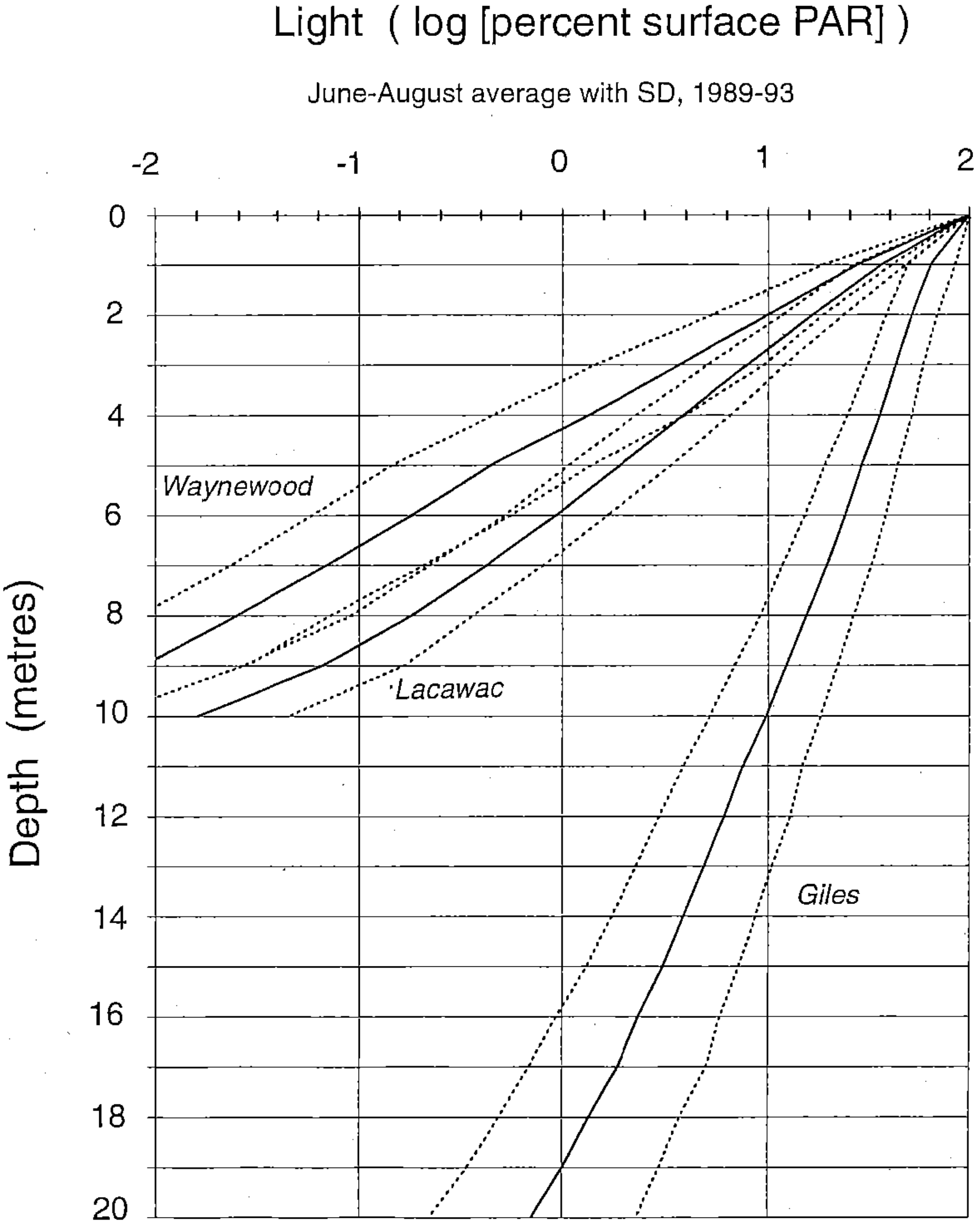


Figure 11. Summertime light (PAR) penetration (1989-93).
Values are means of June-August data with standard deviation calculated after log transformation. Note that "2" is 100%, "1" is 10%, "0" is 1%, etc.

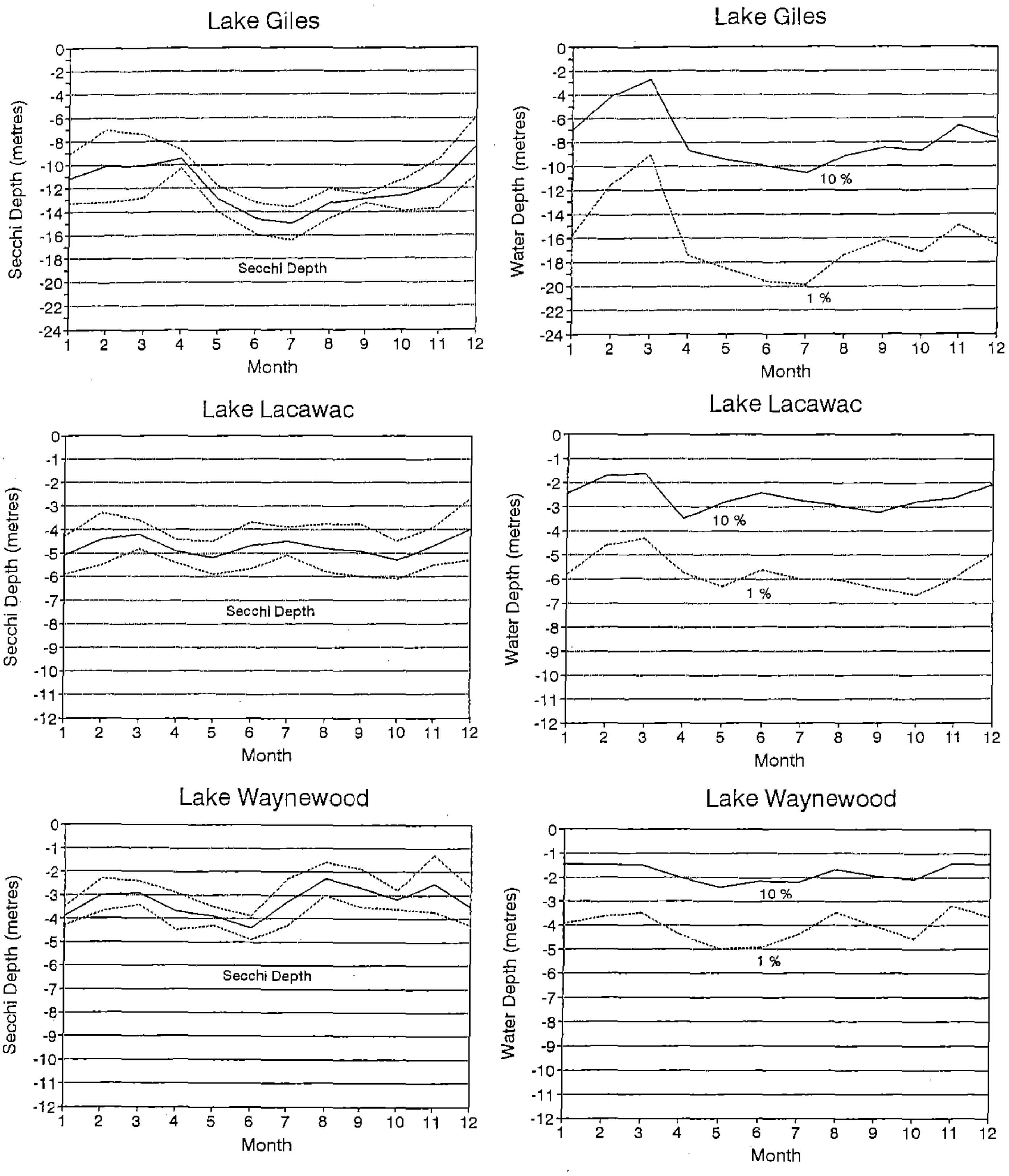
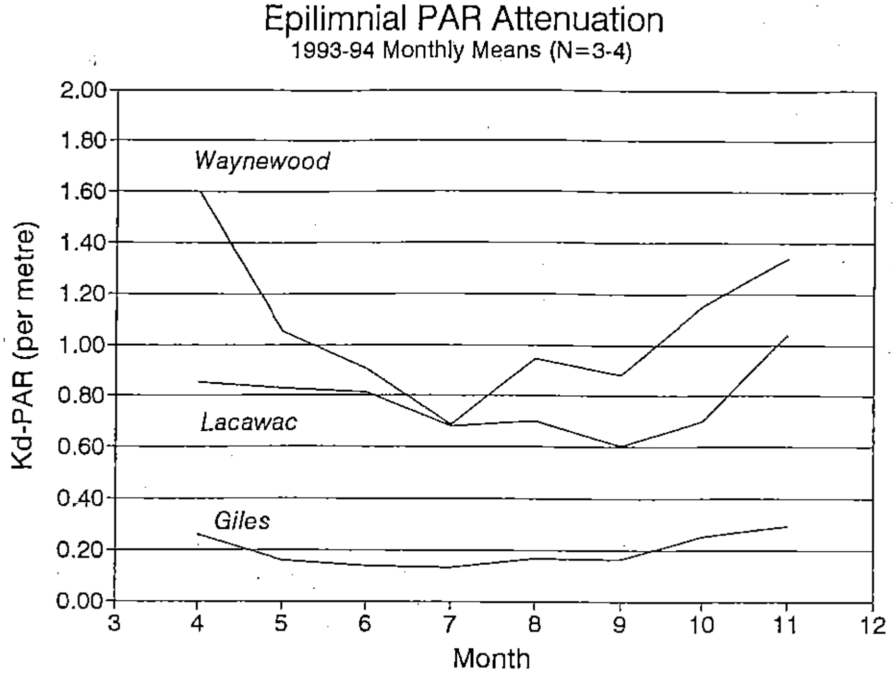


Figure 12. Water transparency as Secchi depth (left) and depths of 10% and 1% of surface PAR (right).
Monthly means are plotted for 1989-93 data. Secchi depth is plotted as mean with a standard deviation--dotted line .



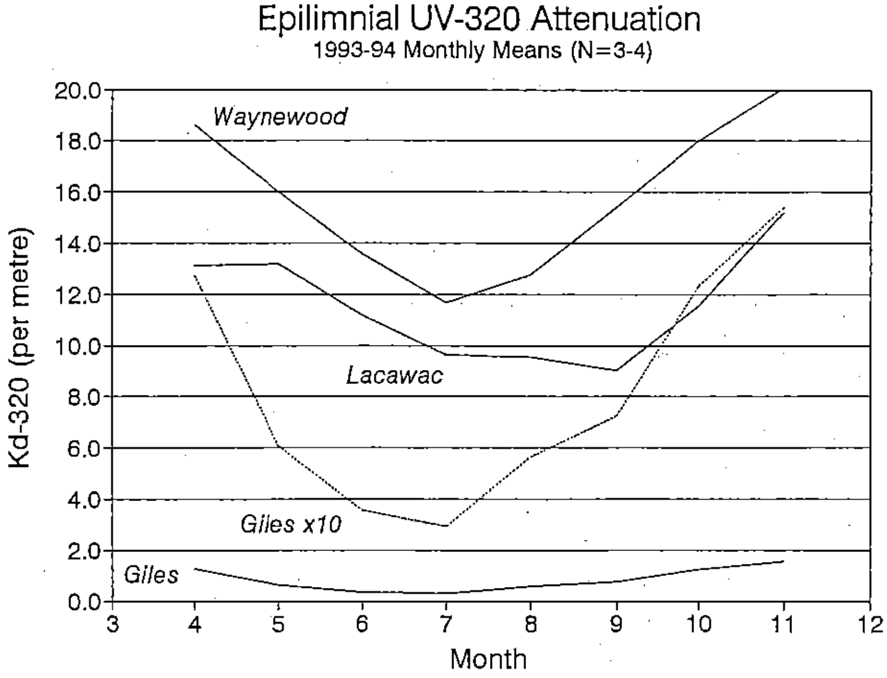


Figure 13. Attenuation of PAR compared to UV-320nm irradiance.
Values are monthly mean extinction coefficients for downwelling radiation from epilimnial depths, 1993-94 data collected with the PUV-500.

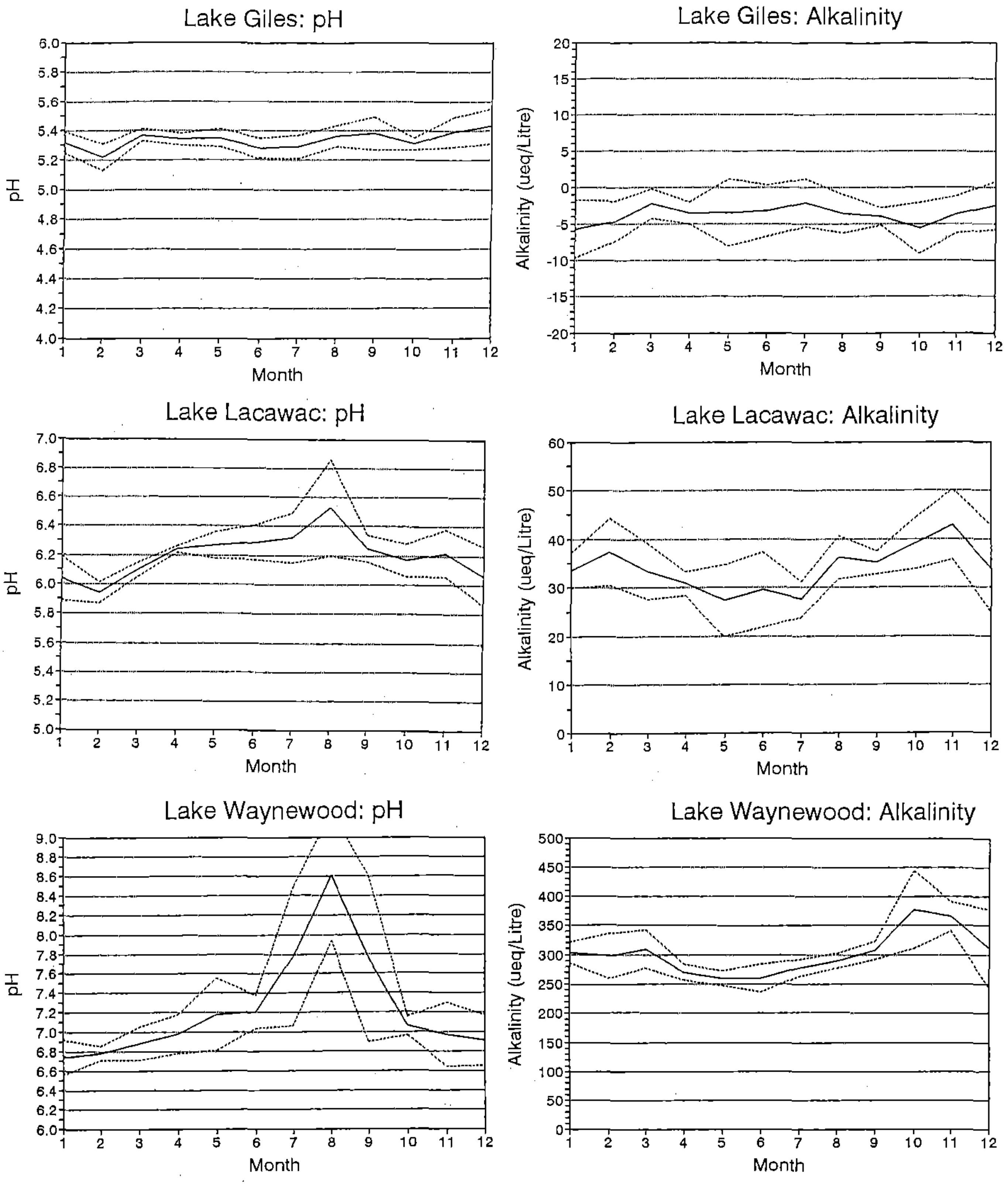


Figure 14. Monthly mean pH (left) and alkalinity (right).
Epilimnial means with standard deviation are plotted from 1989-93 data.

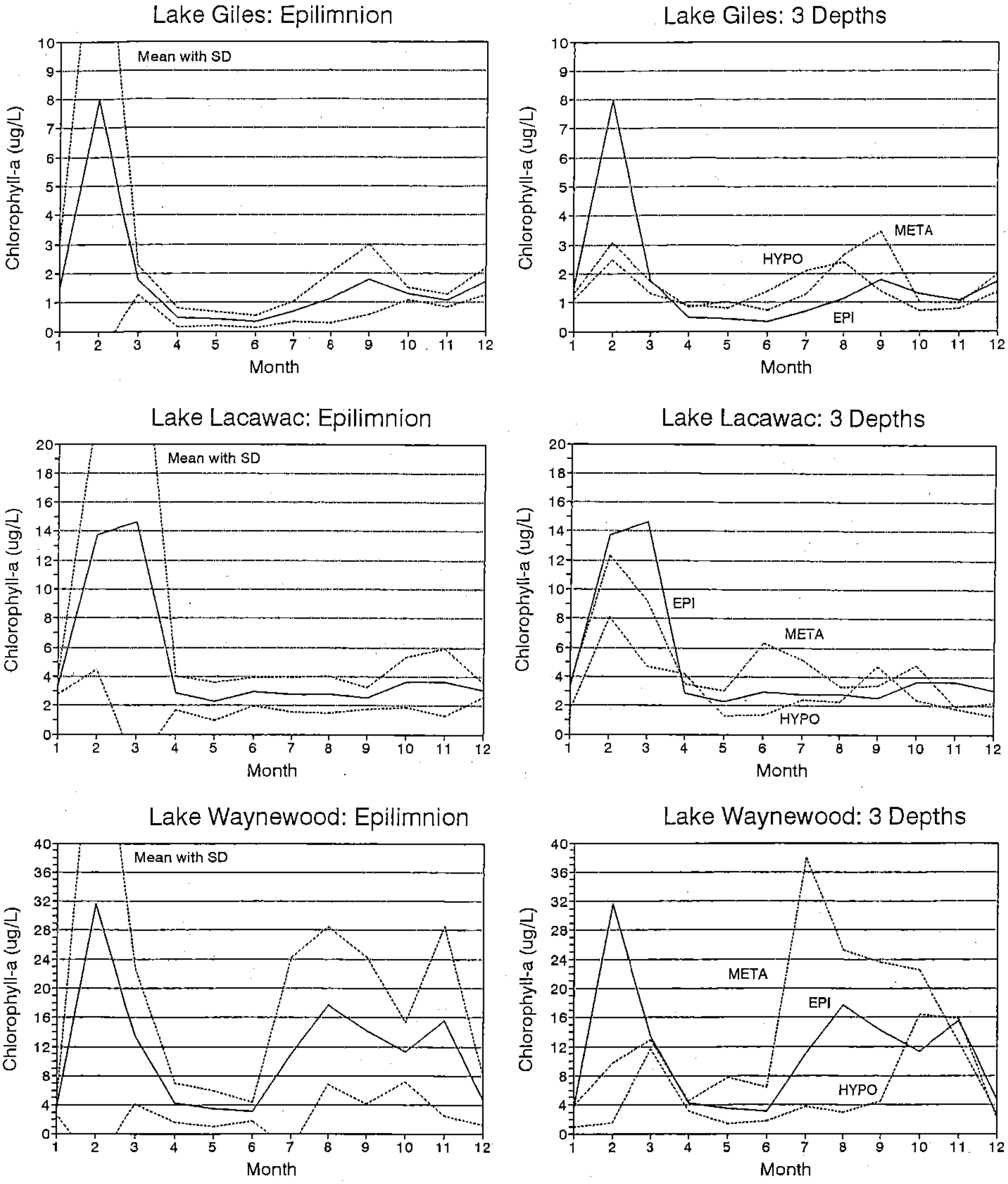


Figure 15. Phytoplanktonic chlorophyll-a (1989-93).
Monthly mean values of chlorophyll-a (corrected for pheopigment) are plotted from the EPI, META, and HYPO depths **(Right)**. EPI means are also plotted with a standard deviation **(Left)**.

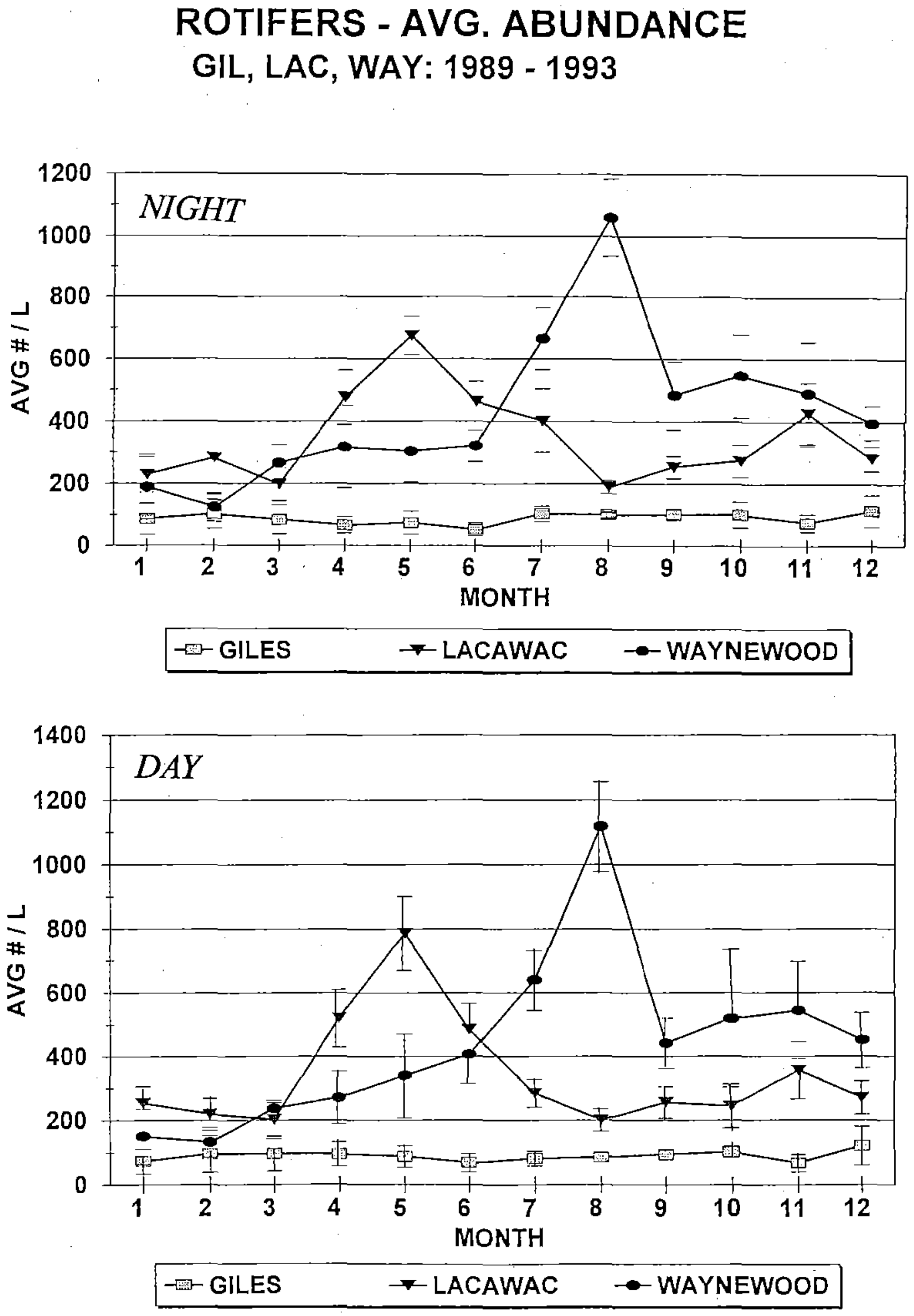


Figure 16. Rotifers (1989-93).
Monthly mean rotifer concentrations (±SD) for the whole water column are plotted for nighttime samples (Top) and daytime samples (**Bottom**). Nighttime samples were not collected from June through December 1993.

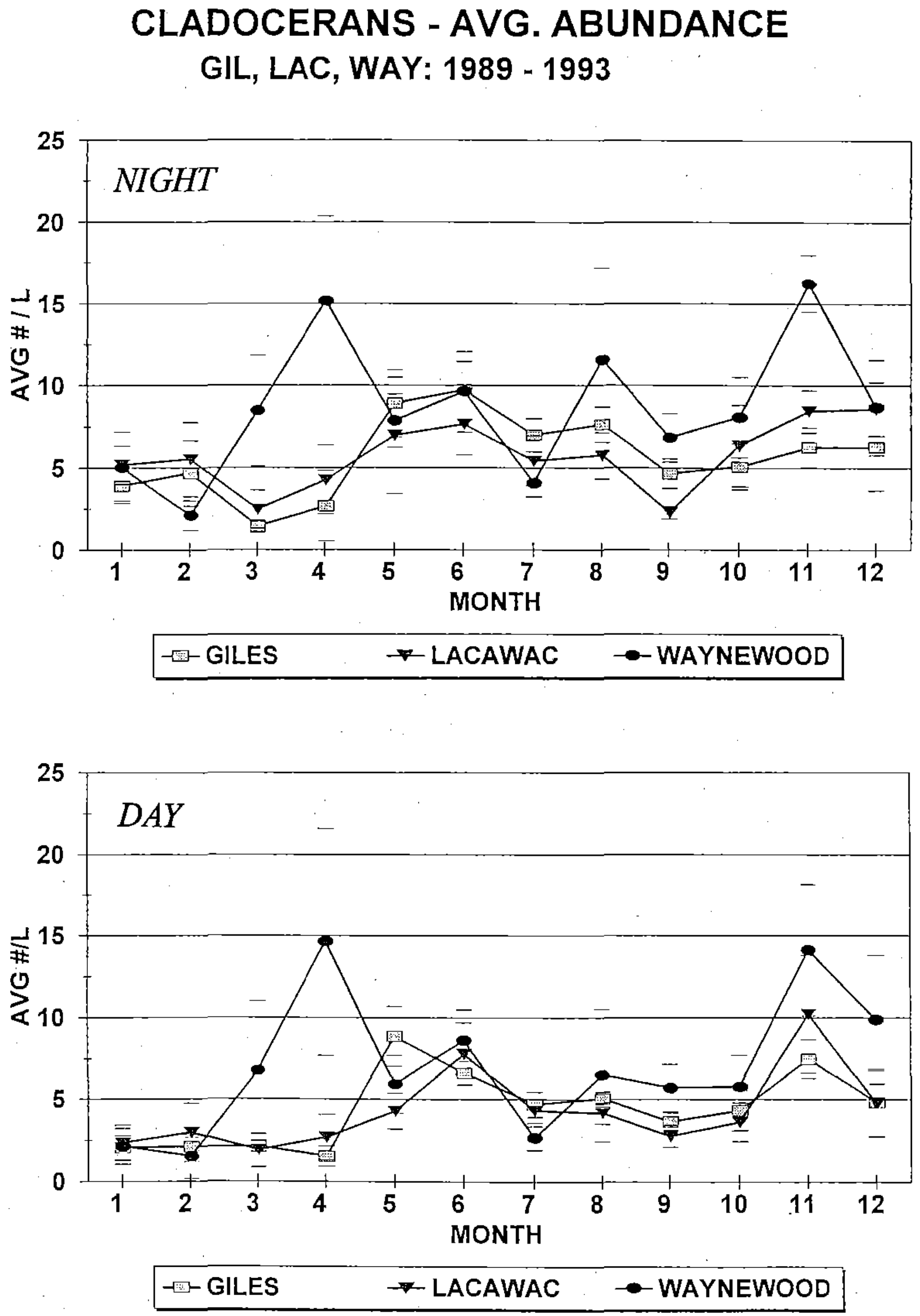


Figure 17. Cladocerans (1989-93).
Monthly mean cladoceran concentrations (±SD) for the whole water column are plotted for nighttime samples **(Top)** and daytime samples **(Bottom)**. Taxa are mainly *Daphnia* (all 3 lakes) plus *Holopedium* (Lacawac only), *Diaphanosoma* (Giles only), or *Bosmina* (Waynewood only). Nighttime samples were not collected from June through December 1993.

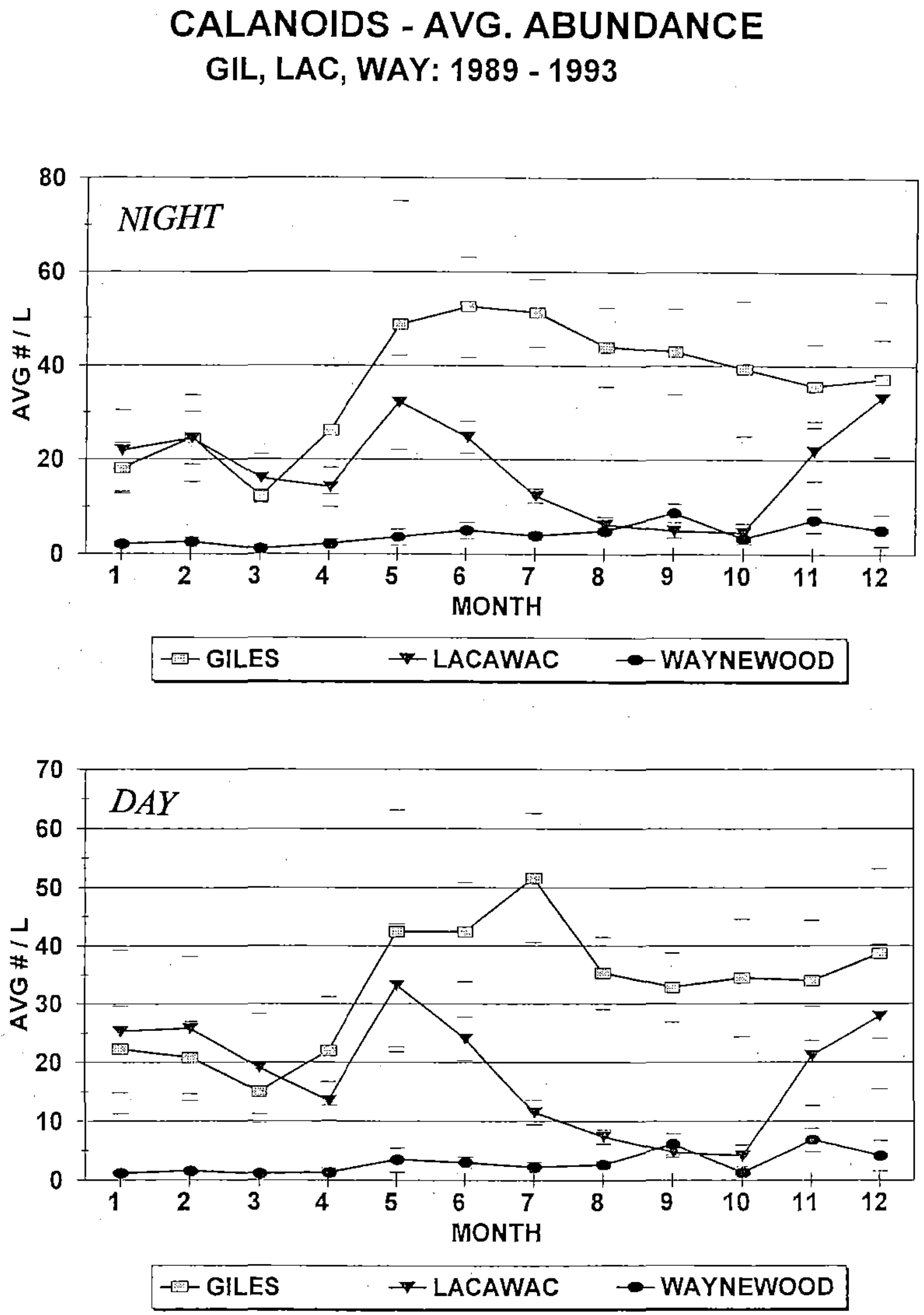


Figure. 18. Calanoid copepods (adults and copepodids; 1989-93).
Monthly mean calanoid concentrations (±SD) for the whole water column are plotted for nighttime samples **(Top)** and daytime samples **(Bottom)**. Taxa include *Diaptomus minutus* (Lacawac and Giles), *D. spatulocrenatus* (Giles only), or *D. oregonensis* (Waynewood only).
Nighttime samples were not collected from June through December 1993.

CYCLOPOIDS - AVG. ABUNDANCE
GIL, LAC, WAY: 1989 - 1993

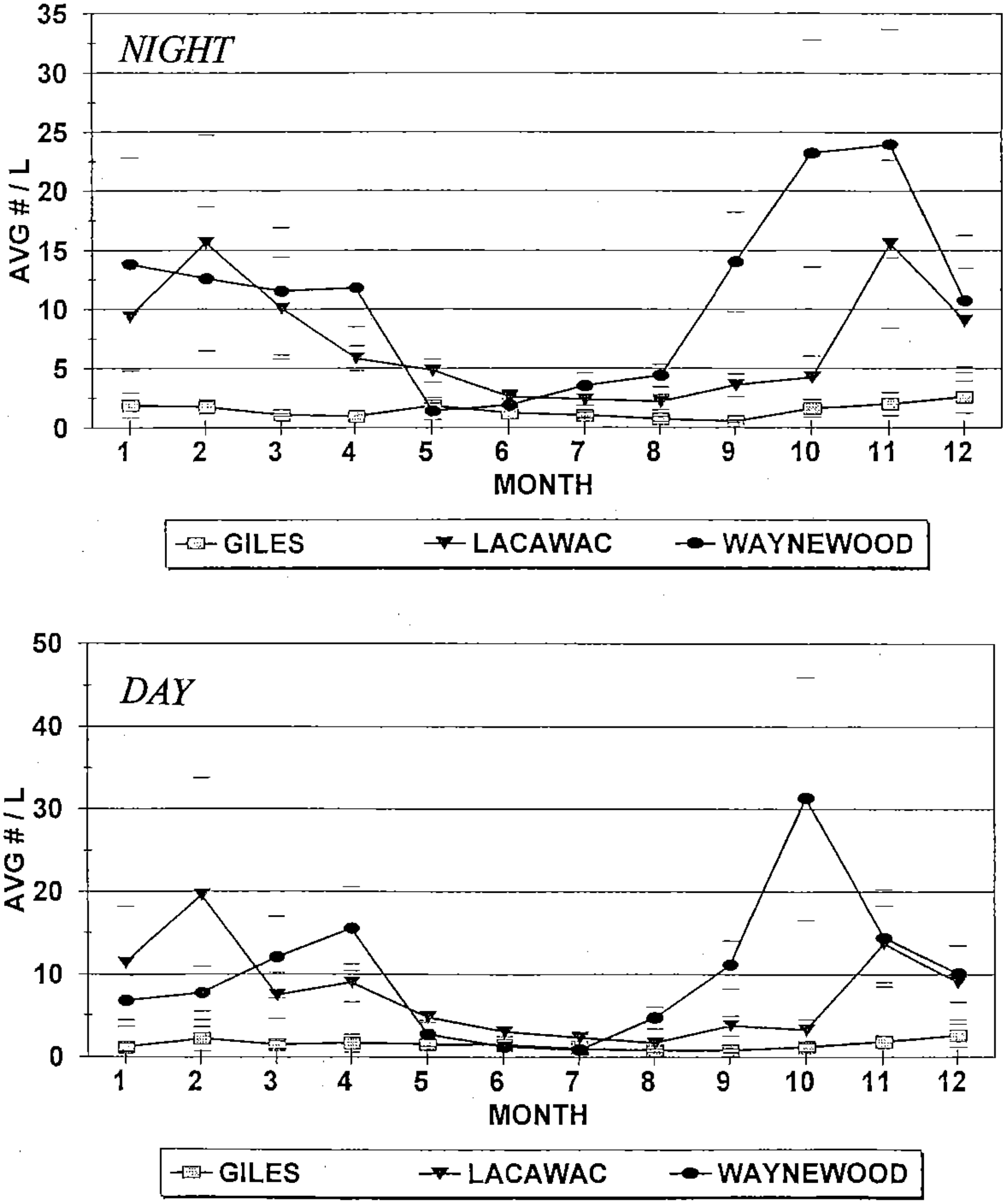


Figure 19. Cyclopoid copepods (adults and copepodids; 1989-93).
Monthly mean cyclopoid concentrations (±SD) for the whole water column are plotted for nighttime samples **(Top)** and daytime samples **(Bottom)**. Main taxa include *Cyclops scutifer* (Lacawac and Giles), *Diacyclops thomasi* (Waynewood only), *Mesocyclops edax* (Lacawac and Waynewood), *Orthocyclops modestus* (Lacawac and Waynewood), and *Tropocyclops prasinus* (Waynewood only). Nighttime samples were not collected from June through December 1993.

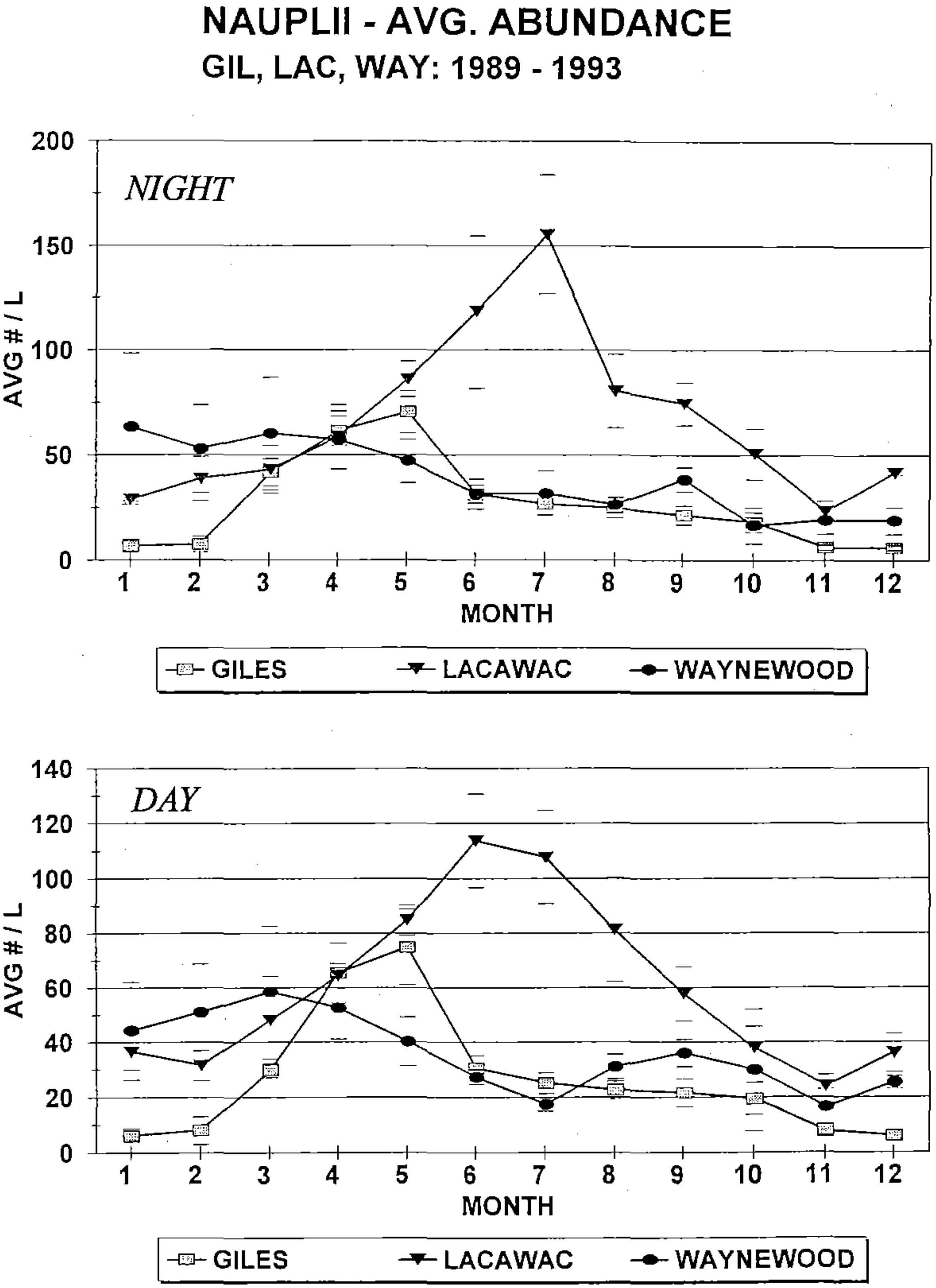


Figure 20. Copepod nauplii (calanoids and cyclopoids; 1989-93).
Monthly mean nauplii concentrations (±SD) for the whole water column are plotted for nighttime samples (Top) and daytime samples (Bottom). Nighttime samples were not collected from June through December 1993.

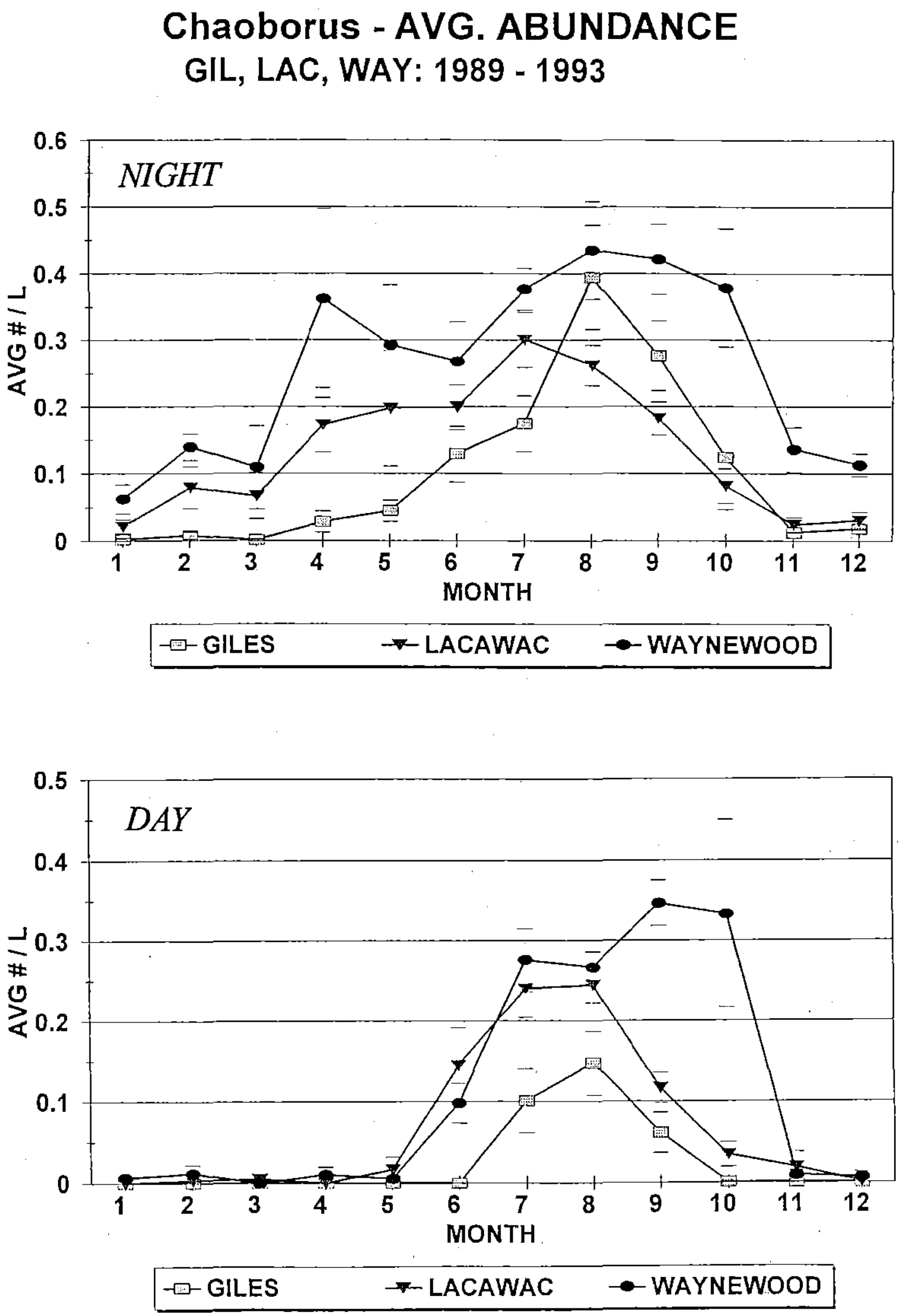


Figure 21. *Chaoborus* in the three study lakes (1989-93).
Monthly mean concentrations (±SD) for the whole water column are plotted for nighttime samples **(Top)** and daytime samples **(Bottom)**. Nighttime samples were not collected from June through December 1993.