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Lake Norman Maintenance Monitoring Program:
2009 Summary

Please find attached a copy of the annual "Lake Norman Maintenance Monitoring Program: 2009 Summary," as required by the National Pollutant Discharge Elimination System (NPDES) permit NC0024392. This report includes detailed results and data comparable to that of previous years. The report was submitted to the North Carolina Department of Environment and Natural Resources on January 11, 2011.

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LAKE NORMAN

MAINTENANCE MONITORING PROGRAM:

2009 SUMMARY

McGuire Nuclear Station: NPDES No. NC0024392

Principal Investigators:

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EXECUTIVE SUMMARY

In accordance with National Pollutant Discharge Elimination System (NPDES) permit number NC0024392 for McGuire Nuclear Station (MNS), the Lake Norman Maintenance Monitoring Program continued during 2009. Overall, no obvious long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. The 2009 station operation data is summarized and continues to demonstrate compliance with thermal limits and cool water requirements.

Annual precipitation in the vicinity of MNS in 2009 totaled 144.3 cm or 25.3 cm more than observed in 2008 (119.0 cm) and 26.7 cm more than the long-term average of 117.6 cm. Year 2009 annual rainfall was also the second highest measured since 1975, exceeded only in 2003. Temporal and spatial trends in water temperature and dissolved oxygen (DO) concentration in 2009 were similar to those observed historically, and all data were within the range of previously measured values. Water temperatures in winter 2009 were either equal to or cooler than measured in 2008 and generally paralleled differences exhibited in monthly air temperature data, but with about a one-month lag time.

Summer (June, July, and August) water temperatures in 2009 were generally slightly cooler (maximum = 3.5 °C) than observed in 2008 in both zones, with the most pronounced differences observed in the upper 15 m of the water column. Fall and early winter water temperatures in 2009 were consistently either equal to or warmer in both zones than those measured in 2008, indicating that the reservoir was cooling at a slower rate in 2009 than 2008. This pattern followed the trend exhibited in air temperatures. Temperatures at the discharge location in 2009 were generally similar to 2008 and historical data. The warmest discharge temperature of 2009 (37.1 °C) occurred in September and was 1.4 °C cooler than the 2008 maximum measured in August.

Seasonal and spatial patterns of DO in 2009 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones. Winter DO values in 2009 were generally equal to or greater than measured in 2008 whereas spring values were either equal to or slightly less than observed in 2008 and were correlated with interannual differences in water temperatures. Summer DO values in 2009 were highly variable throughout the water column in both the mixing and background zones ranging from highs of 6.0 to 8.0 mg/L in surface waters to lows of 0.0 to 2.0 mg/L in bottom waters. The temporal development of the negative heterograde DO curve in summer 2009 occurred earlier and progressed more rapidly than in 2008 and earlier years, and may have been related to increased inputs of allochthonous organic matter associated with above average spring rains.

Considerable differences were observed between 2009 and 2008 late summer and fall DO values in both the mixing and background zone, especially in the metalimnion and hypolimnion. The 2009 fall DO data indicate that convective reaeration of the water column proceeded at a somewhat slower rate than observed in corresponding months in 2008 despite exhibiting similar September profiles. Consequently, 2009 DO levels at most depths were either equal to or less than observed in 2008. These between-year differences in DO corresponded strongly with the degree of thermal stratification which, in turn, was correlated with interannual differences in air temperatures. The seasonal pattern of DO in 2009 at the discharge location was similar to that measured historically, with the highest values observed during the winter and lowest observed in the summer and early fall. The lowest DO concentration measured at the discharge location in 2009 (5.2 mg/L) occurred in July and August and was 1.1 mg/L higher than the historical minimum, measured in August 2003 (4.1 mg/L).

Reservoir-wide isotherm and isopleth information for 2009, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Suitable pelagic habitat for adult striped bass, defined as that layer of water with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L, was found lake-wide from mid-September 2008 through mid-July 2009. Beginning in late June 2009, habitat reduction proceeded rapidly throughout the reservoir both as a result of deepening of the 26 °C isotherm and metalimnetic and hypolimnetic deoxygenation. Habitat reduction was most severe from mid-July through early September. Observed striped bass mortalities in 2009 totaled 362 fish.

All chemical parameters measured in 2009 were similar to 2008 and within concentration ranges previously reported during both preoperational and operational years of MNS. Specific conductance values and all cation and anion concentrations were low. Values of pH were within historical ranges in both the mixing and background zones. A comparison of long-term (1999 – 2009) pH data for Lake Norman with a comparable site sampled by North Carolina Department of Environment and Natural Resources (NCDENR) illustrated discrepancies in descriptive statistics and no temporally decreasing trend, in contrast to that observed by the State. It's not clear why this disparity exists.

Nutrient concentrations were low with most values reported close to or below the analytical reporting limit (ARL) for that test. Total phosphorus concentrations were slightly higher than measured in 2008 but within the historical range. Concentrations of metals in 2009 were low and often below the ARL. All values for cadmium and lead were reported as either equal to or below the ARL for that parameter. All zinc values except two were above the ARL of 1.0 µg/L and all copper concentrations, measured as total recoverable copper, were ≤ 2.5 µg/L. All 2009 values for cadmium, lead, zinc, copper and iron were below the State water quality standard or action level for each of these metals. Manganese concentrations were generally low in 2009, except during the summer and fall when bottom waters were anoxic and redox induced releases of manganese occurred. The highest concentration of manganese reported in 2009 (2,130 µg/L) was measured in November in the bottom waters in the mixing zone.

Lake Norman is classified as oligo-mesotrophic based on long-term, annual mean phytoplankton concentrations. Lake-wide mean chlorophyll *a* concentrations (average of all samples collected during each season) were generally within historical ranges during 2009, but the lake-wide mean for November was very near the long-term minimum for that time of year. The lake-wide average in February was above the long-term mean, while averages for May and August were below long-term means for these periods. Seasonally, chlorophyll *a* concentrations decreased from February through May, increased through August to the annual lake-wide maximum and then declined in November to the annual minimum. All values were below the NC State Water Quality standard of 40 µg/L.

Maximum chlorophyll *a* concentrations among sampling locations were observed at Location 69.0 (furthest uplake) during February and August, while the May and November maxima were recorded from Location 15.9. The trend of increasing chlorophyll concentrations from downlake to uplake, observed during many previous years, was apparent for the most part during all sampling periods of 2009.

Seston dry and ash-free weights were most often higher in 2009 than in 2008. A general pattern of increasing values from downlake to uplake was observed during May and August 2009, as was observed with chlorophylls and algal standing crops; however, in February and November, this pattern was not apparent. Maximum dry and ash-free weights were generally observed at Location 69.0, while minimum values occurred most often at Locations 2.0 through 9.5.

Secchi depths reflected suspended solids, with shallow depths related to high dry weights. The lake-wide mean secchi depth was slightly lower in 2009 than in 2008 and within historical ranges observed since data was first recorded in 1992.

Diversity, or the number of phytoplankton taxa in 2009 was the highest recorded since the beginning of the Program in 1987. Ten taxa previously unrecorded during the Lake Norman Maintenance Monitoring Program were identified during 2009.

The taxonomic compositions of phytoplankton communities during 2009 were similar to those of most previous years with the exception that diatoms were dominant in February rather than cryptophytes. Diatoms were dominant during all sampling months except August, when green algae dominated phytoplankton assemblages. Blue-green algae were slightly more abundant during 2009 than during 2008, but typically comprising 2% or less of total densities.

The diatom *Tabellaria fenestrata* was the most important species during May and November at all locations. The most abundant diatoms in May were *Cyclotella stelligera* and *Fragillaria crotonensis.* The small desmid, *Cosmarium asphearosporum* var. *strigosum*, was dominant in August 2009. All of these taxa have been common and abundant throughout the Lake Norman Maintenance Monitoring Program.

During 2009, seasonal maximum densities among zooplankton assemblages varied considerably and no consistent seasonal trends were observed. Maxima occurred in winter and fall, while minima most often occurred in the spring. As in past years, epilimnetic densities were higher than whole-column densities. Mean zooplankton densities tended to be higher among background locations than among mixing zone locations during 2009. Spatial trends of zooplankton populations were similar to those of the phytoplankton in winter and spring, with increasing densities from downlake to uplake. During summer and fall, this spatial trend was not observed. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations

Epilimnetic zooplankton densities were generally within ranges of those observed in previous years. The exceptions were record high densities uplake in the winter and downlake in the fall.

Since the Lake Norman Maintenance Monitoring Program began in 1987, 123 zooplankton taxa have been observed in samples. Of these, 53 taxa were identified in 2009 as compared to 48 in 2008.

During 2009, rotifers were dominant in most samples collected from Lake Norman. Conversly, in 2008 microcrustaceans (copepods and cladocerans) showed overall predominance, especially in epilimnetic samples of the Mixing Zone (Locations 5.0 and 8.0) where their relative abundances were the highest yet recorded from 1988 – 2009. During 2009, the relative abundances of microcrustaceans were within historical ranges.

Overall, relative abundance of copepods in 2009 was less than in 2008. Rotifers were dominant in over 60% of all samples. The relative abundance of microcrustaceans decreased substantially in the mixing zone in 2009 and their percent compositions at these locations were in the low historical range. At background locations, microcrustaceans showed less dramatic decreases during 2009 and percent compositions were within historical ranges of past years. Historically, copepods and rotifers have most often shown annual peaks in the spring, while cladocerans continued to demonstrate year-to-year variability.

Copepods were dominated by immature forms. Adults rarely accounted for more than 7% of zooplankton densities. As in previous years, the most important adult copepod was *Tropocyclops*. *Epishura* was also important in winter and spring. *Bosminopsis* dominated cladoceran populations during the summer, while *Diaphanosoma* was an important constituent of spring populations. The most abundant rotifers observed in 2009, as in many previous years, were *Polyarthra*, *Keratella*, and *Asplanchna*. *Ptygura*, *Conochilus*, and *Ploeosoma* were also important among rotifer populations.

In accordance with the Lake Norman Maintenance Monitoring Program, monitoring of specific fish population parameters continued during 2009. Spring electrofishing indicated that numbers and biomass of fish in 2009 were generally similar to those noted since 1993. The fish populations in the three sampling areas were comprised of 16 to 20 species of fish and two hybrid complexes. Fish collections were numerically dominated by centrarchids. Largemouth bass number of individuals and biomass were the lowest recorded since sampling began in 1993. Spotted bass number of individuals and biomass continue to increase, possibly displacing largemouth bass. Summer striped bass mortalities were the highest since 2004. The forage fish population estimate was the second highest estimate since surveys began in 1997. Alewife percent composition and modal threadfin shad total length class both increased and were the highest values since 2004.

Lake Norman Maintenance Monitoring Program results from 2009 are consistent with results from previous years. No obvious short-term or long-term impacts were observed in the water quality, phytoplankton, zooplankton, and fish communities of Lake Norman. McGuire Nuclear Station continues to demonstrate compliance with thermal limits and cool water requirements.

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CHAPTER 1

MCGUIRE NUCLEAR STATION

INTRODUCTION

The following annual report was prepared for the McGuire Nuclear Station (MNS) National Pollutant Discharge Elimination System (NPDES) permit (# NC0024392) issued by North Carolina Department of Environment and Natural Resources (NCDENR). This report summarizes environmental monitoring of Lake Norman conducted during 2009.

OPERATIONAL DATA FOR 2009

Station operational data for 2009 are listed in Table 1-1. In most months, the average monthly capacity factor was near or slightly above 100% except in September and October when maintenance was performed on Unit 2. The monthly average capacity factors for MNS were 102.4, 100.4 and 57.0% during July, August and September, respectively. These are the months when conservation of cool water is most critical and compliance with discharge temperatures is most challenging. These three months are also when the thermal limit for MNS increases from a monthly average of 95.0 °F (35.0 °C) to 99.0 °F (37.2 °C). The average 2009 monthly discharge temperature was 95.8 °F (35.4 °C) for July, 98.3 °F (36.8 °C) for August and 94.0 °F (34.4 °C) for September. The volume of cool water in Lake Norman was tracked throughout the year to ensure that an adequate volume was available to comply with both the Nuclear Regulatory Commission Technical Specification requirements and the NPDES discharge water temperature limits.

Table 1-1. Average monthly capacity factors (%) and monthly average discharge water temperatures for MNS during 2009.

	MONTHLY AVERAGE CAPACITY FACTORS (%)			MONTHLY AVERAGE NPDES DISCHARGE TEMPERATURES	
Month	Unit 1	Unit 2	Station	oF	oC
January	105.38	105.65	105.51	68.6	20.3
February	104.99	105.60	105.29	67.2	19.6
March	105.17	105.56	105.36	71.8	22.1
April	105.08	105.24	105.16	77.2	25.1
May	104.19	104.64	104.42	83.8	28.8
June	103.12	103.83	103.48	90.7	32.6
July	102.01	102.74	102.38	95.8	35.4
August	101.27	99.54	100.40	98.3	36.8
September	101.77	12.17	56.97	94.0	34.4
October	103.45	66.60	85.02	84.3	29.1
November	104.16	105.27	104.72	80.1	26.7
December	104.71	105.54	105.13	73.4	23.0
Average	103.77	93.53	98.65	82.1	27.8

CHAPTER 2

WATER QUALITY

INTRODUCTION

The objectives of the water quality portion of the MNS NPDES Maintenance Monitoring Program (MMP) are to:

1. maintain continuity in the water quality data base of Lake Norman to allow detection of any significant station-induced and/or natural change in the physicochemical structure of the lake; and
2. compare, where applicable, these physicochemical data to similar data in other hydropower reservoirs and cooling impoundments in the Southeast.

This report focuses primarily on 2008 and 2009 data. Where appropriate, reference to pre-2008 data will be made by citing reports previously submitted to the NCDENR.

METHODS AND MATERIALS

The complete water quality monitoring program for 2009, including specific variables, locations, depths, and frequencies is outlined in Table 2-1. Sampling locations are identified in Figure 2-1. Sampling locations were selected at the initation of the Lake Norman Maintenance Monitoring Program in 1986 to provide a thorough assessment of water quality throughout the spatial expanse of the reservoir and include sites within the projected impact of the thermal discharge from MNS, and in background zones. Physicochemical data collected at these locations also serve to track the temporal and spatial variability in striped bass habitat in the reservoir during the stratified period.

Measurements of temperature, dissolved oxygen (DO), DO percent saturation, pH, and specific conductance were taken, *in situ*, at each location with a Hydrolab® Data Sonde (Hydrolab 2006) starting at the lake surface (0.3 m) and continuing at one-meter intervals to lake bottom. Pre- and post-calibration procedures associated with operation of the Hydrolab were strictly followed, and documented in hard-copy format. Hydrolab data were captured and stored electronically, and following data validation, converted to spreadsheet format.

Water samples for laboratory analysis were collected with a Kemmerer or Van Dorn water bottle at the surface (0.3 m), and from one meter above bottom, where specified (Table 2-1). Samples not requiring filtration were placed directly in single-use polyethylene terephthalate (PET) bottles which were pre-rinsed in the field with lake water just prior to obtaining a sample. Samples requiring acidification, but no filtration, were placed directly in pre-acidified high density polyethylene (HDPE) bottles. Samples requiring filtration were first processed in the field by filtering through a 0.45-µm filter (Gelman AquaPrep 600 Series Capsule) which was pre-rinsed with 500 mL of sample water, and then placed in pre-acidified HDPE bottles (Table 2-1). Upon collection, all water samples were immediately stored in the dark, and on ice, to minimize the possibility of physical, chemical, or microbial transformation.

Analytical methods, reporting limits, and sample preservation techniques employed were identical to those used in 2008, except where noted, and are summarized in Table 2-2. All laboratory water quality analyses were performed by the Duke Energy analytical laboratory located in Huntersville, NC. This laboratory is certified to perform analytical assessments for inorganic and organic parameters in North Carolina (North Carolina Division of Water Quality, certificate number 248), South Carolina (South Carolina Department of Health and Environmental Control, certificate number 99005), and New York (New York Department of Health, certificate number 11717).

A comprehensive Quality Assurance/Quality Control Program (QA/QCP) is fundamental to the collection, reporting, and interpretation of water quality data, and most investigators implement some type of QA/QCP to identify, quantify, and document bias and variability in data resulting from the collection, processing, shipping, handling and analysis of samples by field and laboratory personnel. Both the United States Environmental Protection Agency (USEPA 1998a, b) and the United States Geological Survey (USGS 1998, 2002) require that any agency-funded project have an approved quality assurance program, and that this program incorporate both a field and laboratory component. USGS also requires that any agency funded study that includes laboratory assessments must also participate in their Standard Reference Program (SRP). This program was originally developed by USGS in the 1960s and currently involves analysis by participating laboratories of standards (blind unknowns) created by the agency on a biannual schedule (USGS 2002).

The QA/QCP employed for this study followed the recommendation of the USEPA and USGS, and included both a field and laboratory component. Field blanks, i.e. deionized water placed in sample bottles, were subjected to the same sample collection and handling procedures, including filtration, applied to actual samples. Periodically, samples were also split prior to submittal to the laboratory for analysis with the goal of quantifying intra-sample analytical variability. The laboratory QA/QCP involved a variety of techniques commonly used in analytical chemistry and included reagent blanks, spikes, replicates, and performance samples. To supplement this program, additional performance samples were run on the major ions and nutrients. Beginning in 2005, standards were purchased from the USGS, through the agency's SRP, and submitted biannually to Duke Energy's laboratory to serve as a "double blind" assessment of analytical performance. These standards allowed quantification of the uncertainty of the analytical results against known values that were within the same concentration matrix as actual samples. The goal of this effort is to assemble analytical uncertainty data for chemical analytes which can be incorporated into statistical analyses assessing trends in time or space.

Water quality data were subjected to various numerical, graphical, and statistical techniques in an attempt to describe spatial and temporal trends within the Lake, and interrelationships among constituents. Whenever analytical results were reported to be equal to or less than the method reporting limit, these values were set equal to the reporting limit for numerical and statistical assessments. Data were analyzed using two approaches, both of which were consistent with earlier Duke Power Company, Duke Power, and Duke Energy studies on the Lake (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; and Duke Energy 2006, 2007, 2008, 2009). The first method involved partitioning the reservoir into mixing, background, and discharge zones, consolidating the data into these sub-sets, and making comparisons among zones and years. In this report, the discharge includes only Location 4.0; the mixing zone, Locations 1.0 and 5.0; the background zone includes Locations 8.0, 11.0, and 15.0 (Figure 2-1). The second approach, applied primarily to the *in situ* data, emphasized a much broader lake-wide investigation and encompassed the plotting of monthly isotherms and isopleths, and summer striped bass habitat. Several quantitative calculations were also performed on the *in situ* data; these included the calculation at the reservoir level of the areal hypolimnetic oxygen deficit (AHOD), maximum whole-water column and hypolimnion oxygen content, maximum whole-water column and hypolimnion heat content, mean epilimnion and hypolimnion heating rates over the stratified period, and the Birgean heat budget (maximum – minimum heat content).

Heat and oxygen content were expressed on an area and volume basis for the entire water column, the epilimnion, and the hypolimnion and were calculated according to Hutchinson (1957), using the following equation:

$$Lt = A_o^{-1} \bullet \int_{z_0}^{z_m} TO \bullet Az \bullet dz$$

where;

Lt = reservoir heat (Kcal/cm^2) or oxygen (mg/cm^2) content
A_0 = surface area of reservoir (cm^2)
TO = mean temperature (°C) or oxygen content (mg/L) of layer z
Az = area (cm^2) at depth z
dz = depth interval (cm)
z_0 = surface
z_m = maximum depth (m)

Precipitation and air temperature data were obtained from a meteorological monitoring site established near MNS in 1975. These data are employed principally by Duke Energy as input variables into meteorological modeling studies to address safety issues associated with potential radiological releases into the atmosphere by MNS (Duke Power 2004b), as required by the Nuclear Regulatory Commission. The data also serve to document localized temporal trends in air temperatures and rainfall patterns. Lake level and hydroelectric flow data were obtained from Duke Energy-Carolinas Fossil/Hydro Generation.

RESULTS AND DISCUSSION

Precipitation and Air Temperature

Annual precipitation in the vicinity of MNS in 2009 totaled 144.3 cm (Figures 2-2a, b) or 25.3 cm more than observed in 2008 (119.0 cm), and 26.7 cm more than the long-term precipitation average for this area (117.6 cm), based on Charlotte, NC airport data. Year 2009 annual rainfall was also the second highest measured since 1975, exceeded only in 2003. Monthly rainfall in 2009 was greatest in May with 19.4 cm and the least in January with 5.6 cm. Monthly rainfall totals in 2009 exceeded 10 cm in eight separate months.

Air temperatures near the McGuire Nuclear Station in 2009 were generally similar to the long-term mean for most of the year, based on monthly average data, except in January, July and December which were cooler than the long-term mean and June and November which were warmer than the historical mean (Figure 2-2c). Differences between 2008 and 2009 air temperatures were most pronounced in November and December (Figure 2-2c).

Temperature and Dissolved Oxygen

Water temperatures measured in 2009 illustrated similar temporal and spatial trends in the background and mixing zones (Figures 2-3 and 2-4), as they did in 2008. This similarity in temperature patterns between zones has been a dominant feature of the thermal regime in Lake Norman since MNS began operations in 1983. When between-zone differences in temperatures are observed, they occur predominately during the cooling period, and can be traced to the influence of the thermal discharge at MNS on mixing zone temperatures. Additionally, interannual differences in water temperatures in Lake Norman, particularly in surface waters in the background zone, typically parallel differences in air temperatures but with a one-month lag time (Duke Power 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Water temperatures in winter 2009 were either equal to or cooler than measured in 2008, with minor differences observed between zones (Figures 2-3 and 2-4). These interannual differences in water temperatures generally parallel differences in air temperatures (Figure 2-2c), but because lake sampling is routinely performed in the first week of each month the observed data reflect the cumulative influences of meteorology and hydrology prior to that date. Minimum water temperatures in 2009 were recorded in early February and ranged from 7.3 °C to 10.0 °C in the background zone and from 8.0 °C to 11.5 °C in the mixing zone. Minimum water temperatures measured in 2009 were within the observed historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Summer (June, July, and August) water temperatures in 2009 were generally slightly cooler (maximum = 3.5 °C) than observed in 2008 in both zones, with the most pronounced differences observed in the upper 15 m of the water column. Fall and early winter water temperatures (October, November, and December) in 2009 were consistently either equal to or warmer in both zones than those measured in 2008, indicating that the reservoir was cooling at a slower rate in 2009 than 2008 (Figures 2-3, 2-4). This pattern followed the trend exhibited in air temperatures (Figures 2-2c).

Temperatures at the discharge location in 2009 were generally similar to 2008 (Figure 2-5) and historical data (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). The warmest discharge temperature of 2009 (37.1 °C) occurred in September and was 1.4 °C cooler than the 2008 maximum measured in August.

Seasonal and spatial patterns of DO in 2009 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones (Figures 2-6 and 2-7). As observed with water column temperatures, this similarity in DO patterns between zones has been a dominant feature of the oxygen regime in Lake Norman since MNS began operations in 1983.

Winter DO values in 2009 were generally equal to or greater than measured in 2008 whereas spring values were either equal to or slightly less than observed in 2008 (Figures 2-6 and 2-7). The interannual differences in DO values measured during this period appeared to be related predominantly to the differences in water column temperatures in 2009 versus 2008 and were consistent with observations made during previous years (Duke Energy 2007, 2008, 2009). Cooler temperatures would be expected to exhibit higher oxygen values because of increased oxygen solubility and an enhanced convective mixing regime associated with increased water column instability. Conversely, warmer water would be expected to exhibit a lesser oxygen content because of the direct effect of temperature on oxygen solubility, which is an inverse relationship, and indirectly via a restricted convective mixing regime which would limit water column reaeration.

Summer DO values in 2009 were highly variable throughout the water column in both the mixing and background zones ranging from highs of 6.0 to 8.0 mg/L in surface waters to lows of 0.0 to 2.0 mg/L in bottom waters. This pattern is similar to that measured in 2008 and earlier years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). Water column summer DO values in 2009 were generally either equal to or lower than observed in 2008 and were well within historical ranges.

One distinct difference observed between the 2009 and 2008 early summer DO profiles was in the temporal and spatial trends of oxygen concentrations within the water column. Both zones exhibited these trends but the differences were most pronounced in the mixing zone. In 2009 DO levels from the lake surface to 7 m were fairly evenly distributed with depth with concentrations ranging from 6.5 to 7.0 mg/L. Beginning at 7 m, a depth corresponding closely to the thermocline, DO concentrations exhibited a sharp and rapid decline with depth culminating in a minimum concentration of 1.0 mg/L at 10 m. This vertical drop in oxygen equated to a 2.0-mg/L decline in oxygen for every 1 m increase in depth. The 1.0-mg/L concentration extended to a depth of about 20 m and then increased to 2.5 to 3.5 mg/L from 21 m to the lake bottom. The corresponding 2008 DO profile was generally similar except that DO concentrations in the 7 to 20 m depth were considerably higher than observed in 2009.

A vertical oxygen profile with a pronounced middle water layer (metalimnion) of low DO positioned between upper (epilimnion) and lower (hypolimnion) zones of higher oxygen content is described as a negative heterograde oxygen curve (Goldman and Horne 1994). Negative heterograde oxygen curves are commonly observed in Southeastern reservoirs and often caused by vertical differences in animal and microbial respiratory activites associated with the consumption and degradation of both autochthonous and allochthonous derived organic materials (Cole and Hannan 1985). In rare instances, the presence of these types of oxygen curves have been traced to interflows of low DO waters entering the waterbody, most frequently from an upstream reservoir (Cole and Hannan 1985).

The development and progression of the metalimnetic oxygen minimum in summer 2009 occurred earlier and progressed more rapidly than in 2008 and other years. No confirmatory evidence is available, but it's likely that the timing and magnitude of the metalimntic oxygen minimum in 2009 was related to higher than normal inputs of allochthonous organic matter associated with above average spring rains. The 2009 precipitation total for the period March – June was 51% greater than the long-term average. Ford (1987) found that nutrient and organic loading to DeGray Resevoir in Arkansas was dominated by rainfall and associated terrestrial runoff events during the spring.

Considerable differences were observed between 2009 and 2008 late summer and fall DO values in both the mixing and background zones, especially in the metalimnion and hypolimnion, during the months of October, November and December (Figures 2-6 and 2-7). These interannual differences in DO levels during the cooling season are common in Catawba River reservoirs and are explained by the effects of variable weather patterns on water column cooling (heat loss) rates and mixing. Cooler air temperatures increase the rate and magnitude of water column heat loss, thereby promoting convective mixing and resulting in higher DO values earlier in the year (Figure 2-2c). Conversely, warmer air temperatures delay water column cooling which, in turn, delays the onset of convective mixing of the water column and the resultant reaeration of the metalimnion and hypolimnion.

The 2009 fall DO data indicate that convective reaeration of the water column proceeded at a somewhat slower rate than observed in corresponding months in 2008 despite exhibiting similar September profiles (Figures 2-6 and 2-7). Consequently, 2009 DO levels at most depths were either equal to or less than observed in 2008. These between-year differences in DO corresponded strongly with the degree of thermal stratification which, as discussed earlier, correlated with interannual differences in air temperatures (Figures 2-2c, 2-3, and 2-4). Interannual differences in DO patterns are common not only within the Catawba River Basin, but throughout Southeastern reservoirs and can reflect yearly differences in hydrologic, meteorologic, and limnologic forcing variables (Cole and Hannan 1985; Petts, 1984).

The seasonal pattern of DO in 2009 at the discharge location was similar to that measured historically, with the highest values observed during the winter and lowest observed in the summer and early fall (Figure 2-5). The lowest DO concentration measured at the discharge location in 2009 (5.2 mg/L) occurred in July and August and was 1.1 mg/L higher than the historical minimum, measured in August 2003 (4.1 mg/L).

Reservoir-Wide Temperature and Dissolved Oxygen

The monthly reservoir-wide temperature and DO data for 2009 are presented in Figures 2-8 and 2-9. These data are similar to those observed in previous years and are characteristic of cooling impoundments and hydropower reservoirs in the Southeast (Cole and Hannan 1985; Hannan et al. 1979; Petts 1984). Detailed discussions on the seasonal and spatial dynamics of temperature and DO during both the cooling and heating periods in Lake Norman have been presented previously (Duke Power Company 1992, 1993, 1994, 1995, 1996).

The seasonal heat content of both the entire water column and the hypolimnion for Lake Norman in 2009 are presented in Figure 2-10a; additional information on the thermal regime in the reservoir for the years 2008 and 2009 are presented in Table 2-3. Annual minimum heat content for the entire water column in 2009 (8.86 Kcal/cm^2; 8.84 °C) occurred in early February, whereas the maximum heat content (28.51 Kcal/cm^2; 28.08 °C) occurred in

August. Heat content of the hypolimnion exhibited a somewhat different temporal trend as that observed for the entire water column. Annual minimum hypolimnetic heat content also occurred in early February and measured 4.94 Kcal/cm^2 (7.72 °C), but the maximum occurred in late September and measured 15.77 Kcal/cm^2 (24.17 °C). Heating of both the entire water column and the hypolimnion occurred at approximately a linear rate from minimum to maximum heat content. The mean heating rate of the eplimnion equaled 0.10 °C/day and 0.08 °C/day for the hypolimnion and were either equal to or slightly less than observed in 2008 (Table 2-3). The 2009 heat content and heating rate data for Lake Norman were generally similar to that observed in previous years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

The seasonal oxygen content and percent saturation of the whole water column, and the hypolimnion, are depicted for 2009 in Figure 2-10b. Additional oxygen data can be found in Table 2-4 which presents the 2009 AHOD for Lake Norman and similar earlier estimates for 18 Tennessee Valley Authority (TVA) reservoirs. Reservoir oxygen content was greatest in mid-winter when DO content measured 10.5 mg/L for the whole water column and 10.4 mg/L for the hypolimnion. Percent oxygen saturation values at this time approached 92% for the entire water column and 89% for the hypolimnion, indicating that reaeration of the reservoir did not achieve 100% saturation in 2009. Beginning in early spring, oxygen content began to decline precipitously in both the whole water column and the hypolimnion, and continued to decline linearly until reaching a minimum in late summer. The minimum summer volume-weighted DO value for the entire water column measured 4.5 mg/L (60% saturation), whereas the minimum for the hypolimnion was 0.3 mg/L (3.0 % saturation). The mean rate of DO decline in the hypolimnion over the stratified period, i.e., the AHOD, was 0.046 mg/cm^2/day (0.071 mg/L/day) (Figure 2-10b), and is similar to that measured in 2008 (Duke Energy 2009).

Hutchinson (1938, 1957) proposed that the decrease of DO in the hypolimnion of a waterbody should be related to the productivity of the trophogenic zone. Mortimer (1941) adopted a similar perspective and proposed the following criteria for AHODs associated with various trophic states; oligotrophic $\leq$ 0.025 mg/cm^2/day, mesotrophic 0.026 mg/cm^2/day to 0.054 mg/cm^2/day, and eutrophic $\geq$ 0.055 mg/cm^2/day. Employing these limits, Lake Norman should be classified as mesotrophic based on the calculated AHOD value of 0.046 mg/cm^2/day for 2009. The oxygen-based mesotrophic classification agrees well with the mesotrophic classification based on chlorophyll *a* levels (Chapter 3). The 2009 AHOD value is also similar to that found in other Southeastern reservoirs of comparable depth, chlorophyll *a* status, and Secchi depth (Table 2-4).

Striped Bass Habitat

Suitable pelagic habitat for adult striped bass, defined as that layer of water with temperatures ≥ 26 °C and DO levels ≥ 2.0 mg/L, was found lake-wide from mid-September 2008 through mid-July 2009. Beginning in late June 2009, habitat reduction proceeded rapidly throughout the reservoir both as a result of deepening of the 26-°C isotherm and metalimnetic and hypolimnetic deoxygenation (Figure 2-11). Habitat reduction was most severe from mid-July through early September when no suitable habitat was observed in the reservoir except in the upper reaches of the reservoir. These conditions were similar to those observed in most previous years. Historically, a small, but spatially variable zone of habitat is typically observed near and upstream of the confluence of Lyles Creek with Lake Norman. Historical data have illustrated that the presence of suitable habitat in the upper reaches of the reservoir is strongly influenced by both inflows from Lyles Creek and discharges from Lookout Shoals Hydroelectric facility, which generally are somewhat cooler than ambient conditions in Lake Norman. Upon entering Lake Norman, these cooler waters mix with ambient waters and create local refugia.

A refuge was observed in the metalimnion and hypolimnion near the Cowans Ford Dam during this period, but this lasted only until 20 July when DO was reduced to < 2.0 mg/L by microbial demands, thereby eliminating suitable habitat in the lower portion of the reservoir. Summer habitat conditions for adult striped bass in 2009 were similar to 2008; both these years also exhibited habitat conditions that were more severe than 2004 when the largest striped bass die-off ever was observed in the reservoir (2,610 fish). Conditions in 2009 were most recently similar to those measured in 2007 and 2008 when habitat elimination was observed for a period of about 50 – 60 days. Observed striped bass mortalities in 2009 totaled 362 fish. Additional discussion on the 2009 striped bass mortalities can be found in Chapter 5.

Physicochemical habitat expanded appreciably by mid-September, primarily as a result of epilimnion cooling and deepening, and in response to changing meteorological conditions (Figure 2-2c). The temporal and spatial patterns of striped bass habitat expansion and reduction observed in 2009 were similar to those previously reported in Lake Norman, and many other Southeastern reservoirs (Coutant 1985; Matthews et al. 1985; Duke Power

Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Turbidity and Specific Conductance

Surface turbidity values were generally low at the MNS discharge, mixing zone, and background locations during 2009, ranging from 0.9 to 2.9 NTUs (Table 2-5). Bottom turbidity values were also low over the 2009 study period, ranging from 0.7 to 5.3 NTUs. Turbidity values observed in 2009 were near the low end of the historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Specific conductance in Lake Norman in 2009 ranged from 65.6 to 105.0 µmhos/cm and was generally similar to that observed in 2008 (Table 2-5), and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). Specific conductance values in surface and bottom waters in 2009 were similar throughout the year except during the period of intense thermal stratification (i.e., August and November) when an increase in bottom conductance values was observed at locations within the mixing and background zones. These increases in bottom conductance values appeared to be related primarily to the release of soluble iron and manganese from the lake bottom under anoxic conditions (Table 2-5). This phenomenon is common in both natural lakes and reservoirs that exhibit extensive hypolimnetic oxygen depletion (Hutchinson 1957, Wetzel 1975) and is an annually recurring phenomenon in Lake Norman.

pH and Alkalinity

During 2009, pH and alkalinity values were similar among MNS discharge, mixing and background zones (Table 2-5). Values of pH were also generally similar to values measured in 2008 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). Values of pH in 2009 ranged from 7.0 to 7.7 in surface waters and from 6.3 to 7.2 in bottom waters. Alkalinity values in 2009 ranged from 14.0 to 16.0 mg/L, expressed as $CaCO^3$, in surface waters and from 14.0 to 22.0 mg/L in bottom waters.

The 2010 Catawba River Basinwide Summary (NCDENR 2010) concluded that pH values throughtout the basin exhibited a significant decline over the period 1997 – 2008, beginnining in 2003. Median pH values within the basin ranged from a high of 7.4 in 2001 to a low of 6.5 in 2008. Acid deposition impacts were implicated as a probable explanation. Included in this database was a site (C3420000) in the upper, riverine reaches of Lake Norman (Figure 1). A plot of surface (0.3 m) pH values in Lake Norman from 1999 – 2009 for Locations 62.0 and 69.0, sites near C3420000 that were measured in conjuction with the MMP for MNS, was constructed for comparison with the State's database (Figure 2-13). These data (N = 462) illustrated pronounced seasonal variability in pH with values ranging from 6.5 to 7 in the winter and from 8 to 9.3 in mid-summer when algal photosynthesis removed CO^2 from solution thereby increasing pH. A slightly increasing temporal trend of pH over this 11-year period was also observed, in contrast to that reported by the State.

Descriptive statistical pH information was reported for site C3420000 for the 2003 through 2007 period and included calculations of maximum, minium and median (NCDENR 2008). Similar calculations were made on the 2003 – 2007 Duke Energy data set for locations 62.0 and 69.0, as well as for the period 1999 – 2009, and compared to the State's data (Figure 2-13). Maximum, minimum and median statistics for the Duke Energy 2003 through 2007 data ranged from 0.7 to 1.4 pH units higher than comparable State data. Differences between statistical metrics generated from the two Duke Energy pH datasets were minimal (Figure 2-13). It's unclear why a discrepancy exists between the Duke Energy and NCDENR databases, but a similar disparity was noted for comparable pH data collected by Duke Energy and NCDENR at sites located in lakes Mtn. Island and Wylie (Duke Energy, unpublished data).

Major Cations and Anions

The concentrations of major ionic species in the MNS discharge, mixing and background zones are provided in Table 2-5. Lake-wide, the major cations were sodium, calcium, magnesium and potassium, whereas the major anions were bicarbonate, sulfate, and chloride. The overall ionic composition of Lake Norman during 2009 was generally similar to that reported for 2008 (Table 2-5) and previously (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Nutrients

Nutrient concentrations in the discharge, mixing and background zones of Lake Norman in 2009 (Table 2-5) were low and generally similar to those measured in 2008 and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). For total phosphorus (TP), all 44 samples analyzed in 2009 except one exceeded 5 µg/L, the analytical reporting limit (ARL), and values were consistently greater than observed in 2008, but within the historical range. The maximum 2009 TP value (27 µg/L) was observed in a bottom sample at Location 11.0. All measurements of orthophosphorus (N = 44) in 2009 were recorded as ≤ 5 µg/L. Nitrite-nitrate and ammonia nitrogen concentrations were low at all locations (Table 2-5) and similar to historical values (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). Overall, nutrients in 2009 were somewhat higher uplake than downlake, but the differences were slight and not statistically significant ($p < 0.05$). Spatial variability in various chemical constituents, especially nutrient concentrations, is common in long, deep reservoirs (Soballe et al. 1992).

Metals

Metal concentrations in the discharge, mixing, and background zones of Lake Norman for 2009 were similar to those measured in 2008 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). Iron concentrations in surface and bottom waters were generally low (≤ 0.2 mg/L) during 2009 with only 9 of 44 samples exceeding 0.20 mg/L. The maximum iron concentration measured in 2009 was 0.614 mg/L in the bottom sample taken at Location 1.0 in November. No sample collected in 2009 exceeded the North Carolina water quality action level for iron (1.0 mg/L; NCDENR 2004).

Similarly, 2009 manganese concentrations in the surface and bottom waters were low (≤ 100 µg/L), except during the summer and fall when bottom waters were anoxic (Table 2-5). Manganese concentrations in the bottom waters rose above the State water quality action (200 µg/L; NCDENR 2004) at various locations throughout the lake in summer and fall, and were characteristic of historical conditions (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). The highest concentration of manganese reported in 2009 (2,130 µg/L) was measured in the bottom waters at Location 1.0; this same sample also recorded the maximum iron concentration for 2009. This phenomenon, i.e., the release of manganese (and iron) from bottom sediments in response to low redox conditions (low oxygen levels), is common in stratified waterbodies (Stumm and Morgan 1970, Wetzel 1975).

Concentrations of other metals in 2009 were low, and often below the ARL for the specific constituent (Table 2-5). These findings are consistent with those reported for earlier years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). All values for cadmium and lead were reported as either equal to or below the ARL for those parameters. All zinc values except two were above the ARL of 1.0 µg/L; the maximum 2009 zinc concentration of 10.8 µg/L was measured in the August surface sample at Location 1.0. All copper concentrations, measured as total recoverable copper, were ≤ 2.5 µg/L and about 20% (9 of 44) of the values were listed as less than or equal to the ARL of 1.0 µg/L. All values reported for cadmium, lead, zinc, and copper in 2009 were below the State action level for each of these metals (NCDENR 2004).

FUTURE STUDIES

No changes are planned for the water chemistry portion of the Lake Norman Maintenance-Monitoring Program.

SUMMARY

Annual precipitation in the vicinity of MNS in 2009 totaled 144.3 cm or 25.3 cm more than observed in 2008 (119.0 cm), and 26.7 cm more than the long-term of 117.6 cm. Year 2009 annual rainfall was also the second highest measured since 1975, exceeded only in 2003. Temporal and spatial trends in water temperature and DO in 2009 were similar to those observed historically, and all data were within the range of previously measured values. Water temperatures in winter 2009 were either equal to or cooler than measured in 2008 and generally paralleled differences exhibited in monthly air temperature data, but with about a one month lag time.

Summer (June, July, and August) water temperatures in 2009 were generally slightly cooler (maximum = 3.5 °C) than observed in 2008 in both zones, with the most pronounced differences observed in the upper 15 m of the water column. Fall and early winter water temperatures in 2009 were consistently either equal to or warmer in both zones than those measured in 2008, indicating that the reservoir was cooling at a slower rate in 2009 than 2008. This pattern followed the trend exhibited in air temperatures. Temperatures at the discharge location in 2009 were generally similar to 2008 and historical data. The warmest discharge temperature of 2009 (37.1 °C) occurred in September and was 1.4 °C cooler than the 2008 maximum measured in August.

Seasonal and spatial patterns of DO in 2009 were reflective of the patterns exhibited for temperature (i.e., generally similar in both the mixing and background zones). Winter DO values in 2009 were generally equal to or greater than measured in 2008 whereas spring values were either equal to or slightly less than observed in 2008 and were correlated with interannual differences in water temperatures. Summer DO values in 2009 were highly variable throughout the water column in both the mixing and background zones ranging from highs of 6.0 to 8.0 mg/L in surface waters to lows of 0.0 to 2.0 mg/L in bottom waters. The temporal development of the negative heterograde DO curve in summer 2009 occurred earlier and progressed more rapidly than in 2008 and earlier years, and may have been related to higher than normal inputs of allochthonous organic matter associated with above average spring rains.

Considerable differences were observed between 2009 and 2008 late summer and fall DO values in both the mixing and background zone, especially in the metalimnion and hypolimnion. The 2009 fall DO data indicate that convective reaeration of the water column proceeded at a somewhat slower rate than observed in corresponding months in 2008 despite exhibiting similar September profiles. Consequently, 2009 DO levels at most depths were either equal to or less than observed in 2008. These between-year differences in DO corresponded strongly with the degree of thermal stratification which, in turn, was correlated with interannual differences in air temperatures. The seasonal pattern of DO in 2009 at the discharge location was similar to that measured historically, with the highest values observed during the winter and lowest observed in the summer and early fall. The lowest DO concentration measured at the discharge location in 2009 (5.2 mg/L) occurred in July and August and was 1.1 mg/L higher than the historical minimum, measured in August 2003 (4.1 mg/L).

Reservoir-wide isotherm and isopleth information for 2009, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Suitable pelagic habitat for adult striped bass, defined as that layer of water with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L, was found lake-wide from mid September 2008 through mid-July 2009. Beginning in late June 2009, habitat reduction proceeded rapidly throughout the reservoir both as a result of deepening of the 26-°C isotherm and metalimnetic and hypolimnetic deoxygenation. Habitat reduction was most severe from mid-July through early September. Observed striped bass mortalities in 2009 totaled 362 fish.

All chemical parameters measured in 2009 were similar to 2008 and within the concentration ranges previously reported during both preoperational and operational years of MNS. Specific conductance values, and all cation and anion concentrations, were low. Values of pH were within historical ranges in both the mixing and background zones. A comparison of long-term (1999 – 2009) pH data for Lake Norman with a comparable site sampled by NCDENR illustrated discrepancies in descriptive statistics and no temporally decreasing trend, in contrast to that observed by the State. It's unclear why this disparity exists.

Nutrient concentrations were low with most values reported close to or below the (ARL) for that test. Total phosphorus concentrations were slightly higher than measured in 2008 but within the historical range. Concentrations of metals in 2009 were low and often below the respective ARLs. All values for cadmium and lead were reported as either equal to or below the ARL for each parameter. All zinc values except two were above the ARL of 1.0 µg/L and all copper concentrations, measured as total recoverable copper, were ≤ 2.5 µg/L. All 2009 values for cadmium, lead, zinc, copper and iron were below the State water quality standard or action level for each of these metals. Manganese concentrations were generally low in 2009, except during the summer and fall when bottom waters were anoxic and redox induced releases of manganese occurred. The highest concentration of manganese reported in 2009 (2,130 µg/L) was measured in November in the bottom waters in the mixing zone.

Table 2-1. Water quality 2009 program for the MNS NPDES Maintenance Monitoring Program on Lake Norman.

		2009 McGUIRE NPDES SAMPLING PROGRAM														
PARAMETERS	LOCATION	1.0	2.0	4.0	5.0	8.0	9.5	11.0	13.0	14.0	15.0	15.9	62.0	69.0	72.0	80.0
	DEPTH (m)	33	33	5	20	32	23	27	21	10	23	23	15	7	5	4
IN-SITU ANALYSIS																
Temperature																
Dissolved Oxygen		In-situ measurements are collected monthly at the above locations at 1m intervals from 0.3m to 1m above bottom.														
pH		Measurements are taken weekly from July-August for striped bass habitat. All measurements are taken with a Hydrolab Datasonde.														
Conductivity																
NUTRIENT ANALYSES																
Ammonia		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Nitrate+Nitrite		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Orthophosphate		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Total Phosphorus		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Silica		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Chloride		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
TKN		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Total Organic Carbon		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Dissolved organic carbon		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
ELEMENTAL ANALYSES																
Aluminum		Q/T,B	S/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Calcium		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Iron		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Magnesium		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Manganese		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Potassium		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Sodium		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Zinc		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Arsenic		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Cadminum		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Copper (TR)[1]		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Copper (Dissolved)		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Lead		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Selenium		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
ADDITIONAL ANALYSES																
Hardness		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Alkalinity		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Turbidity		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Sulfate		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Total Solids		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Total Suspended Solids		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		

1. TR= Total Recoverable

CODES: Frequency Q = Quarterly (Feb, May, Aug, Nov) T = Top (0.3m) B = Bottom (1m above bottom)

Table 2-2. Analytical methods and reporting limits employed in the 2009 MNS NPDES Maintenance Monitoring Program for Lake Norman.

Parameter	Method (EPA/APHA)	Preservation	Reporting Limit
Alkalinity, Total	Total Inflection Point, EPA 310.1	4 °C	0.01 meq/L
Aluminum	ICP, EPA 200.7	0.5% HNO_3	0.05 mg/L
Cadmium, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L[a]
Calcium	ICP, EPA 200.7	0.5% HNO_3	30 µg/L
Chloride	Colorimetric, EPA 325.2	4 °C	1.0 mg/L
Copper, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L
Copper, Dissolved	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L
Iron, Total Recoverable	ICP, EPA 200.7	0.5% HNO_3	10 µg/L
Lead, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L
Magnesium	Atomic Emission/ICP, EPA 200.7	0.5% HNO_3	30 µg/L
Manganese, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L
Nitrogen, Ammonia	Colorimetric, EPA 350.1	0.5% H_2SO_4	20 µg/L
Nitrogen, Nitrite + Nitrate	Colorimetric, EPA 353.2	0.5% H_2SO_4	20 µg/L
Nitrogen, Total Kjeldahl	Colorimetric, EPA 351.2	0.5% H_2SO_4	100 µg/L
Phosphorus, Orthophosphorus	Colorimetric, EPA 365.1	4 °C	5 µg/L
Phosphorus, Total	Colorimetric, EPA 365.1	0.5% H_2SO_4	5 µg/L
Potassium	ICP, EPA 200.7	0.5% HNO_3	250 µg/L
Silica	APHA 4500Si-F	0.5% HNO_3	500 µg/L
Sodium	Atomic Emission/ICP, EPA 200.7	0.5% HNO_3	1.5 mg/L
Solids, Total	Gravimetric, SM 2540B	4 °C	0.1 mg/L
Solids, Total Suspended	Gravimetric, SM 2540D	4 °C	0.1 mg/L
Sulfate	Ion Chromatography	4 °C	0.1 mg/L
Turbidity	Turbidimetric, EPA 180.1	0.5% H_2SO_4	0.05 NTU
Zinc, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L

References: USEPA 1983, and APHA 1995

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[a] Except in May when Reporting Limit equals 0.5 µg/L.

Table 2-3. Heat content calculations for the thermal regime in Lake Norman for 2008 and 2009.

	2009	2008
Maximum Areal Heat Content (Kcal/cm^2)	28.509	29.062
Minimum Areal Heat Content (Kcal/cm^2)	8.859	9.648
Birgean Heat Budget (Kcal/cm^2)	19.650	19.414
Epilimnion (above 11.5 m) Heating Rate (°C/day)	0.10	0.11
Hypolimnion (below 11.5 m) Heating Rate (°C/day)	0.08	0.08

Table 2-4. A comparison of areal hypolimnetic oxygen deficits (AHOD), summer chlorophyll *a* (Chl *a*), Secchi depth, and mean depth of Lake Norman and 18 TVA reservoirs.

Reservoir	AHOD ($mg/cm^2/day$)	Summer Chl *a* (µg/L)	Secchi Depth (m)	Mean Depth (m)
Lake Norman	0.046	5.1	1.7	10.3
TVA[b]				
Mainstem				
Kentucky	0.012	9.1	1.0	5.0
Pickwick	0.010	3.9	0.9	6.5
Wilson	0.028	5.9	1.4	12.3
Wheelee	0.012	4.4		5.3
Guntersville	0.007	4.8	1.1	5.3
Nickajack	0.016	2.8	1.1	6.8
Chickamauga	0.008	3.0	1.1	5.0
Watts Bar	0.012	6.2	1.0	7.3
Fort London	0.023	5.9	0.9	7.3
Tributary				
Chatuge	0.041	5.5	2.7	9.5
Cherokee	0.078	10.9	1.7	13.9
Douglas	0.046	6.3	1.6	10.7
Fontana	0.113	4.1	2.6	37.8
Hiwassee	0.061	5.0	2.4	20.2
Norris	0.058	2.1	3.9	16.3
South Holston	0.070	6.5	2.6	23.4
Tims Ford	0.059	6.1	2.4	14.9
Watauga	0.066	2.9	2.7	24.5

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[b] Data from Higgins et al. (1980), and Higgins and Kim (1981).

Table 2-5. Quarterly surface (0.3 m) and bottom (bottom minus 1 m) water chemistry for the MNS discharge, mixing zone, and background locations on Lake Norman during 2008 and 2009. Values less than detection were assumed to be equal to the detection limit for calculating a mean.

LOCATION:	Mixing Zone 1.0				Mixing Zone 2.0				MNS Discharge 4.0		Mixing Zone 5.0				Background 8.0				Background 11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS YEAR:	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008
Turbidity (NTU)																						
Feb	1.9	2.0	1.8	1.6	2.6	1.2	3.9	1.5	2.8	1.1	2.3	1.4	3.8	1.2	2.1	1.5	5.3	1.7	2.9	1.5	4.3	1.4
May	1.6	1.3	2.3	1.7	1.9	1.3	3.1	1.2	1.8	1.3	1.8	1.3	2.5	2.1	1.1	1.4	2.3	1.4	1.1	1.6	3.0	4.1
Aug	1.0	1.9	0.7	1.1	1.9	3.3	0.7	1.0	0.9	2.1	1.0	1.7	4.1	2.9	1.1	1.5	1.2	1.4	1.4	2.0	1.0	1.7
Nov	1.8	2.1	2.7	2.0	1.6	1.9	2.4	1.6	2.0	1.1	1.7	1.1	2.9	2.6	1.9	1.7	3.9	3.7	2.4	2.9	4.5	3.9
Annual Mean	1.6	1.8	1.9	1.6	2.0	1.9	2.5	1.3	1.9	1.4	1.7	1.4	3.3	2.2	1.6	1.5	3.2	2.1	2.0	2.0	3.2	2.8
Specific Conductance (umho/cm)																						
Feb	72.0	66.0	72.1	65.6	72.7	66.1	72.5	68.1	73.6	67.3	73.4	66.3	72.2	65.6	72.5	65.8	71.8	65.1	71.1	76.4	64.9	72.7
May	71.4	72.4	71.4	71.1	71.7	72.5	71.2	70.9	71.8	73.6	72.5	72.8	71.1	71.5	72.6	72.4	70.8	72.6	71.9	77.7	70.2	76.4
Aug	65.6	76.1	73.6	75.6	66.1	75.0	72.1	75.9	65.9	75.3	65.6	75.6	77.0	79.6	65.9	75.3	72.7	74.4	67.4	80.6	73.9	75.0
Nov	69.0	76.8	105.0	78.2	69.0	76.9	88.0	77.6	70.0	77.3	69.0	77.0	69.0	76.6	69.0	76.9	71.0	77.3	69.0	78.4	69.0	76.6
Annual Mean	69.5	72.8	80.5	72.6	69.9	72.6	76.0	73.1	70.3	73.4	70.1	72.9	72.3	73.3	70.0	72.6	71.6	72.4	69.9	78.3	69.5	75.2
pH (units)																						
Feb	7.0	7.2	6.9	7.1	7.3	7.4	7.1	7.2	7.3	7.3	7.4	7.4	7.1	7.2	7.5	7.3	7.2	7.2	7.3	7.3	7.0	7.2
May	7.0	7.4	6.6	6.9	7.2	7.5	6.6	6.9	7.1	7.4	7.5	7.5	6.7	6.9	7.6	7.6	6.7	6.9	7.7	7.6	6.6	6.8
Aug	7.1	7.6	6.3	6.2	7.1	7.4	6.3	6.3	7.0	7.1	7.1	7.4	6.5	6.4	7.4	8.0	6.3	6.3	7.4	8.4	6.3	6.3
Nov	7.3	7.5	7.0	7.2	7.3	7.6	6.8	7.2	7.4	7.6	7.4	7.6	7.0	7.2	7.3	7.5	7.0	7.2	7.3	7.5	7.2	7.2
Annual Mean	7.1	7.4	6.7	6.9	7.2	7.5	6.7	6.9	7.1	7.4	7.3	7.5	6.8	6.9	7.4	7.6	6.8	6.9	7.4	7.7	6.8	6.9
Alkalinity (mg CaCO3/L)																						
Feb	14	16	14	16	15	16	14	16	15	16	14	16	14	16	15	16	14	16	14	16	14	16
May	15	13	14	15	14	13	14	13	14	13	14	13	14	14	14	13	14	15	14	14	14	15
Aug	15	16	15	16	15	15	15	15	14	15	14	16	19	18	14	15	15	16	14	16	15	16
Nov	15	16	22	16	16	16	17	17	16	16	16	16	17	16	16	17	18	16	16	15	16	15
Annual Mean	14.8	15.3	16.3	15.8	15.0	15.0	15.0	15.3	14.8	15.0	14.5	15.3	16.0	16.0	14.8	15.3	15.3	15.8	14.5	15.3	14.8	15.5
Chloride (mg/L)																						
Feb	8.9	7.3	8.9	7.4	9.0	7.3	8.9	7.7	8.9	7.3	8.8	7.2	8.7	7.1	9.0	7.4	8.9	7.3	8.3	10.0	7.1	9.1
May	8.6	8.3	8.7	8.2	8.6	8.2	8.8	8.1	8.9	8.4	8.9	8.3	8.7	8.3	8.8	8.3	8.8	8.6	8.4	9.7	8.4	9.3
Aug	7.1	9.0	8.0	8.3	6.9	8.8	8.0	8.3	7.0	9.0	6.9	9.0	7.7	8.4	7.2	8.9	8.1	8.4	7.3	10.0	7.8	8.5
Nov	7.0	9.4	7.2	9.4	7.1	9.5	7.3	9.4	7.2	9.5	7.2	9.5	7.2	9.4	7.2	9.4	7.5	9.4	7.1	9.8	7.3	9.6
Annual Mean	7.9	8.5	8.2	8.3	7.9	8.5	8.3	8.4	8.0	8.6	8.0	8.5	8.1	8.3	8.1	8.5	8.3	8.4	7.8	9.9	7.7	9.1
Sulfate (mg/L)																						
Feb	5.3	4.7	5.2	4.7	5.3	4.8	5.3	4.9	5.3	4.8	5.3	4.8	5.2	4.8	5.3	4.8	5.2	4.8	5.1	5.4	4.6	5.1
May	5.3	5.1	5.2	5.0	5.1	5.2	5.2	5.0	5.1	5.1	5.7	5.2	5.2	5.0	5.3	5.1	5.3	5.1	5.5	5.5	5.3	5.2
Aug	4.7	5.3	5.1	5.0	4.7	5.3	5.1	5.0	4.7	5.3	4.7	5.3	4.8	5.0	4.8	5.3	5.1	5.0	4.8	5.5	5.0	5.0
Nov	4.5	5.5	3.7	5.6	4.5	5.5	4.4	5.6	4.5	5.2	4.5	5.5	4.5	5.6	4.6	5.6	4.6	5.6	4.3	5.6	4.2	5.3
Annual Mean	5.0	5.2	4.8	5.1	4.9	5.2	5.0	5.1	4.9	5.1	5.1	5.2	4.9	5.1	5.0	5.2	5.1	5.1	4.9	5.5	4.8	5.2
Calcium (mg/L)																						
Feb	4.51	4.01	4.52	4.01	4.52	4.02	4.50	4.19	4.51	4.02	4.51	3.98	4.50	4.02	4.52	4.10	4.52	4.05	4.60	5.00	4.24	4.68
May	4.70	4.30	4.70	4.26	4.71	4.31	4.73	4.28	4.70	4.30	4.53	4.31	4.62	4.37	4.62	4.28	4.70	4.45	4.48	4.86	4.48	4.73
Aug	4.18	4.61	4.83	4.65	4.21	4.62	4.86	4.71	4.24	4.65	4.23	4.61	4.83	4.94	4.24	4.60	4.31	4.82	4.47	5.26	4.90	4.86
Nov	4.42	4.69	4.85	4.72	4.43	4.67	4.53	4.68	4.42	4.67	4.41	4.66	4.54	4.66	4.54	4.73	4.63	4.70	4.85	4.91	4.72	4.70
Annual Mean	4.45	4.40	4.73	4.41	4.47	4.41	4.66	4.47	4.47	4.41	4.42	4.39	4.62	4.50	4.48	4.43	4.54	4.51	4.60	5.01	4.59	4.74
Magnesium (mg/L)																						
Feb	2.24	2.10	2.26	2.09	2.29	2.08	2.26	2.14	2.24	2.08	2.25	2.07	2.25	2.09	2.25	2.10	2.22	2.07	2.12	2.41	1.87	2.30
May	2.10	2.17	2.15	2.16	2.11	2.18	2.14	2.17	2.08	2.18	2.16	2.19	2.15	2.21	2.15	2.16	2.13	2.23	2.19	2.30	2.14	2.24
Aug	2.04	2.28	2.23	2.24	2.03	2.27	2.21	2.24	2.01	2.29	2.02	2.28	2.21	2.34	2.01	2.27	2.22	2.28	2.06	2.51	2.21	2.26
Nov	2.11	2.42	2.19	2.41	2.11	2.41	2.11	2.38	2.10	2.38	2.11	2.39	2.13	2.39	2.12	2.42	2.14	2.40	2.11	2.49	2.11	2.39
Annual Mean	2.12	2.24	2.21	2.23	2.14	2.24	2.18	2.23	2.11	2.23	2.14	2.23	2.19	2.26	2.13	2.24	2.18	2.25	2.12	2.43	2.08	2.30

Table 2-5 (Continued)

LOCATION:	Mixing Zone 1.0				Mixing Zone 2.0				MNS Discharge 4.0		Mixing Zone 5.0				Background 8.0				Background 11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS YEAR:	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008
Potassium (mg/L)																						
Feb	2.00	1.97	2.01	1.96	2.01	1.96	2.01	1.96	2.05	1.96	2.04	1.94	2.01	1.97	1.98	1.95	2.01	1.95	1.98	1.98	1.94	1.95
May	1.98	1.93	2.01	1.90	1.98	1.93	2.00	1.92	1.94	1.91	2.04	1.93	2.02	1.92	2.03	1.90	1.99	1.91	1.97	1.88	1.93	1.87
Aug	1.94	1.94	1.96	1.94	1.94	1.98	1.96	1.96	1.91	1.92	1.86	1.92	1.99	1.99	1.94	1.94	1.94	1.91	1.87	1.88	1.95	1.85
Nov	2.02	2.02	2.07	2.01	2.05	2.02	2.05	1.99	2.05	2.05	2.04	2.03	2.04	2.00	2.05	2.01	2.07	2.05	2.05	2.02	2.04	2.01
Annual Mean	1.99	1.97	2.01	1.95	2.00	1.97	2.01	1.96	1.99	1.96	2.00	1.96	2.02	1.97	2.00	1.95	2.00	1.96	1.97	1.94	1.97	1.92
Sodium (mg/L)																						
Feb	5.58	5.08	5.61	5.06	5.68	5.06	5.59	5.15	5.59	5.02	5.57	5.01	5.57	5.07	5.64	5.10	5.59	5.07	5.57	5.60	5.38	5.46
May	5.38	5.45	5.48	5.40	5.42	5.45	5.46	5.39	5.36	5.47	5.51	5.46	5.49	5.51	5.52	5.41	5.40	5.63	5.36	5.91	5.20	5.91
Aug	4.77	5.66	5.27	5.43	4.69	5.60	5.26	5.40	4.65	5.63	4.67	5.56	5.12	5.49	4.76	5.59	5.14	5.44	4.65	5.61	5.10	5.45
Nov	4.70	5.71	4.88	5.70	4.70	5.67	4.68	5.64	4.71	5.67	4.70	5.66	4.69	5.63	4.72	5.60	4.73	5.67	4.62	5.61	4.61	5.54
Annual Mean	5.11	5.48	5.31	5.40	5.12	5.45	5.25	5.40	5.08	5.45	5.11	5.42	5.22	5.43	5.16	5.43	5.22	5.45	5.05	5.68	5.07	5.59
Aluminum (mg/L)																						
Feb	0.088	0.054	0.054	0.056	0.067	0.056	0.056	0.050	0.050	0.050	0.050	0.05	0.057	0.050	0.087	0.052	0.087	0.065	0.051	0.050	0.069	0.050
May	0.040	0.050	0.040	0.050	0.022	0.053	0.038	0.050	0.031	0.050	0.018	0.050	0.039	0.053	0.013	0.059	0.046	0.050	0.009	0.050	0.048	0.050
Aug	0.051	0.050	0.051	0.050	0.053	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.093	0.060	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Nov	0.041	0.062	0.043	0.050	0.054	0.050	0.049	0.050	0.046	0.050	0.048	0.050	0.069	0.050	0.043	0.050	0.068	0.050	0.051	0.050	0.058	0.054
Annual Mean	0.055	0.054	0.047	0.052	0.049	0.052	0.048	0.050	0.044	0.050	0.041	0.050	0.065	0.053	0.048	0.053	0.063	0.054	0.040	0.050	0.056	0.051
Iron (mg/L)																						
Feb	0.126	0.091	0.138	0.144	0.124	0.093	0.164	0.136	0.112	0.107	0.122	0.139	0.238	0.105	0.199	0.101	0.392	0.167	0.150	0.107	0.302	0.151
May	0.110	0.069	0.168	0.095	0.100	0.074	0.168	0.103	0.143	0.071	0.088	0.072	0.177	0.130	0.068	0.066	0.184	0.126	0.060	0.072	0.301	0.210
Aug	0.061	0.045	0.051	0.040	0.062	0.030	0.054	0.043	0.061	0.031	0.053	0.033	0.518	0.122	0.048	0.022	0.057	0.053	0.046	0.038	0.064	0.063
Nov	0.097	0.092	0.614	0.131	0.098	0.091	0.151	0.163	0.094	0.094	0.092	0.087	0.201	0.194	0.100	0.117	0.346	0.184	0.116	0.125	0.218	0.209
Annual Mean	0.098	0.074	0.243	0.103	0.096	0.072	0.134	0.111	0.102	0.076	0.089	0.083	0.284	0.138	0.104	0.077	0.245	0.133	0.093	0.086	0.221	0.158
Manganese (ug/L)																						
Feb	13	11	24	34	16	11	21	18	18	13	16	25	38	12	13	10	31	15	17	19	43	27
May	9	5	30	12	10	5	33	16	11	6	10	6	46	29	6	4	32	20	7	4	48	48
Aug	33	16	292	205	40	16	349	305	55	21	46	18	1800	1440	23	12	538	564	23	35	669	523
Nov	41	37	2130	56	45	37	88	106	46	37	44	38	216	105	41	28	676	66	52	46	86	75
Annual Mean	24	17	619	77	28	17	123	111	32	19	29	22	525	397	21	13	319	166	25	26	212	168
Cadmium (ug/L)																						
Feb	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
May	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aug	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
Nov	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Annual Mean	0.9	0.6	0.9	0.6	0.9	0.625	0.9	0.6	0.9	0.6	0.9	0.6	0.9	0.6	0.9	0.6	0.9	0.6	0.9	0.6	0.9	0.6
Copper (ug/L)																						
Feb	1.6	2.0	1.7	2.0	1.7	2.0	1.6	2.0	1.7	2.0	1.7	2.0	1.8	2.0	1.6	2.0	2.0	2.0	2.3	2.8	2.0	2.3
May	2.5	2.0	2.3	2.0	2.3	2.0	2.3	2.0	2.4	2.0	2.2	2.0	2.2	2.0	2.0	2.0	2.2	2.0	2.2	2.2	2.5	2.2
Aug	1.4	2.0	1.2	2.0	1.5	3.7	1.1	2.0	1.6	2.3	1.5	2.3	1.0	2.0	1.3	2.0	1.1	2.0	2.2	2.9	2.0	2.1
Nov	1.8	1.5	1.0	1.4	1.0	1.5	1.0	1.4	1.0	1.6	1.0	1.5	1.0	1.5	1.0	2.1	1.0	2.0	1.9	3.3	1.8	2.1
Annual Mean	1.8	1.9	1.5	1.9	1.6	2.3	1.5	1.9	1.7	2.0	1.6	1.9	1.5	1.9	1.5	2.0	1.6	2.0	2.2	2.8	2.1	2.2
Lead (ug/L)																						
Feb	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0
May	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0
Aug	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0
Nov	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Annual Mean	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.8	1.0	1.0

Table 2-5 (Continued)

	Mixing Zone				Mixing Zone				MNS Discharge		Mixing Zone				Background				Background			
LOCATION:	1.0				2.0				4.0		5.0				8.0				11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS YEAR:	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008
Zinc (ug/L)																						
Feb	1.3	1.5	1.3	1.7	1.2	2.5	1.6	1.9	1.6	1.8	1.4	1.7	1.8	2.2	1.1	1.9	1.5	2.8	1.5	4.0	1.8	1.9
May	1.5	2.2	1.3	4.2	1.0	1.7	1.1	2.3	1.2	2.0	1.1	2.2	1.2	2.8	1.0	3.2	1.2	2.0	1.1	2.0	1.5	2.2
Aug	10.8	1.3	6.1	1.2	7.5	2.1	7.9	1.4	6.6	1.5	11.9	1.1	11.3	1.0	6.5	1.0	9.6	1.2	10.8	1.3	12.3	1.1
Nov	1.5	1.0	1.7	1.0	1.9	1.0	1.5	1.1	1.4	1.0	1.6	1.0	2.7	1.0	1.6	1.4	1.9	1.3	4.6	1.5	2.0	1.4
Annual Mean	3.8	1.5	2.6	2.0	2.9	1.8	3.0	1.7	2.7	1.6	4.0	1.5	4.3	1.7	2.6	1.9	3.6	1.8	4.5	2.2	4.4	1.6
Nitrite-Nitrate (ug/L)																						
Feb	89	150	99	130	88	140	91	160	90	150	91	150	100	140	87	140	110	140	200	210	230	290
May	200	280	240	510	190	450	240	300	200	340	140	450	240	240	140	250	260	300	150	510	290	640
Aug	65	150	290	390	76	150	280	370	81	150	77	160	130	300	45	140	260	360	21	110	240	370
Nov	48	110	320	110	49	120	59	96	50	110	52	110	55	110	58	120	52	100	120	150	120	110
Annual Mean	101	173	237	285	101	215	168	232	105	188	90	218	131	198	83	163	171	225	123	245	220	353
Ammonia (ug/L)																						
Feb	33	120	33	83	28	130	28	130	29	140	29	59	33	150	26	81	33	94	26	71	53	92
May	32	270	25	210	65	200	20	250	37	190	24	200	24	280	110	270	41	280	54	220	210	240
Aug	45	20	66	20	36	20	51	20	36	20	39	20	120	55	73	24	33	20	34	20	84	25
Nov	130	50	300	57	130	59	160	78	140	120	150	61	180	55	210	45	200	79	130	48	140	76
Annual Mean	60	115	106	93	65	102	65	120	61	118	61	85	89	135	105	105	77	118	34	90	122	108
Total Phosphorous (ug/L)																						
Feb	8	6	11	6	9	6	10	6	10	6	8	6	11	6	8	6	12	6	11	6	15	7
May	12	8	11	7	11	7	11	7	12	7	10	8	12	7	11	7	11	7	12	8	13	9
Aug	10	7	7	6	10	7	7	6	9	7	9	7	9	7	8	6	11	7	9	8	27	8
Nov	8	8	10	8	6	7	7	8	7	8	5	7	9	8	8	5	20	8	10	9	10	8
Annual Mean	9	7	10	7	9	7	9	7	9	7	8	7	10	7	9	6	14	7	11	8	16	8
Orthophosphate (ug/L)																						
Feb	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6
May	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Aug	5	5	5	5	5	7	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5
Nov	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Annual Mean	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Silicon (mg/L)																						
Feb	3.8	4.9	3.8	5.0	3.7	4.9	3.7	5.2	3.6	5.0	3.6	5.0	3.8	5.0	3.6	5.0	3.7	5.0	4.0	5.3	4.2	5.3
May	4.1	5.1	4.3	5.0	4.0	4.9	4.3	5.2	4.0	4.9	4.0	4.9	4.4	5.2	4.1	4.8	4.6	5.2	3.9	4.8	4.4	5.4
Aug	3.8	4.5	4.7	5.3	3.8	4.4	4.9	5.4	3.8	4.4	3.8	4.4	5.1	5.5	3.7	4.4	4.9	5.5	3.7	4.4	4.8	5.4
Nov	4.0	5.0	4.5	4.9	4.0	4.9	4.0	4.9	4.0	4.9	4.0	5.0	4.1	5.0	3.9	4.8	4.2	5.0	4.1	4.7	4.2	4.9
Annual Mean	3.9	4.9	4.3	5.1	3.9	4.8	4.2	5.2	3.9	4.8	3.8	4.8	4.4	5.2	3.8	4.8	4.3	5.2	3.9	4.8	4.4	5.3

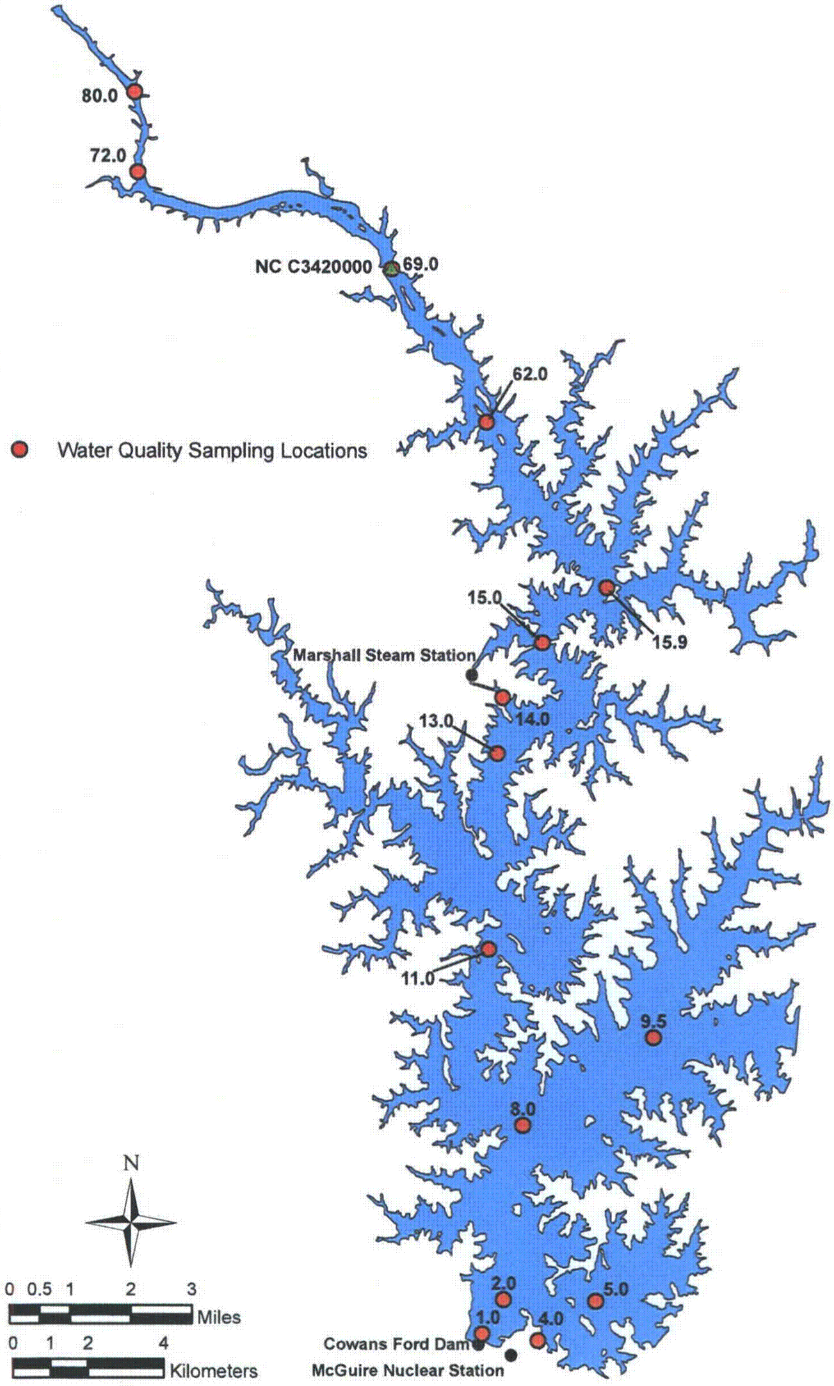

Figure 2-1. Water quality sampling locations (numbered) for Lake Norman. Approximate locations of Marshall Steam Station and McGuire Nuclear Station are also shown.

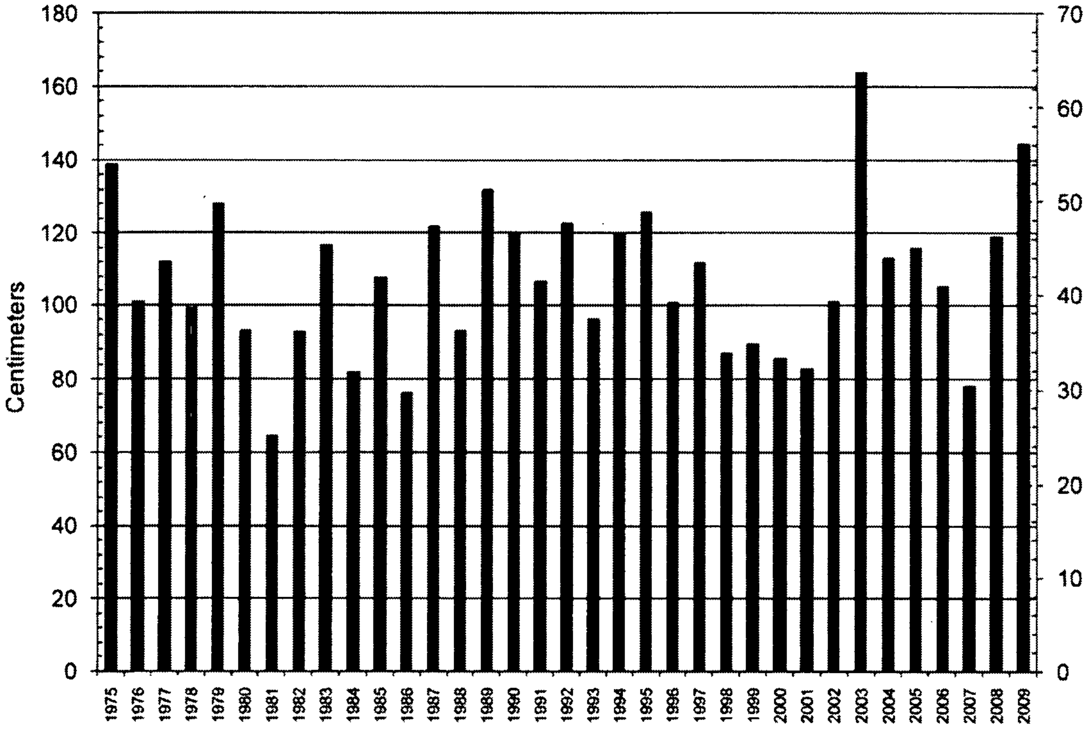

Figure 2-2a. Annual precipitation totals in the vicinity of MNS.

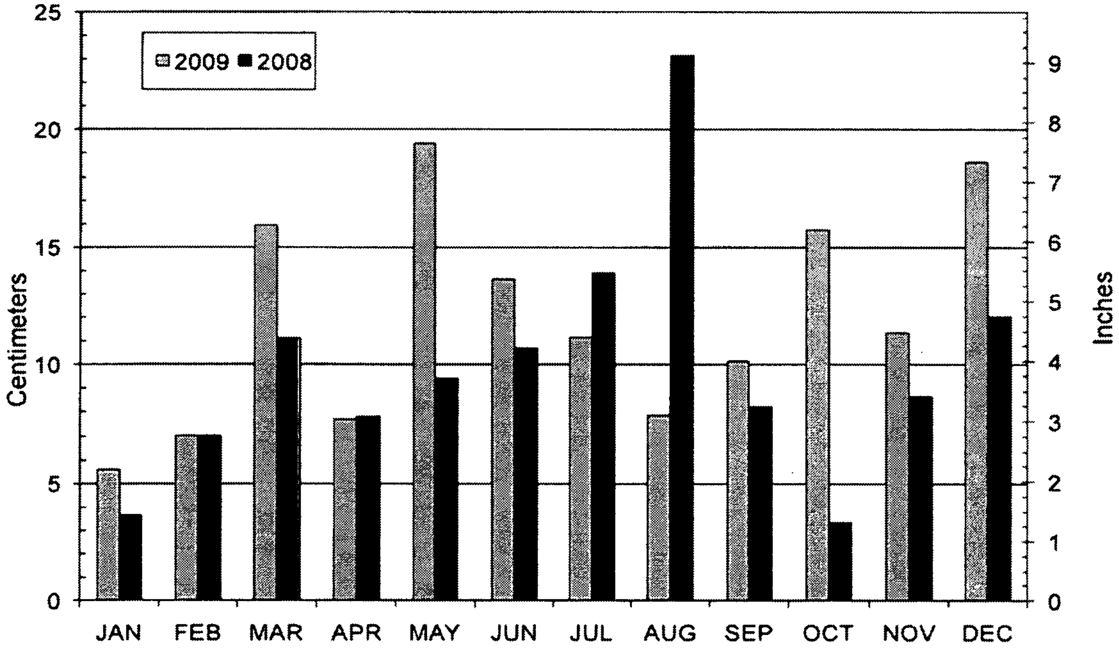

Figure 2-2b. Monthly precipitation totals in the vicinity of MNS in 2008 and 2009.

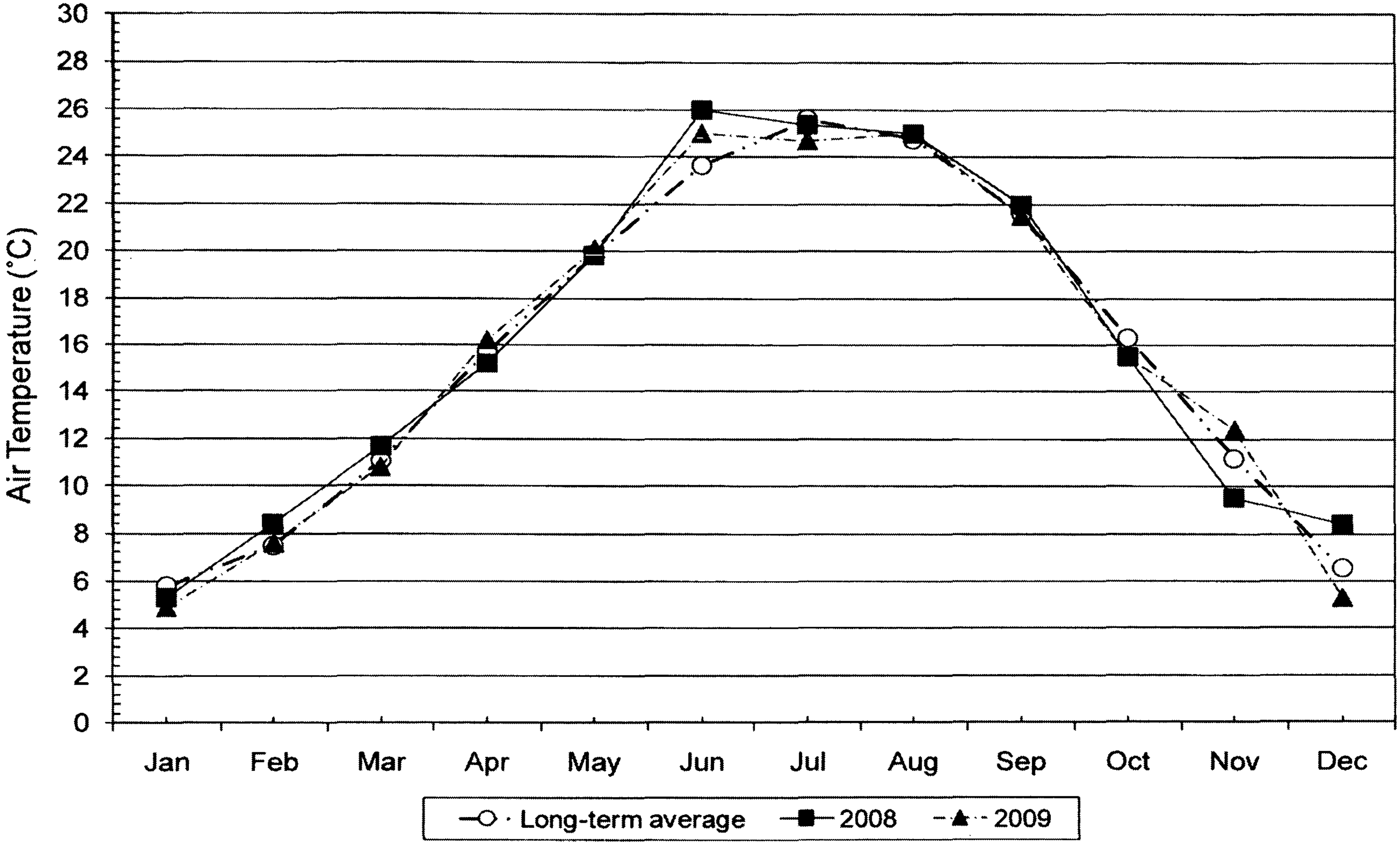

Figure 2-2c. Mean monthly air temperatures recorded at MNS beginning in 1989. Data were complied from average daily temperatures which, in turn, were created from hourly measurements.

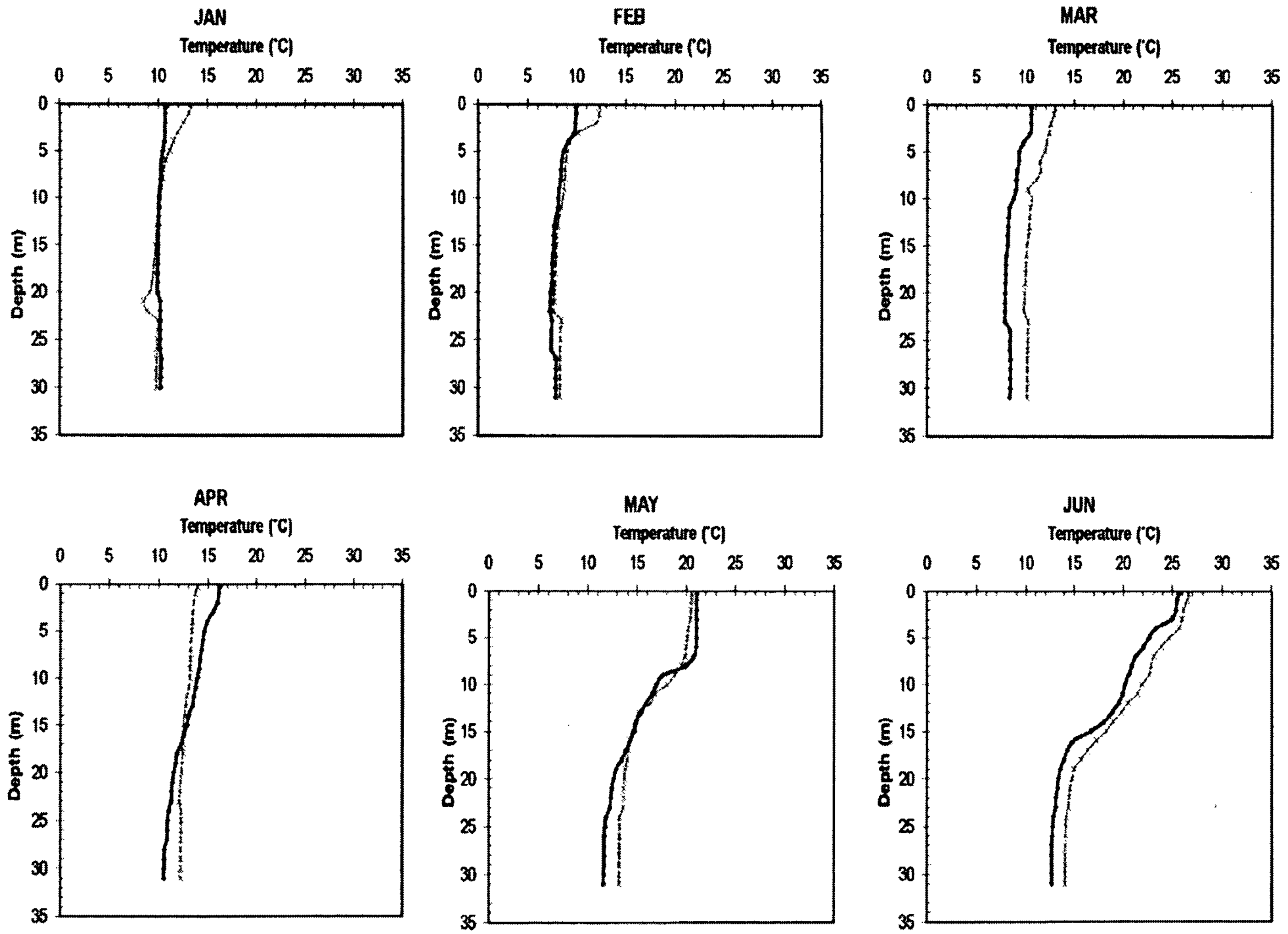

Figure 2-3. Monthly mean temperature profiles for the MNS background zone in 2008 (xx) and 2009 (♦♦).

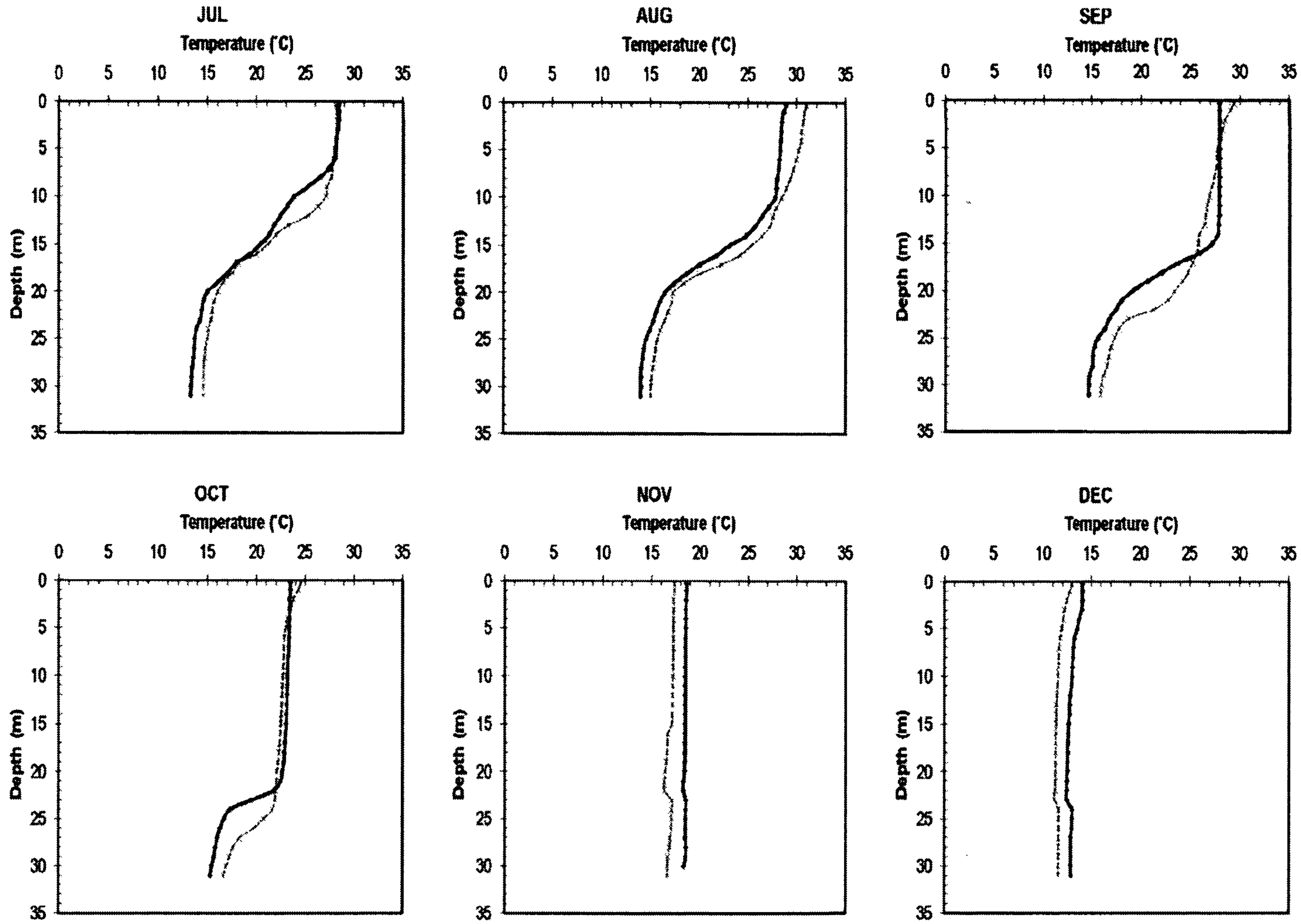

Figure 2-3. (Continued).

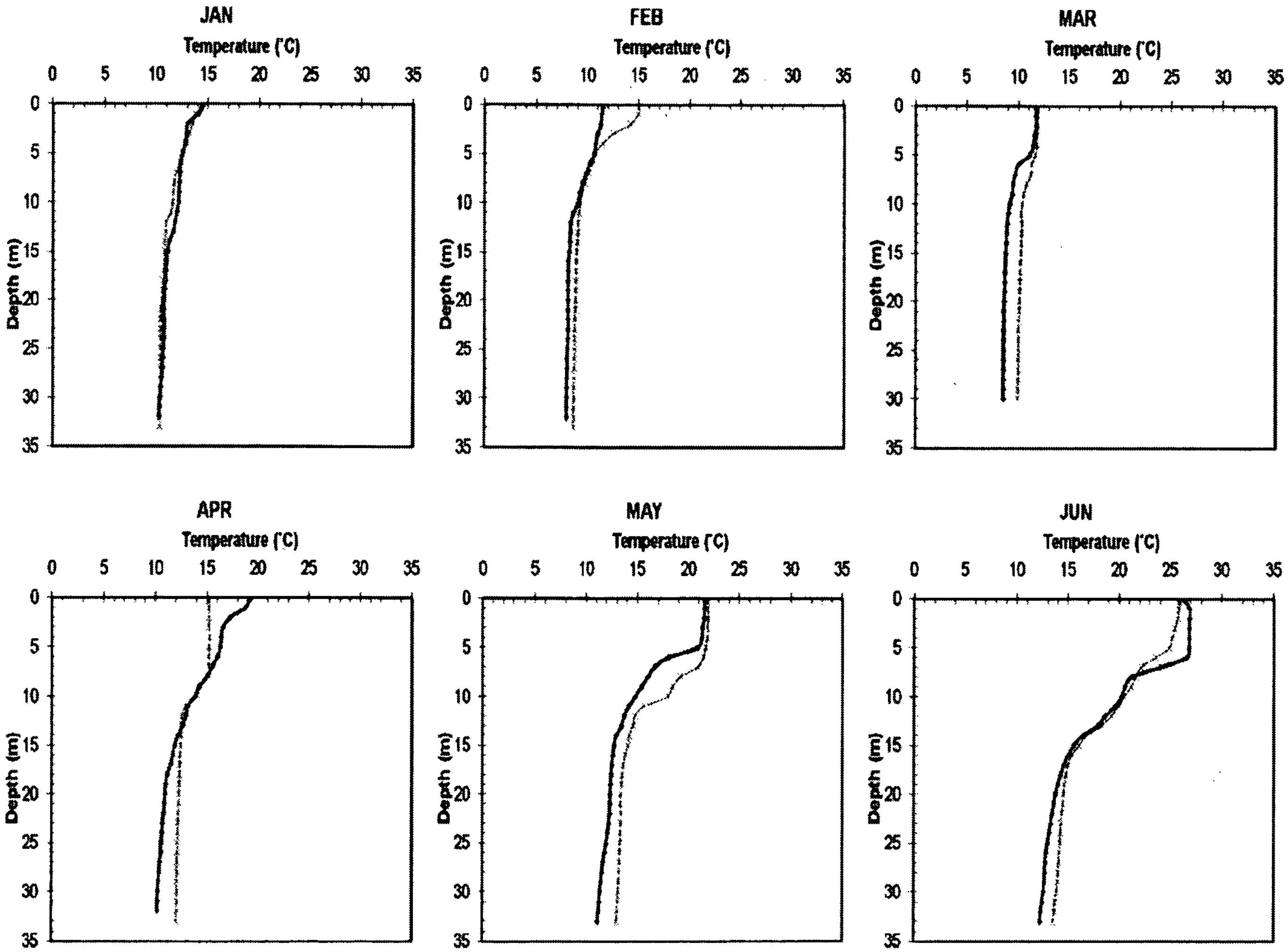

Figure 2-4. Monthly mean temperature profiles for the MNS mixing zone in 2008 (xx) and 2009 (♦♦).

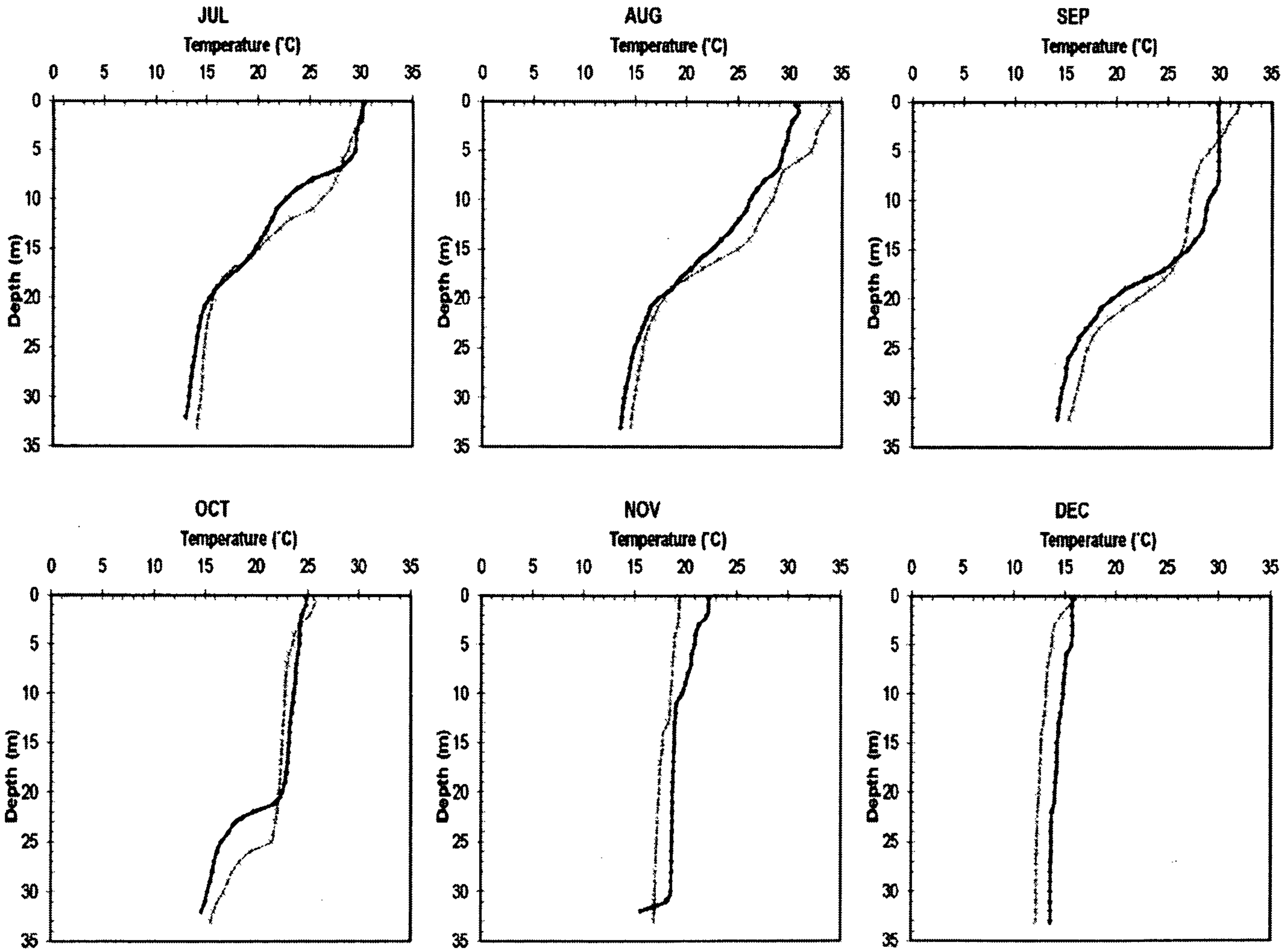

Figure 2-4. (Continued).

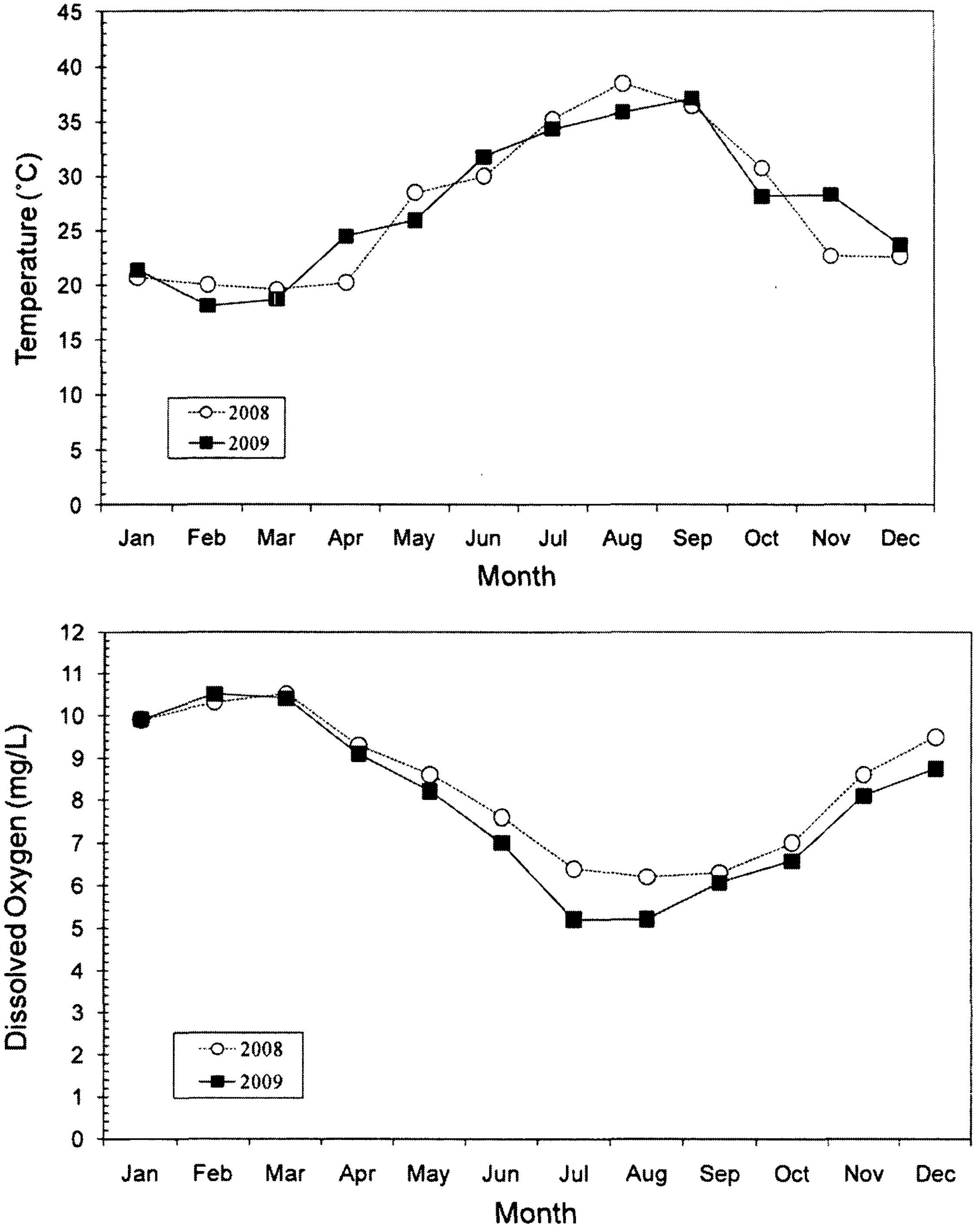

Figure 2-5. Monthly surface (0.3m) temperature and dissolved oxygen data at the discharge location (Location 4.0) in 2008 and 2009.

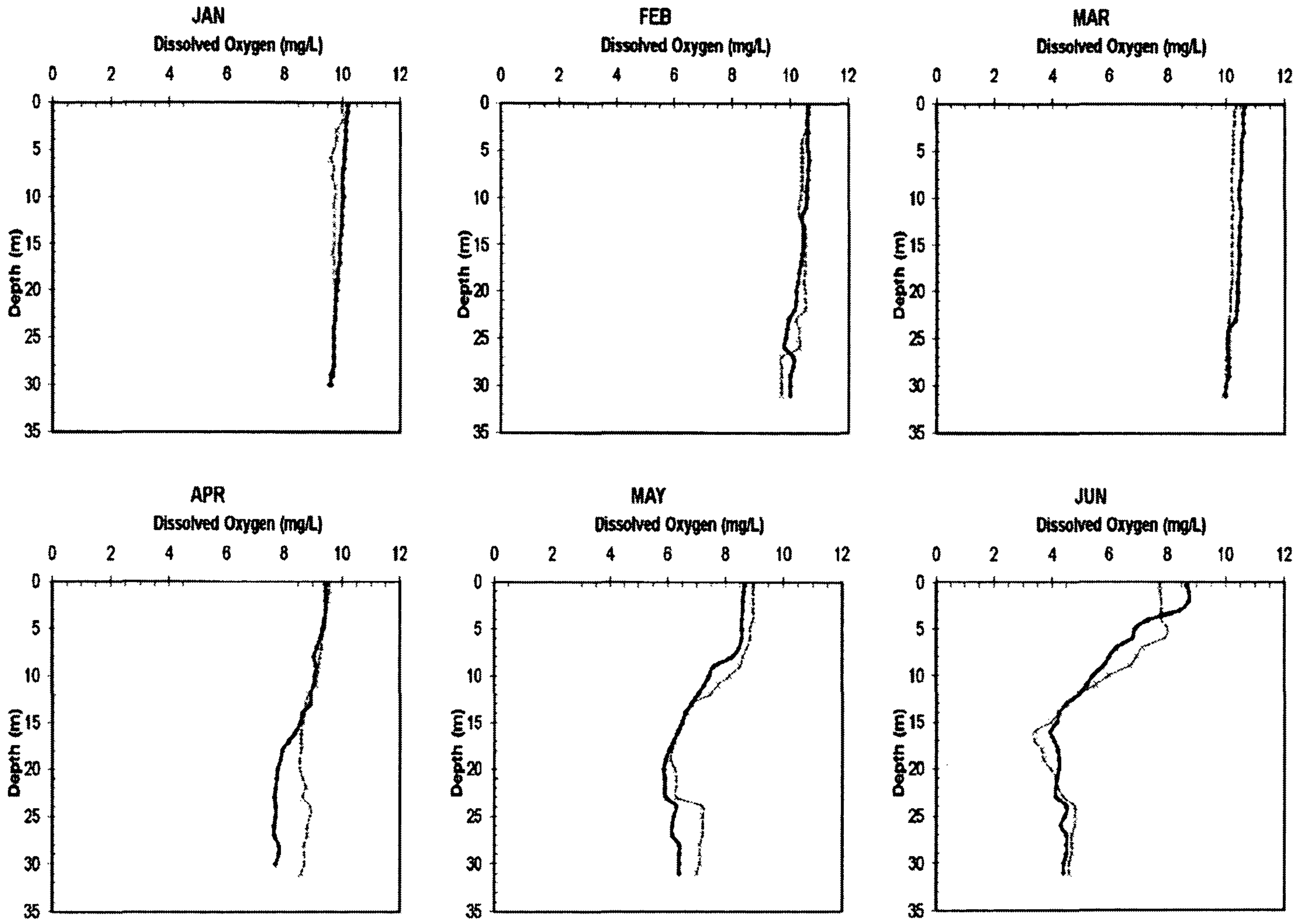

Figure 2-6. Monthly mean dissolved oxygen profiles for the MNS background zone in 2008 (××) and 2009 (♦♦).

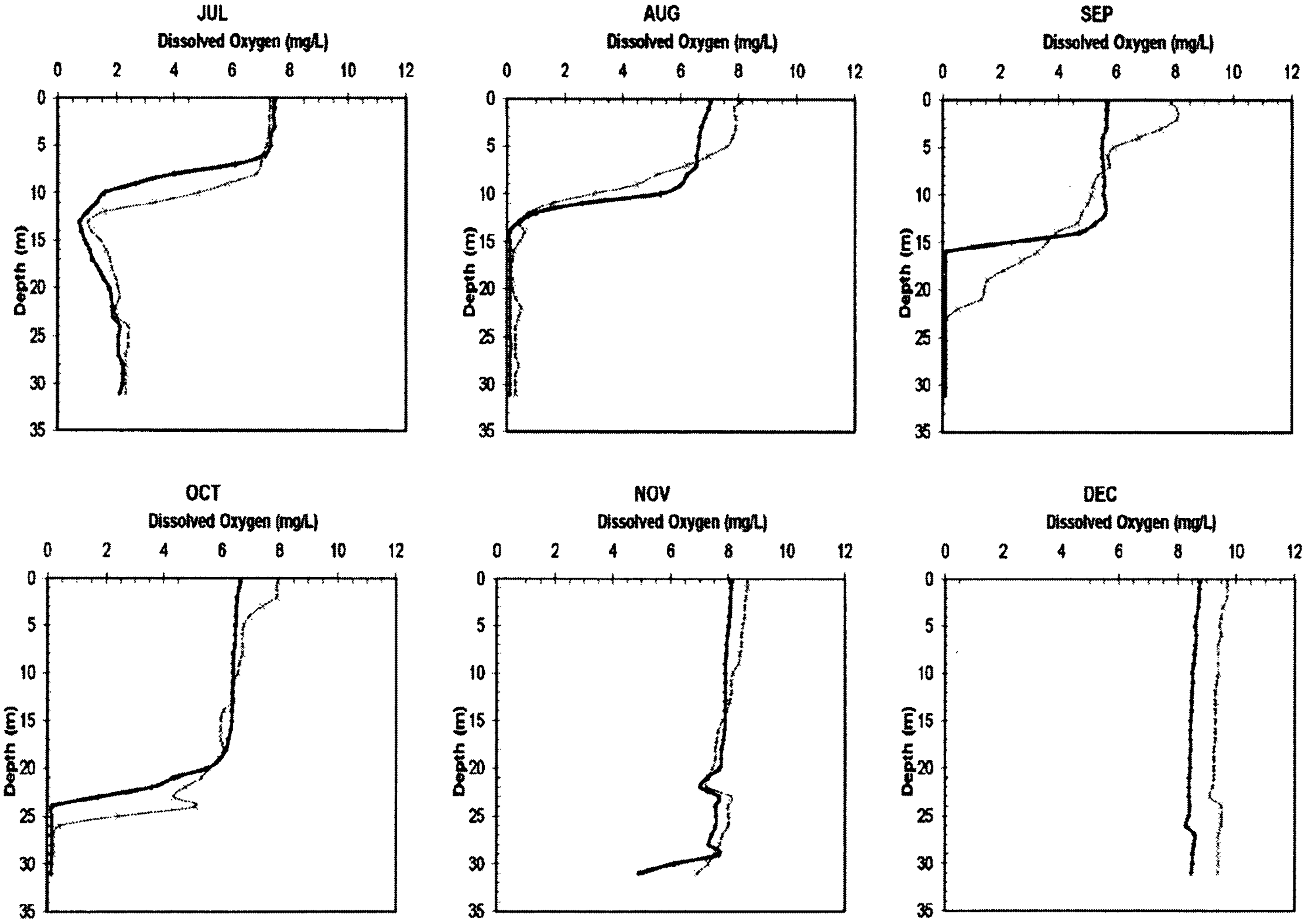

Figure 2-6. (Continued).

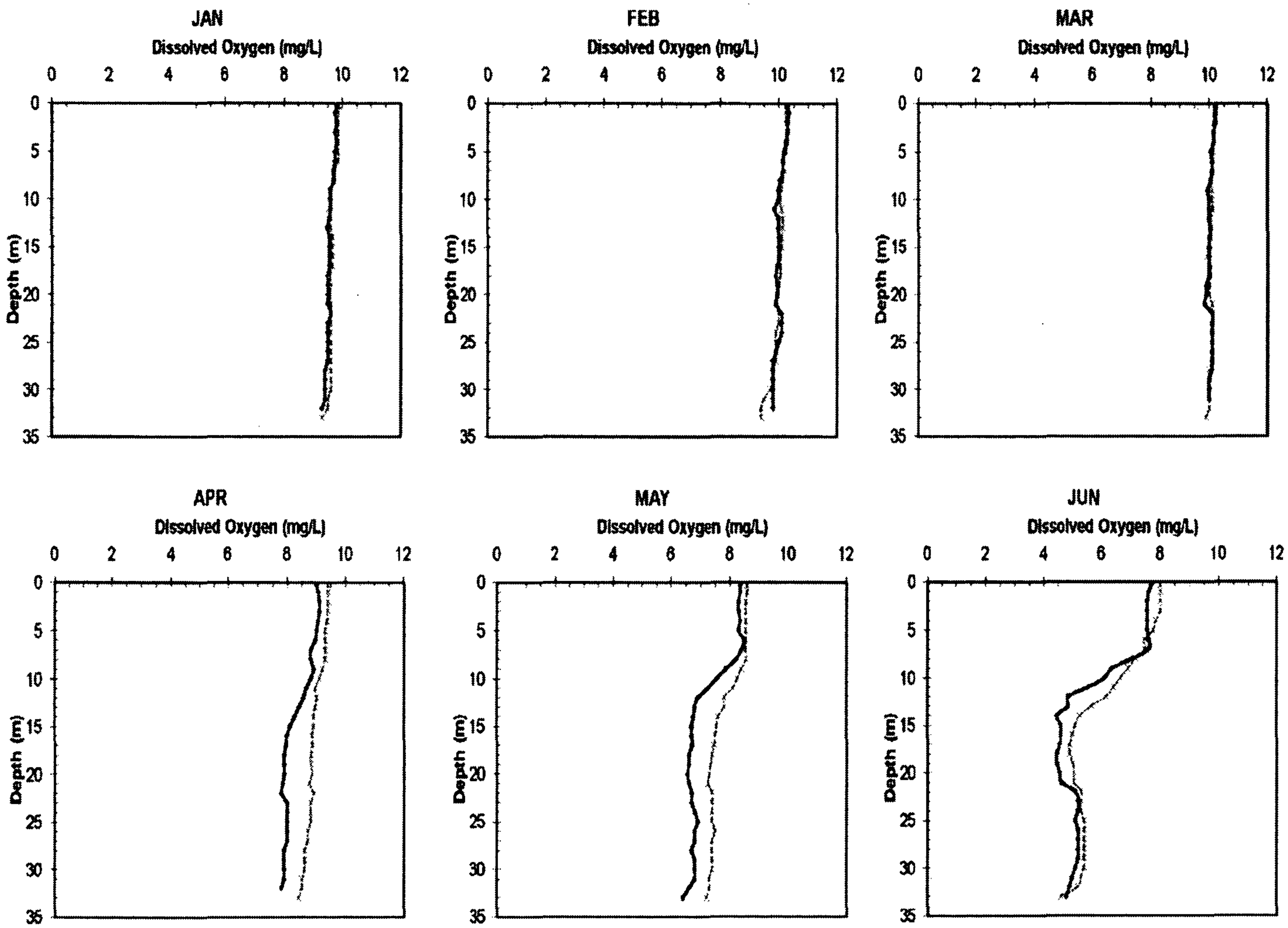

Figure 2-7. Monthly mean dissolved oxygen profiles for the MNS mixing zone in 2008 (××) and 2009 (♦♦).

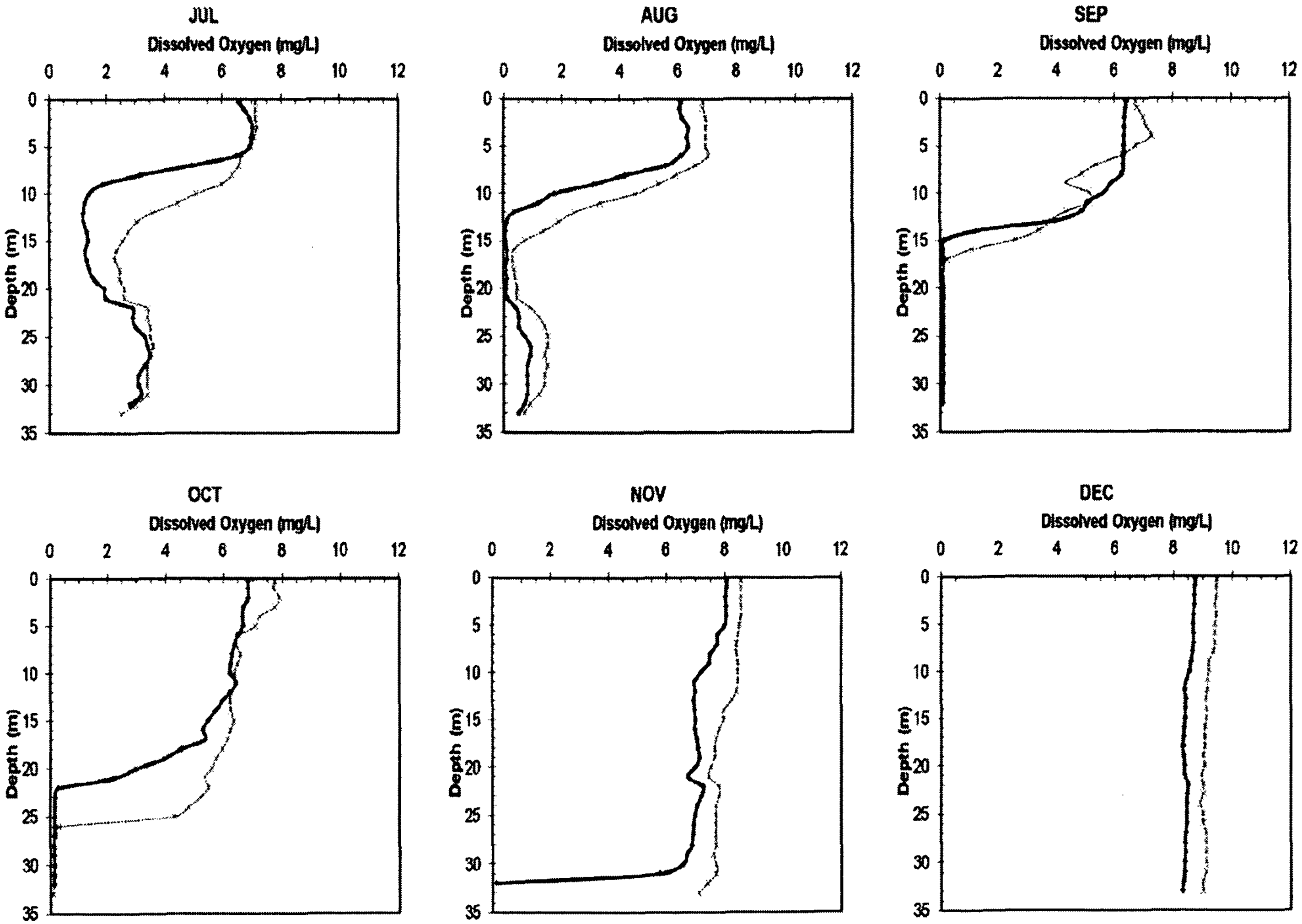

Figure 2-7. (Continued).

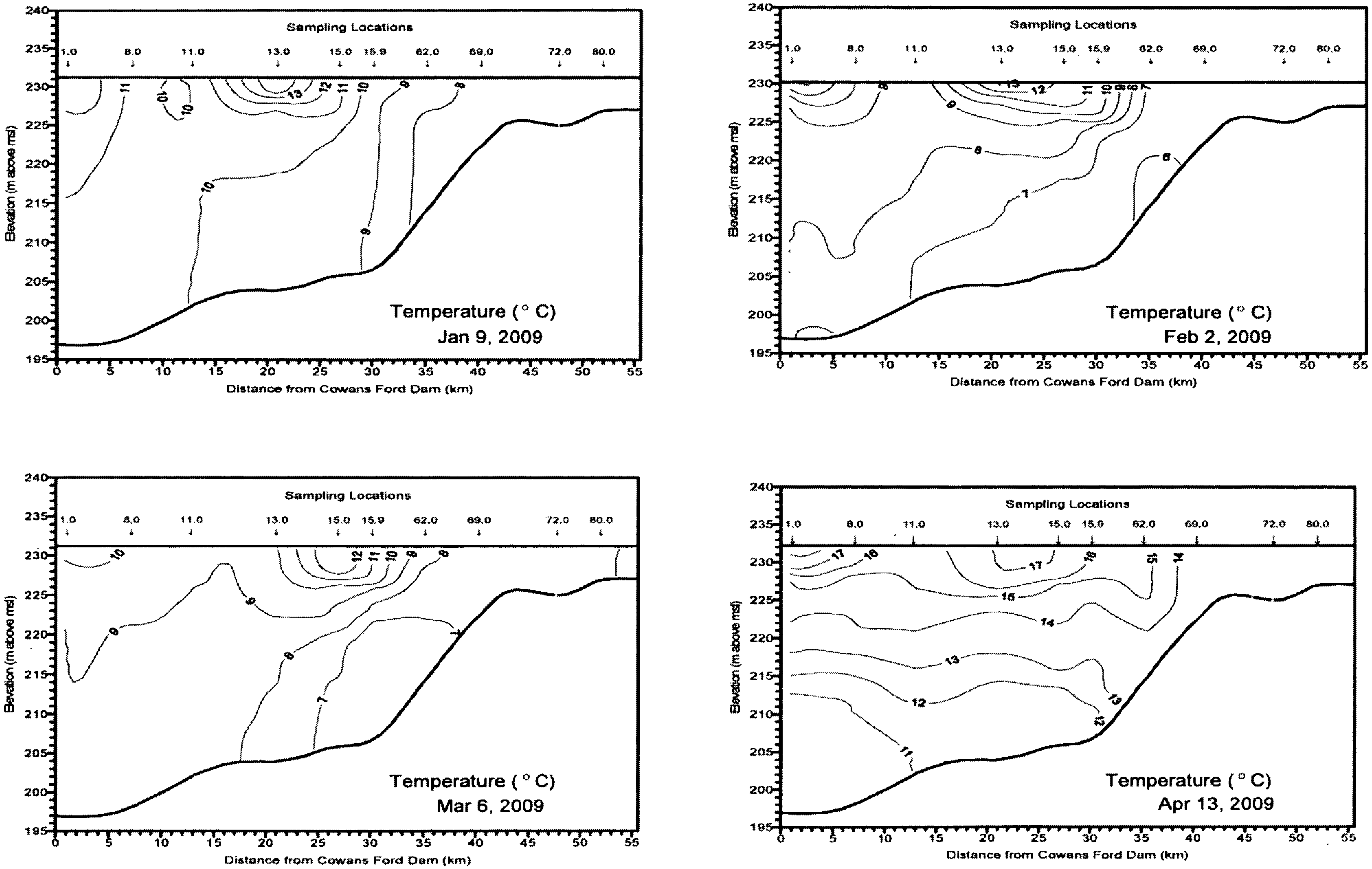

Figure 2-8. Monthly reservoir-wide temperature isotherms for Lake Norman in 2009.

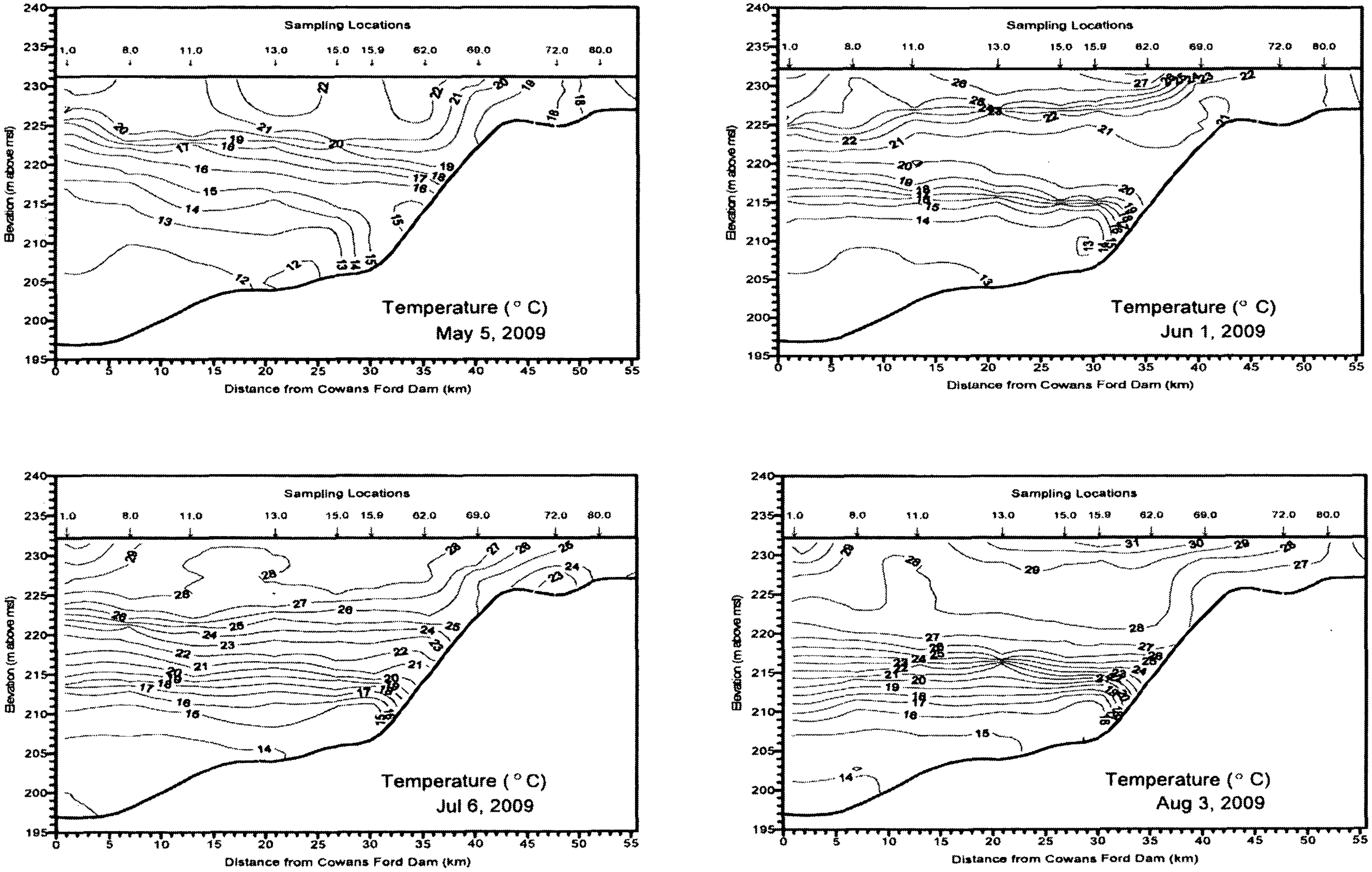

Figure 2-8. (Continued).

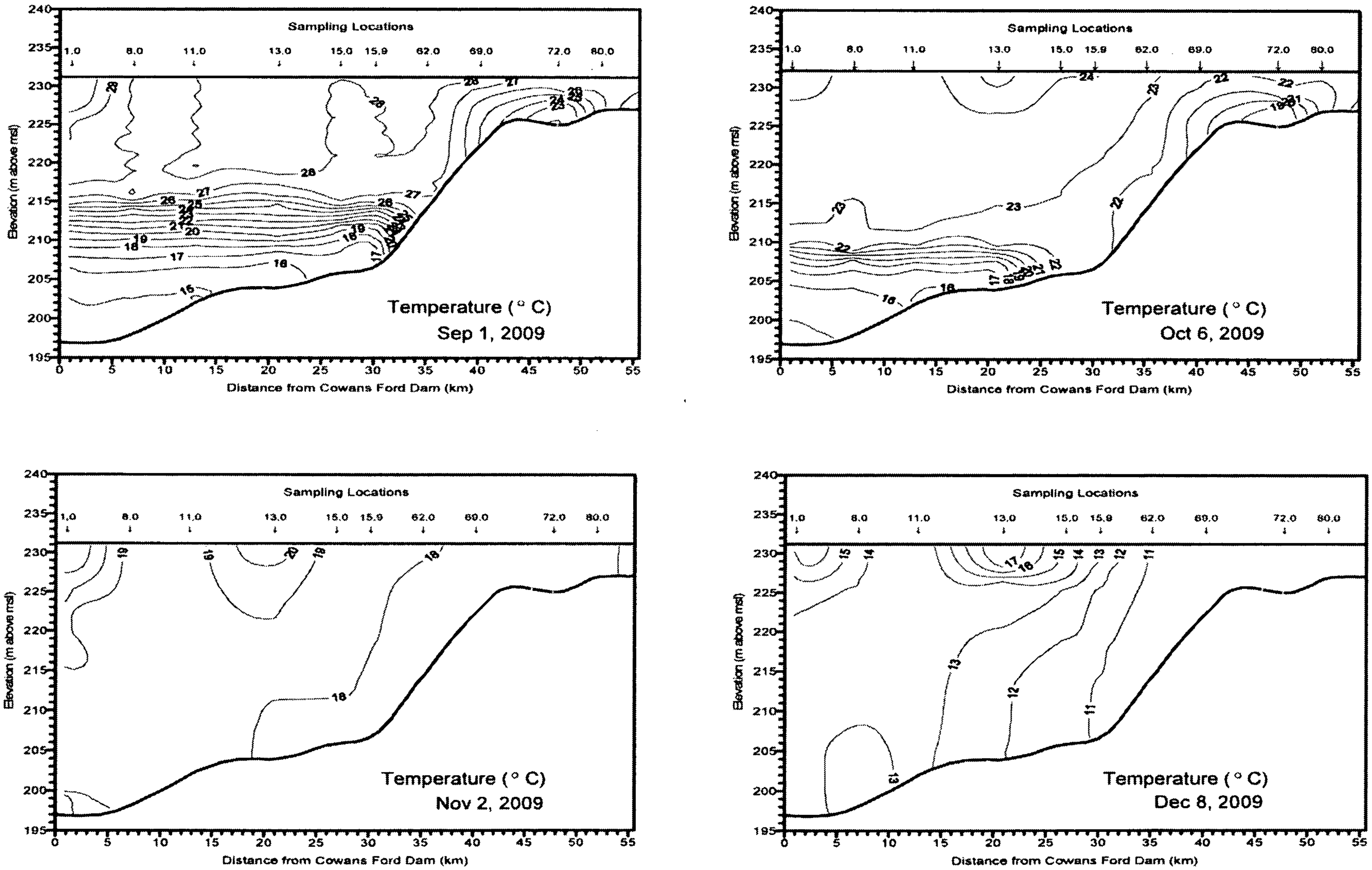

Figure 2-8. (Continued).

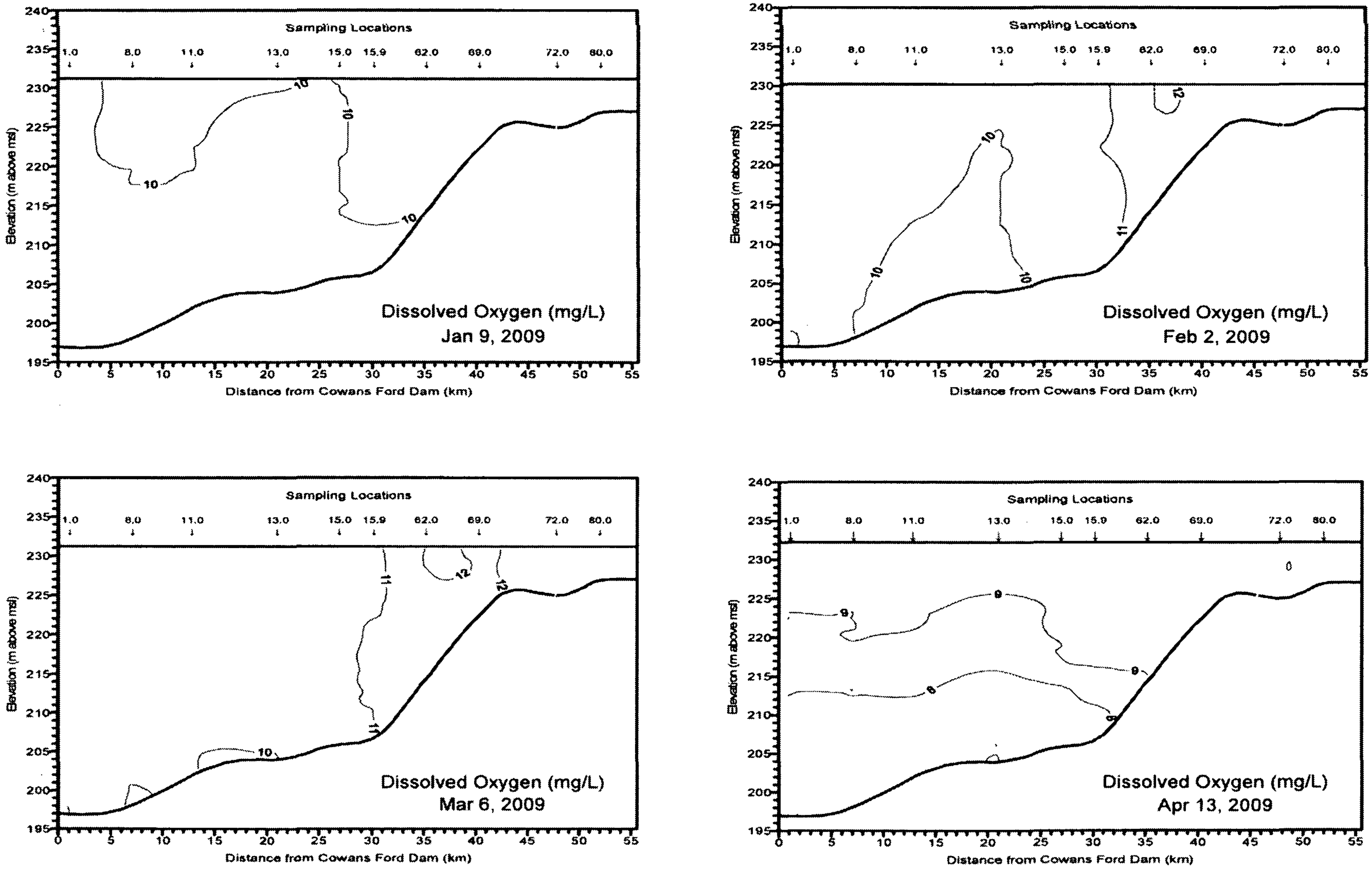

Figure 2-9. Monthly reservoir-wide dissolved oxygen isopleths for Lake Norman in 2009.

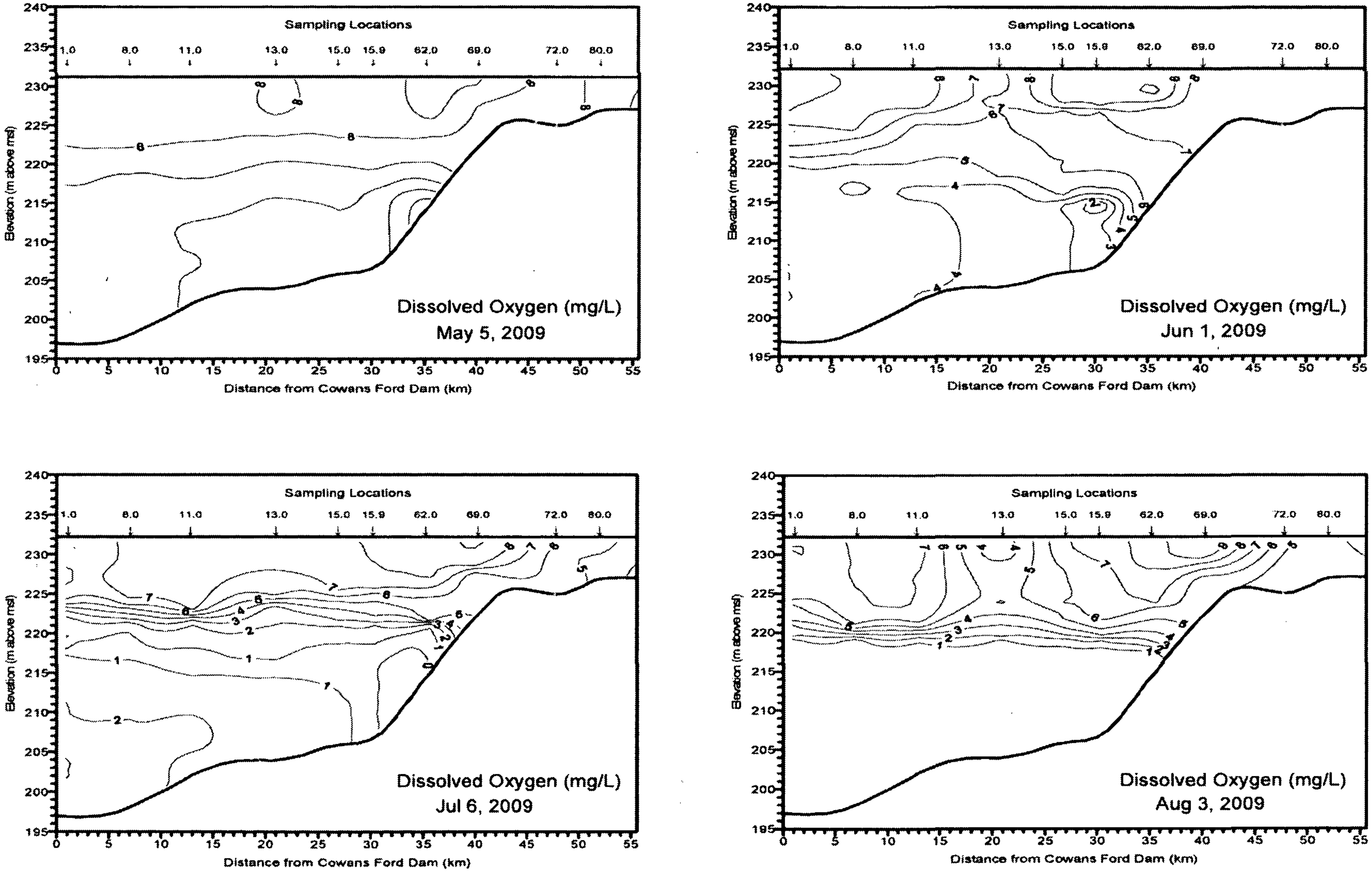

Figure 2-9. (Continued).

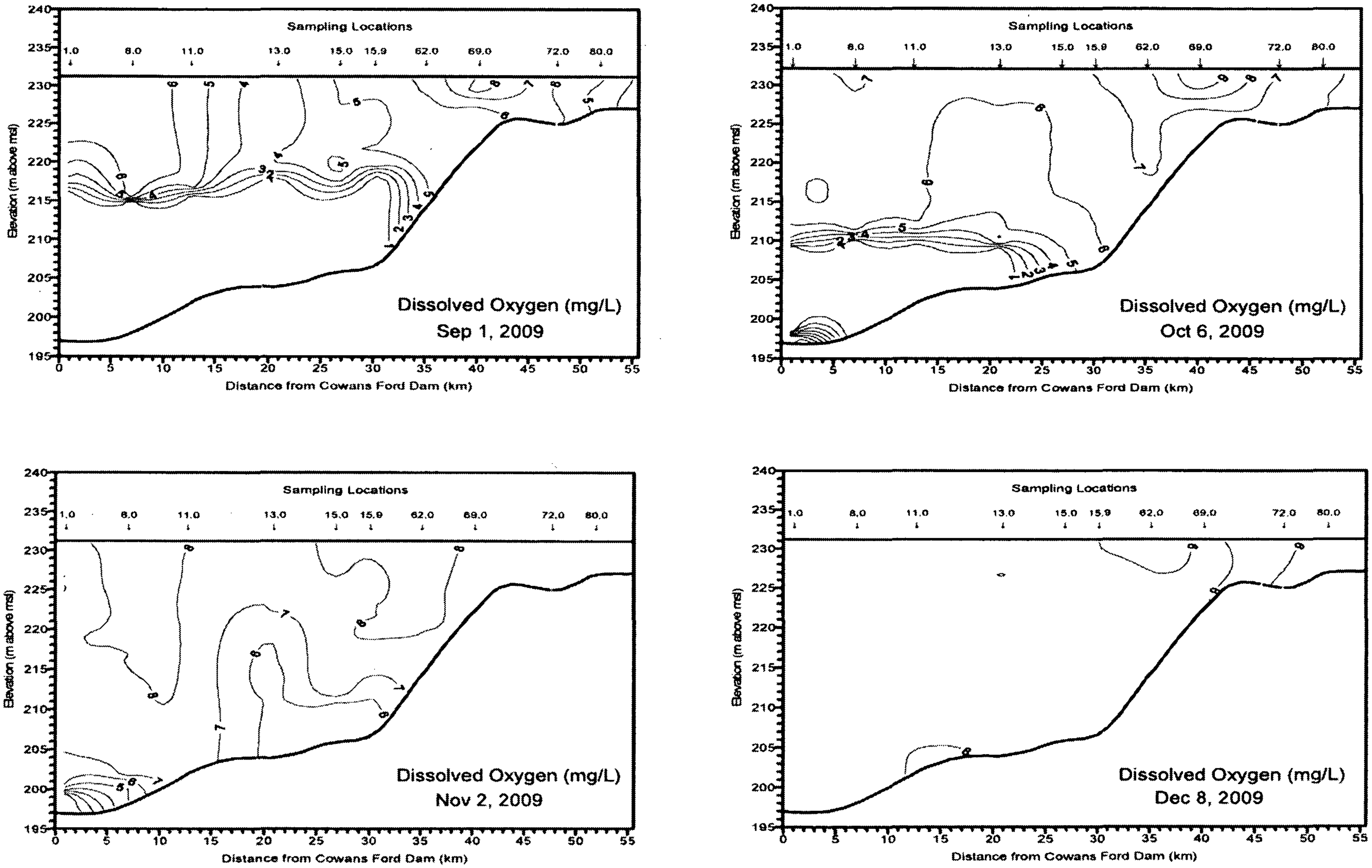

Figure 2-9. (Continued).

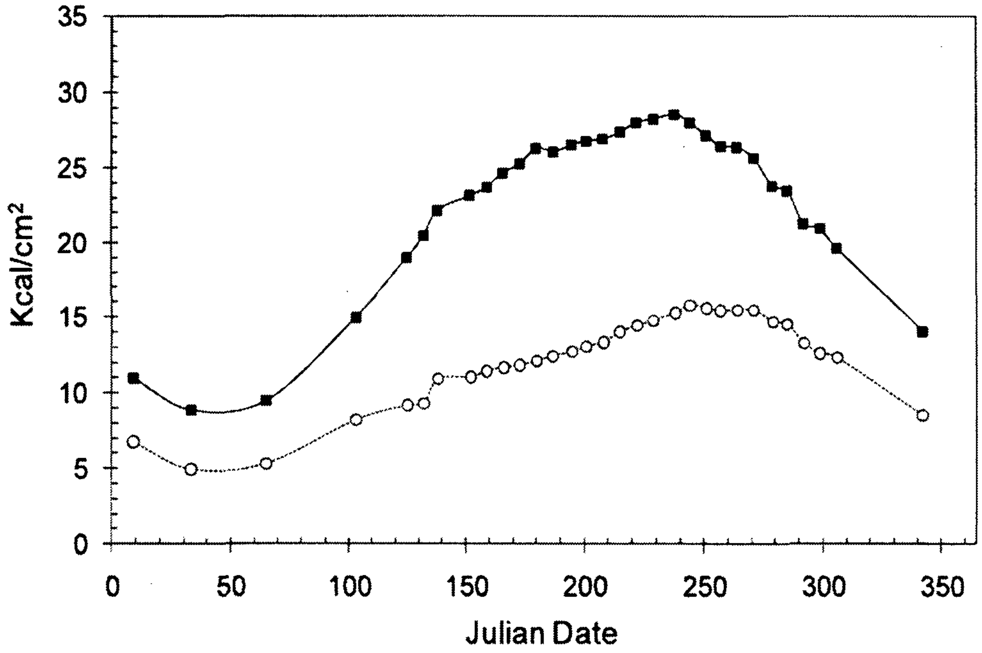

Figure 2-10a. Heat content of the entire water column (■) and the hypolimnion (○) in Lake Norman in 2009.

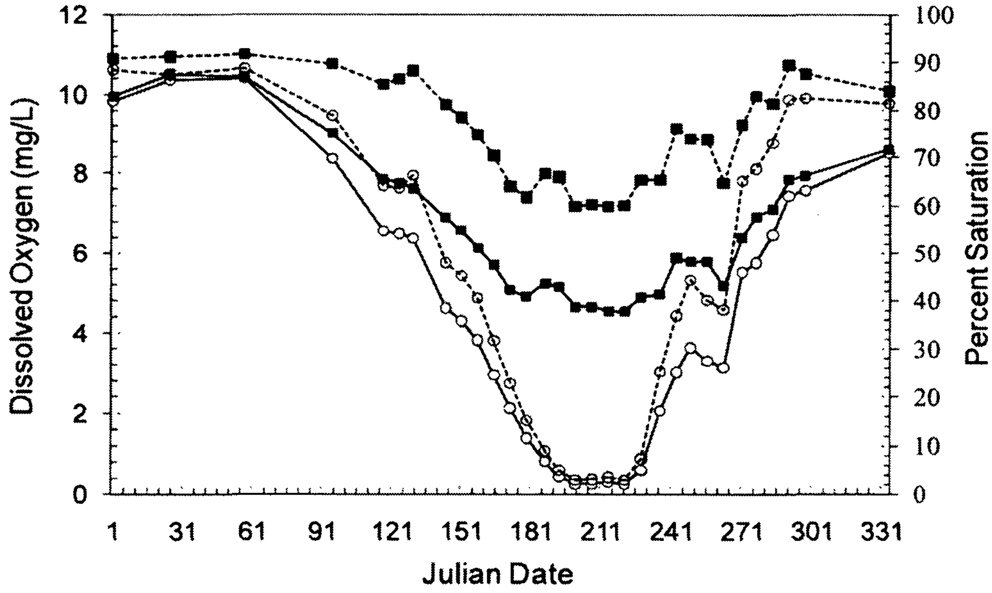

Figure 2-10b. Dissolved oxygen content (–) and percent saturation (---) of the entire water column (■) and the hypolimnion (○) of Lake Norman in 2009.

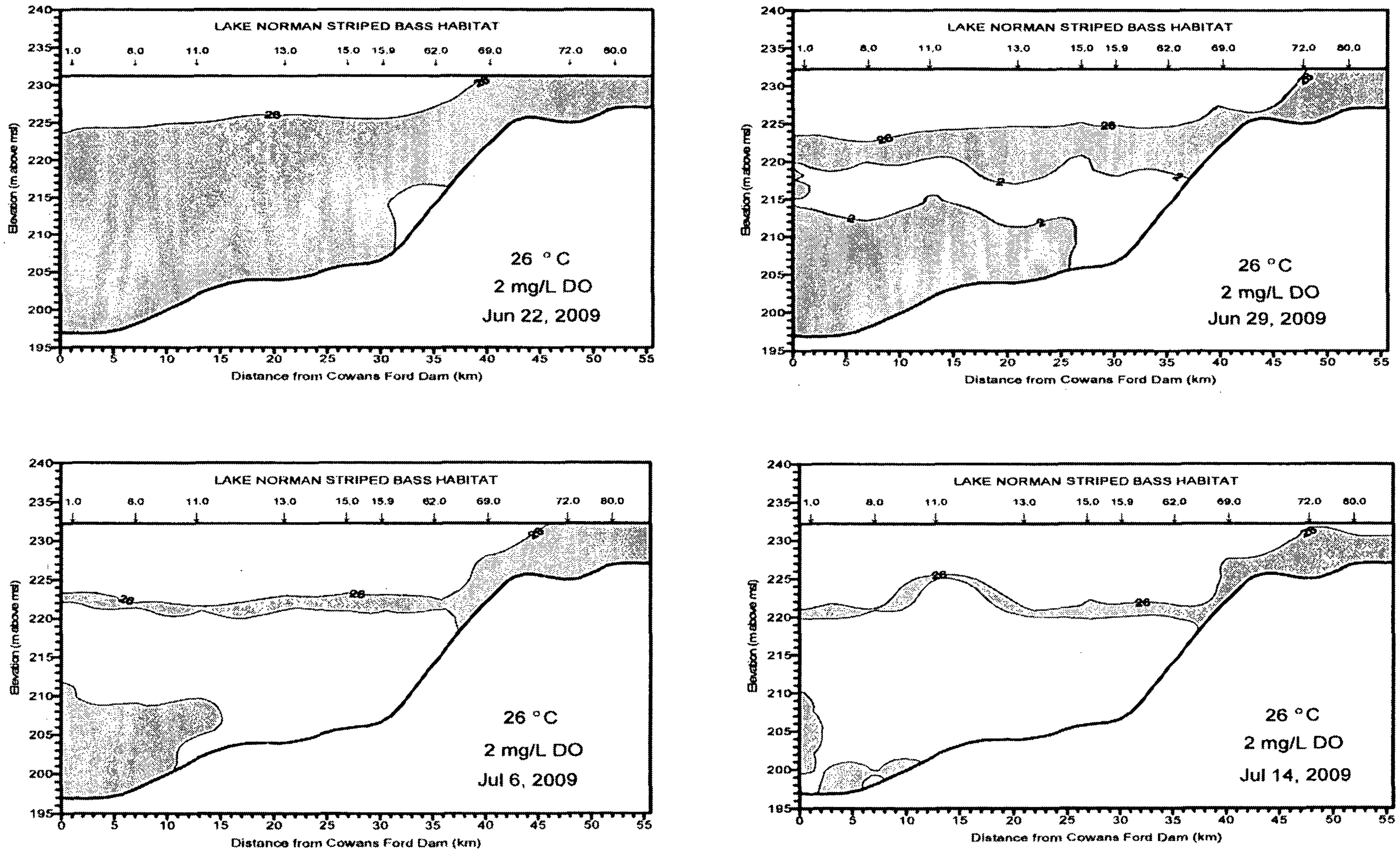

Figure 2-11. Striped bass habitat (shaded areas; temperatures ≤ 26 °C and dissolved oxygen ≥ 2 mg/L) in Lake Norman in June, July, August, and September 2009.

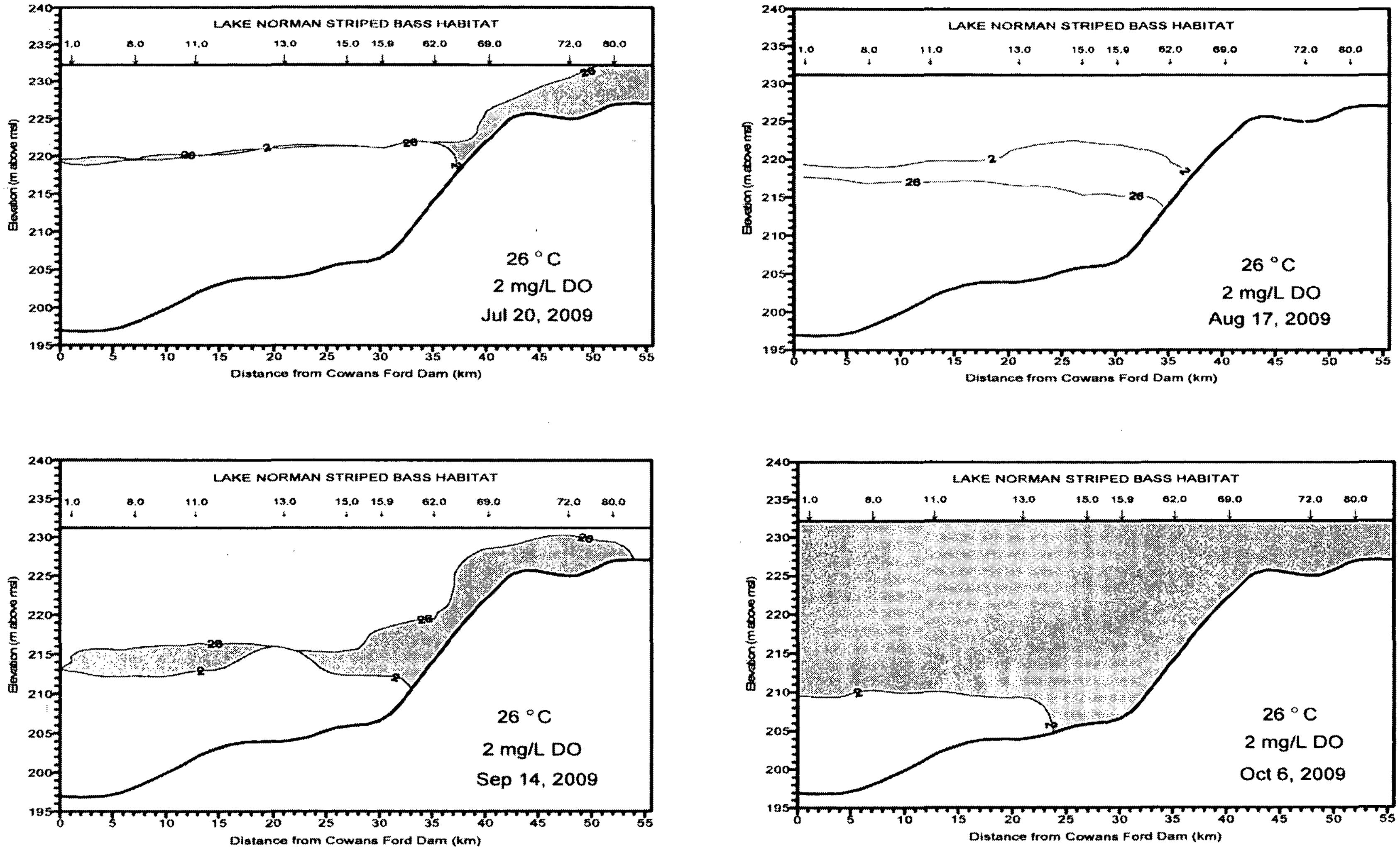

Figure 2-11. (Continued).

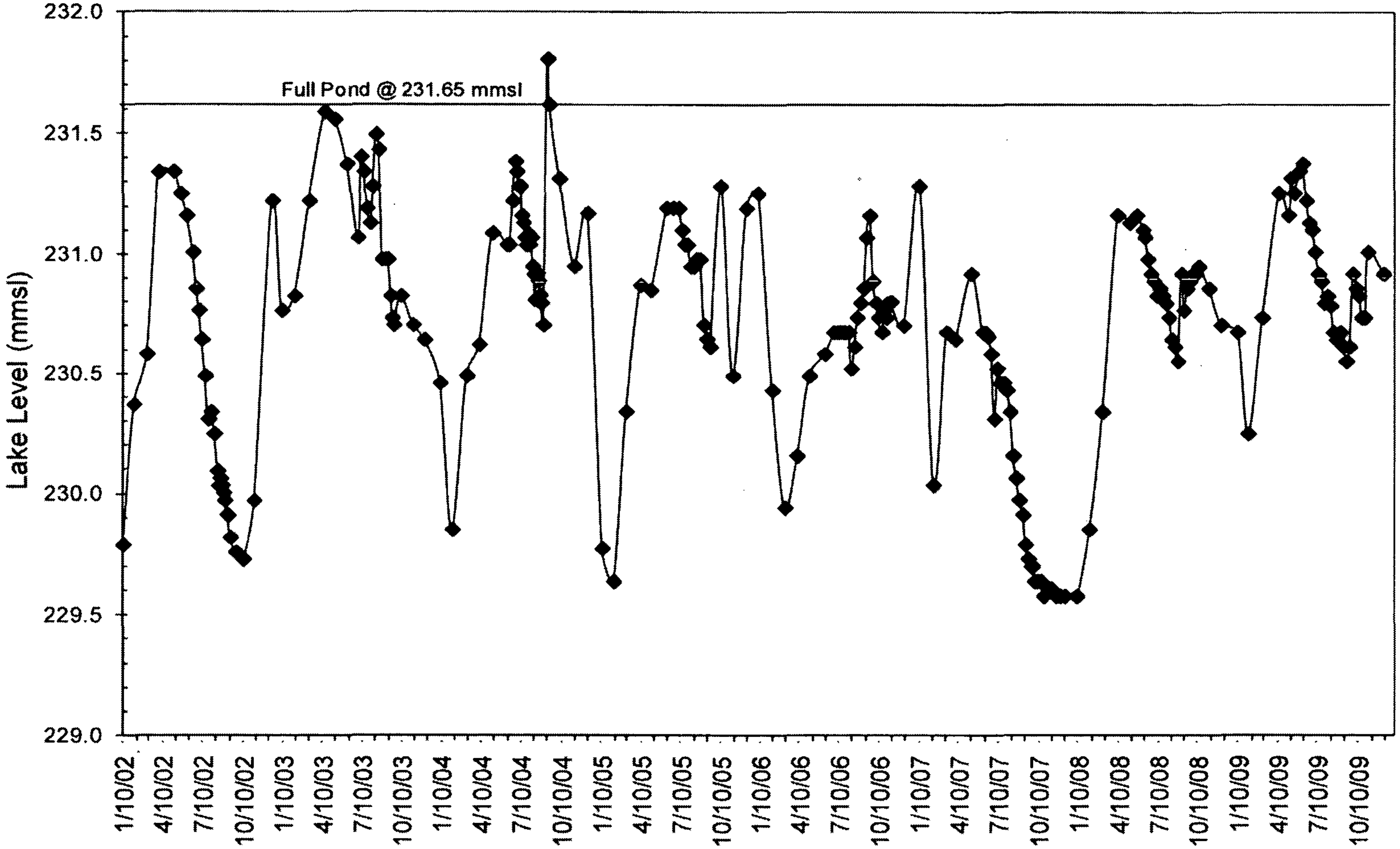

Figure 2-12. Lake Norman lake levels, expressed in meters above mean sea level (mmsl) for 2002, 2003, 2004, 2005, 2006, 2007, 2008, and 2009. Lake level data correspond to the water quality sampling dates over this time period.

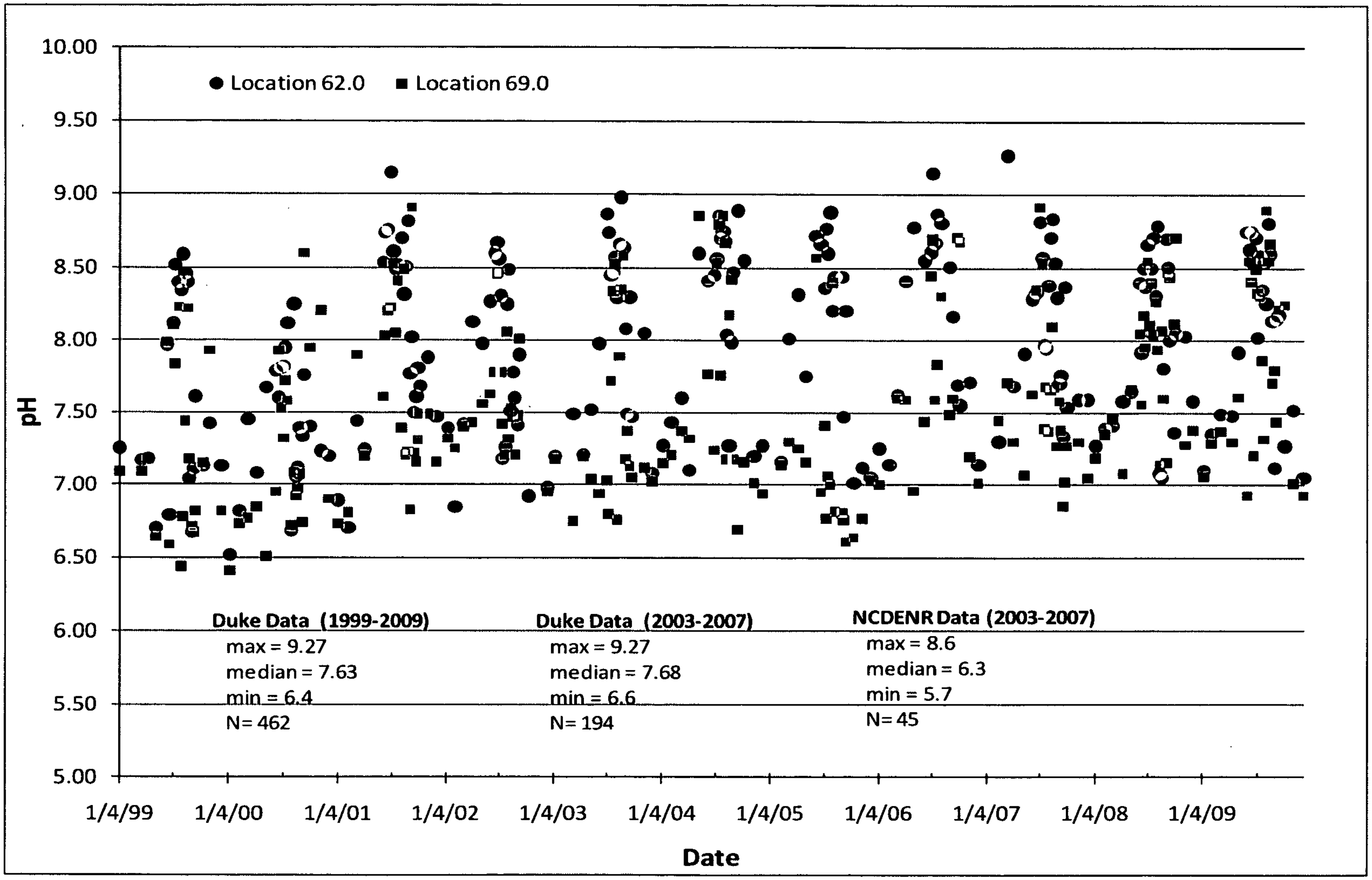

Figure 2-13. Lake Norman pH values for Locations 62.0 and 69.0 over period 1999 – 2009. Also included are corresponding descriptive statistical data.

CHAPTER 3

PHYTOPLANKTON

INTRODUCTION

Phytoplankton standing crop parameters were monitored in 2009 in accordance with the NPDES permit for McGuire Nuclear Station (MNS). The objectives of the phytoplankton study of the Lake Norman Maintenance Monitoring Program are to:

1. describe quarterly/seasonal patterns of phytoplankton standing crop and species composition throughout Lake Norman; and
2. compare phytoplankton data collected during the 2009 study with data collected in prior study years (1987 – 2008).

In studies conducted on Lake Norman prior to the Lake Norman Maintenance Monitoring Program, considerable spatial and temporal variability in phytoplankton standing crops and taxonomic composition were reported (Duke Power Company 1976, 1985; Menhinick and Jensen 1974; Rodriguez 1982). Rodriguez (1982) classified the lake as oligo-mesotrophic (low to intermediate productivity) based on phytoplankton abundance, distribution, and taxonomic composition. Past maintenance monitoring program studies have confirmed this classification (Duke Energy 2009).

METHODS AND MATERIALS

Quarterly sampling was conducted at Locations 2.0 and 5.0 in the Mixing Zone, and Locations 8.0, 9.5, 11.0, 13.0, 15.9, and 69.0 in Lake Norman (Figure 2-1). Duplicate Van Dorn samples from 0.3, 4.0, and 8.0 m (i.e., the estimated euphotic zone) were taken and then composited at all locations except Location 69.0, where Van Dorn samples were taken at 0.3, 3.0, and 6.0 m due to the shallower depth. Sampling was conducted in February, May, August, and November 2009. Secchi depths were recorded from all sampling locations. As in previous years and based on the original study design (Duke Power Company 1988), phytoplankton density, biovolume, and taxonomic composition were determined for samples collected at Locations 2.0, 5.0, 9.5, 11.0, and 15.9; chlorophyll *a* concentrations and seston dry and ash-free dry weights were determined for samples from all locations. Chlorophyll *a* and total phytoplankton densities and biovolumes were used in determining phytoplankton standing crops. Field sampling and laboratory methods used for chlorophyll *a*, seston dry weights, and population identification and enumeration were identical to those used by Rodriguez (1982). Data collected in 2009 were compared with corresponding data from quarterly monitoring beginning in August 1987.

RESULTS AND DISCUSSION

Standing Crop

Chlorophyll a

Chlorophyll concentrations from all locations were averaged each quarter to calculate a lake-wide mean. Lake-wide mean chlorophyll concentrations were within ranges of those reported in previous years, but the lake-wide mean for November was very near the long-term minimum for that time of year (Figure 3-1). The lake-wide average in February was above the long-term mean, while averages for May and August were below long-term means for these periods.

Chlorophyll *a* concentrations (mean of two replicate composites) ranged from a low of 1.53 µg/L at Location 69.0 in November, to a high of 13.24 µg/L also at Location 69.0 in August (Table 3-1 and Figure 3-2). All values were below the North Carolina water quality standard for outfalls of 40 µg/L (NCDENR 1991). Seasonally, chlorophyll *a* concentrations decreased from February through May, and then increased through August to the annual lake-wide maximum followed by a decline to the annual lake-wide minimum in November. Based on quarterly mean chlorophyll concentrations, the trophic level of Lake Norman was in the oligotrophic (low) range during May and November and in the mesotrophic (intermediate) range in February and August of 2009. Over 37% of the mean chlorophyll *a* values were less than 4 µg/L (oligotrophic), while all but one of the remaining chlorophyll *a* values were between 4 and 12 µg/L (mesotrophic). The chlorophyll concentration from Location 69.0 in August was the only one greater than 12 µg/L (eutrophic, or high range). Historically, quarterly mean concentrations of <4 µg/L have been recorded on 22 previous occasions, while lake-wide mean concentrations of >12 µg/L were only recorded during May of 1997 and 2000 (Duke Power 1998, 2001; Duke Energy 2009).

During 2009, chlorophyll *a* concentrations showed typical spatial variability. Maximum concentrations among sampling locations were observed at Location 69.0 (furthest uplake) during February and August, while the May and November maxima were recorded from Location 15.9 (Table 3-1 and Figure 3-1). Minimum concentrations occurred at Locations 2.0, 5.0, and 8.0 during February, May, and August, respectively. The minimum in November occurred at Location 69.0 The trend of increasing chlorophyll concentrations from downlake to uplake, which had been observed during many previous years, was apparent for the most part during all sampling periods of 2009 (Table 3-1 and Figure 3-1).

Flow in the riverine zone of a reservoir is subject to wide fluctuations depending, ultimately, on meteorological conditions (Thornton et al. 1990), although influences may be moderated due to upstream dams. During periods of high flow, algal production and standing crop are depressed due in great part to washout. Conversely, production and standing crop increases during periods of low flow which results in high retention time. However, over long periods of low flow, production and standing crop gradually decline once more. These conditions result in the comparatively high variability in chlorophyll *a* concentrations observed between Locations 15.9 and 69.0 throughout many previous years, as opposed to Locations 2.0 and 5.0 which have usually shown similar concentrations during sampling periods.

Quarterly chlorophyll *a* concentrations during the period of record (August 1987 – November 2009) have varied considerably, resulting in moderate to wide historical ranges. During February 2009, chlorophyll *a* values were in the mid to high ranges for this time of year (Figure 3-3). Long-term February peaks at Locations 2.0, 5.0, 8.0, and 9.5 occurred in 1996, while the long-term February peak at Location 11.0 was observed in 1991. Long-term maxima at Locations 13.0 and 15.9 occurred in 2003. The highest February value at location 69.0 occurred in 2001. All locations demonstrated higher chlorophyll concentrations in February 2009 than in February 2008 (Duke Energy 2009).

During May, mean chlorophyll *a* concentrations at all locations were in the low to mid historical ranges (Figure 3-4). Long-term May peaks at Locations 2.0 and 9.5 occurred in 1992; at Location 5.0 in 1991; at Locations 8.0, 11.0, and 13.0 in 1997; at Location 15.9 in 2000; and at Location 69.0 in 2001. May 2009 mean chlorophyll concentrations at all locations were higher than those of May 2008 (Duke Energy 2009).

The lake-wide mean chlorophyll *a* concentration in August 2009 was slightly below the long-term mean for August. Concentrations from all but Location 8.0 were in the mid historical range. The concentration from Location 8.0 was among the lowest August concentrations yet recorded from this location (Figure 3-5). Long-term August peaks at Locations 2.0, 5.0, and 15.9 were observed in 1998, while August peaks at Locations 8.0 and 9.5 occurred in 1993. The long-term August peak at Location 11.0 was observed in 1991, while Location 69.0 experienced its long-term August peak in 2001. The long-term peak at Location 13.0 occurred in 2008. Mean chlorophyll *a* concentrations at Locations 2.0, 5.0, 9.5, 15.9, and 69.0 in August 2009 were higher than those of August 2008, while Locations 8.0, 11.0, and 13.0 expressed lower concentrations in August 2009 than in August of the previous year (Duke Energy 2009).

The lake-wide mean chlorophyll *a* concentration in November 2009 was the lowest among all four sampling periods and was very near the long-term November minimum (Figure 3-2). Chlorophyll *a* concentrations at locations were in the low historical range (Figure 3-6). Long-term November peaks at Locations 5.0 and 8.0 occurred in 2006, while November maxima at Locations 11.0 and 15.9 occurred in 1996. The highest November value at Location 13.0 was recorded for 1992, while the November maxima at Locations 2.0 and 9.5 were observed in 1997. The highest November chlorophyll *a* concentration at Location 69.0 occurred in 1991. November 2009 chlorophyll *a* concentrations were lower than during November 2008 (Duke Energy 2009).

Total Abundance

Density and biovolume are measurements of phytoplankton numbers and biomass. In most cases, standing crop parameters mirror the temporal trends of chlorophyll concentrations. During 2009 this was not entirely the case. Although phytoplankton densities and biovolumes were typically highest in August, as was the case with chlorophyll *a*, mean standing crop variables demonstrated lowest annual values in May instead of November. The lowest densities (536 units/mL) were recorded from Locations 2.0 and 5.0 in May, while the minimum biovolume (294 mm^3/m^3) occurred at Location 2.0 also in May (Table 3-2 and Figure 3-1). The maximum density (4,569 units/mL) and biovolume (3,855 mm^3/m^3) were observed at Location 15.9 in August. Densities during May, August, and November of 2009 were lower than those observed during these periods of 2008. Biovolumes during February, May, and August of 2009 were higher than in 2008 (Duke Energy 2009). This disparity was likely due to taxonomic variations from year to year with shifts from taxa with lower individual biovolumes to those with higher individual biovolumes. Phytoplankton densities and biovolumes during 2009 never exceeded the NC state guidelines for algae blooms of

10,000 units/mL density and 5,000 mm^3/m^3 biovolume (NCDEHNR 1991). Densities or biovolumes in excess of NC state guidelines were recorded in 1987, 1989, 1997, 1998, 2000, 2003, 2006, and 2008 (Duke Power Company 1988, 1990; Duke Power 1998, 1999, 2001, 2004a; Duke Energy 2007, 2009).

During all sampling periods phytoplankton densities and biovolumes demonstrated a spatial trend similar to that of chlorophyll *a*; that is, lower values at downlake locations verses uplake locations (Table 3-2 and Figure 3-1).

Seston

Seston dry weights represent a combination of algal matter and other organic and inorganic material. Dry weights during February and May of 2009 were most often higher than those recorded during these months in 2008, while August and November values in 2009 were generally lower than August and November of 2008 (Duke Energy 2009 and Table 3-3). A general pattern of increasing values from downlake to uplake was observed during May and August 2009, as was observed with chlorophylls and algal standing crops; however, in February and November, this pattern was not pronounced even though Location 69.0 demonstrated the highest dry weights (Figure 3-1). From 1995 through 1997, seston dry weights had been increasing (Duke Power 1998). Values from 1998 through 2001 represented a reversal of this trend, and were in the low range at most locations during 1999 through 2001 (Duke Power 2002). Low dry weights during these years were likely a result of prolonged drought conditions (Figure 2-2a) resulting in low sedimentation from runoff. From 2002 through 2006 dry weights gradually increased throughout the Lake followed by a dramatic decline in 2007. The lake-wide average dry weight in 2007 was the lowest since dry weights were recorded in 1988. These exceptionally low values were likely due to severe drought conditions throughout the watershed during 2007. During 2008, dry weights increased again compared to 2007. This was followed by a slight decline in 2009.

Seston ash-free dry weights represent organic material and may reflect trends of chlorophyll *a* and phytoplankton standing crop values. This relationship held true for May and August of 2009, especially with respect to increasing values from downlake to uplake areas; however, as with dry weights, this trend was not apparent in February and November (Tables 3-1 through 3-3). Ash-free dry weights also showed the same temporal trend as dry weights when compared to 2008 with values in February and May 2009 higher than in 2008, while the opposite was true in August and November (Duke Energy 2009).

Secchi Depths

Secchi depth is a measure of light penetration. Secchi depths were often the inverse of suspended sediment (seston dry weight), with the shallowest depths at Locations 13.0 through 69.0 and deepest from Locations 9.5 through 2.0 downlake. Depths ranged from 1.1 m at Location 69.0 in August, to 2.8 m at Location 8.0 in May (Table 3-1). The lake-wide mean Secchi depth during 2009 was slightly lower than in 2008 and was within historical ranges for the years since measurements were first reported in 1992. The deepest lake-wide mean Secchi depth was recorded in 1999 (Duke Power 2000).

Community Composition

One indication of "balanced indigenous populations" in a reservoir is the diversity, or number of taxa observed over time. Lake Norman typically supports a rich community of phytoplankton species. This was certainly true in 2009. Ten classes comprising 99 genera and 271 species, varieties, and forms of phytoplankton were identified in samples collected during 2009, as compared to 98 genera and 247 species, varieties, and forms of phytoplankton identified 2008 (Table 3-4). The 2009 total represented the highest number of taxa recorded in any year since monitoring began in 1987 (Duke Energy 2008). Ten taxa previously unrecorded during the Lake Norman Maintenance Monitoring Program were identified during 2009.

Species Composition and Seasonal Succession

The phytoplankton community in Lake Norman varies both seasonally and spatially. Additionally, considerable variation may occur between years for the same months sampled.

During February 2009, diatoms (Bacillariophyceae) dominated densities at all locations (Table 3-5 and Figures 3-7 through 3-11). During most previous years, cryptophytes (Cryptophyceae) and occasionally diatoms dominated February phytoplankton samples in Lake Norman. The most abundant diatom during February 2009 was the pennate, *Tabellaria fenestrata,* one of the most common and abundant forms observed in Lake Norman samples since monitoring began in 1987.

In May, diatoms once again dominated samples at all locations. The most abundant diatom at Locations 2.0, 5.0, and 9.5 was the centrate, *Cyclotella stelligera.* At Locations 11.0 and

15.9, the pennate diatom, *Fragilaria crotonensis* was the most abundant species. Diatoms have typically been the predominant forms in May of previous years; however, cryptophytes were dominant in May 2008 and often dominated May samples from 1988 – 1995 (Duke Power Company 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

During August 2009, green algae (Chlorophyceae) dominated densities at all locations (Table 3-5, Figures 3-7 through 3-11). The most abundant green alga was the small desmid, *Cosmarium asphearosporum var. strigosum* (Table 3-7). Prior to 1999, green algae, with blue-green algae (Myxophyceae) as occasional dominants or co-dominants, were the primary constituents of summer phytoplankton assemblages, and the predominant green alga was also *C. asphearosporum var. strigosum* (Duke Power Company 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999). During August periods of 1999 through 2001, Lake Norman summer phytoplankton assemblages were dominated by diatoms, primarily the small pennate, *Anomoeoneis vitrea* (Duke Power 2000, 2001, 2002). *A. vitrea* has been described as typically periphytic and widely distributed in freshwater habitats, and it was identified as a major contributor to periphyton communities on natural substrates during studies conducted from 1974 through 1977 (Derwort 1982). The possible causes of this significant shift in summer taxonomic composition were discussed in earlier reports and included deeper light penetration (the three deepest lake-wide Secchi depths were recorded from 1999 through 2001), extended periods of low water due to drawdown, and shifts in nutrient inputs and concentrations (Duke Power 2000, 2001, 2002). Whatever the cause, the phenomenon was lake-wide and not localized near MNS or Marshall Steam Station (MSS), therefore, it was most likely due to a combination of environmental factors, and not station operations. Since 2002, taxonomic composition during the summer has shifted back to green algae predominance (Duke Power 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

During November 2009, densities at all locations were once again dominated by diatoms and the most abundant species was again *T. fenestrata* (Table 3-5; Figures 3-7 through 3-11). As is the case with May, diatoms have typically been dominant during past November periods, with occasional dominance by cryptophytes (Duke Power Company 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Blue-green algae, which are often implicated in nuisance blooms, were never abundant in 2009 samples. Their overall contribution to phytoplankton densities was slightly higher than in 2008; however, densities seldom exceeded 2% of totals (Duke Energy 2009). Prior to 1991, blue-green algae were often dominant at uplake locations during the summer (Duke Power Company 1988, 1989, 1990, 1991, 1992).

FUTURE STUDIES

No changes are planned for the phytoplankton portion of the Lake Norman Maintenance Monitoring Program.

SUMMARY

Lake Norman continues to be classified as oligo-mesotrophic based on long-term, annual mean chlorophyll concentrations. Chlorophyll *a* concentrations during 2009 were within historical ranges. Lake-wide mean chlorophyll *a* decreased from February through May then increased through August to the annual maximum. Overall chlorophyll *a* concentrations declined through November to the annual minimum. Some spatial variability was observed in 2009; however, maximum chlorophyll *a* concentrations were most often observed uplake at Locations 15.9 (May, November) and 69.0 (February, August), while minimum chlorophyll *a* concentrations were typically recorded from downlake at Locations 2.0, 5.0 and 8.0. The highest chlorophyll *a* value recorded in 2009, 13.24 µg/L, was well below the NC State water quality standard of 40 µg/L.

Most phytoplankton densities in February, May, and August 2009 were lower than in those months of 2008, while most biovolumes during those months were higher than during the previous year. This disparity was due to taxonomic shifts from taxa with lower individual biovolumes to those with higher biovolumes. Standing crop values in November 2009 were lower than during November of 2008. Phytoplankton densities and biovolumes during 2009 never exceeded the NC guideline for algae blooms of 10,000 units/mL density and 5,000 mm^3/m^3 biovolume. Standing crop values in excess of bloom guidelines have been recorded during eight previous years of the Program. As in past years, standing crop spatial distribution typically mirrored that of chlorophyll *a*, with high values usually observed at uplake locations, while comparatively low values were noted downlake.

Seston dry and ash-free weights were higher in February and May 2009 than in February and May 2008, while the opposite was the case in August and November. Downlake to uplake differences were observed to an extent during all quarters; however, a clear pattern of continually increasing values from downlake to uplake was not as apparent in February and November as in the other two sampling periods. Maximum dry and ash-free weights were generally observed at Location 69.0. Minimum values were most often noted at Locations 2.0 through 9.5.

Secchi depths often reflected suspended solids, with shallow depths loosely related to high dry weights. The lake-wide mean Secchi depth in 2009 was slightly lower than in 2008 and was within historical ranges of lake-wide mean Secchi depths recorded since 1992.

Diversity or the number of taxa of phytoplankton in 2009 was the highest yet recorded. The taxonomic compositions of phytoplankton communities during 2009 were similar to those of most previous years with the exception that diatoms rather than cryptophytes were dominant in February. Diatoms were dominant during all but August, when green algae dominated phytoplankton assemblages. Blue-green algae were slightly more abundant during 2009 than during 2008; however, their contribution to total densities seldom exceeded 2%.

The most abundant alga, on an annual basis, was the diatom, *T. fenestrata* which was the most important species during May and November at all locations. The most abundant diatoms in May were *C. stelligera* and *F. crotonensis.* The small desmid, *C. asphearosporum* var. *strigosum*, was dominant in August 2009. All of these taxa have been common and abundant throughout the Lake Norman Maintenance Monitoring Program.

Lake Norman continues to support highly variable and diverse phytoplankton communities. No obvious short-term or long-term impacts of station operations were observed.

Table 3-1. Mean chlorophyll *a* concentrations (µg/L) in composite samples and Secchi depths (m) observed in Lake Norman in 2009.

Chlorophyll *a* Location	Feb	May	Aug	Nov
2.0	4.38	2.24	4.95	2.10
5.0	5.13	2.07	5.17	2.35
8.0	6.21	2.60	4.02	3.05
9.5	5.31	2.68	5.14	3.55
11.0	4.67	3.42	5.83	3.47
13.0	6.34	5.18	5.43	3.44
15.9	7.24	6.11	9.55	4.43
69.0	9.20	5.14	13.24	1.53

Secchi depths Location	Feb	May	Aug	Nov
2.0	2.00	2.20	2.90	2.00
5.0	2.00	2.10	2.40	1.82
8.0	2.10	2.80	1.71	2.26
9.5	2.10	2.70	2.70	2.44
11.0	1.90	2.20	2.35	2.48
13.0	1.50	1.50	1.25	1.50
15.9	1.60	2.10	2.80	1.63
69.0	1.40	1.30	1.10	1.26
Annual mean from all Locations: 2009				2.05
Annual mean from all Locations: 2008				2.09

Table 3-2. Mean phytoplankton densities (units/mL) and biovolumes (mm^3/m^3) by location and sample month from samples collected in Lake Norman during 2009.

Density	Locations					
Month	2.0	5.0	9.5	11.0	15.9	Mean
Feb	1,789	2,045	2,166	1,919	2,715	2,126
May	536	536	700	1,089	1,949	962
Aug	2,472	2,573	2,946	3,369	4,570	3,186
Nov	1,467	1,496	1,764	1,735	2,025	1,697

Biovolume	Locations					
Month	2.0	5.0	9.5	11.0	15.9	Mean
Feb	2,235	2,846	3,243	2,064	3,460	2,770
May	294	326	369	843	1,199	606
Aug	1,869	1,741	2,473	2,793	3,855	2,546
Nov	1,406	1,570	2,019	2,025	2,839	1,972

Table 3-3. Total mean seston dry and ash free-dry weights (mg/L) from samples collected in Lake Norman during 2009.

Dry weights	Locations								
Month	2.0	5.0	8.0	9.5	11.0	13.0	15.9	69.0	Mean
Feb	3.19	2.56	2.21	2.03	1.84	2.06	1.93	3.76	2.45
May	1.62	1.48	1.09	1.23	1.62	1.83	2.27	4.40	1.94
Aug	1.36	1.61	1.33	1.48	1.83	1.56	1.95	6.25	2.17
Nov	1.05	1.30	0.98	1.57	1.28	1.20	0.92	1.96	1.28
Ash-free dry weights									
Month									
Feb	1.38	0.93	0.85	0.83	0.83	0.76	0.93	1.10	0.95
May	0.75	0.62	0.61	0.61	0.87	1.08	1.10	1.19	0.85
Aug	0.83	0.95	0.93	1.00	1.20	0.81	1.28	2.53	1.19
Nov	0.57	0.58	0.46	0.69	0.59	0.55	0.32	0.35	0.51

Table 3-4. Phytoplankton taxa identified in quarterly samples collected in Lake Norman each year from 1994 to 2009.

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Class: Chlorophyceae																
Acanthosphaera zachariasi Lemm.[a]																
Actidesmium hookeri Reinsch [a]																
Actinastrum hantzchii Lagerheim	X								X							X
Ankistrodesmus braunii (Naegeli) Brunn		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. convolutus Corda							X									
A. falcatus (Corda) Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. fusiformis Corda sensu Korsch.	X															
A. nannoselene Skuja							X									
A. spiralis (Turner) Lemm.				X												
A. spp. Corda[a]																
Arthrodesmus convergens Ehrenberg		X							X	X		X	X	X	X	X
A. incus (Breb.) Hassall		X			X			X	X	X	X	X	X	X	X	X
A. incus v *ralfsii* W. West															X	
A. octocornis Ehrenberg									X	X	X	X		X	X	X
A. ralfsii W. West											X	X	X			X
A. subulatus Kutzing			X	X	X		X	X	X	X	X	X	X	X	X	X
A. validus v. *increassalatus* Scott & Gron.											X					
A. spp. Ehrenberg	X															
Asterococcus limneticus G. M. Smith	X					X			X	X		X	X	X		X
A. superbus (Cienk.) Scherffel											X			X		
Botryococcus braunii Kutzing[a]																
Carteria fritzschii Takeda							X			X	X	X	X	X	X	X
C. globosa Korsch									X		X		X		X	
C. spp. Diesing				X						X						
Characium ambiguum Hermann												X				
C. limneticum Lemmerman										X						
C. spp. Braun [a]																
Chlamydomonas spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chlorella vulgaris Beyerink				X								X	X			X
Chlorogonium euchlorum Ehrenberg			X	X			X				X	X	X	X	X	X
C. spirale Scherffel & Pascher	X	X									X	X	X	X	X	X
Closteriopsis longissima W. & West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Closterium acutum Breb.													X	X		X
C. cornu Ehrenberg						X			X							
C. gracile Brebisson			X											X		
C. incurvum Brebisson	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. parvulum Nageli												X				
C. tumidum Johnson							X									
C. spp. Nitzsch[a]																
Coccomonas orbicularis Stein					X				X		X	X	X	X	X	X
Coelastrum cambricum Archer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. microporum Nageli		X	X		X		X			X		X	X	X	X	X
C. proboscideum Bohlin															X	
C. reticulatum (Dang.) Sinn.						X							X	X		X
C. sphaericum Nageli	X		X			X	X	X	X	X	X	X	X	X	X	X
C. spp. Nageli [a]																

Table 3-4. (Continued). Page 2 of 12

Years

Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Cosmarium angulosum v. *concin.* (Rab) W&W							X		X		X	X			X	
C. asphaerosporum v. *strigosum* Nord.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. contractum Kirchner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. moniliforme (Turp.) Ralfs							X			X		X	X	X	X	X
C. notabile Brebisson									X							
C. phaseolus f. *minor* Boldt.			X	X		X		X				X	X	X	X	
C. pokornyanum (Grun.) W. & G.S. West					X				X			X		X		
C. polygonum (Nag.) Archer		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. portianum Archer																X
C. raciborskii Lagerheim									X			X	X	X		X
C. regnellii Wille			X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. regnesi Schmidle									X							
C. regnesi v. *montana* Schmidle															X	
C. subreniforme Nordstedt									X			X		X		
C. subprotumidum Nordst.													X			
C. tenue Archer		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. tinctum Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. tinctum v. *subretusum* Messik.							X									
C. tinctum v. *tumidum* Borge.				X		X	X	X	X	X	X	X	X	X	X	X
C. trilobatum v. *depressum* Printz									X							
C. tumidum Borge									X							
C. spp. Corda	X															
Crucigenia apiculata (Lemm.) Schmidl									X	X			X	X		X
C. crucifera (Wolle) Collins		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. fenestrata Schmidle									X	X	X	X	X	X	X	X
C. irregularis Wille	X		X		X		X		X	X	X	X	X		X	X
C. quadrata Morren														X	X	X
C. rectangularis (A. Braun) Gay					X								X			X
C. tetrapedia (Kirch.) West & West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dictyospaerium ehrenbergianum Nageli							X		X	X	X	X	X	X	X	X
D. pulchellum Wood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dimorphococcus spp. Braun[a]																
Elakatothrix gelatinosa Wille	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Errerella bornheimiensis Conrad									X	X		X	X	X	X	
Euastrum ansatum v. *dideltiforme* Ducel.									X							
E. banal (Turp.) Ehrenberg									X							
E. denticulatum (Kirch.) Gay		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E. elegans Kutzing										X						
E. turneri West															X	
E. spp. Ehrenberg														X		
Eudorina elegans Ehrenberg			X						X	X		X	X		X	X
Franceia droescheri (Lemm.) G. M. Sm.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F. ovalis (France) Lemm.	X						X		X	X	X	X	X	X	X	X
F. tuberculata G. M. Smith										X						
Gloeocystis botryoides (Kutz.) Nageli							X			X	X		X	X	X	X
G. gigas Kutzing			X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 3-4. (Continued).

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
G. major Gerneck *ex.* Lemmermann					X								X			
G. planktonica (West & West) Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G. vesiculosa Naegeli					X				X	X	X	X	X	X	X	X
G. spp. Nageli	X															
Golenkinia paucispina West & West									X	X	X	X	X	X	X	X
G. radiata Chodat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gonium pectorale Mueller					X				X			X	X	X	X	X
G. sociale (Duj.) Warming		X			X	X			X	X	X	X	X	X	X	X
Kirchneriella contorta (Schmidle) Bohlin	X				X				X	X			X		X	X
K. elongata G.M. Smith							X			X				X	X	X
K. lunaris (Kirch.) Mobius										X	X				X	X
K. lunaris v. *dianae* Bohlin				X			X		X	X	X	X	X	X	X	X
K. lunaris v. *irregularis* G.M. Smith							X			X						X
K. obesa W. West	X												X		X	X
K. subsolitaria G. S. West		X	X	X	X	X	X		X	X	X	X	X	X	X	X
K. spp. Schmidle		X	X	X					X			X	X			
Lagerheimia ciliata (Lagerheim) Chodat									X				X			X
L. citriformis (Snow) G. M. Smith				X								X	X		X	X
L. longiseta (Lemmermann) Printz									X	X	X	X		X	X	
L. longiseta v. *major* G. M. Smith																X
L. quadriseta (Lemm.) G. M. Smith[a]																
L. subsala Lemmerman	X		X	X	X		X		X	X	X	X	X	X	X	X
Mesostigma viride Lauterborne		X	X	X	X	X	X		X	X	X	X	X	X	X	X
Micractinium pusillum Fresen.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Monoraphidium contortum Thuret	X															
M. pusillum Printz	X															
Mougeitia elegantula Whittrock		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Agardh	X													X		X
Nephrocytium agardhianum Nageli									X	X	X	X	X	X	X	X
N. ecdysiscepanum W. West													X			
N. limneticum (G.M. Smith) G.M. Smith						X			X		X		X	X		X
N. obesum West & West													X			
Oocystis borgii Snow					X	X	X		X	X		X	X	X	X	
O. ellyptica W. West					X				X	X	X			X		
O. lacustris Chodat										X	X	X		X		
O. parva West & West		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. pusilla Hansgirg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. pyriformis Prescott					X				X							
O. solitaria Wittrock										X			X			
O. submarina Lagerheim													X		X	
O. spp. Nageli[a]																
Pandorina charkowiensis Kprshikov												X	X			X
P. morum Bory										X		X	X	X		X
Pediastrum biradiatum Meyen												X	X	X	X	
P. duplex Meyen		X	X	X		X	X	X	X	X	X	X	X	X	X	X
P. duplex v. *clatheatum* (A. Braun) Lag.									X							X
P. duplex v. *gracillimum* West and West				X	X				X	X	X	X	X	X		X
P. duplex v. *reticulatum* Lagerheim															X	

Table 3-4. (Continued).

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Taxon	Years 94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
P. tetras v. *tetroadon* (Corda) Rabenhorst	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Meyen [a]																
Phacotus angustus Lemmermann															X	
Planktosphaeria gelatinosa G. M. Smith		X							X		X	X		X	X	X
Quadrigula closterioides (Bohlin) Printz			X	X				X	X	X	X	X	X	X	X	X
Q. lacustris (Chodat) G. M. Smith									X	X	X	X	X	X	X	X
Scenedesmus abundans (Kirchner) Chodat										X		X	X		X	X
S. abundans v. *asymetrica* (Schr.) G. Sm.	X		X	X			X		X	X	X		X	X		
S. abundans v. *brevicauda* G. M. Smith		X								X	X			X	X	X
S. abundans v. *longicauda* G.M. Smith														X		X
S. acuminatus (Lagerheim) Chodat	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
S. arcuatus Lemmermann															X	
S. arcuatus v. *platydisca* G. M. Smith															X	
S. armatus (Chod.) G. M. Smith															X	
S. armatus v. *bicaudatus* (Gug.-Pr..)Chod	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga (Turp.) Lagerheim	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga v. *alterans* (Reinsch) Hansg.											X		X		X	
S. brasiliensis Bohlin		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. denticulatus Lagerheim	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
S. denticulatus v. *recurvatus* Schumacher										X	X	X	X	X	X	X
S. dimorphus (Turp.) Kutzing	X			X	X	X	X		X	X	X	X	X	X	X	X
S. incrassulatus G. M. Smith															X	
S. opoliensis P. Richter												X			X	X
S. parisiensis Chodat										X		X				
S. quadricauda (Turp.) Brebisson	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
S. smithii Teiling			X						X	X		X	X			X
S. serratus (Corda) Bohlin											X					
S. spp. Meyen	X															
Schizochlamys compacta Prescott			X		X		X		X		X	X		X	X	X
S. gelatinosa A. Braun							X		X		X	X	X	X	X	X
Schoederia setigera (Schroed.) Lemm.									X							X
Selenastrum bibraianum Reinsch													X	X		X
S. gracile Reinsch			X						X				X	X		X
S. minutum (Nageli) Collins	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. westii G. M. Smith		X	X		X	X			X	X	X	X	X	X	X	X
Sorastrum americanum (Bohlin) Schm.				X									X			
S. spinulosum Nageli																X
Sphaerocystis schoeteri Chodat		X			X	X	X		X	X	X	X	X	X		X
Sphaerozosma granulatum Roy & Bl. [a]																
Stauastrum americanum (W&W) G. Sm.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. apiculatum Brebisson				X	X	X	X	X	X	X	X	X	X	X	X	X
S. aspinosum v. *annulatum* W.& G.S.Wst.														X		
S. brachiatum Ralfs				X	X	X			X	X	X	X	X	X	X	X
S. brevispinum Brebisson					X											
S. chaetocerus (Schoed.) G. M. Smith	X															
S. capitulum Brebisson													X			
S. curvatum W. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
S. curvatum v. *elongatum* G.M. Smith														X		X
S. cuspidatum Brebisson				X	X	X	X	X	X	X	X	X	X	X	X	X
S. dejectum Brebisson	X						X				X			X		X
S. dickeii v. *maximum* West & West													X			
S. dickeii v. *rhomboidium* W.& G.S. West									X							X
S. gladiosum Turner[a]																
S. leptocladum Nordstedt												X				
S. leptocladum v. *sinuatum* Wolle [a]																
S. manfeldtii v. *fluminense* Schumacher	X	X		X	X		X		X	X	X	X	X	X	X	X
S. megacanthum Lundell	X									X	X	X	X			
S. ophiura v. *cambricum* (Lund) W. & W.							X					X				X
S. orbiculare Ralfs	X								X							
S. paradoxum Meyen	X				X	X					X	X	X	X	X	
S. paradoxum v. *cingulum* W. & W.											X	X	X	X	X	X
S. paradoxum v. *parvum* W. West					X				X	X	X	X	X	X	X	X
S. pentacerum (Wolle) G. M. Smith									X			X	X		X	X
S. subcruciatum Cook & Wille		X		X	X	X	X		X	X	X	X	X	X	X	X
S. tetracerum Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. turgescens de Not.												X		X		X
S. vestitum Ralfs									X	X				X	X	
S. spp. Meyen	X															
Stichococcus scopulinus Hazen									X							
S. spp. Nageli														X		
Stigeoclonium spp. Kutzing								X						X		
Tetraedron arthrodesmiforme (W.) Wol.									X	X		X	X		X	
Tetraedron asymmetricum Prescott																X
T. bifurcatum (Wille) Lagerheim																X
T. bifurcatum v. *minor* Prescott			X													
T. caudatum (Corda) Hansgirg	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. caudatum v. *longispinum*																X
T. limneticum Borge														X		
T. lobulatum (Naegeli) Hansgirg							X								X	
T. lobulatum v. *crassum* Prescott											X			X		
T. minmum (Braun) Hansgirg	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
T. muticum (Braun) Hansgirg	X	X	X		X										X	X
T. obesum (W & W) Wille *ex* Brunnthaler			X												X	X
T. pentaedricum West & West	X											X	X	X		
T. planktonicum G. M. Smith					X		X		X	X	X	X	X	X	X	X
T. regulare Kutzing	X												X			
T. regulare v. *bifurcatum* Wille					X											
T. regulare v. *incus* Teiling													X			
T. trigonum (Nageli) Hansgirg			X	X	X		X	X	X	X	X	X	X	X	X	X
T. trigonum v. *gracile* (Reinsch) DeToni			X				X				X		X		X	
T. spp. Kutzing[a]																
Tetrallantos lagerheimii Teiling								X		X	X			X		
Tetraspora lamellose Prescott							X									
T. spp. Link	X															

Years

TAXON	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
Tetrastrum heteracanthum (Nor.) Chod.									X		X	X			X	
T. staurogeniforme (Schroeder) Lemm.										X					X	
Tomaculum catenatum Whitford																X
Treubaria setigerum (Archer) G. M. Sm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Westella botryoides (W. & W.) Wilde.					X		X				X	X	X	X	X	
W. linearis G. M. Smith					X		X			X	X	X	X	X		
Xanthidium antiloparium.v. floridense Sc. & Gron.											X					
X. cristatatum v. *uncinatum* Breb.									X		X	X	X	X	X	X
X. spp. Ehrenberg	X								X							
Class: Bacillariophyceae																
Achnanthes lanceolata Brebisson									X			X				
A. microcephala Kutzing		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Bory	X		X								X					
Amphiprora ornate Bailey									X							
Amphora ovalis Kutzing													X			
Anomoeoneis vitrea (Grunow) Ross	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Pfitzer	X															
Asterionella formosa Hassall	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Attheya zachariasi J. Brun	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cocconeis placentula Ehrenberg					X	X				X				X	X	
C. spp. Ehrenberg	X															
Cyclotella comta (Ehrenberg) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. glomerata Bachmann		X	X	X	X	X				X	X	X	X	X	X	X
C. meneghiniana Kutzing	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
C. pseudostelligera Hustedt [a]																
C. stelligera Cleve & Grunow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Kutzing[a]																
Cymbella affinis Kutzing							X			X						
C. gracilis (Rabenhorst) Cleve										X	X					
C. minuta (Bliesch & Rabn.) Reim.		X	X		X	X			X	X	X	X	X	X	X	X
C. naviculiformis Auersw. *ex* Heib.														X		
C. tumida (Brebison) van Huerck	X															X
C. turgida (Gregory) Cleve																X
C. spp. Agardh [a]																
Denticula elegans Kutzing									X		X			X	X	X
D. elegans v. *crassa* (Naegeli) Hustedt															X	
D. thermalis Kutzing					X				X			X				X
Diploneis ellyptica (Kutzing) Cleve											X					
D. marginestriata Hustedt														X		
D. ovalis (Hilse) Cleve											X					
D. puella (Schum.) Cleve											X				X	
D. spp. Ehrenberg[a]																
Eunotia flexuosa v. *eurycephala* Grun.							X									
E. zasuminensis (Cab.) Koerner	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Fragilaria crotonensis Kitton	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F. construens (Ehrenberg) Grunow											X					
Frustulia rhomboides (Ehr.) de Toni											X					

Table 3-4. (Continued). Page 7 of 12

Taxon	Years 94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
F. rhomboides v. *saxonica* (Rabh.) de T.										X						
Gomphonema angustatum (Kutz.) Rabh.									X							
G. gracile (Her.) Van Huerk														X		X
G. parvulum Kutz.									X	X			X	X		
G. spp. Agardh	X															
Melosira ambigua (Grunow) O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. distans (Ehrenberg) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. granulata (Ehrenberg) Ralfs												X		X		X
M. granulata v. *angustissima* O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. italica (Ehrenberg) Kutzing [a]																
M. italica v. *tennuissima* (Grun.) O. Mull.													X			X
M. varians Agardh					X							X	X	X	X	X
M. spp. Agardh	X		X			X		X	X	X	X	X	X	X	X	X
Meridion circulare Agardh									X							
Navicula cryptocephala Kutzing			X	X					X						X	
N. exigua (Gregory) O. Muller		X							X		X					
N. exigua v. *capitata* Patrick			X											X		
N. radiosa Kutzing										X		X				X
N. radiosa v. *tenella* (Breb.) Grun.										X	X		X	X	X	
N. subtilissima Cleve		X					X			X		X	X	X		X
N. spp. Bory	X										X					X
Nitzschia acicularis W. Smith			X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. agnita Hustedt	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. communis Rabenhorst													X			
N. holsatica Hustedt		X		X	X	X	X	X	X	X	X	X	X	X	X	X
N. kutzingiana Hilse											X	X		X	X	X
N. linearis W. Smith							X					X		X		
N. palea (Kutzing) W. Smith	X	X	X	X	X				X		X	X	X	X	X	X
N. sublinearis Hustedt			X		X			X	X				X			X
N. thermalis Kutzing															X	
N. spp. Hassall	X								X			X		X		
Pinnularia biceps Gregory												X				
P. mesolepta (Her.) W. Smith														X		
P. spp. Ehrenberg									X			X		X		
Rhizosolenia spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Skeletonema potemos (Weber) Hilse		X	X		X	X	X		X	X		X	X	X	X	X
Stephanodiscus astraea (Her.) Grunow												X		X		X
S. spp. Ehrenberg	X	X	X	X	X					X	X	X	X	X		X
Surirella angustata Kutz.										X						
S. linearis v. *constricta* (Her.) Gro.					X									X		X
S. tenuis Mayer												X				
Synedra actinastroides Lemmerman	X															
S. acus Kutzing	X			X	X		X		X	X	X	X	X	X	X	X
S. amphicephala Kutzing													X	X		
S. delicatissima Lewis	X															
S. filiformis v. *exilis* Cleve-Euler					X		X	X	X	X	X	X	X	X	X	X
S. planktonica Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. rumpens Kutzing		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 3-4. (Continued). Page 8 of 12

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
S. rumpens v. *fragilarioides* Grunow [a]																
S. rumpens v. *scotica* Grunow																X
S. ulna (Nitzsch) Ehrenberg		X	X	X	X	X	X		X	X	X	X	X	X	X	X
S. spp. Ehrenberg	X															
Tabellaria fenestrata (Lyngb) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. flocculosa (Roth.) Kutzing	X						X				X			X	X	X
Class: Chrysophyceae																
Aulomonas purdyii Lackey	X	X	X	X	X	X		X	X		X	X	X	X	X	X
Bicoeca petiolatum (Stien) Pringsheim			X	X												
Calycomonas pascheri (Van Goor) Lund		X					X			X						
Centritractus belanophorus Lemm.												X				
Chromulina nebulosa Pascher													X		X	X
C. spp. Chien.					X				X	X	X		X		X	X
Chrysococcus rufescens Klebs										X						
Chrysosphaerella solitaria Lauterb.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Codomonas annulata Lackey			X	X	X	X	X	X		X	X	X	X	X	X	X
Dinobryon acuminatum Ruttner														X		X
D. bavaricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. cylindricum Imhof	X		X		X				X	X		X	X	X	X	X
D. divergens Imhof	X	X	X			X			X	X	X	X	X	X	X	X
D. pediforme (Lemm.) Syein.													X			X
D. sertularia Ehrenberg		X					X		X	X	X	X	X		X	X
D. sociale Ehrenberg															X	
D. spp. Ehrenberg		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Domatomococcus cylindricum Lackey					X	X				X						X
Erkinia subaequicilliata Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Kephyrion campanuliforme Conrad										X						
K. littorale Lund					X				X	X	X	X	X	X	X	X
K. petasatum Conrad										X						
K. rubi-claustri Conrad									X	X	X	X	X	X	X	X
K. skujae Ettl [a]																
K. valkanovii Conrad												X	X			
K. spp. Pascher	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mallomonas acaroides Perty	X											X	X	X		X
M. akrokomos (Naumann) Krieger					X	X	X			X		X	X	X	X	X
M. allantoides Perty													X		X	
M. allorgii (Defl.) Conrad										X						
M. alpina Pascher					X		X									
M. caudata Conrad	X	X				X	X	X	X	X		X	X	X		X
M. globosa Schiller					X		X	X	X	X	X	X	X	X	X	X
M. producta Iwanoff							X		X	X		X		X	X	X
M. pseudocoronata Prescott	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. tonsurata Teiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Perty	X						X							X		
Ochromonas granularis Doflein					X	X	X	X	X	X	X	X	X	X	X	X
O. mutabilis Klebs							X						X	X		
O. spp. Wyss	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 3-4. (Continued). Page 9 of 12

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Pseudokephyrion concinum (Schill.) Sch.												X			X	
P. schilleri Conrad					X	X		X	X	X		X			X	
P. tintinabulum Conrad					X											
P. spp. Pascher										X		X	X		X	
Rhizochrisis polymorpha Naumann						X	X	X	X	X	X	X	X	X	X	X
R. spp. Pascher																X
Salpingoeca frequentissima (Zach.) Lem.					X	X	X			X		X				
Stelexomonas dichotoma Lackey	X	X	X	X	X		X		X	X		X	X	X	X	X
Stokesiella epipyxis Pascher				X	X	X							X		X	X
Synura sphagnicola Korschikov											X					
S. spinosa Korschikov		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. uvella Ehrenberg	X							X					X		X	X
S. spp. Ehrenberg	X															
Uroglenopsis americana (Caulk.) Lemm.		X	X	X		X										
Class: Haptophyceae																
Chrysochromulina parva Lackey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Class: Xanthophyceae																
Characiopsis acuta Pascher									X			X	X	X	X	X
C. cylindrica (Lambert) Lemm.														X	X	
C. dubia Pascher		X	X		X	X	X	X	X	X	X	X	X	X	X	X
Dichotomococcus curvata Korschikov [a]																
Ophiocytium capitatum v. *longisp.* (M) L.	X									X	X	X	X	X	X	X
Stipitococcus vas Pascher										X						
Class: Cryptophyceae																
Cryptomonas erosa Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. erosa v. *reflexa* Marsson					X	X	X	X	X	X	X	X	X	X	X	X
C. gracilia Skuja							X									
C. marsonii Skuja	X									X				X	X	X
C. obovata Skuja										X		X	X		X	X
C. ovata Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. phaseolus Skuja	X															
C. reflexa Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Ehrenberg	X													X		X
Rhodomonas minuta Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Class: Myxophyceae																
Agmenellum quadriduplicatum Brebisson	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
A. thermale Drouet and Daily										X						X
Anabaena catenula (Kutzing) Born.				X	X											X
Anabaena circinalis (Kutz.) Rabenhorst																X
A. inaequalis (Kutzing) Born.							X							X		X
A. scheremetievi Elenkin				X	X	X		X					X	X		X
A. wisconsinense Prescott		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Bory	X		X			X		X	X		X		X	X	X	X
Anacystis incerta (Lemm.) Druet & Daily	X				X		X	X								

Taxon	Years 94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
A. spp. Meneghini [a]																
Aphanocaspsa rivularis (Carm.) Raben.															X	
Chroococcus dispersus (Keissl.) Lemm.					X		X							X	X	
C. giganteous W. West													X			
C. limneticus Lemmermann				X	X	X	X	X	X	X		X	X	X	X	X
C. minor Kutzing									X	X		X	X	X	X	X
C. turgidus (Kutz.) Lemmermann[a]																
C. spp. Nageli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Coelosphaerium kuetzingiana Nageli[a]																
C. neagleanum Unger													X	X		
Dactylococcopsis irregularis Hansgirg	X									X	X	X		X		X
D. musicola Hustedt														X		
D. raphidiopsis Hansgirg														X		
D. rupestris Hansgirg							X									
D. smithii Chodat and Chodat				X	X		X			X	X	X	X	X		X
D. spp. Hansgirg							X									
Gomphospaeria lacustris Chodat	X											X				
Lyngbya contorta Lemmermann[a]																
L. limnetica Lemmermann	X															
L. ochracea (Kutzing) Thuret							X		X		X	X			X	
L. subtilis W. West	X															
L. tenue Agardh											X				X	X
L. spp. Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Merismopedia tenuissima Lemmermann					X											
Microcystis aeruginosa Kutzing	X	X	X		X	X	X	X			X	X	X	X	X	X
Oscillatoria amoena (Kutz.) Gomont											X					
O. amphibia Agardh									X	X	X		X	X		
O. geminata Meneghini		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. limnetica Lemmermann		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. splendida Greville		X	X		X				X							
O. subtilissima Kutz.							X	X	X	X	X	X	X	X	X	X
O. spp. Vaucher	X							X		X				X		X
Phormidium angustissimum West & West	X															
P. spp. Kutzing	X															
Raphidiopsis curvata Fritsch & Rich	X	X	X	X	X	X	X		X		X			X	X	
R. mediterranea Skuja						X										
R. spp. Fritsch & Rich														X		
Rhabdoderma sigmoidea Schm. & Laut.[a]																
Spirulina subsala Oersted									X						X	X
Synecococcus lineare (Sch. & Lt.) Kom.	X	X	X		X	X	X	X		X	X					
Class: Euglenophyceae																
Euglena acus Ehrenberg						X					X	X				X
E. deses Ehrenberg												X	X			X
E. fusca (Klebs). Lemmermann															X	
E. minuta Prescott							X		X		X	X		X	X	X
E. polymorpha Dangeard			X					X	X		X	X			X	X
E. proxima Dangeard										X	X	X	X			X

Table 3-4. (Continued).

Years

Taxon	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
E. texta (Duj.) Hubn.															X	
E. spp. Ehrenberg	X	X	X		X	X		X			X	X	X	X	X	X
Lepocinclus acicularis France													X			
L. acuta Prescott											X					X
L. fusiformis Lemmermann															X	
L. glabra Drezepolski										X						
L. ovum. (Ehr.) Lemm.							X				X			X	X	X
L. ovum. v. *palatina* Lemmermann																X
L. sphagnophila Lemmermann															X	
L. spp. Perty					X											
Phacus acuminatus Stokes																X
P. cuvicauda Swirenko							X									
P. longicauda (Her.) Dujardin							X							X		
P. orbicularis Hubner												X				X
P. tortus (Lemm.) Skvortzow[a]																
P. triquter Playfair											X					
P. spp. Dujardin [a]																
Trachelomonas abrupta (Swir.) Deflandre													X			
T. abrupta v. *minor* Deflan.												X	X			
T. acanthostoma (Stk.) Defl.								X			X	X	X	X	X	X
T. ensifera Daday										X				X		
T. euchlora (Ehrenberg) Lemmermann															X	
T. hispida (Perty) Stein		X				X		X	X	X	X	X		X	X	X
T. lemmermanii v. *acuminata* Deflandre												X		X		
T. pulcherrima Playfair															X	
T. pulcherrima v. *minor* Playfair											X					
T. varians (Lemm.) Deflandre														X		
T. volvocina Ehrenberg		X				X		X		X	X	X		X	X	X
T. spp. Ehrenberg	X															
Class: Dinophyceae																
Ceratium hirundinella (OFM) Schrank	X	X		X	X	X	X									X
C. hirundinella v. *brachyceras* (Day.) Est.												X			X	X
Glenodinium borgei (Lemm.) Schiller			X												X	X
G. gymnodinium Penard				X							X		X	X	X	
G. palustre (Lemm.) Schiller														X		
G. penardiforme (Linde.) Schiller						X	X				X		X	X	X	X
G. quadridens (Stein) Schiller	X												X	X		
G. spp. (Ehrenberg) Stein	X															
Gymnodinium aeruginosum Stein					X	X	X			X	X	X		X		X
G. neglectum (Schilling) Lindemann															X	
G. spp. (Stein) Kofoid & Swezy	X	X		X	X		X	X	X	X	X	X	X	X		X
Peridinium aciculiferum Lemmermann															X	
P. cinctum (Muller) Ehrenberg									X				X			
P. godlewskii Wolzynska															X	
P. inconspicuum Lemmermann	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. intermedium Playfair					X	X	X	X	X	X	X	X	X	X	X	X
P. limbatum (Stokes) Lemm.												X		X		X

Table 3-4. (Continued).

	Years															
Taxon	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
P. pusillum (Lenard) Lemmermann	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
P. quadridens Stein															X	
P. umbonatum Stein	X															
P. willei Huitfeld-Kass											X	X	X		X	X
P. wisconsinense Eddy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Ehrenberg	X															X
Class: Chloromonadophyceae																
Gonyostomum depresseum Lauterborne		X			X	X			X	X	X	X	X	X	X	X
G. semen (Ehrenberg) Diesing															X	
G. spp. Diesing	X															

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a= taxa found during 1987 - 93 only.

Table 3-5. Dominant classes, their most abundant species, and their percent composition (in parentheses) at Lake Norman locations during each sampling period of 2009.

Location	February	May
2.0	Bacillariophyceae (76.3) *Tabellaria fenestrata* (66.3)	Bacillariophyceae (66.0) *Cyclotella stelligera* (30.9)
5.0	Bacillariophyceae (87.3) *T.fenestrata* (72.3)	Bacillariophyceae (71.1) *C. stelligera* (39.8)
9.5	Bacillariophyceae (89.9) *T.fenestrata* (80.5)	Bacillariophyceae (50.0) *C. stelligera* (35.0)
11.0	Bacillariophyceae (85.6) *T.fenestrata* (36.2)	Bacillariophyceae (60.4) *Fragillaria crotonensis* (21.2)
15.9	Bacillariophyceae (58.3) *T.fenestrata* (27.8)	Bacillariophyceae (69.5) *F. crotonensis* (40.0)
	August	November
2.0	Chlorophyceae (55.8) *Cosmarium asphearosporum* variety *strigosum* (30.0)	Bacillariophyceae (45.4) *Tabellaria fenestrata* (29.7)
5.0	Chlorophyceae (55.0) *C. asphear.* var. *strig.* (28.3)	Bacillariophyceae (48.5) *T. fenestrata* (31.1)
9.5	Chlorophyceae (52.8) *C. asphear.* var. *strig.* (26.9)	Bacillariophyceae (52.3) *T. fenestrata* (39.9)
11.0	Chlorophyceae (46.6) *C. asphear.* var. *strig.* (26.4)	Bacillariophyceae (48.6) *T. fenestrata* (32.4)
15.9	Chlorophyceae (45.3) *C. asphear.* var. *strig.* (24.2)	Bacillariophyceae (53.4) *T. fenestrata* (24.8)

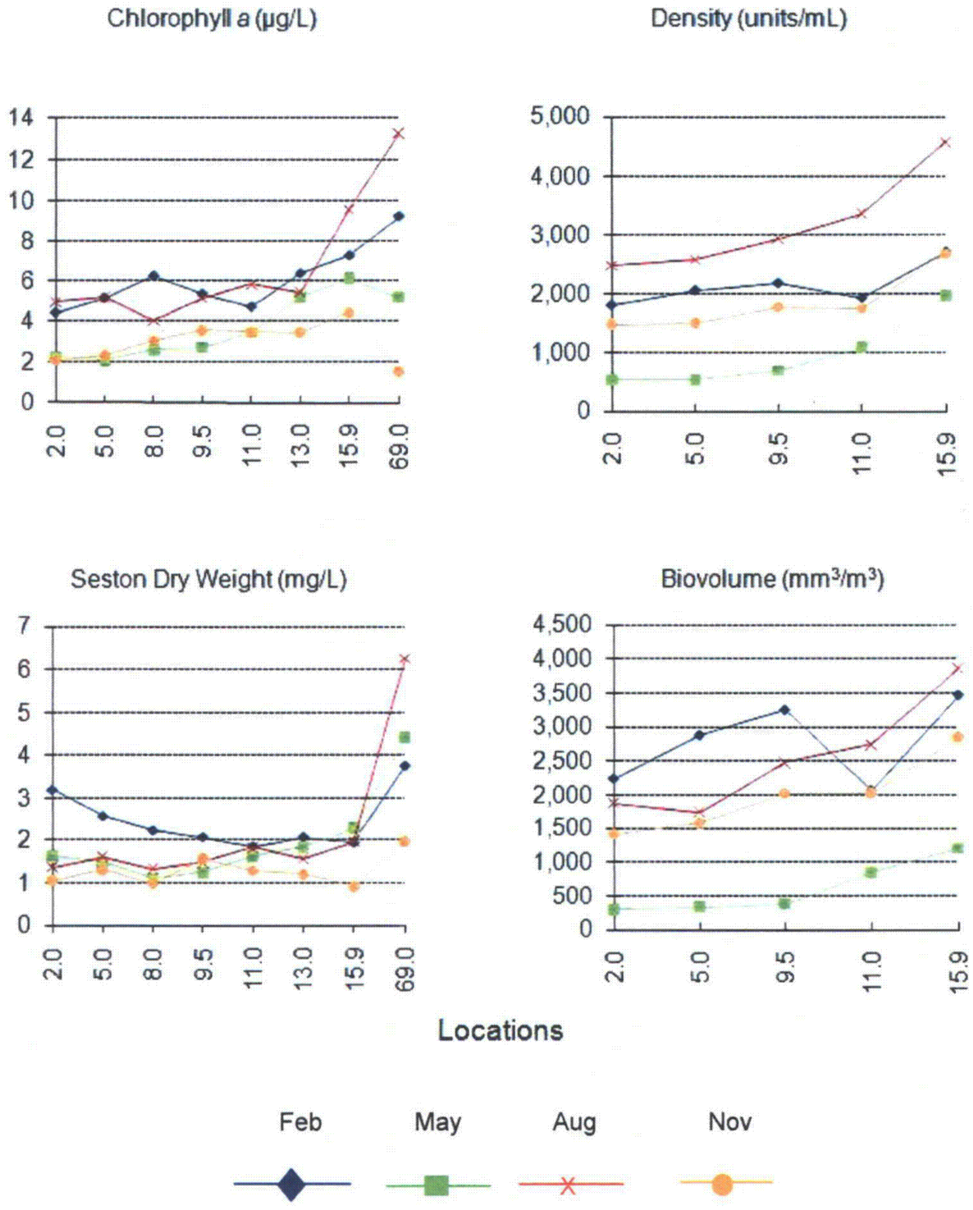


Figure 3-1. Phytoplankton chlorophyll *a*, densities, biovolumes, and seston weights at locations in Lake Norman in February, May, August, and November 2009.

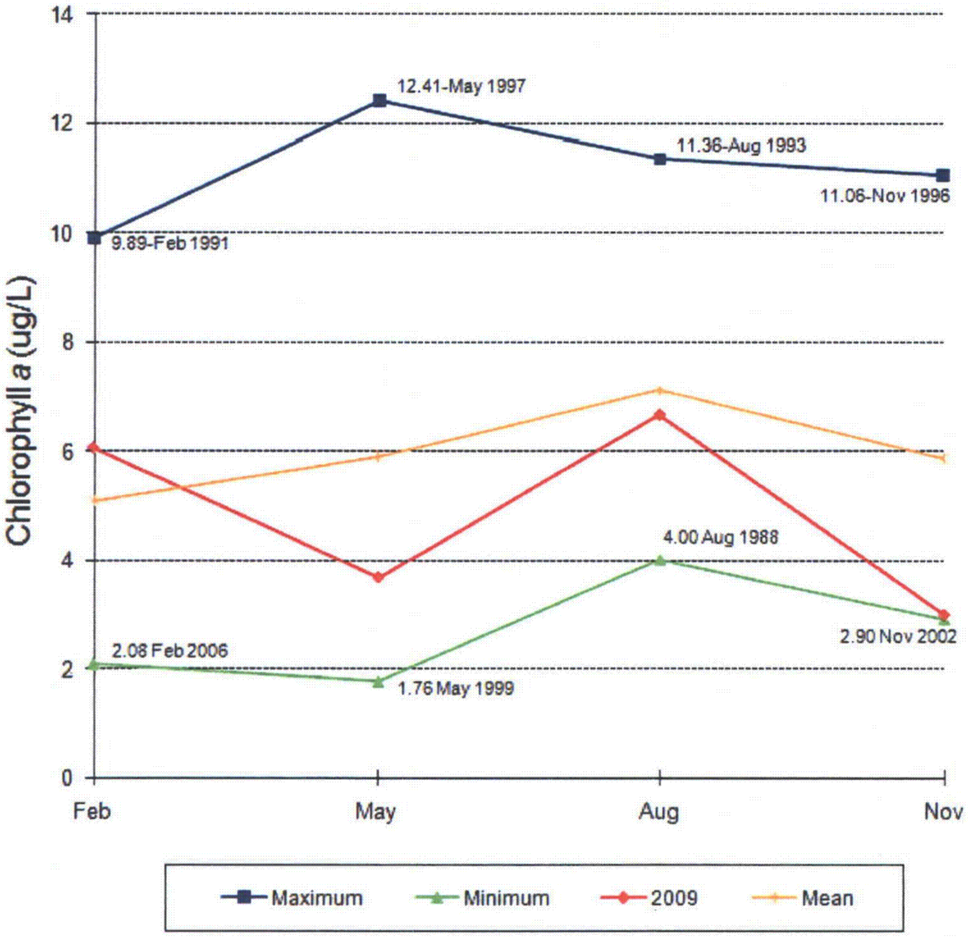


Figure 3-2. Lake Norman phytoplankton chlorophyll *a* seasonal maximum and minimum lake-wide means since August 1987 compared with the long-term seasonal lake-wide means and lak-wide means for 2009.

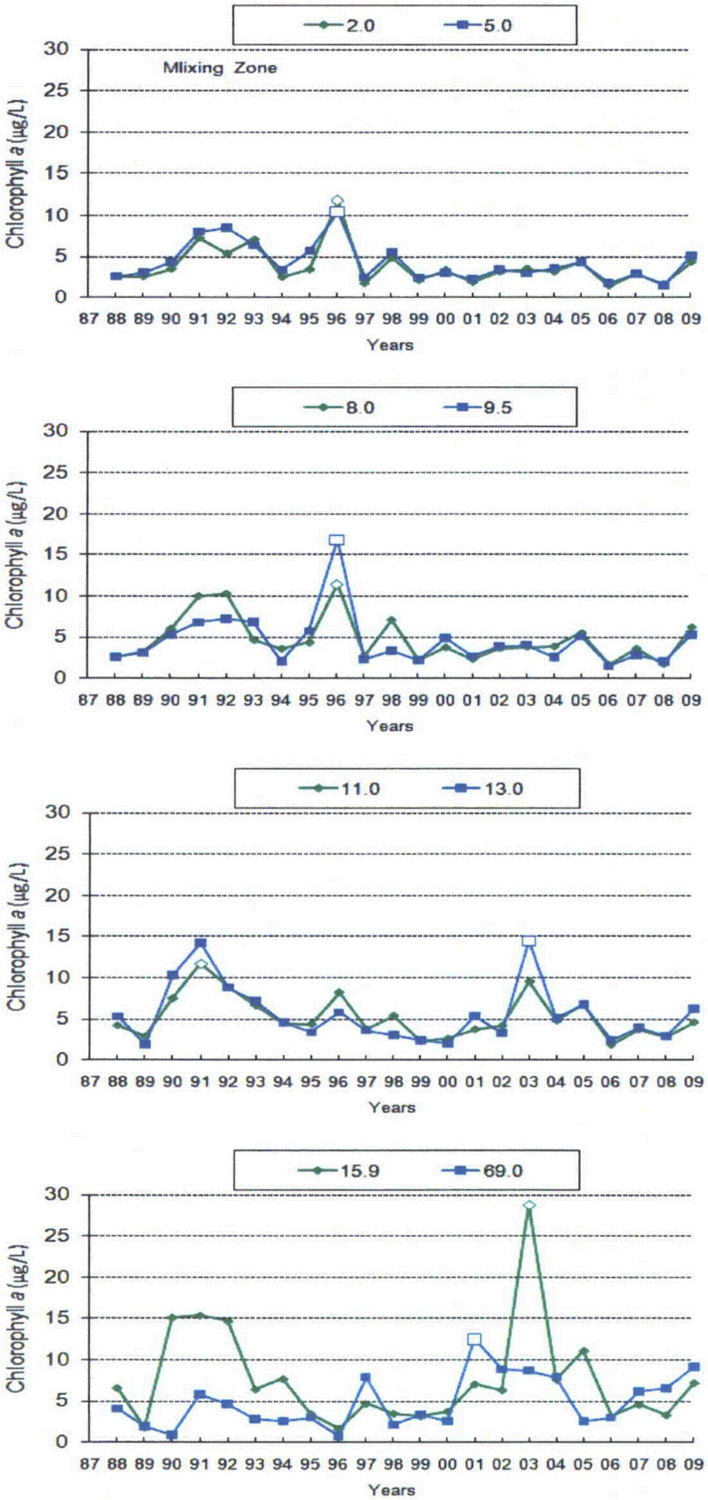


Figure 3-3. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from February 1988 – 2009 (clear data points represent long-term maxima.

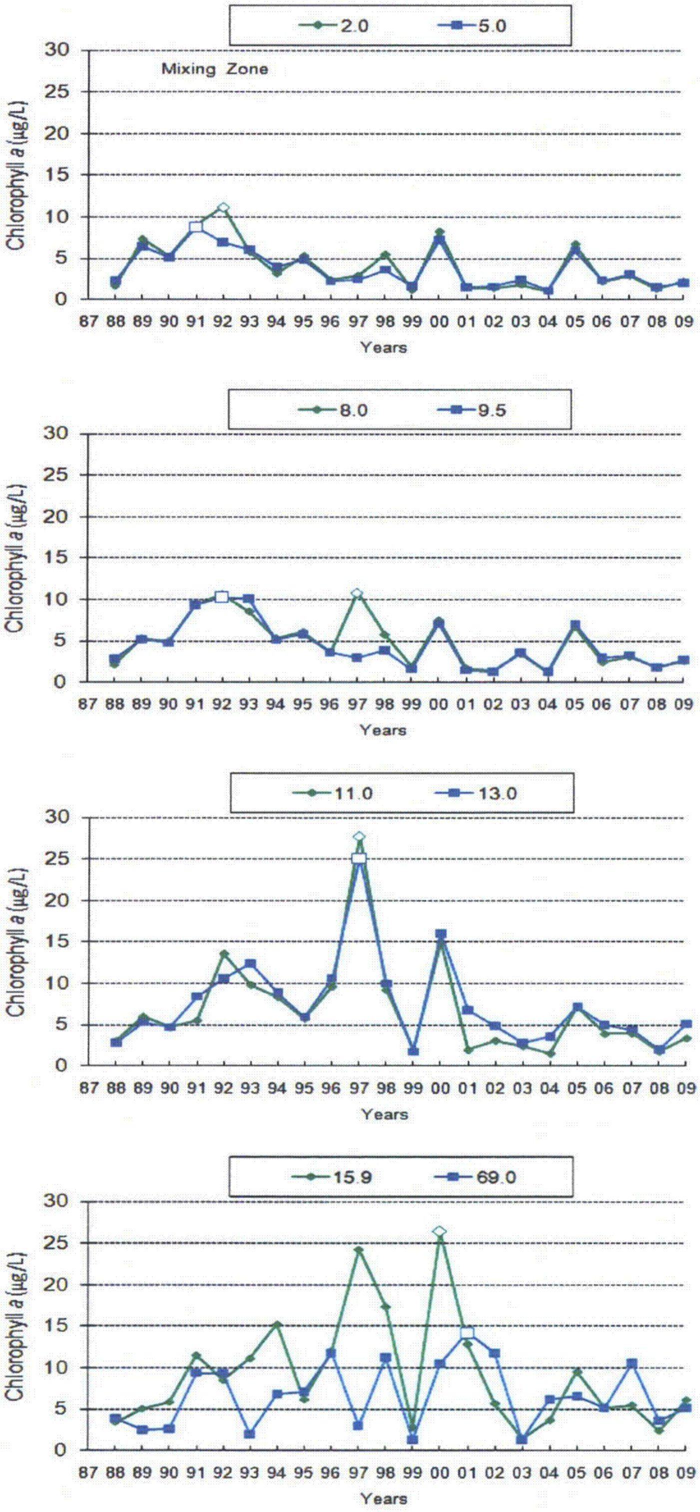


Figure 3-4. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from May 1988 – 2009 (clear data points represent long-term maxima).

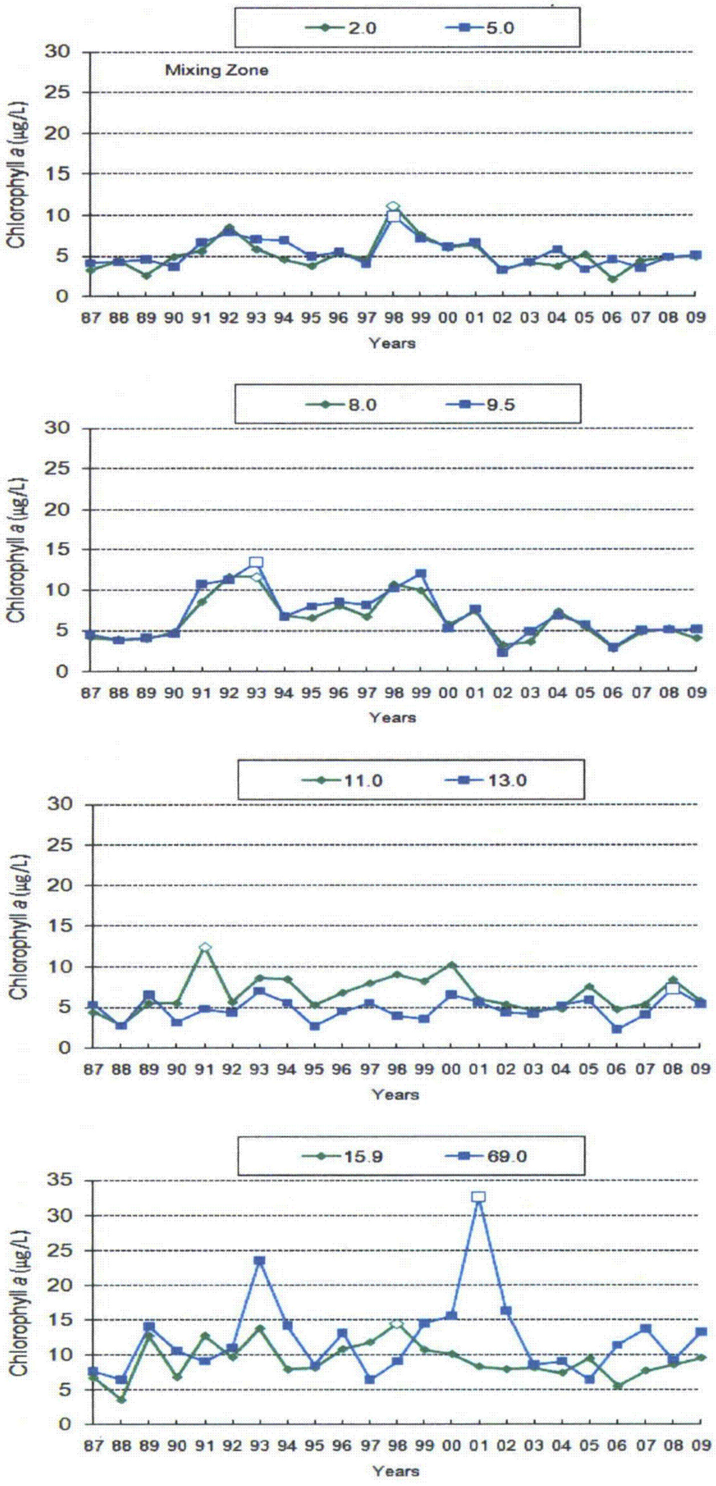


Figure 3-5. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during August 1987 – 2009 (Note: axis for 15.9 and 69.0, and that clear data points represent long-term maxima).

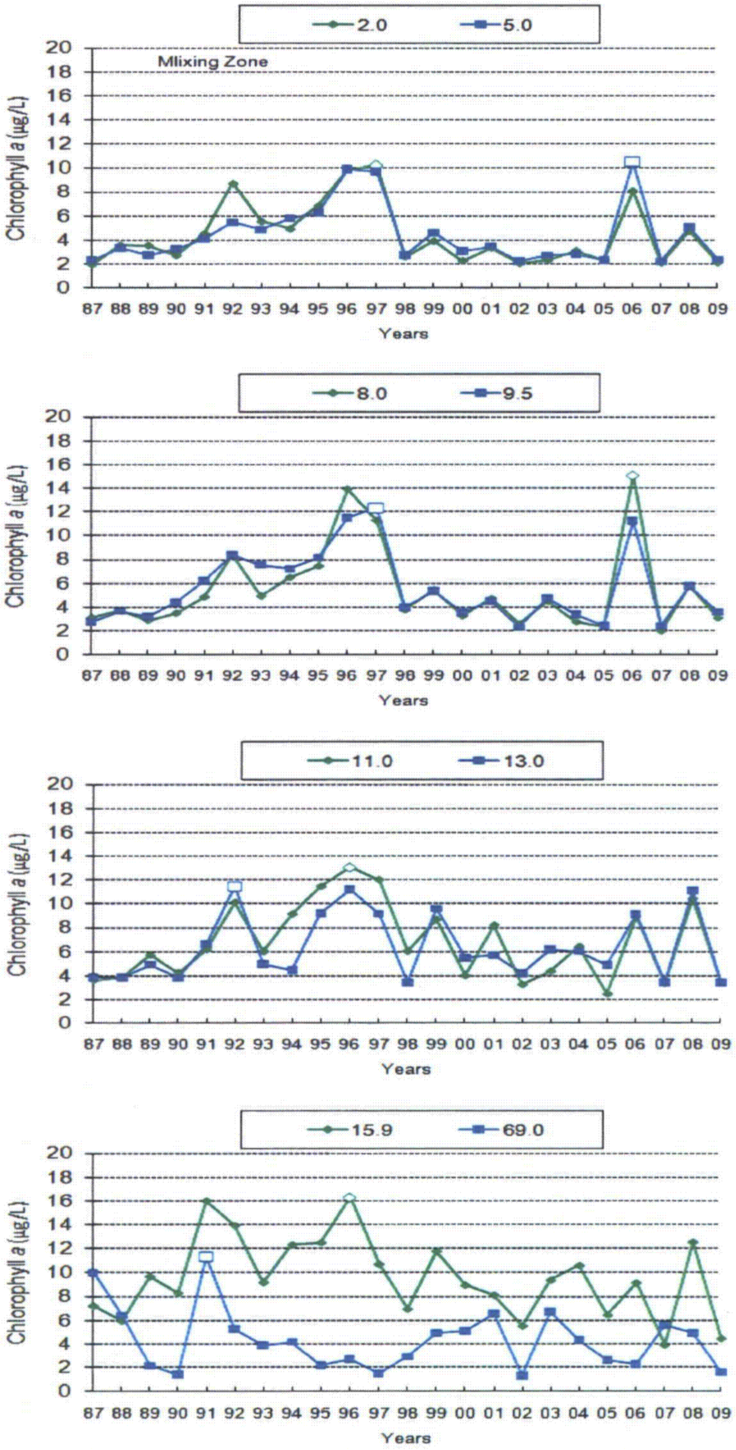


Figure 3-6. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during November 1987 – 2009 (Note: change in axis, and that clear data points represent long-term maxima).

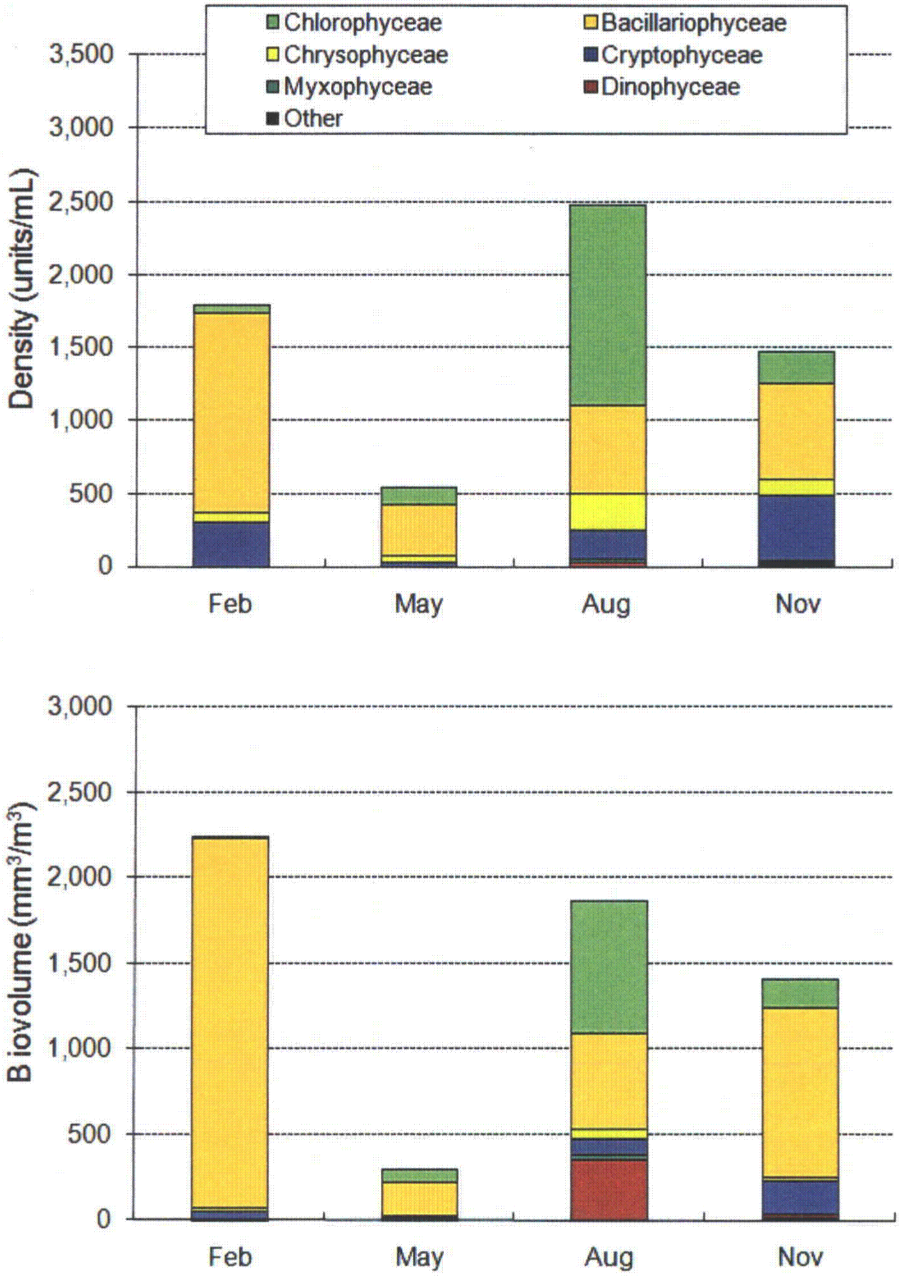


Figure 3-7. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 2.0 in Lake Norman during 2009.

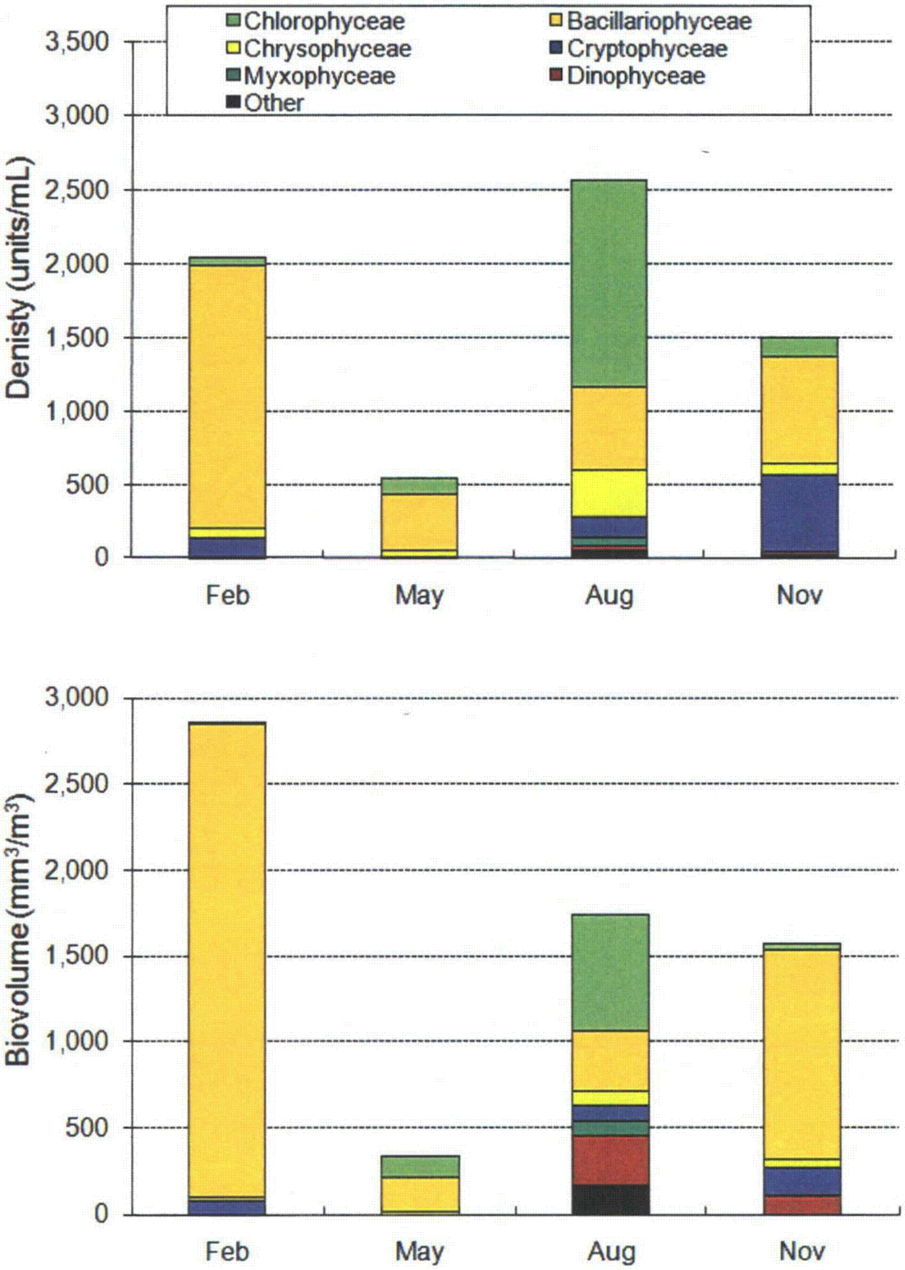


Figure 3-8. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 5.0 in Lake Norman during 2009.

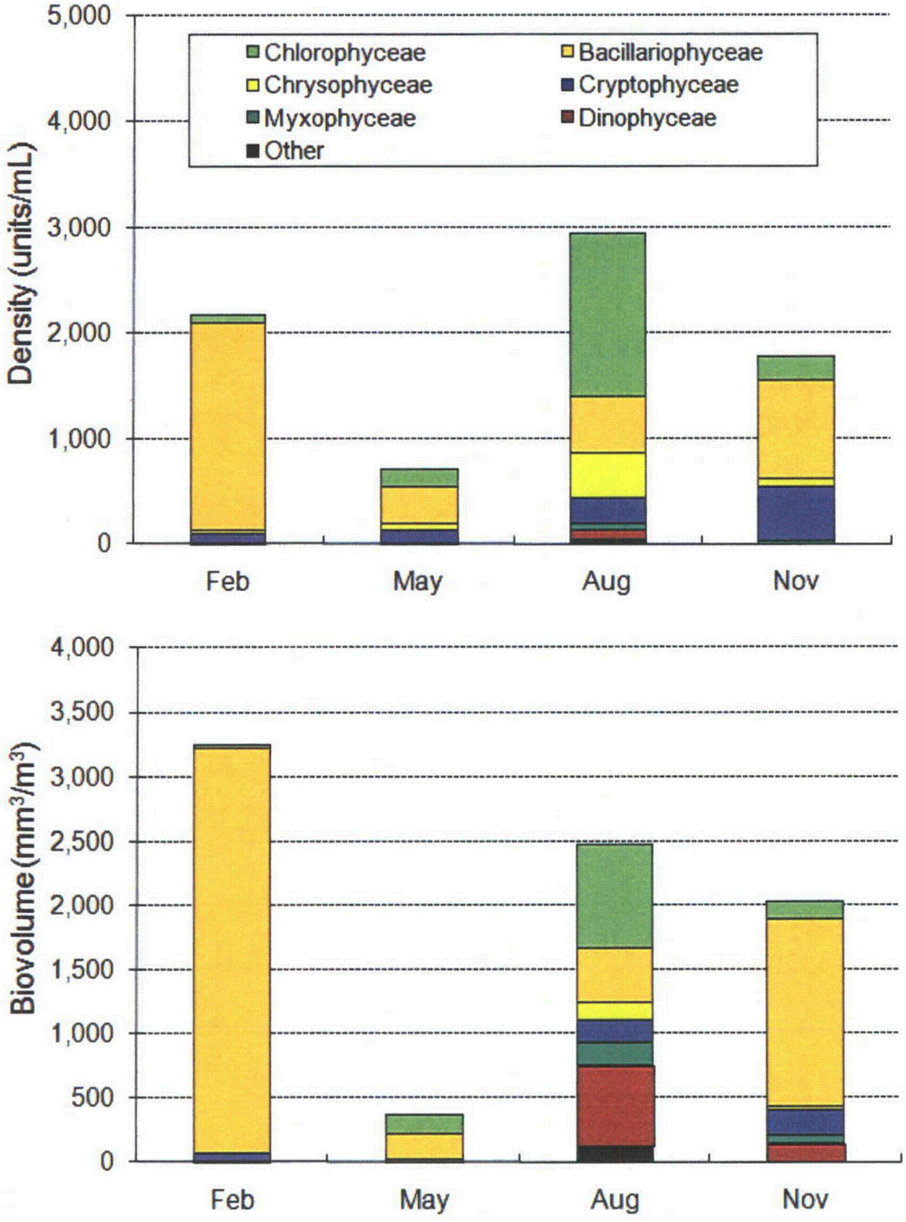


Figure 3-9. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 9.5 in Lake Norman during 2009.

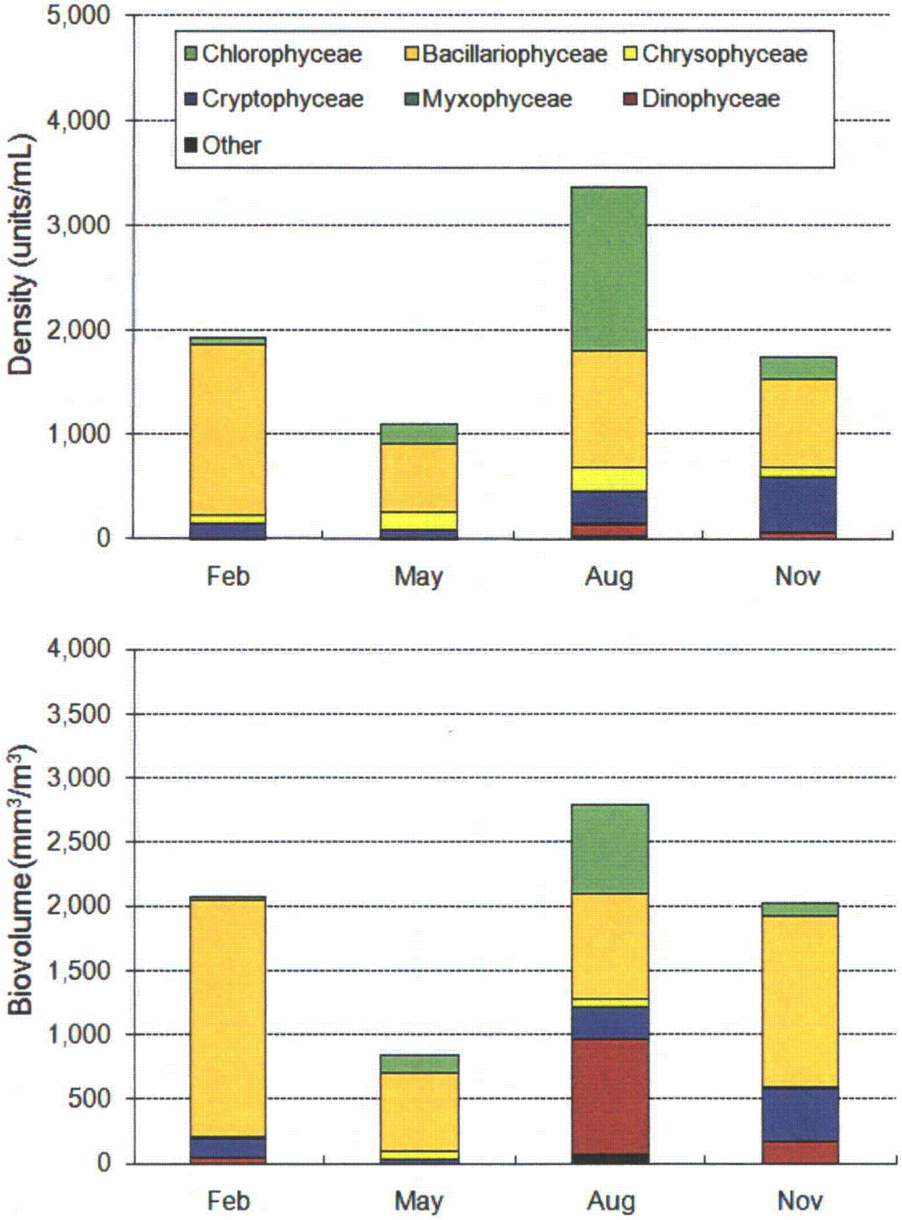
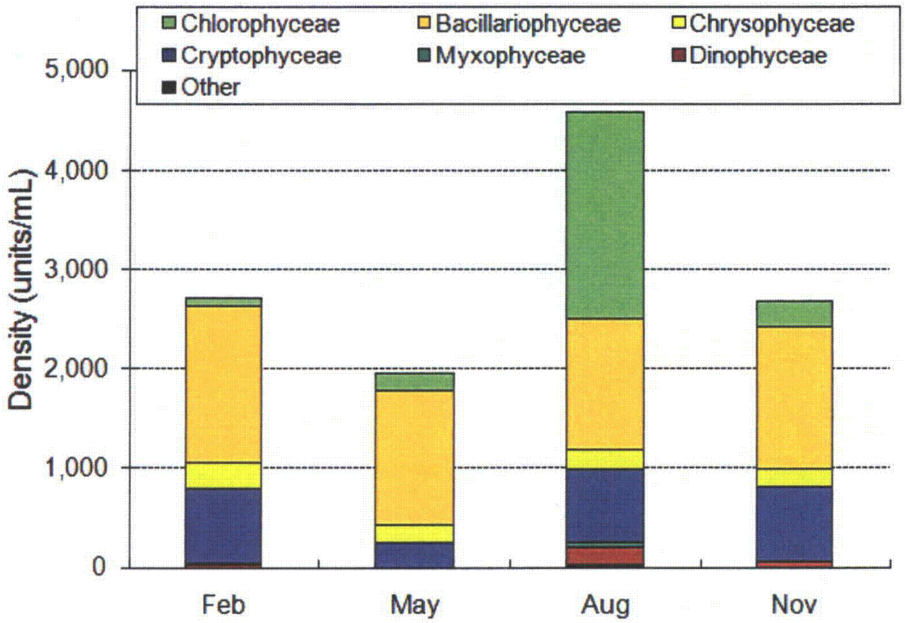


Figure 3-10. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 11.0 in Lake Norman during 2009.



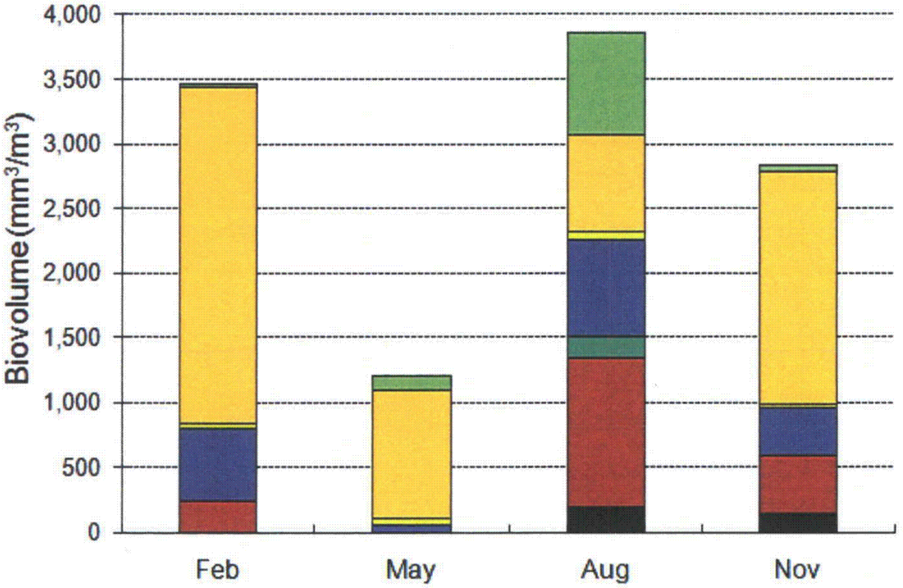


Figure 3-11. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 15.9 in Lake Norman during 2009.

CHAPTER 4

ZOOPLANKTON

INTRODUCTION

The objectives of the Lake Norman Maintenance Monitoring Program for zooplankton are to:

1. describe and characterize quarterly/seasonal patterns of zooplankton standing crops at selected locations on Lake Norman; and
2. compare and evaluate, where possible, zooplankton data collected during 2009 with historical data collected during the period 1987 – 2008.

Studies conducted prior to the Lake Norman Maintenance Monitoring Program, using monthly zooplankton data from Lake Norman, showed that zooplankton populations demonstrated a bimodal seasonal distribution with highest values generally occurring in the spring and a less pronounced fall peak. Considerable spatial and year-to-year variability has been observed in zooplankton abundance in Lake Norman (Duke Power Company 1976, 1985; Hamme 1982; Menhinick and Jensen 1974). Since quarterly sampling was initiated in August 1987, distinct bimodal seasonal distribution has been less apparent due to the lack of transitional data between quarters.

METHODS AND MATERIALS

Duplicate 10-m to surface and bottom to surface net tows were taken at Locations 2.0, 5.0, 9.5, 11.0, and 15.9 in Lake Norman (Figure 2-1) during each season: winter (February), spring (May), summer (August), and fall (November) 2009. For discussion purposes the 10-m to surface tow samples are called "epilimnetic" samples and the bottom to surface net tow samples are called "whole-column" samples. Locations 2.0 and 5.0 are defined as the "mixing zone" and Locations 9.5, 11.0 and 15.9 are defined as "background" locations. Field and laboratory methods for zooplankton standing crop analysis were the same as those reported in Hamme (1982). Zooplankton standing crop data from 2009 were compared with corresponding data from quarterly monitoring begun in August 1987.

RESULTS AND DISCUSSION

Total Abundance

Highest epilimnetic zooplankton densities at Lake Norman locations have predominantly been observed in the spring, with winter peaks observed about 25% of the time. Peaks were observed only occasionally in the summer and fall (Duke Energy 2009). During 2009, there was a considerable amount of variability in annual maxima among Lake Norman locations. The annual epilimnetic maxima were recorded from Locations 2.0, 5.0, and 9.5 in the fall, while Locations 11.0 and 15.9 demonstrated their peak annual densities in the spring and winter, respectively (Table 4-1 and Figures 4-1 and 4-2). The lowest epilimnetic densities occurred at Locations 2.0, 5.0, and 9.5 in the spring, while Locations 11.0 and 15.9 showed annual minima in the summer. Epilimnetic zooplankton densities ranged from a low of 34,507/m^3 at Location 5.0 in May, to a high of 267,781/m^3 at Location 15.9 in February.

Maximum densities in 2009 whole-column samples were observed at all locations in the fall. The seasonal whole-column minima at Locations 2.0, 5.0, and 9.5 occurred in the spring, while minima at Locations 11.0 and 15.9 were observed in the summer (Table 4-1 and Figure 4-1). Whole-column densities ranged from a low of 26,754/m^3 at Location 2.0 in May, to 185,512/m^3 at Location 15.9 in November.

During 2009, as has been the case in all past years, total zooplankton densities were most often higher in epilimnetic samples than in whole-column samples (Duke Energy 2009). This is related to the ability of zooplankton to orient vertically in the water column in response to physical and chemical gradients and the distribution of food sources, primarily phytoplankton, which are generally most abundant in the euphotic zone (Hutchinson 1967). Since epilimnetic zooplankton communities are far more representative of overall seasonal and temporal trends, most of the following discussion will focus primarily on zooplankton communities in this area of the water column.

Spatial distribution varied among locations from season to season. During winter and spring, lower average densities were observed from the mixing zone, as compared to background locations. During summer and fall this trend was not as apparent (Table 4-1; Figures 4-1 and 4-2). Location 15.9, the uppermost background location, had higher epilimnetic densities than mixing zone locations during winter and spring, while the spatial maxima in summer and fall occurred at Location 9.5 (Table 4-1). This spatial trend was similar to that of the phytoplankton (see Chapter 3). In most previous years of the Program, background locations had higher mean densities than mixing zone locations (Duke Energy 2009 and Figures 4-3 through 4-6).

Epilimnetic zooplankton densities during 2009 were most often within historical ranges (Figures 4-3 through 4-6). The exceptions were at Location 15.9 in the winter and Location 5.0 in the fall. On both occasions, these locations demonstrated long-term seasonal maximum densities (Figures 4-3 and 4-6).

The highest winter densities recorded from Locations 2.0 and 11.0 occurred in 1996, while the winter maximum at Location 9.5 was recorded in 1995 (Figure 4-3). The winter maximum from Location 5.0 occurred in 2004, while the long-term winter maximum from Location 15.9 occurred in 2009. Long-term maximum densities for spring were observed at Locations 2.0 and 5.0 in 2005, while the highest spring values from Locations 11.0 and 15.9 occurred in 2002. The highest spring peak at Location 9.5 was observed in 2005 (Figure 4-4). Long-term summer maxima occurred in 1988 at Locations 2.0, 5.0, and 11.0, while summer maxima at Locations 9.5 and 15.9 occurred in 2007 and 2003, respectively (Figure 4-5). Long-term maxima for the fall occurred at Locations 2.0, 9.5, and 11.0 in 2006. The long-term fall maximum at Location 5.0 occurred in 2009, while Location 15.9 demonstrated its fall maximum in 1996 (Figure 4-6).

Year-to-year fluctuations of densities in the mixing zone during the winter have occasionally been quite striking, particularly between 1991 and 1997. From 1998 – 2003, year-to-year fluctuations in the mixing zone were less apparent. Since 2004, higher annual fluctuations were apparent. From 1990 – 2003, the densities at mixing zone locations in the spring, summer, and fall demonstrated moderate degrees of year-to-year variability, and the long-term trend at mixing zone locations in the spring had been a gradual, long-term increase through 2005. During the spring of 2006, zooplankton densities in the mixing zone declined sharply, as compared to 2005, but were well within earlier historical ranges. During the spring of 2007, mixing zone locations demonstrated increases followed by sharp declines at both locations in 2008. In the spring of 2009, slight increases were noted. From 1989 – 2008, year-to-year fluctuations in the mixing zone during the summer were comparatively low, with the exception of a sharp increase in density at Location 5.0 in 2007. This was followed by a decline in 2008 and then increases in 2009. During fall periods of 1989 – 2008, mixing zone densities showed minimal fluctuations in the low range with the exceptions of 2006 and 2009 when values at both locations increased sharply. In fact, the long-term fall peak at Location 5.0 was observed in 2009. The background locations continue to exhibit considerable year-to-year variability in all seasons and all but Location 15.9 in the fall demonstrated higher densities in 2008 than in 2007 (Figures 4-3 through 4-6).

Community Composition

One hundred and twenty-three zooplankton taxa have been identified since the Lake Norman Maintenance Monitoring Program began in August 1987 (Table 4-2). Fifty-three taxa were identified during 2009, as compared to 48 recorded for 2008 (Duke Energy 2009).

During 2008, copepods were dominant in two-thirds of the samples (Duke Energy 2009). During 2009, dominance shifted toward the rotifers, as was the case in 2007, and these zooplankters were dominant in over 60% of the samples (Table 4-1). Copepods were dominant in both epilimnetic and whole-column samples at Locations 2.0, 5.0 and 9.5 in the spring of 2009, and were dominant in whole-column samples from Locations 2.0, 9.5, and 11.0 during the summer. Rotifers were the dominant forms in all whole-column samples and in epilimnetic samples from Locations 11.0 and 15.9 during the winter. Rotifers were also dominant in both epilimnetic and whole-column samples at Locations 11.0 and 15.9 during the spring. During the summer, rotifers dominated epilimnetic samples at Locations 2.0, 5.0, and 9.5, as well as the whole-column sample at Location 9.5. During the fall, they were dominant in all samples. Cladocerans, typically the least abundant forms, were dominant in epilimnetic samples from Locations 2.0, 5.0, and 9.5 in the winter, in epilimnetic samples from Locations 11.0 and 15.9 in the summer, and in the whole-column sample from Location 15.9, also in the summer (Table 4-1). During most years, microcrustaceans (copepods and cladocerans) dominated mixing zone samples, but were less important among background locations (Figures 4-7 and 4-8). Compared to 2008, rotifers showed substantial increases in relative abundances in both the epilimnetic and whole-column samples of the mixing zone. In fact, the percent composition of rotifers had increased dramatically since 2008 (Figure 4-7). This substantial increase in the relative abundances of rotifers in the mixing zone was more in keeping with historical trends. At background locations rotifer relative abundances showed more moderate increases in epilimnetic and whole-column samples since 2008 and percent compositions were within historical ranges (Figure 4-8).

Copepoda

As has always been the case, copepod populations were consistently dominated by immature forms (primarily nauplii) during 2009. Adult copepods seldom comprised more than 7% of the total zooplankton density at any location. *Epishura* was the most important genus in most adult populations during spring and in most epilimnetic samples in the winter. *Tropocyclops* was dominant in the epilimnion of Location 11.0 and in whole column samples of Locations 5.0, 9.5, and 11.0 in the winter. *Tropocyclops* was dominant in all summer samples, as well as most epilimnetic samples in the fall. Similar patterns of copepod taxonomic distributions were observed in previous years (Duke Energy 2009).

Copepods tended to be more abundant at background locations than at mixing zone locations during all but the summer of 2009 (Figure 4-9). Copepod densities peaked at mixing zone locations in the summer and at background locations in the fall. During most past years peaks from both areas were observed in the spring.

Cladocera

Bosmina was the most abundant cladoceran observed in 2009 samples, as has been the case in most previous studies (Duke Energy 2009 and Hamme 1982). *Bosmina* often comprised greater than 5% of the total zooplankton densities in both epilimnetic and whole-column samples, and was the dominant zooplankton taxon in two winter samples (Table 4-3). *Bosminopsis* was important among cladocerans in the summer when it dominated cladoceran populations in all samples. *Diaphanosoma* was the dominant cladoceran in all but one sample during the spring. Similar patterns of cladoceran dominance have been observed in past years (Duke Energy 2008).

Long-term seasonal trends of cladoceran densities were variable. During 2008, maximum densities in the mixing zone occurred in the winter, while peaks at background locations were observed in the spring (Figure 4-10). From 1990 to 1993, and in 2009, peak densities occurred in the winter, while in 1994, 1995, 1997, 2000, 2004, 2005, and 2007 maxima were recorded in the spring (Figure 4-10). During 1996 and 2002, peak cladoceran densities occurred in the spring in the mixing zone, and in the summer among background locations, while in 1999 they peaked in the mixing zone during the summer and among background locations in the fall. Maximum cladoceran densities in 1998 occurred in the summer. In 2001, maximum cladoceran densities in the mixing zone occurred in the fall, while background locations showed peaks in the winter. During 2003, maximum densities in the mixing zone occurred in the fall, while peaks among background locations were observed in the summer. Spatially, cladocerans were well distributed among most locations (Table 4-1, Figure 4-2).

Rotifera

Polyarthra was the most abundant rotifer in 40% of epilimnetic whole-column samples in the spring and fall of 2009 (Table 4-3). *Keratella* was the most abundant rotifer in 15% of epilimnetic samples and 25% of whole-column samples, mostly in the winter. *Asplanchna* was the most abundant rotifer in 15% of eplimnetic and whole column samples collected mostly in the winter. *Ptygura* dominated rotifer populations in one epilimnetic and two whole column samples during the summer. Other rotifers with occasional dominance were *Conochilus, Ploeosoma, Kellicotia, Collotheca*, and *Tricocerca*. All of these taxa have been identified as important constituents of rotifer populations, as well as zooplankton communities, in previous studies (Duke Energy 2009 and Hamme 1982).

Long-term tracking of rotifer populations indicated high year-to-year seasonal variability. Peak densities have most often occurred in the winter and spring, with occasional peaks in the summer and fall (Figure 4-11). During 2009, peak rotifer densities were observed at both mixing zone and background locations in the fall.

FUTURE STUDIES

No changes are planned for the zooplankton portion of the Lake Norman Maintenance Monitoring Program.

SUMMARY

During 2009, seasonal maximum densities among zooplankton assemblages varied considerably and no consistent seasonal trends were observed. Maxima occurred in winter and fall, while minima most often occurred in the spring. As in past years, epilimnetic densities were higher than whole-column densities. Mean zooplankton densities tended to be higher among background locations than among mixing zone locations during 2009. Spatial trends of zooplankton populations were similar to those of the phytoplankton in winter and spring, with increasing densities from downlake to uplake. During summer and fall, this spatial trend was not observed. From around 1997 through 2005, a year-to-year trend of increasing zooplankton densities was observed among mixing zone locations in the spring. Densities at these locations declined sharply in 2006, followed by an increase in 2007. The densities showed a decline in 2008, followed by an increase in 2009. In most cases, densities in 2009 were higher than in 2008. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations.

Epilimnetic zooplankton densities were generally within ranges of those observed in previous years. The exceptions were record high densities at Location 15.9 in the winter and Location 5.0 in the fall.

One hundred and twenty-three zooplankton taxa have been recorded from Lake Norman since the Program began in 1987. Fifty-three taxa were identified in 2009, as compared to 48 in 2008.

Overall, relative abundance of copepods in 2009 decreased over 2008. Rotifers were dominant in over 60% of all samples. The relative abundance of microcrustaceans decreased substantially in the mixing zone in 2009 and their percent compositions at these locations were in the low range. At background locations, microcrustaceans showed less dramatic decreases during 2009 and percent compositions were within historical ranges of past years. Historically, copepods and rotifers have most often shown annual peaks in the spring, while cladocerans continued to demonstrate year-to-year variability.

Copepods were dominated by immature forms with adults rarely accounting for more than 7% of zooplankton densities. The most important adult copepod was *Tropocyclops*, as was the case in previous years. *Epishura* was also important in winter and spring. *Bosmina* was the predominant cladoceran, as has also been the case in most previous years of the Program. *Bosminopsis* dominated cladoceran populations during the summer, while *Diaphanosoma* was an important constituent of spring populations. The most abundant rotifers observed in 2009, as in many previous years, were *Polyarthra, Keratella,* and *Asplanchna. Ptygura, Conochilus,* and *Ploeosoma,* were also important among rotifer populations.

Lake Norman continues to support a highly diverse and viable zooplankton community. Other than somewhat lower productivity from MNS induced mixing at Locations 2.0 and 5.0, no impacts of plant operations were observed.

Table 4-1. Total zooplankton densities (No. X 1000/m^3), densities of major zooplankton taxonomic groups, and percent composition (in parentheses) of major taxa in the epilimnion and whole column net tow samples collected from Lake Norman in winter (February), spring (May), summer (August), and fall (November) 2009.

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
2/13/2009	Epilimnion	Copepoda	10.29	12.24	31.91	34.91	28.12
			(20.5)	(18.2)	(35.2)	(24.5)	(10.5)
		Cladocera	22.54	29.19	38.16	35.64	46.29
			(44.8)	(43.3)	(42.0)	(25.0)	(17.3)
		Rotifera	17.42	25.98	20.64	71.89	193.37
			(34.7)	(38.5)	(22.8)	(50.5)	(72.2)
		Total	50.25	67.41	90.71	142.44	267.78
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	19 m	20 m	25 m	20 m
		Copepoda	9.15	10.99	17.24	24.46	26.04
			(15.1)	(18.4)	(29.5)	(25.8)	(15.0)
		Cladocera	15.52	17.68	16.69	21.46	29.57
			(25.6)	(29.7)	(28.5)	(22.7)	(17.0)
		Rotifera	35.98	30.94	24.57	48.68	118.01
			(59.3)	(51.9)	(42.0)	(51.5)	(68.0)
		Total	60.65	59.61	58.50	94.60	173.62

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
5/22/2009	Epilimnion	Copepoda	20.95	17.27	20.28	51.87	38.52
			(41.7)	(50.0)	(42.3)	(28.8)	(17.5)
		Cladocera	17.22	13.18	18.99	27.05	24.70
			(34.3)	(38.2)	(39.6)	(15.0)	(11.2)
		Rotifera	12.08	4.06	8.70	101.20	157.25
			(24.0)	(11.8)	(18.1)	(56.2)	(71.3)
		Total	50.25	34.51	47.97	180.12	220.47
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	20 m	21 m	25 m	21 m
		Copepoda	12.37	14.45	21.80	21.71	33.08
			(46.3)	(46.3)	(49.0)	(26.3)	(23.2)
		Cladocera	10.58	13.81	15.74	15.84	19.00
			(39.5)	(44.2)	(35.3)	(19.2)	(13.3)
		Rotifera	3.80	2.97	6.99	45.13	90.41
			(14.2)	(9.5)	(15.7)	(54.5)	(63.5)
		Total	26.75	31.23	44.53	82.68	142.49

Table 4-1. (Continued).

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
8/5/2009	Epilimnion	Copepoda	21.83	25.01	15.81	26.38	19.41
			(36.7)	(39.3)	(14.9)	(27.2)	(32.8)
		Cladocera	7.54	9.19	22.64	35.65	32.36
			(12.7)	(14.4)	(21.3)	(36.7)	(54.7)
		Rotifera	30.04	29.48	67.87	35.00	7.34
			(50.6)	(46.3)	(63.8)	(36.1)	(12.4)
		Total	59.41	63.68	106.32	97.03	59.11
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	20 m	21 m	25 m	21 m
		Copepoda	15.84	19.95	14.40	14.52	14.84
			(50.4)	(48.6)	(17.9)	(37.5)	(31.0)
		Cladocera	4.64	5.04	21.60	14.26	27.24
			(14.7)	(12.2)	(26.8)	(36.7)	(56.9)
		Rotifera	10.88	16.12	44.52	10.03	5.53
			(34.6)	(39.2)	(55.3)	(25.8)	(11.5)
		Total	31.46[a]	41.11	80.52	38.81	47.88[b]

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
11/24/2009	Epilimnion	Copepoda	13.40	12.57	29.78	23.33	19.04
			(7.9)	(6.4)	(12.3)	(17.2)	(9.6)
		Cladocera	7.55	8.91	10.26	4.10	1.16
			(4.5)	(4.6)	(4.3)	(3.0)	(0.6)
		Rotifera	148.13	173.54	201.14	108.30	178.68
			(87.6)	(89.0)	(83.4)	(79.8)	(89.8)
		Total	169.08	195.02	241.18	135.73	198.88
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	19 m	21 m	25 m	21m
		Copepoda	10.25	16.58	28.35	27.63	18.28
			(11.0)	(14.9)	(16.2)	(25.5)	(9.9)
		Cladocera	6.73	5.54	3.58	6.02	3.96
			(7.2)	(5.0)	(2.0)	(5.6)	(2.1)
		Rotifera	76.42	88.92	143.30	74.61	163.28
			(81.8)	(80.1)	(81.8)	(68.9)	(88.0)
		Total	93.40	111.04	175.23	108.26	185.52

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[a] = *Chaoborus* (102/m^3, 0.3%)

[b] = *Chaoborus* (272/m^3, 0.6%)

Table 4-2. Zooplankton taxa identified from samples collected quarterly on Lake Norman from 1987 – 2009.

Taxon	87-94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
Copepoda																
Cyclops thomasi Forbes	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
C. vernalis Fischer			X													
C. spp. O. F. Muller	X	X	X	X	X			X	X	X						X
Diaptomus birgei Marsh	X						X									
D. mississippiensis Marsh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. pallidus Herick	X	X	X	X		X				X		X				
D. reighardi Marsh						X										
D. spp. Marsh	X	X	X	X	X	X	X		X	X					X	X
Epishura fluviatilis Herrick		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ergasilus spp. Smith			X										X			
Eucyclops agilis (Koch)					X											
E. prionophorus Kiefer														X		
Mesocyclops edax (S. A. Forbes)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Sars	X	X	X	X				X	X	X					X	
Paracyclops limbricatus v. *poppei*												X				
Tropocyclops prasinus (Fischer)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. spp. (Fischer)	X	X	X	X				X	X		X		X	X	X	X
Cladocera																
Alona spp.Baird			X	X										X		X
Alonella spp. (Birge)	X					X										
Bosmina longirostris (O. F. M.)	X			X	X	X	X	X	X	X	X	X	X	X	X	X
B. spp. Baird	X	X	X	X	X		X	X	X							
Bosminopsis dietersi Richard	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceriodaphnia lacustris Birge	X			X	X	X	X	X		X	X	X	X	X	X	X
C. spp. Dana	X	X	X	X	X	X	X	X	X	X					X	X
Chydorus spp. Leach	X	X	X	X		X		X	X		X	X			X	
Daphnia ambigua Scourfield	X		X	X	X	X		X				X	X	X	X	X
D. catawba Coker			X	X				X							X	
D. galeata Sars			X													
D. laevis Birge			X							X						
D. longiremis Sars			X	X			X	X		X	X					
D. lumholzi Sars	X	X	X		X	X	X					X				
D. mendotae (Sars) Birge				X	X	X	X			X				X		
D. parvula Fordyce	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. pulex (de Geer)			X	X										X		X
D. pulicaria Sars			X	X												
D. retrocurva Forbes			X	X	X	X	X		X	X	X	X			X	X
D. schodleri Sars			X													
D. spp. Mullen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Diaphanosoma brachyurum (Lievin)				X	X	X	X	X	X	X	X	X	X	X	X	X
D. spp. Fischer	X	X	X	X	X		X	X	X	X	X					
Disparalona acutirostris (Birge)											X					
Eubosmina spp. (Baird)	X															
Holopedium amazonicum Stin.	X			X	X	X	X	X	X		X	X	X	X	X	X
H. gibberum Zaddach	X			X	X											

Table 4-2. (Continued).

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Taxon	87-93	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
H. spp. Stingelin	X	X	X	X			X	X	X	X						X
Ilyocryptus sordidus (Lieven)	X															
I. spinifer Herrick						X										
I. spp. Sars	X				X		X								X	
Latona setifera (O.F. Muller)	X															
Leptodora kindtii (Focke)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leydigia acanthoceroides (Fis.)											X					
L. spp. Freyberg	X	X	X	X						X	X			X	X	
Moina spp. Baird	X															
Monospilus dispar Sars										X						
Oxurella spp. (Sars)											X					
Pleuroxus hamulatus Birge										X						X
P. spp. Baird										X						
Sida crystallina O. F. Muller	X															
Simocephalus expinosus (Koch)	X															
Simocephalus spp. Schodler						X										
Rotifera																
Anuraeopsis fissa (Gosse)											X			X		
A. spp. Lauterborne	X	X		X		X					X		X	X		
Asplanchna brightwelli Gosse					X		X									
A. priodonta Gosse					X	X	X				X					X
A. spp. Gosse	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Brachionus calyciflorus												X				
Brachionus caudata Bar. & Dad.	X															
B. bidentata Anderson										X						
B. havanensis Rousselet	X			X												
B. patulus O. F. Muller	X				X											
B. spp. Pallas	X	X	X		X											
Chromogaster ovalis (Berg.)				X	X	X		X				X	X	X	X	X
C. spp. Lauterborne	X	X	X													
Collotheca balatonica Harring			X	X	X	X	X		X	X	X	X	X	X	X	X
C. mutabilis (Hudson)			X	X	X	X	X			X	X	X	X	X	X	X
C. spp. Harring	X	X	X	X	X		X	X	X	X					X	X
Colurella spp. Bory de St. Vin.			X													
Conochiloides dossuarius Hud.				X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Hlava	X	X	X	X				X		X						
Conochilus unicornis (Rouss.)	X			X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Hlava	X	X	X	X				X	X							X
Filinia spp. Bory de St. Vincent	X				X						X					
Gastropus stylifer Imhof					X	X	X	X			X		X	X		
G. spp. Imhof	X	X	X	X	X			X								
Hexarthra mira Hudson				X	X	X	X		X				X	X	X	X
H. spp. Schmada	X	X	X	X				X								
Kellicottia bostoniensis (Rou.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
K. longispina Kellicott				X	X	X	X	X	X	X	X	X	X	X	X	X
K. spp. Rousselet	X	X	X	X				X	X	X	X	X				X
Keratella americana Carlin														X		
K. cochlearis Raderorgan						X	X				X			X	X	X

Table 4-2. (Continued). Page 3 of 3

Taxon	87-93	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
K. taurocephala Myers				X		X					X	X		X	X	
K. spp. Bory de St. Vincent	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Lecane luna O. F. Muller															X	
Lecane spp. Nitzsch	X	X		X	X		X		X	X		X	X			
Macrochaetus subquadratus P.				X	X											
M. spp. Perty	X		X			X	X		X			X				
Monommata spp. Bartsch													X			X
Monostyla stenroosi (Meiss.)	X															
M. spp. Ehrenberg	X	X	X		X					X						
Notholca spp. Gosse	X		X		X											
Platyias patulus Harring									X							
Ploesoma hudsonii Brauer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. truncatum (Levander)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Herrick	X	X	X		X			X								X
Polyarthra euryptera (Weir.)	X				X						X		X	X		
P. major Burckhart				X		X	X		X	X	X	X	X	X	X	X
P. vulgaris Carlin	X			X		X	X	X	X	X	X	X	X	X	X	X
P. spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pompholyx spp. Gosse			X													
Ptygura libra Meyers				X	X		X		X	X	X	X	X	X	X	X
P. spp. Ehrenberg	X	X	X	X					X	X						X
Synchaeta spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichocerca capucina (Weir.)	X	X	X	X	X				X							
T. cylindrica (Imhof)	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
T. longiseta Schrank				X									X	X		X
T. multicrinis (Kellicott)					X	X	X		X	X	X	X	X	X	X	X
T. porcellus (Gosse)		X	X	X		X	X		X		X					
T. pusilla Jennings				X												
T. similis Lamark		X											X			
T. spp. Lamark	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichotria spp. Bory de St. Vin.			X						X		X					
Unidentified Bdelloida	X			X	X	X					X			X	X	
Unidentified Monogonata																
Unidentified Philodinidae											X					X
Unidentified Rotifera	X	X	X	X	X	X	X									
Insecta																
Chaoborus spp. Lichtenstein	X				X	X		X	X		X	X	X	X	X	X
Ostracoda (unidentified)					X					X	X				X	

Table 4-3. Dominant copepod (adults), cladoceran, and rotifer taxa and their percent composition (in parentheses) of the copepod, cladoceran and rotifer densities by location and sample period in Lake Norman in 2009.

Locations	Winter	Spring	Summer	Fall
		Copepoda:	**Epilimnion**	
2.0	*Epishura* (3.1)	*Epishura* (5.7)	*Tropocyclops* (5.7)	*Tropocyclops* (7.0)[c]
5.0	*Epishura* (1.9)	*Epishura* (7.1)	*Tropocyclops* (5.9)	*Tropocyclops* (3.1)
9.5	*Epishura* (2.6)	*Epishura* (9.8)	*Tropocyclops* (9.3)[c]	*Tropocyclops* (7.5)[c]
11.0	*Tropocyclops* (1.9)	*Epishura* (4.5)	*Tropocyclops* (4.1)[c]	*Mesocyclops* (2.8)
15.9	No adults present	*Epishura* (4.1)	*Tropocyclops* (3.2)[c]	*Tropocyclops* (5.3)[c]
		Copepoda:	**Whole-column**	
2.0	No adults present	*Epishura* (7.8)	*Tropocyclops* (5.9)	*Tropocyclops* (3.0)
5.0	*Tropocyclops* (13.5)	*Epishura* (10.0)[c]	*Tropocyclops* (15.1)[c]	*Epishura* (2.5)
9.5	*Tropocyclops* (4.0)	*Epishura* (7.3)	*Tropocyclops* (2.9)	*Epishura* (12.3)
11.0	*Tropocyclops* (5.5)	*Epishura* (5.4)	*Tropocyclops* (10.9)	*Epishura* (4.3)
15.9	*Epishura* (1.1)[c]	*Mesocyclops* (1.4)	*Tropocyclops* (8.6)	*Tropocyclops* (1.6)
		Cladocera:	**Epilimnion**	
2.0	*Bosmina* (94.6)	*Diaphanosoma* (57.0)	*Bosminopsis* (70.7)	*Bosmina* (90.0)
5.0	*Bosmina* (67.7)	*Diaphanosoma* (54.8)	*Bosminopsis* (85.3)	*Bosmina* (97.8)
9.5	*Bosmina* (98.4)	*Diaphanosoma* (36.2)	*Bosminopsis* (71.8)	*Bosmina* (94.6)
11.0	*Bosmina* (96.4)	*Diaphanosoma* (61.4)	*Bosminopsis* (74.0)	*Bosmina* (75.0)
15.9	*Bosmina* (86.8)	*Diaphanosoma* (44.0)	*Bosminopsis* (74.2)	*Bosmina* (100.0)
		Cladocera:	**Whole-column**	
2.0	*Bosmina* (98.1)	*Diaphanosoma* (43.4)	*Bosminopsis* (65.2)	*Bosmina* (86.3)
5.0	*Bosmina* (98.0)	*Diaphanosoma* (50.0)	*Bosminopsis* (74.6)	*Bosmina* (92.3)
9.5	*Bosmina* (95.8)	*Diaphanosoma* (39.2)	*Bosminopsis* (76.1)	*Bosmina* (84.6)
11.0	*Bosmina* (86.2)	*Diaphanosoma* (63.4)	*Bosminopsis* (74.1)	*Bosmina* (60.1)
15.9	*Bosmina* (98.0)	*Bosmina* (61.0)	*Bosminopsis* (65.3)	*Bosmina* (92.6)

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[c] = Only adults present in samples.

Table 4-3. (Continued).

Locations	Winter	Spring	Summer	Fall
		Rotifera:	**Epilimnion**	
2.0	*Keratella* (72.01)	*Polyarthra* (54.2)	*Conochilus* (58.2)	*Polyarthra* (95.4)
5.0	*Keratella* (80.0)	*Kellicottia* (50.9)	*Ptygura* (52.1)	*Polyarthra* (97.3)
9.5	*Asplanchna* (47.0)	*Polyarthra* (87.1)	*Collotheca* (71.2)	*Polyarthra* (84.3)
11.0	*Asplanchna* (57.7)	*Keratella* (80.1)	*Trichocera* (32.3)	*Polyarthra* (66.3)
15.9	*Asplanchna* (60.7)	*Polyarthra* (68.2)	*Ploeosoma* (36.3)	*Polyarthra* (47.0)
		Rotifera:	**Whole-column**	
2.0	*Keratella* (81.3)	*Polyarthra* (53.4)	*Conochilus* (43.9)	*Poluarthra* (90.6)
5.0	*Keratella* (90.2)	*Keratella* (51.6)	*Ptygura* (34.5)	*Polyarthra* (96.9)
9.5	*Keratella* (67.3)	*Polyarthra* (59.4)	*Ptygura* (66.5)	*Polyarthra* (79.4)
11.0	*Asplanchna* (44.8)	*Polyarthra* (81.9)	*Asplanchna* (31.3)	*Polyarthra* (65.7)
15.9	*Asplanchna* (57.6)	*Polyarthra* (63.7)	*Ploeosoma* (49.1)	*Keratella* (52.5)

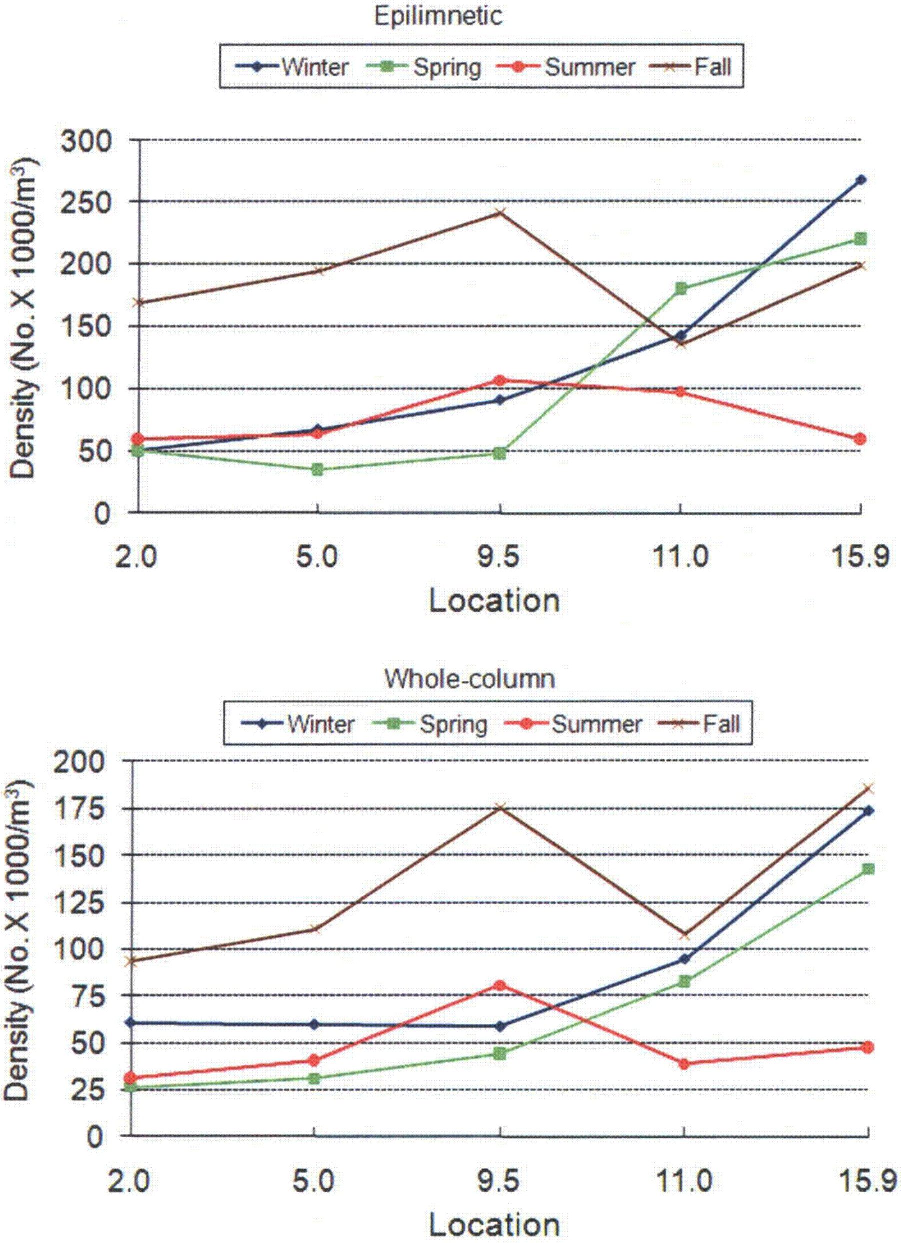


Figure 4-1. Total zooplankton density by location for samples collected in Lake Norman in 2009.

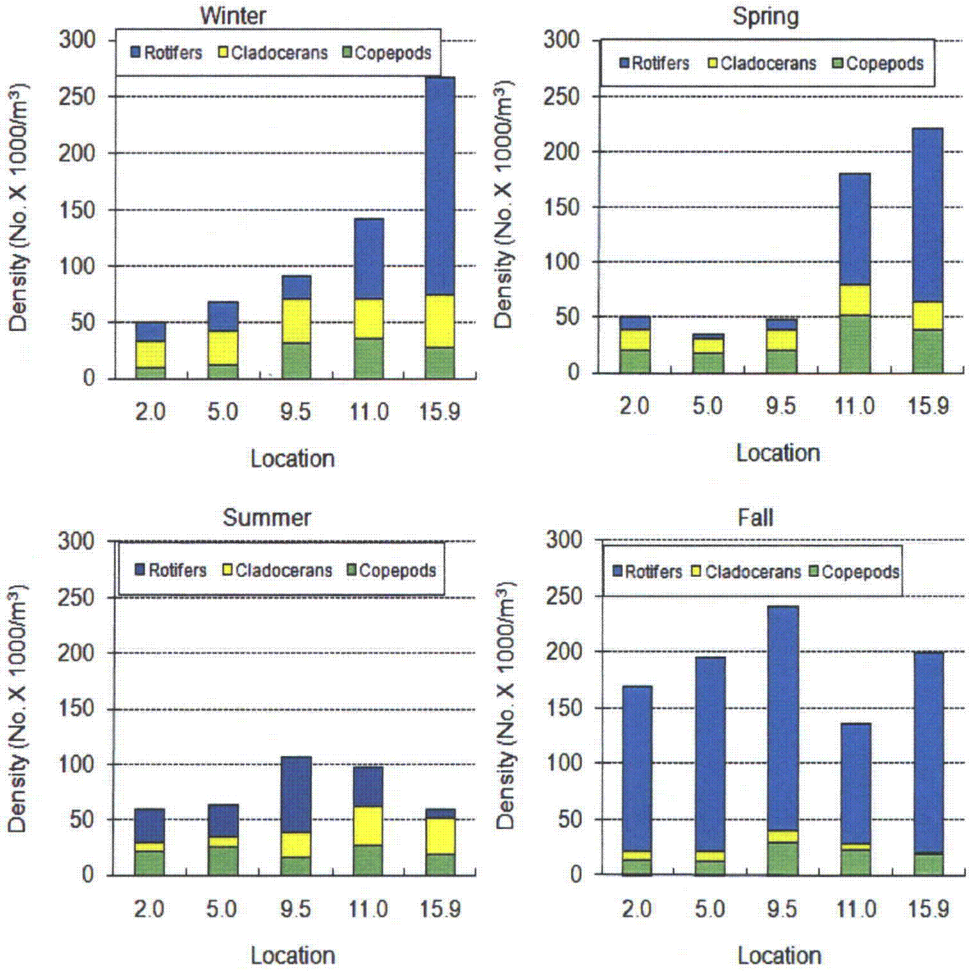
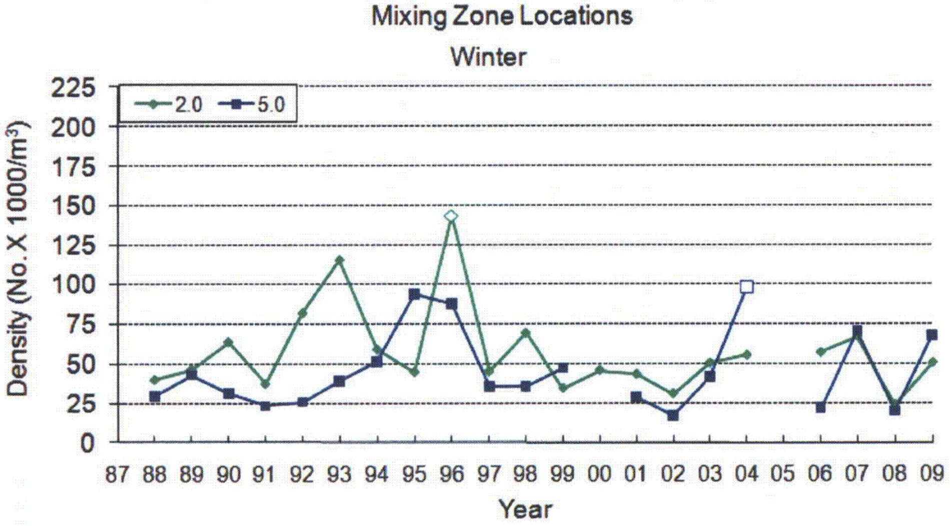


Figure 4-2. Zooplankton community composition by sample period and location for epilimnetic samples collected in Lake Norman in 2009.



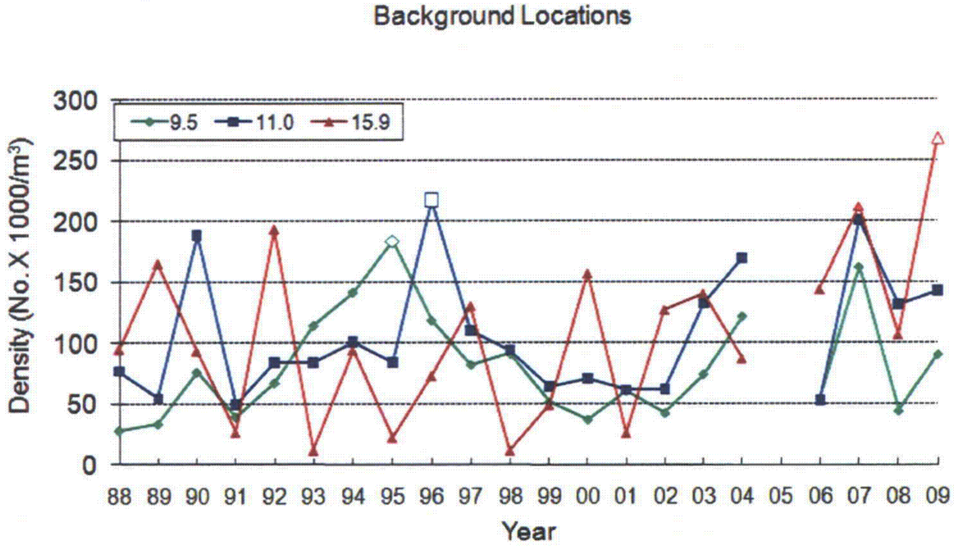
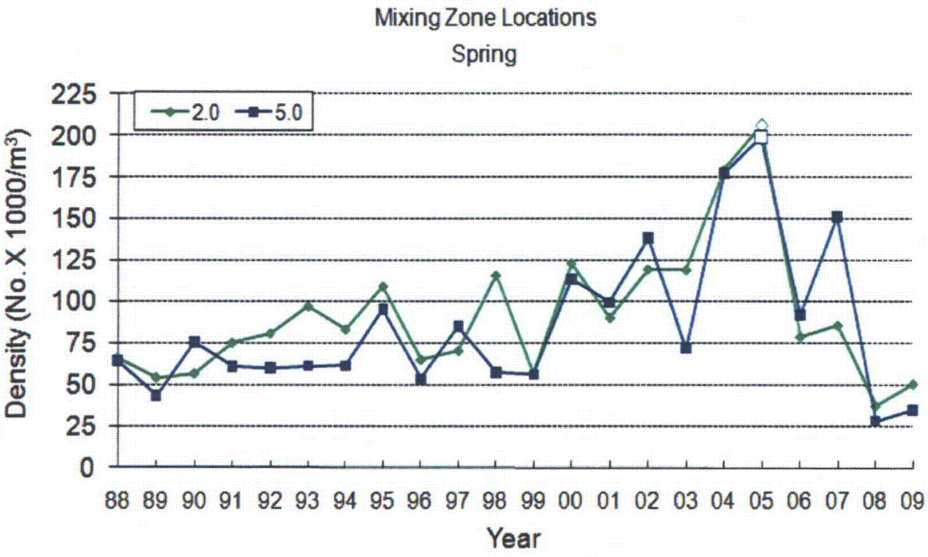


Figure 4-3. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the winter periods of 1988 – 2009 (clear data points represent long-term maxima).



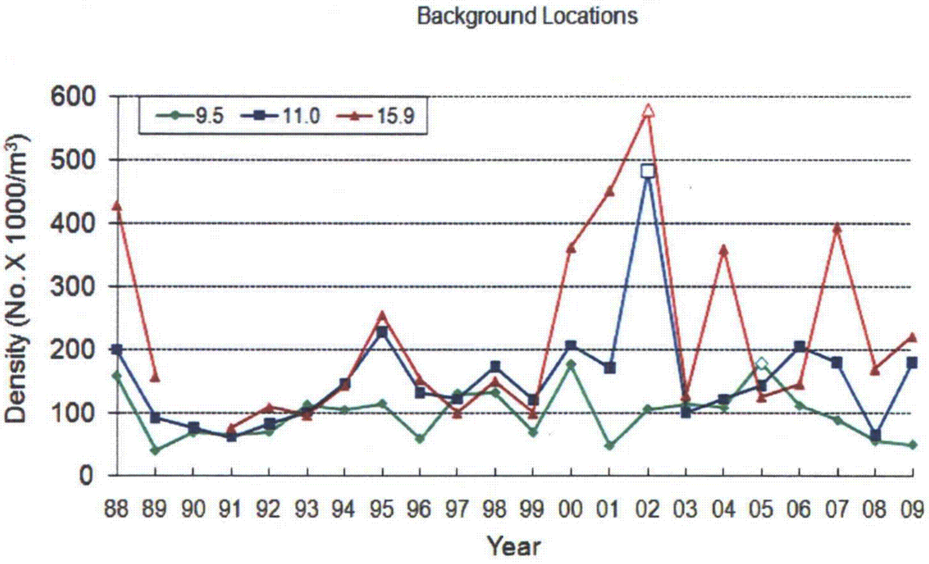


Figure 4-4. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the spring periods of 1988 – 2009 (clear data points represent long-term maxima).

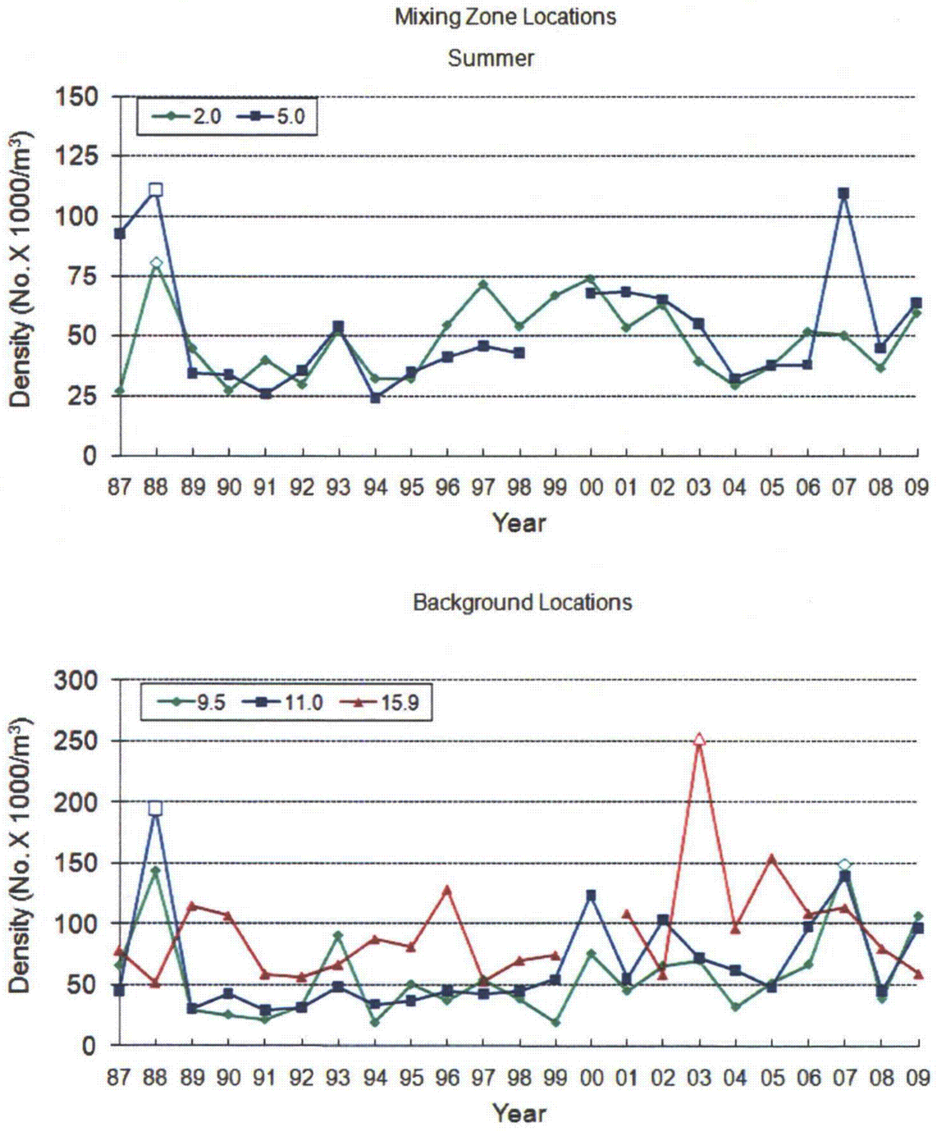
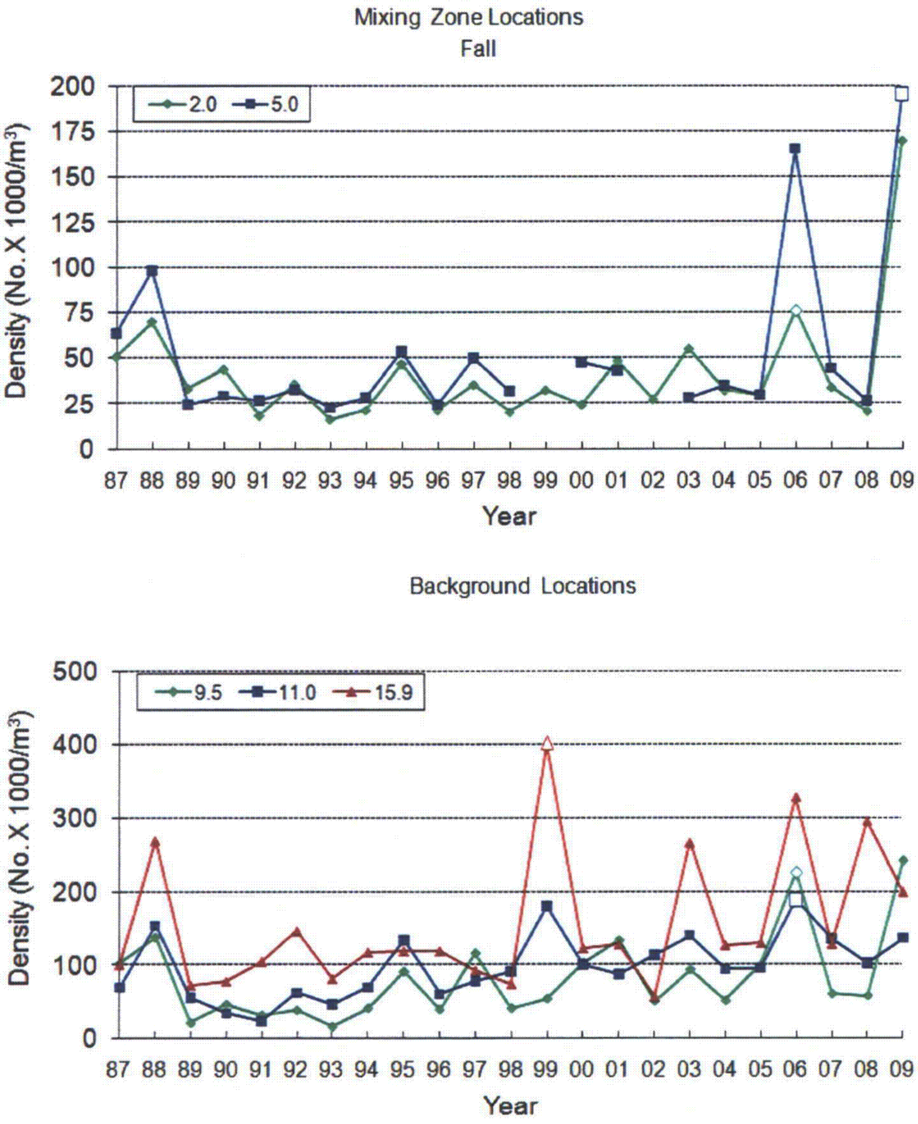


Figure 4-5. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the summer periods of 1987 – 2009 (clear data points represent long-term maxima).


Mixing Zone Locations
Fall

Background Locations

Figure 4-6. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the fall periods of 1987 – 2009 (clear data points represent seasonal maxima).

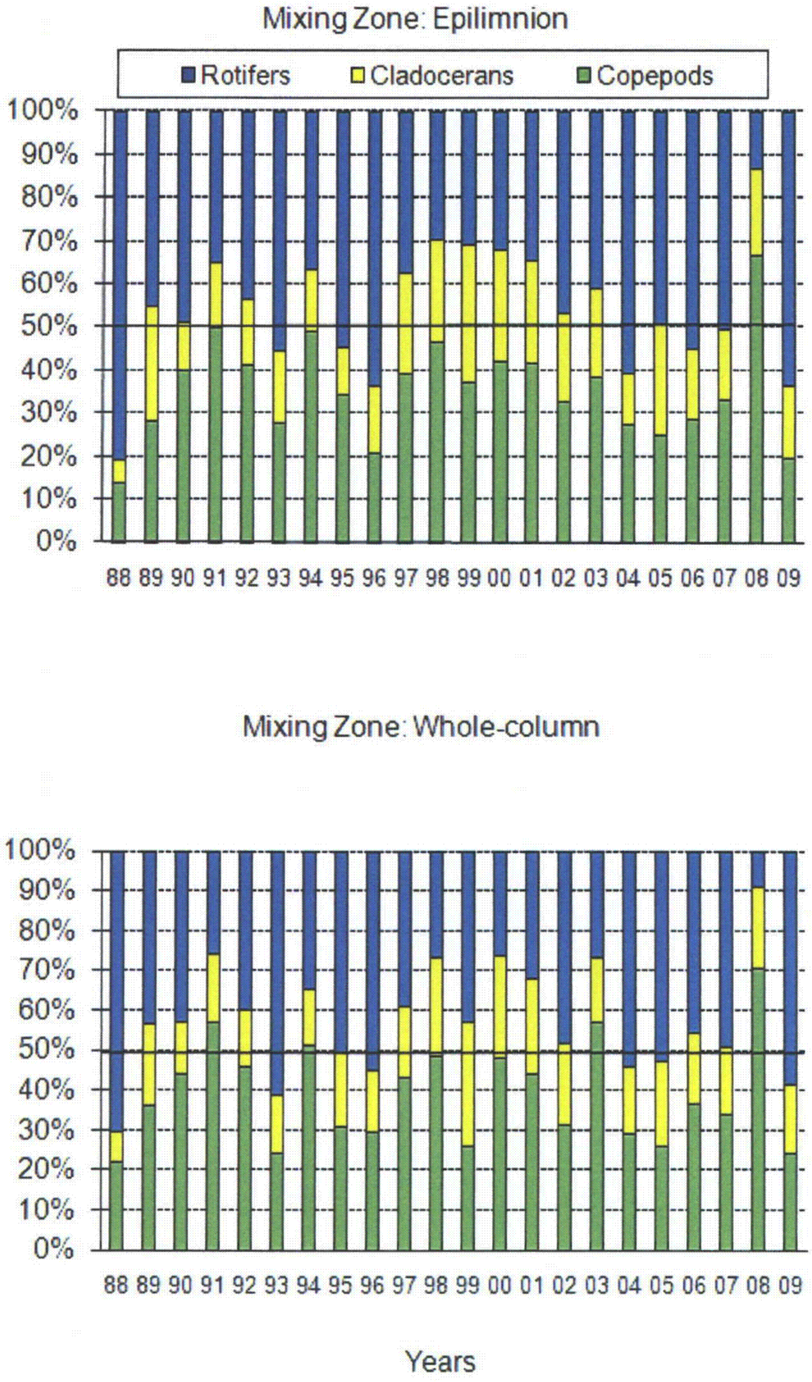
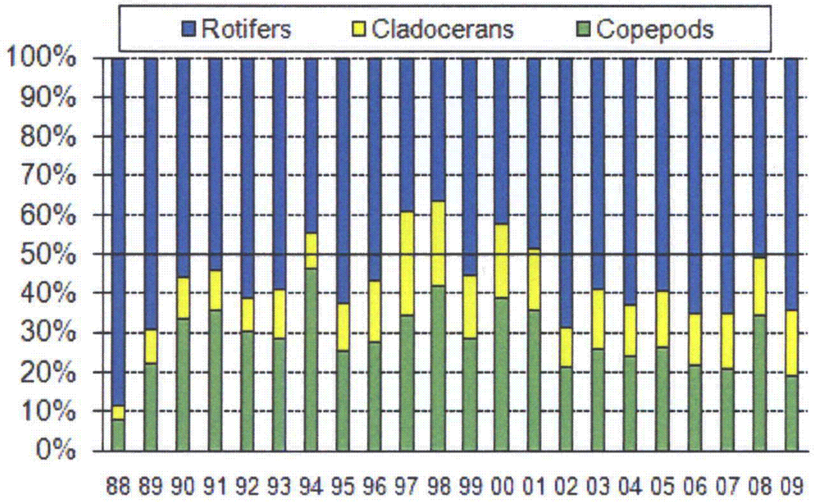


Figure 4-7. Annual percent composition of major zooplankton taxonomic groups from mixing zone locations (Locations 2.0 and 5.0 combined) during 1988 – 2009 (Note: does not include Location 5.0 in the fall of 2002 or winter samples from 2005).


Background: Epilimnion

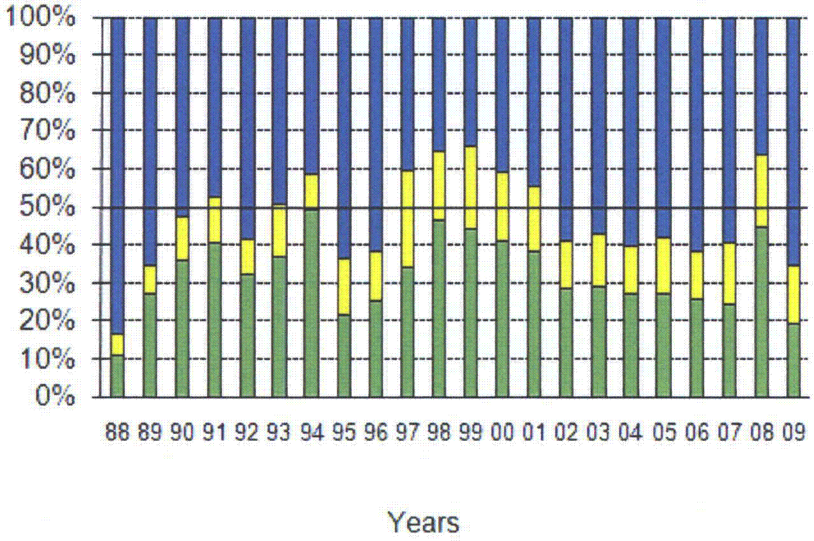

Background: Whole-column

Figure 4-8. Annual percent composition of major zooplankton taxonomic groups from background locations (Locations 9.5, 11.0, and 15.9 combined) during 1988 – 2009 (Note: does not include winter samples from 2005).

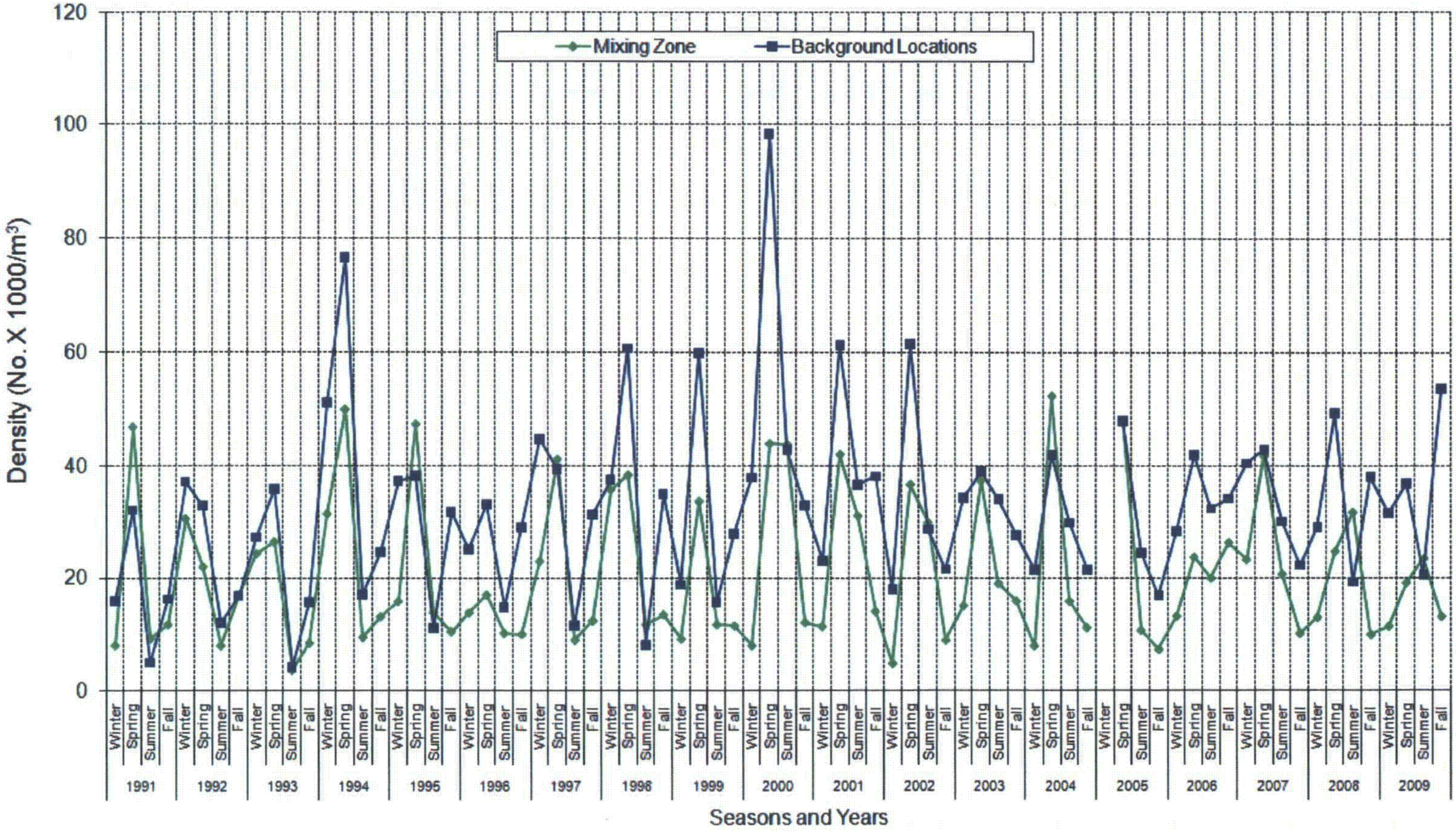


Figure 4-9. Copepod densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2009 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

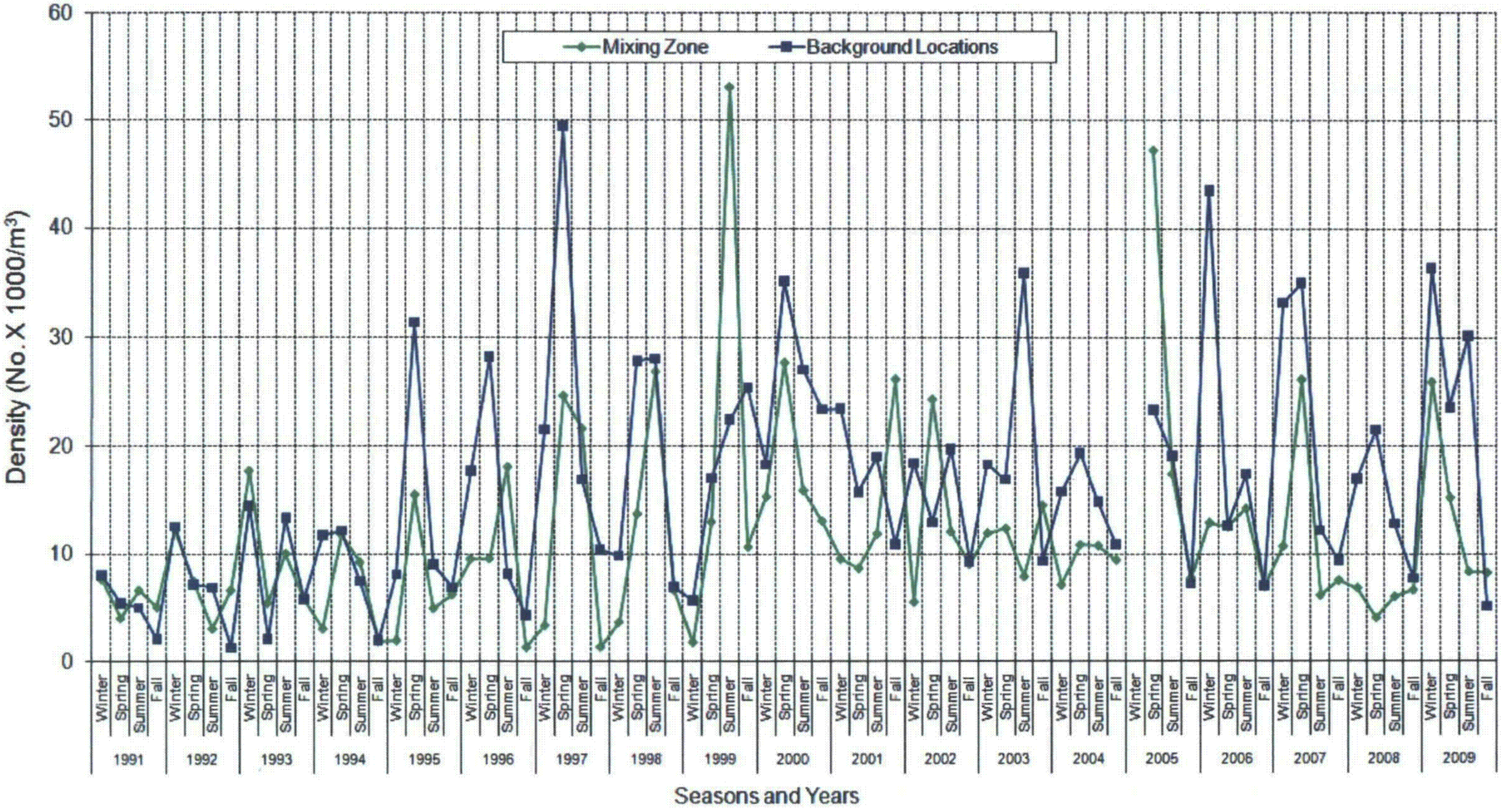


Figure 4-10. Cladoceran densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2009 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

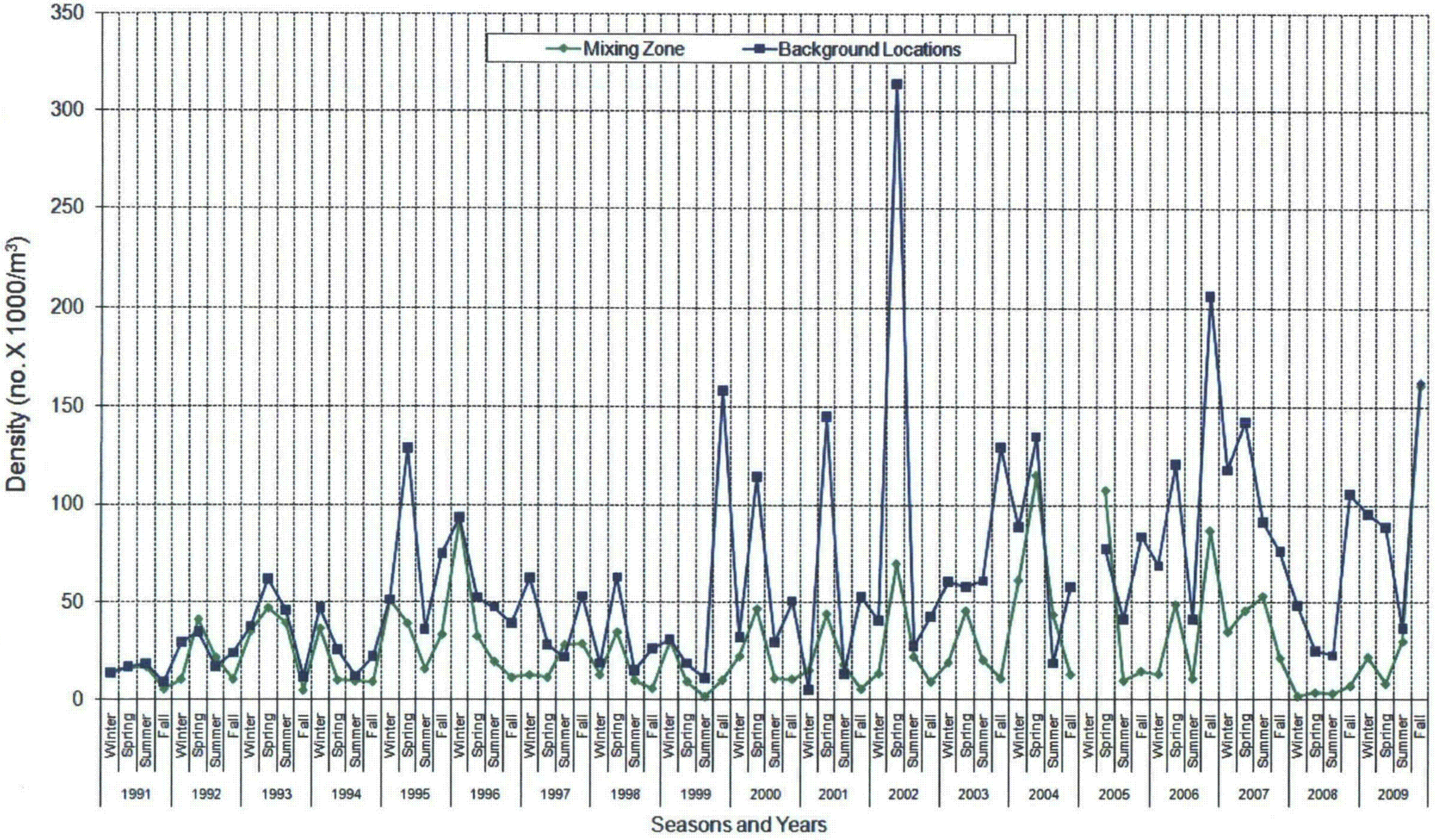


Figure 4-11. Rotifer densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2009 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

CHAPTER 5

FISHERIES

INTRODUCTION

In accordance with the NPDES permit for McGuire Nuclear Station (MNS) and associated requirements from the North Carolina Wildlife Resources Commission (NCWRC), Duke Energy (DE) personnel monitored specific fish population parameters in Lake Norman during 2009. The components of this program were:

1. spring electrofishing survey of littoral fish populations with emphasis on age, growth, size distribution, and condition of black bass (spotted bass *Micropterus punctulatus* and largemouth bass *M. salmoides*);
2. fall electrofishing survey to assess black bass young-of-year abundance;
3. summer striped bass *Morone saxatilis* mortality surveys;
4. winter striped bass gill net survey with the NCWRC with emphasis on age, growth, and condition;
5. fall hydroacoustic and purse seine surveys of pelagic fish abundance and species composition; and
6. support NCWRC fall white crappie *Pomoxis annularis* and black crappie *P. nigromaculatus* trap-net survey with emphasis on age and growth.

METHODS AND MATERIALS

Spring Electrofishing Survey

An electrofishing survey was conducted in Lake Norman in April at three areas (Figure 5-1): near Marshall Steam Station (MSS, Zone 4), a reference (REF, Zone 3) area located between MNS and MSS, and near MNS (Zone 1). Ten 300-m shoreline transects were surveyed in each area and were identical to historical locations surveyed since 1993. Transects included habitats representative of those found in Lake Norman. Shallow flats where the boat could not access within 3 to 4 m of the shoreline were excluded. All sampling was conducted during daylight, when water temperatures were expected to be between 15 and 20 °C.

Surface water temperature (°C) was measured with a calibrated thermistor at each location. Stunned fish were collected by two netters and identified to species. Fish were enumerated and weighed in aggregate by taxon, except for spotted bass and largemouth bass, where total length (TL, mm) and weight (g) were obtained for each individual collected. Catch per unit effort (number of individuals/3,000 m) and the number of species were calculated for each sampling area. Sagittal otoliths were removed from all black bass $\geq$ 125 mm long (black bass < 125 mm were assumed to be age 1 because young-of-year black bass are historically not collected in spring surveys) and sectioned for age determination (Devries and Frie 1996).

Condition (W_r) based on relative weight was calculated for spotted bass $\geq$100 mm long and largemouth bass $\geq$150 mm long, using the formula $W_r = (W/W_s) \times 100$, where W = weight of the individual fish (g) and W_s = length-specific mean weight (g) for a fish as predicted by a weight-length equation for that species (Anderson and Neumann 1996). Growth rates (age 2 to 6 years) were compared between species and among areas with analysis of variance (α = 0.05) and Tukey's pairwise comparison (Analytical Software 2008).

Fall ElectrofishingYoung-of-Year Bass Survey

An electrofishing survey was conducted in November at the same three areas (MSS, REF, MNS) as the spring survey and consisted of five 300-m shoreline transects at each area. Again, shallow flats where the boat could not access within 3 to 4 m of the shoreline were excluded. Stunned black bass were collected by two netters, identified to species, and individually measured and weighed. A young-of-year "cut off" of 150 mm, based upon historical length-frequency data, was used for data analysis.

Summer Striped Bass Mortality Surveys

Mortality surveys were conducted weekly during July and August to specifically search for dead or dying striped bass in Zones 1 to 4. All observed dead striped bass were collected during these surveys and their location noted. Individual TL was measured prior to disposal.

Striped Bass Netting Survey

Striped bass were collected for age, growth, and condition determinations in December by DE and NCWRC personnel. At least four monofilament nets (76.2 m long x 6.1 m deep), two each containing two 38.1-m panels of 38- and 51-mm square mesh and two each containing 38.1-m panels of 63- and 76-mm square mesh, were set overnight in areas where striped bass were previously located. After three nights of low striped bass catch rates local fishermen were asked to retain their catch providing additional fish. Individual total lengths and weights were obtained for all striped bass collected. Sagittal otoliths were removed to determine age, growth, and condition, as described previously for largemouth bass. Additionally, all catfish collected were identified and enumerated by species.

Fall Hydroacoustics and Purse Seine Surveys

Abundance and distribution of pelagic forage fish in Lake Norman were determined using mobile hydroacoustic (Brandt 1996) and purse seine (Hayes et al. 1996) techniques. The lake was divided into six zones (Figure 5-1) due to its large size and spatial heterogeneity. An annual mobile hydroacoustic survey of the lake was conducted in mid-September with multiplexing, side- and down-looking transducers to detect surface-oriented fish and deeper fish (from 2.0 m depth to the bottom), respectively.

Annual purse seine samples were also collected in mid-September from the downlake (Zone 1), midlake (Zone 2), and uplake (Zone 5) areas of Lake Norman. The purse seine measured 122.0 x 9.1 m, with a mesh size of 4.8 mm. A subsample of forage fish collected from each area was used to estimate taxa composition and size distribution.

Fall Crappie Trap-Net Survey

The Lake Norman black and white crappie population was surveyed by NCWRC personnel in late October as described by Nelson and Dorsey (2005). Fifteen locations in each of Zones 1, 2, and 3 were sampled with trap nets over two consecutive nights for a total of 90 net nights. Trap nets measured 1.83 x 0.91 x 0.91 m with a 15.24 x 0.91-m lead and 1.91-cm mesh. Individual total lengths and weights were obtained for all crappie collected. Sagittal otoliths were removed for age and growth analysis.

RESULTS AND DISCUSSION

Spring Electrofishing Survey

Spring 2009 electrofishing resulted in the collection of 5,227 individuals (24 species and two centrarchid hybrid complexes) weighing 314.36 kg at average water temperatures ranging from 16.5 to 21.2 °C (Table 5-1). The survey consisted of 1,418 individuals (20 species and two centrarchid hybrid complexes) weighing 152.64 kg in the MSS area, 2,219 fish (19 species and two centrarchid hybrid complexes) weighing 102.34 kg in the REF area, and 1,590 individuals (16 species and two hybrid centrarchid complexes) weighing 59.38 kg in the MNS area (Figure 5-2). Overall, bluegill *Lepomis macrochirus* dominated samples numerically, while bluegill, common carp *Cyprinus carpio*, largemouth bass, and spotted bass dominated samples gravimetrically.

The total number of individuals collected in spring 2009 was highest in the REF area, intermediate in the MNS area, and lowest in the MSS area. Although the total number of individuals was also highest in the REF area from 2006 – 2008, there is no apparent temporal trend in the number of individuals collected within or among areas since 1993.

Total biomass of fish in 2009 was highest in the MSS area, intermediate in the REF area, and lowest in the MNS area, following the spatial trend of previous years. This spring trend in Lake Norman fish biomass supports the spatial heterogeneity theory noted by Siler et al. (1986). The authors reported that fish biomass was higher uplake than downlake due to higher levels of nutrients and resulting higher productivity uplake versus downlake. The spatial heterogeneity theory is further supported by higher concentrations of chlorophyll *a*, greater phytoplankton standing crops, and elevated epilimnetic zooplankton densities in uplake compared to downlake regions of Lake Norman (see Chapters 3 and 4). There is no apparent temporal trend in the biomass of fish collected within each area since 1993.

Spotted bass, thought to have originated from angler introductions, were first collected in Lake Norman in the MNS area during a 2000 fish health assessment survey. They have increased in number of individuals and biomass since the 2001 spring electrofishing survey (Figure 5-3) and, in 2009, were most abundant in the REF area, intermediate in the MNS area, and least abundant in the MSS area. Similarly, biomass was highest in the REF area, intermediate in the MNS area, and lowest in the MSS area. In 2009, small spotted bass (< 150 mm) dominated the black bass catch in all areas (Figures 5-4a and b).

Spotted bass mean W_r ranged from 66.6 for fish 350 to 399 mm in the MNS area to 81.9 for fish 250 to 299 mm also in the MNS area (Figure 5-5a). Overall, spotted bass mean W_r values were highest in the MSS area (78.4), intermediate in the REF area (74.6), lowest in the MNS area (73.0), and within the range of observed historical values (71.4 to 82.3) (Duke Power unpublished data, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Relative to 2008, the number of individual largemouth bass in 2009 decreased in all areas following a downward trend (Figure 5-6a). Largemouth bass biomass also decreased in all areas (Figure 5-6b). Number of individuals and biomass at all areas were generally similar to data from 2006 – 2008, and the lowest recorded since sampling began in 1993. As in most years, 2009 largemouth bass number of individuals and biomass were highest in the MSS area, intermediate in the REF area, and lowest in the MNS area following a longitudinal gradient reported from similar reservoirs in Georgia (Maceina and Bayne 2001) and Kentucky (Buynak et al. 1989).

Largemouth bass were distributed across all size classes (Figure 5-4b) with mean W_r ranging from 64.6 for fish 300 to 349 mm in the MNS area to 94.0 for fish 400 to 449 mm in the MNS area (Figure 5-5b). The low number of largemouth bass collected diminishes the significance of these comparisons. Overall, largemouth bass mean W_r values were highest in the MNS and MSS areas (83.6), lowest in the REF area (76.5), and within the range of observed historical values (76.0 to 89.9; Duke Power unpublished data, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009).

Largemouth bass numbers were inadequate for growth rate comparisons with spotted bass or with previous years of data (Table 5-2). However, both black bass species when combined showed a decreased growth rate in the REF area relative to the MSS and MNS areas, a difference also reported in the 2009 report when comparing largemouth bass growth rates over all years (1993 – 1994, 2003 – 2008) of data (Duke Energy 2009). Additionally, largemouth bass had significantly lower growth rates from 1993 – 1994 than from 2003 – 2008 (Table 5-3). Although the largemouth bass population parameters have decreased sharply since the introduction of spotted bass, a causal effect, although likely, is indeterminate due to possible confounding effects of other introduced species, including alewife *Alosa pseudoharengus* and white perch *Morone americana* (Kohler and Ney 1980, Madenjian et al. 2000).

Fall Electrofishing Young-of-Year Black Bass Survey

Fall 2009 electrofishing resulted in the collection of 237 spotted, 7 largemouth, and 12 hybrid black bass young-of-year (< 150 mm), continuing an increasing trend in spotted bass young-of-year numbers since 2005 (Figure 5-7). As in 2005 – 2008, young-of-year black bass numbers were highest in the MSS area.

Summer Striped Bass Mortality Surveys

In 2009, a total of 362 dead striped bass were collected during weekly July and August surveys, mostly in Zone 1 (Table 5-4). Since the survey began in 1983, summer mortalities in excess of 25 dead striped bass have occurred previously in three years: 163 in 1983, 43 in 1986, and 2,610 in 2004.

Winter Striped Bass Netting Survey

Striped bass (n = 101) collected in mid to late December 2009 were dominated by age 1 and 2 fish (Figure 5-8). Striped bass growth was fastest through age 3 and slowed with increasing age. Mean W_r was highest for age 4 fish (92.1) and declined thereafter. Mean W_r was 85.8 for all striped bass in 2009, above the range of observed historical values (78.5 to 84.1). Growth and condition in 2009 were similar to historical values since consistent annual gillnetting began in 2003 (Duke Power 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). However, the predominance of age 1 and 2 striped bass collected in 2009 diminishes the significance of this comparison.

The December striped bass gillnetting also yielded 257 catfish. Blue catfish *Ictalurus furcatus* (224) dominated the catch, followed by channel catfish *I. punctatus* (19) and flathead catfish *Pylodictis olivaris* (14).

Fall Hydroacoustics and Purse Seine Surveys

Mean forage fish densities in the six zones of Lake Norman ranged from 3,068 (Zone 1) to 20,706 (Zones 5 and 6) fish/ha in September 2009 (Table 5-5). Zone 6 fish densities were assumed to be the same as Zone 5, as the shallow nature of the riverine Zone 6 limits habitat available for acoustic sampling. The lakewide population estimate in September 2009 was approximately 96.5 million fish, the second highest population estimate since surveys began in 1997 (Figure 5-9). As in most years since 1997, Zone 5 had the highest forage fish density estimates. No temporal trends are evident in lakewide pelagic forage fish population estimates in Lake Norman from 1997 – 2009.

Threadfin shad *Dorosoma petenense* dominated the Lake Norman forage fish community purse seine survey in 2009 (88.4%), similar to surveys since 1993 (Table 5-6). Alewife, first detected in Lake Norman in 1999 (Duke Power 2000), have comprised as much as 25.0% (2002) of mid-September pelagic forage fish surveys. Their percent composition remained relatively low from 2005 – 2008 (range = 1.7 to 5.1%) with a noticeable increase in 2009 (11.60%). The threadfin shad modal TL class increased after alewife introduction, returning to pre-introduction levels by 2005 (46 to 50 mm in 2009; Figure 5-10).

Fall Crappie Trap-Net Survey

In 2009, NCWRC personnel expended 110 trap-net nights of effort in Lake Norman collecting no white crappie and 365 black crappie. Various life history data were collected for use in fish management reports by the NCWRC.

SUMMARY

In accordance with the Lake Norman Maintenance Monitoring Program for the MNS NPDES permit, specific fish monitoring programs continued during 2009. Spring electrofishing indicated that 16 to 20 species of fish and two hybrid complexes comprised diverse fish populations in the three survey areas. The number of individuals and biomass of fish in 2009 were generally similar to those noted annually since 1993. Collections were numerically dominated by centrarchids. Largemouth bass number of individuals and biomass were the lowest recorded since sampling began in 1993. Spotted bass number of individuals and biomass continue to increase, possibly displacing largemouth bass.

During 2009, the number of summer striped bass mortalities (362) was the highest since 2004. Mean W_r (85.8) in winter was slightly higher than in previous years although dominated by age 1 and 2 fish. Hydroacoustic sampling estimated a forage fish population of approximately 96.5 million in 2009, the second highest estimate since surveys began in 1997.

Alewife percent composition in fall purse seine surveys (11.6%) and modal threadfin shad TL class (46 to 50 mm) both increased to the highest values since 2004. The introduction of alewife and inherent, temporal fluctuations in clupeid densities contribute to the variable nature of forage fish populations.

Past studies have indicated that a balanced indigenous fish community exists in Lake Norman (Duke Power 2000, 2001, 2002, 2003, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009). The present study adds another year of comparable data, reinforcing that conclusion. Based on the diversity and numbers of individuals in the Lake Norman littoral fish community during spring and the regular availability of forage fish to limnetic predators, it is concluded that the operation of MNS has not impaired the Lake Norman fish community.

Table 5-1. Number of individuals (No.) and biomass (Kg) of fish collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2009.

		MSS		REF		MNS		**Total**	
Scientific Name	Common Name	No.	Kg	No.	Kg	No.	Kg	**No.**	**Kg**
Lepisosteidae									
Lepisosteus osseus	Longnose gar			4	7.97			**4**	**7.97**
Clupeidae									
Alosa pseudoharengus	Alewife	1	0.01					**1**	**0.01**
Dorosoma cepedianum	Gizzard shad	20	8.02	5	2.77	4	2.12	**29**	**12.91**
Dorosoma petenense	Threadfin shad	1	0.00	135	1.41			**136**	**1.41**
Cyprinidae									
Cyprinella chloristia	Greenfin shiner	1	0.00	23	0.07	19	0.05	**43**	**0.13**
Cyprinella nivea	Whitefin shiner	22	0.10	22	0.12	1	0.00	**45**	**0.22**
Cyprinus carpio	Common carp	25	62.17	6	12.18	2	6.11	**33**	**80.45**
Notemigonus crysoleucas	Golden shiner					1	0.01	**1**	**0.01**
Notropis hudsonius	Spottail shiner	8	0.07	71	0.36	67	0.50	**146**	**0.93**
Catostomidae									
Carpiodes cyprinus	Quillback	1	1.17			1	1.61	**2**	**2.78**
Moxostoma macrolepidotum	Shorthead redhorse	1	0.34					**1**	**0.34**
Ictaluridae									
Ictalurus furcatus	Blue catfish			1	0.99	1	2.28	**2**	**3.26**
Ictalurus punctatus	Channel catfish	12	5.72	8	3.05	2	0.53	**22**	**9.29**
Pylodictis olivaris	Flathead catfish	5	1.67	15	1.96	3	0.07	**23**	**3.71**
Moronidae									
Morone americana	White perch	11	0.57					**11**	**0.57**
Morone saxatilis	Striped bass	8	8.76	2	1.76			**10**	**10.52**
Centrarchidae									
Lepomis auritus	Redbreast sunfish	61	1.81	191	4.84	172	3.79	**424**	**10.44**
Lepomis cyanellus	Green sunfish	77	1.45	49	0.98			**126**	**2.43**
Lepomis gulosus	Warmouth	15	0.10	60	0.59	42	0.40	**117**	**1.09**
Lepomis macrochirus	Bluegill	886	11.37	1,294	18.31	999	14.34	**3,179**	**44.02**
Lepomis microlophus	Redear sunfish	51	4.71	59	6.14	34	2.49	**144**	**13.35**
Lepomis hybrid	Hybrid sunfish	35	1.60	65	2.30	57	1.17	**157**	**5.07**
Micropterus punctulatus	Spotted bass	118	18.56	177	25.73	168	19.34	**463**	**63.63**
Micropterus salmoides	Largemouth bass	51	21.72	26	9.36	10	4.34	**87**	**35.42**
Micropterus hybrid	Hybrid black bass	8	2.72	5	1.09	7	0.23	**20**	**4.03**
Pomoxis nigromaculatus	Black crappie			1	0.38			**1**	**0.38**
Total		**1,418**	**152.64**	**2,219**	**102.34**	**1,590**	**59.38**	**5,227**	**314.36**
Total No. Species		**20**		**19**		**16**		**24**	
Mean Water Temperature (° C)		19.2		16.5		21.2			

Table 5-2. Mean TL (mm) at age (years) for spotted bass and largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2009.

Taxa	Area	Age (years)								
		1	2	3	4	5	6	7	8	9
Spotted bass	MSS	196	276	348	387	426				
	REF	169	254	352	392	438	501	450		
	MNS	194	293	332	373	376	432			
	Mean TL (mm)	**186**	**274**	**344**	**384**	**413**	**466**	**450**		
Largemouth bass	MSS	255	312			434		398		
	REF	216	294	335	377	363	374	410	413	484
	MNS	184	265	326	350	375		346	504	
	Mean TL (mm)	**218**	**290**	**331**	**364**	**391**	**374**	**385**	**459**	**484**

Table 5-3. Comparison of mean TL (mm) at age (years) for largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2009, to historical largemouth bass mean lengths.

Location and year	Age (years)			
	1	2	3	4
MSS 1974-78[a]	170	266	310	377
MSS 1993[b]	170	277	314	338
MSS 1994[b]	164	273	308	332
MSS 2003[c]	216	317	349	378
MSS 2004[d]	176	309	355	367
MSS 2005[e]	190	314	358	396
MSS 2006[f]	184	347	346	408
MSS 2007[g]	215	261	363	394
MSS 2008[h]	213	307	365	390
MSS 2009	255	312	-	-
REF 1993[b]	157	242	279	330
REF 1994[b]	155	279	326	344
REF 2003[c]	139	296	358	390
REF 2004[d]	143	288	364	415
REF 2005[e]	139	307	357	386
REF 2006[f]	180	300	363	378
REF 2007[g]	186	285	371	367
REF 2008[h]	167	236	346	384
REF 2009	216	294	335	377
MNS 1971-78[a]	134	257	325	376
MNS 1993[b]	176	256	316	334
MNS 1994[b]	169	256	298	347
MNS 2003[c]	197	315	248	389
MNS 2004[d]	170	276	335	370
MNS 2005[e]	136	342	359	429
MNS 2006[f]	169	308	361	402
MNS 2007[g]	-	355	402	433
MNS 2008[h]	81	-	399	384
MNS 2009	184	265	326	350

[a] Siler 1981; [b] Duke Power unpublished data; [c] Duke Power 2004;
[d] Duke Power 2005; [e] Duke Energy 2006; [f] Duke Energy 2007;
[g] Duke Energy 2008; [h] Duke Energy 2009

Table 5-4. Striped bass mortalities observed in Lake Norman during weekly July and August surveys. No mortalities were observed Jul 10, 31 or Aug 13, 21, 24.

Date	No.	Zone	Mean TL (mm)
Jul 17	2	1	595
Jul 22	1	4	478
Jul 30	1	1	539
Aug 3	165	1	537
Aug 4	89	1	531
Aug 5	56	1	525
Aug 6	39	1	523
Aug 7	9	1	-
Total	**362**		**531**

Table 5-5. Lake Norman forage fish densities (No./ha) and population estimates from September 2009 hydroacoustic survey.

Zone	No./ha	Population estimate
1	3,068	6,998,295
2	3,867	11,918,918
3	5,124	17,704,647
4	5,201	6,402,898
5	20,706	43,607,611
6	20,706[a]	9,897,644
Lakewide total		96,530,013
95% CI		73,328,424 - 119,731,602

[a] Zone 6 fish density was assumed to be the same as Zone 5

Table 5-6. Number of individuals (No.), percent composition of forage fish, and threadfin shad modal TL class collected from purse seine surveys in Lake Norman during late summer/fall, 1993 – 2009.

Year	No.	Species composition			Threadfin shad modal TL class (mm)
		Threadfin shad	Gizzard shad	Alewife	
1993	13,063	100.00%			31-35
1994	1,619	99.94%	0.06%		36-40
1995	4,389	99.95%	0.05%		31-35
1996	4,465	100.00%			41-45
1997	6,711	99.99%	0.01%		41-45
1998	5,723	99.95%	0.05%		41-45
1999	5,404	99.26%	0.26%	0.48%	36-40
2000	4,265	87.40%	0.22%	12.37%	51-55
2001	9,652	76.47%	0.01%	23.52%	56-60
2002	10,134	74.96%		25.04%	41-45
2003	33,660	82.59%	0.14%	17.27%	46-50
2004	21,158	86.55%	0.24%	13.20%	51-55
2005	23,147	98.10%		1.90%	36-45
2006	14,823	94.87%		5.13%	41-45
2007	27,169	98.34%		1.66%	41-45
2008	47,586	95.58%		4.42%	41-45
2009	16,380	88.40%		11.60%	46-50

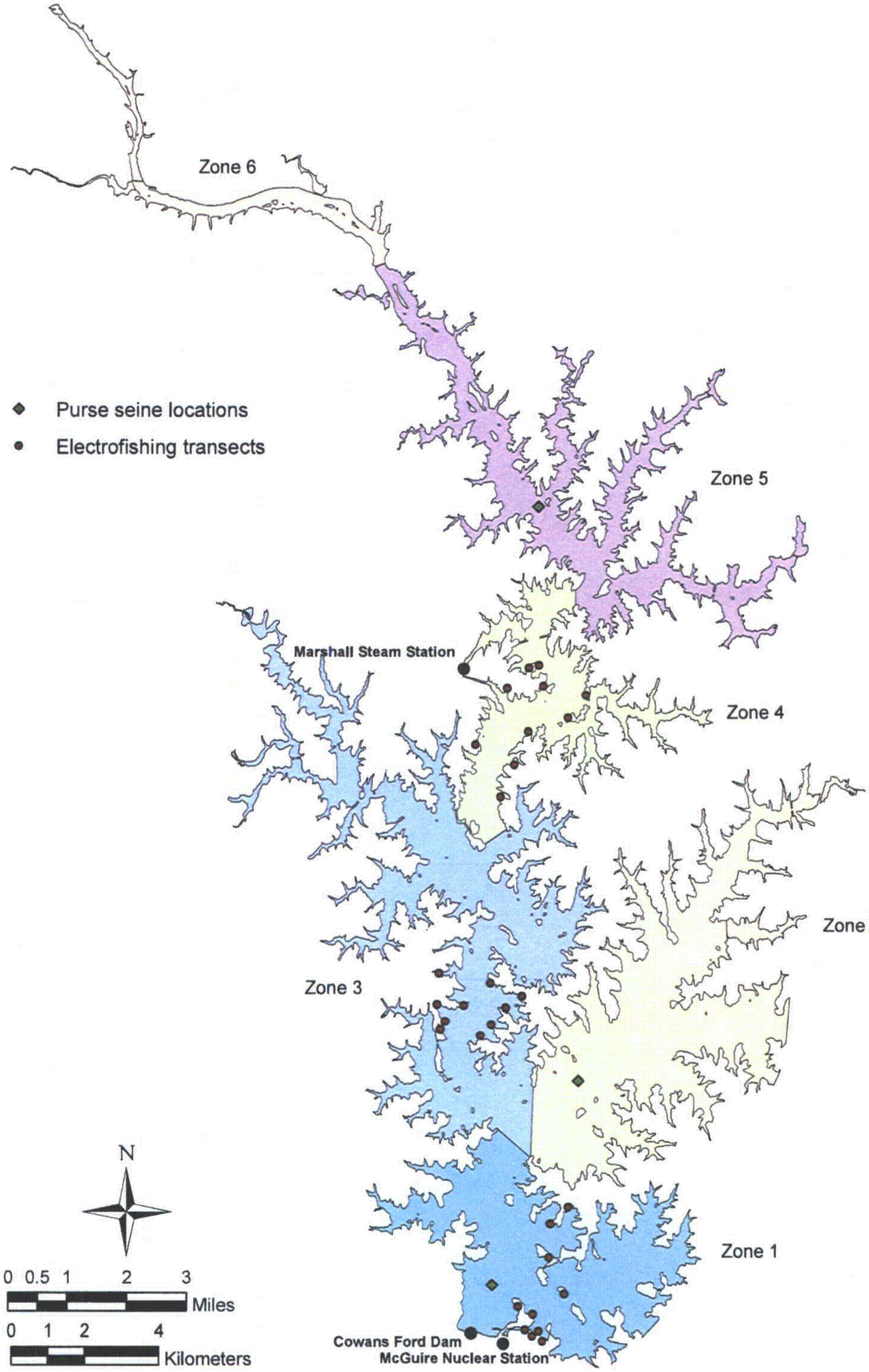


Figure 5-1. Sampling locations and zones associated with fishery assessments in Lake Norman.

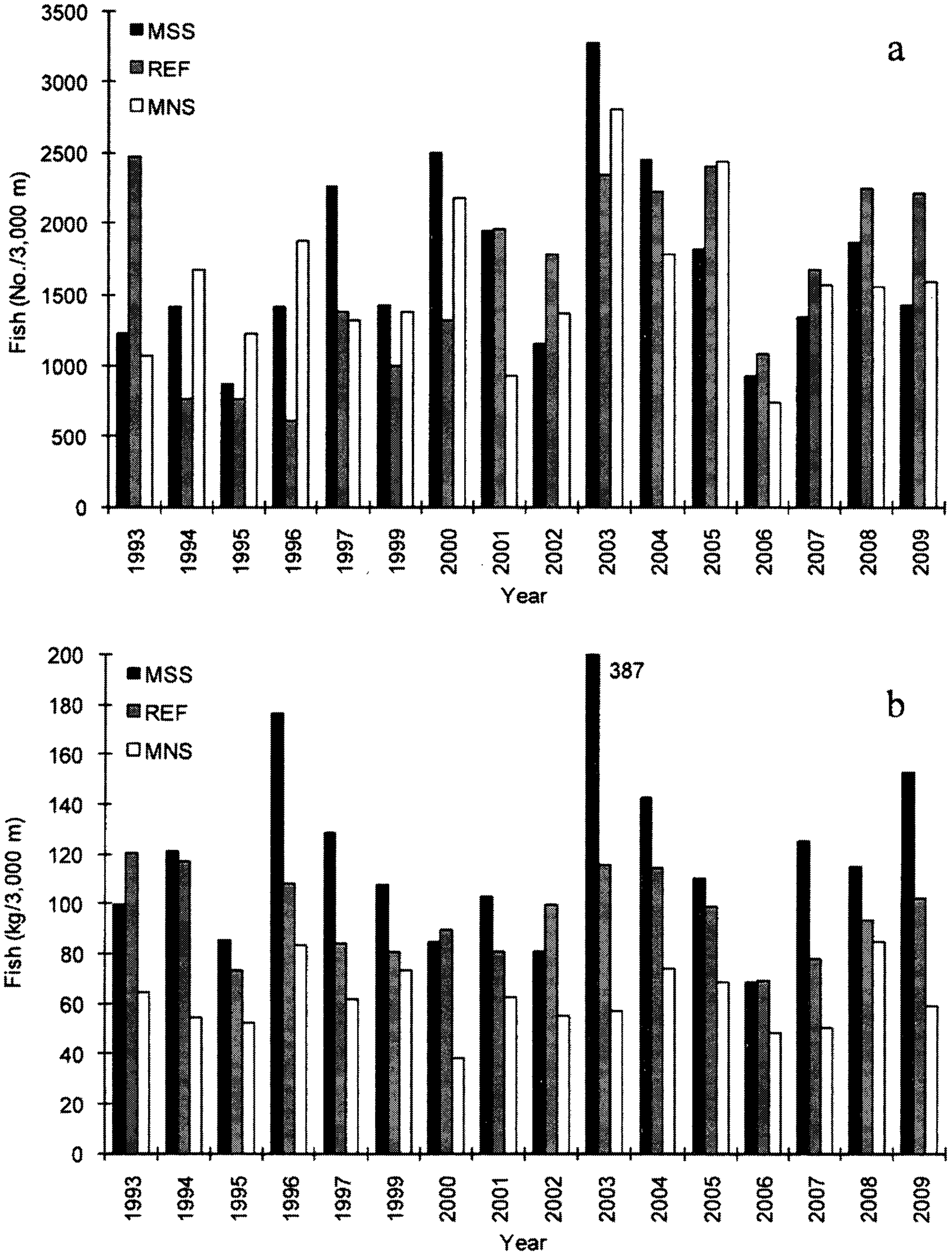


Figure 5-2. Number of individuals (a) and biomass (b) of fish collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2009.

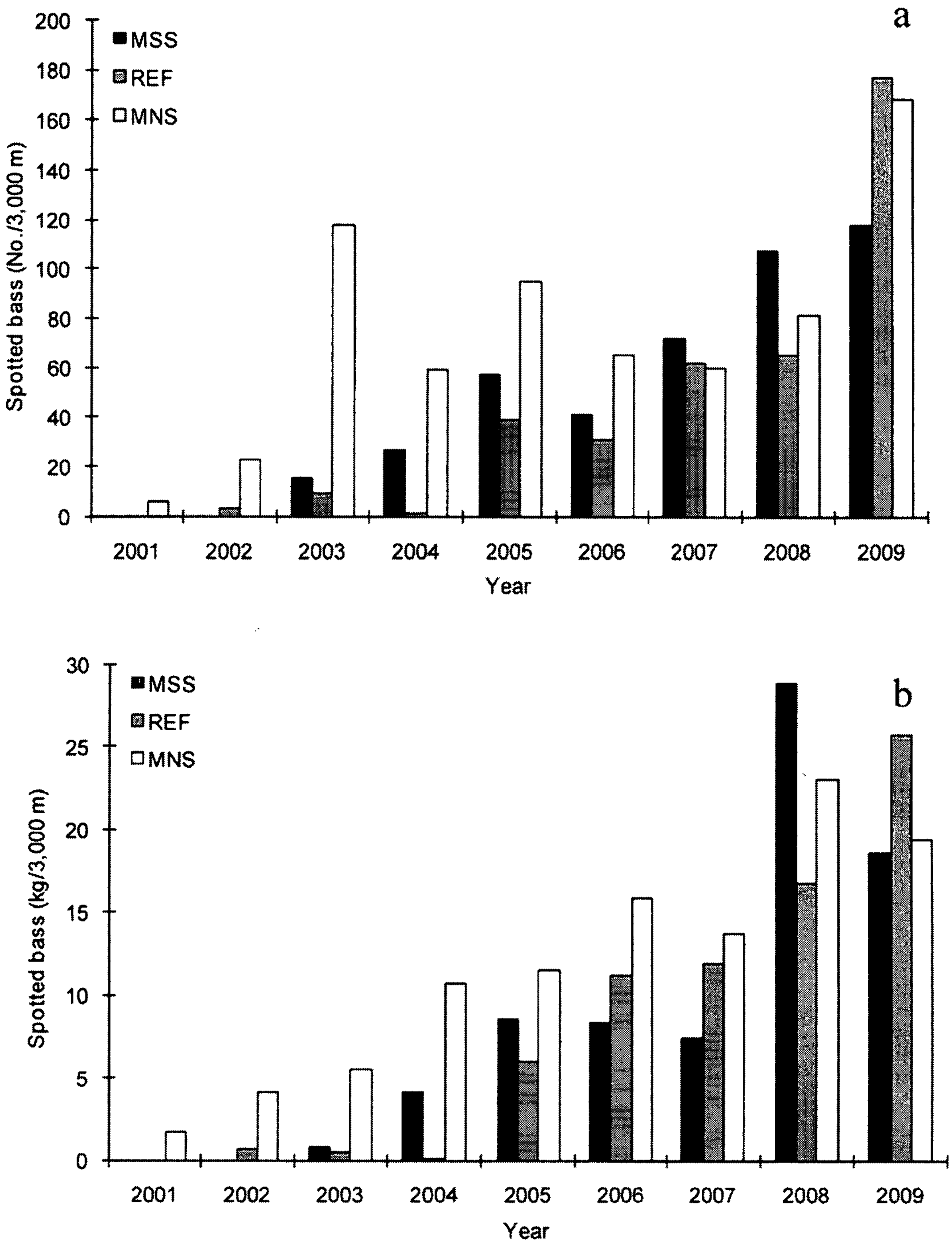


Figure 5-3. Number of individuals (a) and biomass (b) of spotted bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 2001 – 2009.

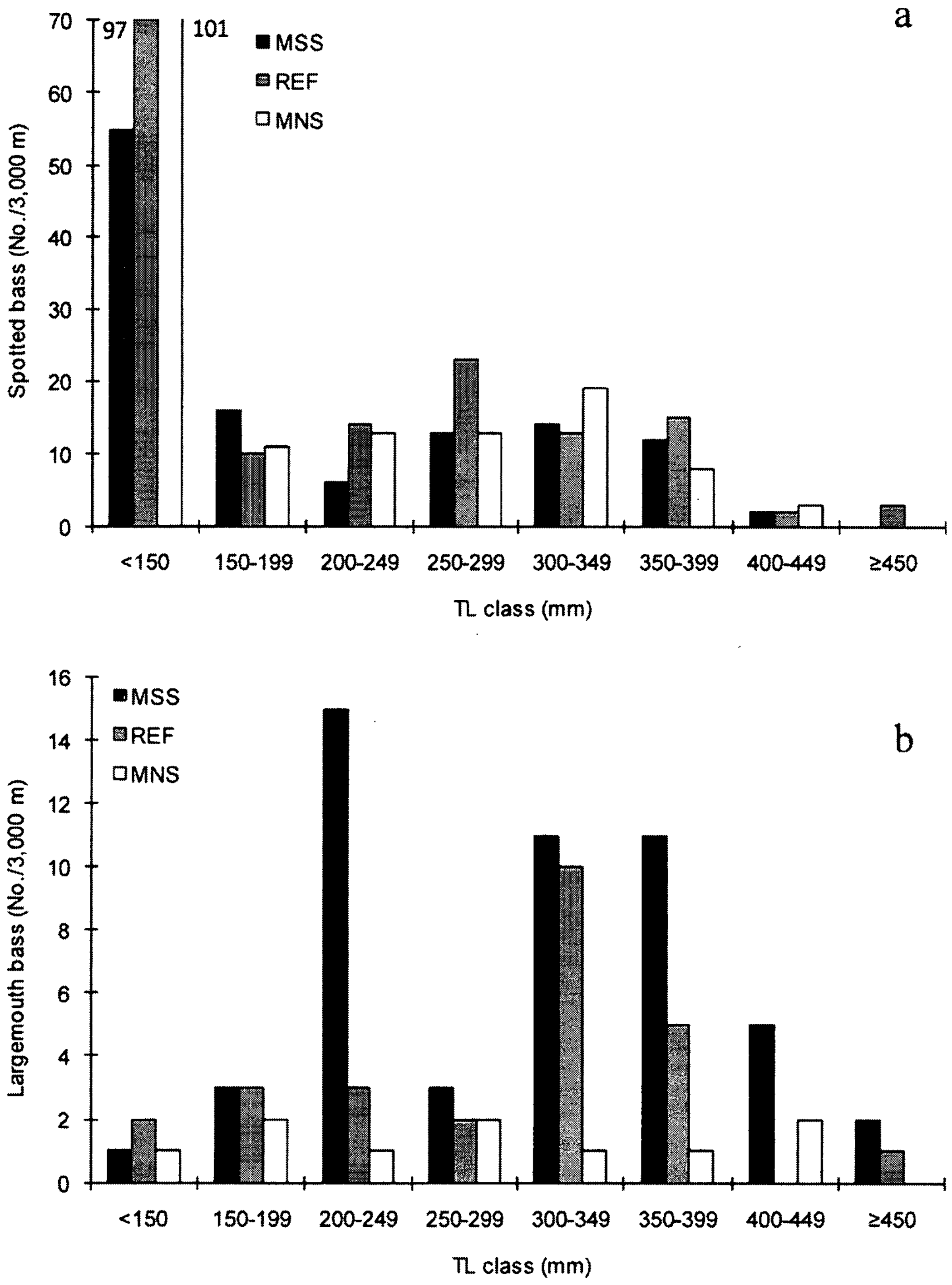
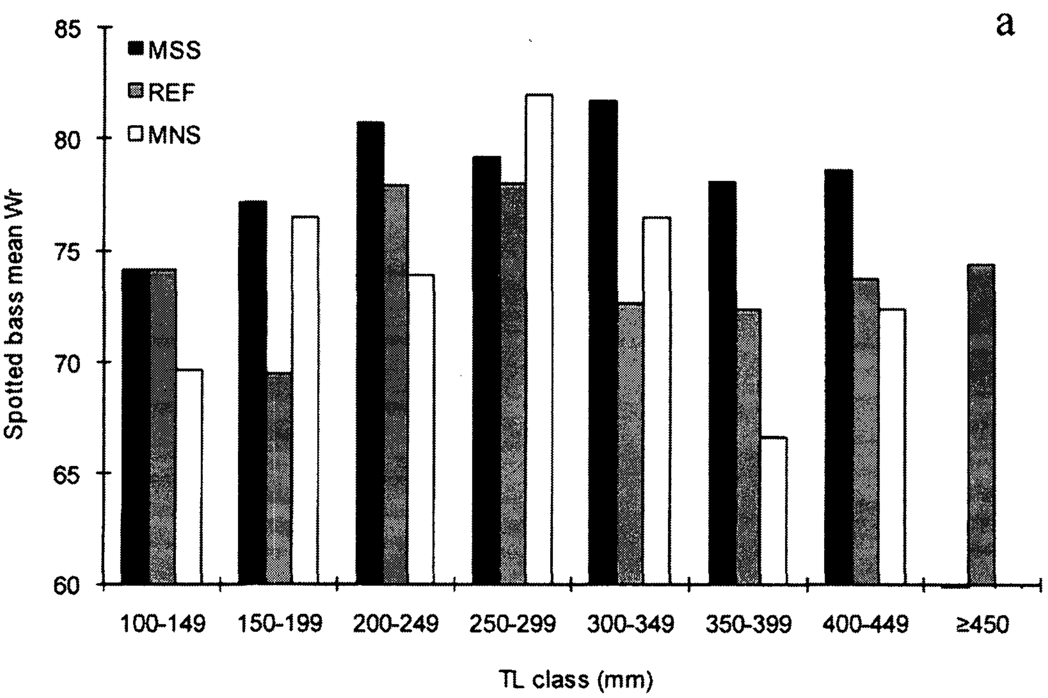


Figure 5-4. Size distributions of spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2009.



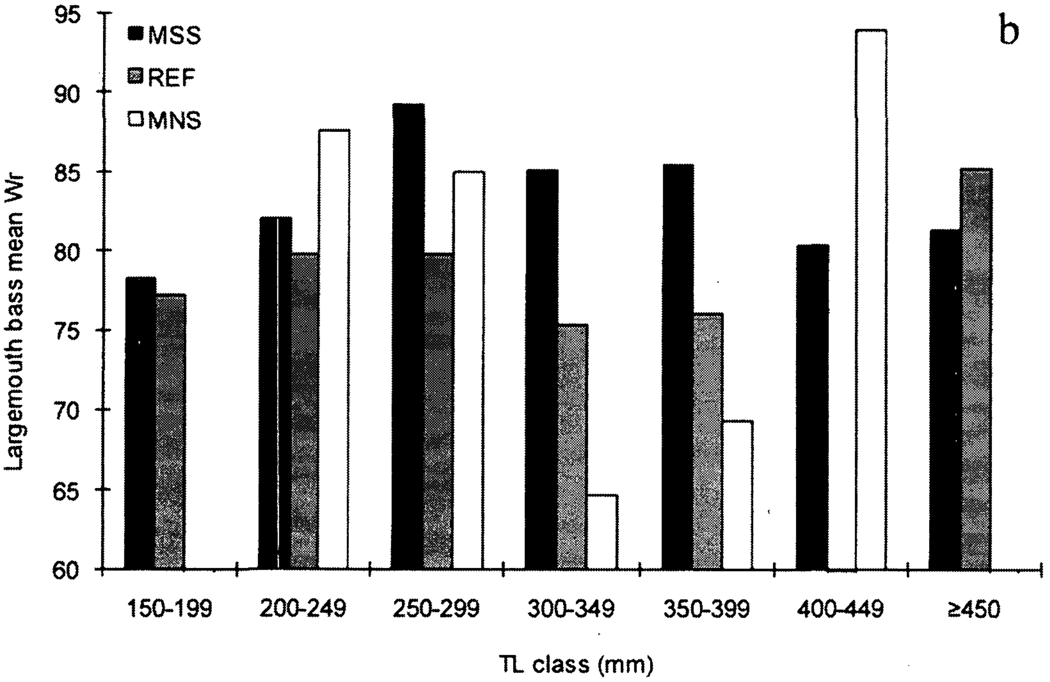


Figure 5-5. Condition (Wr) for spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2009.

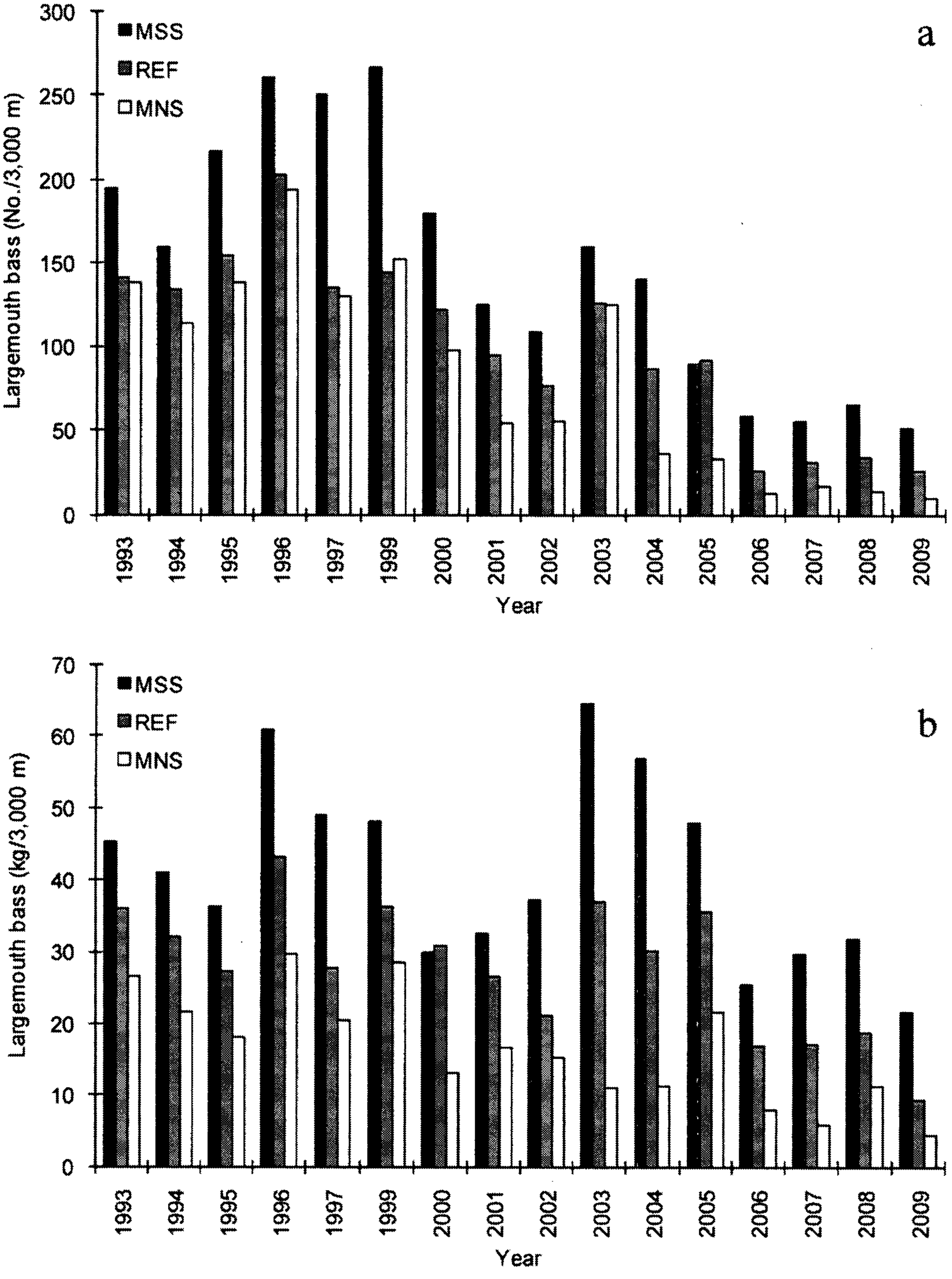


Figure 5-6. Number of individuals (a) and biomass (b) of largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2009.

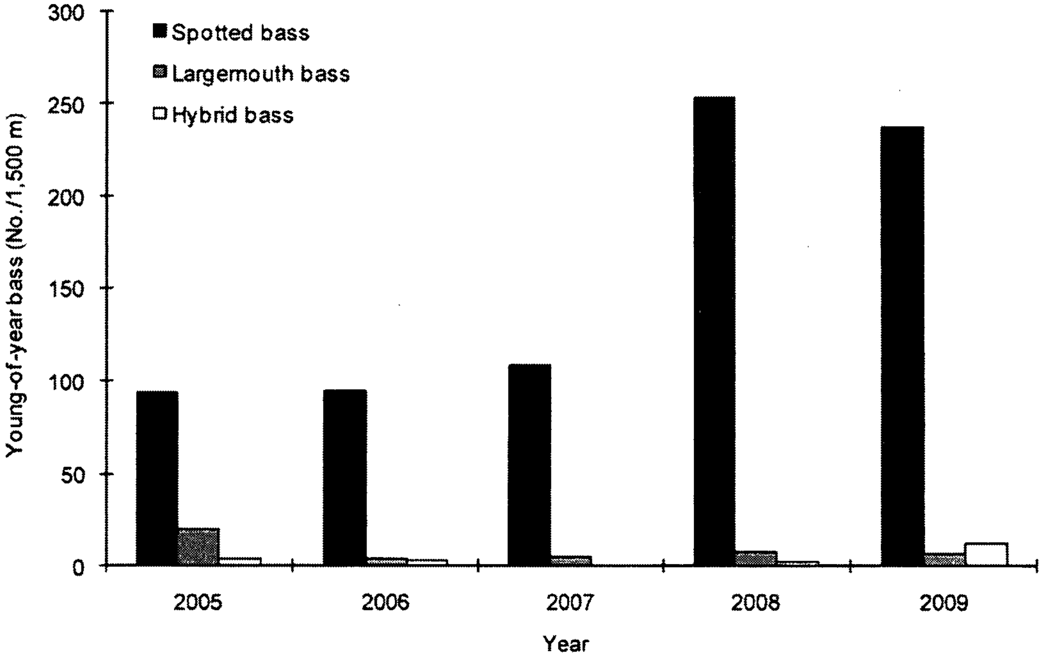


Figure 5-7. Number of young-of-year black bass (< 150 mm) collected from electrofishing five 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, November 2005 – 2009.

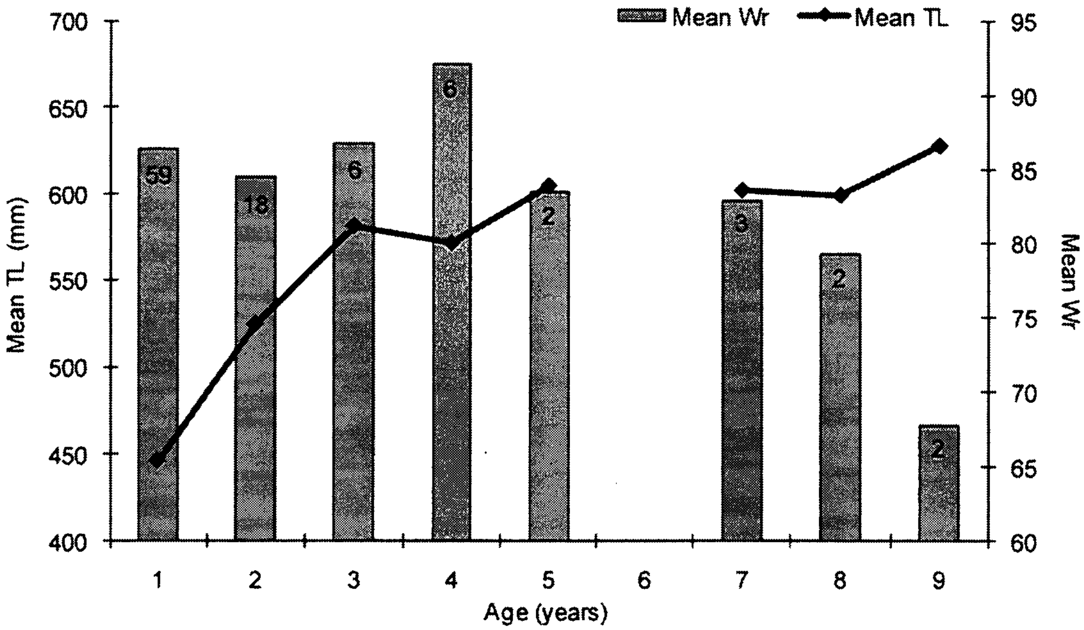


Figure 5-8. Mean TL and condition (Wr) by age of striped bass collected in Lake Norman, December 2009. Numbers of fish by age are inside bars.

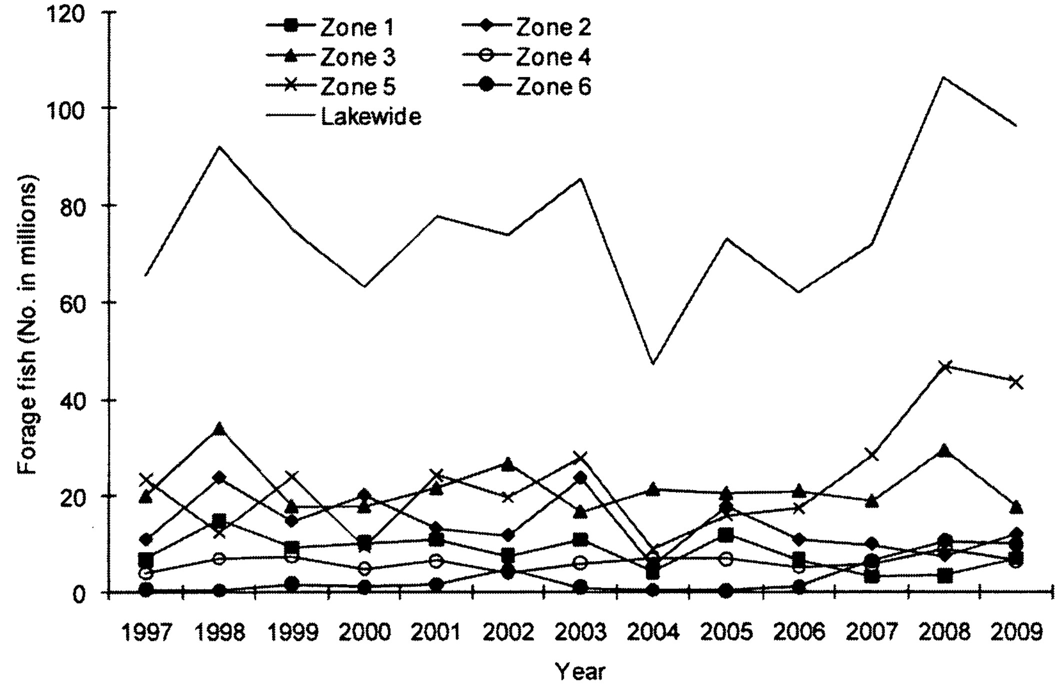


Figure 5-9. Zonal and lake-wide population estimates of pelagic forage fish in Lake Norman, September 1997 – 2009.

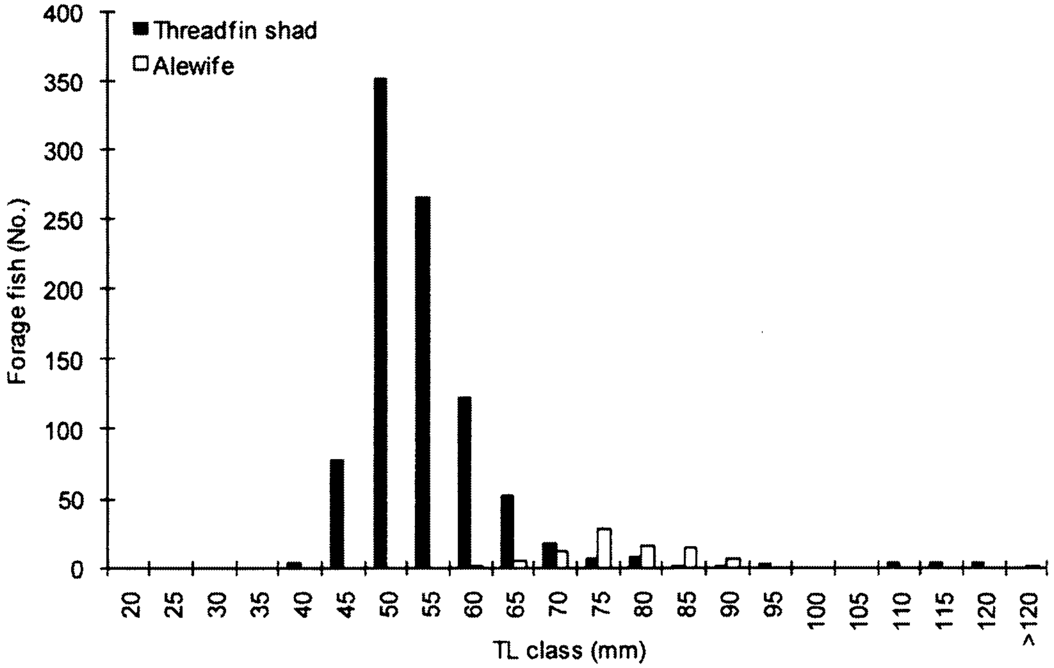


Figure 5-10. Number of individuals and size distribution of threadfin shad and alewife collected from purse seine surveys in Lake Norman, September 2009.

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