Duke Energy®

STEVEN D. CAPPS
Vice President
McGuire Nuclear Station

Duke Energy
MG01VP / 12700 Hagers Ferry Rd.
Huntersville, NC 28078

980-875-4805
980-875-4809 fax
Steven.Capps@duke-energy.com

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Lake Norman Maintenance Monitoring Program:
2011 Summary

Please find attached a copy of the annual "Lake Norman Maintenance Monitoring Program: 2011 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 21, 2013.

Questions regarding the attached report should be directed to Kay L. Crane at (980) 875-4306.

H D Brewer for

Steven D. Capps

IE25
NRR

Mr. V. M. McCree, Regional Administrator
U.S. Nuclear Regulatory Commission, Region II
Marquis One Tower
245 Peachtree Center Ave., NE Suite 1200
Atlanta, Georgia 30303-1257

Mr. Jon H. Thompson
NRC Senior Project Manager
U. S. Nuclear Regulatory Commission
Mail Stop 8G9A
Washington, DC 20555-0001

John Zeiler
NRC Senior Resident Inspector
McGuire Nuclear Station

# LAKE NORMAN

# MAINTENANCE MONITORING PROGRAM:

# 2011 SUMMARY

## McGuire Nuclear Station: NPDES No. NC0024392


**Principal Investigators:**

**Michael A. Abney**
**John E. Derwort**
**William J. Foris**

**DUKE ENERGY**
**Corporate EHS Services**
**McGuire Environmental Center**
**13339 Hagers Ferry Road**
**Huntersville, NC 28078**


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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 2011. The 2011 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 2011 totaled 118.0 cm which was similar to that observed in 2010 and the long-term average. Monthly rainfall in 2011 was greatest in September with 22.4 cm and the least in March with 6.0 cm. Slightly less than one-half the yearly rainfall total in 2011 occurred in the last 4 months of the year. Monthly average air temperatures in 2011 were equal to or above the long-term average for the entire year, except for January. Total degree days for the period May through September in 2011 measured one of the warmest over the last 35 years.

Water temperatures in winter and early spring 2011 were typically either equal to or warmer than measured in 2010, with minor differences observed between zones, whereas fall and early winter water temperatures were consistently cooler in both zones in 2011 than those measured in 2010. Between year differences in seasonal air temperatures corresponded with these between year differences in water temperatures. Epilimnion and metalimnion temperatures during the stratified period in 2011 were generally either equal to or greater than measured in 2010 and followed between year differences in a) monthly average air temperatures and b) station capacity factors. Epilimnion summer temperatures in 2011 were the warmest measured in both the background and mixing zones since 316(a) studies for MNS began on September 1, 1983. Operations began at MNS Unit 1 in 1981 and Unit 2 in 1984. Temperatures at the discharge location in 2011 exhibited historical maxima for the months of May, July, and August with a maximum value of 39.1 °C while temperatures for all other months were within historical ranges. Regulatory thermal discharge limits were met for all months in 2011.

Seasonal and spatial patterns of DO in 2011 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones. 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 1983. DO values in winter and spring 2011 were generally equal to or less than measured in 2010, due predominantly to warmer water temperatures. Summer DO values in 2011 were highly variable throughout the

water column in both zones and were similar to concentrations measured in 2010 and prior MNS operational years. The development and progression of a negative heterograde DO curve in summer 2011 was generally similar to previous MNS operational years, and only slightly less severe than observed in 2010. Fall 2011 DO concentrations were either equal to or greater throughout most of the water column than 2010 values, with these differences explained by interannual variability in the rates of water column cooling and reaeration, as influenced by extant meteorological conditions. The seasonal pattern of DO in 2011 at the MNS discharge location was similar to that measured historically with minimum values well above State water quality standards.

Reservoir-wide isotherm and isopleth information for 2011, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic similar to other Southeastern reservoirs of comparable size, depth, flow conditions and trophic status that provide water for once-through cooling of steam electric stations. The 2011 maximum whole water column and hypolimnion heat content values were the highest calculated for Lake Norman since the reservoir was created in the early 1960s. Whole water column and hypolimnion maximum heat content values in 2011 were 32% and 73%, respectively, higher than measured as baseline in the early 1960's.

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 lakewide from mid-September 2010 through mid-July 2011. Beginning in late June 2011, 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, or approximately for seven weeks, which is within the MNS operational historical range. Striped bass mortalities in 2011 totaled 395 fish and represented the 3rd consecutive year that summertime mortalities of adult striped bass exceeded 300 fish. Mortalities were observed concurrent with habitat elimination and were similar in timing and locations as previous die-offs.

All chemical parameters measured in 2011 were similar to 2010 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. Nutrient concentrations were low with many values reported close to or below the analytical reporting limit (ARL). Total phosphorus and nitrite-nitrate concentrations were lower than measured

in 2010, whereas ammonia nitrogen values were slightly higher than measured in 2010. It was not clear what factor or combination of factors contributed to these interannual differences but values were within historical ranges. Concentrations of metals in 2011 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 values for iron, cadmium, lead, zinc, and copper in 2011 were below the State water quality standard or action level for each of these metals. Manganese concentrations were generally low in 2011, except during the summer when bottom waters at all locations exceeded the State water quality action level (200 µg/L), which is representative of historical conditions.

Monitoring of the biological communities and associated parameters in Lake Norman continued in 2011. Most individual chlorophyll *a* concentrations during 2011 were within historical ranges and were well below the NC State water quality standard of 40 µg/L. The trend of increasing chlorophyll concentrations from downlake to uplake, observed during many previous years, was apparent for the most part during most sampling periods of 2011.

Phytoplankton diversity, or the number of phytoplankton taxa, was the highest yet recorded in 2011 since the beginning of the Program in 1987. The taxonomic compositions of phytoplankton communities during 2011 were similar to those of most previous years. Diatoms were dominant during early November, while cryptophytes were dominant during February and May. Green algae dominated summer assemblages. Blue-green algae typically comprised 2% or less of total densities.

The most abundant algae during 2011 were: the cryptophyte, *Rhodomonas minuta* in February and May; the green alga, *Cosmarium asphearosporum* v. *strigosum* in August; and the diatom *Melosira ambigua* in November. All of these taxa have been common and abundant throughout the Lake Norman Maintenance Monitoring Program.

Seston dry and ash-free weights were most often lower in February 2011 than in February 2010; while values during May, August, and November of 2011 were most often higher than during those periods of 2010. Maximum dry and ash-free weights were generally observed uplake while minimum values were observed most often downlake.

Secchi depths often reflected suspended solids, with shallow depths loosely related to high dry weights. The lakewide mean Secchi depth in 2011 was the highest recorded since 1992.

Zooplankton monitoring also continued in 2011. In most cases, zooplankton densities varied considerably and no consistent seasonal trends were observed. As in past years, epilimnetic densities were higher than whole-column densities and within the ranges of those observed in previous years. Spatial trends of zooplankton populations were generally similar to those of the phytoplankton, with increasing densities from downlake to uplake. Mean zooplankton densities tended to be higher among background locations than among mixing zone locations during 2011. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations.

Zooplankton samples from Lake Norman in 2011 were dominated by rotifers although their abundance declined since 2010. The most abundant rotifers observed in 2011, as in many previous years, were *Polyarthra*, *Kellicotia*, and *Asplanchna*. Microcrustaceans (copepods and cladocerans) increased in relative abundance in 2011 and their percent compositions were within historical ranges. Copepods were dominated by immature forms. Adults rarely accounted for more than 7% of zooplankton densities. As in previous years, the most important adult copepods were *Tropocyclop* and *Epishura*. *Bosmina* was the predominant cladoceran as often the case in previous years of the Progam.

In accordance with the Lake Norman Maintenance Monitoring Program, monitoring of specific fish population parameters continued during 2011. Spring electrofishing indicated that numbers and biomass of fish in 2011 were generally similar to those noted since 1993 although there was a considerable increase in the numbers of sunfish at the Marshall Steam Station location. The fish populations in the three sampling areas were comprised of 13 to 17 species of fish and two hybrid complexes. Fish collections were numerically and gravimetrically dominated by centrarchids. The forage fish population estimate, dominated by threadfin shad, was slightly below the average population estimate since surveys began in 1997. Largemouth bass number of individuals and biomass increased slightly from 2010, but remained very low. Spotted bass number of individuals and biomass remain high, possibly displacing largemouth bass. Summer striped bass mortalities were the third highest number ever recorded.

Lake Norman Maintenance Monitoring Program results from 2011 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 2011.

## OPERATIONAL DATA FOR 2011

Station operational data for 2011 are listed in Table 1-1. The monthly average station capacity factors exceeded 100% for the months of November, December and June – August when both Units 1 and 2 were fully operational. Unit maintenance issues resulted in capacity factors being less than 100% at other times. The thermal compliance discharge limit for MNS is 95 °F (35.0 °C) for the period October – June and increases to 99 °F (37.0 °C) for July – September. Thermal discharge limits were met for each month in 2011. The volume of cool water in Lake Norman was also 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 2011.

| | Monthly average capacity factors (%) | | | Monthly average NPDES discharge temperatures | |
|---|---|---|---|---|---|
| Month | Unit 1 | Unit 2 | Station | °F | °C |
| Jan | 87.93 | 80.29 | 84.11 | 61.5 | 16.4 |
| Feb | 105.43 | 93.56 | 99.50 | 65.7 | 18.7 |
| Mar | 104.32 | 0.00 | 52.33 | 69.0 | 20.6 |
| Apr | 102.36 | 86.49 | 94.42 | 75.4 | 24.1 |
| May | 104.92 | 105.28 | 105.10 | 86.4 | 30.2 |
| Jun | 103.85 | 104.03 | 103.94 | 94.5 | 34.7 |
| Jul | 103.10 | 102.79 | 102.95 | 98.8 | 37.1 |
| Aug | 103.56 | 102.46 | 103.01 | 98.4 | 36.9 |
| Sep | 54.47 | 103.56 | 79.01 | 94.7 | 34.8 |
| Oct | 49.83 | 104.82 | 77.32 | 83.5 | 28.6 |
| Nov | 105.41 | 104.96 | 105.18 | 78.1 | 25.6 |
| Dec | 105.55 | 105.55 | 105.55 | 74.3 | 23.5 |
| Average | 94.31 | 91.15 | 92.72 | 81.7 | 27.6 |

# CHAPTER 2

# WATER QUALITY

## INTRODUCTION

The objectives of the water quality portion of the McGuire Nuclear Station (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 South.

This report focuses primarily on 2010 and 2011 data. Where appropriate, reference to pre-2010 data will be made by citing reports previously submitted to the NCDENR.

## METHODS AND MATERIALS

The complete water quality monitoring program for 2011, 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 initiation of the Lake Norman MMP 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 converted to spreadsheet format following data validation.

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 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 2010, 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 and 1998b) and the United States Geological Survey (USGS 1998 and 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 either annually or 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 additional data on analytical uncertainty 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 studies on the lake (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010 and 2011). 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 lakewide 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 calculation 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. Heat and dissolved oxygen mass calculations

provide a convenient approach of integrating the influence of various physical, chemical, and biological processes on the thermal and DO structure of a waterbody. Heat and oxygen mass were calculated at one meter intervals within the water column employing the in-situ profile data, bathymetric (area and volume) data for Lake Norman and the following equation, modified after Hutchinson (1957):

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

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 2011 totaled 118.0 cm (Figures 2-2a and 2-2b) which was similar to that observed in 2010 (120.3 cm), and the long-term average (117.6 cm), based on Charlotte, NC airport data. Monthly rainfall in 2011 was greatest in September with 22.4 cm and the least in March with 6.0 cm. Slightly less than one-half the yearly rainfall total in 2011 occurred in the last 4 months of the year.

Monthly average air temperatures measured near MNS in 2011 were similar to that measured in 2010 except for the months of February, September, October and December, and were equal to or above the long-term average for the entire year, except for January (Figure 2-2c). Further, although colder than the long-term average, the winter of 2011 was not as cold as observed in 2010, differing by approximately 6 °C in the month of February. December 2011 air temperatures were also unusually warm with an average of 9.9 °C or approximately 3.0 °C warmer than the long-term average and 7.5 °C warmer than 2010.

Degree day calculations, a convenient method to quantify the influence of air temperatures on water temperatures, were calculated for the period May through September from 1975-2011. Total degree days over this 5 month period were the highest (warmest) in 2010 and 2011 and were also 8% and 5%, respectively, greater than the average.

Water temperatures measured in 2011 illustrated similar temporal and spatial trends in the background and mixing zones (Figures 2-3 and 2-4) as they did in 2010. This similarity in temperature patterns between zones has been a dominant feature of the thermal regime in Lake Norman since 316(a) studies for MNS began 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 typically parallel differences in air temperatures but with a one-month lag time (Duke Power 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Water temperatures in winter and early spring 2011 were typically either equal to or warmer than measured in 2010, with minor differences observed between zones (Figures 2-3 and 2-4). Winter water temperatures in 2010 were the coldest measured in Lake Norman over the last two decades reaching a water column average of 6.03 °C in the background zone, contrasted with a water column average of 7.0 °C in 2011. Typically, background zone temperatures are slightly cooler than measured in the mixing zone regardless of the year because of the influence of the thermal discharge from MNS in the mixing zone. 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 often reflects the cumulative influences of meteorology and hydrology prior to that date.

Differences in winter and early spring water temperatures between 2010 and 2011 tracked air temperatures (Figure 2-2c) and are consistent with historical observations. Minimum winter 2011 water temperatures recorded in early January and February ranged from 6.8 °C to 8.5 °C in the background zone and from 7.0 °C to 13.2 °C in the mixing zone. Minimum water temperatures measured in 2011 were within the observed historical operational range for MNS (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Epilimnion and metalimnion temperatures in 2011 during the stratified period (June through August) were generally either equal to or greater than measured in 2010 (Figures 2-3 and 2-4) and generally followed between year differences in monthly average air temperatures (Figure 2-2c). Capacity factors at MNS during this time period were also approximately 7.5% greater in 2011 than 2010 and likely contributed to the observed differences in water temperatures. Temperature differences between years were generally small with the greatest difference measured at the surface waters (0.3 m and 1 m depth) in the mixing zone in August (Figures 2-3 and 2-4). Epilimnion (0 -15 m depth) temperatures in 2011 during the summer were the warmest measured in both the background and mixing zones since MNS became fully operational in 1983 (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Late-summer, fall, and early winter (September – November) water temperatures in the upper and mid portions of the water column were consistently cooler in both zones in 2011 than those measured in 2010, indicating that the reservoir was cooling at a faster rate in 2011 than 2010 (Figures 2-3 and 2-4). This pattern followed the trend exhibited in air temperatures (Figures 2-2c). December temperature profiles, in contrast, illustrated a reversal of this trend with 2010 temperatures being cooler than 2011, in parallel with air temperatures differences between these two years. The most striking differences in fall temperature profiles were observed in the mixing zone in November when 2011 temperatures were as much as 3.6 °C cooler throughout most of the water column than measured in 2010.

Temperatures at the discharge location in 2011 were generally similar to but slightly warmer than 2010, particularly during the summer (Figure 2-5). Historical maxima in 2011 for the monthly sampling at this location were recorded for May, July, and August with a maximum value of 39.1 °C. Temperatures for all other months in 2011 were within historical ranges

(Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Dissolved Oxygen

Seasonal and spatial patterns of DO in 2011 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 1983.

Winter and spring DO values in 2011 were generally equal to or slightly less throughout the water column in both zones than measured in 2010, the coldest winter recorded over the last 30 years (Figures 2-6 and 2-7). This difference is less pronounced in the mixing zone than the background zone. The interannual differences in DO values measured during this period appeared related predominantly to the differences in water column temperatures in 2010 versus 2011 and were consistent with observations made during previous years (Duke Energy 2007, 2008, 2009, 2010, and 2011). 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.

One consistent but variable feature in terms of spatial distribution and severity of the vertical DO pattern observed in Lake Norman during the stratified period is the presence of a negative heterograde oxygen curve (NHOC), also commonly called a "metalimnetic oxygen minimum". The NHOC is characterized by a vertical oxygen profile with a moderate to pronounced middle water layer (metalimnion) of low DO positioned between upper (epilimnion) and lower (hypolimnion) zones of higher oxygen content (Horne and Goldman 1994). The NHOCs are more common in Southeastern reservoirs than reservoirs located farther north, but vary widely in distribution and severity (Cole and Hannan 1985, Horne and Goldman 1994). Reservoirs with warm metalimnion temperatures and elevated levels of organic matter associated with allochthonous inputs from the watershed or autochthonous (in lake) sources associated with nutrient enrichment, especially in eutrophic waterbodies, have been linked to NHOCs (Cole and Hannan 1985). The NHOC's are most often caused by

vertical differences in animal and microbial aerobic respiration associated with the consumption and degradation of both autochthonous and allochthonous derived organic matter within the water column (Cole and Hannan 1985).

The NHOCs are typically formed via a combination of two processes; differential oxygen consumption within the middle section of the water column by aerobic degradation of organic matter and oxygen consuming microbial decomposition of organic matter in the bottom sediments, often coined "sediment oxygen demand" (SOD). Rates of SOD within a reservoir are generally higher in the upper, shallow reaches of the waterbody where allochthonous inputs of labile (readily decomposable) organic matter tend to accumulate at higher levels, than the deeper, downlake segments. These higher up-reservoir rates of SOD result in oxygen being depleted sooner and faster in the hypolimnion of these areas than downreservoir. And as these waters at the same elevation are pulled downlake by power generation withdrawals, a mid-water zone of low DO layered between zones of higher oxygen is observed. In rare instances, the presence of NHOCs have been traced to interflows of low DO waters entering the waterbody, most frequently from an upstream, hypolimnetic withdrawal reservoir (Cole and Hannan 1985). Seasonal progression of these two important water column oxygen consuming processes within the waterbody eventually create a reservoir-wide zone of water below the thermocline that is anoxic (Figures 2-6, 2-7, 2-9, and 2-11).

The development and progression of the NHOC in summer 2011 occurred later and progressed slower than in 2010 (Figures 2-6, 2-7, and 2-9). By early July, water column and sediment oxygen demands had reduced DO concentrations in the middle and lower portions of the water column in both the background and mixing zones. Metalimnetic and hypolimnetic DO levels at this time were depleted more severely in the background zone with concentrations ranging from a low of 0.60 mg/L at 13 m to a high of 2.1 mg/L at 24 m. In the mixing zone, DO levels were slightly higher ranging from a minimum of 1.8 mg/L at 17 m to 3.5 mg/L at 25 m.

Normally, by early August DO values in Lake Norman are < 1.0 mg/L below the thermocline (10-12 m) and often approach anoxic conditions, with the background zone exhibiting slightly more severe conditions than the mixing zone. August 2011 DO profiles exhibited patterns consistent with historical trends in both zones (Figures 2-6, 2-7, and 2-9). It was previously postulated (Duke Energy 2010) that elevated levels of allochthonous organic loading associated with higher than normal spring rains might explain the yearly variability in the timing and severity of NHOC occurrences. This hypothesis was formulated based on

study results presented by Ford (1987) who found that nutrient and organic loading to DeGray Reservoir in Arkansas was dominated by rainfall and associated terrestrial runoff events during the spring. Spring rainfall totals in 2011 were actually about 30 % greater than in measured 2010; a similar disconnect between annual spring rainfall totals and subsequent severity of the corresponding NHOC was observed in others years. Clearly, additional factors not yet identified also influence the development of the NHOCs in Lake Norman.

Considerable differences were observed between 2010 and 2011 late summer and fall DO values in both the mixing and background zones, especially in the metalimnion and hypolimnion, during the months of September, 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 2011 late summer and autumn DO data indicate that convective reaeration of the water column proceeded faster and was more advanced than observed in corresponding months in 2010. Consequently, 2011 DO levels at most depths were either equal to or greater than observed in 2010. 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 2011 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). Despite exhibiting record discharge temperatures in summer 2011 DO concentrations were either equal to or greater than measured in 2010. The lowest DO concentration measured at the discharge location in 2011 (5.4 mg/L) occurred in September and was 1.1 mg/L higher than in 2010, and 1.3 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 2011 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, and 1996).

The seasonal heat content of both the entire water column and the hypolimnion for Lake Norman in 2011 are presented in Figure 2-10a; additional information on the thermal regime in the reservoir for the years 2010 and 2011 are presented in Table 2-3. Annual minimum heat content for the entire water column in 2011 (8.02 Kcal/cm$^2$, 7.90 °C) occurred in early February, whereas the maximum heat content (29.68 Kcal/cm$^2$, 29.12 °C) occurred in August. Heat content of the hypolimnion exhibited a somewhat different temporal trend compared to that observed for the entire water column. Annual minimum hypolimnetic heat content also occurred in early February and measured 4.29 Kcal/cm$^2$ (6.59 °C), but the maximum occurred in early September and measured 16.65 Kcal/cm$^2$ (26.00 °C). The 2011 maximum whole water column and hypolimnion heat content values were the highest calculated for Lake Norman since the reservoir was created in the early 1960s. The maximum water column heat content in 2011, expressed in degrees centigrade (29.12 °C), was approximately 7 °C (32%) warmer than measured in the early 1960's. Similarly, but more extreme, the maximum heat content of the hypolimnion in 2011 (26.00 °C) was close to 11 °C (73%) warmer than observed in the early 1960's (15 °C). Progressive increases observed in both the annual maximum water column and annual maximum hypolimnion heat content of Lake Norman since reservoir impoundment (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011) correlate strongly with steam electric operations.

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 rates of the eplimnion equaled 0.13 °C/day and 0.10 °C/day for the hypolimnion and were slightly greater than observed in 2010 (Table 2-3).

The seasonal oxygen content and percent saturation of the whole water column, and the hypolimnion, are depicted for 2011 in Figure 2-10b. Additional oxygen data can be found in Table 2-4 which presents the 2011 AHOD for Lake Norman and similar earlier estimates for 18 Tennessee Valley Authority (TVA) reservoirs. Reservoir oxygen content, expressed as a volume-weighted average, was greatest in mid-winter when DO content measured 10.8 mg/L for the whole water column and 10.7 mg/L for the hypolimnion, equaling that observed in 2010. Percent oxygen saturation values at this time approached 90% for the entire water column and 88% for the hypolimnion, indicating that reaeration of the reservoir did not achieve 100% saturation in 2011, which is typical. Beginning in early spring, oxygen content began to decline rapidly 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 4.17 mg/L (57% saturation), whereas the minimum for the hypolimnion was 0.19 mg/L (2.0 % saturation). The mean rate of DO decline in the hypolimnion over the stratified period, i.e., the AHOD, was 0.041 $mg/cm^2/day$ (0.061 mg/L/day) (Figure 2-10b), and is similar to that measured in 2010 and historically for MNS operational years (Duke Energy 2010).

Hutchinson (1938 and 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 0.041 $mg/cm^2/day$ for 2011. The oxygen-based mesotrophic classification agrees well with the mesotrophic classification based on chlorophyll *a* levels (Chapter 3). The 2010 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 and Fish Mortalities

Striped bass, a coolwater predator often introduced in Southeastern reservoirs to enhance and diversify the sport fishery, have been stocked in Lake Norman by the North Carolina Wildlife Resources Commission (NCWRC) since the late 1960's. In many instances these introductions have been successful; however, periodic summertime mortalities have been observed. Coutant (1985) hypothesized that summertime mortalities of adult striped bass could be explained by a temperature-dissolved oxygen "squeeze" within the water column.

Seasonal warming of the oxygenated epilimnion would force fish downward to seek deeper, cooler waters offering their preferred temperatures, whereas microbial deoxygenation of the middle and bottom waters would force fish upward to seek oxygenated but warmer water. As stratification intensified, continued epilimnion warming and deepening, coupled with mid and bottom water deoxygenation, would ultimately force fish to occupy water layers that lack the appropriate physicochemical conditions critical for survival, and eventually would lead to mortalities. Coutant (1985) proposed that suitable physicochemical habitat critical for survival of adult striped bass included water temperatures of about 18-25 °C and DO concentrations above about 2-3 mg/L.

Preferred habitat for adult striped bass in this report is defined as pelagic waters with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L. These individual criteria were originally selected to define critical habitat based on analyses of physicochemical conditions observed during the summer of 1983 when the first reported die-off (163 fish) of adult striped bass occurred in lower Lake Norman near Cowans Ford Dam

Physicochemical habitat expanded appreciably by approximately the 3rd week in September, primarily as a result of epilimnion cooling and deepening, and in response to changing meteorological conditions (Figure 2-2c). By early October, preferred habitat was present both vertically and horizontally throughout most of the reservoir. The temporal and spatial patterns of habitat reduction observed in Lake Norman during the stratified period in 2011 were similar to historical observations during the MNS operational period and generally similar to other Southeastern reservoirs (Coutant 1985; Matthews et al. 1985; Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Striped bass mortalities in 2011 totaled 395 fish and represented the third consecutive year that summertime mortalities of adult striped bass exceeded 100 fish. Mortalities were observed concurrent with habitat elimination and were similar in timing and locations as previous die-offs. It was hypothesized (Duke Energy 2011) that these mortalities are linked to the introduction of alewife (*Alosa pseudoharengus*) into Lake Norman in the late 1990's which resulted in a shift in the seasonal distribution of striped bass within the reservoir, in response to seasonal migration patterns of coolwater habitat seeking adult alewife. Additional discussion of these mortalities is presented in Chapter 5.

Turbidity and Specific Conductance

Surface turbidity values were generally low at the MNS discharge, mixing zone, and background locations during 2011 ranging from 0.9 to 2.3 NTUs (Table 2-5). Bottom turbidity values were also low but slightly higher than surface readings and ranged from 0.94 to 9.1 NTUs. Turbidity values observed in 2011 were within the historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Specific conductance in Lake Norman in 2011 ranged from 65 to 81 µmhos/cm and was generally similar to that observed in 2010 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). Conductance values in surface and bottom waters in 2010 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 both the mixing and background zones. These increases in bottom conductance values appeared 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 and Wetzel 1975) and recurs annually in Lake Norman.

pH and Alkalinity

During 2011, 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 2010 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). Values of pH in 2011 ranged from 7.0 to 8.3 in surface waters and from 6.4 to 7.4 in bottom waters. Alkalinity values in 2011 ranged from 10.0 to 16.0 mg/L, expressed as $CaCO^3$, in surface waters and from 13.0 to 21.0 mg/L in bottom waters.

## Major Cations and Anions

The concentrations of major ionic species in the MNS discharge, mixing and background zones are provided in Table 2-5. Lakewide, 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 2011 was generally similar to that reported for 2009 (Table 2-5) and previously (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

## Nutrients

Nutrient concentrations in the discharge, mixing and background zones of Lake Norman in 2011 (Table 2-5) were low and generally similar to those measured in 2010 and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). For total phosphorus (TP), 40 of 44 samples analyzed in 2011 exceeded 5 µg/L, the analytical reporting limit (ARL) and values were consistently lower than observed in 2010, but within the historical range. All measurements of orthophosphorus (N = 44) in 2011 were ≤ 5 µg/L, the ARL. Nitrite-nitrate values were low at all locations in 2011 and consistently averaged less than observed in 2010. Ammonia nitrogen concentrations were also low in 2011 but in contrast to TP and nitrite-nitrate values were often greater than in 2010. It's not clear why these between year differences in phosphorus and nitrogen species occurred. Nitrite-nitrate and ammonia nitrogen concentrations in 2011 were similar to historical values (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

## Metals

Metal concentrations in the discharge, mixing, and background zones of Lake Norman for 2011 were similar to those measured in 2011 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). Iron concentrations in surface and bottom waters were

generally low (≤ 0.2 mg/L) during 2011 with only 3 of 44 samples exceeding 0.20 mg/L. The maximum iron concentration measured in 2011 (0.446 mg/L) was from the bottom water sample at Location 8.0 in November. No samples collected in 2011 exceeded the North Carolina water quality action level for iron (1.0 mg/L; NCDENR 2004).

Manganese concentrations in the surface and bottom waters in 2011 were also generally low (≤ 100 µg/L), except during the summer stratified period 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 were characteristic of historical conditions (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). The highest concentration of manganese reported in 2011 (2,040 µg/L) was measured in the bottom waters at Location 8.0 in August. 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 2011 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, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). All values for cadmium and lead were reported as either equal to or below the ARL for those parameters. Approximately seventy three percent of zinc values (32 of 44 samples) in 2011 were below the ARL of 2.0 µg/L with the maximum concentration (3.7 µg/L) measured at Location 8.0 in February. All copper concentrations, measured as total recoverable copper, were ≤ 2.5 µg/L and 6 of 44 values were less than the ARL of 1.0 µg/L. All values reported for cadmium, lead, zinc, and copper in 2011 were below the State action level for each of these metals (NCDENR 2004). Manganese concentrations in each bottom sample collected in August 2011 exceeded the State water quality action level (200 µg/L), which is representative of historical conditions.

## SUMMARY

Annual precipitation in the vicinity of MNS in 2011 totaled 118.0 cm which was similar to that observed in 2010 and the long-term average. Monthly rainfall in 2011 was greatest in September with 22.4 cm and the least in March with 6.0 cm. Slightly less than one-half the yearly rainfall total in 2011 occurred in the last 4 months of the year. Monthly average air temperatures in 2011 were equal to or above the long-term average for the entire year, except for January. Total degree days for the period May through September in 2011 measured one of the warmest over the last 35 years.

Water temperatures in winter and early spring 2011 were typically either equal to or warmer than measured in 2010, with minor differences observed between zones, whereas fall and early winter water temperatures were consistently cooler in both zones in 2011 than those measured in 2010. Between year differences in seasonal air temperatures corresponded with these between year differences in water temperatures. Epilimnion and metalimnion temperatures in 2011 during the stratified period were generally either equal to or greater than measured in 2010 and followed between year differences in a) monthly average air temperatures and b) station capacity factors. Epilimnion summer temperatures in 2011 were the warmest measured in both the background and mixing zones since 1983. Temperatures at the discharge location in 2011 exhibited historical maxima for the months of May, July, and August with a maximum value of 39.1 °C while temperatures for all other months were within historical ranges. Regulatory thermal discharge limits at MNS were met for all months in 2011.

Seasonal and spatial patterns of DO in 2011 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones. 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 1983. DO values in winter and spring 2011 were generally equal to or less than measured in 2010, due predominantly to warmer water temperatures. Summer DO values in 2011 were highly variable throughout the water column in both zones and were similar to concentrations measured in 2010 and prior MNS operational years. The development and progression of a negative heterograde DO curve in summer 2011 was generally similar to previous MNS operational years, and only slightly less severe than observed in 2010. Fall 2011 DO concentrations were either equal to or greater throughout most of the water column than 2010 values, with these differences explained by interannual variability in the rates of water column cooling and reaeration, as

influenced by extant meteorological conditions. The seasonal pattern of DO in 2011 at the MNS discharge location was similar to that measured historically with minimum values well above State water quality standards.

Reservoir-wide isotherm and isopleth information for 2011, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic to other Southeastern reservoirs of comparable size, depth, flow conditions and trophic status that provide water for once-through cooling of steam electric stations. The 2011 maximum whole water column and hypolimnion heat content values were the highest calculated for Lake Norman since the reservoir was created in the early 1960s. Whole water column and hypolimnion maximum heat content values in 2011 were 32% and 73%, respectively, higher than measured as baseline in the early 1960's.

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 lakewide from mid-September 2010 through mid-July 2011. 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, or approximately for seven weeks, which is within the MNS operational historical range. Striped bass mortalities in 2011 totaled 395 fish and represented the 3rd consecutive year that summertime mortalities of adult striped bass exceeded 300 fish. Mortalities were observed concurrent with habitat elimination and were similar in timing and locations as previous die-offs.

All chemical parameters measured in 2011 were similar to 2010 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. Nutrient concentrations were low with many values reported close to or below the (ARL) for that test. Total phosphorus and nitrite-nitrate concentrations were lower than measured in 2010, whereas ammonia nitrogen values were slightly higher than measured in 2010. It was not clear what factor or combination of factors contributed to these interannual differences but values were within historical ranges. Concentrations of metals in 2011 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 values in 2011 for iron, cadmium, lead, zinc, and copper were below the State water quality standard or action level for each of these

metals. Manganese concentrations were generally low in 2011, except during the summer when bottom waters at all locations exceeded the State water quality action level (200 μg/L), which is representative of historical conditions.

Table 2-1. Water quality 2011 program for the MNS NPDES Maintenance Monitoring Program on Lake Norman.

| PARAMETERS | LOCATIONS | 1 | 2 | 4 | 5 | 8 | 9.5 | 11 | 13 | 14 | 15 | 15.9 | 62 | 69 | 72 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 McGUIRE NPDES SAMPLING PROGRAM | | | | | | | | | | | | | | |
| | DEPTH (m) | 33 | 33 | 5 | 20 | 32 | 23 | 27 | 21 | 10 | 23 | 23 | 15 | 7 | 5 | 4 |
| IN-SITU ANALYSIS | | | | | | | | | | | | | | | | |
| | Method | | | | | | | | | | | | | | | |
| Temperature | Hydrolab | In-situ measurements are collected monthly at the above locations at 1m intervals from 0.3m to 1m above bottom. Measurements are taken weekly from July-August for striped bass habitat at all locations except 5 & 9.5. | | | | | | | | | | | | | | |
| Dissolved Oxygen | Hydrolab | | | | | | | | | | | | | | | |
| pH | Hydrolab | | | | | | | | | | | | | | | |
| Conductivity | Hydrolab | | | | | | | | | | | | | | | |
| NUTRIENT ANALYSES | | | | | | | | | | | | | | | | |
| Ammonia | C_NH3 | 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 | C_NO2NO3 | 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 | C_OPO4 | 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 | C_TP | 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 | C_SIO2 | 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 | | |
| Cl | C_CL | 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 | C_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 | TOC | 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 | DOC | 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 | ICP Undigested | 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 | ICP Undigested | 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 | IMS_TRM | 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 | ICP Undigested | 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 | IMS_TRM | 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 | ICP Undigested | 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 | ICP Undigested | 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 (TR)[1] | IMS_TRM | 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 (TR)[1] | IMS_TRM | 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 | | |
| Boron (TR)[1] | IMS_TRM | 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 | | |
| Cadmium (TR)[1] | IMS_TRM | 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] | IMS_TRM | 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) | IMS 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 (TR)[1] | IMS_TRM | 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 (TR)[1] | IMS_TRM | 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 | | | | | | | | | | | | | | |
| Alkalinity | ALK_FIX5.1 | 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 | | |
| Turbidity | TURB | 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 | DIONEX | 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 | TS | 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 | TSS | 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 2011 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 |
| 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% $HNO_3$ | 2.0 µg/L |

References: USEPA 1983, and APHA 1995

Table 2-3. Heat content calculations for the thermal regime in Lake Norman for 2010 and 2011.

| | 2011 | 2010 |
|---|---|---|
| Maximum Areal Heat Content (Kcal/cm$^2$) | 29.678 | 29.616 |
| Minimum Areal Heat Content (Kcal/cm$^2$) | 8.018 | 6.904 |
| Birgean Heat Budget (Kcal/cm$^2$) | 21.660 | 22.712 |
| Epilimnion (above 11.5 m) Heating Rate (°C/day) | 0.13 | 0.11 |
| Hypolimnion (below 11.5 m) Heating Rate (°C/day) | 0.10 | 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 (2010) | 0.051 | 5.6 | 2.7 | 10.3 |
| TVA[a] | | | | |
| 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 |

[a] 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 2010 and 2011. 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: | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 |
| Turbidity (NTU) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 1.2 | 2.3 | 2.0 | 6.3 | 1.2 | 2.8 | 2.5 | 5.6 | 1.3 | 3.1 | 1.3 | 3.3 | 1.9 | 4.3 | 1.0 | 5.0 | 2.2 | 12.0 | 2.1 | 35.0 | 2.0 | 28.0 |
| May | 1.8 | 2.1 | 1.8 | 8.2 | 0.9 | 2.2 | 2.7 | 8.9 | 1.3 | 2.2 | 1.1 | 2.5 | 2.1 | 7.8 | 1.1 | 1.2 | 2.9 | 4.4 | 1.2 | 1.2 | 2.6 | 8.1 |
| Aug | 1.2 | 1.2 | 2.7 | 2.4 | 1.9 | 1.3 | 2.1 | 2.2 | 1.1 | 1.0 | 1.0 | 1.7 | 1.5 | 4.2 | 1.2 | 1.7 | 1.0 | 1.3 | 2.3 | 1.4 | 0.9 | 1.1 |
| Nov | 1.1 | 3.5 | 1.9 | 2.2 | 1.6 | 2.4 | 2.9 | 5.6 | 1.5 | 2.5 | 1.7 | 2.4 | 1.8 | 4.6 | 1.4 | 2.7 | 9.1 | 4.3 | 2.2 | 2.5 | 4.1 | 6.2 |
| Annual Mean | 1.3 | 2.3 | 2.1 | 4.8 | 1.4 | 2.2 | 2.6 | 5.6 | 1.3 | 2.2 | 1.3 | 2.5 | 1.8 | 5.2 | 1.2 | 2.7 | 3.8 | 5.5 | 2.0 | 10.0 | 2.4 | 10.9 |
| Specific Conductance (umho/cm) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 66.0 | 61.0 | 66.0 | 58.0 | 66.0 | 61.0 | 66.0 | 58.0 | 67.0 | 61.0 | 67.0 | 61.0 | 66.0 | 59.0 | 65.0 | 59.0 | 66.0 | 55.0 | 70.0 | 52.0 | 69.0 | 53.0 |
| May | 69.0 | 58.0 | 68.0 | 56.0 | 69.0 | 58.0 | 68.0 | 56.0 | 70.0 | 59.0 | 69.0 | 58.0 | 69.0 | 56.0 | 69.0 | 59.0 | 68.0 | 56.0 | 70.0 | 60.0 | 68.0 | 55.0 |
| Aug | 69.0 | 62.0 | 81.0 | 61.0 | 69.0 | 62.0 | 79.0 | 61.0 | 69.0 | 62.0 | 69.0 | 63.0 | 79.0 | 69.0 | 68.0 | 62.0 | 80.0 | 62.0 | 77.0 | 65.0 | 77.0 | 61.0 |
| Nov | 69.0 | 68.0 | 69.0 | 105.0 | 69.0 | 68.0 | 69.0 | 108.0 | 70.0 | 69.0 | 69.0 | 68.0 | 68.0 | 72.0 | 68.0 | 68.0 | 69.0 | 104.0 | 76.0 | 70.0 | 75.0 | 69.0 |
| Annual Mean | 68.3 | 62.3 | 71.0 | 70.0 | 68.3 | 62.3 | 70.5 | 70.8 | 69.0 | 62.8 | 68.5 | 62.5 | 70.5 | 64.0 | 67.5 | 62.0 | 70.8 | 69.3 | 73.3 | 61.8 | 72.3 | 59.5 |
| pH (units) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 7.1 | 6.8 | 7.0 | 6.8 | 7.3 | 7.1 | 7.0 | 6.9 | 7.3 | 7.2 | 7.3 | 7.2 | 7.1 | 7.0 | 7.4 | 7.1 | 7.1 | 6.9 | 7.2 | 6.8 | 7.1 | 6.8 |
| May | 7.6 | 7.1 | 6.6 | 6.4 | 7.5 | 7.1 | 6.7 | 6.5 | 7.4 | 7.1 | 7.5 | 7.2 | 6.8 | 6.6 | 7.6 | 7.7 | 6.8 | 6.6 | 7.7 | 7.7 | 6.8 | 6.6 |
| Aug | 7.4 | 7.3 | 6.5 | 6.1 | 7.3 | 7.3 | 6.4 | 6.0 | 7.0 | 7.0 | 7.3 | 7.0 | 6.5 | 6.2 | 8.3 | 7.3 | 6.5 | 6.1 | 7.5 | 7.1 | 6.4 | 6.1 |
| Nov | 7.2 | 7.3 | 7.2 | 7.1 | 7.3 | 7.2 | 7.2 | 7.2 | 7.4 | 7.2 | 7.5 | 7.3 | 7.2 | 6.9 | 7.4 | 7.2 | 7.4 | 7.1 | 7.5 | 7.2 | 7.3 | 7.2 |
| Annual Mean | 7.3 | 7.1 | 6.8 | 6.6 | 7.3 | 7.2 | 6.8 | 6.7 | 7.1 | 7.1 | 7.4 | 7.2 | 6.9 | 6.7 | 7.7 | 7.3 | 6.9 | 6.7 | 7.5 | 7.2 | 6.9 | 6.7 |
| Alkalinity (mg CaCO3/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 15 | 14 | 15 | 13 | 14 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 12 | 16 | 12 | 15 | 12 |
| May | 14 | 12 | 15 | 12 | 15 | 12 | 15 | 11 | 15 | 12 | 15 | 12 | 16 | 12 | 15 | 12 | 15 | 13 | 14 | 12 | 15 | 12 |
| Aug | 14 | 14 | 19 | 14 | 14 | 14 | 17 | 14 | 15 | 14 | 14 | 14 | 21 | 19 | 10 | 14 | 21 | 15 | 16 | 15 | 17 | 15 |
| Nov | 14 | 18 | 14 | 33 | 15 | 17 | 13 | 35 | 14 | 19 | 14 | 17 | 15 | 19 | 15 | 17 | 15 | 19 | 16 | 18 | 16 | 19 |
| Annual Mean | 14.3 | 14.5 | 15.8 | 18.0 | 14.5 | 14.3 | 15.0 | 18.5 | 14.8 | 14.8 | 14.5 | 14.3 | 16.8 | 16.0 | 13.8 | 14.3 | 16.5 | 14.8 | 15.5 | 14.3 | 15.8 | 14.5 |
| Chloride (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 7.1 | 6.5 | 7.1 | 6.0 | 7.1 | 6.2 | 7.2 | 6.0 | 7.2 | 6.1 | 7.2 | 6.3 | 7.1 | 6.1 | 7.2 | 6.0 | 7.2 | 4.7 | 8.1 | 5.2 | 7.6 | 5.2 |
| May | 7.9 | 5.8 | 7.6 | 5.6 | 7.6 | 5.8 | 8.0 | 5.8 | 7.4 | 5.8 | 7.9 | 5.7 | 7.9 | 5.7 | 7.7 | 6.1 | 7.7 | 5.8 | 7.9 | 6.3 | 7.7 | 5.7 |
| Aug | 7.1 | 7.1 | 6.8 | 6.5 | 7.0 | 6.8 | 6.9 | 6.1 | 7.1 | 6.8 | 7.3 | 7.0 | 6.7 | 6.0 | 7.3 | 7.1 | 6.7 | 6.7 | 8.3 | 7.7 | 6.9 | 5.8 |
| Nov | 7.7 | 7.4 | 7.7 | 6.2 | 7.6 | 7.4 | 7.7 | 6.8 | 7.7 | 7.3 | 7.6 | 7.6 | 7.6 | 7.4 | 7.6 | 7.6 | 7.7 | 7.5 | 8.6 | 7.4 | 8.4 | 7.2 |
| Annual Mean | 7.5 | 6.7 | 7.3 | 6.1 | 7.3 | 6.6 | 7.5 | 6.2 | 7.4 | 6.5 | 7.5 | 6.7 | 7.3 | 6.3 | 7.5 | 6.7 | 7.3 | 6.2 | 8.2 | 6.7 | 7.7 | 6.0 |
| Sulfate (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 4.2 | 4.3 | 4.2 | 4.2 | 4.2 | 4.3 | 4.2 | 4.2 | 4.2 | 4.3 | 4.2 | 4.3 | 4.2 | 4.3 | 4.2 | 4.3 | 4.2 | 4.1 | 4.3 | 3.9 | 4.3 | 3.9 |
| May | 4.1 | 4.2 | 4.1 | 4.1 | 4.2 | 4.1 | 4.1 | 4.1 | 4.1 | 4.2 | 4.1 | 4.1 | 4.1 | 4.1 | 4.0 | 4.2 | 4.0 | 4.1 | 4.2 | 4.2 | 4.0 | 4.1 |
| Aug | 4.3 | 2.6 | 4.1 | 2.8 | 4.0 | 2.7 | 4.1 | 2.7 | 4.1 | 2.6 | 4.3 | 2.5 | 3.9 | 2.4 | 4.2 | 2.4 | 3.9 | 2.5 | 4.5 | 2.7 | 4.1 | 2.8 |
| Nov | 4.1 | 4.2 | 4.2 | 1.4 | 4.1 | 4.1 | 5.7 | 0.7 | 4.2 | 4.1 | 4.1 | 4.2 | 4.1 | 4.2 | 4.1 | 4.3 | 4.2 | 4.0 | 4.4 | 4.3 | 4.3 | 4.2 |
| Annual Mean | 4.2 | 3.8 | 4.2 | 3.1 | 4.1 | 3.8 | 4.5 | 2.9 | 4.2 | 3.8 | 4.2 | 3.8 | 4.1 | 3.8 | 4.1 | 3.8 | 4.1 | 3.7 | 4.4 | 3.8 | 4.2 | 3.8 |
| Calcium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 4.44 | 4.12 | 4.42 | 4.01 | 4.35 | 4.11 | 4.44 | 3.99 | 4.34 | 4.09 | 4.41 | 4.08 | 4.37 | 4.09 | 4.42 | 4.04 | 4.49 | 3.87 | 4.70 | 3.64 | 4.64 | 3.67 |
| May | 4.59 | 3.94 | 4.57 | 3.72 | 4.47 | 3.84 | 4.66 | 3.81 | 4.57 | 3.89 | 4.52 | 3.77 | 4.66 | 3.81 | 4.58 | 4.08 | 4.64 | 3.88 | 4.73 | 4.21 | 4.58 | 3.89 |
| Aug | 4.27 | 4.25 | 5.17 | 4.18 | 4.13 | 4.33 | 5.11 | 4.29 | 4.31 | 4.23 | 4.24 | 4.35 | 5.19 | 4.47 | 4.16 | 4.28 | 5.18 | 4.41 | 5.28 | 4.75 | 5.06 | 4.27 |
| Nov | 4.00 | 4.54 | 4.07 | 4.89 | 4.05 | 4.60 | 4.08 | 4.70 | 4.05 | 4.57 | 4.08 | 4.54 | 3.98 | 4.64 | 4.07 | 4.57 | 4.20 | 4.65 | 5.07 | 4.73 | 4.86 | 4.76 |
| Annual Mean | 4.33 | 4.21 | 4.56 | 4.20 | 4.25 | 4.22 | 4.57 | 4.20 | 4.32 | 4.20 | 4.31 | 4.19 | 4.55 | 4.25 | 4.31 | 4.24 | 4.63 | 4.20 | 4.95 | 4.33 | 4.79 | 4.15 |
| Magnesium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 1.88 | 1.81 | 1.86 | 1.74 | 1.85 | 1.81 | 1.86 | 1.72 | 1.85 | 1.79 | 1.85 | 1.80 | 1.85 | 1.79 | 1.86 | 1.76 | 1.86 | 1.64 | 1.86 | 1.53 | 1.87 | 1.55 |
| May | 1.90 | 1.62 | 1.89 | 1.56 | 1.87 | 1.61 | 1.91 | 1.60 | 1.90 | 1.63 | 1.91 | 1.59 | 1.94 | 1.61 | 1.90 | 1.65 | 1.90 | 1.63 | 1.93 | 1.69 | 1.88 | 1.62 |
| Aug | 2.07 | 1.78 | 2.06 | 1.74 | 2.01 | 1.82 | 2.05 | 1.78 | 2.01 | 1.76 | 2.03 | 1.83 | 2.12 | 1.86 | 2.00 | 1.80 | 2.07 | 1.82 | 2.27 | 1.93 | 2.04 | 1.76 |
| Nov | 2.00 | 1.94 | 2.02 | 1.96 | 2.04 | 1.96 | 2.03 | 1.85 | 2.03 | 1.94 | 2.04 | 1.95 | 2.04 | 1.98 | 2.03 | 1.95 | 2.05 | 1.97 | 2.21 | 2.20 | 2.15 | 2.20 |
| Annual Mean | 1.96 | 1.79 | 1.96 | 1.75 | 1.94 | 1.80 | 1.96 | 1.74 | 1.95 | 1.78 | 1.96 | 1.79 | 1.99 | 1.81 | 1.95 | 1.79 | 1.97 | 1.77 | 2.07 | 1.84 | 1.99 | 1.78 |

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

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: | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 |
| Potassium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 1.68 | 1.83 | 1.66 | 1.76 | 1.65 | 1.82 | 1.67 | 1.74 | 1.64 | 1.81 | 1.67 | 1.82 | 1.65 | 1.81 | 1.68 | 1.78 | 1.68 | 1.68 | 1.71 | 1.68 | 1.72 | 1.69 |
| May | 1.74 | 1.63 | 1.72 | 1.60 | 1.72 | 1.60 | 1.75 | 1.65 | 1.74 | 1.61 | 1.74 | 1.58 | 1.75 | 1.64 | 1.74 | 1.64 | 1.71 | 1.63 | 1.72 | 1.52 | 1.70 | 1.62 |
| Aug | 1.91 | 1.64 | 1.88 | 1.68 | 1.87 | 1.67 | 1.87 | 1.71 | 1.85 | 1.60 | 1.88 | 1.67 | 1.90 | 1.72 | 1.86 | 1.65 | 1.88 | 1.79 | 1.87 | 1.63 | 1.86 | 1.66 |
| Nov | 1.81 | 1.71 | 1.82 | 1.78 | 1.81 | 1.74 | 1.82 | 1.67 | 1.83 | 1.73 | 1.83 | 1.72 | 1.84 | 1.73 | 1.83 | 1.72 | 1.83 | 1.74 | 1.85 | 1.74 | 1.83 | 1.74 |
| Annual Mean | 1.79 | 1.70 | 1.77 | 1.71 | 1.76 | 1.71 | 1.78 | 1.69 | 1.77 | 1.69 | 1.78 | 1.70 | 1.79 | 1.73 | 1.78 | 1.70 | 1.78 | 1.71 | 1.79 | 1.64 | 1.78 | 1.68 |
| Sodium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 4.09 | 4.03 | 4.10 | 3.85 | 4.01 | 4.02 | 4.15 | 3.81 | 4.03 | 3.99 | 4.08 | 4.02 | 4.08 | 3.97 | 4.09 | 3.91 | 4.21 | 3.63 | 4.44 | 3.34 | 4.41 | 3.46 |
| May | 4.50 | 3.64 | 4.44 | 3.48 | 4.40 | 3.63 | 4.50 | 3.56 | 4.46 | 3.69 | 4.46 | 3.59 | 4.45 | 3.56 | 4.47 | 3.68 | 4.49 | 3.63 | 4.50 | 3.75 | 4.47 | 3.61 |
| Aug | 4.97 | 3.90 | 4.85 | 3.75 | 4.84 | 3.95 | 4.84 | 3.78 | 4.84 | 3.80 | 4.87 | 3.94 | 4.83 | 3.79 | 4.87 | 3.89 | 4.88 | 4.03 | 4.82 | 3.96 | 4.88 | 3.74 |
| Nov | 4.54 | 4.03 | 4.59 | 3.79 | 4.58 | 4.06 | 4.61 | 3.53 | 4.60 | 4.04 | 4.62 | 4.03 | 4.60 | 4.07 | 4.59 | 4.06 | 4.55 | 4.08 | 4.72 | 4.16 | 4.63 | 4.18 |
| Annual Mean | 4.53 | 3.90 | 4.50 | 3.72 | 4.46 | 3.92 | 4.53 | 3.67 | 4.48 | 3.88 | 4.51 | 3.90 | 4.49 | 3.85 | 4.51 | 3.89 | 4.53 | 3.84 | 4.62 | 3.80 | 4.60 | 3.75 |
| Aluminum (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 0.039 | 0.047 | 0.048 | 0.070 | 0.040 | 0.053 | 0.064 | 0.075 | 0.042 | 0.050 | 0.045 | 0.0303 | 0.049 | 0.055 | 0.039 | 0.058 | 0.056 | 0.110 | 0.061 | 0.214 | 0.061 | 0.183 |
| May | 0.046 | 0.064 | 0.062 | 0.097 | 0.027 | 0.058 | 0.056 | 0.091 | 0.035 | 0.122 | 0.032 | 0.076 | 0.050 | 0.135 | 0.030 | 0.047 | 0.058 | 0.089 | 0.031 | 0.057 | 0.073 | 0.112 |
| Aug | 0.021 | 0.020 | 0.009 | 0.048 | 0.019 | 0.022 | 0.010 | 0.053 | 0.031 | 0.021 | 0.020 | 0.025 | 0.044 | 0.033 | 0.017 | 0.020 | 0.012 | 0.026 | 0.019 | 0.020 | 0.009 | 0.031 |
| Nov | 0.044 | 0.057 | 0.078 | 0.013 | 0.055 | 0.054 | 0.079 | 0.013 | 0.051 | 0.057 | 0.059 | 0.055 | 0.077 | 0.142 | 0.039 | 0.064 | 0.105 | 0.081 | 0.069 | 0.065 | 0.097 | 0.086 |
| Annual Mean | 0.038 | 0.047 | 0.049 | 0.057 | 0.035 | 0.047 | 0.052 | 0.058 | 0.040 | 0.062 | 0.039 | 0.046 | 0.055 | 0.091 | 0.031 | 0.047 | 0.058 | 0.077 | 0.045 | 0.089 | 0.060 | 0.103 |
| Iron (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 0.045 | 0.107 | 0.093 | 0.237 | 0.053 | 0.113 | 0.121 | 0.236 | 0.062 | 0.124 | 0.058 | 0.024 | 0.092 | 0.156 | 0.047 | 0.172 | 0.095 | 0.504 | 0.092 | 1.170 | 0.111 | 0.942 |
| May | 0.050 | 0.094 | 0.116 | 0.411 | 0.046 | 0.107 | 0.115 | 0.432 | 0.049 | 0.134 | 0.041 | 0.110 | 0.071 | 0.407 | 0.040 | 0.064 | 0.150 | 0.225 | 0.054 | 0.053 | 0.162 | 0.423 |
| Aug | 0.022 | 0.027 | 0.046 | 0.061 | 0.020 | 0.029 | 0.039 | 0.067 | 0.107 | 0.029 | 0.023 | 0.035 | 0.124 | 0.542 | 0.020 | 0.033 | 0.066 | 0.088 | 0.063 | 0.044 | 0.029 | 0.055 |
| Nov | 0.062 | 0.079 | 0.150 | 1.970 | 0.076 | 0.090 | 0.200 | 3.500 | 0.096 | 0.115 | 0.082 | 0.079 | 0.106 | 0.260 | 0.061 | 0.093 | 0.446 | 0.381 | 0.103 | 0.099 | 0.245 | 0.280 |
| Annual Mean | 0.045 | 0.077 | 0.101 | 0.670 | 0.049 | 0.085 | 0.119 | 1.059 | 0.078 | 0.100 | 0.051 | 0.062 | 0.098 | 0.341 | 0.042 | 0.090 | 0.189 | 0.300 | 0.078 | 0.342 | 0.137 | 0.425 |
| Manganese (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 10 | 13 | 21 | 23 | 11 | 14 | 26 | 23 | 12 | 15 | 12 | 1 | 20 | 22 | 9 | 16 | 17 | 30 | 24 | 55 | 23 | 47 |
| May | 7 | 6 | 48 | 25 | 7 | 6 | 52 | 29 | 7 | 7 | 7 | 7 | 30 | 27 | 6 | 4 | 42 | 12 | 8 | 6 | 42 | 32 |
| Aug | 32 | 25 | 1340 | 631 | 31 | 25 | 1110 | 974 | 223 | 42 | 36 | 34 | 1800 | 2030 | 15 | 21 | 2040 | 400 | 179 | 34 | 489 | 909 |
| Nov | 28 | 101 | 46 | 5300 | 36 | 120 | 46 | 5280 | 42 | 177 | 37 | 110 | 47 | 800 | 26 | 82 | 61 | 408 | 45 | 82 | 114 | 104 |
| Annual Mean | 19 | 36 | 364 | 1495 | 21 | 42 | 309 | 1576 | 71 | 60 | 23 | 38 | 474 | 720 | 14 | 31 | 540 | 212 | 64 | 44 | 167 | 273 |
| Cadmium (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 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 |
| May | 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 |
| Aug | 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 |
| 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 | 1.0 | 1.0 | 1.0 | 1.0 | 1 | 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 |
| Copper (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 1.6 | 1.8 | 1.8 | 2.1 | 1.6 | 2.0 | 1.7 | 1.9 | 1.6 | 1.9 | 1.4 | 1.8 | 1.5 | 2.0 | 2.0 | 1.8 | 1.6 | 1.9 | 2.2 | 2.2 | 2.3 | 1.9 |
| May | 1.6 | 2.6 | 2.8 | 1.9 | 1.6 | 1.7 | 1.5 | 1.8 | 1.6 | 1.7 | 1.5 | 1.7 | 1.3 | 1.8 | 1.4 | 1.7 | 1.6 | 1.7 | 1.8 | 1.8 | 1.7 | 1.9 |
| Aug | 1.6 | 1.2 | 1.4 | 1.2 | 1.4 | 1.2 | 1.5 | 1.3 | 2.4 | 1.3 | 1.4 | 1.3 | 1.3 | 1.1 | 1.4 | 1.0 | 1.3 | 1.1 | 1.9 | 1.2 | 1.3 | 1.1 |
| Nov | 1.0 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.7 | 1.0 | 1.6 | 1.1 | 1.5 | 1.5 |
| Annual Mean | 1.5 | 1.9 | 1.8 | 1.6 | 1.4 | 1.5 | 1.4 | 1.5 | 1.7 | 1.5 | 1.3 | 1.5 | 1.3 | 1.5 | 1.4 | 1.4 | 1.5 | 1.4 | 1.9 | 1.6 | 1.7 | 1.6 |
| Lead (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 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 |
| May | 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 |
| Aug | 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 |
| 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 | 1.0 | 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 |

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

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: | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 | 2011 | 2010 |
| Zinc (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 2.0 | 2.4 | 2.5 | 3.0 | 2.0 | 3.0 | 2.0 | 2.5 | 2.0 | 2.5 | 2.0 | 2.2 | 2.0 | 2.3 | 3.7 | 3.1 | 2.0 | 2.7 | 2.0 | 3.8 | 2.0 | 3.8 |
| May | 2.8 | 2.6 | 2.9 | 2.5 | 2.0 | 2.0 | 2.0 | 2.2 | 2.0 | 2.0 | 2.0 | 2.0 | 2.6 | 2.5 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.7 | 2.3 |
| Aug | 2.0 | 2.0 | 2.2 | 2.1 | 2.0 | 2.0 | 2.0 | 2.1 | 2.6 | 2.6 | 2.0 | 2.0 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.8 | 2.0 | 2.1 |
| Nov | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.9 | 2.3 | 2.0 | 2.0 | 2.8 | 2.0 | 2.0 | 2.0 | 2.1 | 5.1 |
| Annual Mean | 2.2 | 2.2 | 2.4 | 2.4 | 2.0 | 2.3 | 2.0 | 2.2 | 2.2 | 2.3 | 2.0 | 2.1 | 2.6 | 2.3 | 2.4 | 2.3 | 2.2 | 2.2 | 2.0 | 2.7 | 2.2 | 3.3 |
| Nitrite-Nitrate (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 180 | 250 | 180 | 290 | 170 | 260 | 190 | 290 | 180 | 290 | 180 | 250 | 180 | 270 | 170 | 270 | 190 | 330 | 240 | 370 | 240 | 360 |
| May | 220 | 300 | 280 | 380 | 220 | 310 | 280 | 390 | 230 | 310 | 220 | 330 | 250 | 380 | 220 | 270 | 300 | 340 | 240 | 280 | 300 | 410 |
| Aug | 76 | 110 | 280 | 390 | 81 | 110 | 270 | 380 | 100 | 120 | 93 | 120 | 220 | 140 | 34 | 81 | 230 | 200 | 76 | 55 | 290 | 360 |
| Nov | 60 | 73 | 60 | 11 | 61 | 70 | 63 | 13 | 61 | 70 | 60 | 68 | 63 | 63 | 60 | 71 | 71 | 64 | 120 | 100 | 120 | 100 |
| Annual Mean | 134 | 183 | 200 | 268 | 133 | 188 | 201 | 268 | 143 | 198 | 138 | 192 | 178 | 213 | 121 | 173 | 198 | 234 | 169 | 201 | 238 | 308 |
| Ammonia (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 21 | 32 | 48 | 56 | 33 | 52 | 44 | 48 | 28 | 43 | 26 | 40 | 37 | 56 | 27 | 43 | 46 | 61 | 36 | 80 | 36 | 78 |
| May | 72 | 33 | 75 | 34 | 100 | 43 | 160 | 41 | 76 | 36 | 95 | 43 | 96 | 32 | 62 | 33 | 87 | 36 | 66 | 29 | 110 | 33 |
| Aug | 130 | 27 | 140 | 27 | 240 | 26 | 270 | 29 | 140 | 28 | 240 | 25 | 290 | 85 | 150 | 26 | 220 | 63 | 20 | 44 | 180 | 33 |
| Nov | 180 | 110 | 180 | 510 | 230 | 120 | 230 | 530 | 180 | 150 | 170 | 100 | 210 | 210 | 180 | 110 | 140 | 130 | 190 | 98 | 180 | 110 |
| Annual Mean | 101 | 51 | 111 | 157 | 151 | 60 | 176 | 162 | 106 | 64 | 133 | 52 | 158 | 96 | 105 | 53 | 123 | 73 | 34 | 63 | 127 | 64 |
| Total Phosphorous (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 7 | 12 | 8 | 15 | 7 | 12 | 9 | 15 | 7 | 12 | 9 | 12 | 8 | 11 | 7 | 14 | 9 | 23 | 10 | 48 | 10 | 38 |
| May | 7 | 9 | 8 | 15 | 6 | 12 | 8 | 12 | 18 | 14 | 9 | 10 | 7 | 13 | 6 | 8 | 9 | 13 | 8 | 9 | 8 | 15 |
| Aug | 8 | 9 | 8 | 6 | 6 | 8 | 6 | 7 | 9 | 8 | 6 | 12 | 6 | 7 | 6 | 8 | 6 | 7 | 8 | 9 | 6 | 6 |
| Nov | 5 | 7 | 5 | 9 | 5 | 8 | 6 | 12 | 7 | 9 | 6 | 7 | 6 | 14 | 5 | 7 | 11 | 10 | 9 | 11 | 7 | 15 |
| Annual Mean | 7 | 9 | 7 | 11 | 6 | 10 | 7 | 12 | 10 | 11 | 7 | 10 | 7 | 11 | 6 | 9 | 9 | 13 | 9 | 19 | 8 | 19 |
| Orthophosphate (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 7 | 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 | 5 | 5 | 5 | 5 | 5 | 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 | 5.0 | 4.6 | 4.7 | 4.5 | 4.8 | 4.6 | 4.8 | 4.6 | 4.9 | 4.6 | 4.7 | 4.6 | 4.7 | 4.6 | 4.7 | 4.5 | 4.7 | 4.4 | 4.6 | 4.3 | 4.6 | 4.4 |
| May | 4.6 | 4.1 | 5.1 | 4.4 | 4.7 | 4.1 | 5.0 | 4.4 | 4.7 | 4.1 | 4.9 | 4.0 | 5.0 | 4.4 | 4.8 | 4.0 | 5.1 | 4.2 | 4.6 | 4.1 | 5.1 | 4.5 |
| Aug | 4.6 | 4.0 | 5.3 | 4.8 | 4.4 | 4.0 | 5.2 | 4.8 | 4.4 | 4.0 | 4.5 | 4.1 | 5.1 | 5.0 | 4.4 | 4.0 | 5.3 | 4.4 | 4.6 | 3.8 | 5.1 | 4.9 |
| Nov | 4.7 | 4.3 | 4.8 | 4.8 | 4.8 | 4.4 | 4.8 | 5.0 | 4.8 | 4.4 | 4.8 | 4.4 | 4.9 | 4.9 | 4.8 | 4.4 | 4.8 | 4.5 | 4.8 | 4.6 | 4.9 | 4.5 |
| Annual Mean | 4.7 | 4.3 | 5.0 | 4.6 | 4.7 | 4.3 | 4.9 | 4.7 | 4.7 | 4.3 | 4.7 | 4.3 | 4.9 | 4.7 | 4.7 | 4.2 | 5.0 | 4.4 | 4.6 | 4.2 | 4.9 | 4.6 |

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

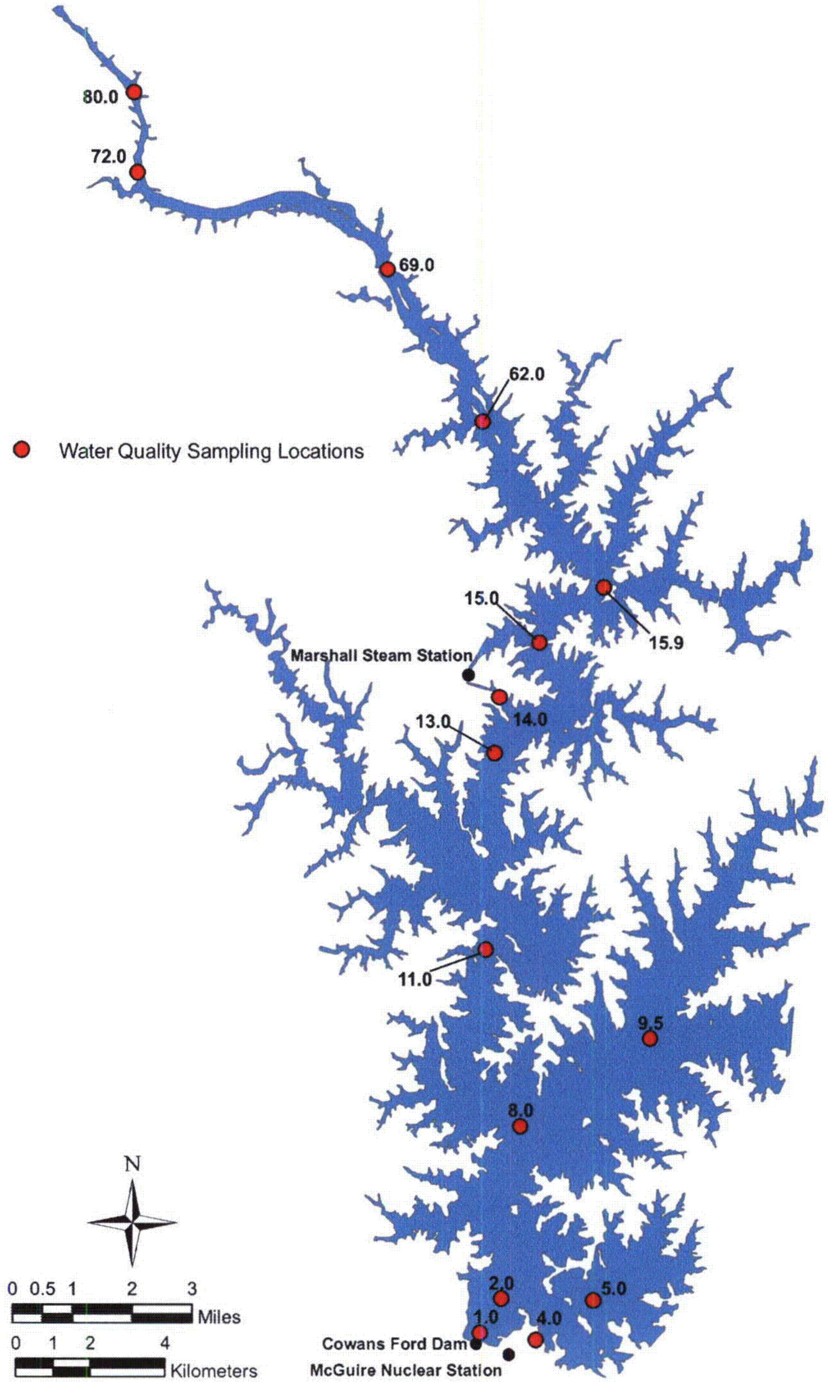



Figure 2-1. Water quality sampling locations (numbered) for Lake Norman. Approximate locations of MSS and MNS are also shown.

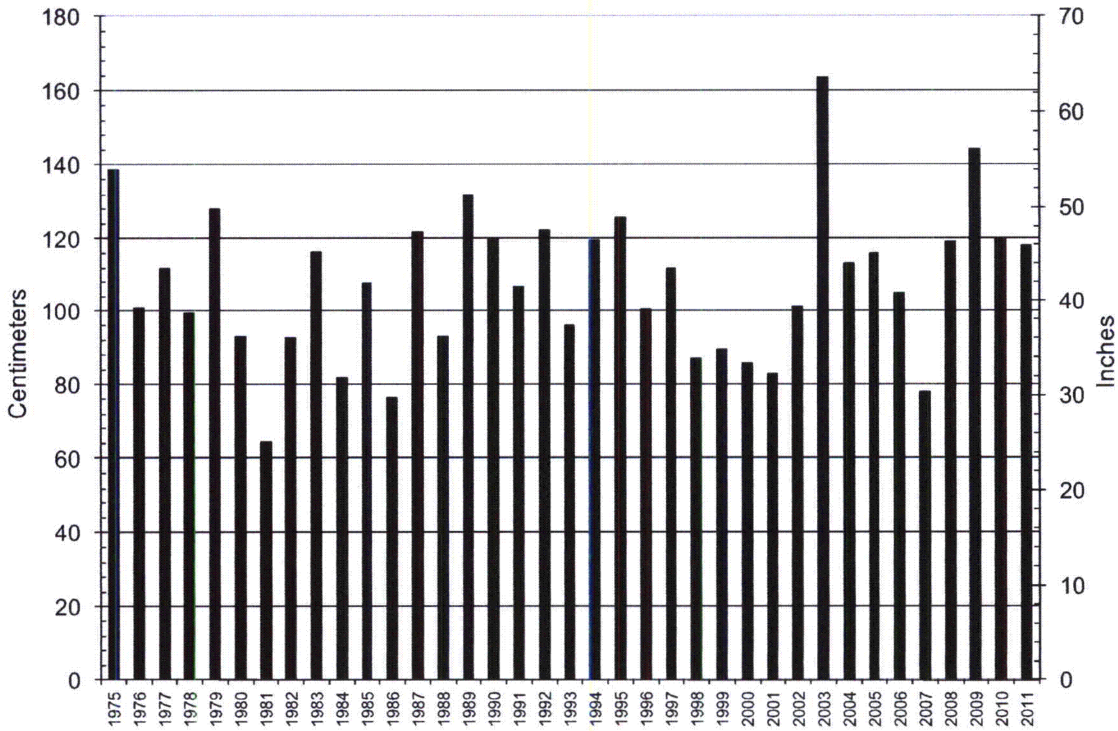



Figure 2-2a. Annual precipitation totals in the vicinity of MNS.

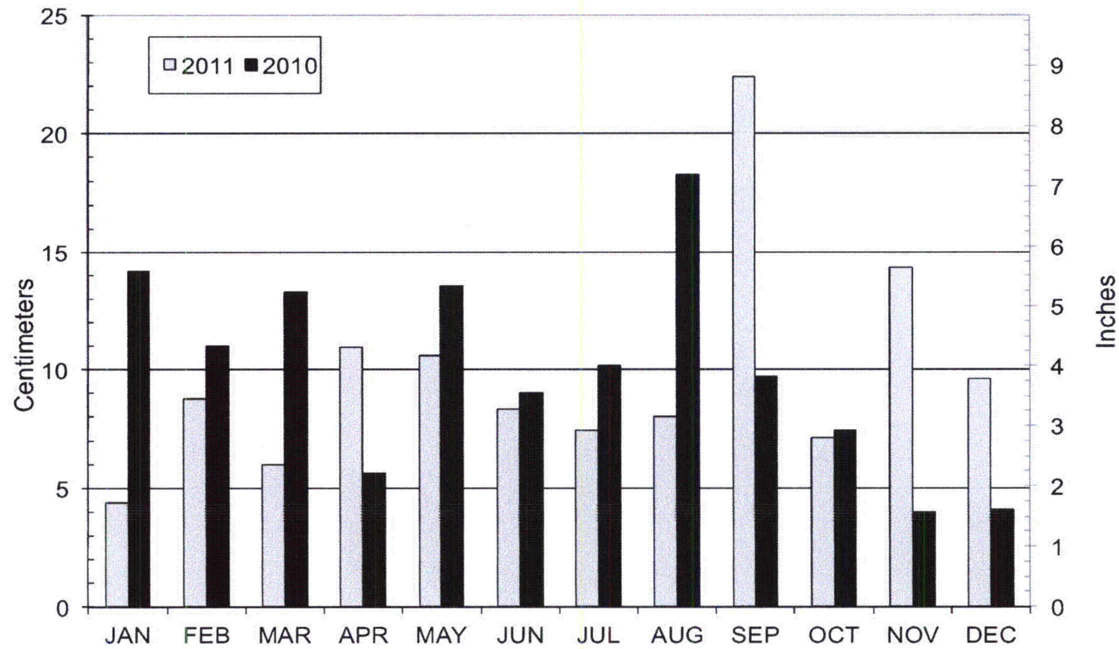



Figure 2-2b. Monthly precipitation totals in the vicinity of MNS in 2010 and 2011.

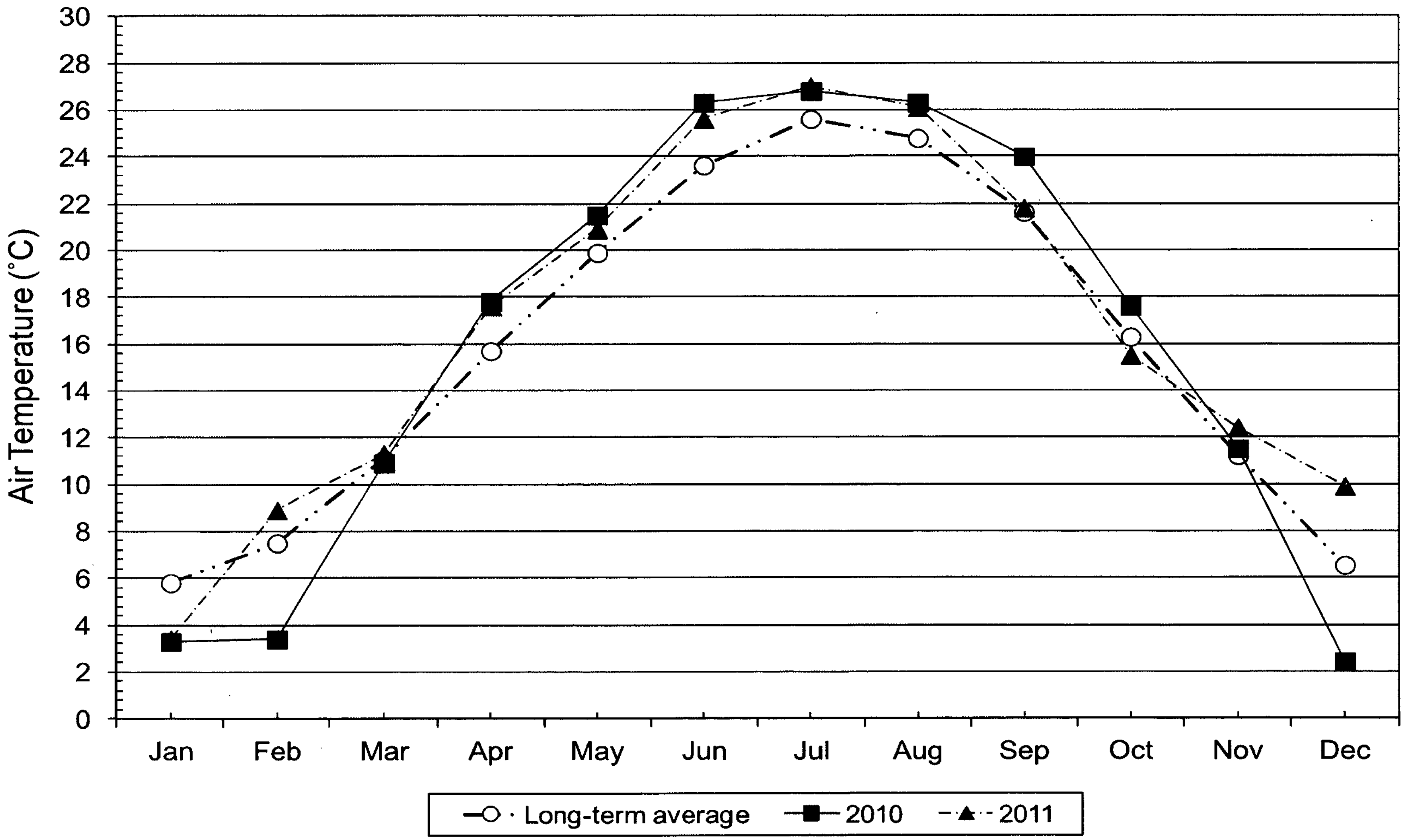



Figure 2-2c. Mean monthly air temperatures recorded at MNS beginning in 1989. Data were compiled from average daily temperatures which, in turn, were created from hourly measurements.

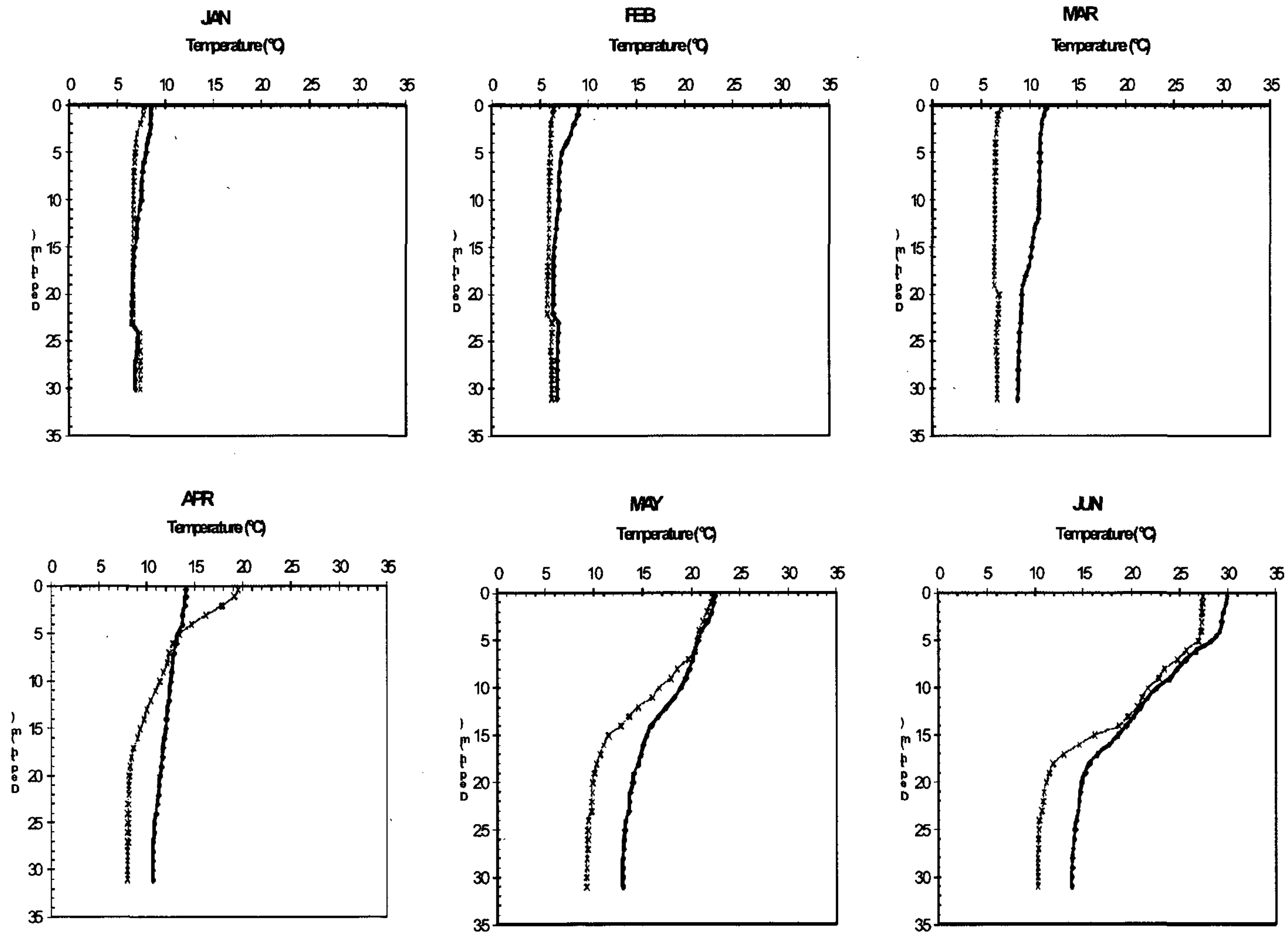



Figure 2-3. Monthly mean temperature profiles for the McGuire Nuclear Station background zone in 2010 (××) and 2011 (♦♦).

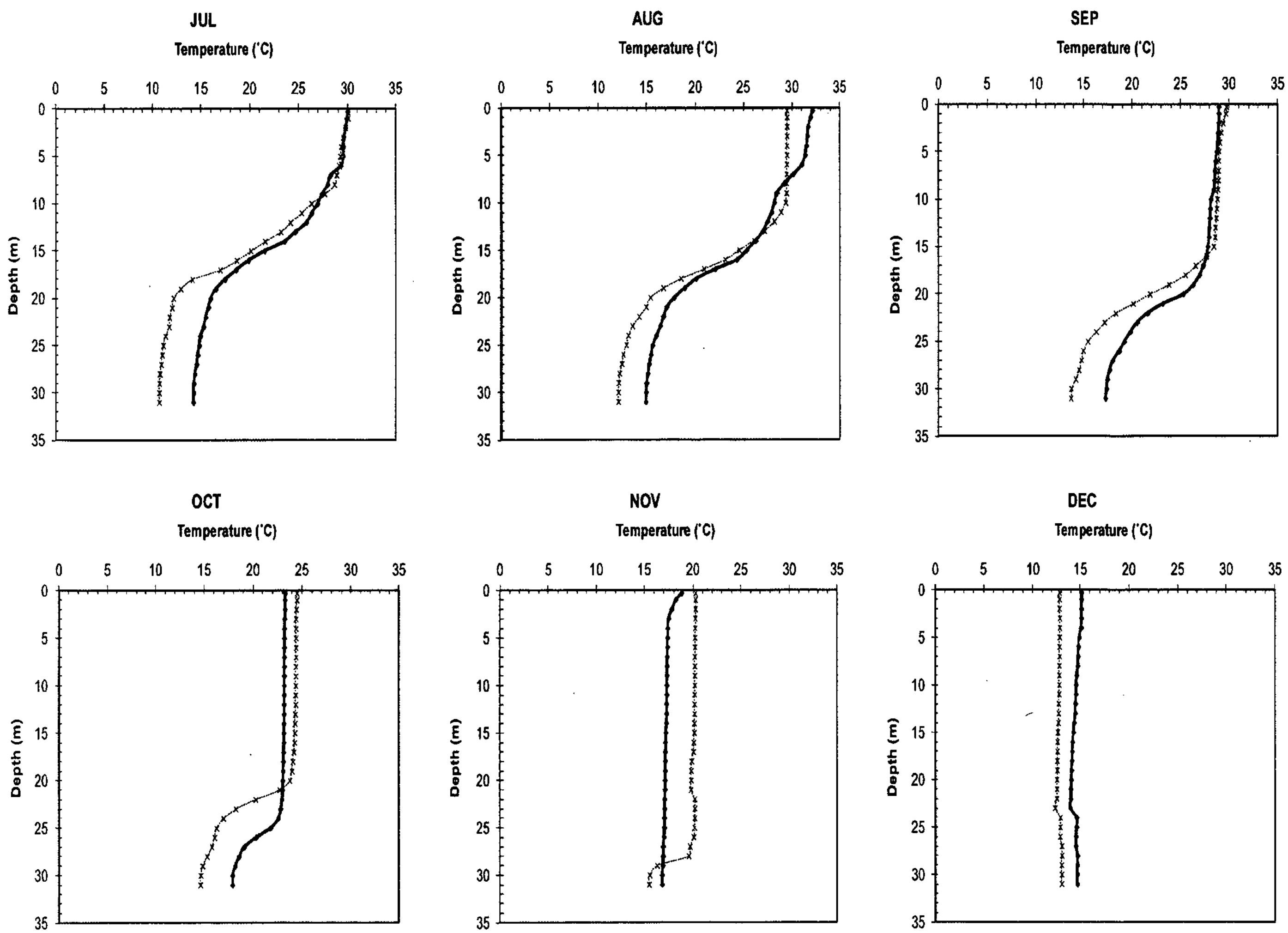



Figure 2-3. (Continued).

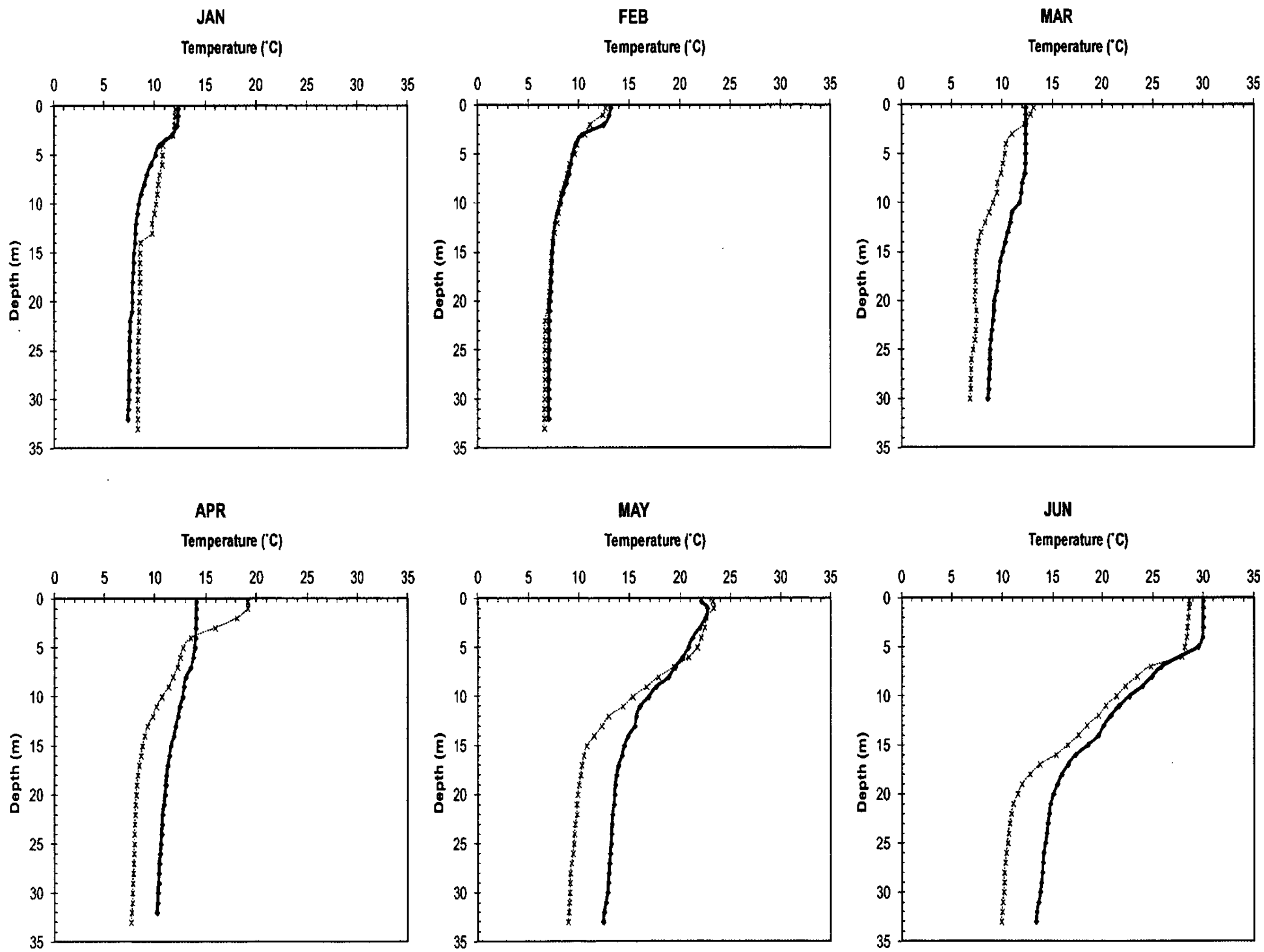



Figure 2-4. Monthly mean temperature profiles for the MNS mixing zone in 2010 (××) and 2011 (♦♦).

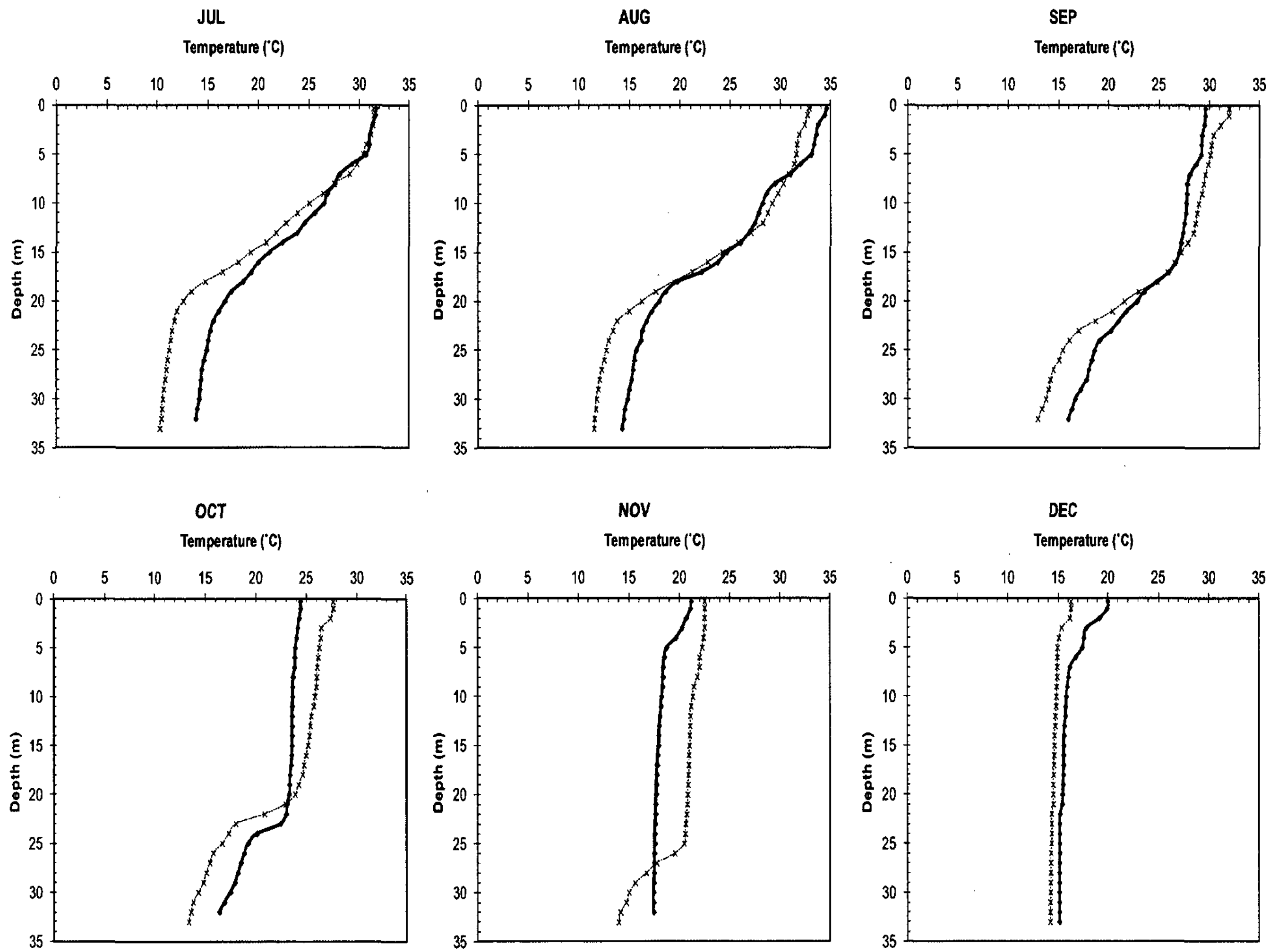



Figure 2-4. (Continued).

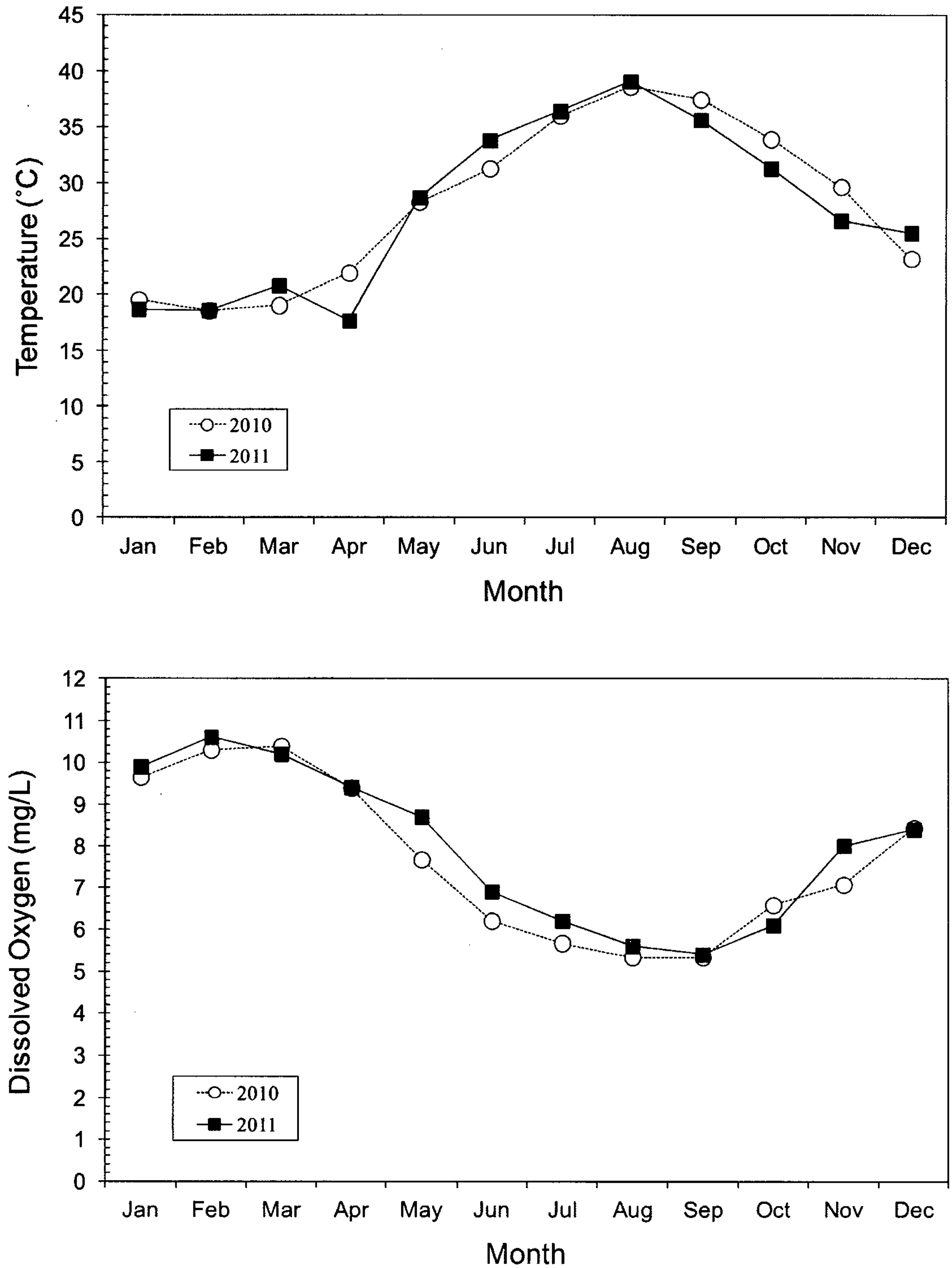



Figure 2-5. Monthly surface (0.3m) temperature and dissolved oxygen data at the discharge location (Location 4.0) in 2010 and 2011.

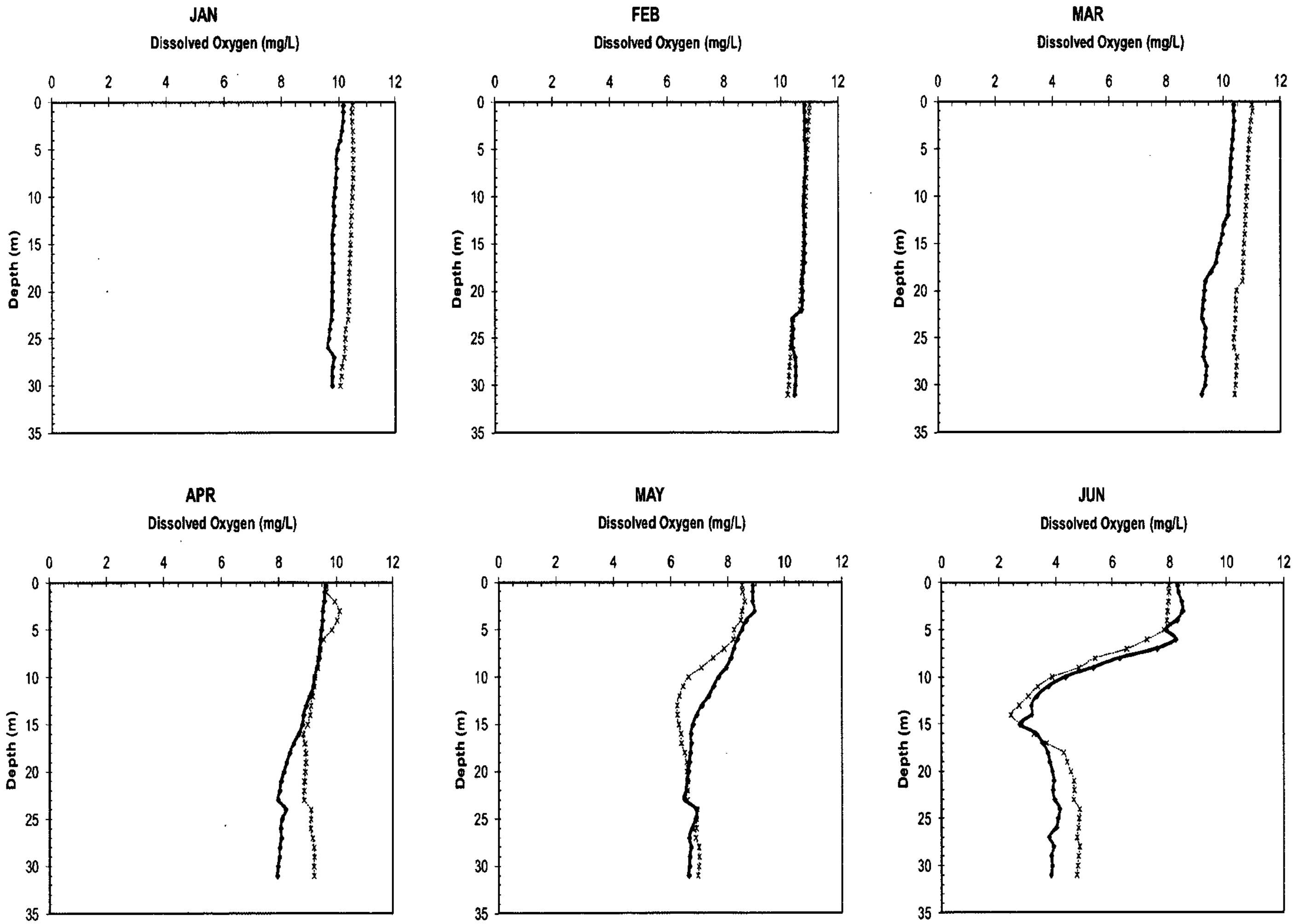



Figure 2-6. Monthly mean dissolved oxygen profiles for the MNS background zone in 2010 (××) and 2011 (♦♦).

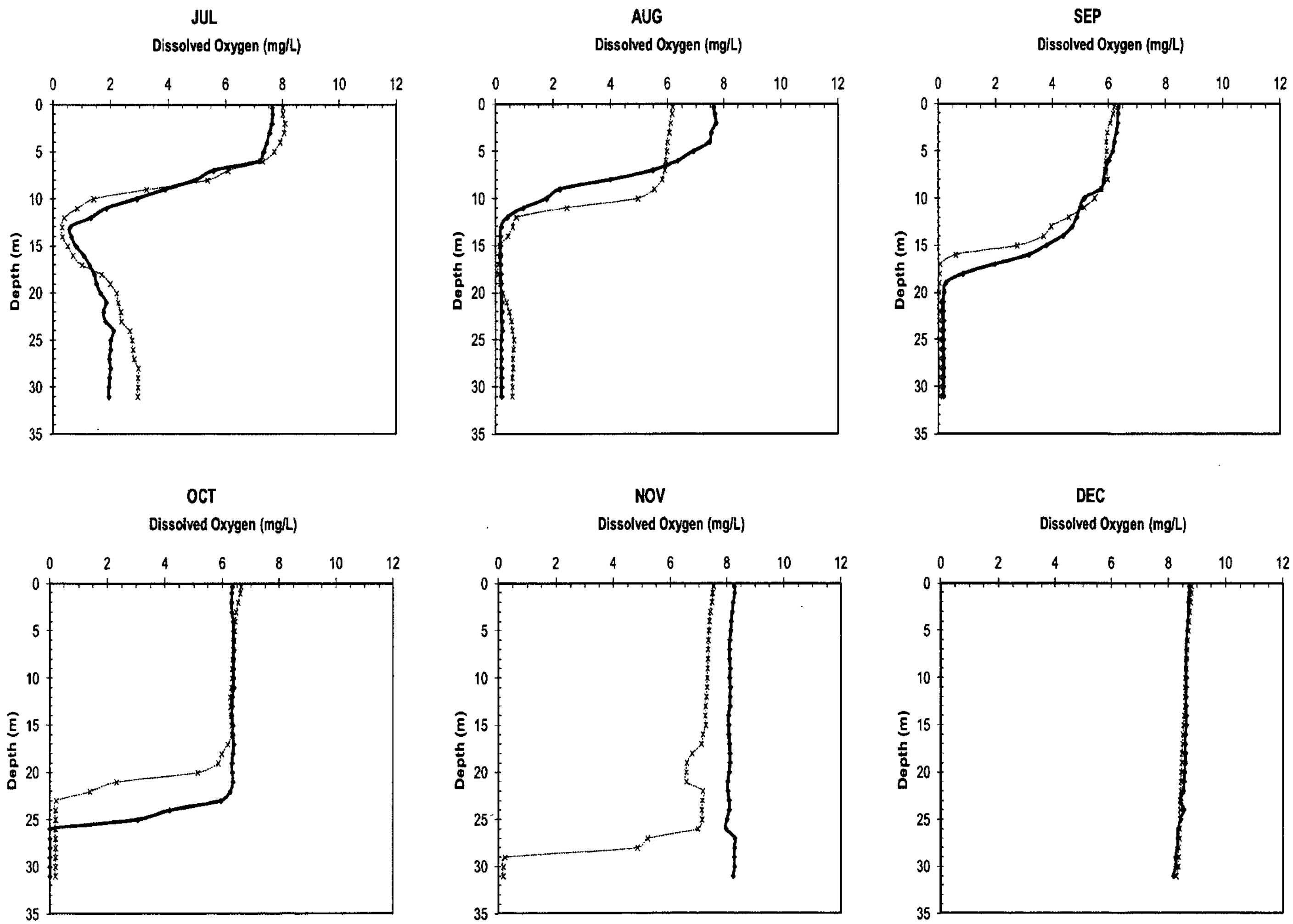



Figure 2-6. (Continued).

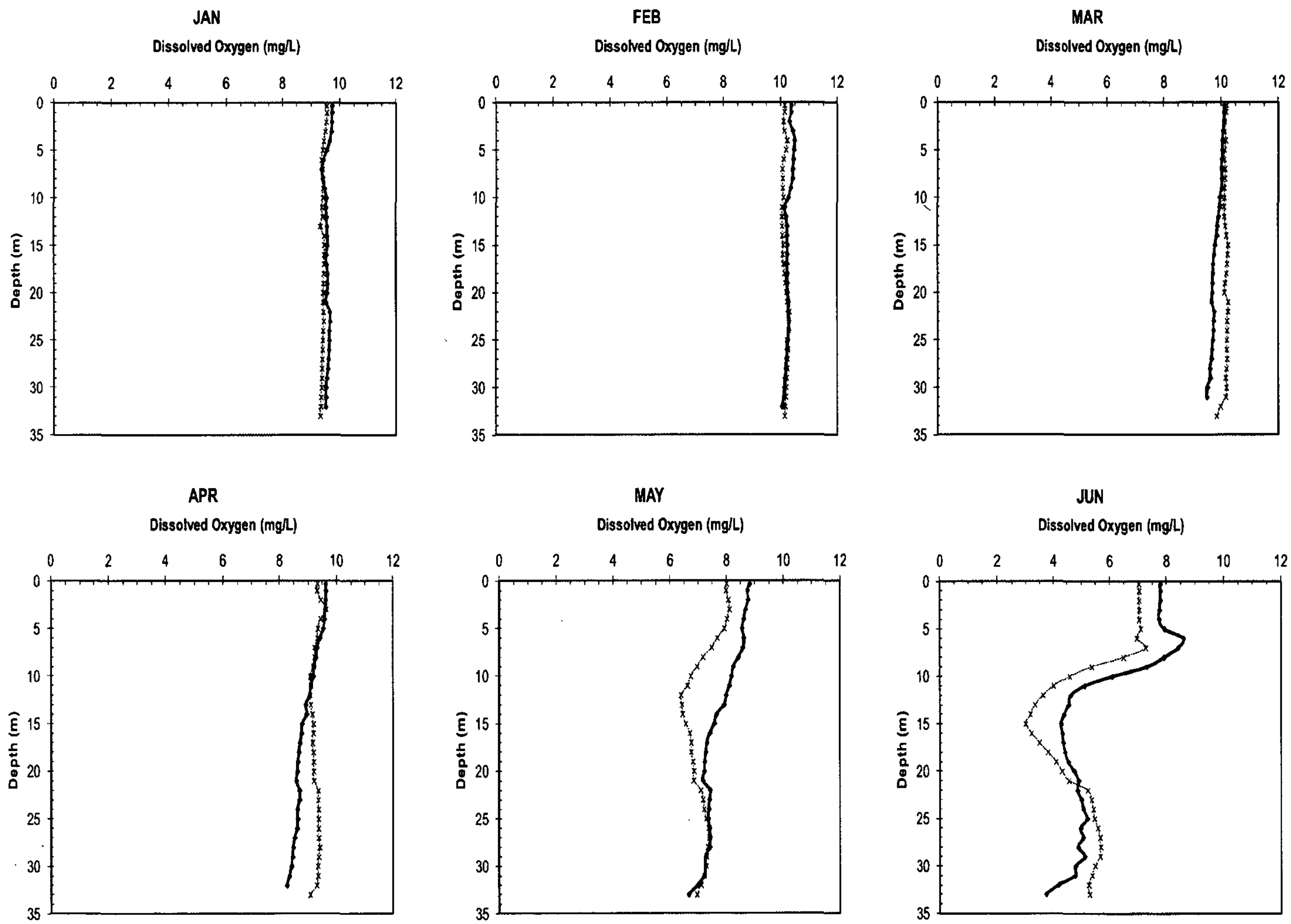



Figure 2-7. Monthly mean dissolved oxygen profiles for the MNS mixing zone in 2010 (××) and 2011 (♦♦).

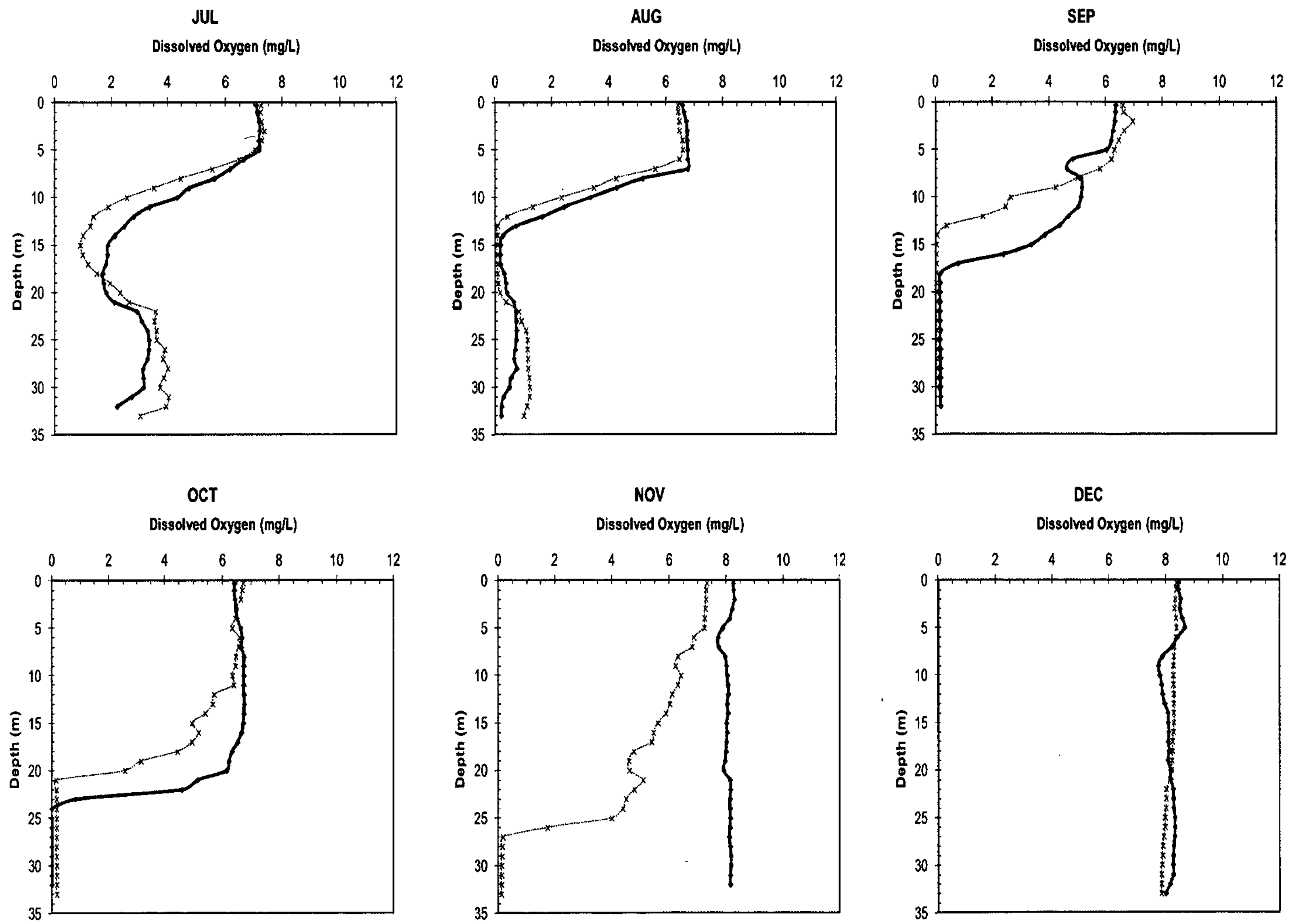



Figure 2-7. (Continued).

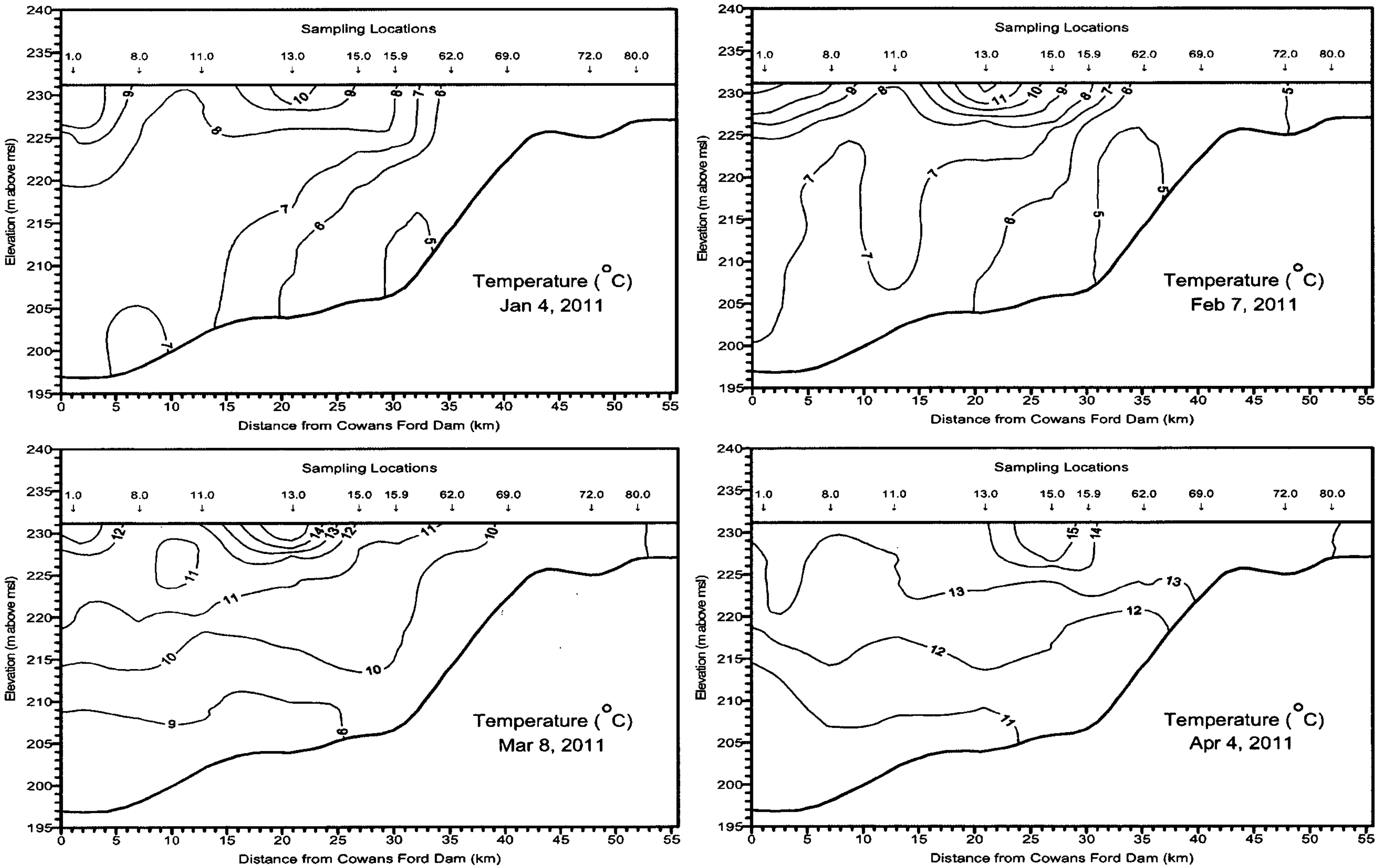



Figure 2-8. Monthly reservoir-wide temperature isotherms for Lake Norman in 2011.

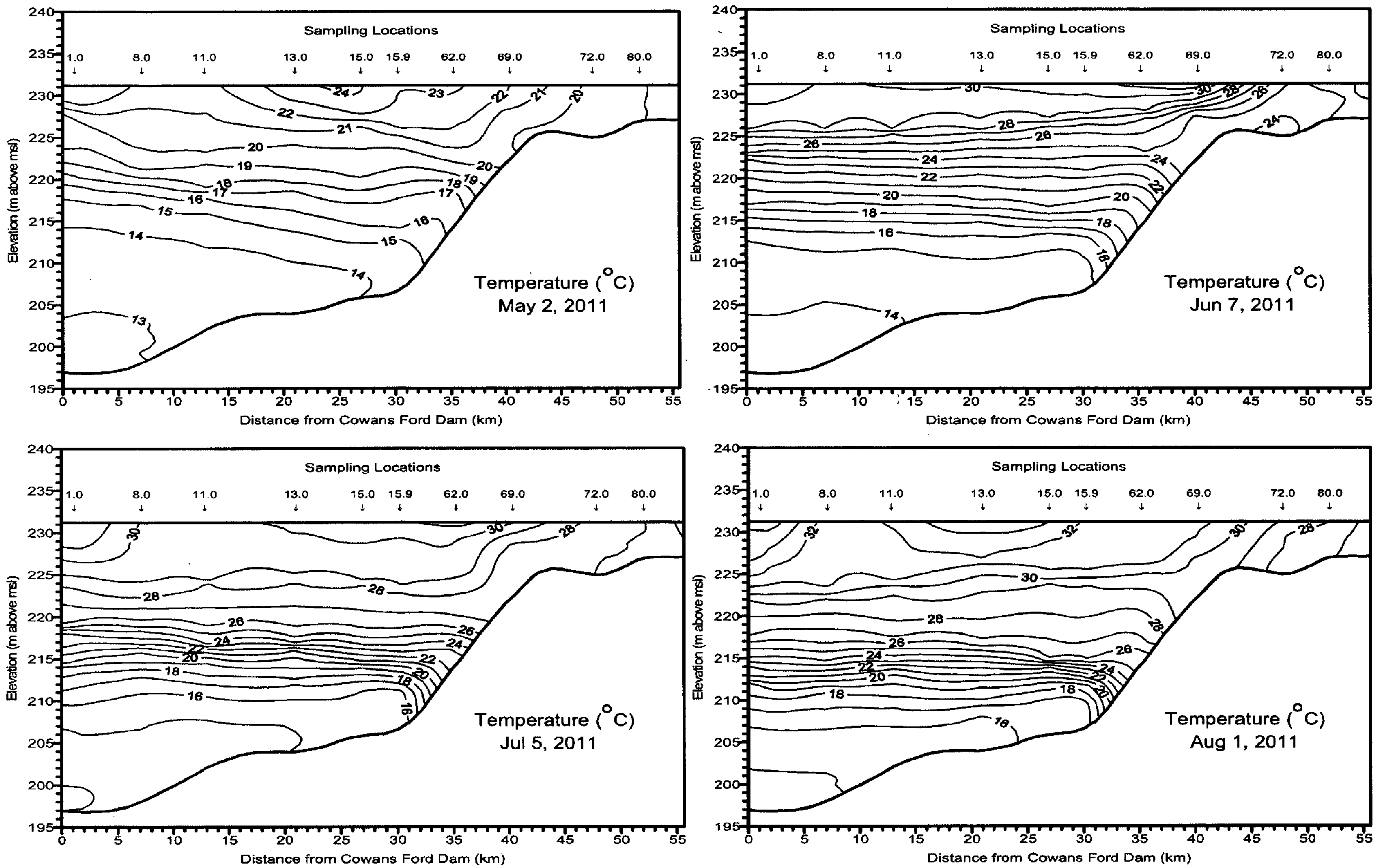



Figure 2-8. (Continued).

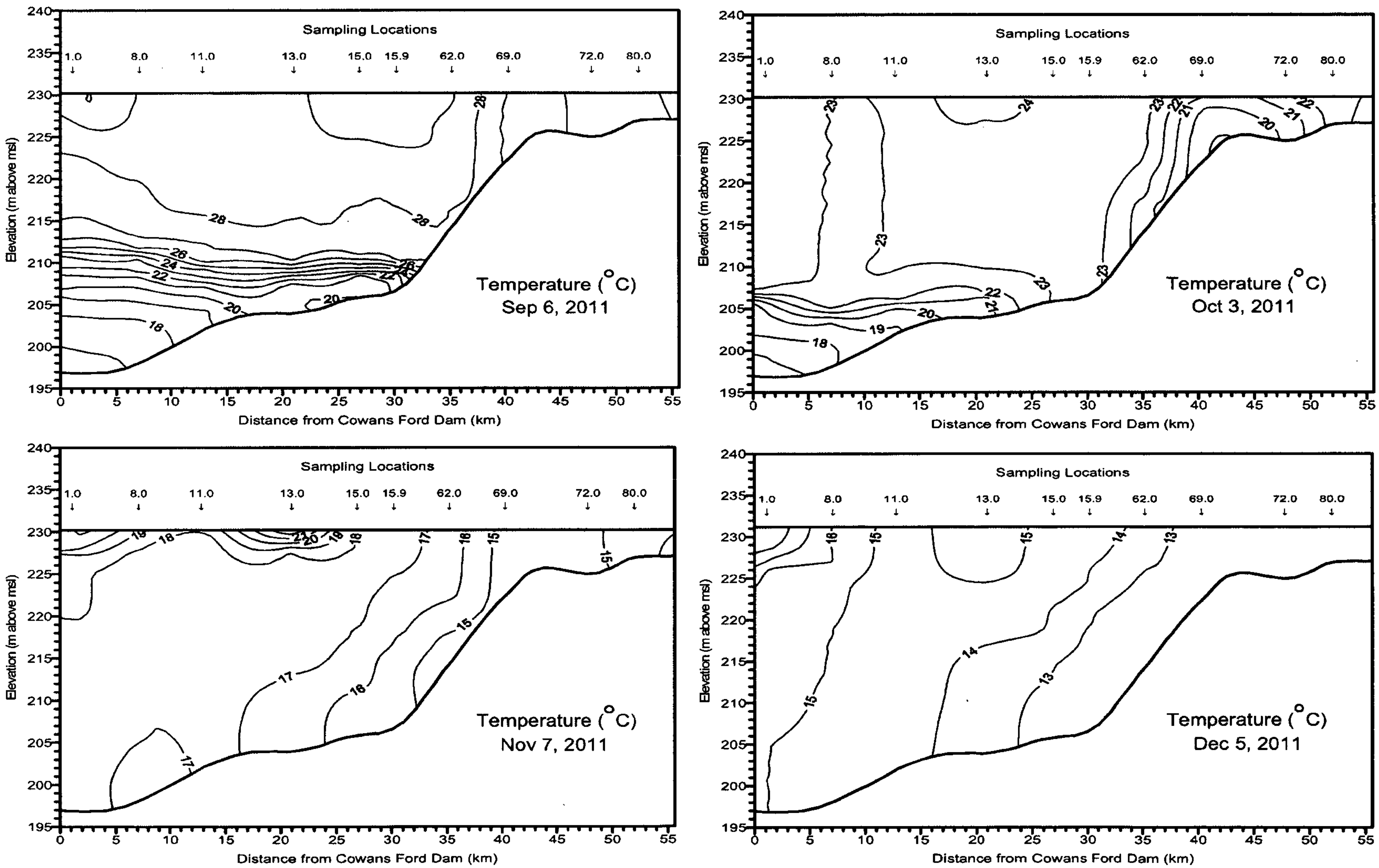



Figure 2-8. (Continued).

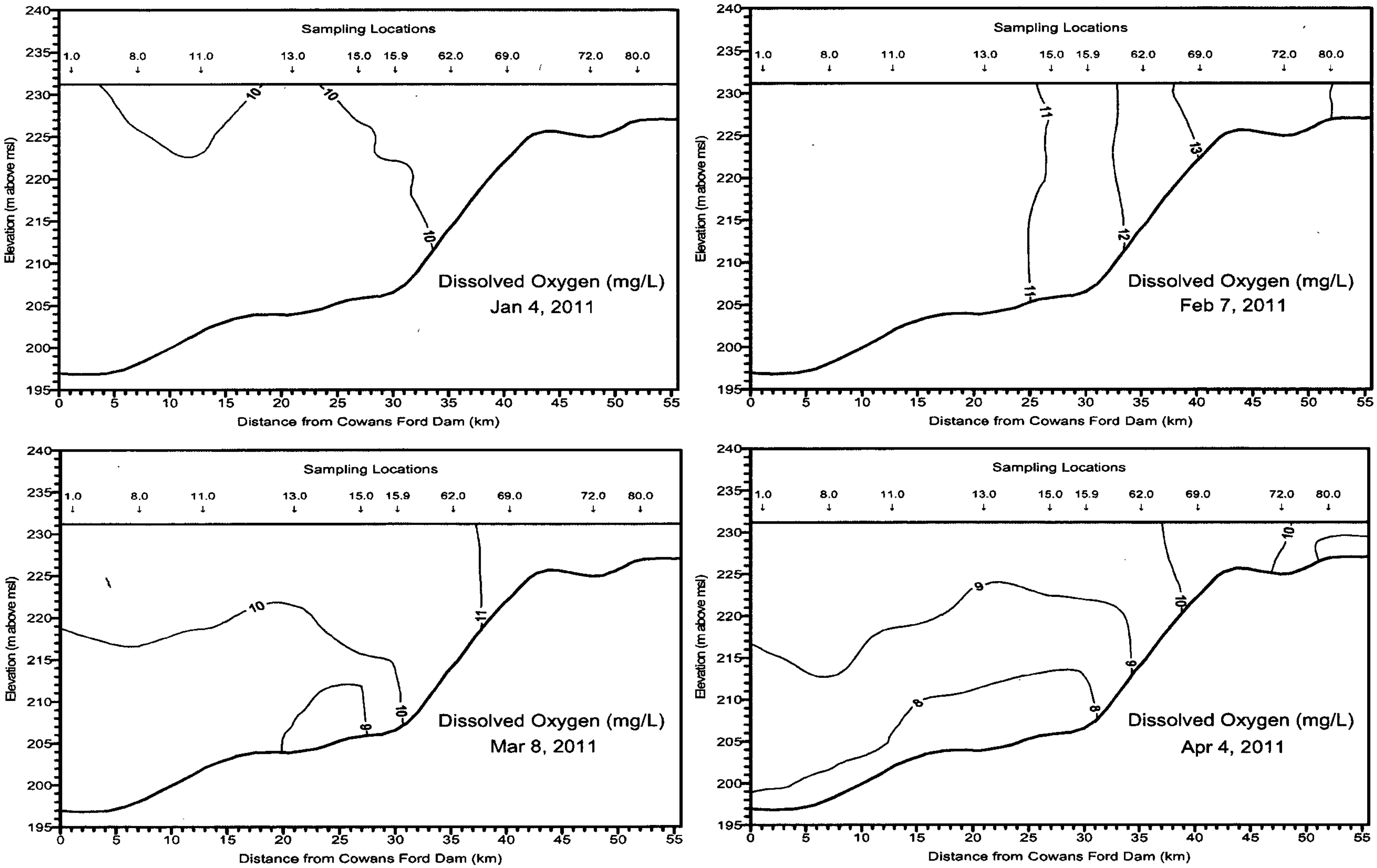



Figure 2-9. Monthly reservoir-wide dissolved oxygen isopleths for Lake Norman in 2011.

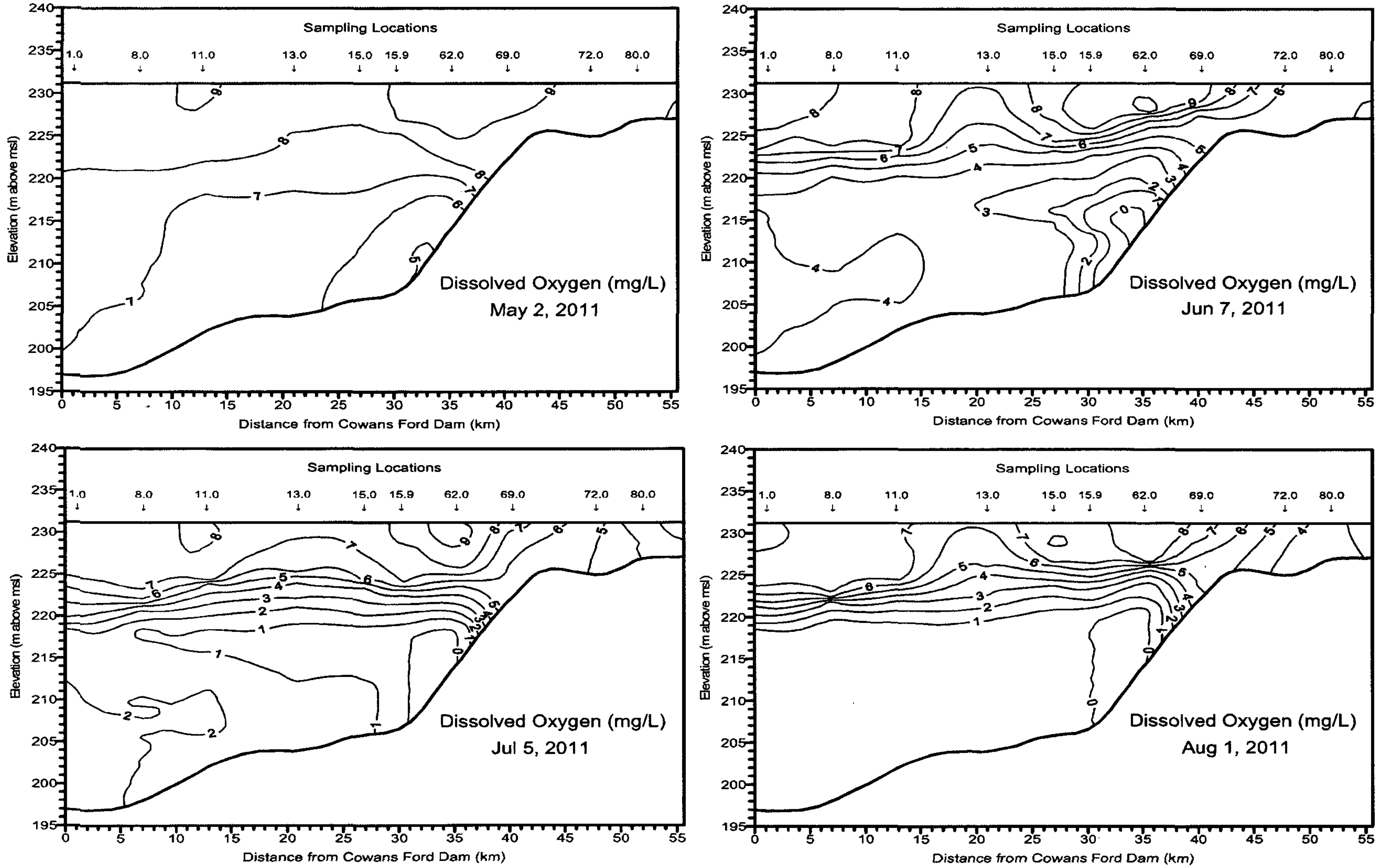



Figure 2-9. (Continued).

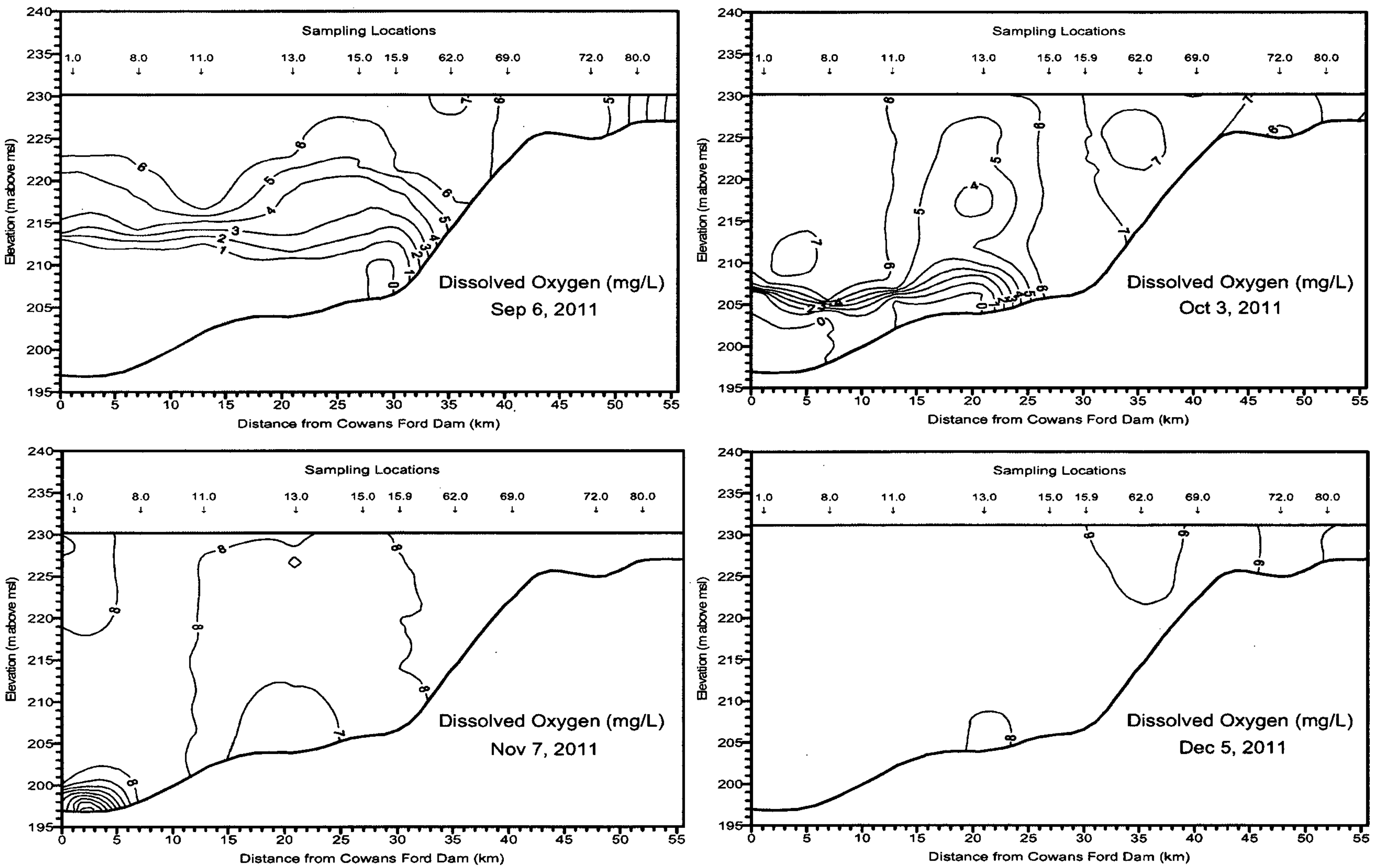



Figure 2-9. (Continued).

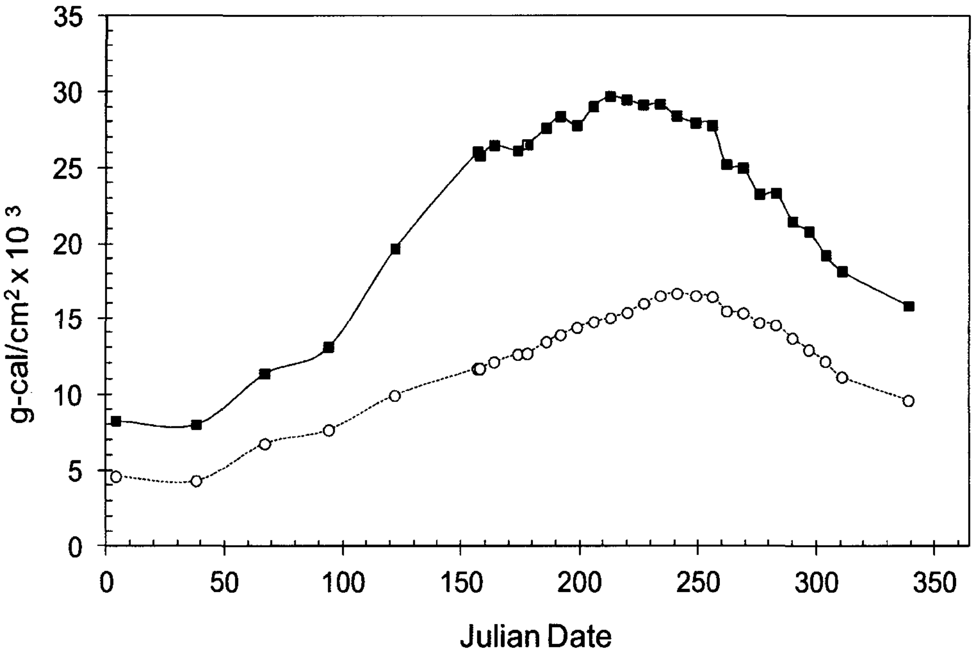



Figure 2-10a. Heat content of the entire water column (■) and the hypolimnion (○) in Lake Norman in 2011.

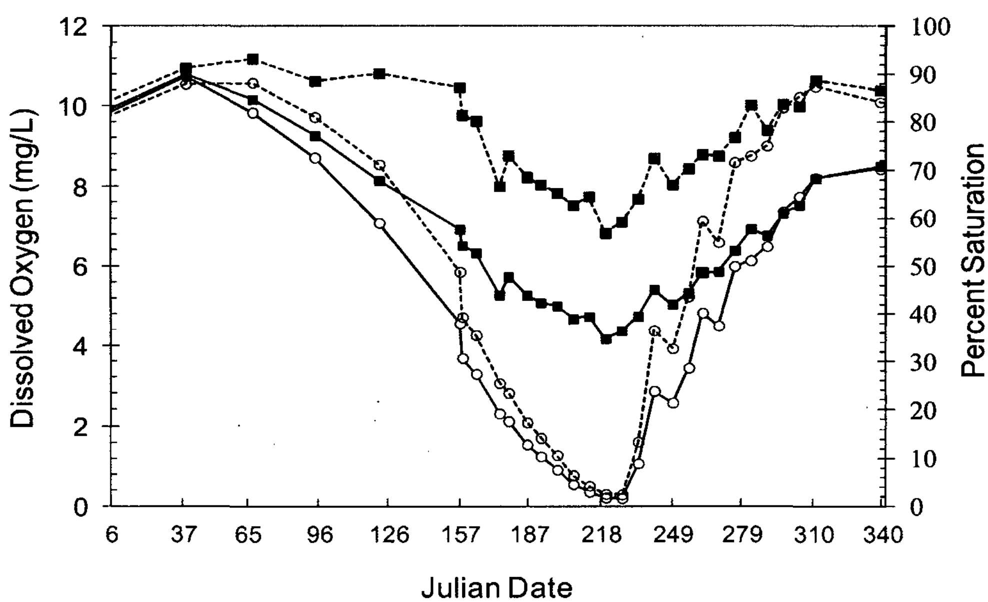



Figure 2-10b. Dissolved oxygen content (–) and percent saturation (---) of the entire water column (■) and the hypolimnion (○) of Lake Norman in 2011.

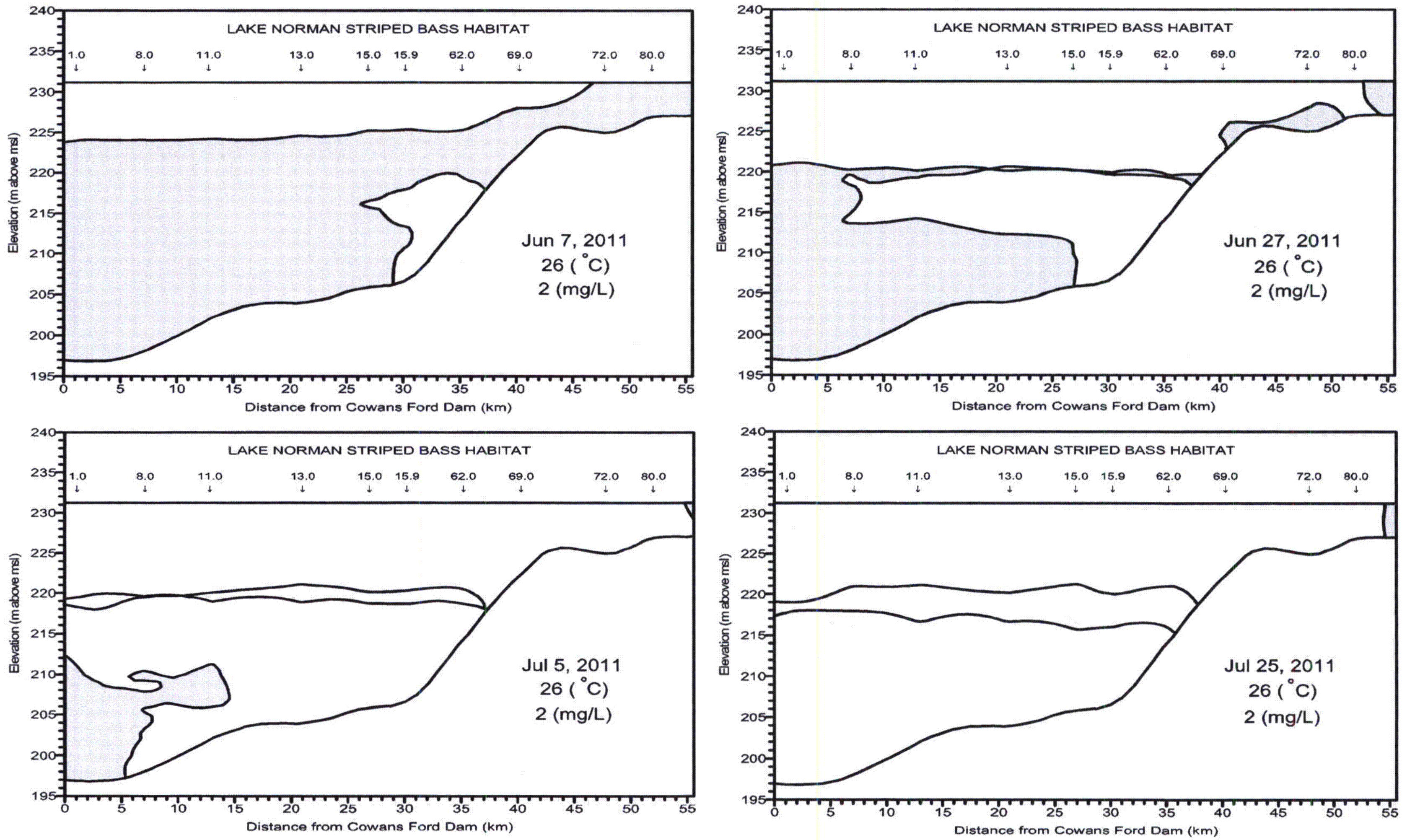



Figure 2-11. Striped bass habitat (shaded areas; temperatures ≤ 26 °C and dissolved oxygen ≥ 2 mg/L) in Lake Norman in June, July, August, and September 2011.

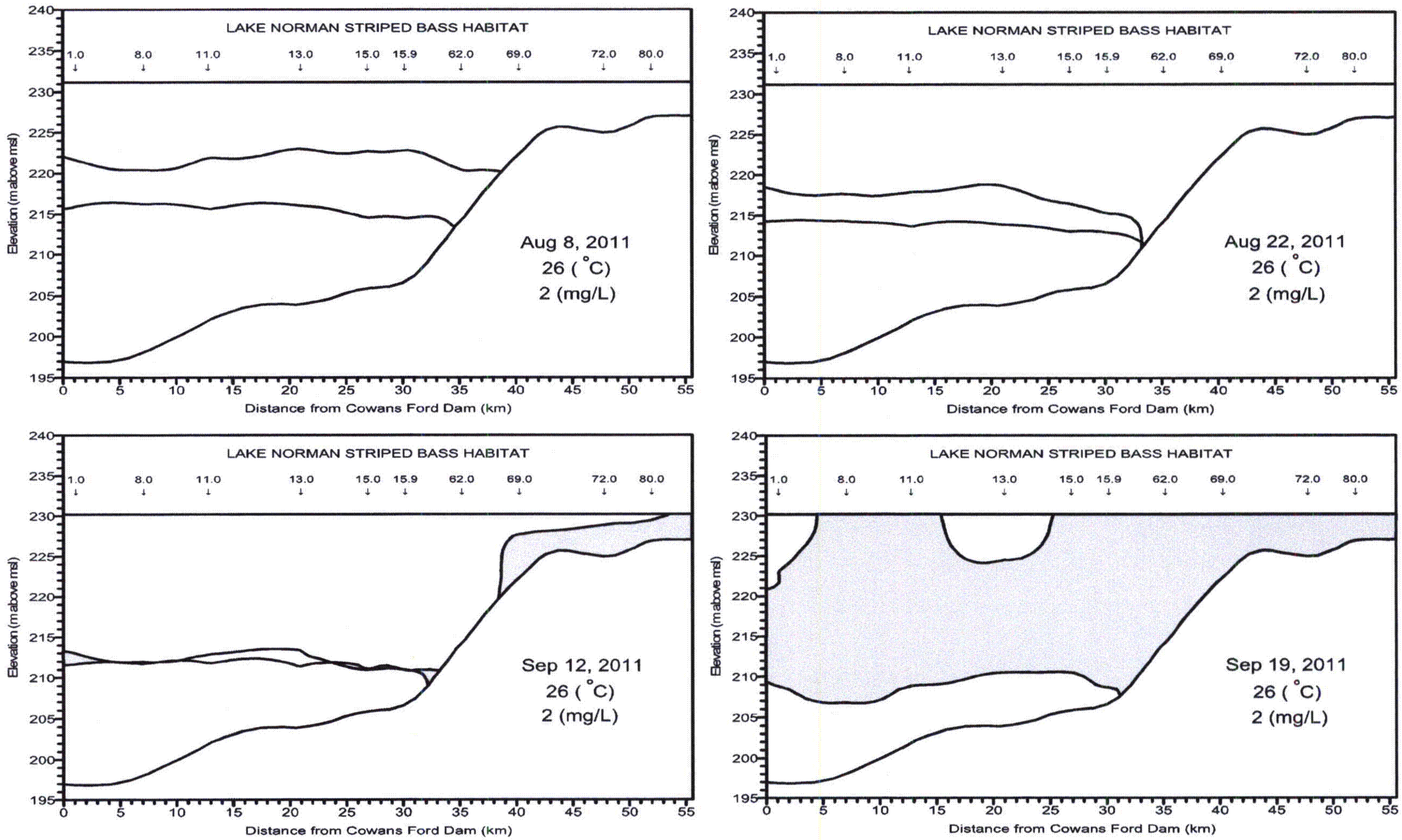



Figure 2-11. (Continued).

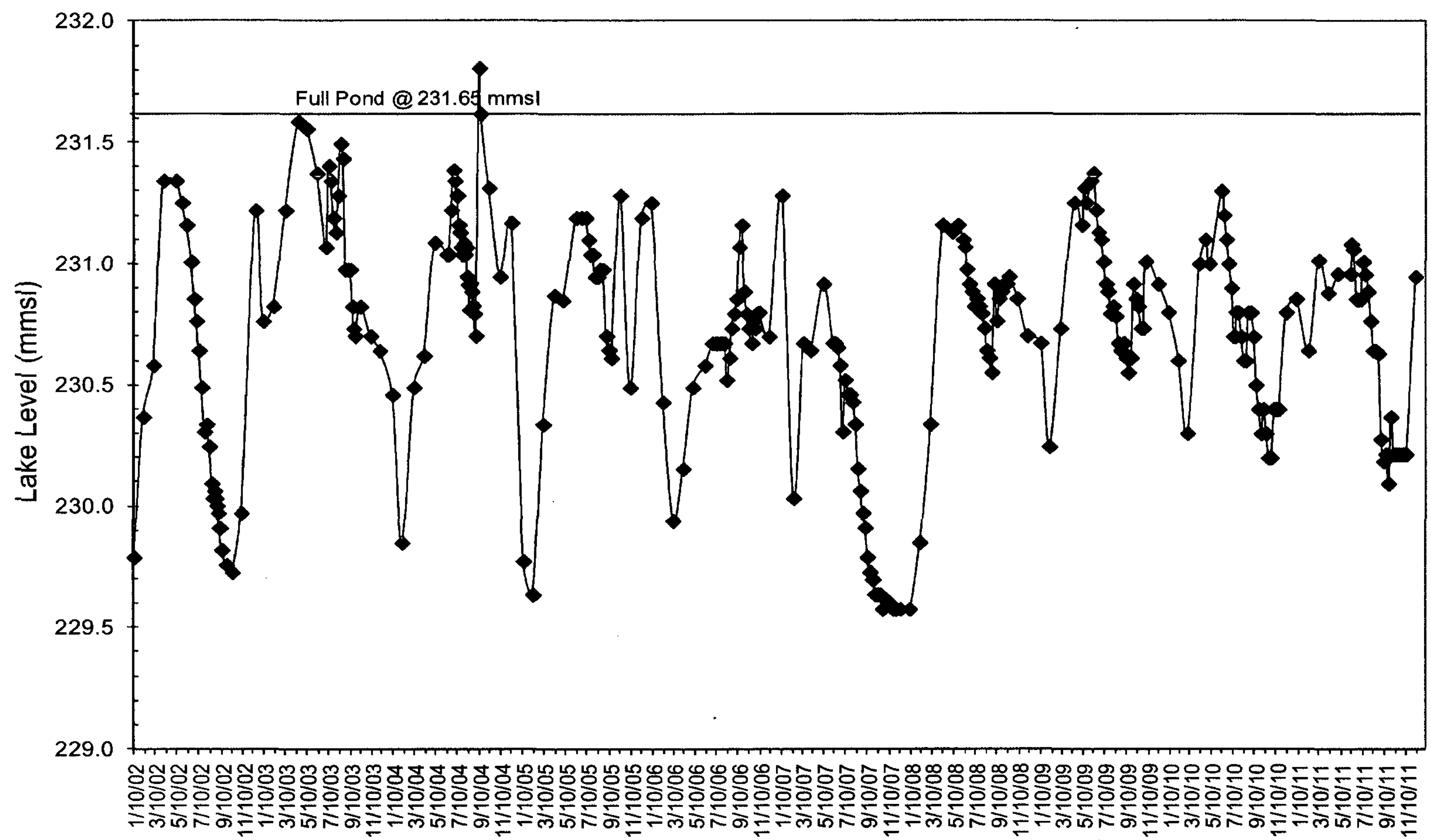



Figure 2-12. Lake Norman lake levels, expressed in meters above mean sea level (mmsl) for 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, and 2011. Lake level data correspond to the water quality sampling dates over this time period.

# CHAPTER 3

# PHYTOPLANKTON

## INTRODUCTION

Phytoplankton standing crop parameters were monitored in 2011 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 2011 study with data collected in prior study years (1987 – 2010).

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 and 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 2011).

## 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 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 has typically been conducted in February (winter), May (spring), August (summer), and November (fall) of most years. 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 2011 were compared with corresponding data from quarterly monitoring that began in August 1987.

## RESULTS AND DISCUSSION

### Standing Crop

#### *Chlorophyll a*

Chlorophyll concentrations from all locations were averaged to calculate a lakewide mean for each quarter. Quarterly lakewide mean chlorophyll concentrations were within ranges of those reported in previous years; however, all quarterly lakewide means were below the long-term means for those periods and the November 2011 mean was very close to the long-term minimum for that quarter (Figure 3-1).

Chlorophyll *a* concentrations (mean of two replicate composites) showed temporal variability consistent with previous long-term means. Concentrations ranged from a low of 2.03 µg/L at Location 9.5 in November, to a high of 11.11 µg/L at Location 69.0 in August (Table 3-1 and Figure 3-2). All values were well below the North Carolina water quality standard for chlorophyll *a* of 40 µg/L (NCDEHNR 1991). Seasonally, chlorophyll *a* concentrations increased from February through May to the annual lakewide maximum in August, and then declined from August to the lakewide minimum in November (Figure 3-1). Based on quarterly mean chlorophyll concentrations, the trophic level of Lake Norman was in the mesotrophic (intermediate) range during all but November, when the mean chlorophyll concentration was in the oligotrophic (low) range. Over 40% of the mean chlorophyll *a* values were less than 4 µg/L (oligotrophic), while all of the remaining chlorophyll *a* values were between 4 and 12 µg/L (mesotrophic). Historically, quarterly mean concentrations of less than 4 µg/L have been recorded on 25 previous occasions, while lakewide mean concentrations of greater than 12 µg/L were only recorded during May of 1997 and 2000 (Duke Power 1998 and 2001; Duke Energy 2011).

During 2011, chlorophyll *a* concentrations showed typical spatial variability. Maximum concentrations among sampling locations were observed at Location 69.0 (furthest uplake) during May and August, while the February and November maxima were recorded from Location 15.9 (Table 3-1; Figure 3-1). Minimum concentrations occurred at Location 2.0 in February, Location 9.5 in May and November, and Location 8.0 in August. 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 2011 (Table 3-1 and Figure 3-2).

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 by 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. 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 2011) have varied considerably, resulting in moderate to wide historical ranges. During February periods of 1987 through 2011, chlorophyll *a* concentrations ranged from 0.75 to 28.84 µg/L. For historical purposes, February concentrations up to 3.0 µg/L were considered in the low range, concentrations from greater than 3.0 to 6.0 µg/L were placed in the intermediate range, and concentrations greater than 6.0 µg/L were in the high range. During February 2011, chlorophyll *a* concentrations at Locations 2.0, 5.0, and 8.0 were in the low range for this time of year, while concentrations from Locations 9.5, 11.0, and 13.0 were in the intermediate range (Figure 3-3). At Locations 15.9 and 69.0, February chlorophyll concentrations were in the high historical range.

During May periods, chlorophyll *a* concentrations have ranged from 0.97 to 27.77 µg/L. May chlorophyll concentrations up to 3.0 µg/L were placed in the low range, while concentrations from greater than 3.0 to 7.0 µg/L were considered in the intermediate range. Concentrations above 7.0 µg/L were characterized as high. During May, mean chlorophyll *a* concentrations at most locations were in the mid-historical range (Figure 3-4). At Location 69.0, the concentration was in the high range.

August periods showed a chlorophyll *a* of 2.19 to 32.57 µg/L. For historical purposes, concentrations up to 5.0 µg/L were placed in the low range, while concentrations between 5 and 9.0 µg/L were considered intermediate. Values greater than 9.0 µg/L were in the high range. Most August 2011 chlorophyll concentrations were in the mid-historical range with the concentration at Location 69.0 in the high range (Figure 3-5).

Long-term chlorophyll concentrations in November ranged from 1.28 to 16.29 µg/L. Concentrations up to 4.0 µg/L were considered low, from greater than 4.0 to 8.0 µg/L intermediate, and those greater than 8.0 µg/L were placed in the high range. Chlorophyll *a* concentrations at all locations in November were in the low historical range (Figure 3-6).

*Total Abundance*

Density and biovolume are standing crop measurements of phytoplankton numbers and biomass. In most cases, these parameters mirror the temporal trends of chlorophyll concentrations. During 2011 this was most often the case. 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 February, while minimum chlorophyll concentrations most often occurred in November. The lowest density (440 units/mL) and biovolume (122 $mm^3/m^3$) were recorded from Locations 5.0 and 2.0, respectively, in February (Table 3-2 and Figure 3-2). The maximum density (3,901 units/mL) was recorded at Location 15.9 in August, while the maximum biovolume (3,081 $mm^3/m^3$) was also recorded at this location in November. The maximum biovolume at Location 15.9 was due to the high relative abundance of large diatoms with very low chlorophyll to volume ratios. Most standing crops during 2011 were lower than those observed during 2010 (Duke Energy 2011). Phytoplankton densities and biovolumes during 2011 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 and 1990; Duke Power 1998, 1999, 2001, and 2004a; Duke Energy 2007 and 2009).

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 3-2).

Seston

Seston dry weights represent a combination of algal matter and other organic and inorganic material. Dry weights during February 2011 were most often lower than those recorded during February of 2010, while May, August, and November values in 2011 were generally higher than in these periods of 2010 (Duke Energy 2011 and Table 3-3). A general pattern of increasing values from downlake to uplake was observed during all periods (Figure 3-2). For the most part, this spatial trend was similar to that of chlorophyll concentrations and standing crops.

Seston ash-free dry weights represent organic material and may reflect spatial trends of chlorophyll *a* and phytoplankton standing crop values. This relationship was generally noticeable to varying extents during all seasons, especially with respect to increasing values from downlake to uplake areas; however, most often, ash-free dry weights declined from Locations 2.0 through 9.5, and then increased through the uplake Location 69.0 (Tables 3-1 through 3-3).

Secchi Depths

Secchi depth is a visual 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 1.0 m at Location 69.0 in May, to 3.8 m at Location 8.0 in February (Table 3-1). The lakewide mean Secchi depth during 2011 was the highest yet recorded since measurements were first reported in 1992 (Duke Energy 2011).

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 2011. Ten classes comprising 107 genera and 279 species, varieties, and forms of phytoplankton were identified in samples collected during 2011, as compared to 96 genera and 252 species, varieties, and forms of phytoplankton identified 2010 (Appendix Table 3-1). The 2011 total represented the highest number of taxa recorded in any year since monitoring began in 1987 (Duke Energy 2011).

Twenty-one taxa previously unrecorded during the Lake Norman Maintenance Monitoring Program were identified during 2011.

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 2011, cryptophytes (Chryptophyceae) dominated densities at all locations (Table 3-4; Figures 3-7 through 3-11). During most previous years, cryptophytes and occasionally diatoms (Bacillariophyceae) dominated February phytoplankton samples in Lake Norman. The most abundant cryptophyte during February 2011 was the small flagellate, *Rhodomonas minuta,* certainly one of the most common and abundant forms observed in Lake Norman samples since monitoring began in 1987.

In May, cryptophytes, primarily, *R. minuta*, also dominated samples at all locations (Table 3-4; Figures 3-7 through 3-11). Diatoms have typically been the predominant forms in spring periods 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, and 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

During August 2011, green algae (Chlorophyceae) dominated densities at all locations (Table 3-4; Figures 3-7 through 3-11). The most abundant green alga was the small desmid, *Cosmarium asphearosporum var. strigosum*. Prior to 1999, green algae 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, and 1997; Duke Power 1998 and 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 and 2002). The possible causes of this significant shift in summer taxonomic composition during 1999 – 2001 were discussed in earlier reports and included deeper light penetration, extended periods of low water due to drawdown, and shifts in nutrient inputs and concentrations (Duke Power 2000, 2001, and 2002). Whatever the cause, the phenomenon was lakewide and not localized near MNS or Marshall Steam Station; 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, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

During November 2011, densities at all locations were dominated by diatoms and the most abundant species was the centrate *Melosira ambigua* (Table 3-4; Figures 3-7 through 3-11). 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, and 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Blue-green algae, which are often implicated in nuisance blooms, were not abundant in 2011 samples. Their overall contribution to phytoplankton densities seldom exceeded 2% of totals (Duke Energy 2011). Prior to 1991, blue-green algae were often dominant at uplake locations during the summer (Duke Power Company 1988, 1989, 1990, 1991, and 1992).

## SUMMARY

Lake Norman continues to be classified as oligo-mesotrophic based on long-term, annual mean chlorophyll concentrations. Most individual chlorophyll *a* concentrations during 2011 were within historical ranges. The exception was a record low concentration at Location 9.5 in November. Lakewide mean chlorophyll *a* increased from February to the annual peak in August, and then declined to the annual minimum in November. Some spatial variability was observed in 2011; however, maximum chlorophyll *a* concentrations were most often observed uplake at Locations 15.9 (February and November) and 69.0 (May and August), while minimum chlorophyll *a* concentrations were typically recorded from downlake at Locations 2.0 (Febraury), 8.0 (August) and 9.5 (May and November). The highest chlorophyll *a* value recorded in 2011 (11.11 µg/L) was well below the NC State water quality standard of 40 µg/L.

Most phytoplankton standing crops in 2011 were lower than in 2010. Phytoplankton densities and biovolumes during 2011 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 sampling. 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 most often lower in February of 2011 than in February 2010; while values during May, August, and November of 2011 were most often higher than during those periods of 2010. The trend of increasing values from downlake to uplake was generally apparent during most sampling periods. Maximum dry and ash-free weights were generally observed at uplake Locations 11.0 through 69.0. Minimum values were most often noted at downlake Locations 2.0 through 9.5.

Secchi depths often reflected suspended solids, with shallow depths loosely related to high dry weights. The lakewide mean Secchi depth in 2011 was the highest recorded since 1992.

Diversity, or the number of phytoplankton taxa identified in 2011 was the highest yet recorded. The taxonomic compositions of phytoplankton communities during 2011 were similar to those of most previous years. Diatoms were dominant during November, while cryptophytes were dominant during February and May. During August, green algae consistently dominated algal assemblages. Contribution of blue-green algae to total densities seldom exceeded 2%.

The most abundant algae during 2011 were: the cryptophyte, *Rhodomonas minuta* in February and May; the green alga, *Cosmarium asphearosporum* v. *strigosum* in August; and, the diatom *Melosira ambigua* in November. 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 2011.

| Chlorophyll *a* | Feb | May | Aug | Nov |
|---|---|---|---|---|
| Location | | | | |
| 2.0 | 2.36 | 4.03 | 5.73 | 2.08 |
| 5.0 | 2.39 | 4.12 | 5.97 | 2.16 |
| 8.0 | 2.42 | 3.76 | 5.23 | 2.23 |
| 9.5 | 2.84 | 3.18 | 5.65 | 2.03 |
| 11.0 | 4.58 | 3.84 | 5.42 | 3.85 |
| 13.0 | 4.56 | 4.24 | 5.45 | 3.91 |
| 15.9 | 8.30 | 4.34 | 7.77 | 4.89 |
| 69.0 | 8.14 | 9.13 | 11.11 | 4.13 |

| Secchi depths | Feb | May | Aug | Nov |
|---|---|---|---|---|
| Location | | | | |
| 2.0 | 3.1 | 3.2 | 3.0 | 3.0 |
| 5.0 | 3.0 | 3.0 | 2.8 | 2.6 |
| 8.0 | 3.8 | 3.0 | 2.7 | 3.2 |
| 9.5 | 3.1 | 3.0 | 2.7 | 2.4 |
| 11.0 | 2.7 | 3.0 | 2.0 | 1.5 |
| 13.0 | 2.0 | 2.0 | 1.3 | 1.5 |
| 15.9 | 2.2 | 2.4 | 2.2 | 2.0 |
| 69.0 | 1.2 | 1.0 | 1.2 | 1.4 |
| Annual mean from all Locations: 2011 | | | | 2.41 |
| Annual mean from all Locations: 2010 | | | | 1.87 |

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 2011.

| Density | Locations | | | | | |
|---|---|---|---|---|---|---|
| Month | 2.0 | 5.0 | 9.5 | 11.0 | 15.9 | Mean |
| Feb | 459 | 440 | 476 | 593 | 1,232 | 640 |
| May | 1,035 | 1,364 | 1,236 | 1,259 | 1,540 | 1,287 |
| Aug | 1,634 | 1,672 | 2,057 | 2,078 | 3,901 | 2,268 |
| Nov | 589 | 733 | 647 | 1,025 | 2,275 | 1,054 |

| Biovolume | Locations | | | | | |
|---|---|---|---|---|---|---|
| Month | 2.0 | 5.0 | 9.5 | 11.0 | 15.9 | Mean |
| Feb | 122 | 124 | 161 | 176 | 806 | 277 |
| May | 532 | 628 | 462 | 513 | 953 | 618 |
| Aug | 1,101 | 1,052 | 884 | 907 | 2,933 | 1,375 |
| Nov | 532 | 788 | 662 | 1,366 | 3,081 | 1,286 |

Table 3-3. Total mean seston dry and ash free-dry weights (mg/L) from samples collected in Lake Norman during 2011.

| Dry weights | Locations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | 2.0 | 5.0 | 8.0 | 9.5 | 11.0 | 13.0 | 15.9 | 69.0 | Mean |
| Feb | 1.39 | 1.45 | 1.28 | 1.57 | 1.47 | 2.09 | 2.79 | 6.77 | 2.35 |
| Jun | 1.20 | 1.04 | 1.01 | 1.37 | 1.03 | 1.50 | 2.79 | 7.09 | 2.15 |
| Aug | 1.86 | 1.72 | 2.13 | 2.48 | 1.91 | 2.62 | 2.52 | 10.61 | 3.23 |
| Nov | 2.34 | 2.02 | 1.90 | 2.20 | 3.41 | 3.34 | 2.78 | 16.64 | 4.33 |
| Ash-free dry weights | | | | | | | | | |
| Month | | | | | | | | | |
| Feb | 0.59 | 0.65 | 0.61 | 0.90 | 0.93 | 1.25 | 0.82 | 2.17 | 0.99 |
| Jun | 0.73 | 0.66 | 0.53 | 0.72 | 0.60 | 0.68 | 0.82 | 1.89 | 0.83 |
| Aug | 1.33 | 1.22 | 1.75 | 1.75 | 1.41 | 1.26 | 1.41 | 3.54 | 1.71 |
| Nov | 0.90 | 0.72 | 0.67 | 0.78 | 1.05 | 1.02 | 0.97 | 4.59 | 1.34 |

Table 3-4. Dominant classes, their most abundant species, and their percent composition (in parentheses) at Lake Norman locations during each sampling period of 2011.

| Location | Feb | May |
|---|---|---|
| 2.0 | Cryptophyceae (54.8)<br>*Rhodomonas minuta* (51.6) | Cryptophyceae (42.5)<br>*Rhodomonas minuta* (38.1) |
| 5.0 | Cryptophyceae (50.5)<br>*R. minuta* (46.7) | Cryptophyceae (41.2)<br>*R. minuta* (37.6) |
| 9.5 | Cryptophyceae (51.1)<br>*R. minuta* (49.3) | Cryptophyceae (36.9)<br>*R. minuta* (35.4) |
| 11.0 | Cryptophyceae (70.0)<br>*R. minuta* (67.5) | Cryptophyceae (55.2)<br>*R. minuta* (53.9) |
| 15.9 | Cryptophyceae (46.9)<br>*R. minuta* (36.4) | Cryptophyceae (36.3)<br>*R. minuta* (33.1) |
| | **Aug** | **Nov** |
| 2.0 | Chlorophyceae (77.4)<br>*Cosmarium asphearosphorum* v. *strigosum* (42.2) | Bacillariophyceae (55.5)<br>*Melosira ambigua* (14.2) |
| 5.0 | Chlorophyceae (76.3)<br>*C. asphear.* v *strig.* (41.6) | Bacillariophyceae (52.6)<br>*M. ambigua* (18.3) |
| 9.5 | Chlorophyceae (78.4)<br>*C. asphear.* v *strig.* (45.5) | Bacillariophyceae (51.5)<br>*M. ambigua* (18.8) |
| 11.0 | Chlorophyceae (74.2)<br>*C. asphear.* v *strig.* (37.9) | Bacillariophyceae (46.2)<br>*M. ambigua* (19.2) |
| 15.9 | Chlorophyceae (60.9)<br>*C. asphear.* v *strig.* (37.8) | Bacillariophyceae (49.0)<br>*M. ambigua* (23.2) |

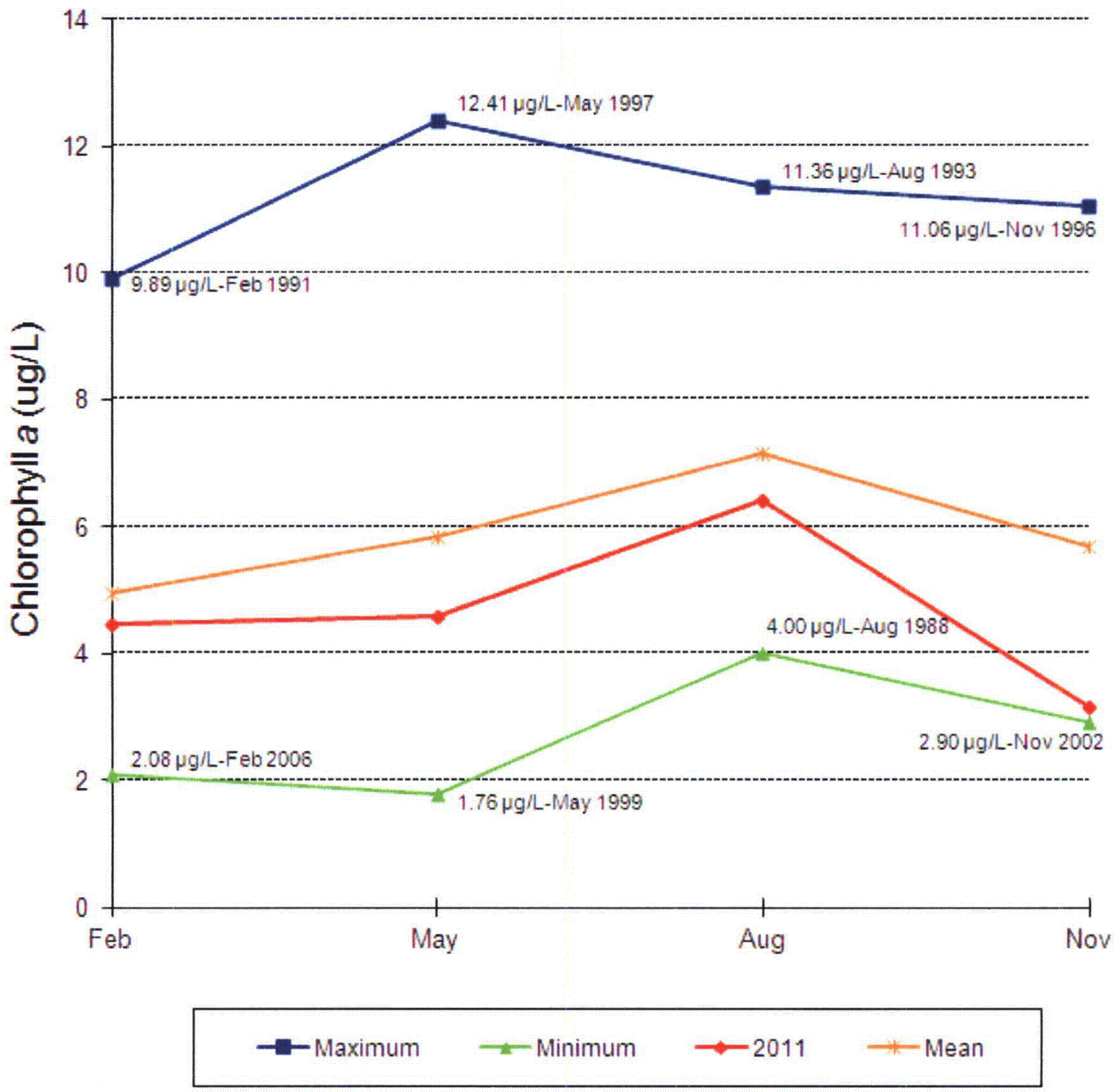



Figure 3-1. Lake Norman phytoplankton chlorophyll *a* seasonal maximum and minimum lakewide means since August 1987 compared with the long-term seasonal lakewide means and lakewide means for 2011.

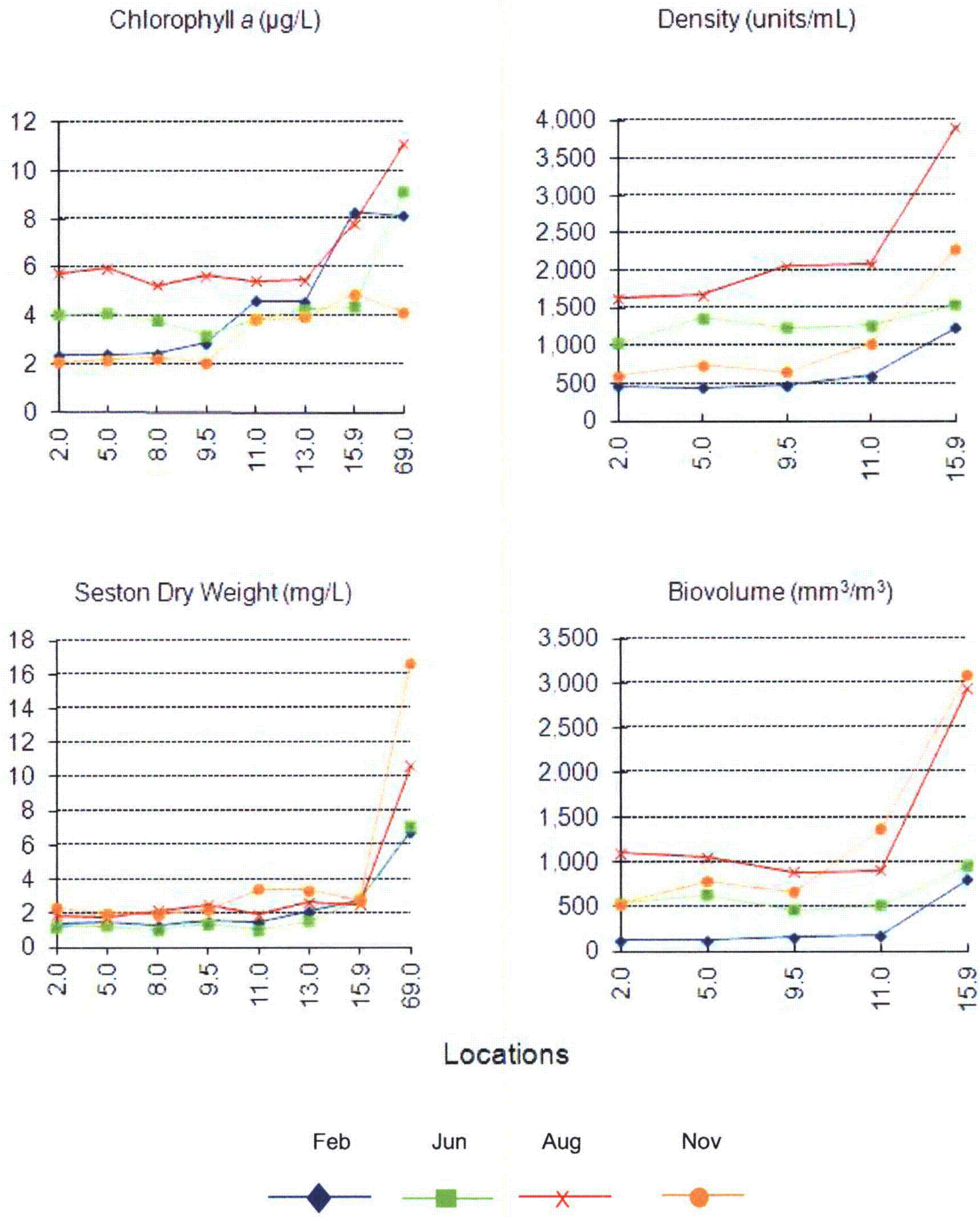



Figure 3-2. Phytoplankton chlorophyll *a*, densities, biovolumes, and seston dry weights at locations in Lake Norman in February, May, August, and November 2011.

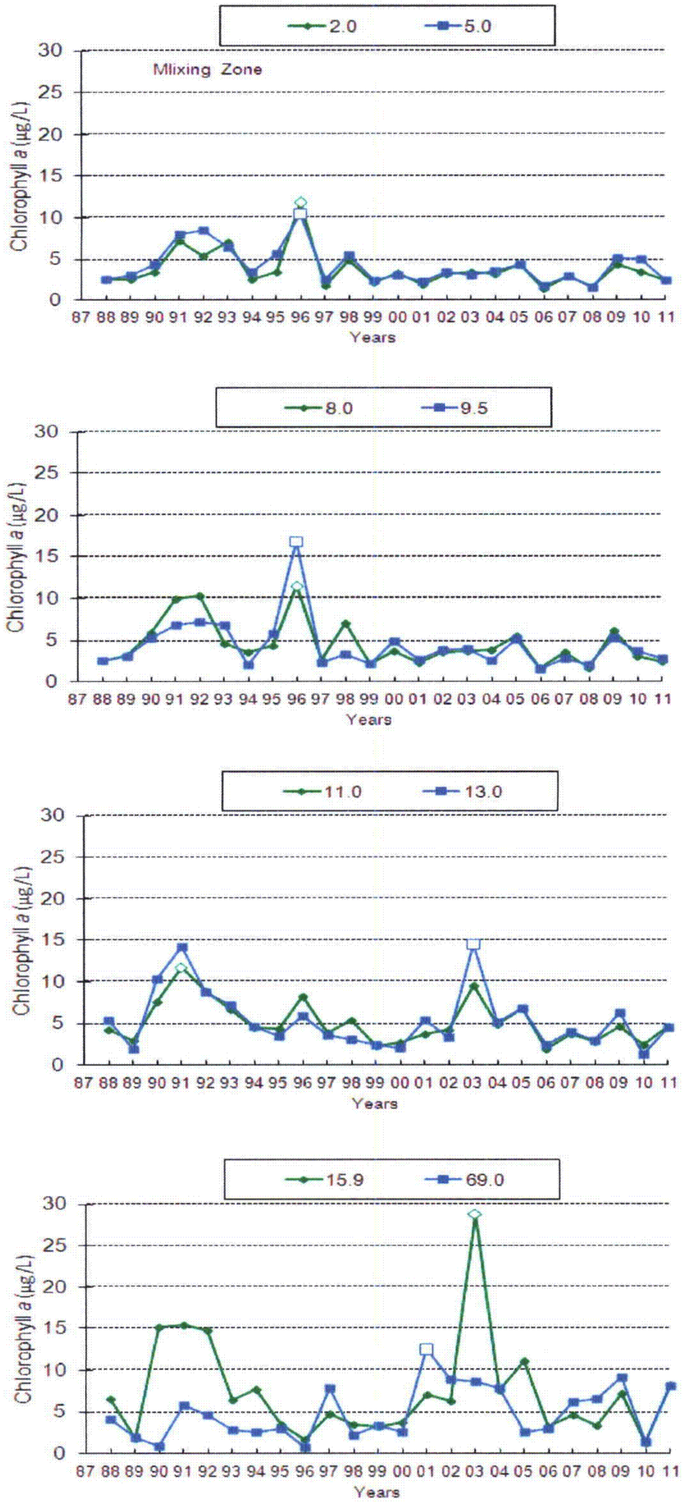



Figure 3-3. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from February 1988 – 2011 (Note: clear data points represent long-term maxima).

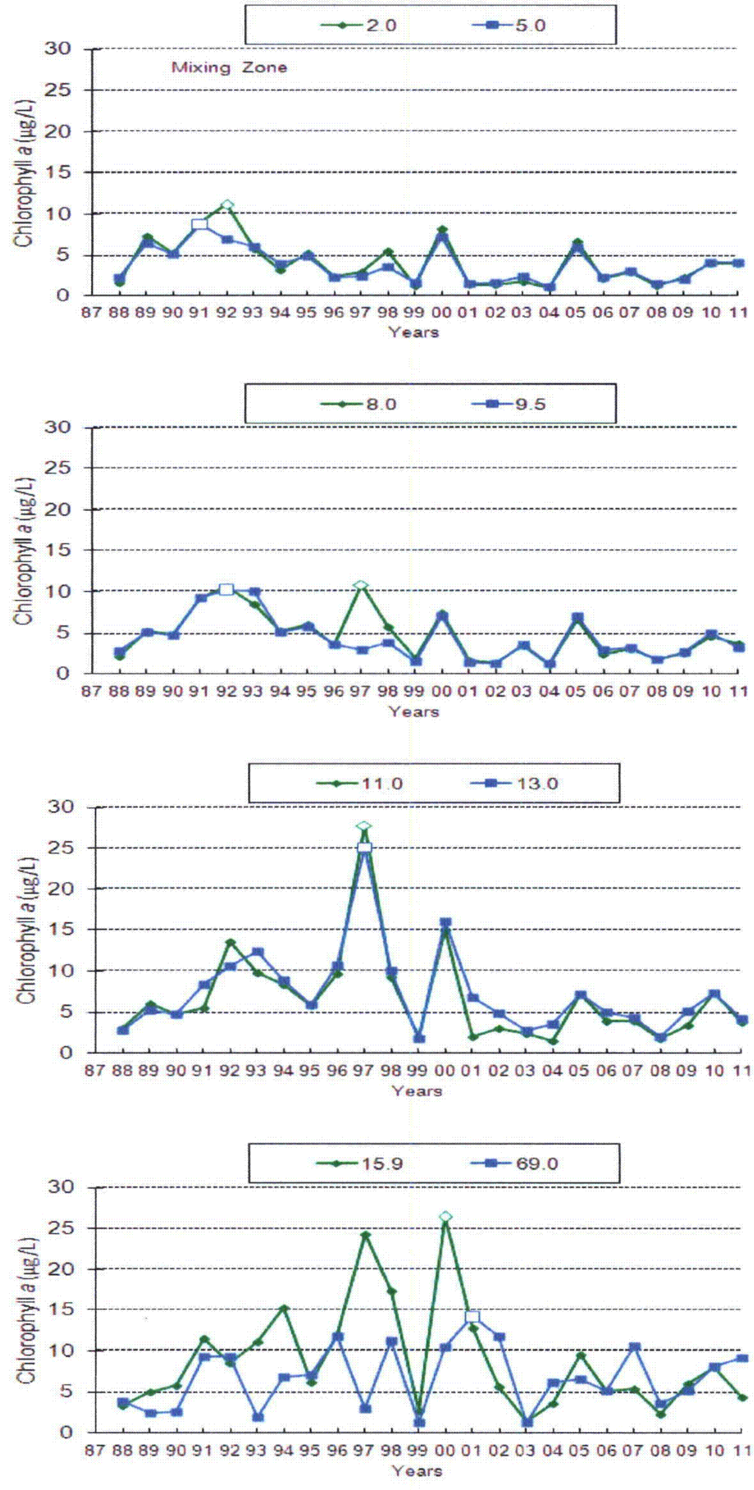



Figure 3-4. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from May 1988 – 2011 (Note: clear data points represent long-term maxima).

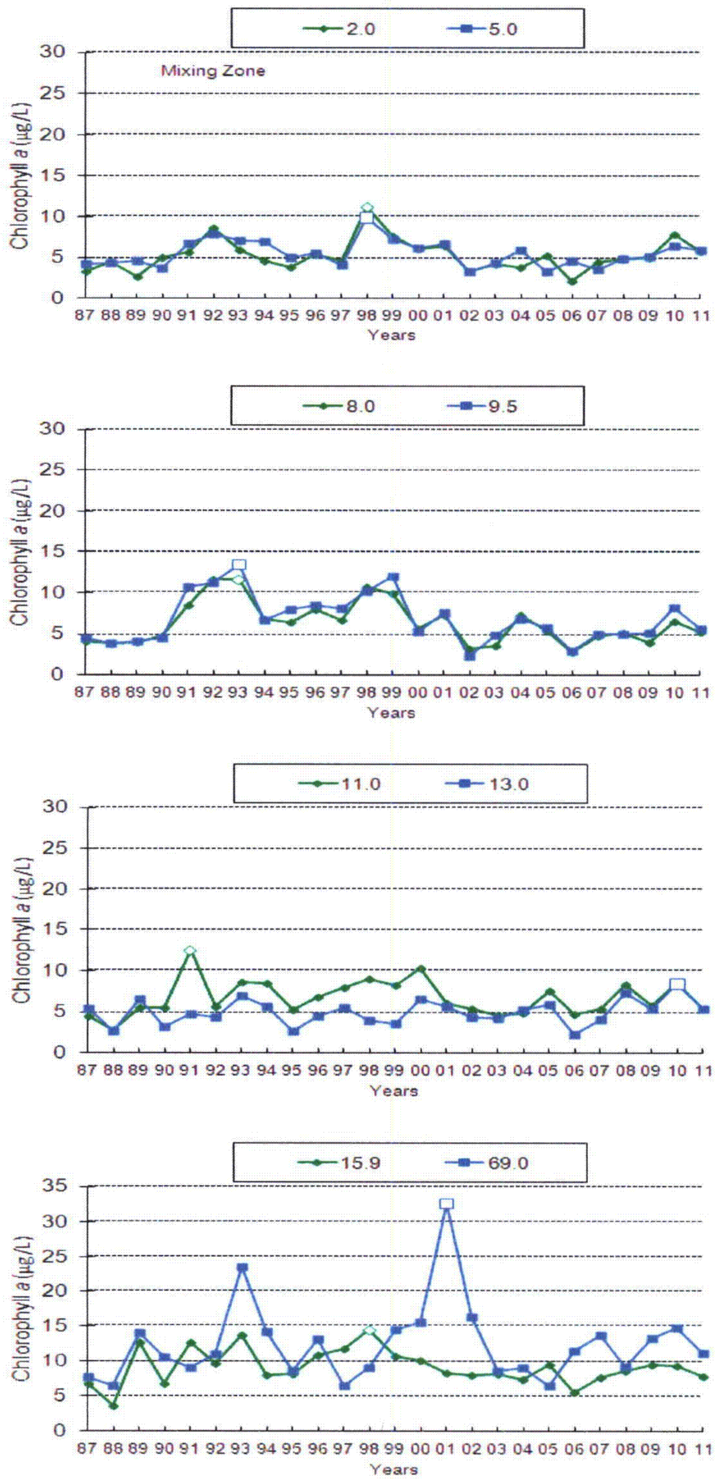



Figure 3-5. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during August 1987 – 2011 (Note: change in axis for 15.9 and 69.0, and that clear data points represent long-term maxima).

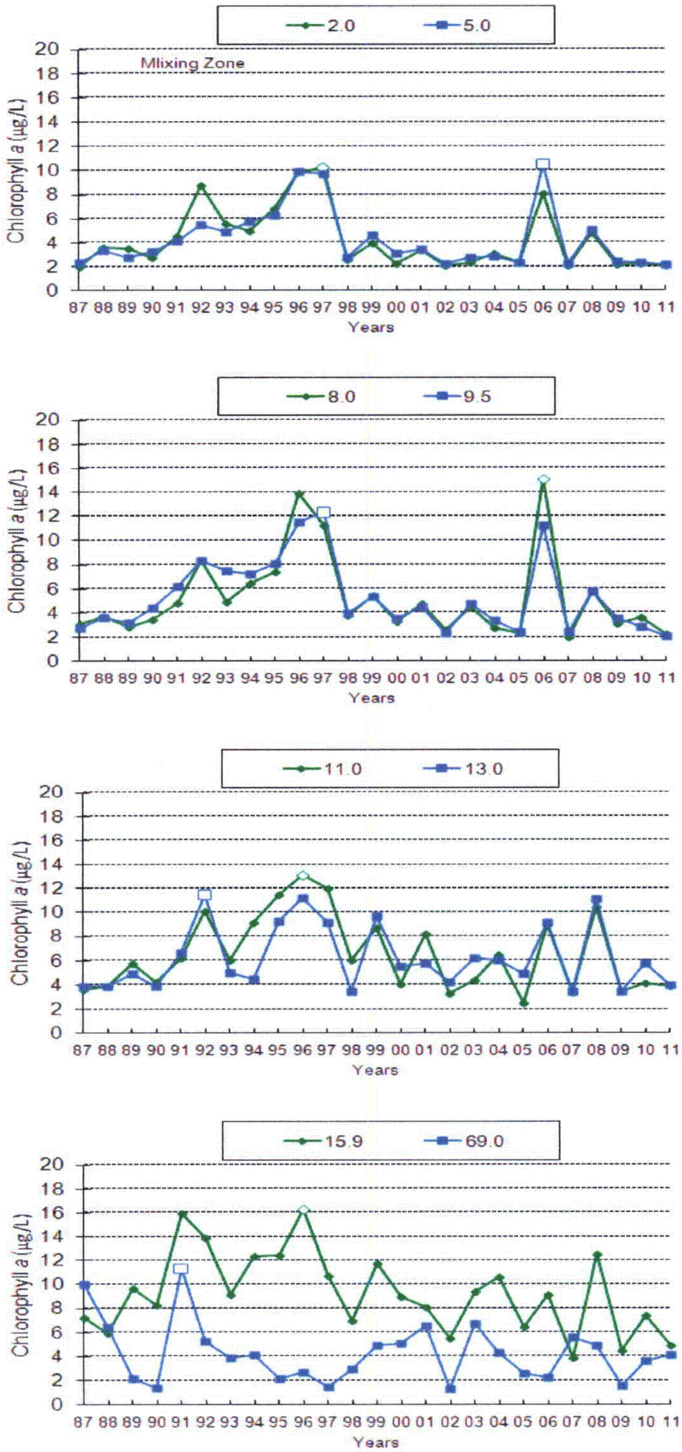



Figure 3-6. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during November 1987 – 2011 (Note that clear data points represent long-term maxima).

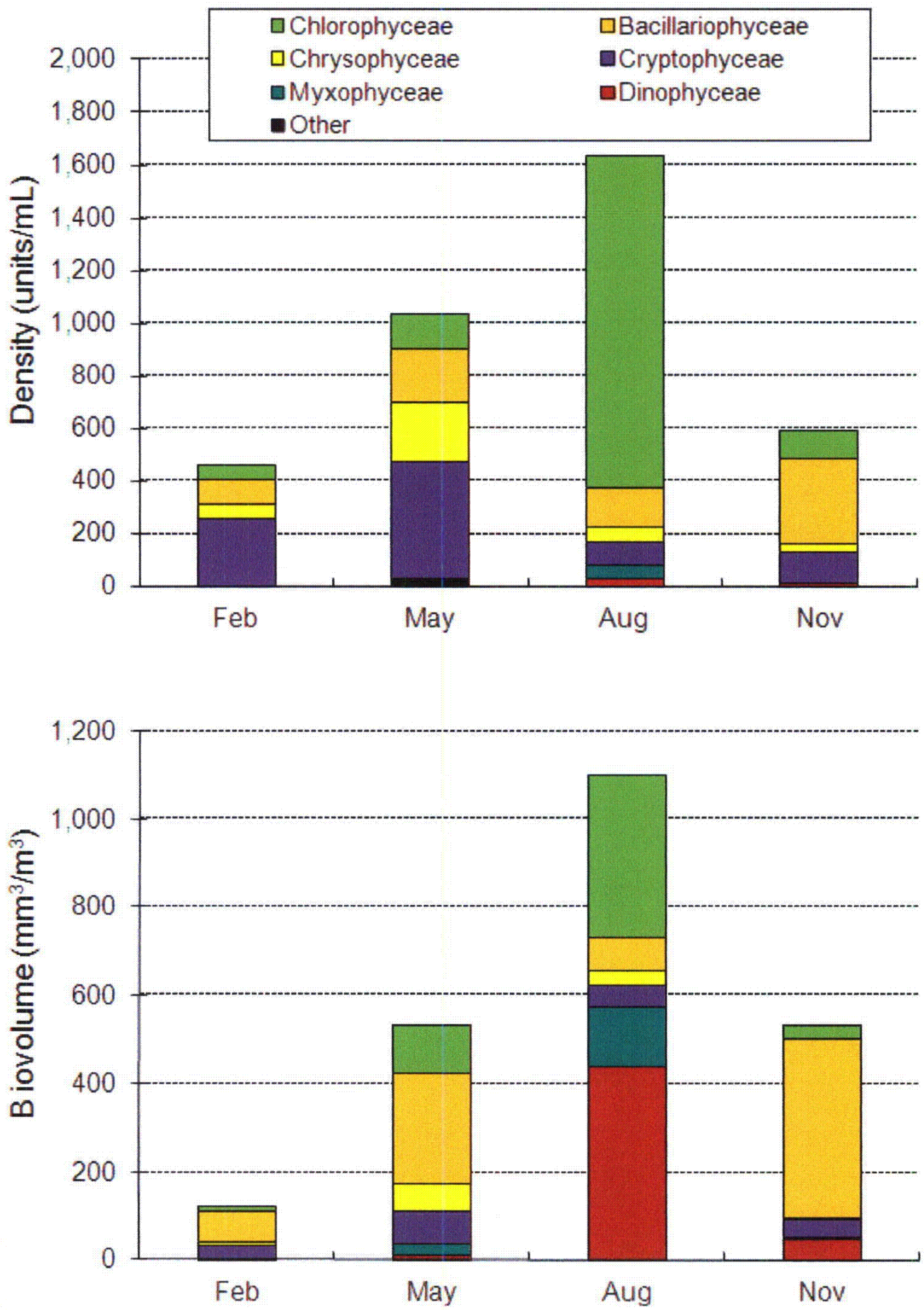



Figure 3-7. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 2.0 in Lake Norman during 2011.

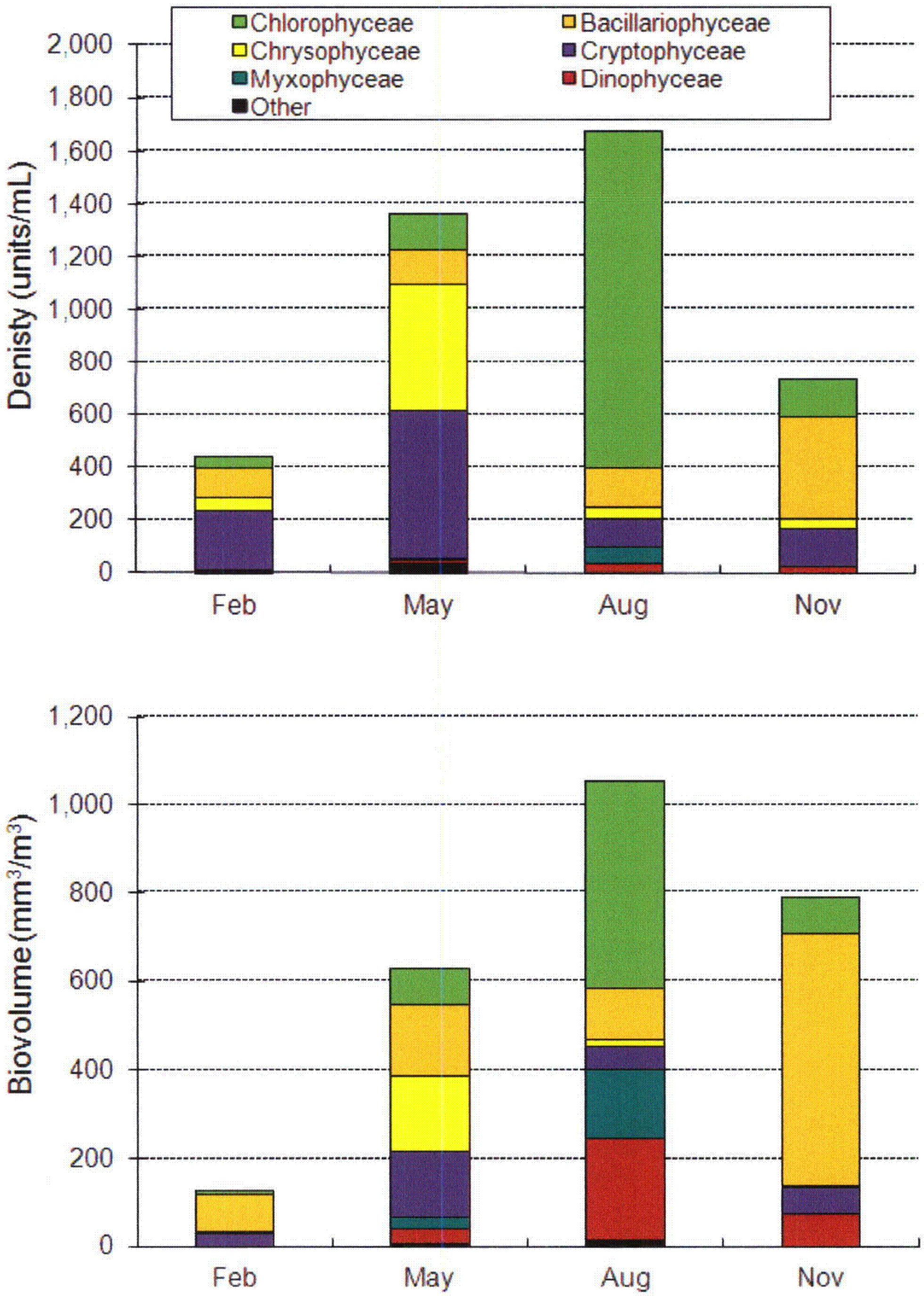



Figure 3-8. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 5.0 in Lake Norman during 2011.

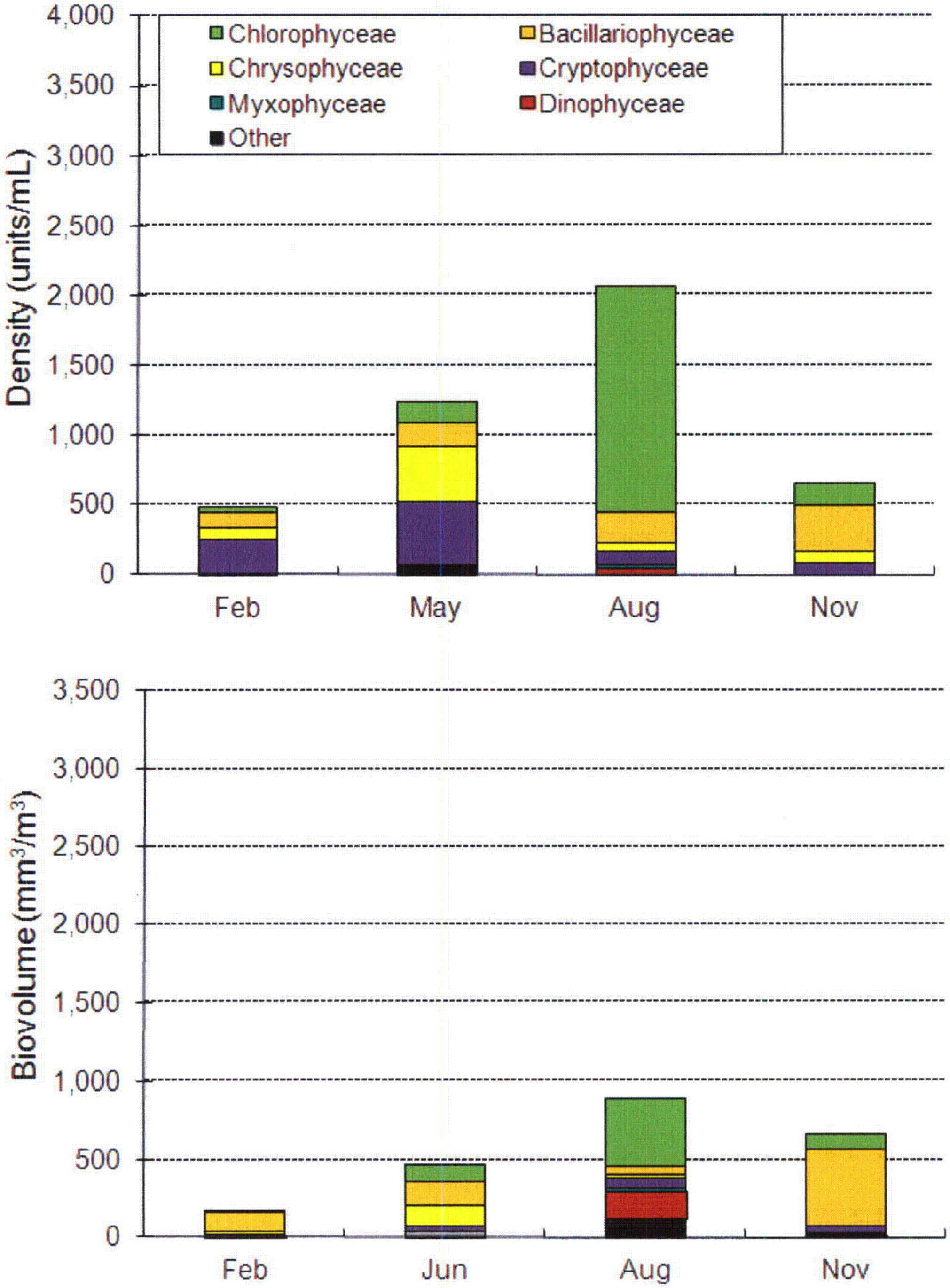



Figure 3-9. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 9.5 in Lake Norman during 2011.

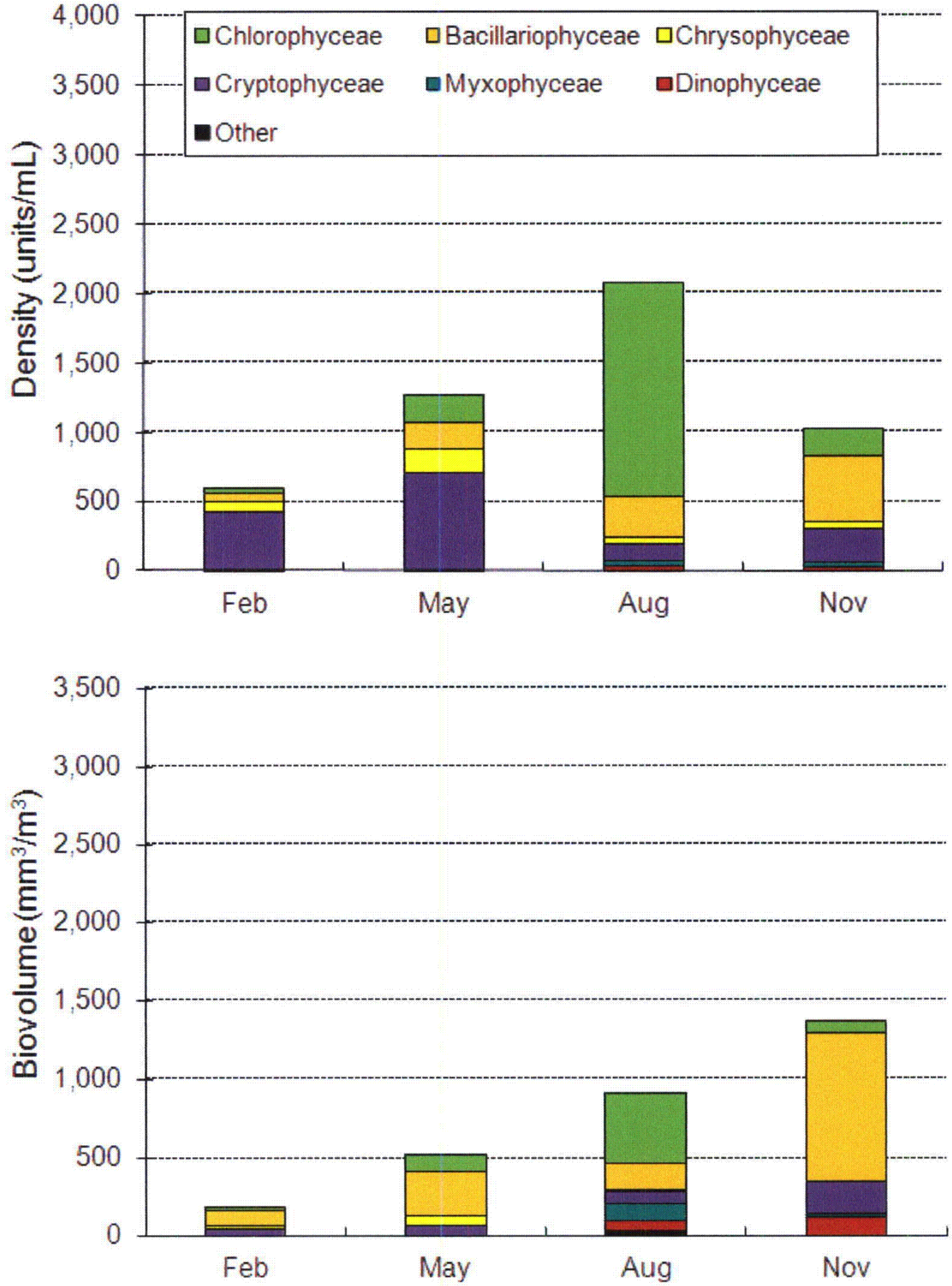
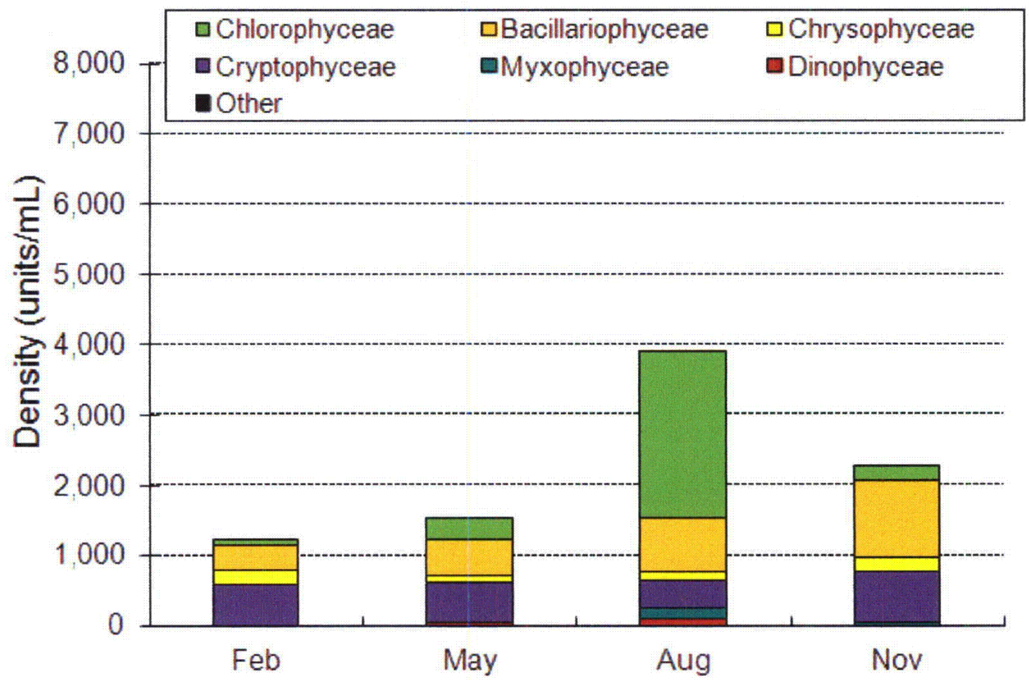



Figure 3-10. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 11.0 in Lake Norman during 2011.



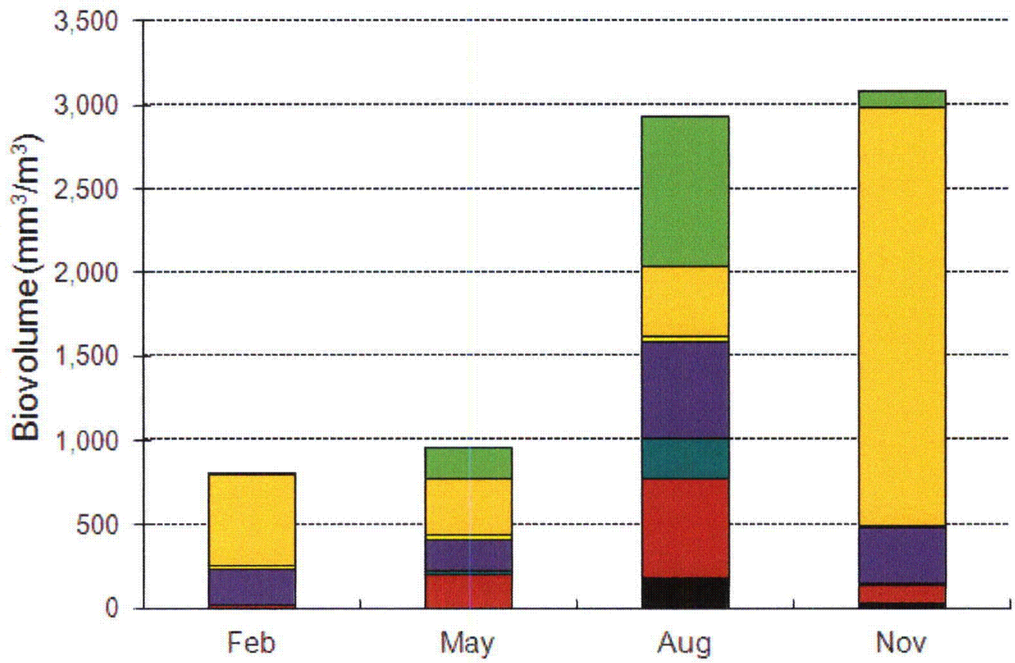




Figure 3-11. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 15.9 in Lake Norman during 2011.

# 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 2011 with historical data collected during the period 1987 – 2010.

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 and 1985; Hamme 1982; Menhinick and Jensen 1974). Since quarterly sampling was initiated in August 1987, distinct bimodal seasonal distributions have 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) 2011. 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 2011 were compared with corresponding data from quarterly monitoring begun in August 1987.

## RESULTS AND DISCUSSION

### Total Abundance

Epilimnetic zooplankton densities during 2011 ranged from a low of 17,448/$m^3$ at Location 2.0 in November, to a high of 279,214/$m^3$ at Location 15.9 in February. During 2011, there was a certain amount of spatial variability in annual maxima and minima among Lake Norman locations, but generally, densities increased from downlake to up-lake (Table 4-1; Figures 4-1 and 4-2). Over the long-term, the 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 2011).

Whole-column densities ranged from a low of 16,604/$m^3$ at Location 5.0 in November to 113,148/$m^3$ at Location 15.9 in February (Table 4-1 and Figure 4-1). Spatial and temporal trends among whole-column densities were typically similar to those of epilimnetic densities

During 2011, 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 2011). 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.

Epilimnetic zooplankton densities during all seasons of 2011 were generally within historical ranges (Figures 4-3 through 4-6). The exceptions were a record high at Location 15.9 in the winter, and a record low density at this same location in the summer. 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 2011. 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). The long-term maxima for the fall occurred at Locations 2.0 and 5.0 in 2009 and Locations 9.5 and 11.0 in 2006, while the fall maximum at Location 15.9 occurred in 1999 (Figure 4-6).

Year-to-year fluctuations of epilimnetic densities among background locations, particularly Locations 11.0 and 15.9 have generally been far more apparent than in the mixing zone (Figures 4-3 through 4-6). These uplake locations are far more susceptible to hydrological fluctuations associated with the more riverine zone of the reservoir which can have direct influences on phytoplankton communities (see Chapter 3). These impacted phytoplankton communities subsequently provide a food source for zooplankton, particularly microcrustaceans. Conditions at Locations 2.0 and 5.0 in the mixing zone are less variable due to the dampening influences of the Cowans Ford dam.

<u>Community Composition</u>

Since the Lake Norman Maintenance Monitoring Program began in August 1987, 126 zooplankton taxa have been identified (Table 4-2). During 2011, 50 taxa were identified, as compared to 48 recorded for 2010 (Duke Energy 2009). The number of taxa identified during 2011 was within ranges of previous years.

During 2011, rotifers were dominant in nearly 48% 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 winter and fall of 2011 and were dominant in the epilimnetic and whole column samples at Locations 2.0 and 9.5 in the spring. Copepods were also dominant in whole column samples at Location 5.0 in the spring, Locations 2.0 and 15.9 in the summer, and Location 11.0 in the fall. Rotifers were the dominant forms in epilimnetic and whole column samples at Locations 11.0 and 15.9 in the winter and spring, in all epilimnetic samples in the summer, in epilimnetic samples at Locations 11.0 and 15.9 in the fall, and in the epilimnetic samples from Location 5.0 in the spring. They were also dominant in most whole column samples at Locations 5.0 and 9.5 in the summer and whole column samples from Location 15.9 in the fall. Cladocerans, typically the least abundant forms, were dominant in two summer samples in 2011: the whole-column sample from Location 11.0 and the epilimnetic sample from Location 15.9 (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 2010, rotifers declined in relative abundances in both the epilimnetic and whole-column samples of the mixing zone during 2011 and their

percent compositions were within historical ranges (Figure 4-7). At background locations rotifer relative abundances showed more moderate decreases in epilimnetic and whole-column samples since 2010 and percent compositions were also within historical ranges (Figure 4-8).

*Copepoda*

As has always been the case, copepod populations were consistently dominated by immature forms (primarily nauplii) during 2011. Adult copepods seldom comprised more than 7% of the copepod densities at any location. In order of seasonal importance, *Epishura* was most common among winter and spring samples, while *Tropocyclops* and *Mesocyclops* were most important among summer assemblages (Table 4-3). During the fall period, *Tropocyclops* was the most important constituent in most samples. Those taxa which demonstrated occasional importance were *Diaptomus* and *Cyclops*. Similar patterns of copepod taxonomic distributions were observed in previous years (Duke Energy 2011).

Copepods tended to be more abundant among background locations than among mixing zone locations during winter and fall, while the opposite was true in spring and summer of 2011 (Figure 4-9). Copepods peaked in the mixing zone during spring and at background locations in the winter. During most past years, peaks from both areas were observed in the spring (Duke Energy 2011).

*Cladocera*

*Bosmina* was the most abundant cladoceran observed in 2011 samples, as has been the case in most previous studies (Duke Energy 2011 and Hamme 1982). *Bosmina* generally comprised greater than 80% of the cladoceran densities in both epilimnetic and whole-column samples, especially during winter and fall (Table 4-3). *Diaphanosoma* was the dominant cladoceran in most spring samples. *Bosminopsis* was the dominant cladoceran in all summer samples. Similar patterns of cladoceran dominance have been observed in past years (Duke Energy 2011).

Long-term seasonal trends of cladoceran densities were variable and have been described in detail in previous maintenance monitoring reports (Duke Energy 2011). During 2011, maximum densities in the mixing zone and at background locations occurred during the fall

and spring, respectively (Figure 4-10). Cladoceran peaks were most often in the winter and spring, with occasional peaks recorded in the summer and fall (Table 4-1 and Figure 4-2).

*Rotifera*

*Asplanchna* was the most abundant rotifer at most locations in the winter of 2011 (Table 4-3). *Kellicotia* dominated most rotifer populations during the spring, while *Ptygura* dominated most summer populations. *Polyarthra* was dominant in six fall samples, while *Kellicotia* was dominant in three other samples. Other important taxa were *Keratella* (three winter samples and one fall sample) and *Conochilus* (two summer samples). All of these taxa have been identified as important constituents of rotifer populations, as well as zooplankton communities, in previous studies (Duke Energy 2011 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 2011, peak rotifer densities were observed in the spring at mixing zone locations and in winter at background locations.

## SUMMARY

During 2011, seasonal maximum densities among zooplankton assemblages varied considerably and no consistent seasonal trends were observed. Historically, maxima most often occurred in winter and spring, while minima most often occurred in the fall. 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 2011. Spatial trends of zooplankton populations were generally similar to those of the phytoplankton, with increasing densities from downlake to uplake during all seasons but summer. From around 1997 through 2005, a year-to-year trend of increasing zooplankton densities was observed among mixing zone locations in the spring. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations, likely due to the influences associated with uplake riverine conditions as opposed to relatively stable conditions in the main area of the reservoir. Epilimnetic zooplankton densities were within ranges of those observed in previous years, with the exceptions of a record high winter density at Location 15.9 and a record low summer density at this same location.

Since the Lake Norman Maintenance Monitoring Program began in 1987, 126 zooplankton taxa have been recorded from Lake Norman. During 2011, 50 taxa were identified, as compared to 48 in 2010. The number of taxa recorded for 2011 was within the historical range.

Rotifers were dominant in nearly half of all samples; however, their overall relative abundances declined since 2010 in epilimnetic and whole-column samples from mixing zone and background locations. Overall, relative abundance of copepods in 2011 increased over 2010. The relative abundance of all microcrustaceans (copepods and cladocerans) increased throughout the lake in 2011 and their percent compositions at these locations were within historical ranges. 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 copepods were *Tropocyclops* and *Epishura,* as was often the case in previous years. *Cyclops* and *Diaptomus* were of occasional importance during all seasons. *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 most often dominant among spring populations. The most abundant rotifers observed in 2011, as in many previous years, were *Polyarthra, Kellicotia,* and *Asplanchna. Keratella* and *Conochilus* were also occasionally important among rotifer populations.

Lake Norman continues to support a highly diverse and longitudinally variable zooplankton community. No discernable 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) 2011.

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| 2/23/2011 | Epilimnion | Copepoda | 30.33 | 30.59 | 80.86 | 61.03 | 98.57 |
| | | | (68.7) | (54.3) | (75.2) | (32.4) | (35.3) |
| | | Cladocera | 10.41 | 5.58 | 15.14 | 24.10 | 16.20 |
| | | | (23.6) | (9.9) | (14.1) | (12.8) | (5.8) |
| | | Rotifera | 3.44 | 20.18 | 11.46 | 103.03 | 164.44 |
| | | | (7.7) | (35.8) | (10.7) | (54.8) | (58.9) |
| | | Total | 44.18 | 56.35 | 107.46 | 188.16 | 279.21 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 31 m | 19 m | 20 m | 25 m | 21 m |
| | | Copepoda | 21.48 | 22.30 | 62.98 | 22.41 | 39.69 |
| | | | (68.6) | (70.6) | (70.6) | (29.3) | (35.1) |
| | | Cladocera | 6.18 | 5.03 | 13.92 | 6.06 | 7.50 |
| | | | (19.7) | (15.9) | (15.6) | (7.9) | (6.6) |
| | | Rotifera | 3.66 | 4.27 | 12.36 | 47.98 | 65.96 |
| | | | (11.7) | (13.5) | (13.8) | (62.8) | (58.3) |
| | | Total | 31.33 | 31.60 | 89.26 | 76.45 | 113.15 |

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| 5/25/2011 | Epilimnion | Copepoda | 46.15 | 38.95 | 23.37 | 37.83 | 40.38 |
| | | | (50.7) | (41.2) | (43.0) | (23.9) | (25.0) |
| | | Cladocera | 6.33 | 6.86 | 12.67 | 30.34 | 49.56 |
| | | | (7.0) | (7.3) | (23.3) | (19.1) | (30.7) |
| | | Rotifera | 38.46 | 48.62 | 18.308 | 90.36 | 71.420 |
| | | | (42.3) | (51.5) | (33.7) | (57.0) | (44.3) |
| | | Total | 90.94 | 94.42 | 54.34 | 158.53 | 161.36 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 31 m | 19 m | 21 m | 25 m | 22 m |
| | | Copepoda | 21.68 | 36.37 | 15.90 | 27.31 | 29.45 |
| | | | (44.5) | (47.1) | (46.3) | (36.3) | (32.0) |
| | | Cladocera | 10.56 | 12.37 | 10.72 | 17.46 | 28.73 |
| | | | (21.7) | (16.0) | (31.2) | (23.2) | (31.2) |
| | | Rotifera | 16.47 | 28.55 | 7.69 | 30.41 | 33.98 |
| | | | (33.8) | (36.9) | (22.4) | (40.4) | (36.9) |
| | | Total | 48.70 | 77.29 | 34.30 | 75.18 | 92.16 |

Table 4-1. (Continued).

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| 8/2/2011 | Epilimnion | Copepoda | 12.83 | 13.67 | 12.82 | 10.37 | 12.09 |
| | | | (20.0) | (22.4) | (11.1) | (12.0) | (33.2) |
| | | Cladocera | 11.21 | 5.28 | 28.76 | 25.26 | 12.38 |
| | | | (17.5) | (8.6) | (25.0) | (29.2) | (34.0) |
| | | Rotifera | 40.00 | 42.08 | 73.54 | 50.78 | 11.96 |
| | | | (62.5) | (69.0) | (63.9) | (58.8) | (32.8) |
| | | Total | 64.03 | 61.03 | 115.12 | 86.42 | 36.44 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 31 m | 20 m | 20 m | 25 m | 21 m |
| | | Copepoda | 13.82 | 9.91 | 11.07 | 7.67 | 12.27 |
| | | | (48.3) | (30.7) | (25.6) | (23.0) | (42.2) |
| | | Cladocera | 5.11 | 3.76 | 11.10 | 13.07 | 10.92 |
| | | | (17.9) | (11.6) | (25.6) | (39.2) | (37.5) |
| | | Rotifera | 9.62 | 18.58 | 21.13 | 12.56 | 5.82 |
| | | | (33.6) | (57.6) | (48.8) | (37.7) | (20.0) |
| | | Total | 28.63[a] | 32.24 | 43.30 | 33.29 | 85.14 [b] |

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| 11/8/2011 | Epilimnion | Copepoda | 8.85 | 15.91 | 21.69 | 59.24 | 52.53 |
| | | | (50.8) | (54.9) | (49.5) | (35.9) | (34.3) |
| | | Cladocera | 7.86 | 11.85 | 11.76 | 34.14 | 10.49 |
| | | | (45.0) | (40.9) | (26.9) | (20.7) | (6.9) |
| | | Rotifera | 0.73 | 1.22 | 10.33 | 71.59 | 89.95 |
| | | | (4.2) | (4.2) | (23.6) | (43.4) | (58.8) |
| | | Total | 17.45 | 28.97 | 43.78 | 164.97 | 152.98 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 30 m | 18 m | 21 m | 26 m | 21m |
| | | Copepoda | 9.76 | 9.65 | 16.62 | 44.98 | 32.83 |
| | | | (53.6) | (58.1) | (57.2) | (41.4) | (30.8) |
| | | Cladocera | 7.42 | 5.83 | 6.83 | 25.58 | 9.25 |
| | | | (40.7) | (35.1) | (23.5) | (23.6) | (8.7) |
| | | Rotifera | 1.03 | 1.13 | 5.59 | 37.96 | 64.65 |
| | | | (5.6) | (6.8) | (19.2) | (35.0) | (60.6) |
| | | Total | 18.21 | 16.60 | 29.04 | 108.52 | 106.73 |

[a] = *Chaoborus* (81/$m^3$, 0.3% )
[b] = *Chaoborus* (85/$m^3$, 0.3% )

Table 4-2. Zooplankton taxa identified from samples collected quarterly on Lake Norman from 1987 – 2011.

| Taxon | 87-96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copepoda | | | | | | | | | | | | | | | | |
| *Cyclops thomasi* Forbes | X | 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 | |
| *Diaptomus birgei* Marsh | | | | | 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 | | | | | | |
| *D. reighardi* Marsh | | | | X | | | | | | | | | | | | |
| *D.* spp. Marsh | 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 | 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 | | | |
| *Paracyclops fimbriatus* v. *poppei* (Rehb.) | | | | | | | | | | 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 | |
| | | | | | | | | | | | | | | | | |
| 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 | X |
| *B.* spp. Baird | 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 dubia* | | | | | | | | | | | | | | | X | X |
| *C. lacustris* Birge | | X | 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 | |
| *Chydorus* spp. Leach | X | X | | X | | X | X | | X | X | | | X | | | |
| *Daphnia ambigua* Scourfield | X | X | X | X | | X | | | | X | X | X | X | X | X | X |
| *D. catawba* Coker | X | X | | | | X | | | | | | | X | | X | |
| *D. galeata* Sars | X | | | | | | | | | | | | | | | |
| *D. laevis* Birge | X | | | | | | | X | | | | | | | X | |
| *D. longiremis* Sars | X | X | | | X | X | | X | X | | | | | | | |
| *D. lumholzi* Sars | X | | X | X | X | | | | | X | | | | | | X |
| *D. mendotae* (Sars) Birge | | X | X | 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 | X | X |
| *D. pulicaria* Sars | X | X | | | | | | | | | | | | | | |
| *D. retrocurva* Forbes | X | X | 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* (Leivi.) | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *D.* spp. Fischer | X | X | X | | X | X | X | X | X | | | | | | | |

| Taxon | 87-96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 09 | 09 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Disparalona acutirostris* (Birge) | | | | | | | | | X | | | | | | | |
| *Eubosmina* spp. (Baird) | X | | | | | | | | | | | | | | | |
| *Holopedium amazonicum* Stin. | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X |
| *H. gibberum* Zaddach | X | X | X | | | | | | | | | | | | | |
| *H.* spp. Stingelin | X | X | | | X | X | X | X | | | | | | X | | |
| *Ilyocryptus sordidus* (Lieven) | X | | | | | | | | | | | | | | | |
| *I. spinifer* Herrick | | | | X | | | | | | | | | | | | |
| *I.* spp. Sars | X | | 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 |
| *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 | | | | |
| *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 angularis* Gosse | | | | | | | | | | | | | | | X | |
| *B. calyciflorus* Pallas | | | | | | | | | | X | | | | | | |
| *B. caudata* Bar. & Dad. | X | | | | | | | | | | | | | | | |
| *B. bidentata* Anderson | | | | | | | | X | | | | | | | | |
| *B. havanensis* Rousselet | X | X | | | | | | | | | | | | | | |
| *B. patulus* O. F. Muller | X | | X | | | | | | | | | | | | X | |
| *B.* spp. Pallas | X | | X | | | | | | | | | | | | X | |
| *Chromogaster ovalis* (Berg.) | | X | X | X | | X | | | | X | X | X | X | X | | X |
| *C.* spp. Lauterborne | X | | | | | | | | | | | | | | | |
| *Collotheca balatonica* Harring | X | X | 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 | 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 | X | X |
| *C.* spp. Hlava | X | X | | | | X | | X | | | | | | | | |
| *Conochilus unicornis* (Rouss.) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *C.* spp. Hlava | X | X | | | | X | X | | | | | | | X | | |
| *Filinia* spp. Bory de St. Vincent | X | | X | | | | | | X | | | | | | X | |
| *Gastropus stylifer* Imhof | | | X | X | X | X | | | X | | X | X | | | X | X |
| *G.* spp. Imhof | X | X | X | | | X | | | | | | | | | | |
| *Hexarthra mira* Hudson | | X | X | X | X | | X | | | | X | X | X | X | X | |
| *H.* spp. Schmada | X | X | | | | X | | | | | | | | | | |

| Taxon | 87-96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *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 | X | X |
| *K.* spp. Rousselet | X | X | | | | X | X | X | X | X | | | | X | | |
| *Keratella americana* Carlin | | | | | | | | | | | | X | | | | |
| *K. cochlearis* Raderorgan | | | | X | X | | | | X | | | X | X | X | X | X |
| *K. quadrata* Mannchen | | | | | | | | | | | | | | | X | X |
| *K. taurocephala* Myers | | X | | 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 | | | | | | |
| *Monommata* spp. Bartsch | | | | | | | | | | | X | | | X | | |
| *Monostyla stenroosi* (Meiss.) | X | | | | | | | | | | | | | | | |
| *M.* spp. Ehrenberg | X | | X | | | | | X | | | | | | | X | |
| *Notholca* spp. Gosse | 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 | X | X |
| *P. vulgaris* Carlin | X | X | | 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 | X | X |
| *P.* spp. Ehrenberg | 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 |
| *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 | X | X |
| *T. porcellus* (Gosse) | X | X | | X | X | | X | | X | | | | | | | |
| *T. pusilla* Jennings | | X | | | | | | | | | | | | | | |
| *T. similis* Lamark | | | | | | | | | | | 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 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Insecta | | | | | | | | | | | | | | | | |
| *Chaoborus* spp. Lichtenstein | X | | X | 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 2011.

| Locations | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| | | **Copepoda:** | **Epilimnion** | |
| 2.0 | *Tropocyclops* (3.2) | *Epishura* (2.7) | *Tropocyclops* (1.6)[b] | *Tropocyclops* (5.5)[b] |
| 5.0 | *Epishura* (4.0) | *Epishura* (1.7) | No adults present | *Tropocyclops* (2.0) |
| 9.5 | *Epishura* (3.5) | *Epishura* (3.8) | *Tropocyclops* (1.4)[b] | *Tropocyclops* (7.6) |
| 11.0 | *Cyclops* (2.5) | *Epishura* (2.4) | *Tropocyclops* (6.2)[b] | *Tropocyclops* (1.8) |
| 15.9 | *Cyclops* (4.2) | *Epishura* (11.3) | *Mesocyclops* (1.4)[b] | *Tropocyclops* (4.7) |
| | | **Copepoda:** | **Whole-column** | |
| 2.0 | *Epishura* (2.1) | *Epishura* (3.8) | *Mesocyclops* (10.1) | *Tropocyclops* (5.5)[b] |
| 5.0 | *Epishura* (5.5) | *Epishura* (2.3) | *Mesocyclops* (2.0)[b] | *Tropocyclops* (2.9) |
| 9.5 | *Epishura* (2.5) | *Epishura* (4.4) | *Tropocyclops* (1.9) | *Tropocyclops* (6.2) |
| 11.0 | *Epishura* (1.6) | *Epishura* (4.7) | *Mesocyclops* (3.3) | *Diaptomus* (4.6) |
| 15.9 | *Cyclops* (12.2) | *Epishura* (8.7) | *Mesocyclops* (4.1)[b] | *Tropocyclops* (3.1) |
| | | **Cladocera:** | **Epilimnion** | |
| 2.0 | *Bosmina* (92.2) | *Diaphanosoma* (64.9) | *Bosminopsis* (98.7) | *Bosmina* (96.4) |
| 5.0 | *Bosmina* (87.0) | *Diaphanosoma* (62.8) | *Bosminopsis* (96.0) | *Bosmina* (97.6) |
| 9.5 | *Bosmina* (87.3) | *Diaphanosoma* (52.1) | *Bosminopsis* (99.4) | *Bosmina* (86.7) |
| 11.0 | *Bosmina* (77.2) | *Diaphanosoma* (53.6) | *Bosminopsis* (91.3) | *Bosmina* (96.3) |
| 15.9 | *Bosmina* (86.1) | *Diaphanosoma* (37.1) | *Bosminopsis* (90.1) | *Bosmina* (85.4) |
| | | **Cladocera:** | **Whole-column** | |
| 2.0 | *Bosmina* (93.0) | *Bosmina* (40.1) | *Bosimopsis* (87.1) | *Bosmina* (95.4) |
| 5.0 | *Bosmina* (66.8) | *Diaphanosoma* (58.1) | *Bosminopsis* (79.8) | *Bosmina* (96.7) |
| 9.5 | *Bosmina* (83.5) | *Diaphanosoma* (44.6) | *Bosminopsis* (98.2) | *Bosmina* (87.6) |
| 11.0 | *Bosmina* (75.8) | *Diaphanosoma* (47.7) | *Bosminopsis* (91.3) | *Bosmina* (90.5) |
| 15.9 | *Bosmina* (92.9) | *Diaphanosoma* (51.6) | *Bosminopsis* (98.2) | *Bosmina* (88.9) |

Table 4-3. (Continued).

| **Locations** | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| | | **Rotifera:** | **Epilimnion** | |
| 2.0 | *Keratella* (44.0) | *Kellicotia* (63.2) | *Ptygura* (86.3) | *Kellicotia* (38.4) |
| 5.0 | *Asplanchna* (87.7) | *Kellicotia* (47.1) | *Ptygura* (83.4) | *Kellicotia* (44.2) |
| 9.5 | *Asplanchna* (92.1) | *Polyarthra* (43.9) | *Ptygura* (93.7) | *Polyarthra* (38.4) |
| 11.0 | *Asplanchna* (95.6) | *Kellicotia* (89.9) | *Ptygura* (78.4) | *Polyarthra* (68.0) |
| 15.9 | *Asplanchna* (92.2) | *Kellicotia* (96.6) | *Conochilus* (41.9) | *Polyarthra* (76.8) |
| | | **Rotifera:** | **Whole-column** | |
| 2.0 | *Keratella* (63.0) | *Kellicotia* (54.0) | *Ptygura* (71.8) | *Keratella* (44.0) |
| 5.0 | *Keratella* (63.0) | *Kellicotia* (52.8) | *Ptygura* (78.6) | *Polyarthra* (55.3) |
| 9.5 | *Asplanchna* (90.7) | *Polyarthra* (56.1) | *Ptygura* (86.1) | *Kellicotia* (48.6) |
| 11.0 | *Asplanchna* (84.3) | *Kellicotia* (80.4) | *Ptygura* (61.6) | *Polyarthra* (58.8) |
| 15.9 | *Asplanchna* (80.1) | *Kellicotia* (89.0) | *Conochilus* (31.7) | *Polyarthra* (81.3) |

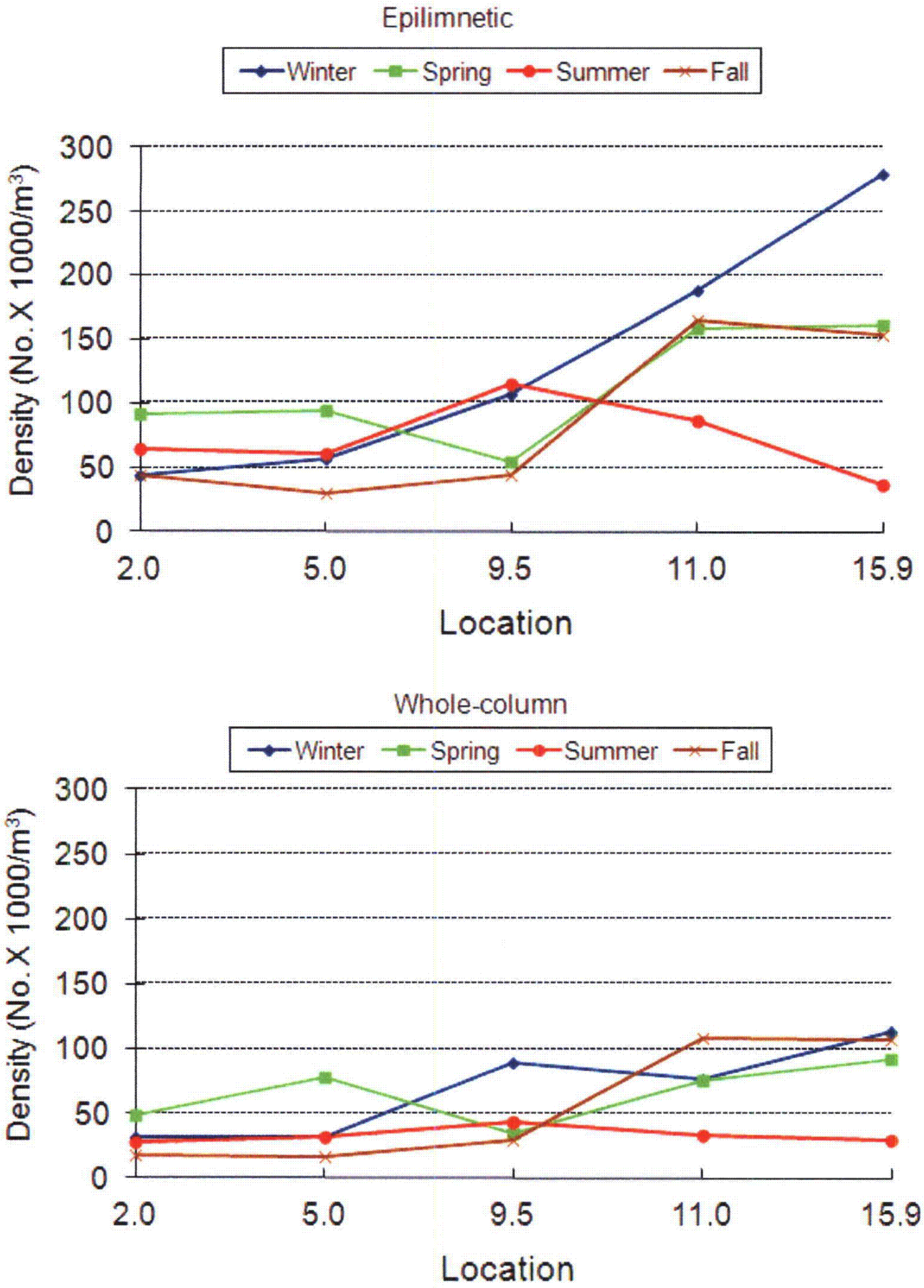



Figure 4-1. Total zooplankton density by location for samples collected in Lake Norman in 2011.

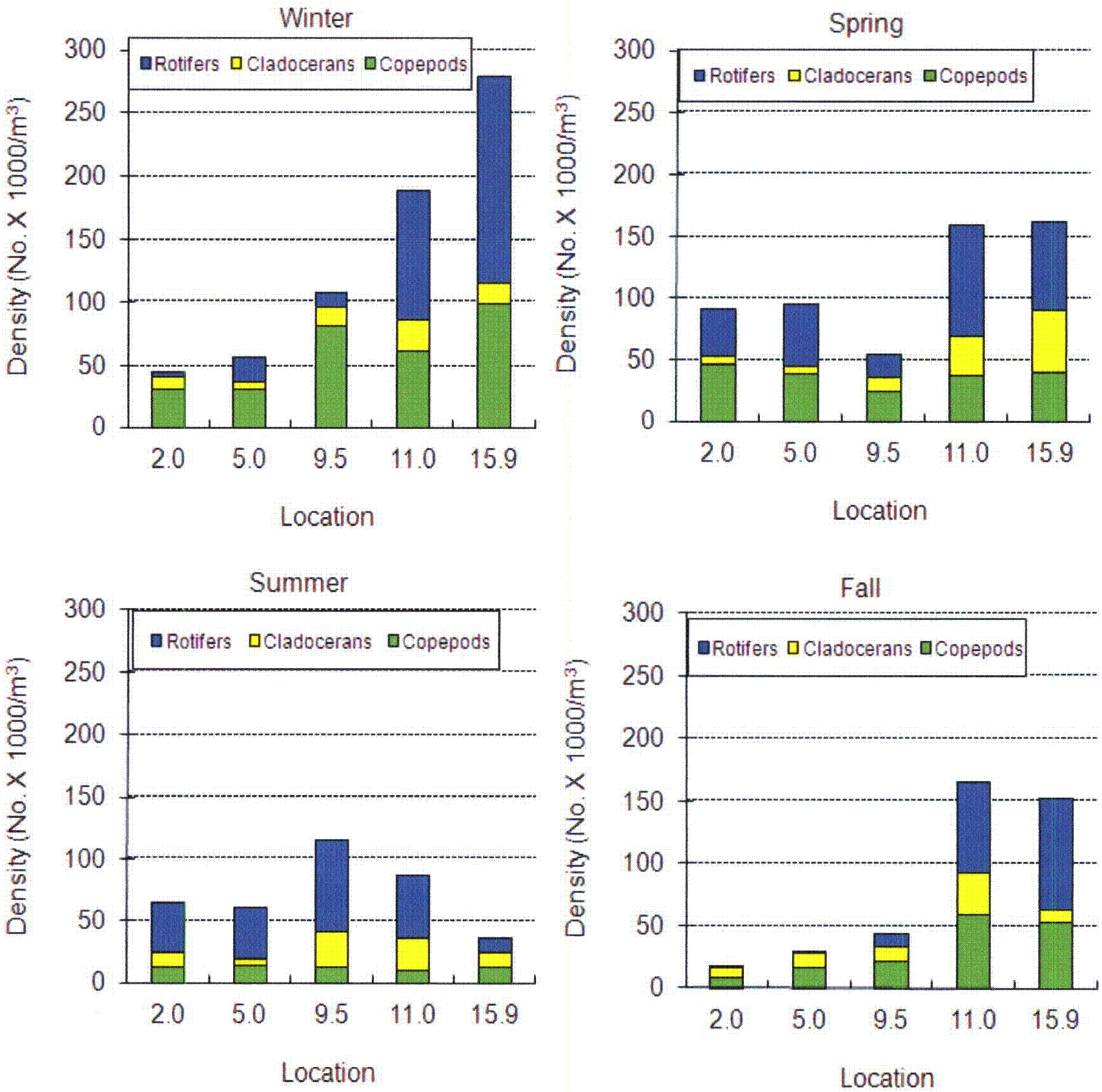



Figure 4-2. Zooplankton community composition by sample period and location for epilimnetic samples collected in Lake Norman in 2011.

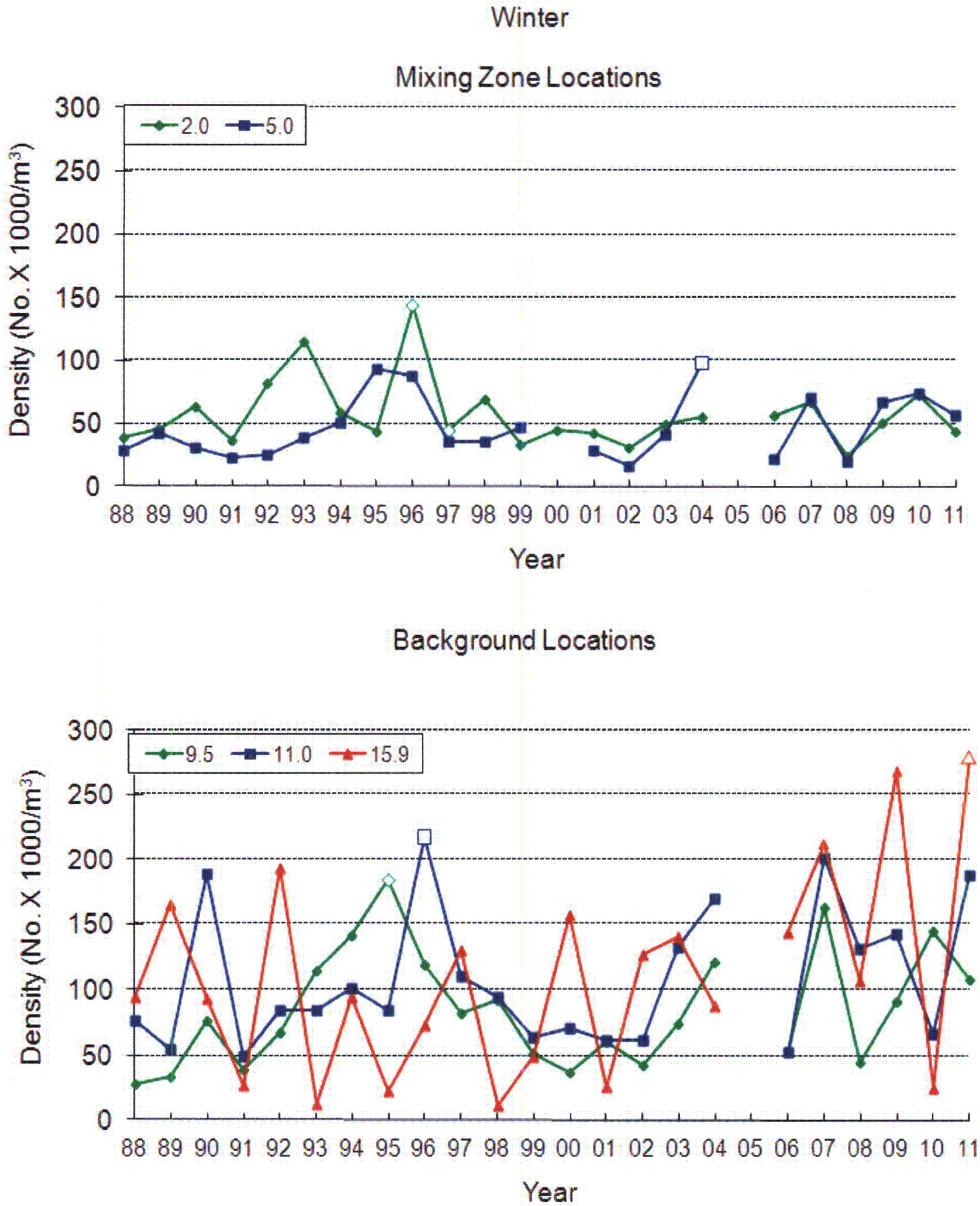
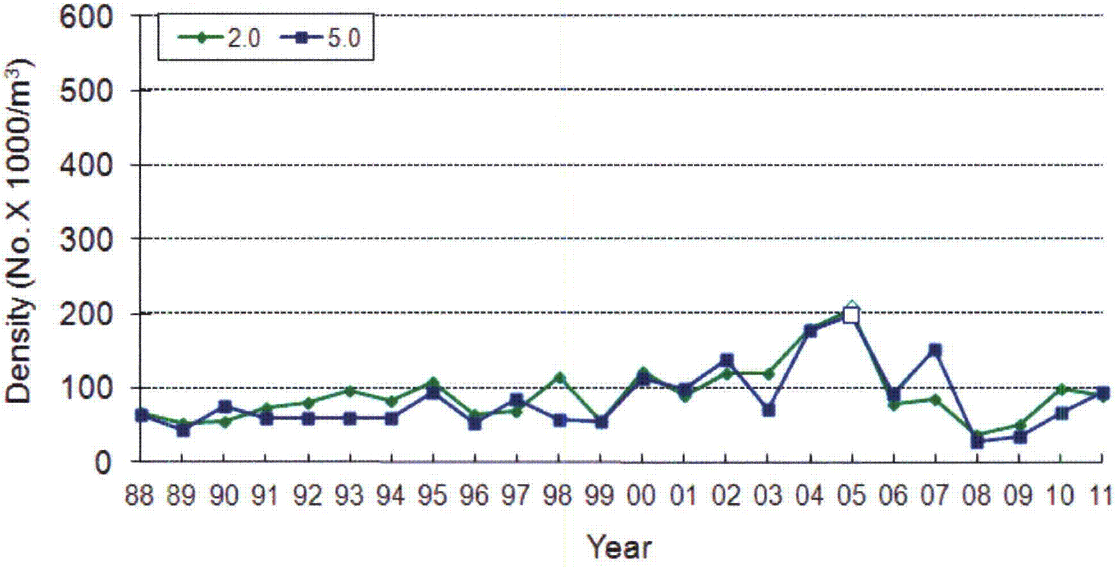



Figure 4-3. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the winter periods of 1988 – 2011 (clear data points represent long-term maxima).

Spring

Mixing Zone Locations




Background Locations

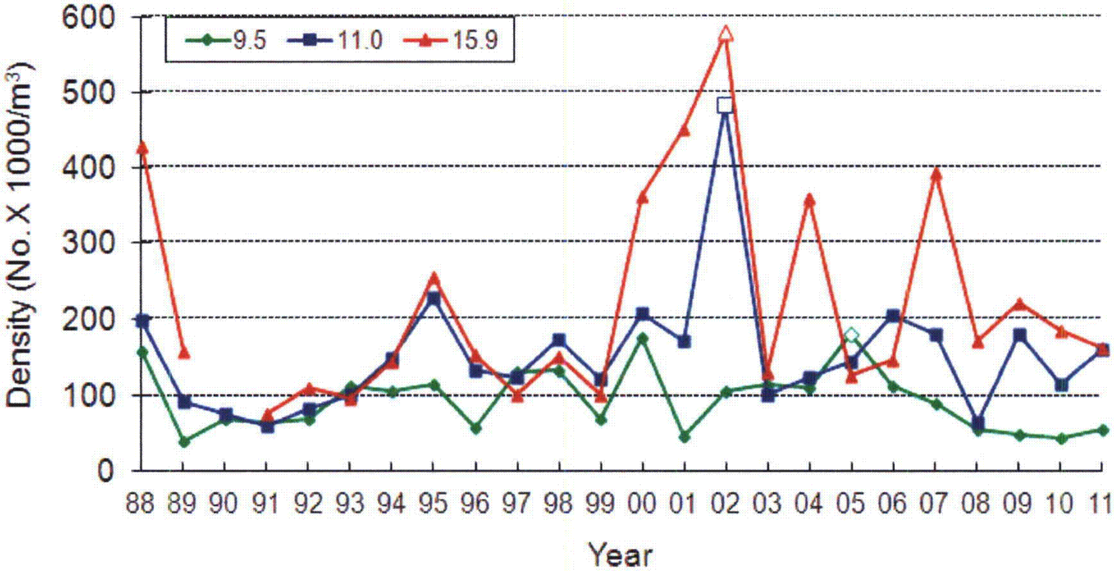



Figure 4-4. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the spring periods of 1988 – 2011 (clear data points represent long-term maxima).

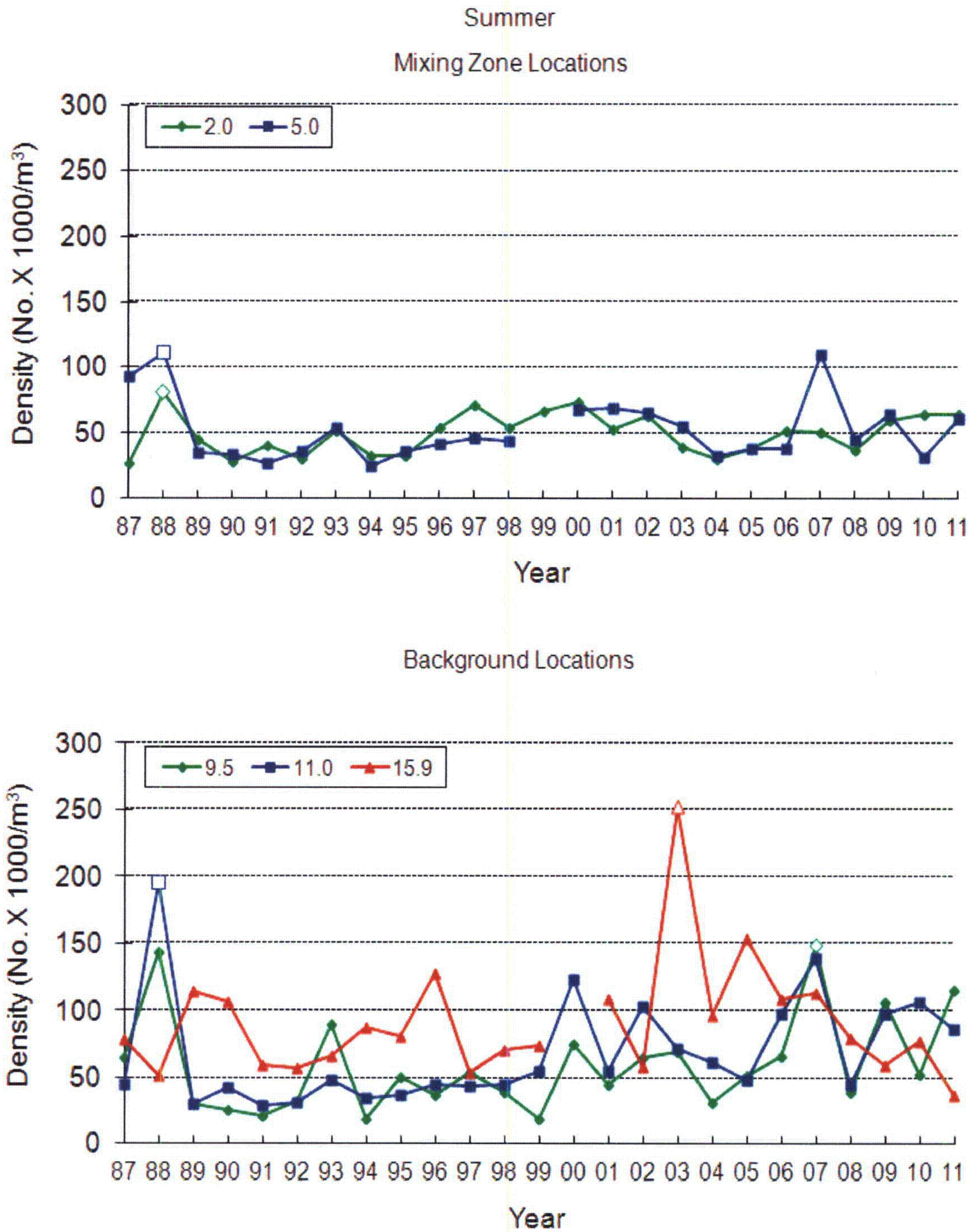



Figure 4-5. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the summer periods of 1987 – 2011 (clear data points represent long-term maxima).

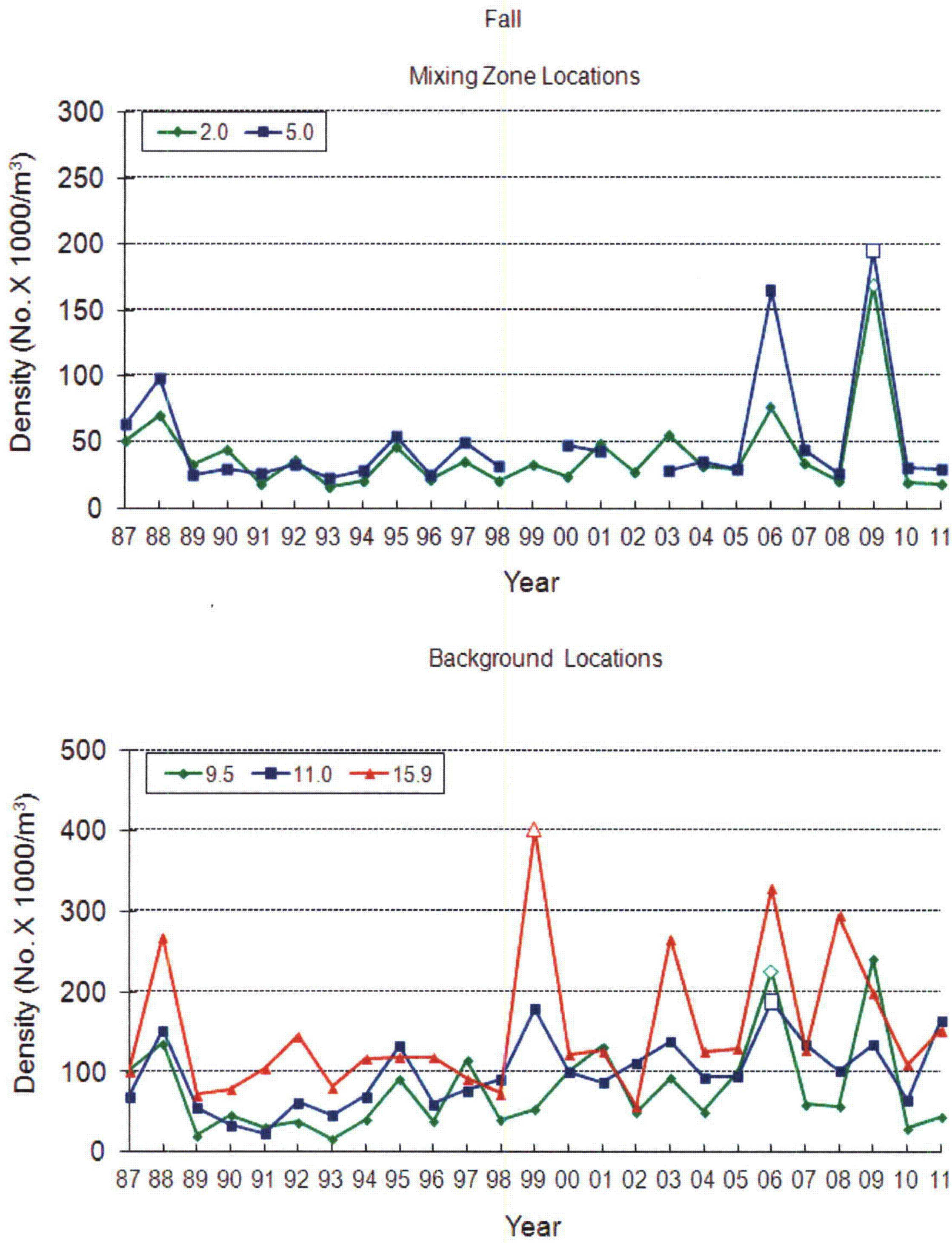
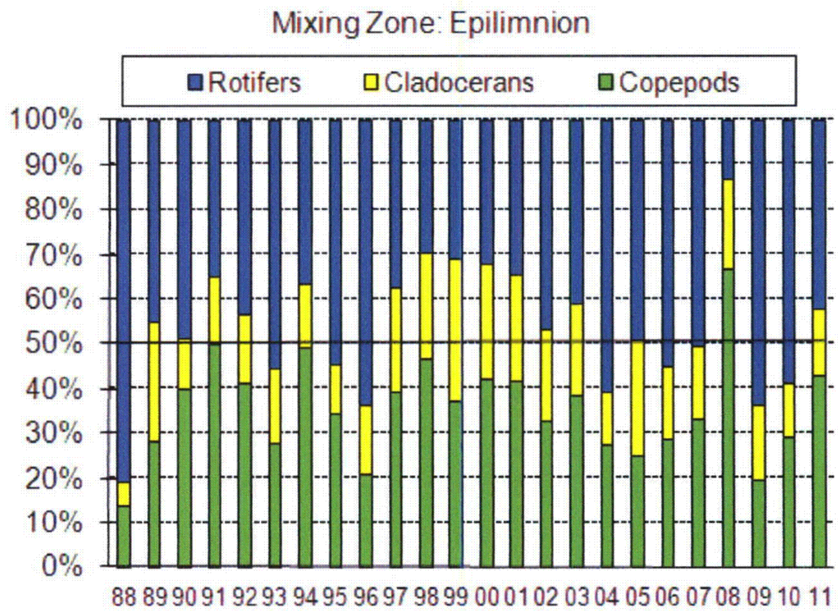



Figure 4-6. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the fall periods of 1987 – 2011 (clear data points represent seasonal maxima).



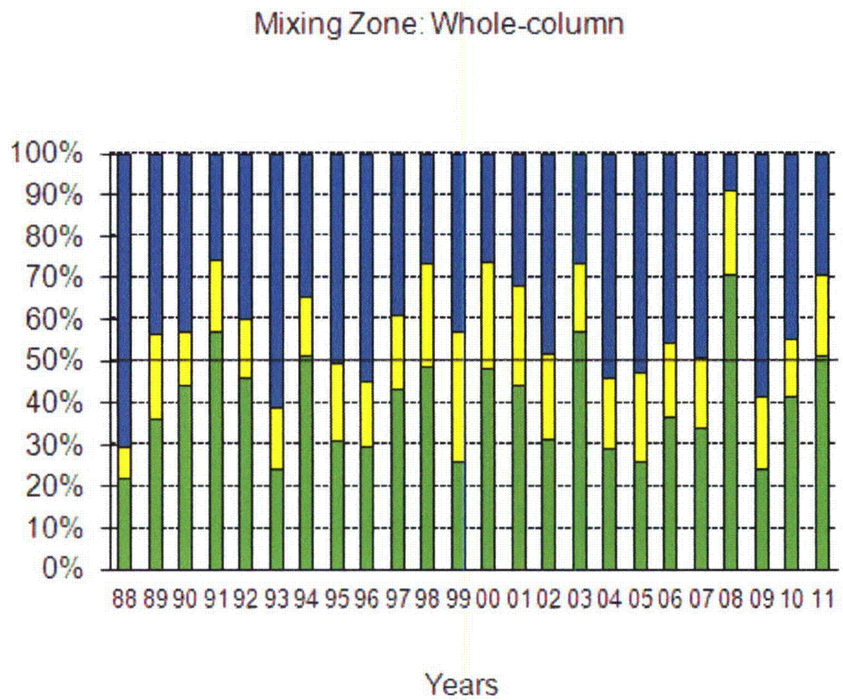




Figure 4-7. Annual percent composition of major zooplankton taxonomic groups from mixing zone locations (Locations 2.0 and 5.0 combined) during 1988 – 2011 (Note: does not include Location 5.0 in the fall of 2002 or winter samples from 2005).

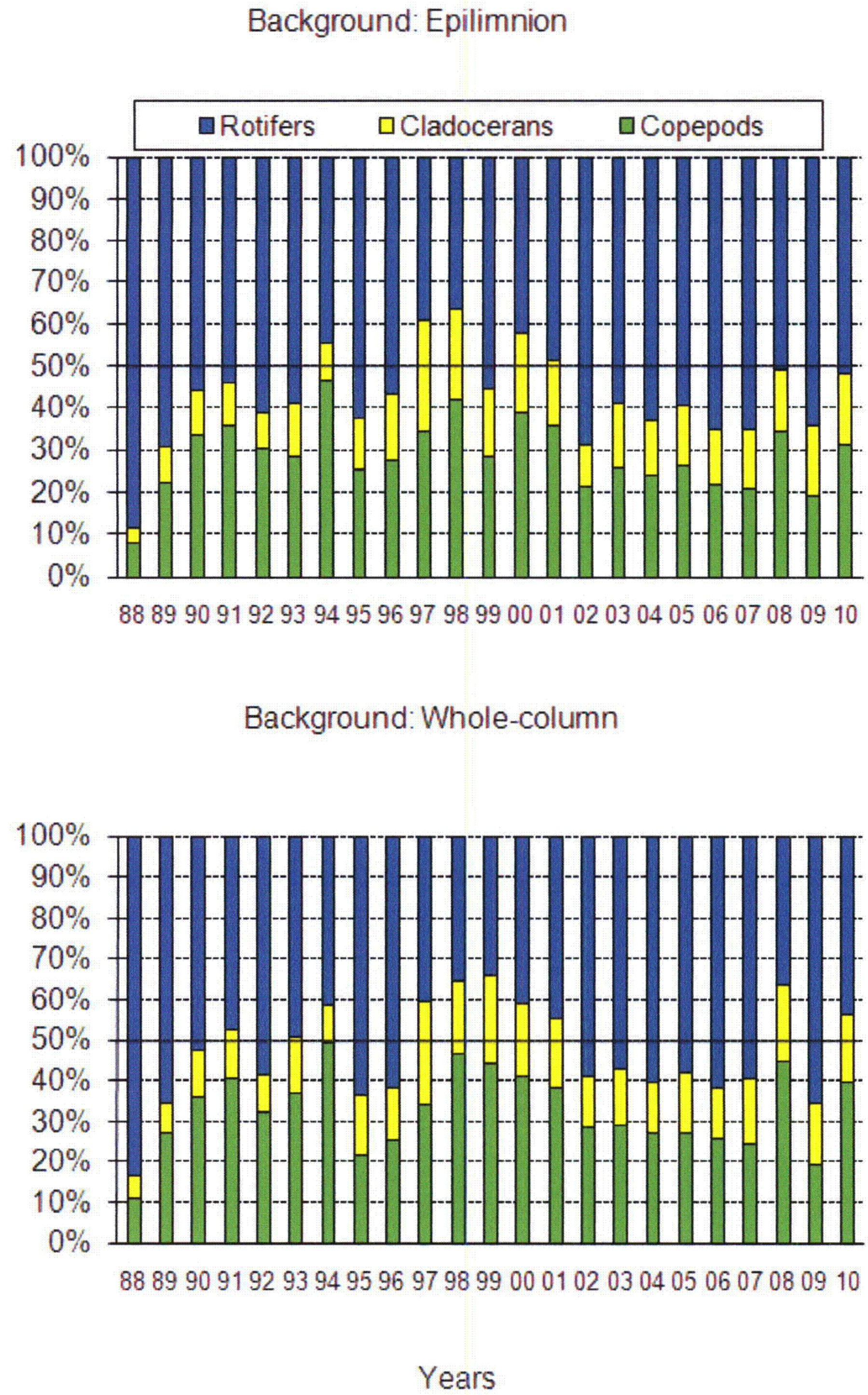



Figure 4-8. Annual percent composition of major zooplankton taxonomic groups from background locations (Locations 9.5, 11.0, and 15.9 combined) during 1988 – 2011 (Note: does not include winter samples from 2005).

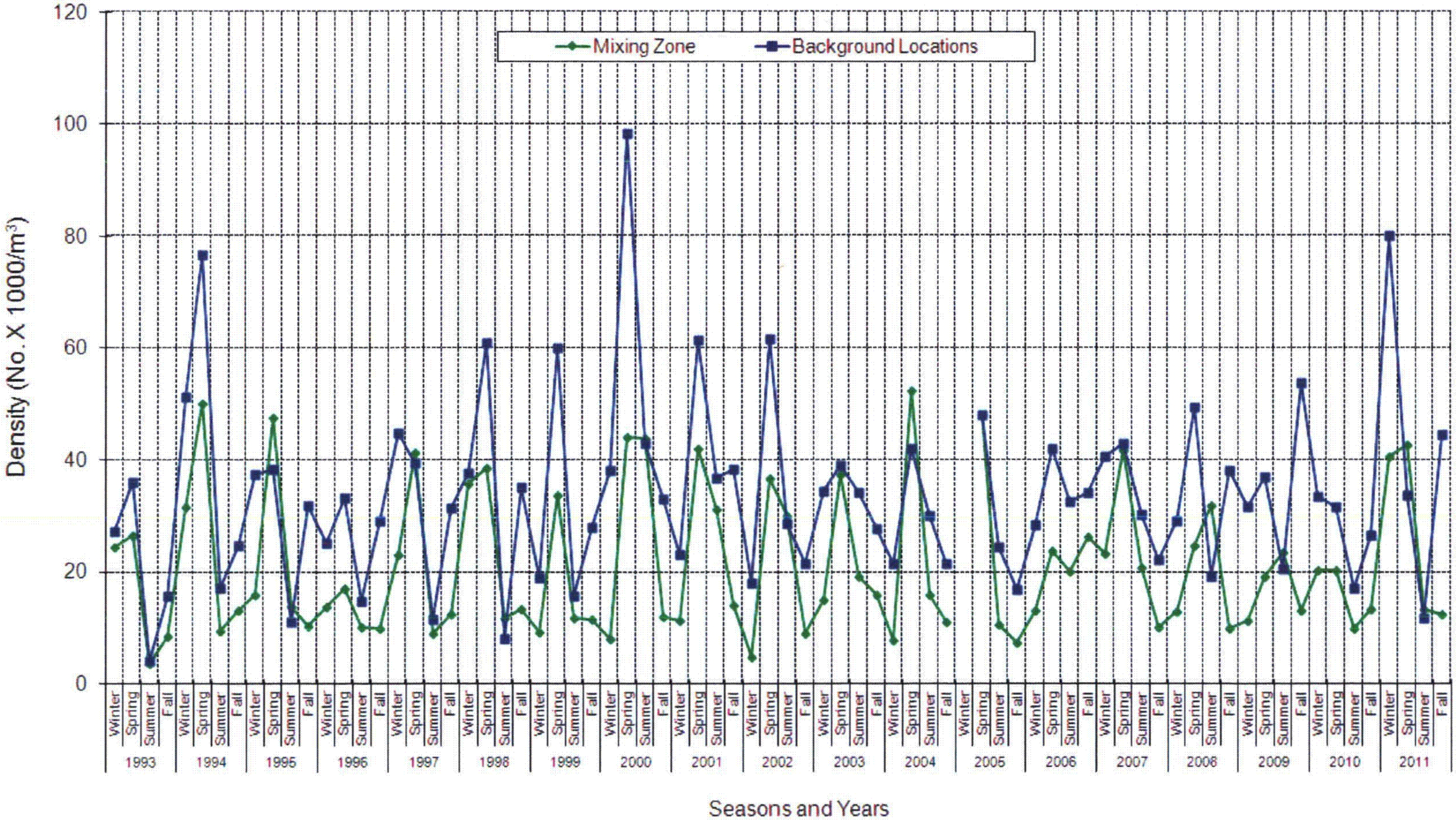



Figure 4-9. Copepod densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2011 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

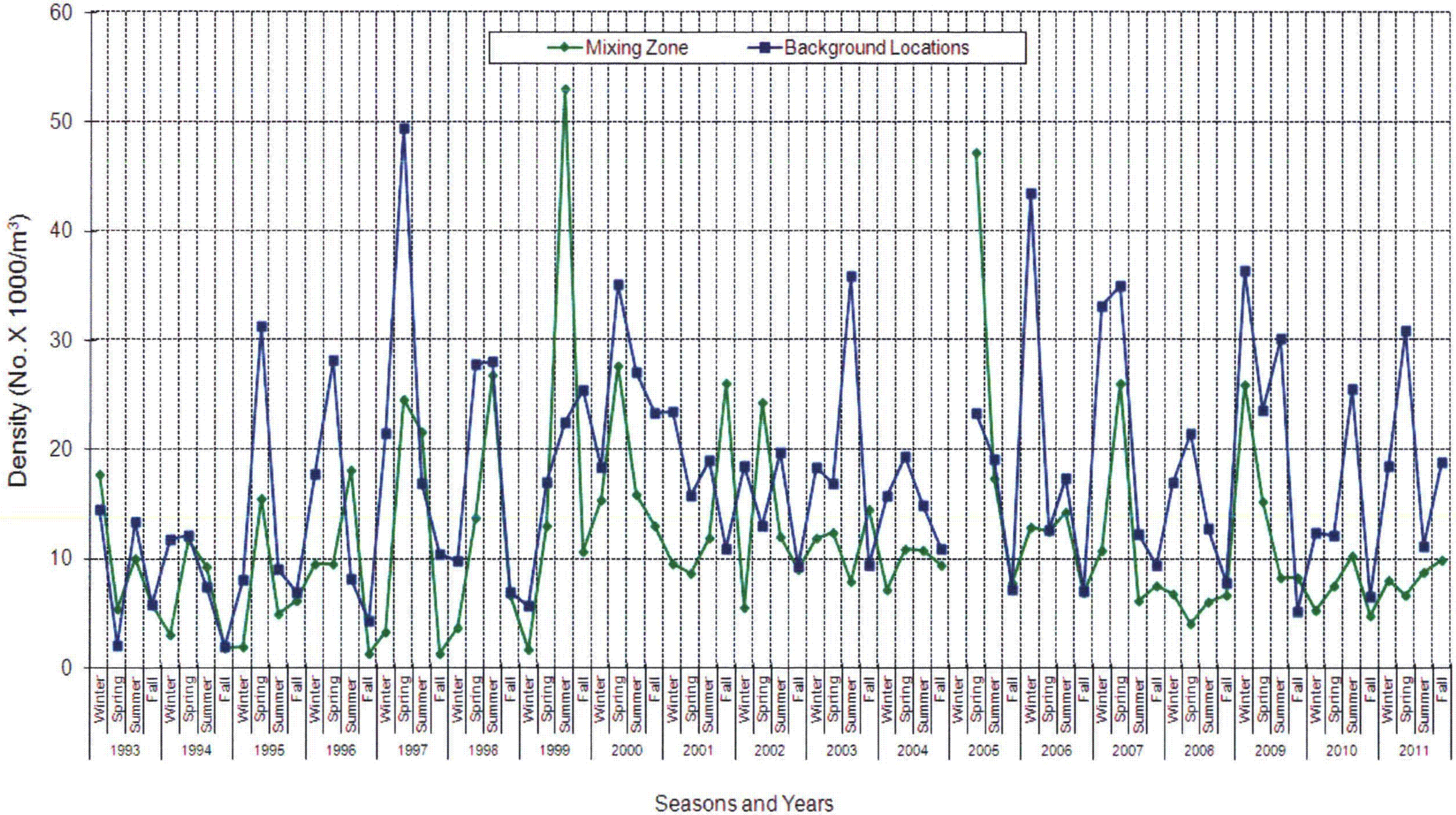



Figure 4-10. Cladoceran densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2011 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9)

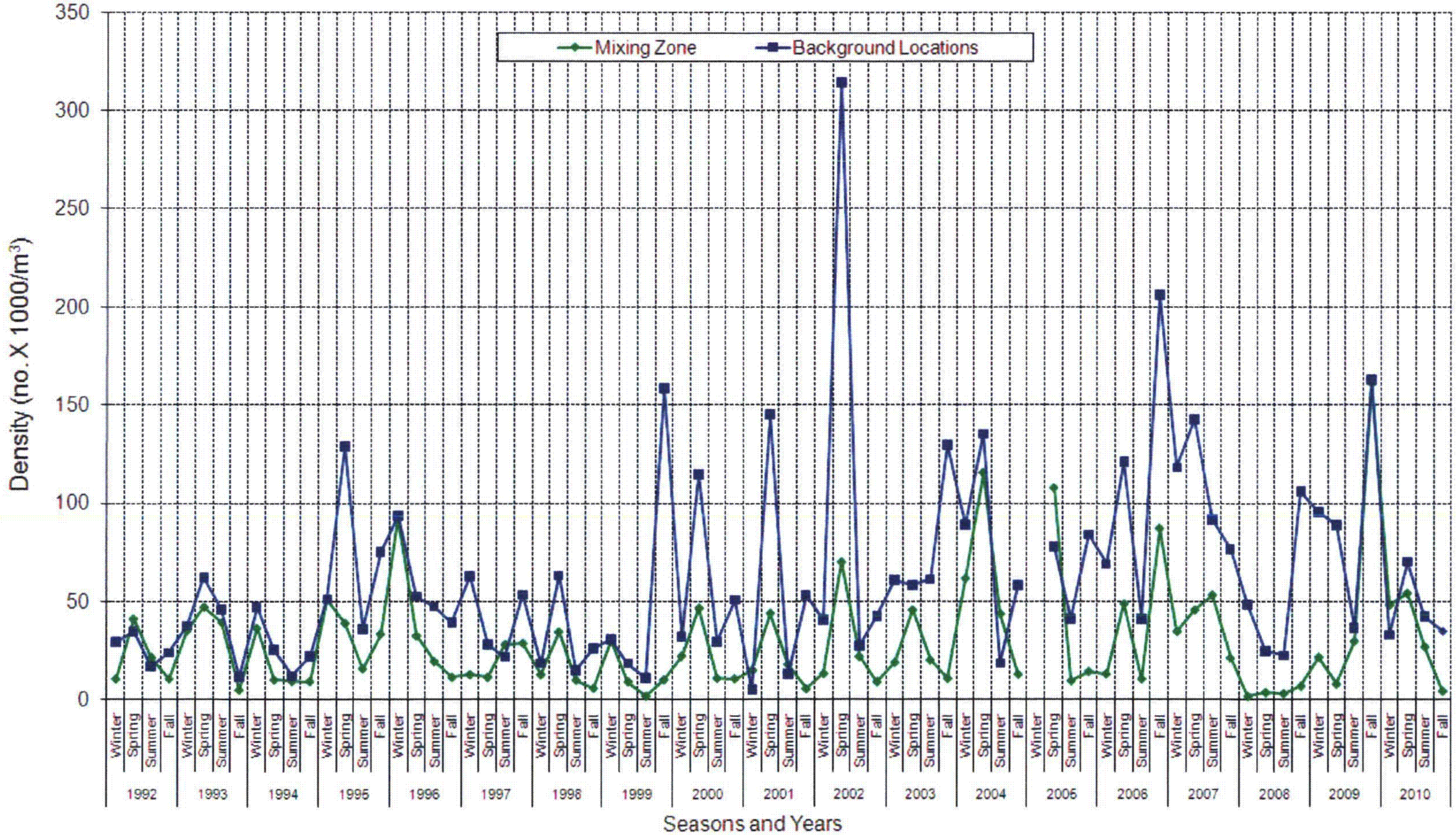



Figure 4-11. Rotifer densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2011 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

# CHAPTER 5

# FISHERIES

## INTRODUCTION

In accordance with the Lake Norman Maintenance Monitoring Program for the McGuire Nuclear Station (MNS) NPDES permit, and associated requirements from the North Carolina Wildlife Resources Commission (NCWRC), Duke Energy personnel monitored specific fish population parameters in Lake Norman during 2011. 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 emphasis on age, growth, and condition; and
5. fall hydroacoustic and purse seine surveys of pelagic forage fish abundance and species composition.

## 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 electrofished in each area and were identical to historical locations sampled 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 black 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 kg/3,000 m) and the number of species were calculated for each sampling area. Sagittal otoliths were removed from all largemouth bass ≥ 150 mm and a subsample of spotted bass (4 from each 25 mm TL size class 150 – 350 mm per area and all ≥ 350 mm) and sectioned for age determination (Devries and Frie 1996). Black bass < 150 mm were assumed to be age 1 because young-of-year bass are not historically collected during spring surveys. Condition ($W_r$) based on relative weight was calculated for spotted bass and largemouth bass ≥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 each species (Anderson and Neumann 1996). Growth rates were compared between species and among areas.

Fall ElectrofishingYoung-of-Year Bass Survey

An electrofishing survey was conducted in mid-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. Based upon historical length-frequency data, only bass < 150 mm were considered to be young-of-year and used for data analysis.

Summer Striped Bass Mortality Surveys

Mortality surveys were conducted at least weekly during July and August to specifically search for dead or dying striped bass in Zones 1 to 4. All observed dead and dying striped bass were collected and a subsample of individual TLs was measured prior to disposal.

Striped Bass Netting Survey

Striped bass were collected in early December for age, growth, and condition determinations. Fish were collected from local fishermen and in monofilament gill nets. The nets measured 76.2 m long x 6.1 m deep and contained two 38.1-m panels of either 38- and 51-mm square mesh or 63- and 76-mm square mesh. Nets were set overnight in areas where striped bass

were previously located. Individual TL and weight were obtained and sagittal otoliths removed and sectioned for age determination (Devries and Frie 1996). Growth and condition ($W_r$) were determined as described previously for black bass. Additionally, all catfish collected were identified, measured, 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. A 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 epilimnion of 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.

## RESULTS AND DISCUSSION

### Spring Electrofishing Survey

Spring 2011 electrofishing resulted in the collection of 7,729 individuals (18 species and two centrarchid hybrid complexes) weighing 331.72 kg at average water temperatures ranging from 15.9 to 19.2 °C (Table 5-1). Bluegill *Lepomis macrochirus* dominated samples numerically while spotted bass dominated samples gravimetrically. The survey consisted of 4,298 individuals (17 species and two centrarchid hybrid complexes) in the MSS area, 1,960 fish (15 species and two centrarchid hybrid complexes) in the REF area, and 1,471 individuals (13 species and two hybrid centrarchid complexes) in the MNS area (Figure 5-2a). There is no apparent temporal trend in the number of individuals collected within or among areas since 1993. The MSS area had a considerable increase in the number of sunfish.

Total biomass of fish in 2011 was 195.96 kg in the MSS area, 88.73 kg in the REF area, and 47.04 kg in the MNS area, following the spatial trend of previous years (Figure 5-2b). This trend of increasing fish biomass with increased distance uplake follows historical spring electrofishing data and similar spatial heterogeneity noted by Siler et al. (1986). Those 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 is further evident 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 5-3a and b) and, in 2011, were most abundant in the MSS area, intermediate in the REF area, and least abundant in the MNS area. Spotted bass biomass showed the same spatial heterogeneity trend as total fish biomass: highest in the MSS area, intermediate in the REF area, and lowest in the MNS area. In 2011, small spotted bass (< 150 mm) dominated the black bass catch in all areas (Figures 5-4a and b).

Spotted bass (> 150 mm) mean $W_r$ ranged from 67.1 for fish 150 to 199 mm in the MNS area to 80.0 for fish 400 to 449 mm in the REF area (Figure 5-5a). Overall, spotted bass (≥ 150 mm) mean $W_r$ values were highest in the REF area (78.6), intermediate in the MSS area (74.3), and lowest in the MNS area (70.5) which was slightly lower than the range of observed historical values (71.4 to 82.3) (Duke Power 2004a, 2005, and unpublished data; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

The number of individuals and biomass of largemouth bass from all areas in 2011 were low and similar to 2006 – 2010 data, signifying a downward trend (Figure 5-6a and b). As in most years, 2011 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 (>150 mm) were distributed across all size classes (Figure 5-4b) with mean $W_r$ ranging from 68.7 for two fish 150 to 199 mm in the REF area to 94.6 for two fish ≥ 450

mm in the MSS area (Figure 5-5b). The low number of largemouth bass collected diminishes the significance of these comparisons. Overall, largemouth bass (≥ 150 mm) mean $W_r$ values were highest in the MSS area (80.5), similar in the REF and MNS areas (77.5), and within the range of observed historical values (76.0 to 89.9; Duke Power 2004a, 2005, and unpublished data; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

Largemouth bass numbers in 2011 were inadequate for growth rate comparisons with spotted bass or with previous years of largemouth bass data (Tables 5-2 and 5-3). The highest mean TL by age varied among areas as in most previous years. Spotted bass growth for all areas was fastest through age 3 and slowed with increasing age as in previous years. Although the largemouth bass population parameters have decreased sharply since the introduction of spotted bass, it is unclear what role this introduction or the effects of other introduced species (e.g., alewife *Alosa pseudoharengus* and white perch *Morone americana*) have had in largemouth bass declines (Kohler and Ney 1980 and Madenjian et al. 2000).

<u>Fall Electrofishing Young-of-Year Black Bass Survey</u>

Fall 2011 electrofishing resulted in the collection of 110 spotted, 1 largemouth, and no hybrid black bass young-of-year (< 150 mm), showing an overall decrease in the number of young-of-year black bass compared since 2008 (Figure 5-7). As in 2005 – 2010, young-of-year black bass numbers were highest in the MSS area.

<u>Summer Striped Bass Mortality Surveys</u>

During July and August 2011 surveys, a total of 395 dead striped bass were collected, representing a sharp decrease from 2010 (6,981), the largest recorded die-off of this Lake Norman sport fish species (Figure 5-8). Striped bass TL varied (450-647 mm) with a subsample (n = 149) mean of 552 mm. Most fish were collected from Zone 1. Although some mortalities were likely incidental (i.e., hooking-related mortalities associated with the capture of meta- and hypolimnetic striped bass from cooler depths and release in warm epilimnetic waters), this number was indeterminate. Fish mortalities were associated with the elimination of preferred striped bass habitat in the hypolimnion, first reported July 25 (see Chapter 2 including Figure 2-11). Death of Lake Norman striped bass at approximately 2.0 mg/L further supports the lethal DO component of the striped bass habitat "squeeze" model (Coutant 1985) as measured hypolimnetic temperatures were non-stressful (< 20 °C).

Since the survey began in 1983, summer mortalities in excess of 100 striped bass have also occurred in 1983 (163), 2004 (2,609), 2009 (362), and 2010 (6,981).

Continuous water quality monitoring in Lake Norman throughout the year and a rigorous schedule during summer since 1983 have shown that habitat has remained fairly constant and within a range of historical bounds (see Chapter 2). While similar, and somewhat variable, DO regimes have been observed since 1983, their potential detrimental impact on striped bass survival appears to be linked to the recent colonization of Lake Norman by alewife. Adult alewife seek cool water in summer and are a significant nutritive improvement over the typically smaller, threadfin shad *Dorosoma petenense* which prefer warm water and dominate the forage community (Table 5-4; Brandt et al. 1980). The presence of large adult alewives in cool hypolimnetic waters during summer attracts striped bass which may, or may not, get trapped there as the habitat "squeeze" progresses. As recent research by Thompson (2006) has implicated a forage component to the stressful habitat "squeeze" period, the presence of striped bass in the hypolimnion during warm summer months appears to be a logical and recent occurrence. Slight nuances in the progression and severity of the metalimnetic oxygen minima from year to year may mean the difference between the deaths of large numbers of striped bass or few to none (Dr. James Rice, NC State University, personal communication). A thick and anoxic metalimnion may trap and kill striped bass while a thin or hypoxic metalimnion may allow fish to escape and attempt to survive the summer in warmer epilimnetic waters. Whatever the mechanism, while striped bass deaths can be attributed to this temperature-oxygen "squeeze", their attraction into the hypolimnion is primarily due to the presence of adult alewife.

Winter Striped Bass Netting Survey

Striped bass (111 via gill netting, 4 from anglers) collected in December 2011 ranged in TL from 338 to 674 mm and were dominated by age 1 fish (Figure 5-9). Striped bass growth was fastest through age 3 and slowed with increasing age, although the low number of older striped bass collected diminishes the significance of this comparison. Mean $W_r$ was highest for age 1 fish (87.4) and declined thereafter. Mean $W_r$ was 83.3 for all striped bass in 2011, within the range of observed historical values (78.5 to 86.1). However, the predominance of age 1 striped bass collected in 2011 diminishes the value of this comparison. Growth in 2011 was also consistent with historical values measured since consistent annual gillnetting began in 2003, given the preponderance of young fish (Duke Power 2004a and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011).

The December striped bass gillnetting also yielded 149 catfish. Blue catfish *Ictalurus furcatus* (119) dominated the catch and ranged in length from 313 to 979 mm. Flathead catfish *Pylodictis olivaris* (17) and channel catfish *I. punctatus* (13) were less numerous and ranged in length from 330 to 820 mm and 314 to 453 mm, respectively.

Fall Hydroacoustics and Purse Seine Surveys

Mean forage fish densities in the six zones of Lake Norman ranged from 1,148 (Zone 1) to 15,796 (Zones 5 and 6) fish/ha in September 2011 (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 2011 was approximately 68.9 million fish, slightly below the average population estimate (74.1 million) since surveys began in 1997 (Figure 5-10). As in most years since 1997, Zone 5 had the highest forage fish density estimates. Forage fish populations in Lake Norman have demonstrated considerable variability with no temporal trends evident since 1997.

Threadfin shad dominated the epilimnetic Lake Norman forage fish community purse seine survey in mid-September 2011 (98.3%), similar to surveys since 1993 (Table 5-4). The modal length class of threadfin shad collected in 2011 was 41 to 45 mm (Figure 5-11) and indicates most fish to be young-of-the-year. Alewife, first detected in Lake Norman in 1999 (Duke Power 2000), have comprised as much as 25.0% (2002) of the pelagic forage fish surveys. Their percent composition has remained relatively low from 2005 to 2011 (range = 1.5 to 5.1%) with a noticeable exception in 2009 (11.6%). The threadfin shad modal TL class measured in mid-September of each year increased after alewife introduction, returning to pre-introduction levels by 2005.

## SUMMARY

In accordance with the Lake Norman Maintenance Monitoring Program for the MNS NPDES permit, specific fish monitoring programs continued during 2011. Spring electrofishing indicated that 13 to 17 species of fish and two hybrid complexes comprised diverse, littoral fish populations in the three survey areas. The number of individuals and biomass of fish in 2011 were generally similar to those noted annually since 1993, although the MSS area had a considerable increase in the number and biomass of sunfish. Collections were numerically and gravimetrically dominated by centrarchids. Largemouth bass number of individuals and

biomass increased slightly from 2010, but remained very low. Spotted bass, adults and young-of-year, number of individuals and biomass remain high, possibly displacing largemouth bass. Introductions of other non-native species (e.g., alewife, blue catfish, flathead catfish, and white perch) may also contribute to changes in the composition and distribution of resident and stocked fish in Lake Norman.

In 2011, striped bass mortalities (395) during summer stratification were the third highest number ever collected, ranging in TL from 450 to 647 mm. Striped bass populations through 2003 existed through most summer periods by residing in warm epilimnetic waters near their physiological tolerance limits. The introduction of alewives by fishermen provided an alternative, and larger, prey item that striped bass have followed into the Lake Norman hypolimnion during natural summer stratification. In some years (2004, 2009, 2010, and 2011), striped bass became trapped by the temperature-oxygen "squeeze", and died. This new forage fish species has turned the marginal striped bass habitat of Lake Norman into one that periodically causes the deaths of large numbers of this stocked sport fish species. It should be noted that preferred striped bass habitat has always been eliminated during the summer in Lake Norman since the first reported die-off in 1983.

Winter mean $W_r$ (83.3) of striped bass was similar to historical values although dominated by age 1 fish. Hydroacoustic sampling estimated a forage fish population of approximately 68.9 million in 2011, slightly below the average population estimate (74.1 million) since surveys began in 1997. Alewife percent composition in fall purse seine surveys was 1.5% and modal threadfin shad TL class was 41 to 45 mm. Temporal fluctuations in clupeid densities contribute to the variable nature of forage fish populations.

The present study adds another year of comparable data to past studies indicating that a balanced indigenous fish community exists in Lake Norman (Duke Power 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, and 2011). 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 2011.

| | | MSS | | REF | | MNS | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| Scientific name | Common name | No. | Kg | No. | Kg | No. | Kg | No. | Kg |
| **Clupeidae** | | | | | | | | | |
| *Dorosoma cepedianum* | Gizzard shad | 30 | 11.86 | 9 | 4.50 | | | 39 | 16.36 |
| **Cyprinidae** | | | | | | | | | |
| *Cyprinella chloristia* | Greenfin shiner | 14 | 0.04 | 2 | 0.00 | 1 | 0.01 | 17 | 0.05 |
| *Cyprinella nivea* | Whitefin shiner | | | 5 | 0.03 | 1 | 0.00 | 6 | 0.03 |
| *Cyprinus carpio* | Common carp | 19 | 58.54 | 5 | 19.19 | | | 24 | 77.73 |
| *Notropis hudsonius* | Spottail shiner | 10 | 0.08 | 26 | 0.31 | 10 | 0.09 | 46 | 0.47 |
| **Catostomidae** | | | | | | | | | |
| *Carpiodes cyprinus* | Quillback | 1 | 1.74 | | | | | 1 | 1.74 |
| **Ictaluridae** | | | | | | | | | |
| *Ictalurus furcatus* | Blue catfish | 1 | 3.58 | | | | | 1 | 3.58 |
| *Ictalurus punctatus* | Channel catfish | 5 | 1.69 | 1 | 0.31 | | | 6 | 2.00 |
| *Pylodictis olivaris* | Flathead catfish | 6 | 0.76 | 3 | 0.37 | 4 | 0.25 | 13 | 1.38 |
| **Moronidae** | | | | | | | | | |
| *Morone americana* | White perch | 2 | 0.28 | | | 1 | 0.05 | 3 | 0.33 |
| **Centrarchidae** | | | | | | | | | |
| *Lepomis auritus* | Redbreast sunfish | 237 | 4.77 | 317 | 5.18 | 360 | 7.06 | 914 | 17.00 |
| *Lepomis cyanellus* | Green sunfish | 994 | 3.75 | 150 | 1.82 | 17 | 0.15 | 1,161 | 5.72 |
| *Lepomis gulosus* | Warmouth | 33 | 0.29 | 11 | 0.32 | 12 | 0.16 | 56 | 0.77 |
| *Lepomis* hybrid | Hybrid sunfish | 98 | 2.99 | 58 | 1.29 | 123 | 1.34 | 279 | 5.62 |
| *Lepomis macrochirus* | Bluegill | 2,443 | 25.89 | 1,181 | 12.61 | 784 | 10.17 | 4,408 | 48.67 |
| *Lepomis microlophus* | Redear sunfish | 60 | 8.48 | 39 | 1.92 | 19 | 2.20 | 118 | 12.61 |
| *Micropterus punctulatus* | Spotted bass | 275 | 43.17 | 125 | 29.95 | 118 | 16.91 | 518 | 90.03 |
| *Micropterus salmoides* | Largemouth bass | 66 | 26.68 | 22 | 8.74 | 16 | 7.72 | 104 | 43.15 |
| *Micropterus* hybrid | Hybrid black bass | 2 | 0.94 | 3 | 1.30 | 4 | 0.94 | 9 | 3.18 |
| *Pomoxis nigromaculatus* | Black crappie | 2 | 0.42 | 3 | 0.90 | 1 | 0.01 | 6 | 1.32 |
| **Total** | | 4,298 | 195.96 | 1,960 | 88.73 | 1,471 | 47.04 | 7,729 | 331.72 |
| **Total no. species** | | 17 | | 15 | | 13 | | | |
| **Mean water temperature (° C)** | | 19.2 | | 15.9 | | 18.4 | | | |

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 2011.

| | | Age (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa | Area | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Spotted bass | MSS | 183 | 233 | 336 | 382 | 396 | 442 | 493 | | | |
| | REF | | 225 | 338 | 372 | 404 | 383 | 433 | | | |
| | MNS | 189 | 264 | 348 | 380 | | 404 | | | | |
| | **Mean TL (mm)** | **186** | **241** | **341** | **378** | **400** | **410** | **463** | | | |
| Largemouth bass | MSS | 201 | 279 | 318 | 403 | 403 | 399 | 416 | 425 | 419 | 444 |
| | REF | 202 | | 290 | 357 | 405 | | 565 | 414 | | |
| | MNS | 239 | 253 | 333 | 410 | 386 | 422 | | | 430 | |
| | **Mean TL (mm)** | **214** | **266** | **314** | **390** | **398** | **410** | **491** | **419** | **425** | **444** |

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 2011, to historical largemouth bass mean lengths.

| | Age (years) | | | |
|---|---|---|---|---|
| Location and year | 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[i] | 216 | 294 | 335 | 377 |
| MSS 2010[j] | 197 | 293 | 361 | 361 |
| MSS 2011 | 201 | 279 | 318 | 403 |
| | | | | |
| 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[i] | 184 | 265 | 326 | 350 |
| REF 2010[j] | 172 | 298 | 348 | - |
| REF 2011 | 202 | - | 290 | 357 |
| | | | | |
| 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[i] | 255 | 312 | - | - |
| MNS 2010[j] | 193 | 232 | - | 400 |
| MNS 2011 | 239 | 253 | 333 | 410 |

[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; [i] Duke Energy 2010;
[j] Duke Energy 2011

Table 5-4. Comparison of Lake Norman forage fish densities (No./ha) and population estimates from September 2011 hydroacoustic survey to historical data.

| | | Species composition | | | Threadfin shad modal |
|---|---|---|---|---|---|
| Year | No. | Threadfin shad | Gizzard shad | Alewife | TL class (mm) |
| 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 |
| 2010 | 15,860 | 95.38% | 0.36% | 4.26% | 41-45 |
| 2011 | 24,837 | 98.32% | 0.15% | 1.52% | 41-45 |

Table 5-5. Lake Norman forage fish densities (No./ha) and population estimates from September 2011 hydroacoustic survey.

| Zone | No./ha | Population estimate |
|---|---|---|
| 1 | 1,148 | 2,618,697 |
| 2 | 2,546 | 7,848,071 |
| 3 | 4,067 | 14,054,992 |
| 4 | 2,922 | 3,596,573 |
| 5 | 15,796 | 33,266,713 |
| 6 | 15,796[a] | 7,550,564 |
| | | |
| Lakewide total | | 68,935,612 |
| 95% CI | | 56,583,403 – 81,287,821 |

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

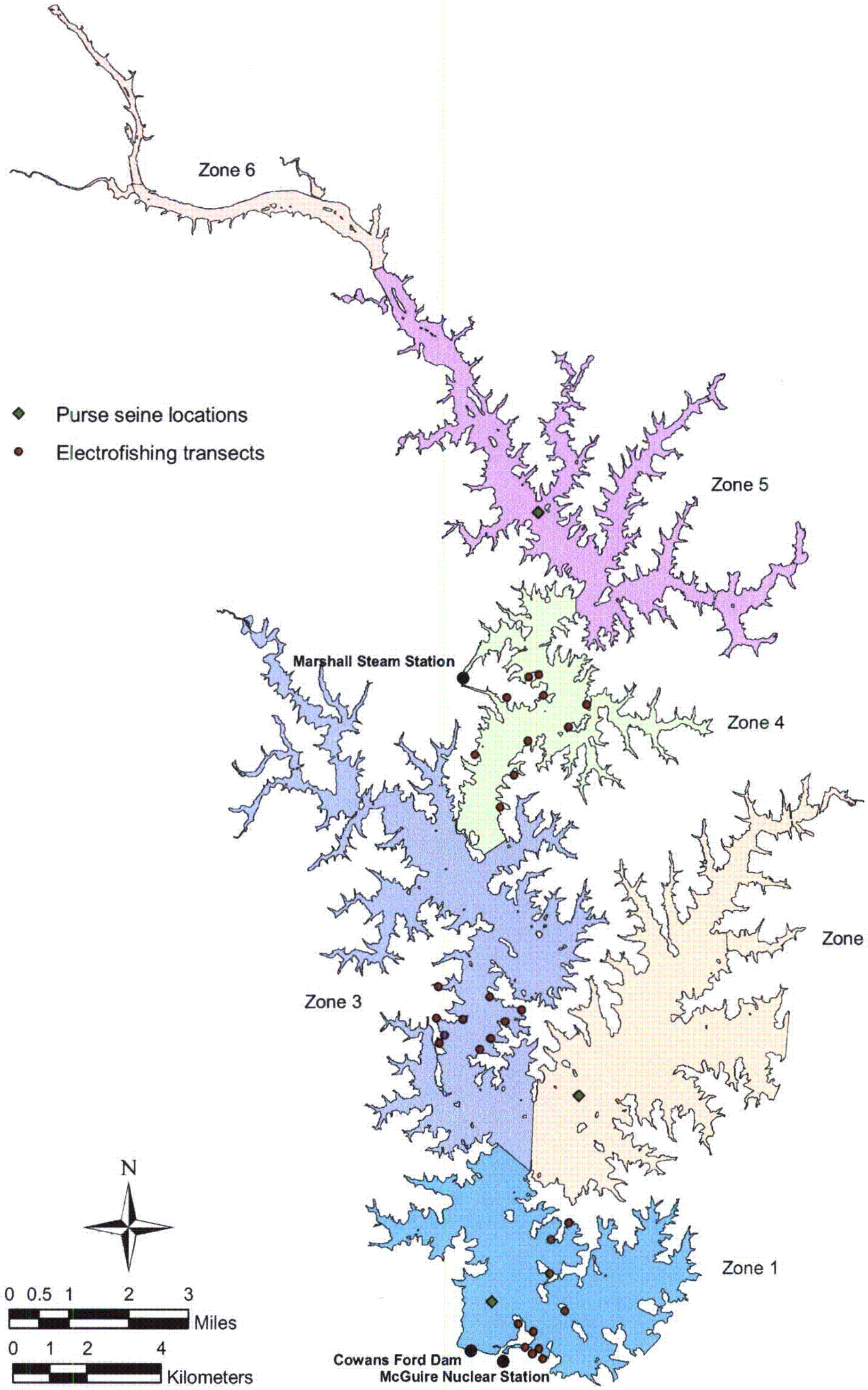



Figure 5-1. Sampling locations and zones associated with fishery assessments in Lake Norman.

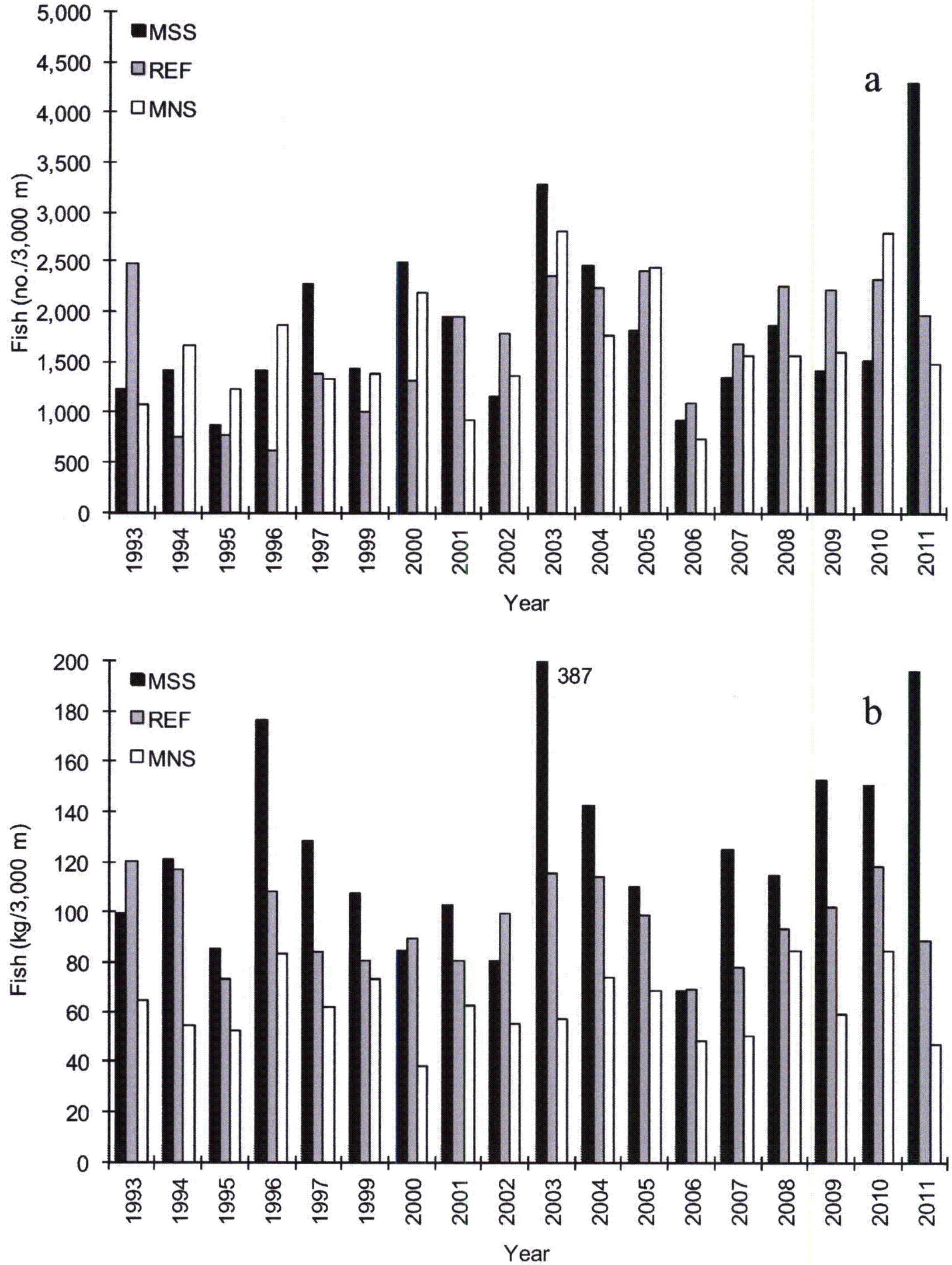



Figure 5-2. Number of individuals (a) and biomass (b) of fish collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2011.

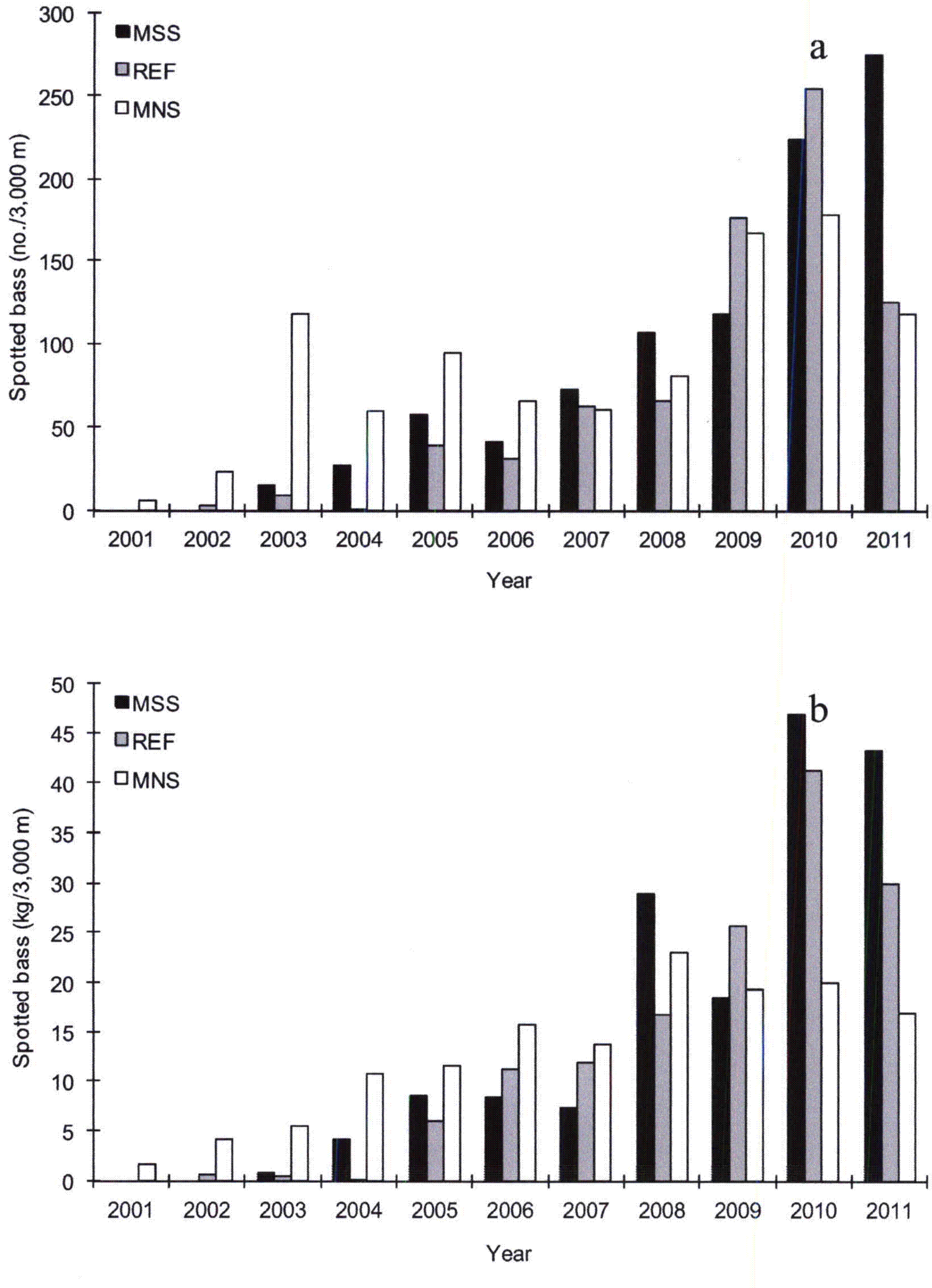
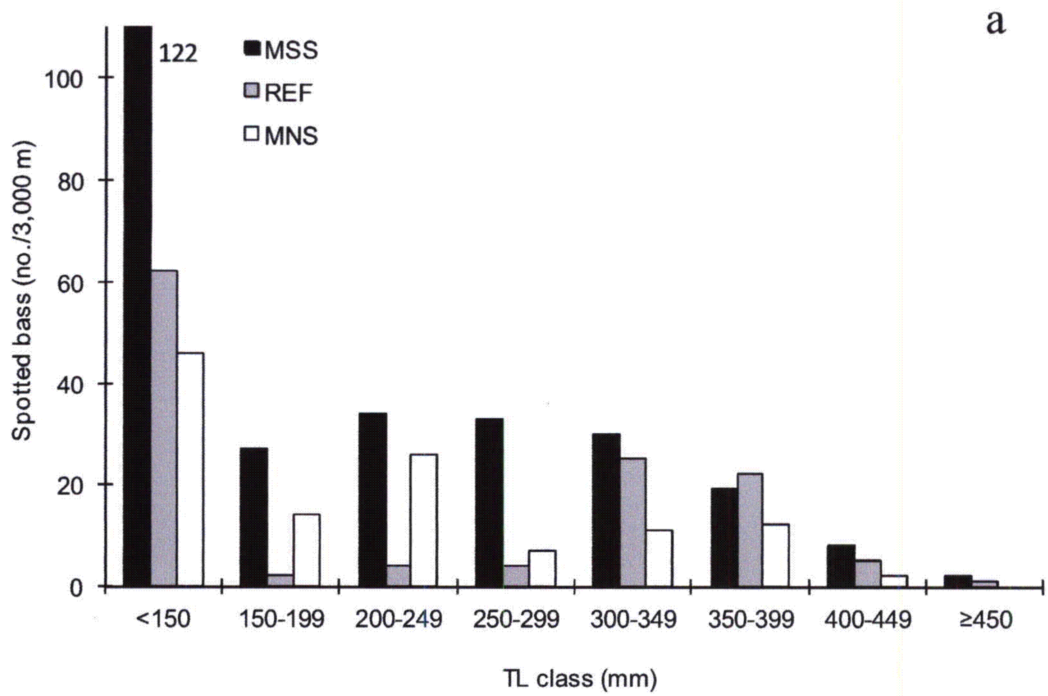



Figure 5-3. Number of individuals (a) and biomass (b) of spotted bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 2001 – 2011.



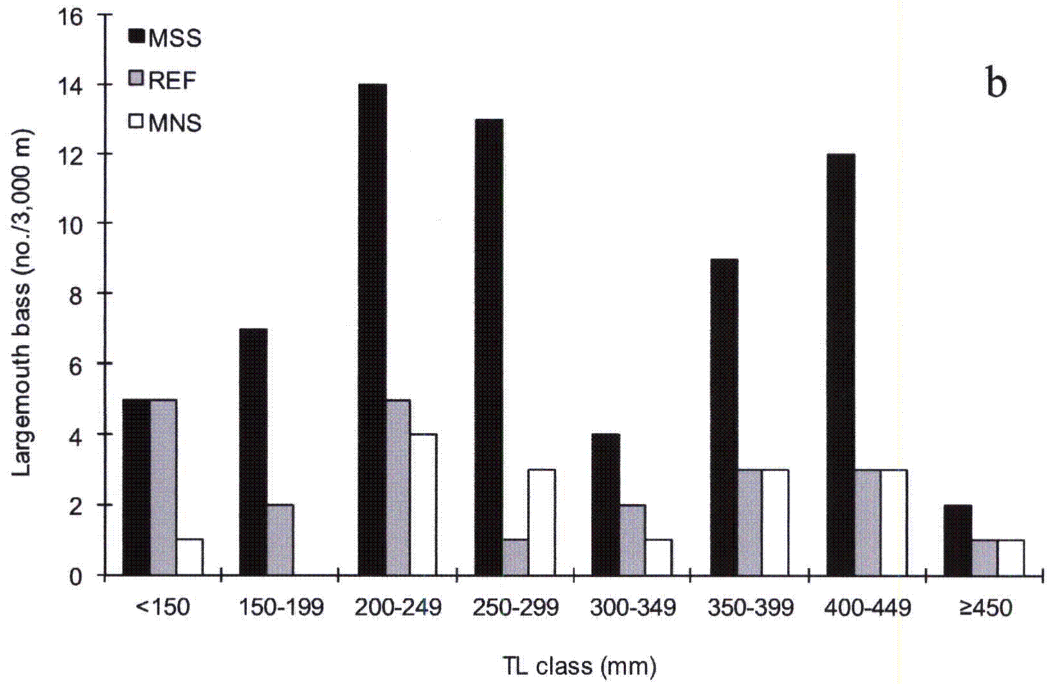




Figure 5-4. Size distributions of spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2011.

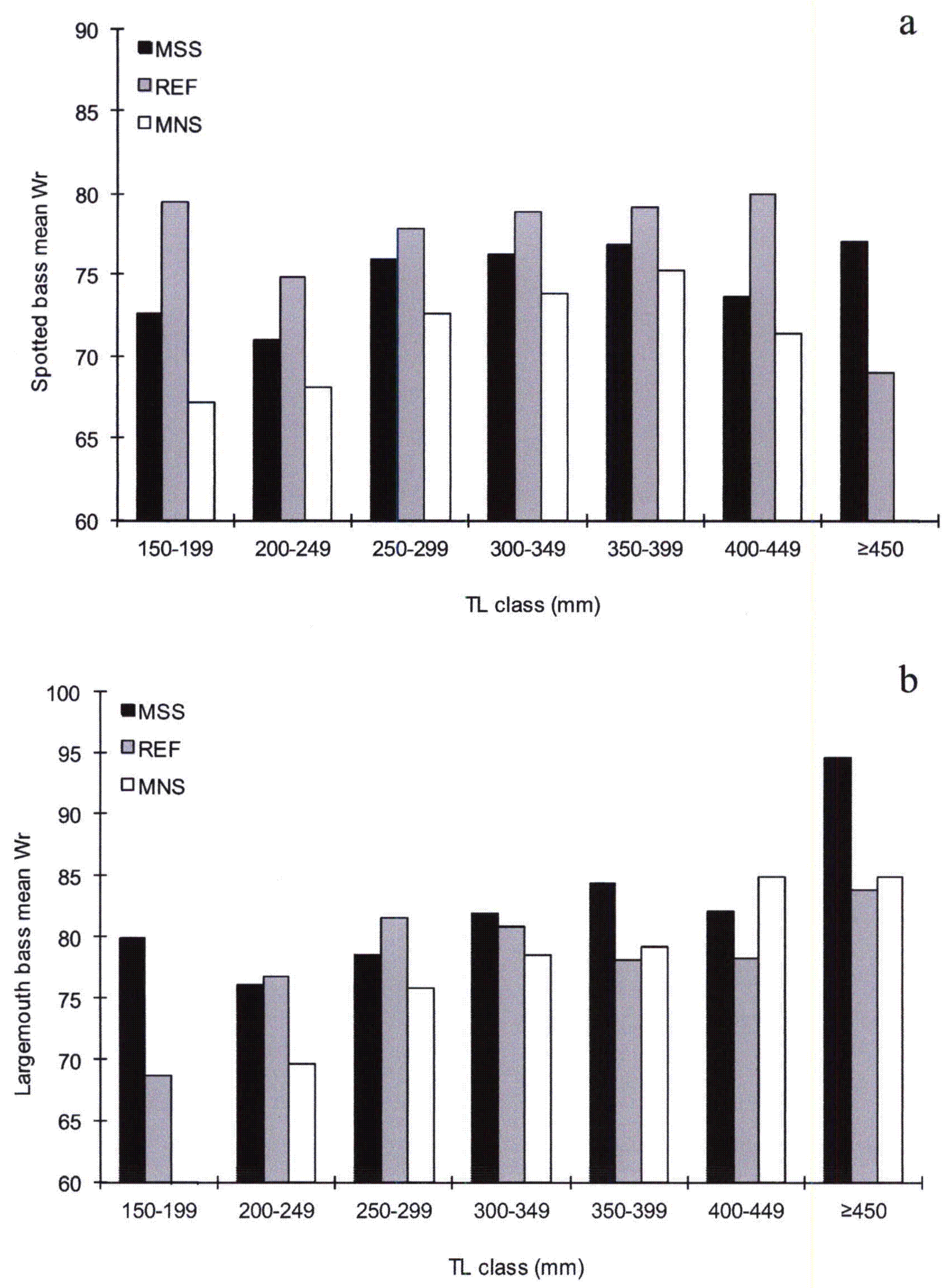



Figure 5-5. Condition (Wr) for spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2011.

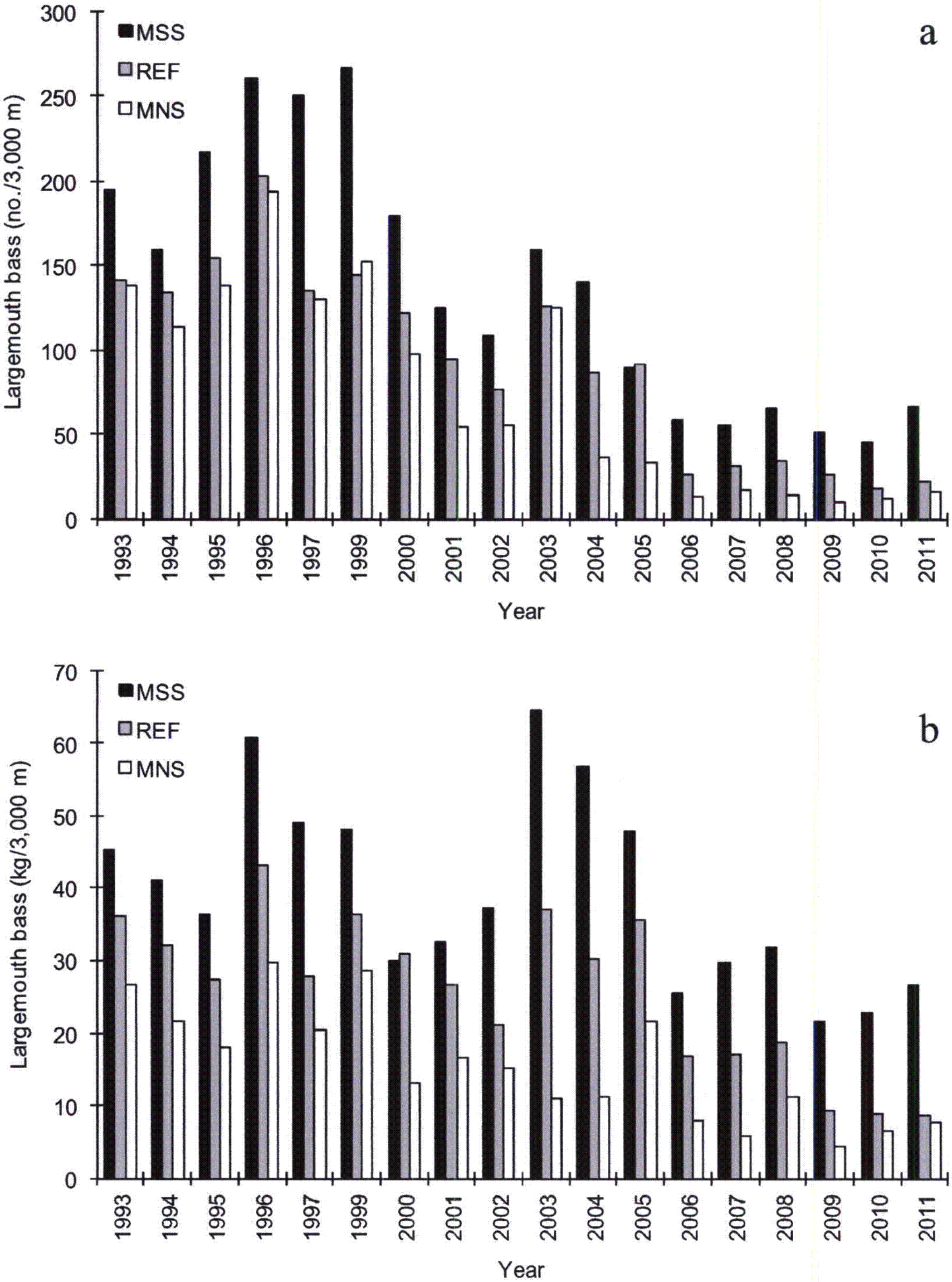



Figure 5-6. Number of individuals (a) and biomass (b) of largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2011.

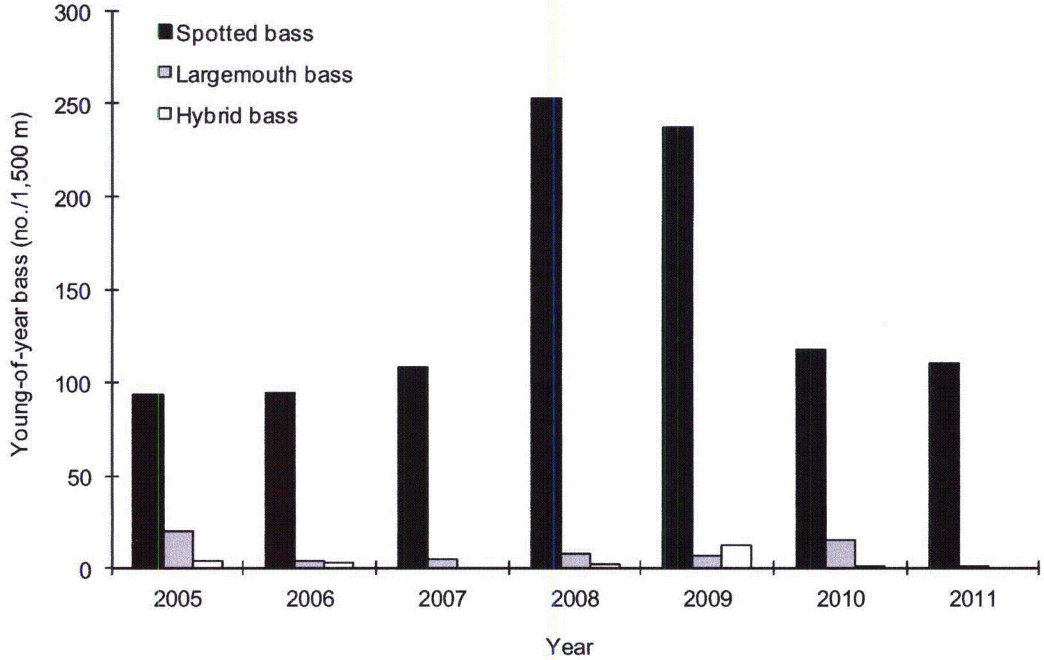



Figure 5-7. Number of young-of-year black bass (< 150 mm) collected from electrofishing five 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, November 2005 – 2011.

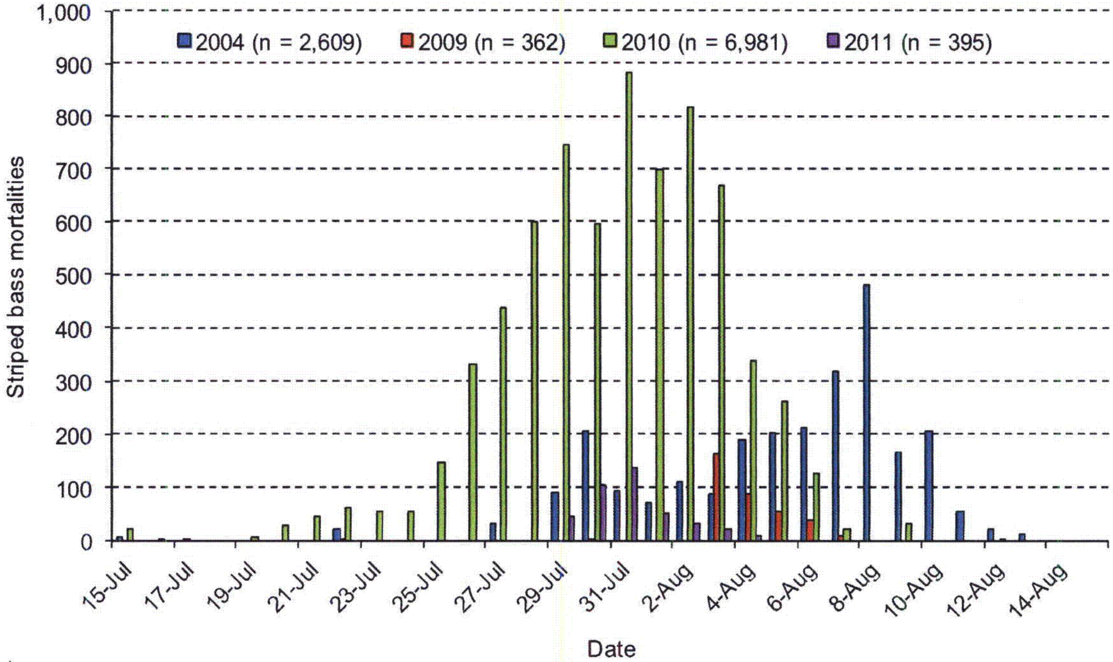



Figure 5-8. Number of striped bass mortalities by date in July/August 2004, 2009, 2010, and 2011.

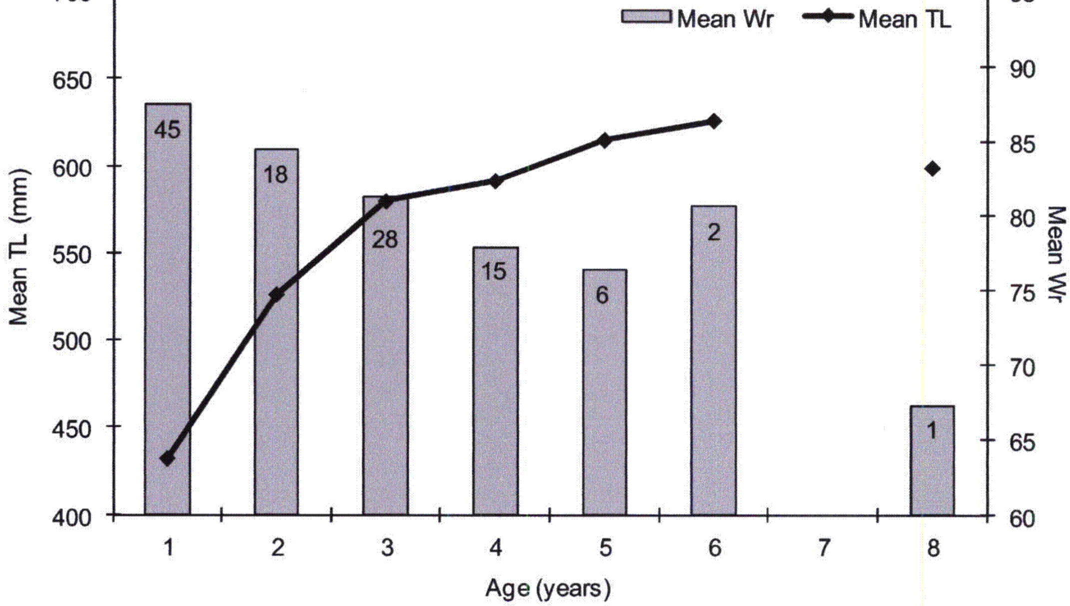



Figure 5-9. Mean TL and condition (Wr) by age of striped bass collected in Lake Norman, December 2011. Numbers of fish by age are inside bars.

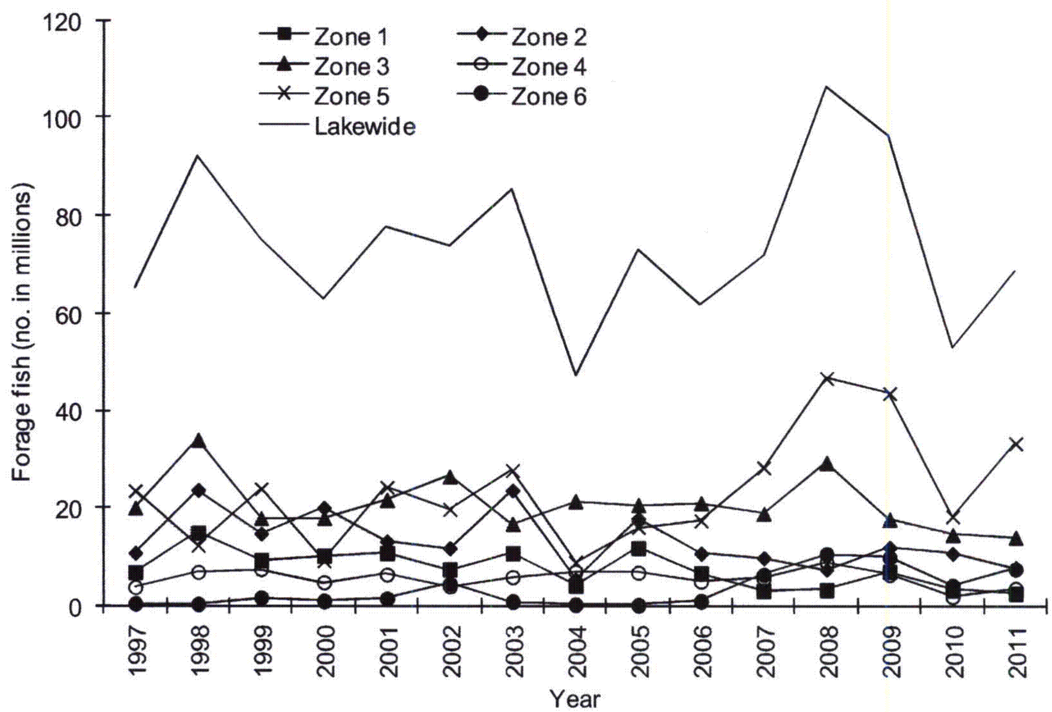



Figure 5-10. Zonal and lake-wide population estimates of pelagic forage fish in Lake Norman, September 1997 – 2011.

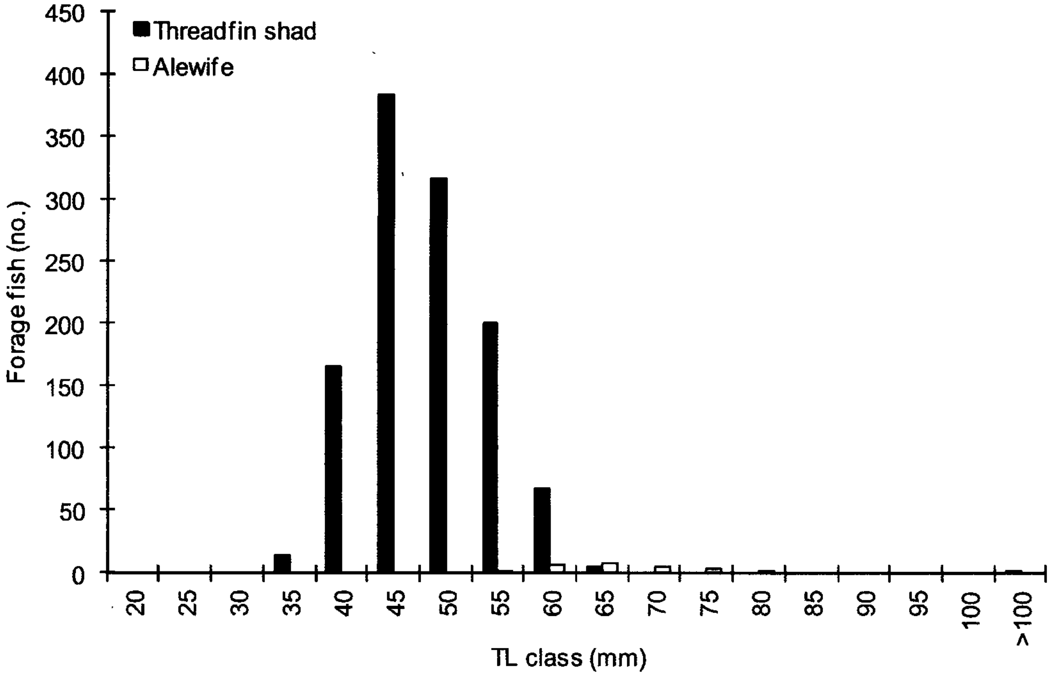



Figure 5-11. Number of individuals and size distribution of threadfin shad and alewife collected from purse seine surveys in Lake Norman, September 2011.

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