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February 16, 2012

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

SUBJECT: Duke Energy Carolinas, LLC
McGuire Nuclear Station
Docket No. 50-369, 370
Lake Norman Maintenance Monitoring Program:
2010 Summary

Please find attached a copy of the annual "Lake Norman Maintenance Monitoring Program: 2010 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 24, 2012.

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

Regis T. Repko

IE25
NRR

Mr. V. M. McCree, Regional Administrator
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Mr. Jon H. Thompson
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John Zeiler
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McGuire Nuclear Station

Duke Energy Carolinas LLC
McGuire Nuclear Station
12700 Hagers Ferry Road
Huntersville, NC 28078

January 24, 2012

Mr. Jay Sauber
North Carolina Department of Environment
and Natural Resources
Environmental Sciences Section
1621 Mail Service Center
Raleigh, NC 27699-1621

Subject: McGuire Nuclear Station
Lake Norman Environmental Monitoring Program: 2010 Summary Report

Dear Mr. Sauber:

Enclosed are three copies of the annual Lake Norman Environmental Monitoring Program: 2010 Summary Report, as required by NPDES Permit NC0024392.

Results of the 2010 data were comparable with that of previous years. No obvious short-term or long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. Additionally, 2010 station operation data demonstrates compliance with permit thermal limits and cool water management requirements.

Fishery studies continue to be coordinated with the Division of Inland Fisheries of the North Carolina Wildlife Resource Commission to address Lake Norman's fishery management issues.

If you have any questions concerning this report, please contact John Williamson by phone at (980) 875-5894 or by email at John.Williamson@duke-energy.com

Sincerely,

Regis T. Repko
Site Vice President
Duke Energy Carolinas, LLC
McGuire Nuclear Station

cc:	Bill Foris	MG03A3
	Mike Abney	MG03A3
	Sherry Reid	MG03A3

John Derwort	MG03A3
Allen Stowe	EC13K
John Williamson	MG01EM - 6 copies (4 for NRC, RGC, EHS)
3 copies to NCDENR	
1 copy NCWRC	

bcc w/attch: Record No. MN-004775

Duke Energy Carolinas LLC
McGuire Nuclear Station
12700 Hagers Ferry Road
Huntersville, NC 28078

January 24, 2012

Mr. Brian McRae
NC Wildlife Resources Commission
2312 Summit Drive
Hillsboro, NC 27278

Subject: McGuire Nuclear Station
Lake Norman Environmental Monitoring Program: 2010 Summary Report

Dear Mr. McRae:

Enclosed is a copy of the annual Lake Norman Environmental Monitoring Program: 2010 Summary Report, as required by NPDES permit NC0024392.

Results of the 2010 data were comparable with that of previous years. No obvious short-term or long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. Additionally, 2010 station operation data demonstrates compliance with permit thermal limits and cool water management requirements.

Fishery studies continue to be coordinated with the Division of Inland Fisheries of the North Carolina Wildlife Resource Commission to address Lake Norman's fishery management issues.

If you have any questions concerning this report, please contact John Williamson by phone at (980) 875-5894 or by email at John.Williamson@duke-energy.com

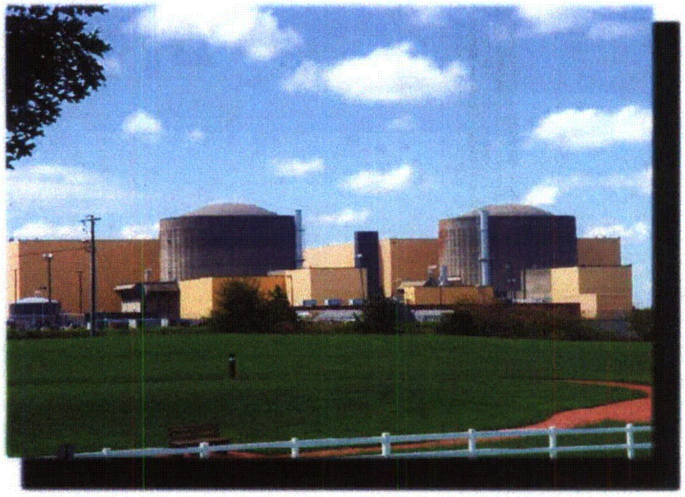
Sincerely,

Regis T. Repko
Site Vice President
Duke Energy Carolinas, LLC
McGuire Nuclear Station

LAKE NORMAN

MAINTENANCE MONITORING PROGRAM:

2010 SUMMARY



LAKE NORMAN

MAINTENANCE MONITORING PROGRAM:

2010 SUMMARY

McGuire Nuclear Station: NPDES No. NC0024392

Principal Investigators:

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December 2011

ACKNOWLEDGMENTS

The authors wish to express their gratitude to a number of individuals who made significant contributions to this report. First, we are much indebted to the EHS Scientific Services field staff in carrying out a complex, multiple-discipline sampling effort that provides the foundation of this report. Kim Baker, Dave Coughlan, Bob Doby, Duane Harrell, Glenn Long, Todd Lynn, and Mark Auten conducted fisheries collections and sample processing. Chuck Campbell, Bill Foris, Chase Fulk, Ben Lastra, Glenn Long, Josh Quinn, and Jan Williams performed water quality field collections and data analyses. John Williamson assembled the plant operating data. John Derwort, Glenn Long, and Jan Williams conducted plankton sampling, sorting, and taxonomic processing.

We would also like to acknowledge the valuable contributions of Sherry Reid. The benefit of her diligent efforts and patience in assembling and editing several drafts of the report can hardly be overstated. Finally, we are indebted to multiple reviewers; including Dave Coughlan, Keith Finley, Penny Franklin, and Duane Harrell. The insightful commentary and suggestions from these individuals and also between co-authors have benefited the report in myriad ways.

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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 2010. Overall, no obvious long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. The 2010 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 2010 totaled 120.3 cm or 24.0 cm less than observed in 2009 and 2.7 cm more than the long-term average. Monthly average air temperatures in winter 2010 were colder than both 2009 and the long term average, whereas air temperatures from April – October were warmer than both 2009 and the long-term average. Seasonal variability in lake level was similar to 2009.

Temporal and spatial trends in water temperature and dissolved oxygen (DO) concentrations in 2010 were similar to those observed historically and all data were within the range of previously measured values. Water temperatures in winter 2010 were either equal to or cooler than measured in 2009 and generally paralleled differences exhibited in monthly air temperatures, but with about a one-month lag time. Beginning in April, and extending into late fall, 2010 upper and middle water column temperatures in both the background and mixing zones were warmer than in 2009 and closely followed between-year differences in monthly average air temperatures. Epilimnion (0-15 m) temperatures during this period ranged from 1.8 to 3.2 warmer than in 2009, with the most pronounced differences observed in the mixing zone in August. Temperatures at the discharge location in 2010 were generally similar to but slightly warmer than 2009 and within the historical range. The warmest discharge temperature of 2010 (38.6 °C) occurred in August and was 1.5 °C higher than the 2009 maximum.

Seasonal and spatial patterns of DO in 2010 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 MNS began operations in 1983. Winter and spring DO values in 2010 were generally equal to or greater throughout the water column in both zones than measured in 2009, due predominantly to cooler water temperatures. Summer DO values in 2010 were highly variable throughout the water column in both zones and were similar to concentrations measured in prior years. The development of a negative heterograde DO curve in late spring – early summer 2010 was similar to, and only slightly more severe, than observed in previous years. Fall 2010 DO concentrations throughout most of the water column were either equal to or slightly lower than 2009 values, with these differences explained by interannual variability in the rates of water column cooling and reaeration. The seasonal pattern of DO in 2010 at the discharge location was similar to that measured historically.

Reservoir-wide isotherm and isopleth information for 2010, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Preferred pelagic habitat for adult striped bass, defined as that layer of water with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L, was found lake-wide from late September 2009 through mid-July 2010. Beginning in late June 2010, 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 in 2010 was most severe from mid-July through mid-September and was similar in severity and duration to conditions observed in previous years. Total reported striped bass mortalities in 2010 equaled approximately 7,000 fish and represented the largest die-off of these sport fish recorded in Lake Norman. Based on recent research and changes in the Lake Norman forage fish community since 1999, it is hypothesized that forage, primarily alewife, has played a contributing role in recent striped bass mortalities.

All chemical parameters measured in 2010 were similar to 2009 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) for that test. Total phosphorus concentrations were slightly higher than measured in 2009 but within the historical range. Concentrations of metals in 2010 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 cadmium, lead, zinc, copper in 2010 were below the State water quality standard or action level for each of these metals. Manganese and iron concentrations were generally low in 2010, except during the summer and fall when bottom waters exhibited anoxic and redox induced releases of these chemical species. The highest concentrations of iron and manganese reported in 2010, 3.5 mg/L and 5.3 mg/L, respectively, were measured in November in the bottom waters in the mixing zone.

Monitoring of the biological communities and associated parameters in Lake Norman continued in 2010. Most individual chlorophyll *a* concentrations during 2010 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 2010.

Phytoplankton diversity, or the number of phytoplankton taxa, was very high during 2010 although lower than in 2009 when the highest number of taxa was recorded since the beginning of the Program in 1987. The taxonomic compositions of phytoplankton communities during 2010 were similar to those of most previous years. Diatoms were dominant during early June and November while cryptophytes were dominant during February. Green algae dominated summer assemblages. Blue-green algae were slightly more abundant during 2010 than during 2009, but typically comprised 2% or less of total densities.

The most abundant algae during 2010 were: the cryptophyte, *Rhodomonas minuta* in February; the diatoms *Fragillaria crotonensis* and *Melosira distans* in early June; 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 and early June 2010 than in February and May 2009, while the opposite was the case in August and November. Maximum dry and ash-free weights were generally observed uplake while minimum values occurred most often downlake.

Secchi depths often reflected suspended solids, with shallow depths loosely related to high dry weights. The lake-wide mean secchi depth was lower in 2010 than in 2009 and within historical ranges observed since data were first recorded in 1992.

Zooplankton monitoring also continued in 2010. In most cases, zooplankton densities in 2010 were lower than in 2009. During 2010, seasonal maximum densities among zooplankton assemblages 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 2010. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations.

Zooplankton samples from Lake Norman in 2010 were dominated by rotifers although their abundance declined since 2009. The most abundant rotifers observed in 2010, as in many previous years, were *Polyarthra*, *Keratella*, and *Asplanchna.* Microcrustaceans (copepods and cladocerans) increased in relative abundance in 2010 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 most important cladoceran among zooplankton samples during most periods of 2010.

In accordance with the Lake Norman Maintenance Monitoring Program, monitoring of specific fish population parameters continued during 2010. Spring electrofishing indicated that numbers and biomass of fish in 2010 were generally similar to those noted since 1993. The fish populations in the three sampling areas were comprised of 17 to 19 species of fish and two hybrid complexes. Fish collections were numerically and gravimetrically dominated by centrarchids, as in previous years. The forage fish population estimate, dominated by threadfin shad, was the second lowest estimate since surveys began in 1997. Largemouth bass numbers of individuals were the lowest recorded since sampling began in 1993, although biomass increased slightly from 2009. Spotted bass number of individuals and biomass continue to increase, possibly displacing largemouth bass. Summer striped bass mortalities were the highest ever recorded.

Lake Norman Maintenance Monitoring Program results from 2010 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 2010.

OPERATIONAL DATA FOR 2010

Station operational data for 2010 are listed in Table 1-1. The average monthly capacity factor for the station was near or slightly above 100% except in March, April and June when maintenance was performed on Unit 1. The monthly average capacity factors for MNS were 102.8 for both July and August, and 103.0 during September. These are the months when conservation of cool water is most critical and compliance with discharge temperatures is most challenging. These three months are also when the thermal limit for MNS increases from a monthly average of 95.0 °F (35.0 °C) to 99.0 °F (37.2 °C). The average 2010 monthly discharge temperature was 98.8 °F (37.1 °C) for July, 98.6 °F (37.0 °C) for August and 98.0 °F (36.7 °C) for September. The volume of cool water in Lake Norman was tracked throughout the year to ensure that an adequate volume was available to comply with both the Nuclear Regulatory Commission Technical Specification requirements and the NPDES discharge water temperature limits.

Table 1-1. Average monthly capacity factors (%) and monthly average discharge water temperatures for MNS during 2010.

	Monthly average capacity factors (%)			Monthly average NPDES discharge temperatures	
Month	Unit 1	Unit 2	Station	°F	°C
Jan	103.84	104.45	104.15	65.8	18.8
Feb	104.80	105.52	105.16	65.0	18.3
Mar	40.48	105.36	72.92	67.2	19.6
Apr	32.90	104.65	68.78	73.6	23.1
May	104.56	103.73	104.14	85.7	29.8
Jun	87.17	102.16	94.67	88.6	31.4
Jul	103.28	102.36	102.82	98.8	37.1
Aug	103.53	101.99	102.76	98.6	37.0
Sep	103.44	102.46	102.95	98.0	36.7
Oct	105.09	104.29	104.69	88.3	31.3
Nov	105.50	104.91	105.20	80.0	26.7
Dec	105.71	105.39	105.55	71.0	21.7
Average	91.69	103.94	97.82	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 2009 and 2010 data. Where appropriate, reference to pre-2009 data will be made by citing reports previously submitted to the NCDENR.

METHODS AND MATERIALS

The complete water quality monitoring program for 2010, 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 following data validation, converted to spreadsheet format.

Water samples for laboratory analysis were collected with a Kemmerer or Van Dorn water bottle at the surface (0.3 m), and from one meter above bottom, where specified (Table 2-1). Samples not requiring filtration were placed directly in 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 2009, 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, and 2010). The first method involved partitioning the reservoir into mixing, background, and discharge zones, consolidating the data into these sub-sets, and making comparisons among zones and years. In this report, the discharge includes only Location 4.0; the mixing zone, Locations 1.0 and 5.0; the background zone includes Locations 8.0, 11.0, and 15.0 (Figure 2-1). The second approach, applied primarily to the *in situ* data, emphasized a much broader lake-wide investigation and encompassed the plotting of monthly isotherms and isopleths, and summer striped bass habitat. Several quantitative calculations were also performed on the *in situ* data; these included 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 and were calculated according to Hutchinson (1957), using the following equation:

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

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

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

RESULTS AND DISCUSSION

Precipitation and Air Temperature

Annual precipitation in the vicinity of MNS in 2010 totaled 120.3 cm (Figures 2-2a and 2-2b) or 24.0 cm less than observed in 2009 (144.3 cm), and 2.7 cm more than the long-term precipitation average for this area (117.6 cm), based on Charlotte, NC airport data. Monthly rainfall in 2010 was greatest in August with 18.3 cm and the least in November with 4.0 cm. Monthly rainfall totals in 2010 exceeded 10 cm in six separate months.

Monthly average air temperatures near the MNS in 2010 were consistently either cooler or warmer than observed both in 2009, and the long-term monthly means, except in March and November (Figure 2-2c). Differences between 2010 and historical data were most pronounced during the cooling period (February and December) when mean monthly air temperatures measured almost 4 °C cooler than the long-term mean (Figure 2-2c). The 2010 winter air temperatures (months of December 2009 and January and February of 2010) were the coldest recorded over the last two decades.

Temperature

Water temperatures measured in 2010 illustrated similar temporal and spatial trends in the background and mixing zones (Figures 2-3 and 2-4) as they did in 2009. This similarity in temperature patterns between zones has been a dominant feature of the thermal regime in Lake Norman since MNS began operations in 1983. When between-zone differences in temperatures are observed, they occur predominately during the cooling period, and can be traced to the influence of the thermal discharge at MNS on mixing zone temperatures. Additionally, interannual differences in water temperatures in Lake Norman, particularly in surface waters in the background zone, typically parallel differences in air temperatures but with a one-month lag time (Duke Power 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, and 2010).

Water temperatures in winter 2010 were either equal to or cooler than measured in 2009, with minor differences observed between zones (Figures 2-3 and 2-4). Further, winter water temperatures in the background zone were the coldest measured over the last two decades. 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 water temperatures between 2009 and 2010 tracked air temperatures (Figure 2-2c) and are consistent with historical observations. Minimum winter 2010 water temperatures recorded in early February ranged from 5.8 °C to 6.4 °C in the background zone and from 6.6 °C to 12.7 °C in the mixing zone. Minimum water temperatures measured in 2010 were within the observed 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, and 2010).

Beginning in April, and extending into late fall, a reversal in the winter pattern of water temperature differences between 2010 versus 2009 was observed, especially in the upper water column. Epilimnion and metalimnion temperatures in 2010 were noticeably warmer than in 2009 throughout the summer (Figures 2-3 and 2-4) and closely followed between year differences in monthly average air temperatures (Figure 2-2c). Epilimnion (0-15 m depth) temperatures in 2010 were greater than in 2009 in both the background and mixing zones during the summer stratified period, with the most pronounced differences observed in the mixing zone in August. Temperatures over this depth range ranged from 1.8 to 3.2 °C higher in 2010 versus 2009 and were likely related to the above average air temperatures observed in 2010 (Figure 2-2c).

Fall and early winter water temperatures (October, November, and December) in 2010 were consistently either equal to or warmer in both zones than those measured in 2009, indicating that in 2010 the reservoir was cooling at a slower rate than in 2009 (Figures 2-3 and 2-4). This pattern followed the trend exhibited in air temperatures between 2010 and 2009 (Figure 2-2c).

Temperatures at the discharge location in 2010 were generally similar to but slightly warmer than 2009 (Figure 2-5) and 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, and 2010). The warmest discharge temperature of 2010 (38.6 °C) occurred in August and was 1.5 °C higher than the 2009 maximum (37.1 °C) measured in September.

Dissolved Oxygen

Seasonal and spatial patterns of DO in 2010 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones (Figures 2-6 and 2-7). As observed with water column temperatures, this similarity in DO patterns between zones has been a dominant feature of the oxygen regime in Lake Norman since MNS began operations in 1983.

Winter and spring DO values in 2010 were generally equal to or greater throughout the water column in both zones than measured in 2009 (Figures 2-6 and 2-7). The interannual differences in DO values measured during this period appeared related predominantly to the differences in water column temperatures in 2010 versus 2009 and were consistent with observations made during previous years (Duke Energy 2007, 2008, 2009, and 2010). 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.

A reversal in the DO differences between the two years was evident in both zones by May with lower values observed in 2010 versus 2009, especially in the middle to upper water column. This trend continued into June when a distinct mid-water column depletion of DO was observed in both zones, with the background zone exhibiting slightly more severe conditions. Metalimnnetic DO values in June 2010 were as much as 1.9 mg/L lower than 2009 in the background zone and as much as 1.6 mg/L lower than 2009 in the mixing zone.

One consistent feature of the vertical DO pattern in Lake Norman, observed during the stratified period, is the presence of a negative heterograde oxygen curve (NHOC), also commonly called a "metalimnetic oxygen minimum". The NHOCs are characterized by a vertical oxygen profile with a pronounced middle water layer (metalimnion) of low DO positioned between upper (epilimnion) and lower (hypolimnion) zones of higher oxygen content (Horne and Goldman 1994). The NHOCs are common in Southeastern reservoirs and often caused by vertical differences in animal and microbial respiratory activities associated with the consumption and degradation of both autochthonous and allochthonous derived organic materials (Cole and Hannan 1985). The NHOCs are typcially formed via a combination of two processes; differential oxygen consumption within the water column 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 down-reservoir 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 oxygen consuming processes within the waterbody eventually create a reservoir-wide zone of water below the thermocline that is totally devoid of oxygen (Figures 2-6, 2-7, 2-9, and 2-11).

The development and progression of the NHOC in summer 2010 occurred earlier and progressed slightly more rapidly than in 2009 (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 by close to 2 mg/L, resulting in lower DO values (2-4 mg/L) in the hypolimnion and near anoxic conditions in the metalimnion. Normally, by early August DO values 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 2010 DO profiles illustrated only slightly higher (by 0.5 mg/L) values below the thermocline than in 2009. 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 idea was formulated based on study results presented by Ford (1987) who found that nutrient and organic loading to DeGray Resevoir in Arkansas was dominated by rainfall and associated terrestrial runoff events during the spring. Spring rainfall totals for 2010 were six inches less than 2009 and close to the long-term average, suggesting that additional factors likely influence the development of the NHOCs in Lake Norman.

Considerable differences were observed between 2010 and 2009 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 2010 fall DO data indicate that convective reaeration of the water column proceeded at a somewhat slower rate than observed in corresponding months in 2009 despite exhibiting similar September profiles (Figures 2-6 and 2-7). Consequently, 2010 DO levels at most depths were either equal to or less than observed in 2009. December data illustrated a reversal in the earlier trend with higher DO values observed in 2010 versus 2009. 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 hydrology, meteorology and nutrient and organic matter loading (Cole and Hannan 1985; Petts 1984).

The seasonal pattern of DO in 2010 at the discharge location was similar to that measured historically, with the highest values observed during the winter and lowest observed in the summer and early fall (Figure 2-5). The lowest DO concentration measured at the discharge location in 2010 (5.3 mg/L) occurred in August and September and was 1.2 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 2010 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 2010 are presented in Figure 2-10a; additional information on the thermal regime in the reservoir for the years 2009 and 2010 are presented in Table 2-3. Annual minimum heat content for the entire water column in 2010 (6.90 Kcal/cm^2, 6.81 °C) occurred in early February, whereas the maximum heat content (29.62 Kcal/cm^2, 29.0 °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 3.97 Kcal/cm^2 (6.10 °C), but the maximum occurred in early September and measured 16.63 Kcal/cm^2 (24.88 °C). Heating of both the entire water column and the hypolimnion occurred at approximately a linear rate from minimum to maximum heat content. The mean heating rate of the eplimnion equaled 0.10 °C/day and 0.08 °C/day for the hypolimnion and were either equal to or slightly greater than observed in 2009 (Table 2-3). The 2010 heat content and heating rate data for Lake Norman were generally similar to that observed in previous years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, and 2010).

The seasonal oxygen content and percent saturation of the whole water column, and the hypolimnion, are depicted for 2010 in Figure 2-10b. Additional oxygen data can be found in Table 2-4 which presents the 2010 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. Percent oxygen saturation values at this time approached 89% for the entire water column and 86% for the hypolimnion, indicating that reaeration of the reservoir did not achieve 100% saturation in 2010. Beginning in early spring, oxygen content began to decline precipitously in both the whole water column and the hypolimnion, and continued to decline linearly until reaching a minimum in late summer. The minimum summer volume-weighted DO value for the entire water column measured 4.0 mg/L (52% saturation), whereas the minimum for the hypolimnion was 0.3 mg/L (4.0 % saturation). The mean rate of DO decline in the hypolimnion over the stratified period, i.e., the AHOD, was 0.051 mg/cm^2/day (0.078 mg/L/day) (Figure 2-10b), and is similar to that measured in 2009 and historically (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 0.051 mg/cm^2/day for 2010. 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

Coutant (1985), in an attempt to explain the variable success of striped bass populations in Southern reservoirs, including periodic instances of summer mortalities of adult fish, expanded the thermal niche paradigm of fishery ecology (Magnuson et al. 1979) to include both temperature and DO concentrations as critical environmental factors influencing temporal and spatial distribution patterns of adult striped bass. Based largely on extensive studies performed in eastern Tennessee reservoirs (Coutant and Carrol 1980, Cheek et al. 1985, and Waddle et al. 1980), Coutant 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 (Coutant did not include a time or duration component in his suitable habitat definition). If waters meeting these criteria were not available within the waterbody, mortalities of adult striped bass were predicted. Similarly, Van Horn et al. (1996) suggested DO ≥ 2.0 mg/L and water temperature ≤ 27.0 °C would prevent summer striped bass mortalities in Lake Norman following a radio tagging and tracking study. Other studies of Southeastern and Southwestern reservoirs demonstrated an expanded thermal range (from > 25 to 29 °C) with no reported summertime mortalities despite fish being restricted by low DO (Matthews 1985, Matthews et al. 1985, Farquhar and Gutreuter 1989, and Zale et al. 1990). Exposure time to elevated temperatures was also considered a factor in striped bass mortalities. Matthews (1985) also reported that summer mortalities of striped bass, although highly variable, were widespread geographically in reservoirs with an increase in mean surface area, volume, maximum depth, and depth of water release.

Recent studies in North Carolina have also provided additional refinements of Coutant's (1985) summertime thermal range for habitat-limited striped bass. Jackson and Hightower (2001) found fish in Lake Gaston, North Carolina - Virginia, to tolerate 27-28 °C for approximately one month. Thompson (2006) studied striped bass in Lakes Norman and Badin and identified an additional nutritional or forage component (termed growth rate potential) helpful in explaining periodic summertime deaths. In short, biotic conditions in a reservoir can strongly modify the effects of temperature (even as high as 27-31°C) and DO on the growth and habitat selection of striped bass. Striped bass in a eutrophic reservoir with a diverse forage base (i.e., Badin Lake, NC) tolerated unsuitable summertime conditions (i.e., habitat "squeeze") better than striped bass residing in a relatively unproductive lake with a narrow size range of forage (i.e., Lake Norman). Bioenergetics modeling demonstrated that Lake Norman striped bass would tolerate summertime conditions better if forage availability was similar to that typically found in Badin Lake. Although the introduction of alewife (*Alosa pseudoharengus*) into Lake Norman may have improved forage availability, that benefit is likely negated in the absence of suitable habitat during the summer.

For consistency with past reports and calculations, preferred habitat for adult striped bass 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 of adult striped bass occurred in lower Lake Norman near Cowans Ford Dam. The timing of the 1983 die-off coincided with the disappearance of water in the reservoir meeting these combined limits. Despite the absence of preferred striped bass habitat every summer since 1983, over two decades elapsed before another sizable mortality occurred. Mortalities of more than 100 adult fish in 2004 and 2009 indicated that some combination of temperature, DO level, and another factor (possibly forage) were necessary to explain large-scale mortalities in Lake Norman (Duke Energy 2005 and 2010).

Preferred habitat for striped bass was found lake-wide from mid-September 2009 through mid-July 2010 (Figure 2-11). Beginning in late June 2010, as thermal stratification intensified, habitat reduction proceeded rapidly throughout the reservoir both as a result of deepening of the 26 °C isotherm and metalimnetic and hypolimnetic deoxygenation (Figure 2-11). Wind-induced and power generation mixing were primarily responsible for deepening of the 26 °C isotherm and reduction of habitat in the upper layers of the water column during the summer. Spatial differences in the magnitude and rates of metalimnetic and hypolimnetic deoxygenation throughout the reservoir contributed to habitat depletion in the middle and lowers layers of the water column. Commonly, horizontal and vertical differences in the rates of water column warming and deoxygenation result in a small zone of preferred habitat in the lower epilimnion (elevation 220-223 mmsl). This small zone is often observed reservoir-wide between late June to early July (Figure 2-11), layered between an upper zone of water devoid of habitat due to high temperatures and a lower zone also lacking preferred habitat due to low oxygen levels. This zone is formed because thermal deepening of the 26 °C isotherm proceeds somewhat slower during the summer than the deoxygenation processes in the middle and lower portions of the water column. (See DO section in Chapter 2 for a discussion of the specific factors responsible for the temporal and spatial development of metalimnetic and hypolimnetic oxygen patterns). Typically, this lower epilimnetic habitat is short-lived, lasting an average of less than two weeks and normally absent by early July. In contrast, relatively large areas of preferred habitat remain in the hypolimnion, eventually eliminated via DO depletion in late July (Figure 2-11). Based on water volume calculations, approximately 75% of the annual reduction in preferred striped bass habitat in Lake Norman during the stratified period was associated with deepening of the 26 °C isotherm and 25 % was related to oxygen consumption processes in the metalimnion and hypolimnion.

Habitat conditions in 2010 were most severe from late July through mid-September when no preferred habitat was observed in the reservoir except for a small refuge in the lower hypolimnion near Cowans Ford Dam in July, and in the bottom waters between Locations 69 and 80 in early August (Figure 2-11). Preferred habitat was present in the hypolimnion on July 19; however, none remained in the reservoir by July 26. Approximately 7,000 dead adult striped bass were collected from July 14 to August 16, the majority near Cowans Ford Dam. Preferred habitat for adult striped bass was totally eliminated from the reservoir for slightly more than two months in 2010, which is similar to historical conditions.

Physicochemical habitat expanded appreciably by late 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 2010 were similar to historical observations 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, and 2010).

The observed mortalities of adult striped bass in 2010 represented the largest die-off of these sport fish recorded in Lake Norman since the lake was created in 1963. Prior to 2010, the previous largest recorded annual die-off (2,610 fish) occurred in 2004. Only one (1983) of the four striped bass mortality incidences exceeding 100 fish in Lake Norman has occurred outside of the last decade. Despite exhibiting similar patterns in the timing and severity of summertime habitat reductions and absent evidence identifying other physicochemical explanations, annual mortalities have ranged from no fish to approximately 7,000 fish. Based on recent research and changes in the Lake Norman forage fish community since

1999, it is hypothesized that forage has played a contributing role in recent striped bass mortalities.

The available evidence suggests a possible linkage of Lake Norman striped bass kills to a shift in their seasonal distribution within the reservoir in response to seasonal migration patterns of coolwater seeking adult alewife. Striped bass appear to have shifted from reliance on the traditional epilimnetic forage fish (threadfin shad *Dorosoma petenense*) to the introduced alewife, an exotic prey species that was introduced into the reservoir about a decade ago. Adult alewife prefer cooler hypolimnetic waters during summer. This possible linkage and associated historical background is discussed further in Chapter 5.

Turbidity and Specific Conductance

Surface turbidity values were generally low at the MNS discharge, mixing zone, and background locations during 2010 with only 2 of 24 samples exceeding 5 NTUs. The maximum value recorded in 2010 was 35 NTUs at Location 11.0 in February (Table 2-5). Bottom turbidity values were also low but slightly higher than surface readings. Bottom turbidity readings exceeded 5 NTUs in 10 of the 20 samples taken with the maximum of 28 NTUs measured in February at Location 11.0. Turbidity values observed in 2010 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, and 2010).

Specific conductance in Lake Norman in 2010 ranged from 52.0 to 108.0 µmhos/cm and was generally similar to that observed in 2009 (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, and 2010). 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 2010, 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 2009 (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, and 2010). Values of pH in 2010 ranged from 6.6 to 7.7 in surface waters and from 6.0 to 7.2 in bottom waters. Alkalinity values in 2010 ranged from 12.0 to 18.0 mg/L, expressed as $CaCO^3$, in surface waters and from 12.0 to 35.0 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. Lake-wide, the major cations were sodium, calcium, magnesium and potassium, whereas the major anions were bicarbonate, sulfate, and chloride. The overall ionic composition of Lake Norman during 2010 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, and 2010).

Nutrients

Nutrient concentrations in the discharge, mixing and background zones of Lake Norman in 2010 (Table 2-5) were low and generally similar to those measured in 2009 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, and 2010). For total phosphorus (TP), all 44 samples analyzed in 2010 exceeded 5 μg/L, the analytical reporting limit (ARL), and values were frequently greater than observed in 2009 but within the historical range. The maximum 2010 TP value (48 μg/L) was observed in a surface sample collected at Location 11.0 in February, and coincided with the maximum turbidity measurement for 2010 (Table 2-5). All except two measurements of orthophosphorus (N = 42/44) in 2010 were recorded as ≤ 5 μg/L, the ARL. The maximum orthoposhosphate concentration measured in 2010 (6.6 ug/L) was measured at the same depth, location and time as the maximum TP concentration. Nitrite-nitrate and ammonia nitrogen concentrations were low at all locations (Table 2-5) and similar to historical values (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, and 2010).

Metals

Metal concentrations in the discharge, mixing, and background zones of Lake Norman for 2010 were similar to those measured in 2009 (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, and 2010). Iron concentrations in surface and bottom waters were generally low (≤ 0.2 mg/L) during 2010 with 16 of 44 samples exceeding 0.20 mg/L. The maximum iron concentration measured in 2010 (3.5 mg/L) was from the bottom sample taken at Location 2.0 in November. A total of three (3) samples collected in 2010 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 2010 were also generally low (≤ 100 µg/L), except during the summer and fall when bottom waters were anoxic (Table 2-5). Manganese concentrations in the bottom waters rose above the State water quality action (200 µg/L; NCDENR 2004) at various locations throughout the lake in summer and fall, and were characteristic of historical conditions (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, and 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, and 2010). The highest concentration of manganese reported in 2010 (5,300 µg/L) was measured in the bottom waters at Location 1.0 in November. 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 2010 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, and 2010). All values for cadmium and lead were reported as either equal to or below the ARL for those parameters. Approximately one-half of zinc values (20 of 44 samples) in 2010 were below the ARL of 2.0 µg/L with the maximum concentration (5.1 µg/L) measured in the November bottom sample at Location 11.0. All copper concentrations, measured as total recoverable copper, were ≤ 2.6 µg/L and about 16% (7 of 44) of the values were listed as less than or equal to the ARL of 1.0 µg/L. All values reported for cadmium, lead, zinc, and copper in 2010 were below the State action level for each of these metals (NCDENR 2004).

FUTURE STUDIES

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

SUMMARY

Annual precipitation in the vicinity of MNS in 2010 totaled 120.3 cm or 24.0 cm less than observed in 2009 and 2.7 cm more than the long-term average. Monthly average air temperatures in winter 2010 were colder than both 2009 and the long term average, whereas air temperatures from April through October were warmer than both 2009 and the long-term average. Seasonal variability in lake level was similar to 2009.

Temporal and spatial trends in water temperature DO concentration in 2010 were similar to those observed historically, and all data were within the range of previously measured values. Water temperatures in winter 2010 were either equal to or cooler than measured in 2009 and generally paralleled differences exhibited in monthly air temperatures, but with about a one-month lag time. Beginning in April, and extending into late fall, 2010 upper and middle water column temperatures in both the background and mixing zones were warmer than in 2009 and closely followed between-year differences in monthly average air temperatures. Epilimnion (0-15 m) temperatures during this period ranged from 1.8 to 3.2 °C greater than in 2009, with the most pronounced differences observed in the mixing zone in August. Temperatures at the discharge location in 2010 were generally similar to but slightly warmer than 2009 and within the historical range. The warmest discharge temperature of 2010 (38.6 °C) occurred in August and was 1.5 °C higher than the 2009 maximum.

Seasonal and spatial patterns of DO in 2010 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 MNS began operations in 1983. Winter and spring DO values in 2010 were generally equal to or greater throughout the water column in both zones than measured in 2009, due predominantly to cooler water temperatures. Summer DO values in 2010 were highly variable throughout the water column in both zones and were similar to concentrations measured in prior years. The development of a negative heterograde DO curve in late spring – early summer 2010 was similar to, and only slightly more severe, than observed in previous years. Fall 2010 DO concentrations throughout most of the water column were either equal to or slightly lower than 2009 values, with these differences explained by interannual variability in the rates of water column cooling and reaeration. The seasonal pattern of DO in 2010 at the discharge location was similar to that measured historically.

Reservoir-wide isotherm and isopleth information for 2010, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Preferred pelagic habitat for adult striped bass, defined as that layer of water with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L, was found lake-wide from late September 2009 through mid-July 2010. Beginning in late June 2010 as thermal stratification intensified, 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 in 2010 was most severe from mid-July through mid-September and was similar in severity and duration to conditions observed in previous years. Significant mortalities of adult striped bass were observed in 2010 and reported concurrent with reservoir-wide elimination of preferred striped bass habitat in the deeper depths where coolwater-seeking alewives were present. Total reported striped bass mortalities in 2010 equaled approximately 7,000 fish and represented the largest die-off of these sport fish recorded in Lake Norman. The lack of preferred habitat alone could not explain the historical annual differences in the number of mortalities in the reservoir, which have ranged from no fish to almost 7,000 fish. Striped bass preference for larger and more nutritive prey items (i.e., adult alewife) that reside in the hypolimnetic waters of Lake Norman during summer has, in some years, led to high mortalities due to their inability to escape the hypolimnion when it becomes hypoxic.

All chemical parameters measured in 2010 were similar to 2009 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 concentrations were slightly higher than measured in 2009 but within the historical range. Concentrations of metals in 2010 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 cadmium, lead, zinc, copper in 2010 were below the State water quality standard or action level for each of these metals. Manganese and iron concentrations were generally low in 2010, except during the summer and fall when bottom waters exhibited anoxic and redox induced releases of these chemical species. The highest concentrations of iron and manganese reported in 2010, 3.5 mg/L and 5.3 mg/L, respectively, were measured in November in the bottom waters in the mixing zone.

Table 2-1. Water quality 2010 program for the MNS NPDES Maintenance Monitoring Program on Lake Norman.

		2010 McGUIRE NPDES SAMPLING PROGRAM														
PARAMETERS	LOCATIONS	1	2	4	5	8	9.5	11	13	14	15	15.9	62	69	72	80
	DEPTH (m)	33	33	5	20	32	23	27	21	10	23	23	15	7	5	4
		IN-SITU ANALYSIS														
	Method															
Temperature	Hydrolab															
Dissolved Oxygen	Hydrolab	In-situ measurements are collected monthly at the above locations at 1m intervals from 0.3m to 1m above bottom.														
pH	Hydrolab	Measurements are taken weekly from July-August for striped bass habitat.														
Conductivity	Hydrolab															
		NUTRIENT ANALYSES														
Ammonia	AA-Nut	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	AA-Nut	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	AA-Nut	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	AA-TP,DG-P	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	AA-Nut	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	AA-Nut	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	AA-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-MS-D	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-24	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	ICP-MS-D	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-24	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	ICP-MS-D	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	306-K	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-24	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	ICP-MS-D	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	ICP-MS-D	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	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Cadminum	ICP-MS-D	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))	ICP-MS-D	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)	ICP-MS	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	ICP-MS-D	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	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
		ADDITIONAL ANALYSES														
Hardness ©		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B		
Alkalinity	T-ALKT	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	F-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	UV_SO4	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	S-TSE	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	S-TSSE	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		

TR = Total Recoverable; C = Calculated

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 2010 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 2009 and 2010.

	2009	2010
Maximum Areal Heat Content (Kcal/cm^2)	28.509	29.616
Minimum Areal Heat Content (Kcal/cm^2)	8.859	6.904
Birgean Heat Budget (Kcal/cm^2)	19.650	22.712
Epilimnion (above 11.5 m) Heating Rate (°C/day)	0.10	0.11
Hypolimnion (below 11.5 m) Heating Rate (°C/day)	0.08	0.08

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

Reservoir	AHOD (mg/cm^2/day)	Summer Chl *a* (µg/L)	Secchi Depth (m)	Mean Depth (m)
Lake Norman (2010)	0.051	7.9	2.1	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

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[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 2009 and 2010. Values less than detection were assumed to be equal to the detection limit for calculating a mean.

		Mixing Zone				Mixing Zone				MNS Discharge		Mixing Zone				Background				Background			
	LOCATION:	1.0				2.0				4.0		5.0				8.0				11.0			
	DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS	YEAR:	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Turbidity (NTU)																							
	Feb	1.9	2.3	1.8	6.3	2.6	2.8	3.9	5.6	2.8	3.1	2.3	3.3	3.8	4.3	2.1	5.0	5.3	12.0	2.9	35.0	4.3	28.0
	May	1.6	2.1	2.3	8.2	1.9	2.2	3.1	8.9	1.8	2.2	1.8	2.5	2.5	7.8	1.1	1.2	2.3	4.4	1.1	1.2	3.0	8.1
	Aug	1.0	1.2	0.7	2.4	1.9	1.3	0.7	2.2	0.9	1.0	1.0	1.7	4.1	4.2	1.1	1.7	1.2	1.3	1.4	1.4	1.0	1.1
	Nov	1.8	3.5	2.7	2.2	1.6	2.4	2.4	5.6	2.0	2.5	1.7	2.4	2.9	4.6	1.9	2.7	3.9	4.3	2.4	2.5	4.5	6.2
	Annual Mean	1.6	2.3	1.9	4.8	2.0	2.2	2.5	5.6	1.9	2.2	1.7	2.5	3.3	5.2	1.6	2.7	3.2	5.5	2.0	10.0	3.2	10.9
Specific Conductance (umho/cm)																							
	Feb	72.0	61.0	72.1	58.0	72.7	61.0	72.5	58.0	73.6	61.0	73.4	61.0	72.2	59.0	72.5	59.0	71.8	55.0	71.1	52.0	64.9	53.0
	May	71.4	58.0	71.4	56.0	71.7	58.0	71.2	56.0	71.8	59.0	72.5	58.0	71.1	56.0	72.6	59.0	70.8	56.0	71.9	60.0	70.2	55.0
	Aug	65.6	62.0	73.6	61.0	66.1	62.0	72.1	61.0	65.9	62.0	65.6	63.0	77.0	69.0	65.9	62.0	72.7	62.0	67.4	65.0	73.9	61.0
	Nov	69.0	68.0	105.0	105.0	69.0	68.0	88.0	108.0	70.0	69.0	69.0	68.0	69.0	72.0	69.0	68.0	71.0	104.0	69.0	70.0	69.0	69.0
	Annual Mean	69.5	62.3	80.5	70.0	69.9	62.3	76.0	70.8	70.3	62.8	70.1	62.5	72.3	64.0	70.0	62.0	71.6	69.3	69.9	61.8	69.5	59.5
pH (units)																							
	Feb	7.0	6.8	6.9	6.8	7.3	7.1	7.1	6.9	7.3	7.2	7.4	7.2	7.1	7.0	7.5	7.1	7.2	6.9	7.3	6.8	7.0	6.8
	May	7.0	7.1	6.6	6.4	7.2	7.1	6.6	6.5	7.1	7.1	7.5	7.2	6.7	6.6	7.6	7.7	6.7	6.6	7.7	7.7	6.6	6.6
	Aug	7.1	7.3	6.3	6.1	7.1	7.3	6.3	6.0	7.0	7.0	7.1	7.0	6.5	6.2	7.4	7.3	6.3	6.1	7.4	7.1	6.3	6.1
	Nov	7.3	7.3	7.0	7.1	7.3	7.2	6.8	7.2	7.4	7.2	7.4	7.3	7.0	6.9	7.3	7.2	7.0	7.1	7.3	7.2	7.2	7.2
	Annual Mean	7.1	7.1	6.7	6.6	7.2	7.2	6.7	6.7	7.1	7.1	7.3	7.2	6.8	6.7	7.4	7.3	6.8	6.7	7.4	7.2	6.8	6.7
Alkalinity (mg CaCO3/L)																							
	Feb	14	14	14	13	15	14	14	14	15	14	14	14	14	14	15	14	14	12	14	12	14	12
	May	15	12	14	12	14	12	14	11	14	12	14	12	14	12	14	12	14	13	14	12	14	12
	Aug	15	14	15	14	15	14	15	14	14	14	14	14	19	19	14	14	15	15	14	15	15	15
	Nov	15	18	22	33	16	17	17	35	16	19	16	17	17	19	16	17	18	19	16	18	16	19
	Annual Mean	14.8	14.5	16.3	18.0	15.0	14.3	15.0	18.5	14.8	14.8	14.5	14.3	16.0	16.0	14.8	14.3	15.3	14.8	14.5	14.3	14.8	14.5
Chloride (mg/L)																							
	Feb	8.9	6.5	8.9	6.0	9.0	6.2	8.9	6.0	8.9	6.1	8.8	6.3	8.7	6.1	9.0	6.0	8.9	4.7	8.3	5.2	7.1	5.2
	May	8.6	5.8	8.7	5.6	8.6	5.8	8.8	5.8	8.9	5.8	8.9	5.7	8.7	5.7	8.8	6.1	8.8	5.8	8.4	6.3	8.4	5.7
	Aug	7.1	7.1	8.0	6.5	6.9	6.8	8.0	6.1	7.0	6.8	6.9	7.0	7.7	6.0	7.2	7.1	8.1	6.7	7.3	7.7	7.8	5.8
	Nov	7.0	7.4	7.2	6.2	7.1	7.4	7.3	6.8	7.2	7.3	7.2	7.6	7.2	7.4	7.2	7.6	7.5	7.5	7.1	7.4	7.3	7.2
	Annual Mean	7.9	6.7	8.2	6.1	7.9	6.6	8.3	6.2	8.0	6.5	8.0	6.7	8.1	6.3	8.1	6.7	8.3	6.2	7.8	6.7	7.7	6.0
Sulfate (mg/L)																							
	Feb	5.3	4.3	5.2	4.2	5.3	4.3	5.3	4.2	5.3	4.3	5.3	4.3	5.2	4.3	5.3	4.3	5.2	4.1	5.1	3.9	4.6	3.9
	May	5.3	4.2	5.2	4.1	5.1	4.1	5.2	4.1	5.1	4.2	5.7	4.1	5.2	4.1	5.3	4.2	5.3	4.1	5.5	4.2	5.3	4.1
	Aug	4.7	2.6	5.1	2.8	4.7	2.7	5.1	2.7	4.7	2.6	4.7	2.5	4.8	2.4	4.8	2.4	5.1	2.5	4.8	2.7	5.0	2.8
	Nov	4.5	4.2	3.7	1.4	4.5	4.1	4.4	0.7	4.5	4.1	4.5	4.2	4.5	4.2	4.6	4.3	4.6	4.0	4.3	4.3	4.2	4.2
	Annual Mean	5.0	3.8	4.8	3.1	4.9	3.8	5.0	2.9	4.9	3.8	5.1	3.8	4.9	3.8	5.0	3.8	5.1	3.7	4.9	3.8	4.8	3.8
Calcium (mg/L)																							
	Feb	4.51	4.12	4.52	4.01	4.52	4.11	4.50	3.99	4.51	4.09	4.51	4.08	4.50	4.09	4.52	4.04	4.52	3.87	4.60	3.64	4.24	3.67
	May	4.70	3.94	4.70	3.72	4.71	3.84	4.73	3.81	4.70	3.89	4.53	3.77	4.62	3.81	4.62	4.08	4.70	3.88	4.48	4.21	4.48	3.89
	Aug	4.18	4.25	4.83	4.18	4.21	4.33	4.86	4.29	4.24	4.23	4.23	4.35	4.83	4.47	4.24	4.28	4.31	4.41	4.47	4.75	4.90	4.27
	Nov	4.42	4.54	4.85	4.89	4.43	4.60	4.53	4.70	4.42	4.57	4.41	4.54	4.54	4.64	4.54	4.57	4.63	4.65	4.85	4.73	4.72	4.76
	Annual Mean	4.45	4.21	4.73	4.20	4.47	4.22	4.66	4.20	4.47	4.20	4.42	4.19	4.62	4.25	4.48	4.24	4.54	4.20	4.60	4.33	4.59	4.15
Magnesium (mg/L)																							
	Feb	2.24	1.81	2.26	1.74	2.29	1.81	2.26	1.72	2.24	1.79	2.25	1.80	2.25	1.79	2.25	1.76	2.22	1.64	2.12	1.53	1.87	1.55
	May	2.10	1.62	2.15	1.56	2.11	1.61	2.14	1.60	2.08	1.63	2.16	1.59	2.15	1.61	2.15	1.65	2.13	1.63	2.19	1.69	2.14	1.62
	Aug	2.04	1.78	2.23	1.74	2.03	1.82	2.21	1.78	2.01	1.76	2.02	1.83	2.21	1.86	2.01	1.80	2.22	1.82	2.06	1.93	2.21	1.76
	Nov	2.11	1.94	2.19	1.96	2.11	1.96	2.11	1.85	2.10	1.94	2.11	1.95	2.13	1.98	2.12	1.95	2.14	1.97	2.11	2.20	2.11	2.20
	Annual Mean	2.12	1.79	2.21	1.75	2.14	1.80	2.18	1.74	2.11	1.78	2.14	1.79	2.19	1.81	2.13	1.79	2.18	1.77	2.12	1.84	2.08	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:	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Potassium (mg/L)																						
Feb	2.00	1.83	2.01	1.76	2.01	1.82	2.01	1.74	2.05	1.81	2.04	1.82	2.01	1.81	1.98	1.78	2.01	1.68	1.98	1.68	1.94	1.69
May	1.98	1.63	2.01	1.60	1.98	1.60	2.00	1.65	1.94	1.61	2.04	1.58	2.02	1.64	2.03	1.64	1.99	1.63	1.97	1.52	1.93	1.62
Aug	1.94	1.64	1.96	1.68	1.94	1.67	1.96	1.71	1.91	1.60	1.86	1.67	1.99	1.72	1.94	1.65	1.94	1.79	1.87	1.63	1.95	1.66
Nov	2.02	1.71	2.07	1.78	2.05	1.74	2.05	1.67	2.05	1.73	2.04	1.72	2.04	1.73	2.05	1.72	2.07	1.74	2.05	1.74	2.04	1.74
Annual Mean	1.99	1.70	2.01	1.71	2.00	1.71	2.01	1.69	1.99	1.69	2.00	1.70	2.02	1.73	2.00	1.70	2.00	1.71	1.97	1.64	1.97	1.68
Sodium (mg/L)																						
Feb	5.58	4.03	5.61	3.85	5.68	4.02	5.59	3.81	5.59	3.99	5.57	4.02	5.57	3.97	5.64	3.91	5.59	3.63	5.57	3.34	5.38	3.46
May	5.38	3.64	5.48	3.48	5.42	3.63	5.46	3.56	5.36	3.69	5.51	3.59	5.49	3.56	5.52	3.68	5.40	3.63	5.36	3.75	5.20	3.61
Aug	4.77	3.90	5.27	3.75	4.69	3.95	5.26	3.78	4.65	3.80	4.67	3.94	5.12	3.79	4.76	3.89	5.14	4.03	4.65	3.96	5.10	3.74
Nov	4.70	4.03	4.88	3.79	4.70	4.06	4.68	3.53	4.71	4.04	4.70	4.03	4.69	4.07	4.72	4.06	4.73	4.08	4.62	4.16	4.61	4.18
Annual Mean	5.11	3.90	5.31	3.72	5.12	3.92	5.25	3.67	5.08	3.88	5.11	3.90	5.22	3.85	5.16	3.89	5.22	3.84	5.05	3.80	5.07	3.75
Aluminum (mg/L)																						
Feb	0.088	0.047	0.054	0.070	0.067	0.053	0.056	0.075	0.050	0.050	0.050	0.0303	0.057	0.055	0.087	0.058	0.087	0.110	0.051	0.214	0.069	0.183
May	0.040	0.064	0.040	0.097	0.022	0.058	0.038	0.091	0.031	0.122	0.018	0.076	0.039	0.135	0.013	0.047	0.046	0.089	0.009	0.057	0.048	0.112
Aug	0.051	0.020	0.051	0.048	0.053	0.022	0.050	0.053	0.050	0.021	0.050	0.025	0.093	0.033	0.050	0.020	0.050	0.026	0.050	0.020	0.050	0.031
Nov	0.041	0.057	0.043	0.013	0.054	0.054	0.049	0.013	0.046	0.057	0.048	0.055	0.069	0.142	0.043	0.064	0.068	0.081	0.051	0.065	0.058	0.086
Annual Mean	0.055	0.047	0.047	0.057	0.049	0.047	0.048	0.058	0.044	0.062	0.041	0.046	0.065	0.091	0.048	0.047	0.063	0.077	0.040	0.089	0.056	0.103
Iron (mg/L)																						
Feb	0.126	0.107	0.138	0.237	0.124	0.113	0.164	0.236	0.112	0.124	0.122	0.024	0.238	0.156	0.199	0.172	0.392	0.504	0.150	1.170	0.302	0.942
May	0.110	0.094	0.168	0.411	0.100	0.107	0.168	0.432	0.143	0.134	0.088	0.110	0.177	0.407	0.068	0.064	0.184	0.226	0.060	0.053	0.301	0.423
Aug	0.061	0.027	0.051	0.061	0.062	0.029	0.054	0.067	0.061	0.029	0.053	0.035	0.518	0.542	0.048	0.033	0.057	0.088	0.046	0.044	0.064	0.055
Nov	0.097	0.079	0.614	1.970	0.098	0.090	0.151	3.500	0.094	0.115	0.092	0.079	0.201	0.260	0.100	0.093	0.346	0.381	0.116	0.099	0.218	0.280
Annual Mean	0.098	0.077	0.243	0.670	0.096	0.085	0.134	1.059	0.102	0.100	0.089	0.062	0.284	0.341	0.104	0.090	0.246	0.300	0.093	0.342	0.221	0.425
Manganese (ug/L)																						
Feb	13	13	24	23	16	14	21	23	18	15	16	1	38	22	13	16	31	30	17	55	43	47
May	9	6	30	25	10	6	33	29	11	7	10	7	46	27	6	4	32	12	7	6	48	32
Aug	33	25	292	631	40	25	349	974	55	42	46	34	1800	2030	23	21	538	400	23	34	669	909
Nov	41	101	2130	5300	45	120	88	5280	46	177	44	110	216	800	41	82	676	408	52	82	66	104
Annual Mean	24	36	619	1495	28	42	123	1576	32	60	29	38	525	720	21	31	319	212	25	44	212	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	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	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	0.9	1.0	0.9	1.0	0.9	1	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0
Copper (ug/L)																						
Feb	1.6	1.8	1.7	2.1	1.7	2.0	1.6	1.9	1.7	1.9	1.7	1.8	1.8	2.0	1.6	1.8	2.0	1.9	2.3	2.2	2.0	1.9
May	2.5	2.6	2.3	1.9	2.3	1.7	2.3	1.8	2.4	1.7	2.2	1.7	2.2	1.8	2.0	1.7	2.2	1.7	2.2	1.8	2.5	1.9
Aug	1.4	1.2	1.2	1.2	1.5	1.2	1.1	1.3	1.6	1.3	1.5	1.3	1.0	1.1	1.3	1.0	1.1	1.1	2.2	1.2	2.0	1.1
Nov	1.8	2.0	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	1.9	1.1	1.8	1.5
Annual Mean	1.8	1.9	1.5	1.6	1.6	1.5	1.5	1.5	1.7	1.5	1.6	1.5	1.5	1.6	1.5	1.4	1.6	1.4	2.2	1.6	2.1	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)

		Mixing Zone				Mixing Zone				MNS Discharge		Mixing Zone				Background				Background			
	LOCATION:	1.0				2.0				4.0		5.0				8.0				11.0			
	DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS	YEAR:	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Zinc (ug/L)																							
Feb		1.3	2.4	1.3	3.0	1.2	3.0	1.6	2.5	1.6	2.5	1.4	2.2	1.8	2.3	1.1	3.1	1.5	2.7	1.5	3.8	1.8	3.8
May		1.5	2.6	1.3	2.5	1.0	2.0	1.1	2.2	1.2	2.0	1.1	2.0	1.2	2.5	1.0	2.0	1.2	2.0	1.1	2.0	1.5	2.3
Aug		10.8	2.0	6.1	2.1	7.5	2.0	7.9	2.1	6.6	2.6	11.9	2.0	11.3	2.0	6.5	2.0	9.6	2.0	10.8	2.8	12.3	2.1
Nov		1.5	2.0	1.7	2.0	1.9	2.0	1.5	2.0	1.4	2.0	1.6	2.0	2.7	2.3	1.6	2.0	1.9	2.0	4.6	2.0	2.0	5.1
Annual Mean		3.8	2.2	2.6	2.4	2.9	2.3	3.0	2.2	2.7	2.3	4.0	2.1	4.3	2.3	2.6	2.3	3.6	2.2	4.5	2.7	4.4	3.3
Nitrite-Nitrate (ug/L)																							
Feb		89	250	99	290	88	260	91	290	90	290	91	250	100	270	87	270	110	330	200	370	230	360
May		200	300	240	380	190	310	240	390	200	310	140	330	240	380	140	270	260	340	150	280	290	410
Aug		65	110	290	390	76	110	280	380	81	120	77	120	130	140	45	81	260	200	21	55	240	360
Nov		48	73	320	11	49	70	59	13	50	70	52	68	55	63	58	71	52	64	120	100	120	100
Annual Mean		101	183	237	268	101	188	168	268	105	198	90	192	131	213	83	173	171	234	123	201	220	308
Ammonia (ug/L)																							
Feb		33	32	33	56	28	52	28	48	29	43	29	40	33	56	26	43	33	61	26	80	53	78
May		32	33	25	34	65	43	20	41	37	36	24	43	24	32	110	33	41	36	54	29	210	33
Aug		45	27	66	27	36	26	51	29	36	28	39	25	120	85	73	26	33	63	34	44	84	33
Nov		130	110	300	510	130	120	160	530	140	150	150	100	180	210	210	110	200	130	130	98	140	110
Annual Mean		60	51	106	157	65	60	65	162	61	64	61	52	89	96	105	53	77	73	34	63	122	64
Total Phosphorous (ug/L)																							
Feb		8	12	11	15	9	12	10	15	10	12	8	12	11	11	8	14	12	23	11	48	15	38
May		12	9	11	15	11	12	11	12	12	14	10	10	12	13	11	8	11	13	12	9	13	15
Aug		10	9	7	6	10	8	7	7	9	8	9	12	9	7	8	8	11	7	9	9	27	6
Nov		8	7	10	9	6	8	7	12	7	9	5	7	9	14	8	7	20	10	10	11	10	15
Annual Mean		9	9	10	11	9	10	9	12	9	11	8	10	10	11	9	9	14	13	11	19	16	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		3.8	4.6	3.8	4.5	3.7	4.6	3.7	4.6	3.6	4.6	3.6	4.6	3.8	4.6	3.6	4.5	3.7	4.4	4.0	4.3	4.2	4.4
May		4.1	4.1	4.3	4.4	4.0	4.1	4.3	4.4	4.0	4.1	4.0	4.0	4.4	4.4	4.1	4.0	4.6	4.2	3.9	4.1	4.4	4.5
Aug		3.8	4.0	4.7	4.8	3.8	4.0	4.9	4.8	3.8	4.0	3.8	4.1	5.1	5.0	3.7	4.0	4.9	4.4	3.7	3.8	4.8	4.9
Nov		4.0	4.3	4.5	4.8	4.0	4.4	4.0	5.0	4.0	4.4	4.0	4.4	4.1	4.9	3.9	4.4	4.2	4.5	4.1	4.6	4.2	4.5
Annual Mean		3.9	4.3	4.3	4.6	3.9	4.3	4.2	4.7	3.9	4.3	3.8	4.3	4.4	4.7	3.8	4.2	4.3	4.4	3.9	4.2	4.4	4.6

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

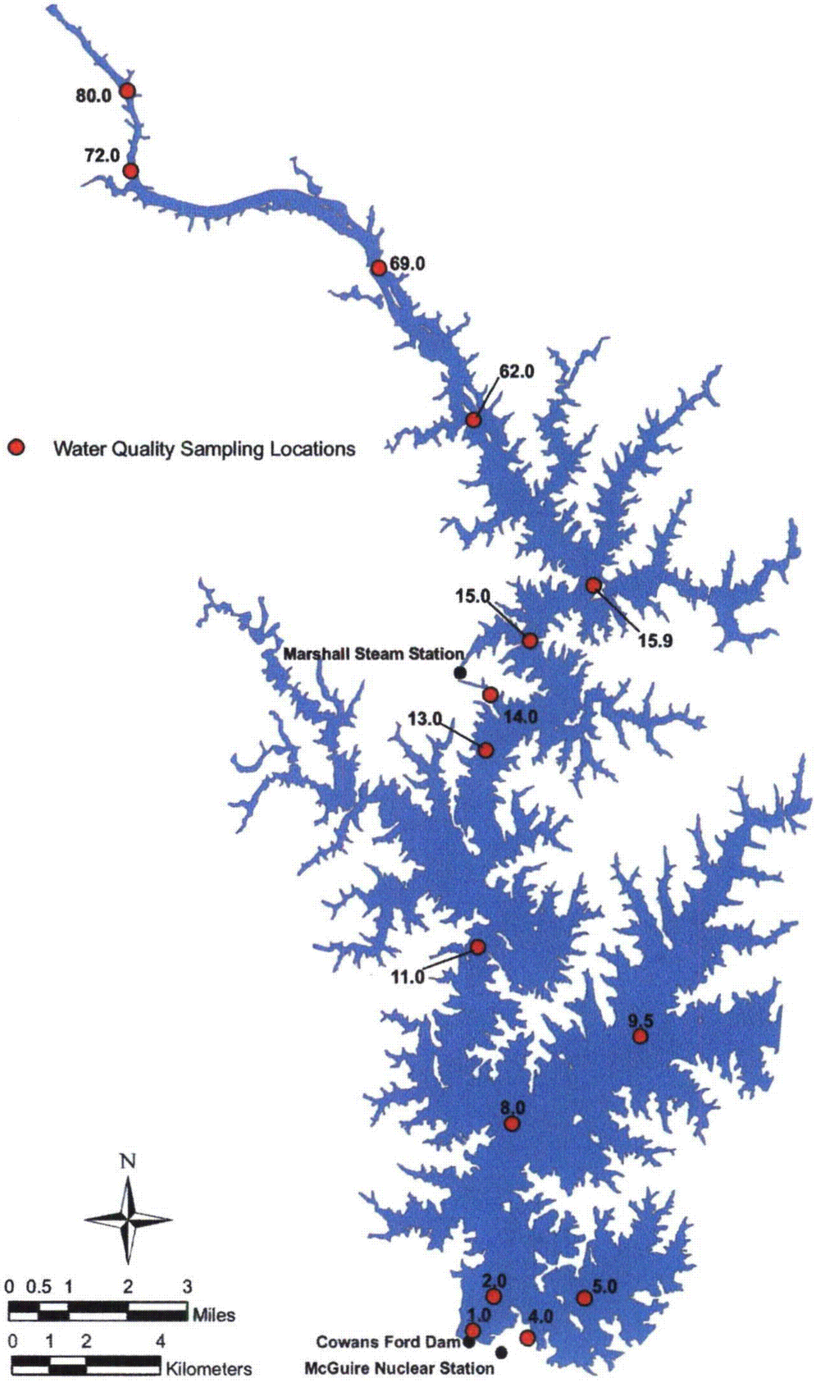


Figure 2-1. Water quality sampling locations (numbered) for Lake Norman. Approximate locations of MSS and MNS are also shown.

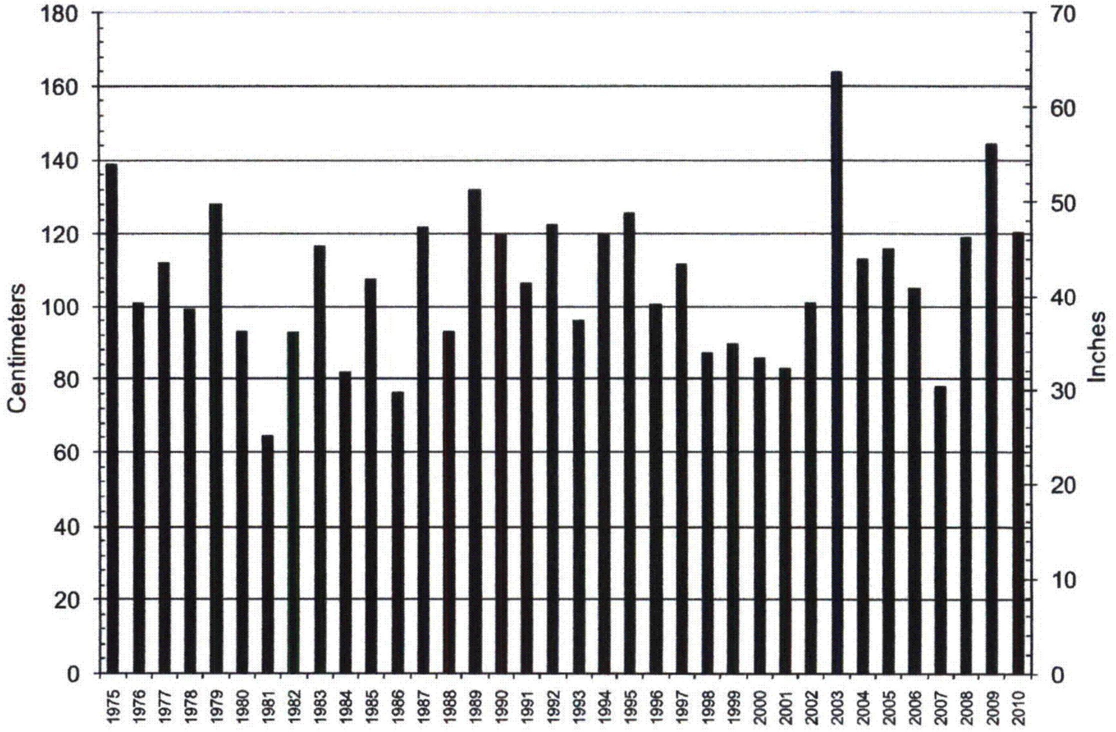


Figure 2-2a. Annual precipitation totals in the vicinity of MNS.

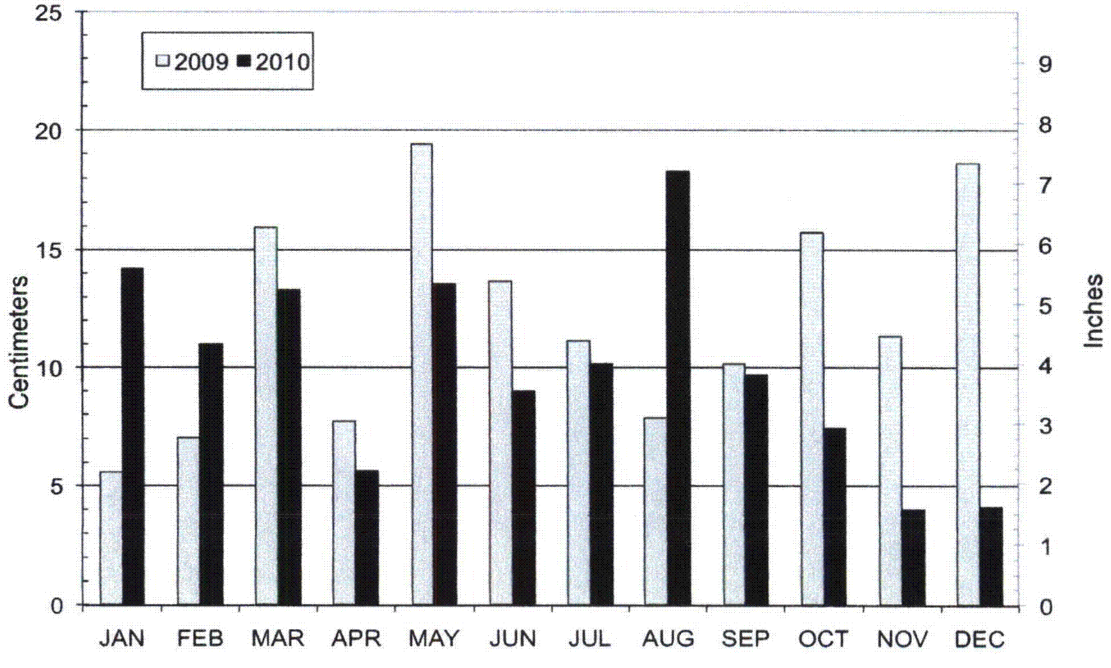


Figure 2-2b. Monthly precipitation totals in the vicinity of MNS in 2009 and 2010.

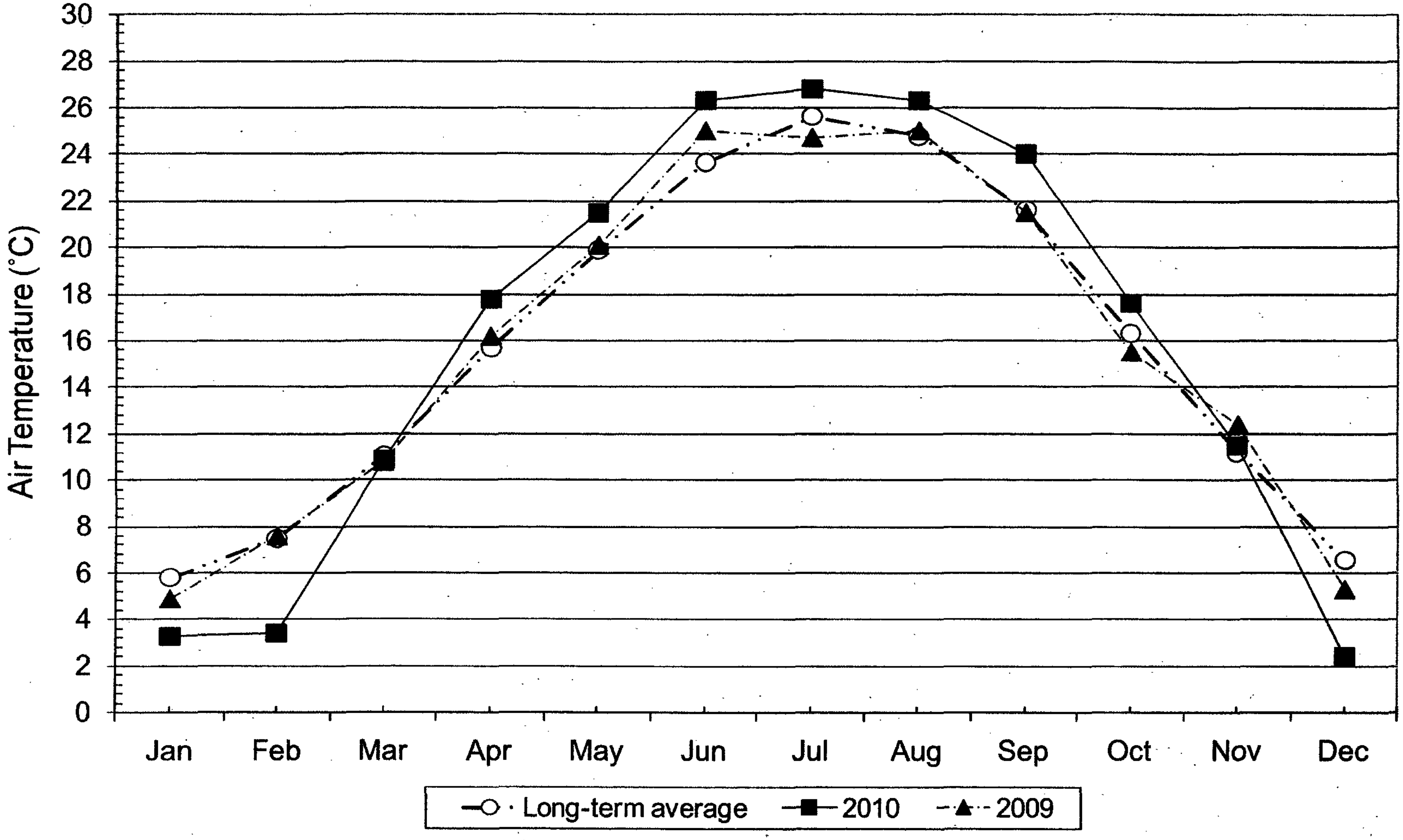


Figure 2-2c. Mean monthly air temperatures recorded at MNS beginning in 1989. Data were compiled from average daily temperatures which, in turn, were created from hourly measurements.

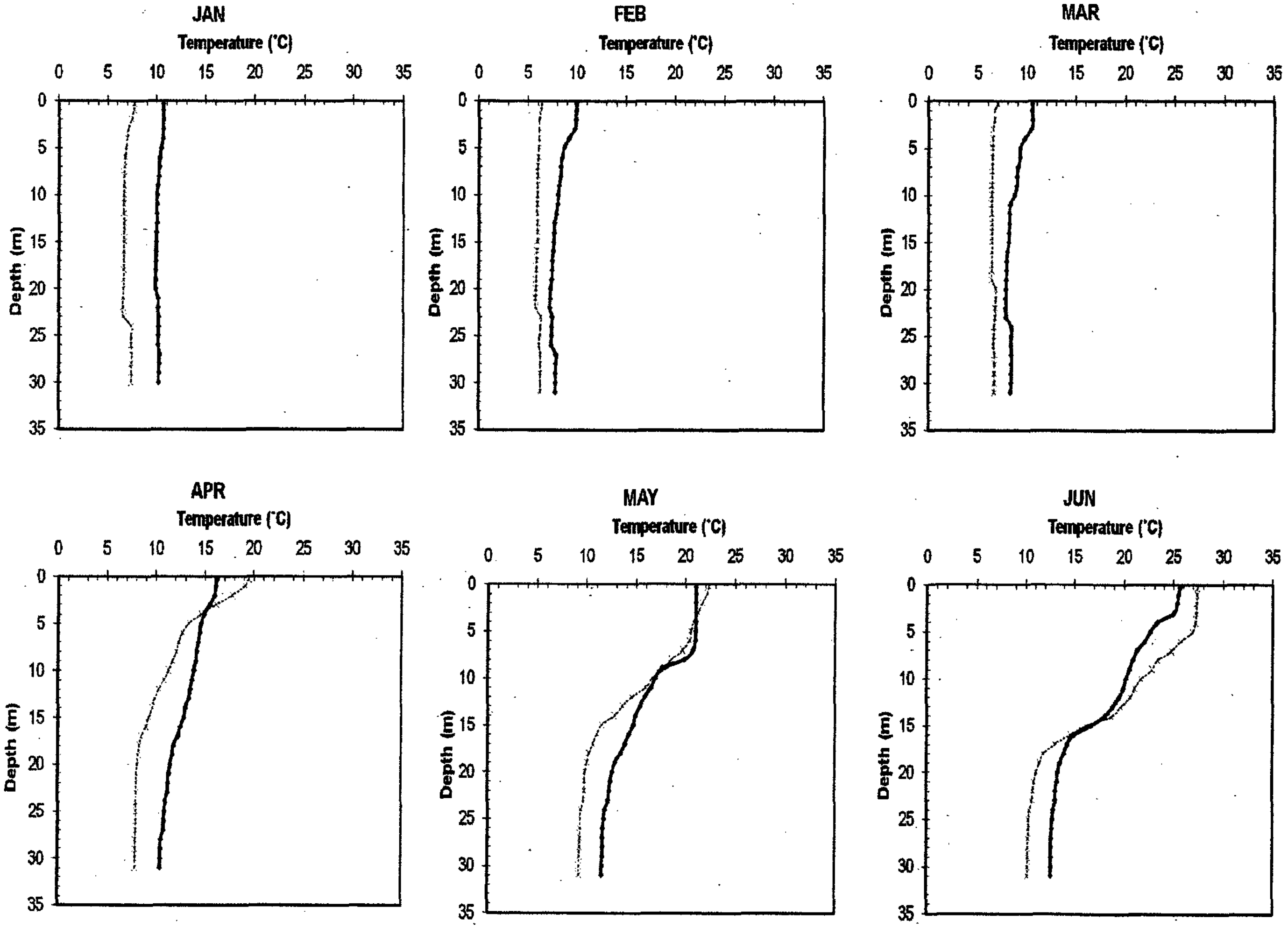


Figure 2-3. Monthly mean temperature profiles for the MNS background zone in 2009 (♦♦) and 2010 (xx).

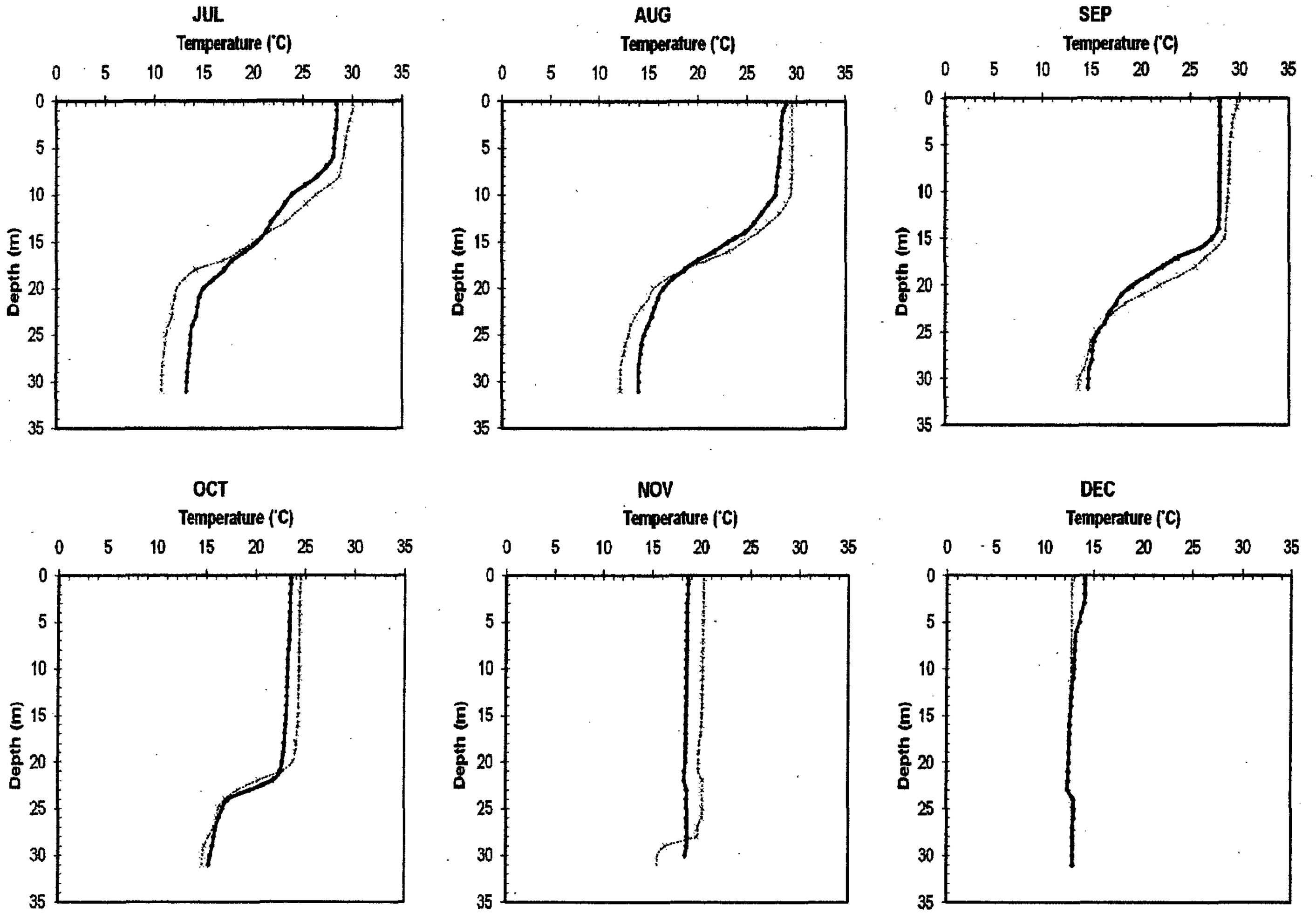


Figure 2-3. (Continued).

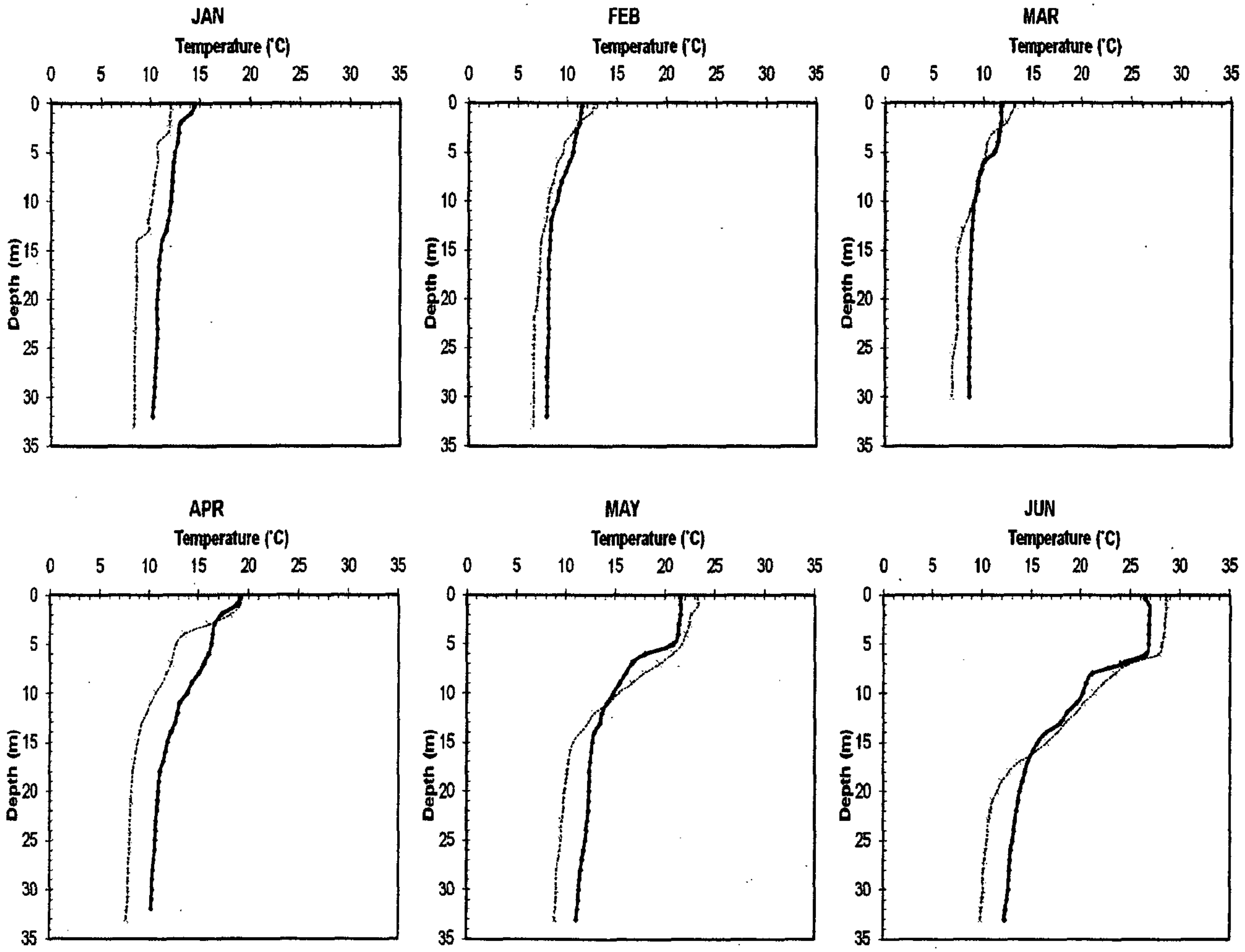


Figure 2-4. Monthly mean temperature profiles for the MNS mixing zone in 2009 (♦♦) and 2010 (xx).

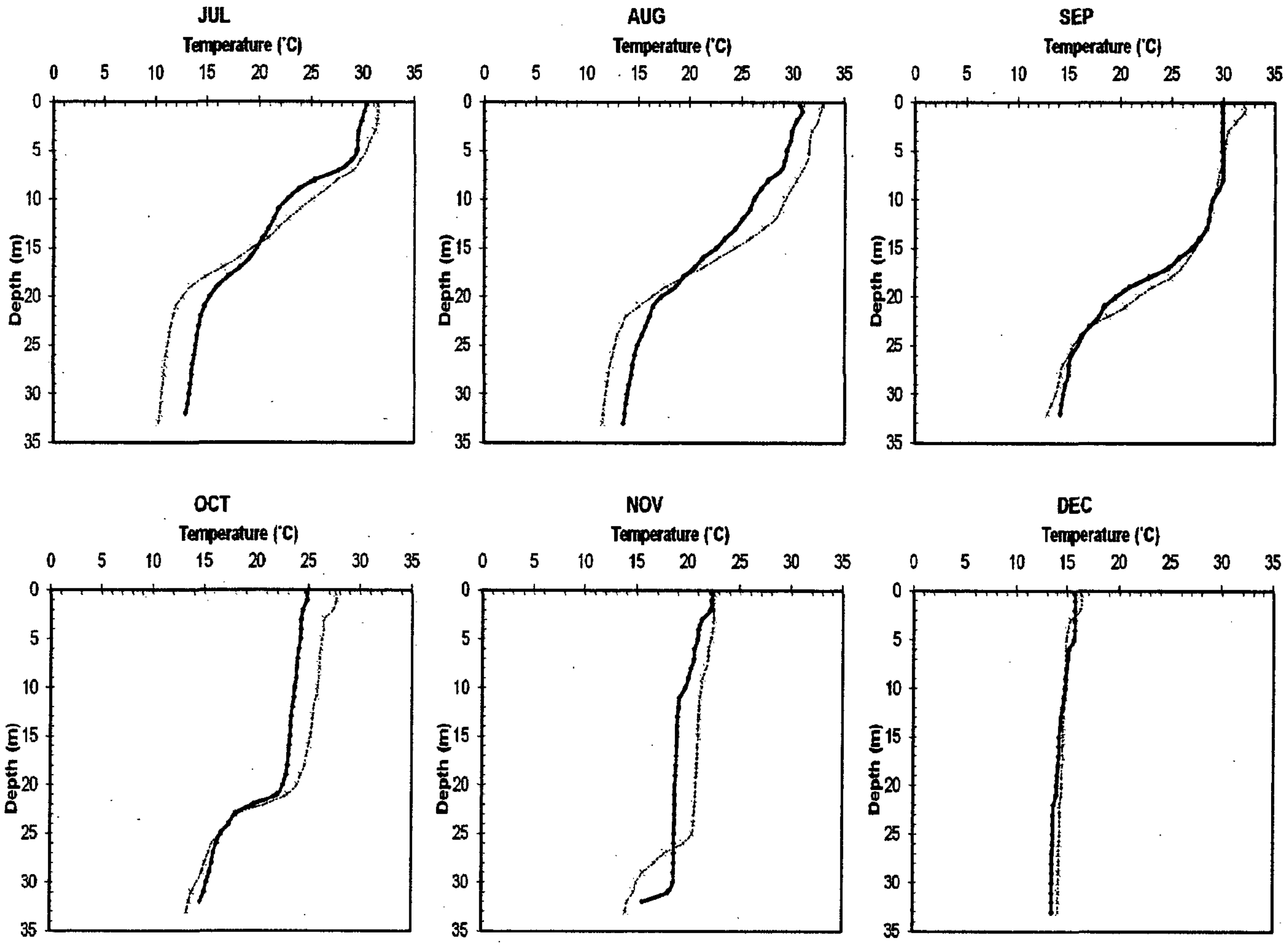


Figure 2-4. (Continued).

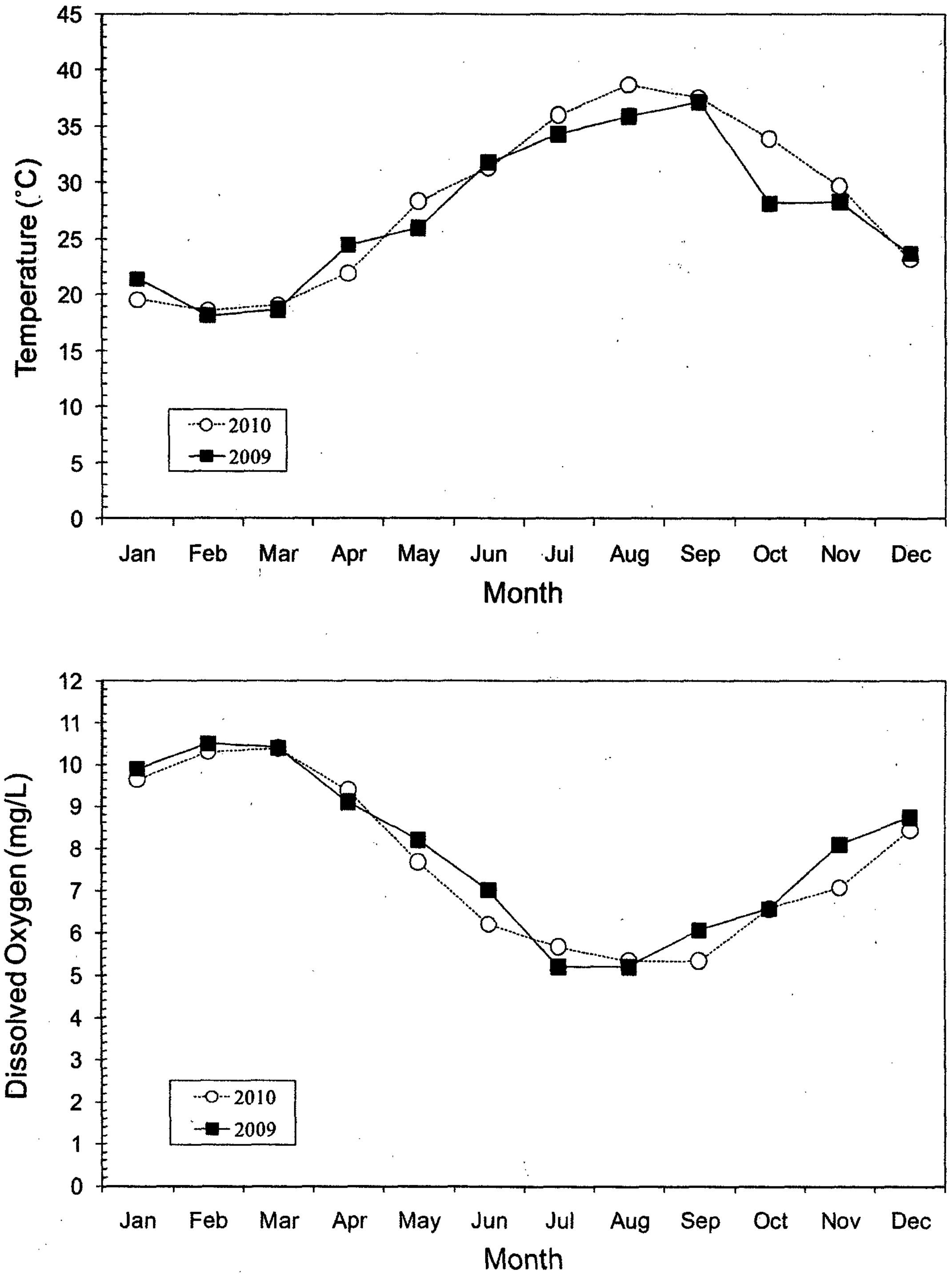


Figure 2-5. Monthly surface (0.3m) temperature and dissolved oxygen data at the discharge location (Location 4.0) in 2009 and 2010.

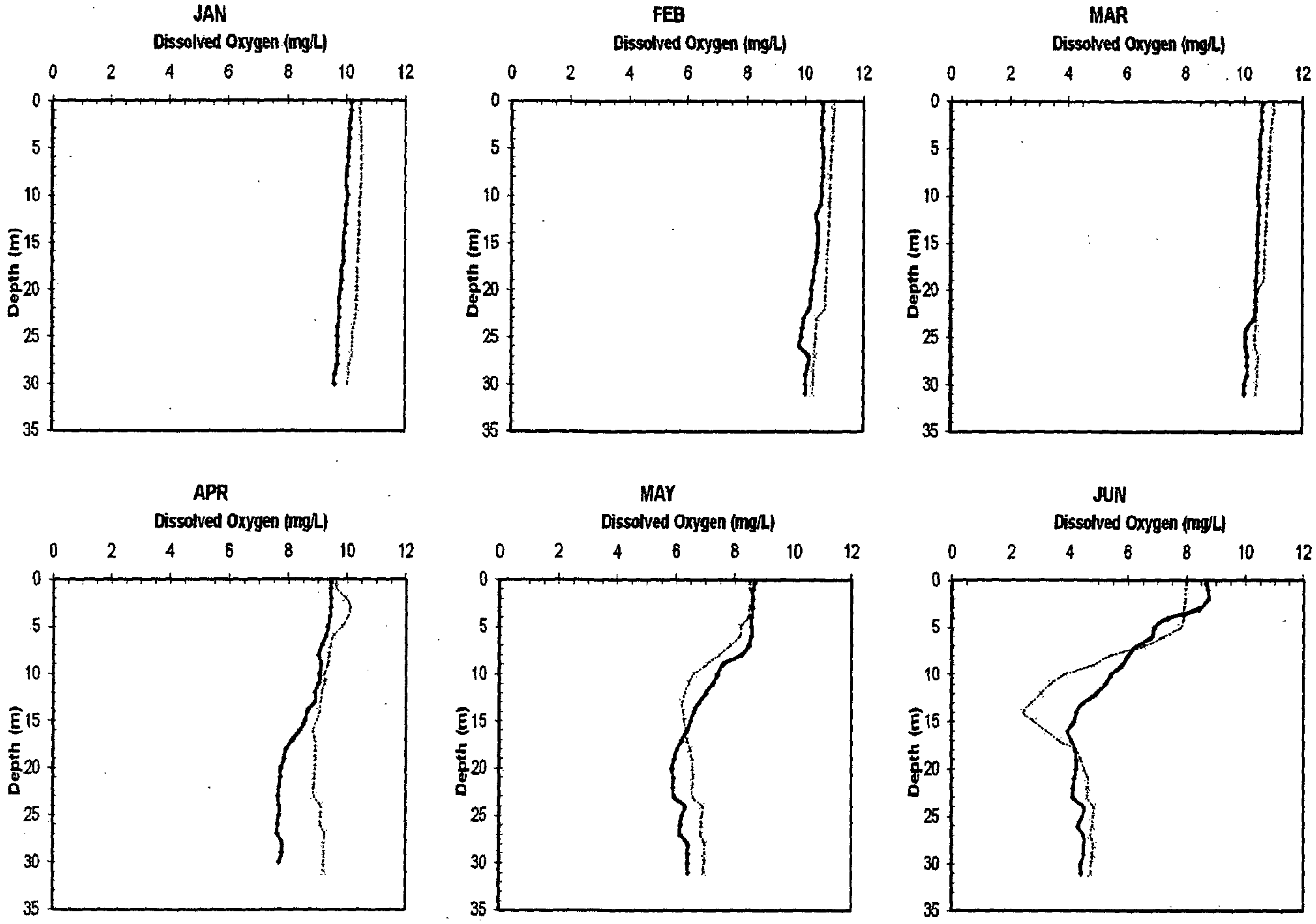


Figure 2-6. Monthly mean dissolved oxygen profiles for the MNS background zone in 2009 (♦♦) and 2010 (xx).

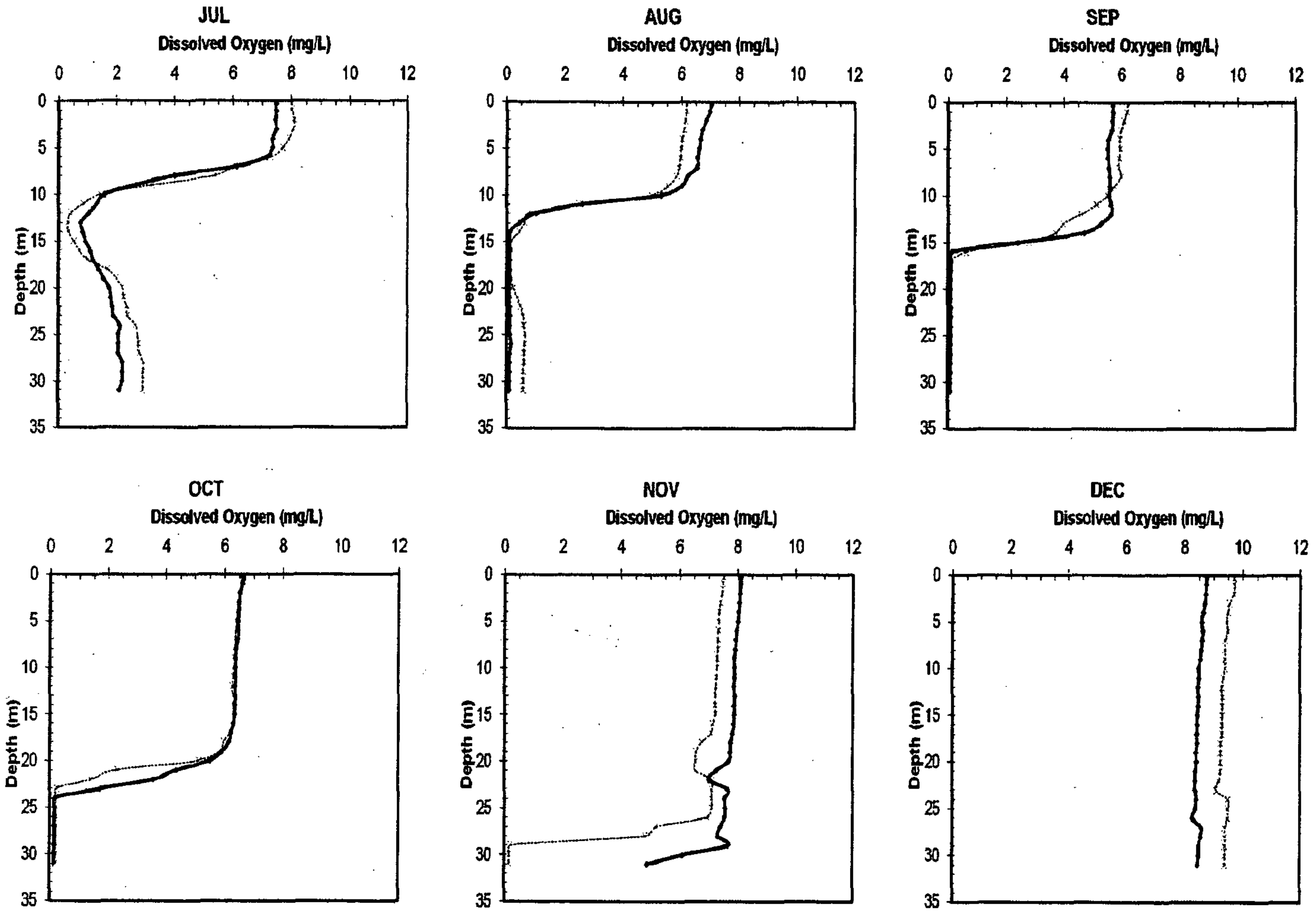


Figure 2-6. (Continued).

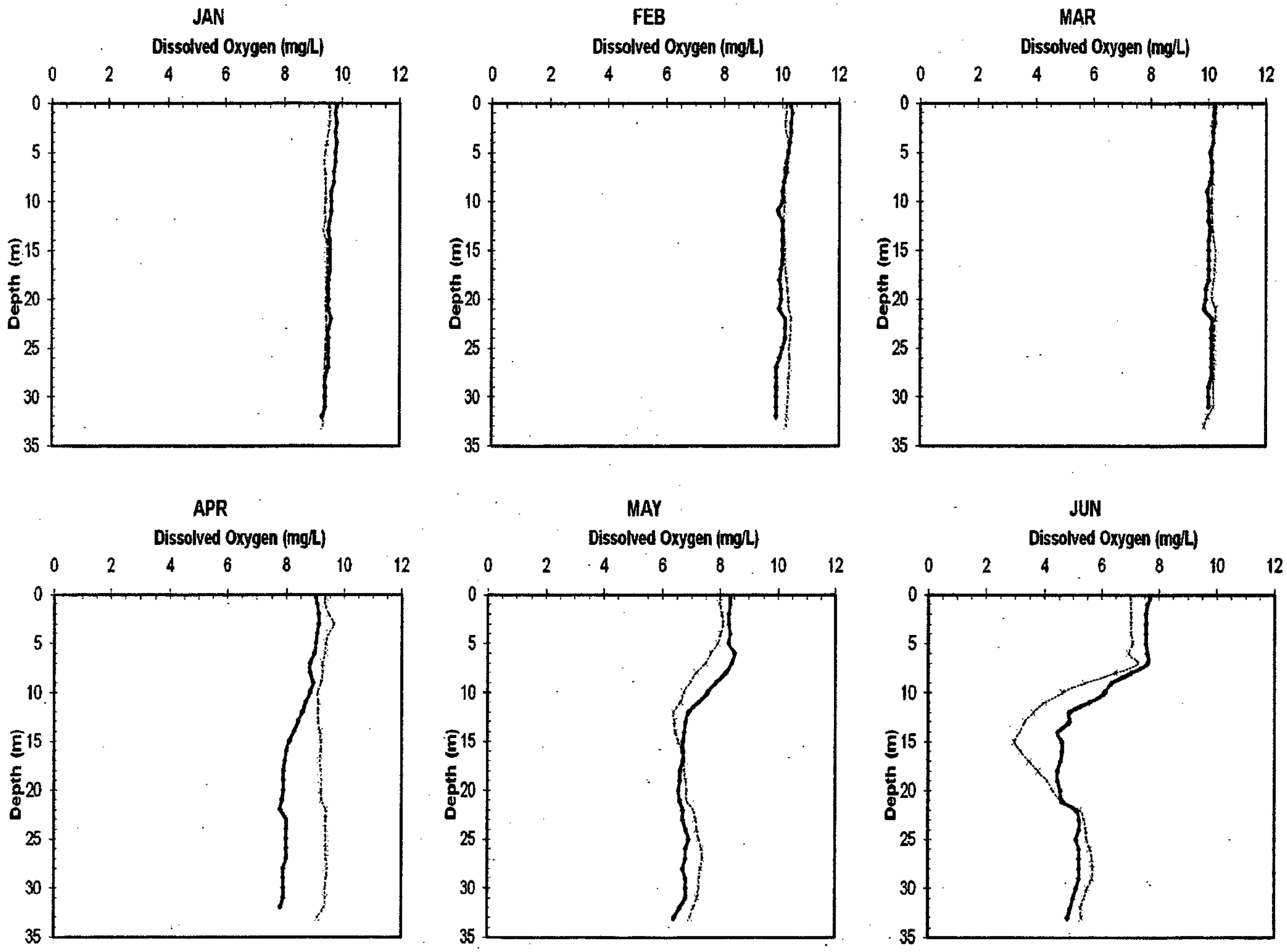


Figure 2-7. Monthly mean dissolved oxygen profiles for the MNS mixing zone in 2009 (♦♦) and 2010 (xx).

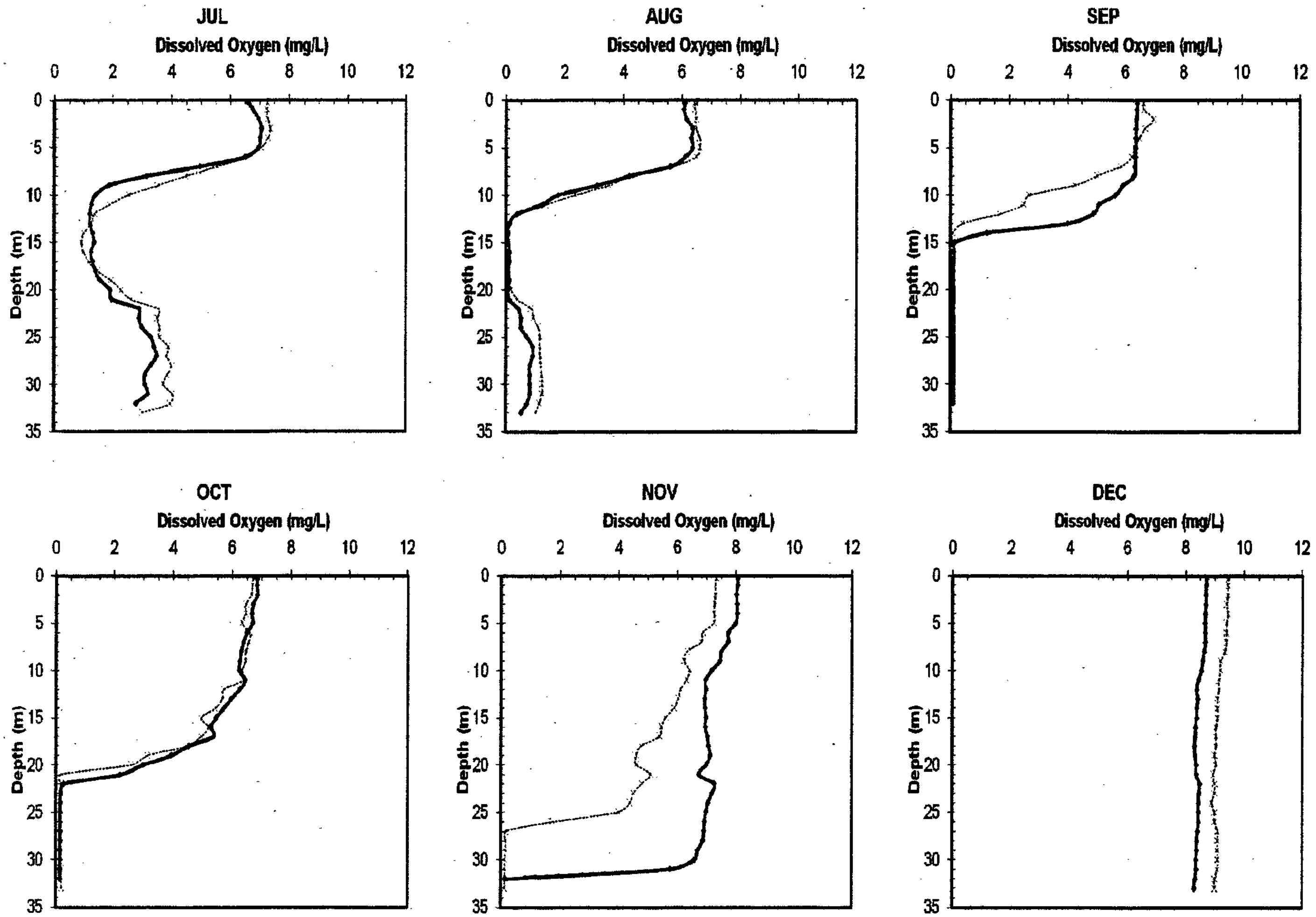


Figure 2-7. (Continued).

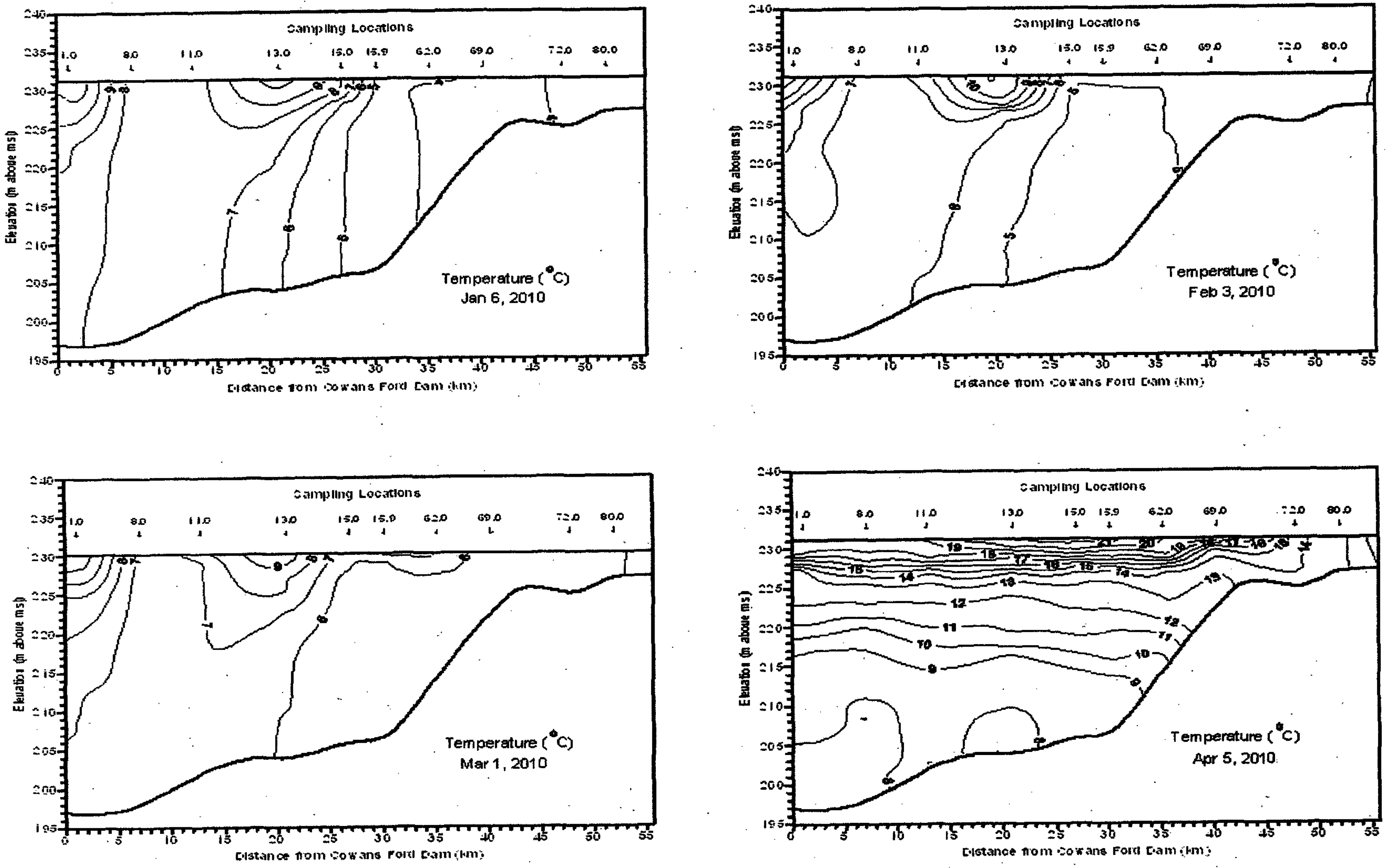


Figure 2-8. Monthly reservoir-wide temperature isotherms for Lake Norman in 2010.

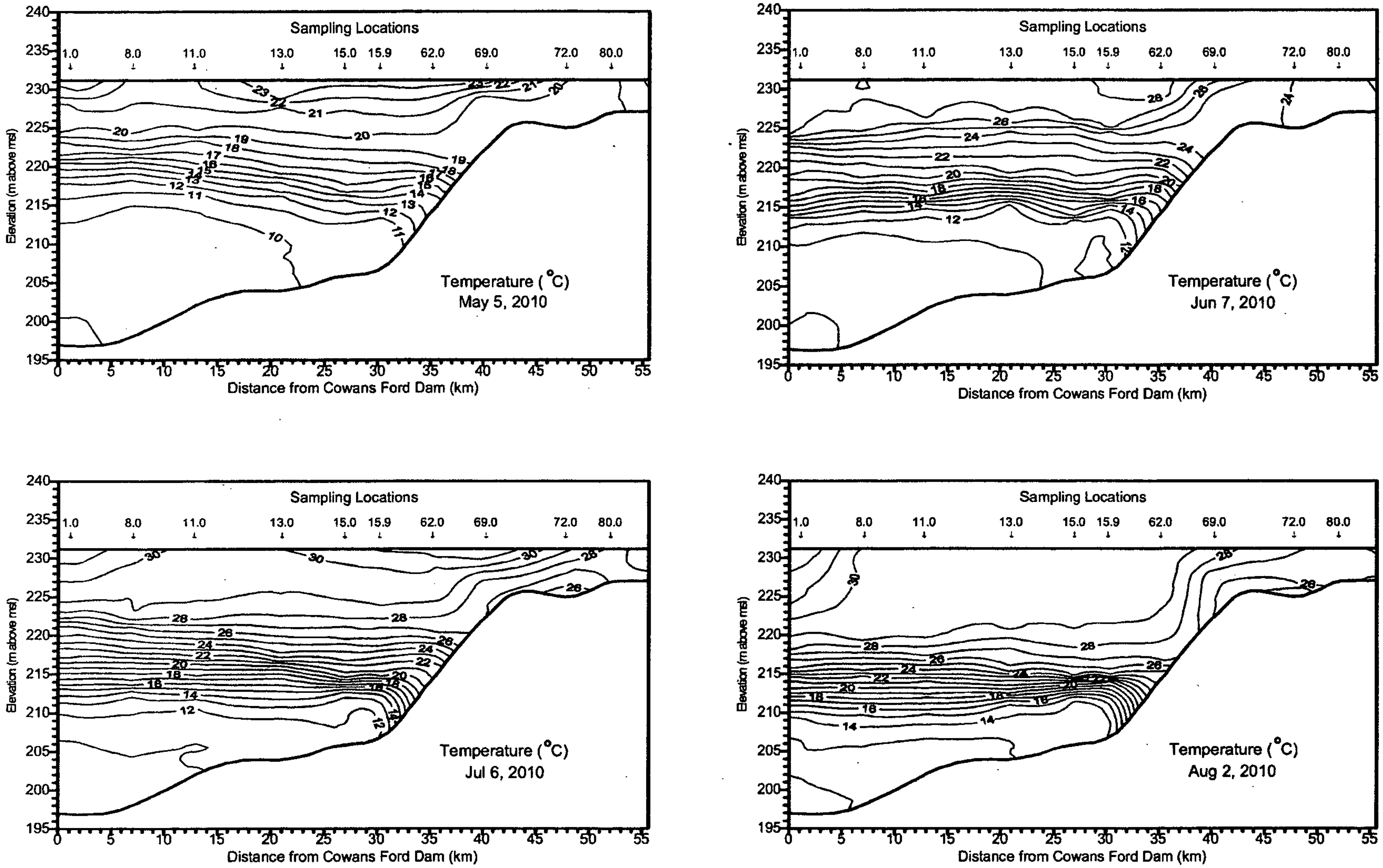


Figure 2-8. (Continued).

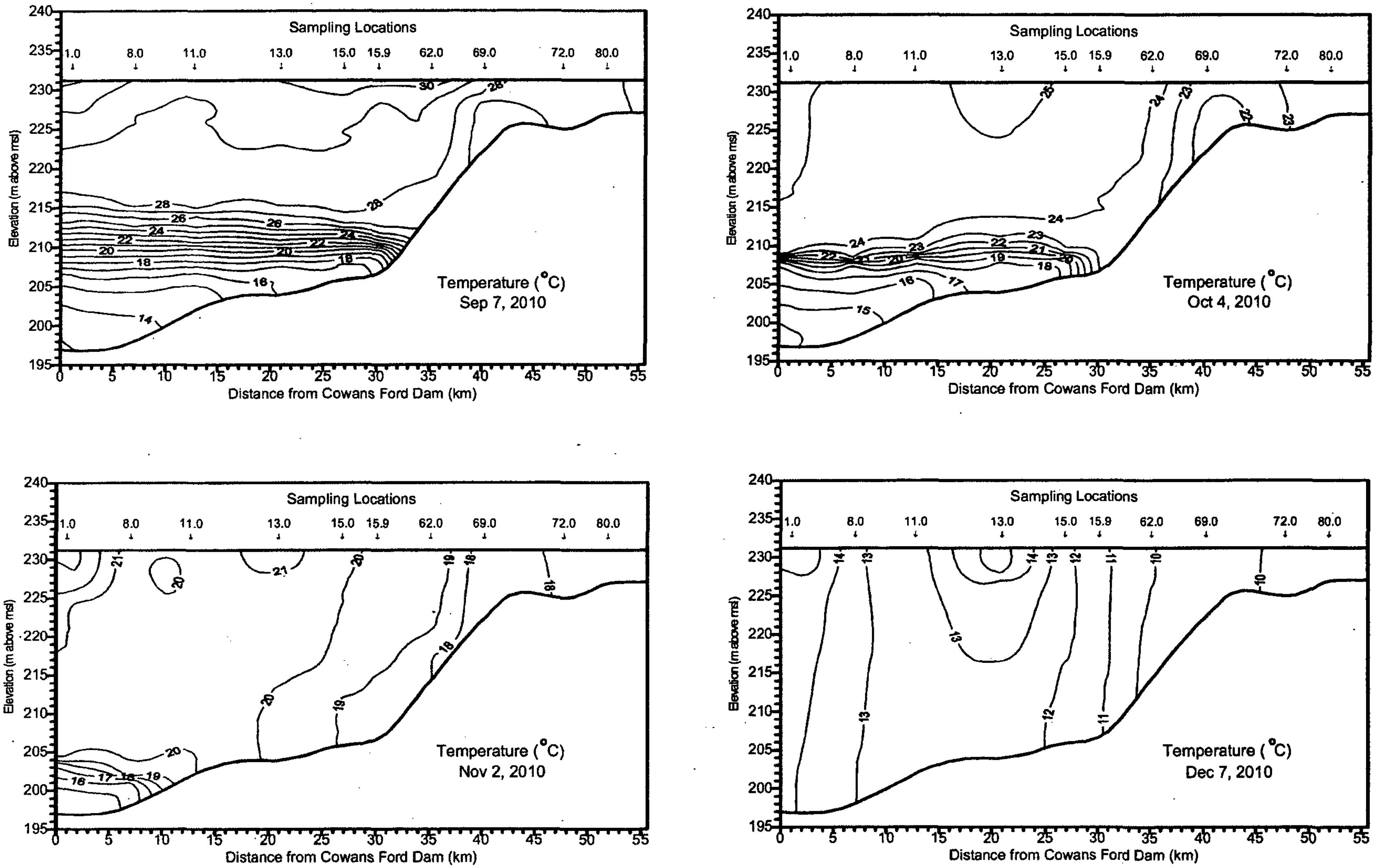


Figure 2-8. (Continued).

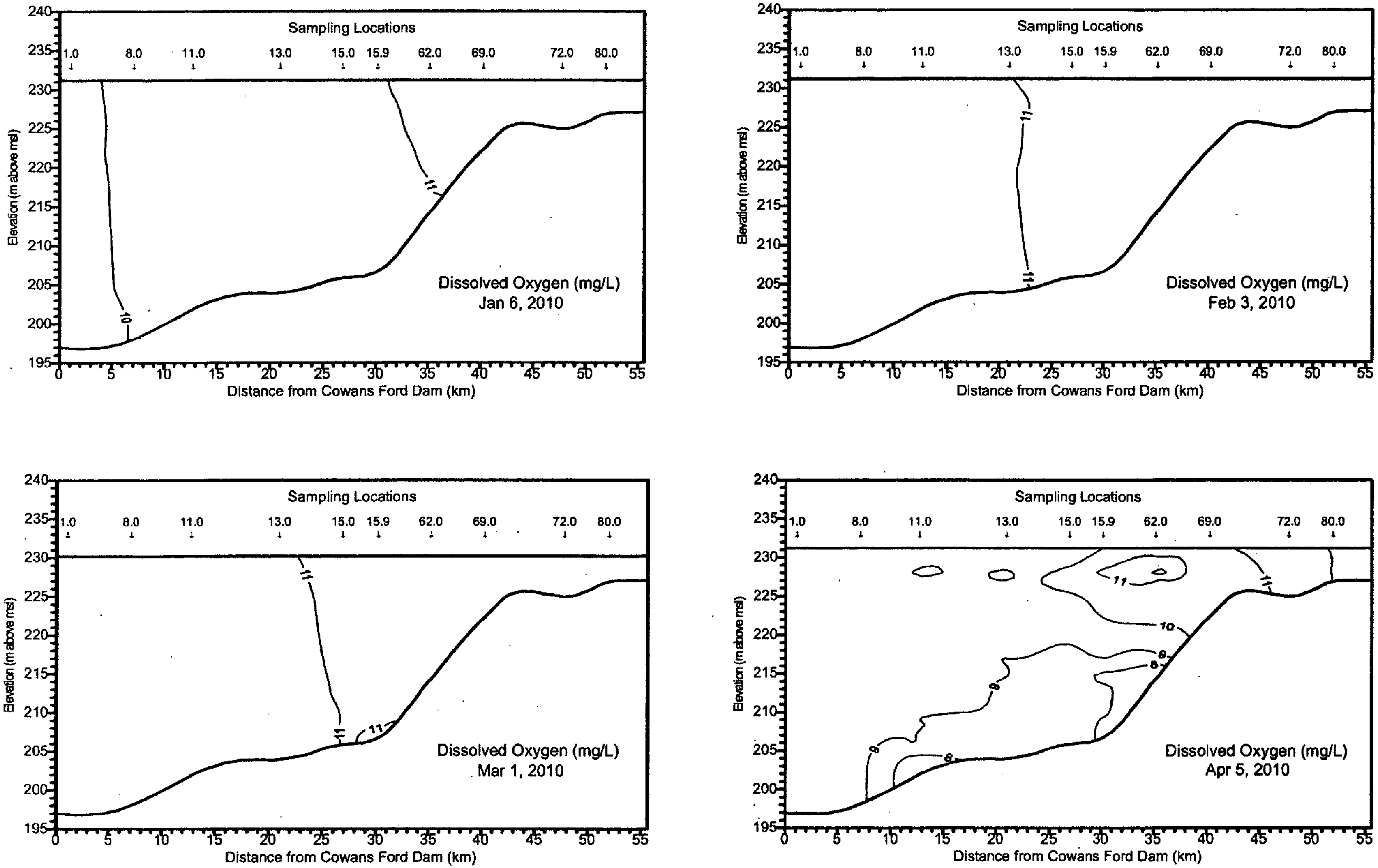
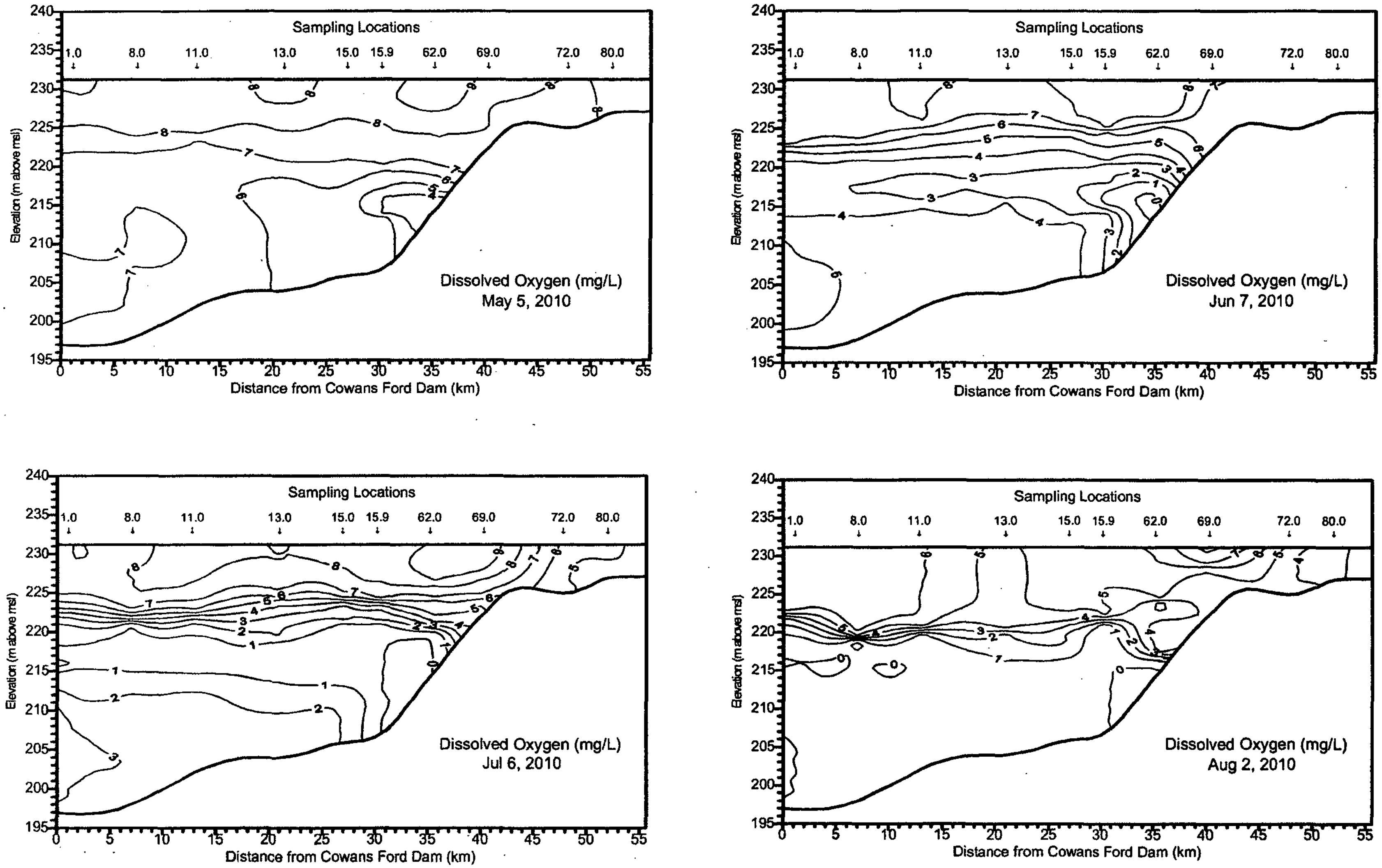


Figure 2-9. Monthly reservoir-wide dissolved oxygen isopleths for Lake Norman in 2010.



Dissolved Oxygen (mg/L)
May 5, 2010

Dissolved Oxygen (mg/L)
Jun 7, 2010

Dissolved Oxygen (mg/L)
Jul 6, 2010

Dissolved Oxygen (mg/L)
Aug 2, 2010

Figure 2-9. (Continued).

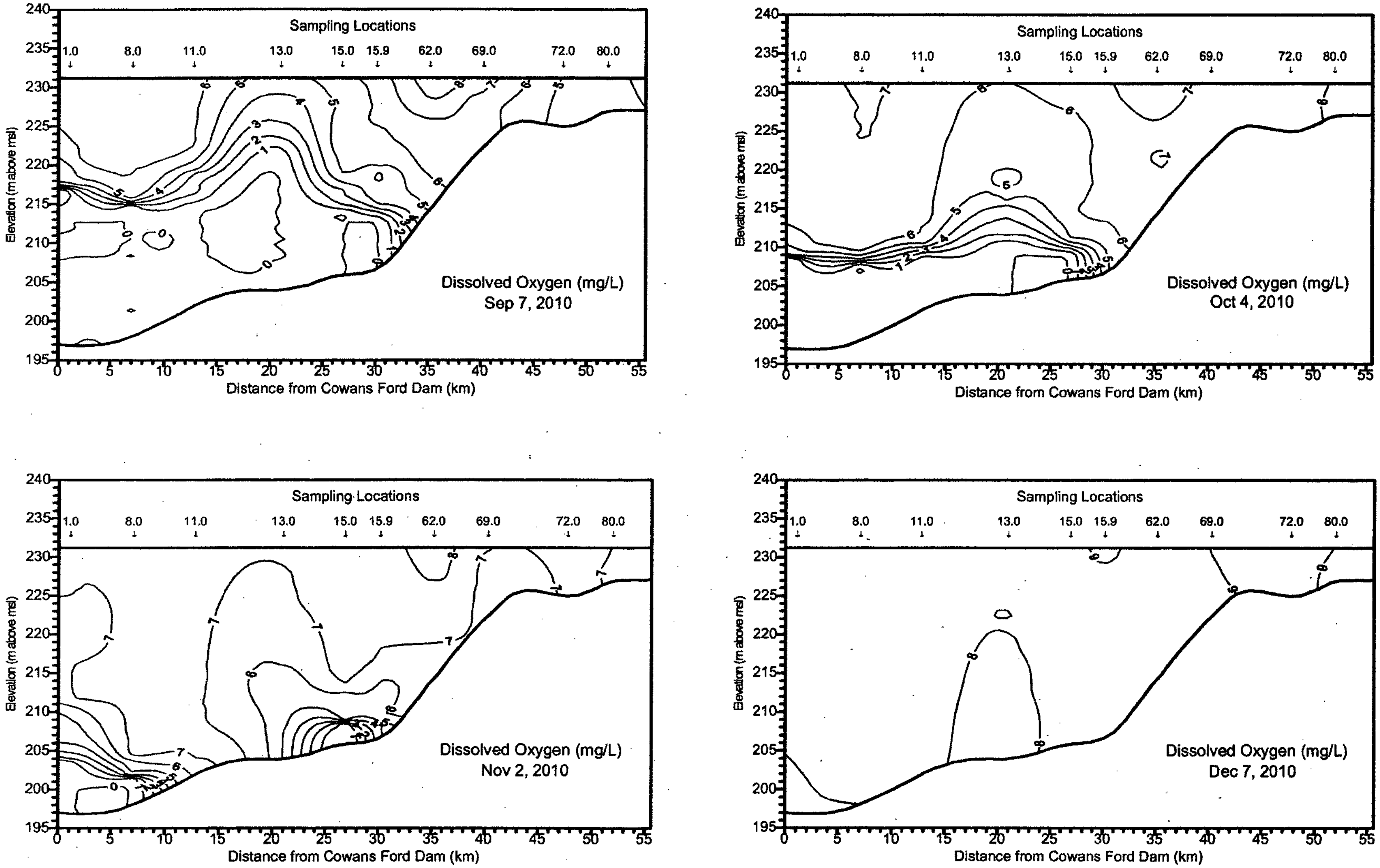


Figure 2-9. (Continued).

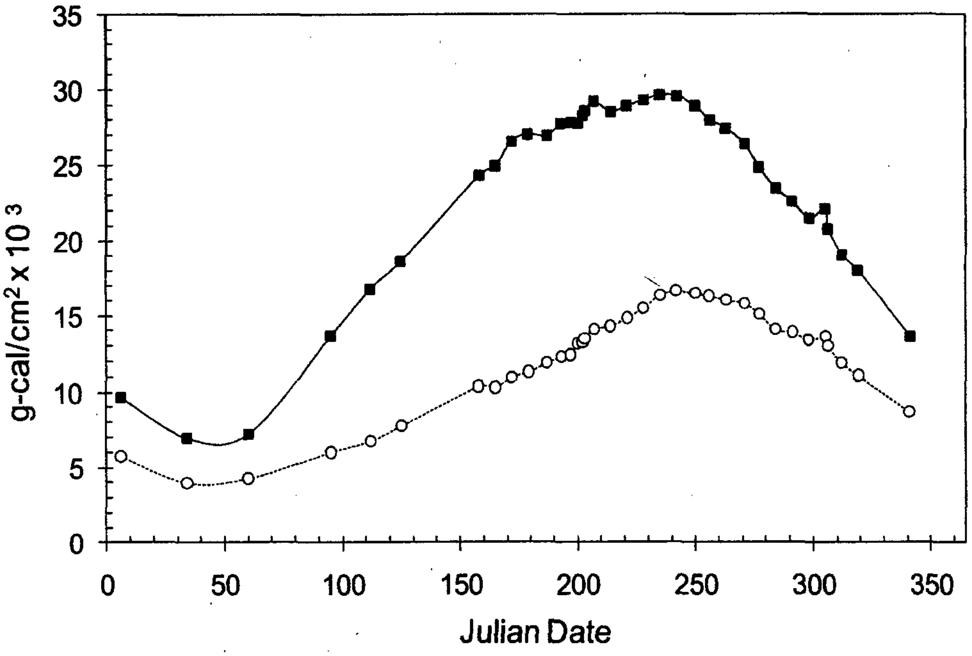


Figure 2-10a. Heat content of the entire water column (■) and the hypolimnion (○) in Lake Norman in 2010.

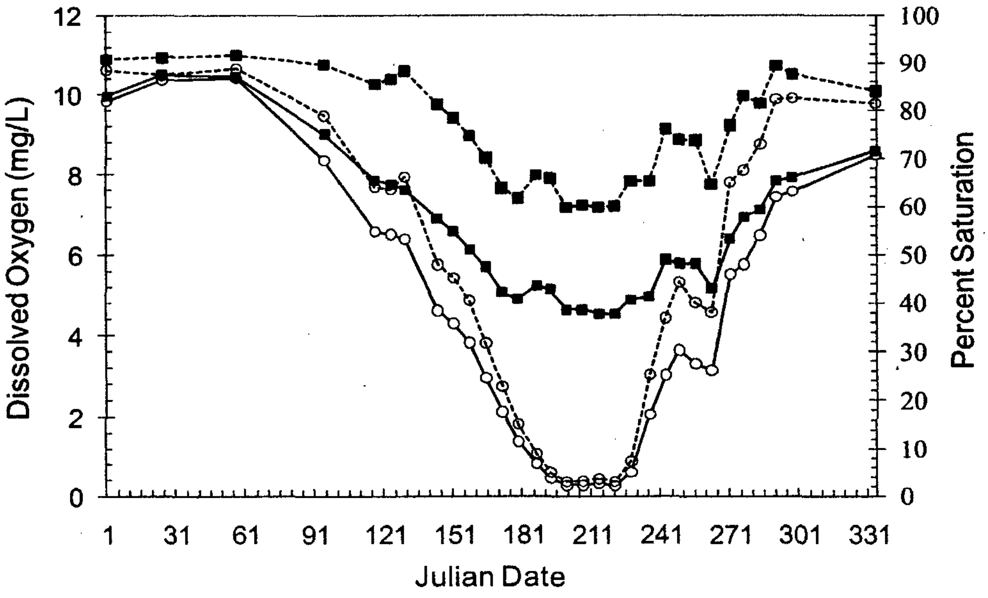


Figure 2-10b. Dissolved oxygen content (–) and percent saturation (---) of the entire water column (■) and the hypolimnion (○) of Lake Norman in 2010.

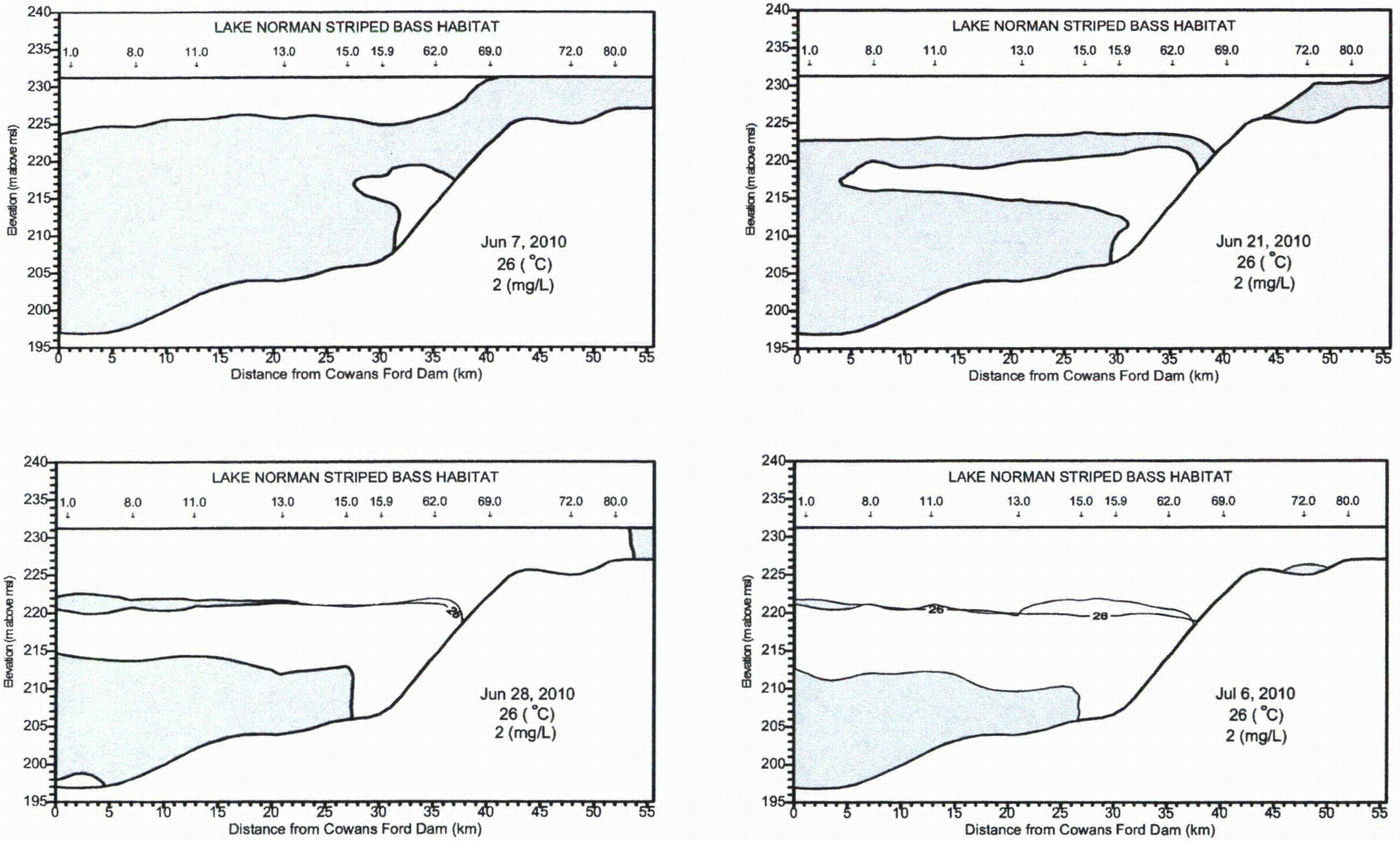


Figure 2-11. Striped bass habitat (shaded areas; temperatures ≤ 26 °C and dissolved oxygen ≥ 2 mg/L) in Lake Norman in June, July, August, and September 2010.

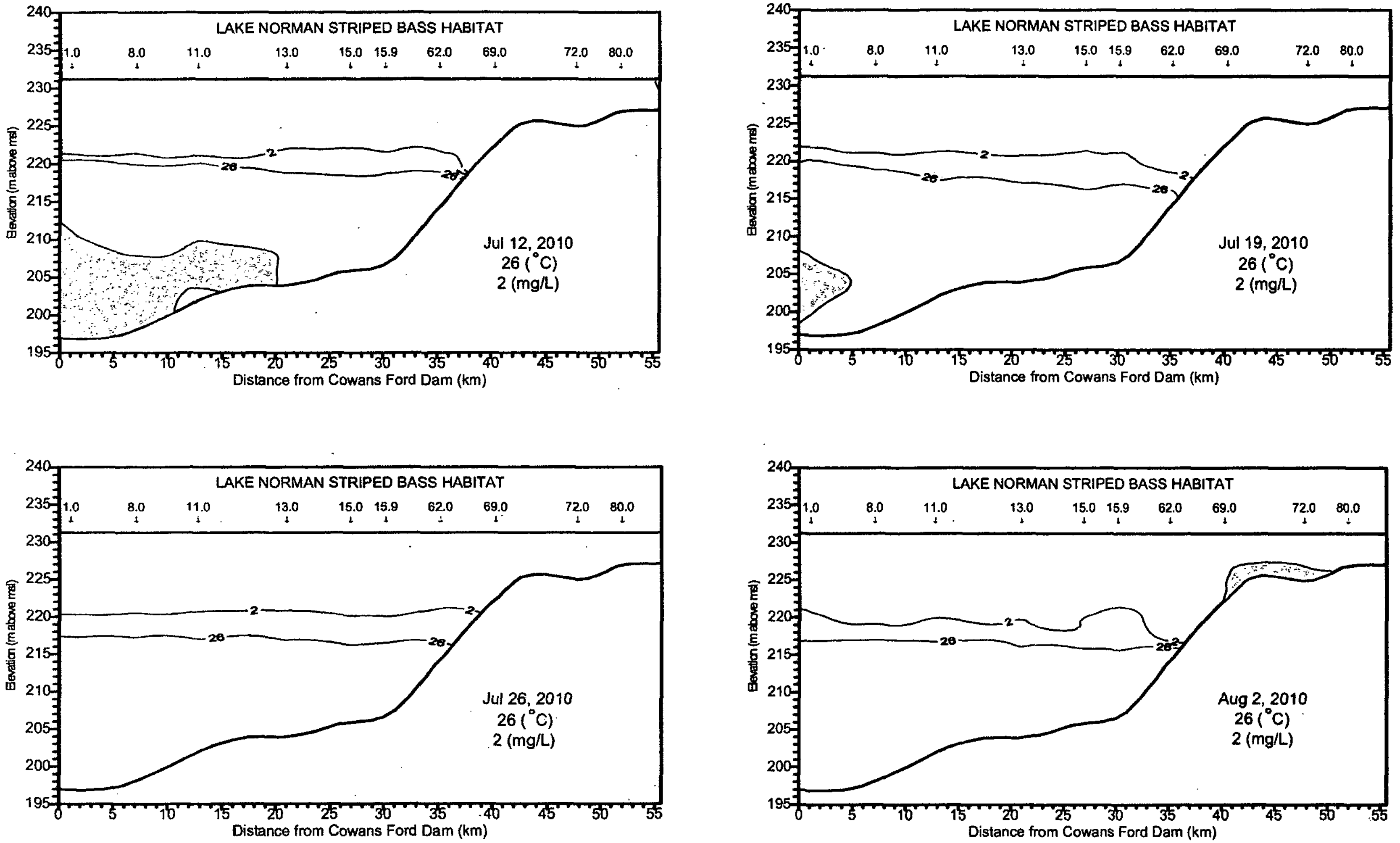


Figure 2-11. (Continued).

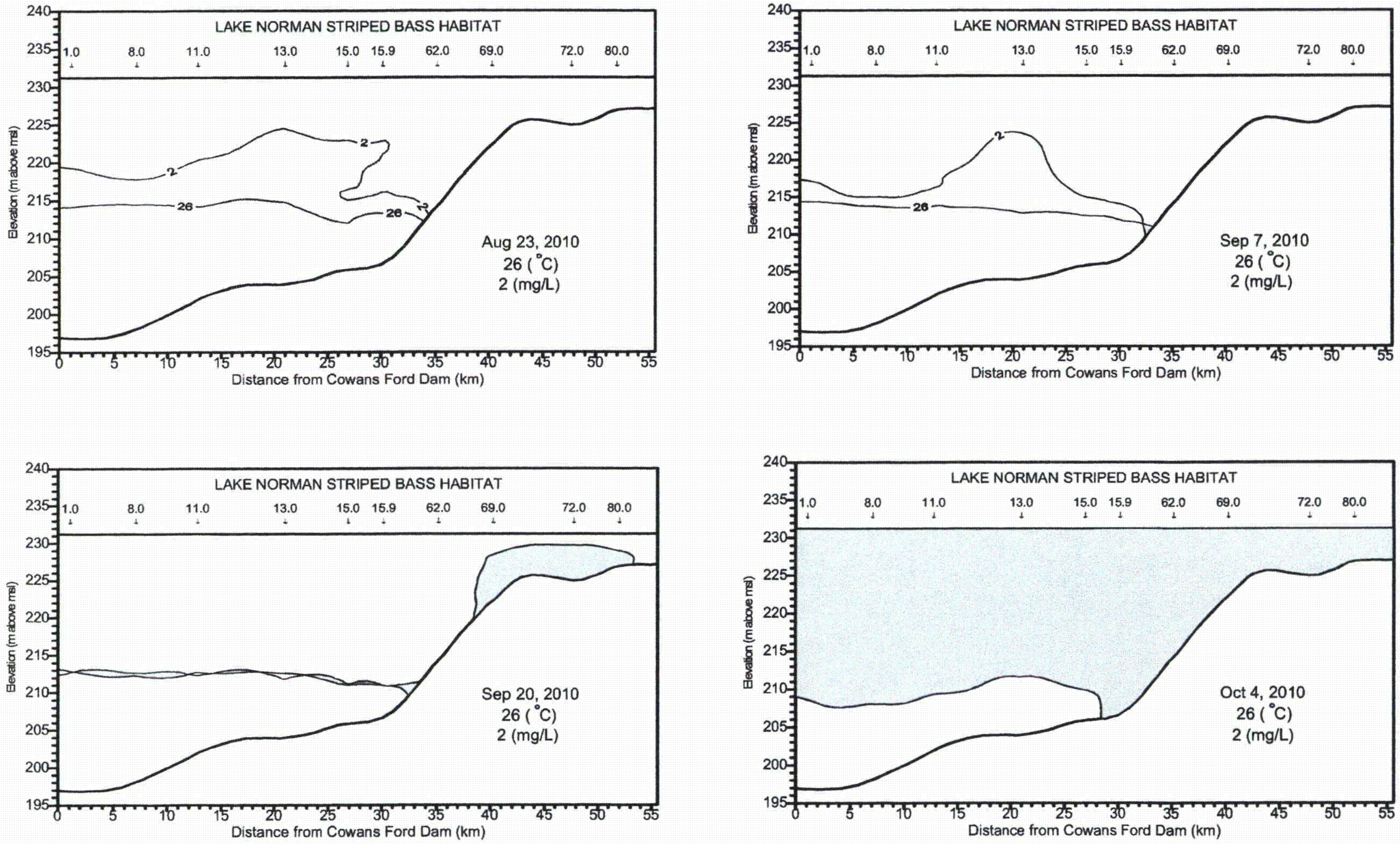


Figure 2-11. (Continued).

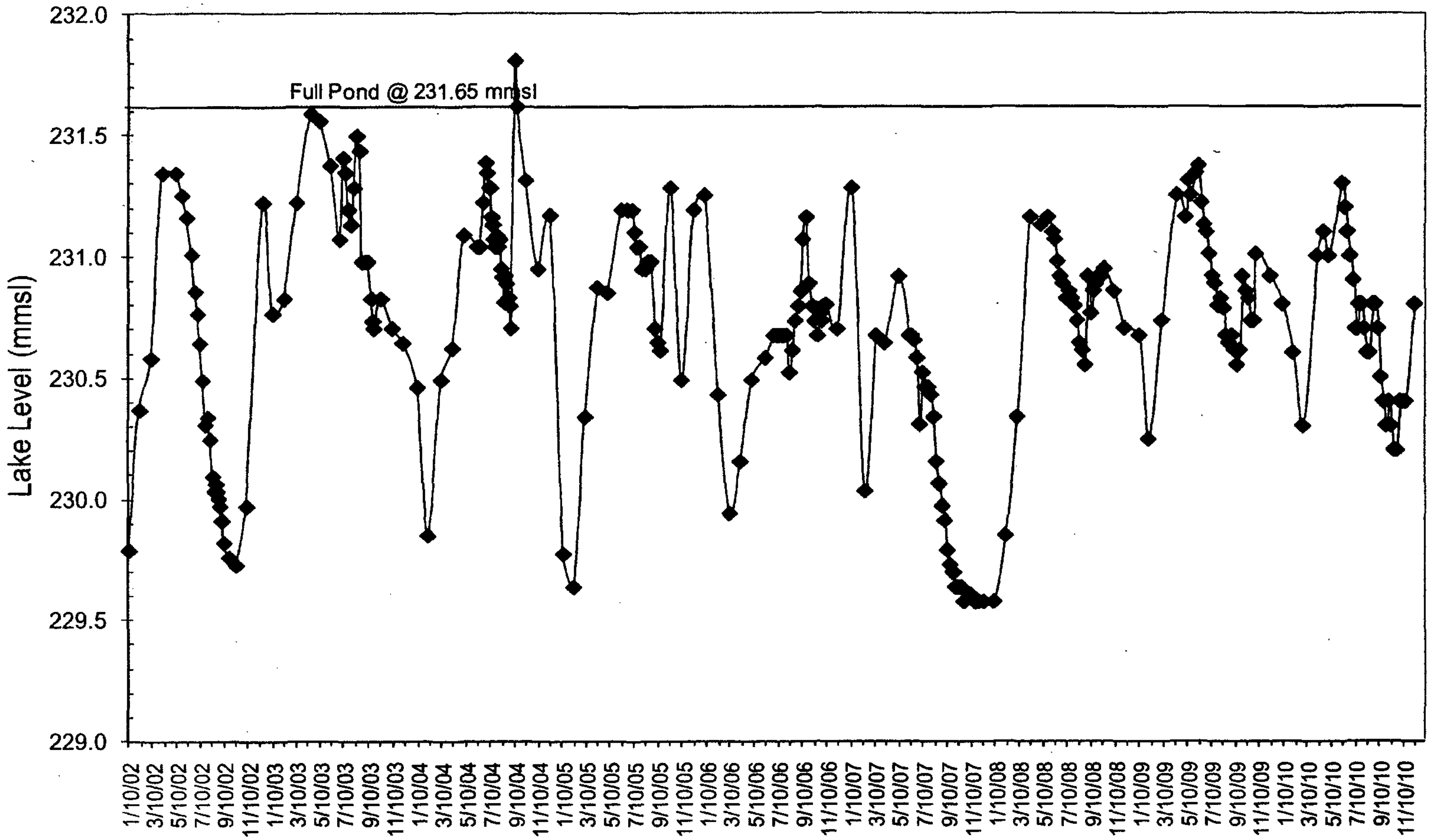


Figure 2-12. Lake Norman lake levels, expressed in meters above mean sea level (mmsl) for 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009 and 2010. Lake level data correspond to the water quality sampling dates over this time period.

CHAPTER 3

PHYTOPLANKTON

INTRODUCTION

Phytoplankton standing crop parameters were monitored in 2010 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 2010 study with data collected in prior study years (1987 – 2009).

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 2010).

METHODS AND MATERIALS

Quarterly sampling was conducted at Locations 2.0 and 5.0 in the mixing zone, and Locations 8.0, 9.5, 11.0, 13.0, 15.9, and 69.0 in Lake Norman (Figure 2-1). Duplicate Van Dorn samples from 0.3, 4.0, and 8.0 m (i.e., the estimated euphotic zone) were taken and then composited at all locations except Location 69.0, where Van Dorn samples were taken at 0.3, 3.0, and 6.0 m due to the shallower depth. Sampling has typically been conducted in February (winter), May (spring), August (summer), and November (fall) of most years. During 2010, scheduling difficulties caused the spring sampling to be delayed unitil early June. Secchi depths were recorded from all sampling locations. As in previous years and based on the original study design (Duke Power Company 1988), phytoplankton density, biovolume, and taxonomic composition were determined for samples collected at Locations

2.0, 5.0, 9.5, 11.0, and 15.9; chlorophyll *a* concentrations and seston dry and ash-free dry weights were determined for samples from all locations. Chlorophyll *a* and total phytoplankton densities and biovolumes were used in determining phytoplankton standing crops. Field sampling and laboratory methods used for chlorophyll *a*, seston dry weights, and population identification and enumeration were identical to those used by Rodriguez (1982). Data collected in 2010 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 each quarter to calculate a lake-wide mean. Lake-wide mean chlorophyll concentrations were within ranges of those reported in previous years; however, the lake-wide means for February and November were well below the long-term means for those periods, while the August value was above the norm (Figure 3-1). The lake-wide average in early June (substituting for May) was very close to the long-term mean.

Chlorophyll *a* concentrations (mean of two replicate composites) ranged from a low of 1.22 µg/L at Location 15.9 in February, to a high of 14.74 µg/L at Location 69.0 in August (Table 3-1 and Figure 3-2). All values were below the North Carolina water quality standard for outfalls of 40 µg/L (NCDEHNR 1991). Seasonally, chlorophyll *a* concentrations increased from the annual lake-wide minimum in February to the annual lake-wide maximum in August, and then declined from August through November (Figure 3-1). Based on quarterly mean chlorophyll concentrations, the trophic level of Lake Norman was in the oligotrophic (low) range during February and November and in the mesotrophic (intermediate) range in June and August of 2010. Over 40% of the mean chlorophyll *a* values were less than 4 µg/L (oligotrophic), while all but one of the remaining chlorophyll *a* values were between 4 and 12 µg/L (mesotrophic). The chlorophyll concentration from Location 69.0 in August was the only one greater than 12 µg/L (eutrophic, or high range). Historically, quarterly mean concentrations of less than 4 µg/L have been recorded on 24 previous occasions, while lake-wide mean concentrations of greater than 12 µg/L were only recorded during May of 1997 and 2000 (Duke Power 1998 and 2001; Duke Energy 2010).

During 2010, chlorophyll *a* concentrations showed typical spatial variability. Maximum concentrations among sampling locations were observed at Location 69.0 (furthest uplake) during June and August, while the February and November maxima were recorded from Locations 5.0 and 15.9, respectively (Table 3-1; Figures 3-1 and 3-2). Minimum concentrations occurred at Location 15.9 in February, Location 2.0 in June and November, and Location 5.0 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 all but February of 2010 (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 2010) have varied considerably, resulting in moderate to wide historical ranges. During February 2010, most chlorophyll *a* concentrations were in the low range for this time of year (Figure 3-3). At Locations 13.0 and 15.9, February chlorophyll concentrations were the lowest yet recorded for this time of year. At Locations 2.0, 5.0, and 9.5, concentrations were in the mid historical range. Long-term February peaks at Locations 2.0, 5.0, 8.0, and 9.5 occurred in 1996, while the long-term February peak at Location 11.0 was observed in 1991. Long-term maxima at Locations 13.0 and 15.9 occurred in 2003. The highest February value at location 69.0 occurred in 2001. All locations demonstrated lower chlorophyll concentrations in February 2010 than in February 2009 (Duke Energy 2010).

During early June (compared with May periods of previous years), mean chlorophyll *a* concentrations at all locations were in the mid historical range (Figure 3-4). Long-term May peaks at Locations 2.0 and 9.5 occurred in 1992; at Location 5.0 in 1991; at Locations 8.0, 11.0, and 13.0 in 1997; at Location 15.9 in 2000; and at Location 69.0 in 2001. In early June 2010, mean chlorophyll concentrations at all locations were higher than those of May 2009 (Duke Energy 2010).

The lake-wide mean chlorophyll *a* concentration in August 2010 was above the long-term mean for August. Concentrations from Locations 5.0, 8.0, 9.5, and 15.9 were in the mid historical range, while concentrations from Locations 2.0, 11.0, 13.0, and 15.9 were in the high range. The chlorophyll concentration from Location 13.0 was the highest yet recorded from that location for this time of year (Figure 3-5). Long-term August peaks at Locations 2.0, 5.0, and 15.9 were observed in 1998, while August peaks at Locations 8.0 and 9.5 occurred in 1993. The long-term August peak at Location 11.0 was observed in 1991, while Location 69.0 experienced its long-term August peak in 2001. The long-term peak at Location 13.0 occurred in 2010. Mean chlorophyll *a* concentrations at all but Location 15.9 in August 2010 were higher than those of August 2009 (Duke Energy 2010).

Chlorophyll *a* concentrations at all but Locations 13.0 and 69.0 in November were in the low historical range, while the exceptions were in the mid range (Figure 3-6). Long-term November peaks at Locations 5.0 and 8.0 occurred in 2006, while November maxima at Locations 11.0 and 15.9 occurred in 1996. The highest November value at Location 13.0 was recorded for 1992, while the November maxima at Locations 2.0 and 9.5 were observed in 1997. The highest November chlorophyll *a* concentration at Location 69.0 occurred in 1991. November 2010 chlorophyll *a* concentrations at all but Locations 5.0 and 9.5 were higher than during November 2009 (Duke Energy 2010).

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 2010 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, as was also the case with chlorophyll concentrations. The lowest density (358 units/mL) and biovolume (169 mm^3/m^3) were recorded from Location 15.9 in February (Table 3-2 and Figure 3-2). The maximum density (6,897 units/mL) and biovolume (4,827 mm^3/m^3) were also observed at Location 15.9 in August. Standing crops during February and November of 2010 were lower than those observed during these periods of 2009, while standing crop values in early June and August of 2010 were higher than those of May and August of 2009 (Duke Energy 2010). Phytoplankton densities and biovolumes during 2010 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). During February, the opposite trend was observed.

Seston

Seston dry weights represent a combination of algal matter and other organic and inorganic material. Dry weights during February and early June of 2010 were most often lower than those recorded during similar periods of 2009, while August and November values in 2010 were consistently higher than in August and November of 2009 (Duke Energy 2010 and Table 3-3). A general pattern of increasing values from downlake to uplake was observed during all periods; however, during February, concentrations peaked at Location 13.0, and then dropped off through Location 69.0 (Figure 3-2). For the most part, this spatial trend was similar to that of chlorophyll concentrations.

Seston ash-free dry weights represent organic material and may reflect trends of chlorophyll *a* and phytoplankton standing crop values. This relationship was generally most noticeable in early June and August of 2010, especially with respect to increasing values from downlake to uplake areas; however, as with dry weights, this trend was not apparent in February and November (Tables 3-1 through 3-3).

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 0.4 m at Locations 11.0, 13.0, 15.9, and 69.0 in February, to 3.7 m at Location 11.0 in early June (Table 3-1). The lake-wide mean Secchi depth during 2010 was lower than in 2009 and was within historical ranges for the years since measurements were first reported in 1992 (Duke

Energy 2010). The deepest lake-wide mean Secchi depth was recorded in 1999 (Duke Power 2000).

Community Composition

One indication of "balanced indigenous populations" in a reservoir is the diversity, or number of taxa observed over time. Lake Norman typically supports a rich community of phytoplankton species. This was certainly true in 2010. Ten classes comprising 96 genera and 252 species, varieties, and forms of phytoplankton were identified in samples collected during 2010, as compared to 99 genera and 271 species, varieties, and forms of phytoplankton identified 2009 (Table 3-4). The 2009 total represented the highest number of taxa recorded in any year since monitoring began in 1987 (Duke Energy 2010). Seventeen taxa previously unrecorded during the Lake Norman Maintenance Monitoring Program were identified during 2010.

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 2010, cryptophytes (Chryptophyceae) dominated densities at all locations (Table 3-5; 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 2010 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 early June, diatoms dominated samples at all locations (Table 3-5; Figures 3-7 through 3-11). The most abundant diatom at Locations 2.0 and 15.9 was the pennate, *Fragillaria crotonensis*. At Locations 5.0, 9.5, and 11.0, the centrate *Melosira distans* was the most abundant species. 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, and 2010).

During August 2010, green algae (Chlorophyceae) dominated densities at all locations (Table 3-5; Figures 3-7 through 3-11). The most abundant green alga was the small desmid, *Cosmarium asphearosporum var. strigosum.* 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). *A. vitrea* has been described as typically periphytic and widely distributed in freshwater habitats, and it was identified as a major contributor to periphyton communities on natural substrates during studies conducted from 1974 through 1977 (Derwort 1982). The possible causes of this significant shift in summer taxonomic composition were discussed in earlier reports and included deeper light penetration (the three deepest lake-wide Secchi depths were recorded from 1999 through 2001), extended periods of low water due to drawdown, and shifts in nutrient inputs and concentrations (Duke Power 2000, 2001, and 2002). Whatever the cause, the phenomenon was lake-wide 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, and 2010).

During November 2010, densities at all locations were once again dominated by diatoms and the most abundant species was the centrate *Melosira ambigua* (Table 3-5 and Figures 3-7 through 3-11). As is the case with spring periods, 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, and 2010).

Blue-green algae, which are often implicated in nuisance blooms, were never abundant in 2010 samples. Their overall contribution to phytoplankton densities seldom exceeded 2% of totals (Duke Energy 2010). 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 2010 were within historical ranges. Exceptions were record low concentrations at Locations 13.0 and 15.9 in February and a record high concentration at Location 13.0 in August. Lake-wide mean chlorophyll *a* increased from the annual minimum in February to the annual peak in August, and then declined through November. Some spatial variability was observed in 2010; however, maximum chlorophyll *a* concentrations were most often observed uplake at Locations 15.9 (November) and 69.0 (early June, August), while minimum chlorophyll *a* concentrations were typically recorded from downlake at Locations 2.0 and 5.0. During February, the reverse of this trend was observed. The highest chlorophyll *a* value recorded in 2010, 14.74 µg/L, was well below the NC State water quality standard of 40 µg/L.

Most phytoplankton standing crops in February and November 2010 were lower than in those months of 2009, while standing crops in spring and summer of 2010 were higher than during these periods of the previous year. Phytoplankton densities and biovolumes during 2010 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. The exception was observed in February.

Seston dry and ash-free weights were most often lower in February and early June 2010 than in February and May 2009, while the opposite was the case in August and November. The trend of increasing values from downlake to uplake was generally apparent during most sampling periods; however, a clear pattern of continually increasing values from downlake to uplake was not apparent in February. 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 lake-wide mean Secchi depth in 2010 was lower than in 2009 and was within historical ranges of lake-wide mean Secchi depths recorded since 1992.

Diversity or the number of taxa of phytoplankton in 2010 was lower than in 2009, but still reflected very high diversity. The taxonomic compositions of phytoplankton communities during 2010 were similar to those of most previous years. Diatoms were dominant during early June and November, while cryptophytes were dominant during February. During August, green algae consistently dominated algal assemblages. Contribution of blue-green algae to total densities seldom exceeded 2%.

The most abundant algae during 2010 were: the cryptophyte, *Rhodomonas minuta* in February; the diatoms *Fragillaria crotonensis* and *Melsoira distans* in early June; 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 2010.

Chlorophyll *a* Location	Feb	Jun	Aug	Nov
2.0	3.48	3.99	7.86	2.20
5.0	4.97	4.31	6.44	2.30
8.0	3.06	4.57	6.52	3.56
9.5	3.74	4.97	8.25	2.82
11.0	2.36	7.30	8.60	4.12
13.0	1.27	7.40	8.45	5.78
15.9	1.22	8.02	9.38	7.40
69.0	1.34	8.10	14.74	3.67

Secchi depths Location	Feb	Jun	Aug	Nov
2.0	2.10	2.60	2.50	1.80
5.0	2.20	2.40	2.20	1.60
8.0	1.90	3.00	2.30	1.90
9.5	2.30	3.10	2.20	2.00
11.0	0.40	3.70	2.10	1.60
13.0	0.40	2.00	1.40	1.10
15.9	0.40	2.90	2.20	1.60
69.0	0.40	1.40	1.20	1.00
Annual mean from all Locations: 2010				1.87
Annual mean from all Locations: 2009				2.05

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 2010.

Density	Locations					
Month	2.0	5.0	9.5	11.0	15.9	Mean
Feb	809	1,075	957	566	358	753
Jun	1,494	2,175	2,309	3,400	5,072	2,890
Aug	4,299	3,451	4,249	4,268	6,897	4,632
Nov	497	505	534	1,119	1,655	862

Biovolume	Locations					
Month	2.0	5.0	9.5	11.0	15.9	Mean
Feb	549	924	552	184	169	475
Jun	922	1,335	1,345	1,931	3,623	1,831
Aug	2,783	1,932	2,979	3,005	4,827	3,105
Nov	790	548	624	1,553	3,455	1,394

Table 3-3. Total mean seston dry and ash free-dry weights (mg/L) from samples collected in Lake Norman during 2010.

Dry weights	Locations								
Month	2.0	5.0	8.0	9.5	11.0	13.0	15.9	69.0	Mean
Feb	2.45	1.33	2.18	1.30	3.89	4.94	3.64	2.76	2.81
Jun	1.08	1.10	0.92	1.25	1.22	2.16	2.79	2.84	1.67
Aug	1.90	2.12	1.74	2.02	1.98	2.40	2.47	9.46	3.01
Nov	1.55	1.30	0.99	1.67	1.57	2.38	3.06	3.06	1.95
Ash-free dry weights									
Month									
Feb	0.92	0.56	0.64	0.65	0.83	1.07	0.81	0.68	0.77
Jun	0.66	0.89	0.82	0.95	0.89	1.15	1.34	1.13	0.98
Aug	1.02	1.14	1.02	1.07	0.82	0.85	1.49	2.40	1.23
Nov	0.64	0.49	0.61	0.55	0.68	0.80	1.21	1.03	0.75

Table 3-4. Phytoplankton taxa identified in quarterly samples collected in Lake Norman each year from 1994 to 2010.

	Years															
Taxon	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Class: Chlorophyceae																
Acanthosphaera zachariasi Lemm[a]																
Actidesmium hookeri Reinsch[a]																
Actinastrum hantzchii Lagerheim								X							X	
Ankistrodesmus braunii (Naegeli) Brunn	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. convolutus Corda						X										X
A. falcatus (Corda) Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. fusiformis Corda sensu Korsch.																
A. nannoselene Skuja						X										
A. spiralis (Turner) Lemm.			X													
A. spp. Corda[a]																
Arthrodesmus convergens Ehrenberg	X							X	X		X	X	X	X	X	X
A. incus (Breb.) Hassall	X			X			X	X	X	X	X	X	X	X	X	X
A. incus v *extensus* Anderson																X
A. incus v *ralfsii* W. West														X		X
A. octocornis Ehrenberg								X	X	X	X		X	X	X	X
A. ralfsii W. West										X	X	X			X	
A. subulatus Kutzing		X	X	X		X	X	X	X	X	X	X	X	X	X	X
A. validus v. *increassalatus* Scott & Gron.										X						
A. spp. Ehrenberg[a]																
Asterococcus limneticus G. M. Smith					X			X	X		X	X	X		X	X
A. superbus (Cienk.) Scherffel										X			X			
Botryococcus braunii Kutzing[a]																
Carteria fritzschii Takeda						X			X	X	X	X	X	X	X	
C. globosa Korsch								X		X		X		X		X
C. spp. Diesing			X						X							
Characium ambiguum Hermann											X					
C. limneticum Lemmerman									X							
C. spp. Braun[a]																
Chlamydomonas spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chlorella vulgaris Beyerink			X								X	X			X	X
Chlorogonium euchlorum Ehrenberg		X	X			X				X	X	X	X	X	X	X
C. spirale Scherffel & Pascher	X									X	X	X	X	X	X	X
Closteriopsis longissima W. & G.S. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. abruptum v *brevis* W. & G.S. West																X
Closterium acutum Breb.												X	X		X	
C. cornu Ehrenberg					X			X								
C. gracile Brebisson		X											X			
C. incurvum Brebisson	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. parvulum Nageli											X					
C. pusillum Hantzsch																X
C. tumidum Johnson						X										
C. spp. Nitzsch[a]																
Coccomonas orbicularis Stein				X				X		X	X	X	X	X	X	X
Coelastrum cambricum Archer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. microporum Nageli	X	X		X		X			X		X	X	X	X	X	X
C. proboscideum Bohlin														X		X

Taxon	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
	Years															
C. reticulatum (Dang.) Sinn.					X							X	X		X	X
C. sphaericum Nageli		X			X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Nageli[a]																
Cosmarium angulosum v. *concin.* (Rab) W&W						X		X		X	X			X		
C. asphaerosporum v. *strigosum* Nord.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. contractum Kirchner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. moniliforme (Turp.) Ralfs						X			X		X	X	X	X	X	X
C. notabile Brebisson								X								
C. phaseolus f. *minor* Boldt.		X	X		X		X				X	X	X	X		
C. pokornyanum (Grun.) W. & G.S. West				X				X			X		X			X
C. polygonum (Nag.) Archer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. portianum Archer															X	
C. raciborskii Lagerheim								X			X	X	X		X	X
C. regnellii Wille		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. regnesi Schmidle								X								X
C. regnesi v. *montana* Schmidle														X		
C. subreniforme Nordstedt								X			X		X			
C. subprotumidum Nordst.												X				
C. tenue Archer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. tinctum Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. tinctum v. *subretusum* Messik.						X										
C. tinctum v. *tumidum* Borge.			X		X	X	X	X	X	X	X	X	X	X	X	X
C. trilobatum v. *depressum* Printz								X								
C. tumidum Borge								X								
C. spp. Corda[a]																
Crucigenia apiculata (Lemm.) Schmidl								X	X			X	X		X	X
C. crucifera (Wolle) Collins	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. fenestrata Schmidle								X	X	X	X	X	X	X	X	X
C. irregularis Wille		X		X		X		X	X	X	X	X		X	X	X
C. quadrata Morren													X	X	X	X
C. rectangularis (A. Braun) Gay				X								X			X	
C. tetrapedia (Kirch.) West & West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dictyospaerium ehrenbergianum Nageli						X		X	X	X	X	X	X	X	X	X
D. planktonicum Tiffany & Ahlstrom																X
D. pulchellum Wood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dimorphococcus spp. Braun[a]																
Elakatothrix gelatinosa Wille	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Errerella bornheimiensis Conrad								X	X		X	X	X	X		X
Euastrum ansatum v. *dideltiforme* Ducel.								X								
E. banal (Turp.) Ehrenberg								X								
E. denticulatum (Kirch.) Gay	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E. elegans Kutzing									X							
E. turneri West														X		
E. spp. Ehrenberg													X			
Eudorina elegans Ehrenberg		X						X	X		X	X		X	X	
Franceia droescheri (Lemm.) G. M. Sm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F. ovalis (France) Lemm.						X		X	X	X	X	X	X	X	X	X

Table 3-4. (Continued).

	Years															
Taxon	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
F. tuberculata G. M. Smith									X							
Gloeocystis botryoides (Kutz.) Nageli						X			X	X		X	X	X	X	X
G. gigas Kutzing		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G. major Gerneck *ex.* Lemmermann				X								X				
G. planktonica (West & West) Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G. vesciculosa Naegeli				X				X	X	X	X	X	X	X	X	X
G. spp. Nageli[a]																
Golenkinia paucispina West & West								X	X	X	X	X	X	X	X	X
G. radiata Chodat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gonium pectorale Mueller				X				X			X	X	X	X	X	X
G. sociale (Duj.) Warming	X			X	X			X	X	X	X	X	X	X	X	
Kirchneriella contorta (Schmidle) Bohlin				X				X	X			X		X	X	X
K. elongata G.M. Smith						X			X				X	X	X	X
K. lunaris (Kirch.) Mobius									X	X				X	X	
K. lunaris v. *dianae* Bohlin			X			X		X	X	X	X	X	X	X	X	X
K. lunaris v. *irregularis* G.M. Smith						X			X						X	X
K. obesa W. West												X		X	X	X
K. subsolitaria G. S. West	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
K. spp. Schmidle	X	X	X					X			X	X				X
Lagerheimia ciliata (Lagerheim) Chodat								X				X			X	X
L. citriformis (Snow) G. M. Smith			X								X	X		X	X	
L. longiseta (Lemmermann) Printz								X	X	X	X		X	X		
L. longiseta v. *major* G. M. Smith															X	
L. quadriseta (Lemm.) G. M. Smith																X
L. subsala Lemmerman		X	X	X		X		X	X	X	X	X	X	X	X	X
Mesostigma viride Lauterborne	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Micractinium pusillum Fresen.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Monoraphidium contortum Thuret																
M. pusillum Printz																
Mougeitia elegantula Whittrock	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Agardh													X		X	
Nephrocytium agardhianum Nageli								X	X	X	X	X	X	X	X	
N. ecdysiscepanum W. West												X				
N. limneticum (G.M. Smith) G.M. Smith					X			X		X		X	X		X	
N. obesum West & West												X				
Oocystis borgii Snow				X	X	X		X	X		X	X	X	X		
O. ellyptica W. West				X				X	X	X			X			
O. lacustris Chodat									X	X	X		X			X
O. parva West & West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. pusilla Hansgirg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. pyriformis Prescott				X				X								
O. solitaria Wittrock									X			X				
O. submarina Lagerheim												X		X		
O. spp. Nageli[a]																
Pandorina charkowiensis Kprshikov											X	X			X	X
P. morum Bory									X		X	X	X		X	X
Pediastrum biradiatum Meyen											X	X	X	X		X
P. duplex Meyen	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X

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

Taxon	Years 95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
P. duplex v. *clatheatum* (A. Braun) Lag.								X							X	
P. duplex v. *gracillimum* West and West			X	X				X	X	X	X	X	X		X	X
P. duplex v. *reticulatum* Lagerheim														X		
P. tetras v. *tetroadon* (Corda) Rabenhorst	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Meyen[a]																
Phacotus angustus Lemmermann														X		
Planktosphaeria gelatinosa G. M. Smith	X							X		X	X		X	X	X	X
Quadrigula closterioides (Bohlin) Printz		X	X				X	X	X	X	X	X	X	X	X	X
Q. lacustris (Chodat) G. M. Smith								X	X	X	X	X	X	X	X	X
Scenedesmus abundans (Kirchner) Chodat									X		X	X		X	X	X
S. abundans v. *asymetrica* (Schr.) G. Sm.		X	X			X		X	X	X		X	X			
S. abundans v. *brevicauda* G. M. Smith	X								X	X			X	X	X	X
S. abundans v. *longicauda* G.M. Smith													X		X	
S. acuminatus (Lagerheim) Chodat	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
S. arcuatus Lemmermann														X		
S. arcuatus v. *platydisca* G. M. Smith														X		
S. armatus (Chod.) G. M. Smith														X		
S. armatus v. *bicaudatus* (Gug.-Pr..)Chod	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga (Turp.) Lagerheim	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga v. *alterans* (Reinsch) Hansg.										X		X		X		X
S. brasiliensis Bohlin	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. denticulatus Lagerheim	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
S. denticulatus v. *recurvatus* Schumacher									X	X	X	X	X	X	X	
S. dimorphus (Turp.) Kutzing			X	X	X	X		X	X	X	X	X	X	X	X	X
S. incrassulatus G. M. Smith														X		
S. opoliensis P. Richter											X			X	X	X
S. parisiensis Chodat									X		X					
S. quadricauda (Turp.) Brebisson	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
S. smithii Teiling		X						X	X		X	X			X	
S. serratus (Corda) Bohlin										X						
S. spp. Meyen [a]																
Schizochlamys compacta Prescott		X		X		X		X		X	X		X	X	X	X
S. gelatinosa A. Braun						X		X		X	X	X	X	X	X	X
Schoederia setigera (Schroed.) Lemm.								X							X	
Selenastrum bibraianum Reinsch												X	X		X	
S. gracile Reinsch		X						X				X	X		X	
S. minutum (Nageli) Collins	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. westii G. M. Smith	X	X		X	X			X	X	X	X	X	X	X	X	X
Sorastrum americanum (Bohlin) Schm.			X									X				X
S. spinulosum Nageli															X	
Sphaerocystis schoeteri Chodat	X			X	X	X		X	X	X	X	X	X		X	X
Sphaerozosma granulatum Roy & Bl[a]																
Stauastrum americanum (W&W) G. Sm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. apiculatum Brebisson			X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. arctison v *glabrum* W. & G.S. West																X
S. aspinosum v. *annulatum* W.& G.S.Wst.													X			
S. brachiatum Ralfs			X	X	X			X	X	X	X	X	X	X	X	X
S. breviaculeatum G. M. Smith																X

Table 3-4. (Continued).

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Years

Taxon	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
S. brevispinum Brebisson				X												
S. chaetocerus (Schoed.) G. M. Smith[a]																
S. capitulum Brebisson												X				
S. cingulum v *floridense* Scott & Gron.																X
S. clevii (Wittr.) Roy & Bill																X
S. curvatum W. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. curvatum v. *elongatum* G.M. Smith													X		X	
S. cuspidatum Brebisson			X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. dejectum Brebisson						X				X			X		X	X
S. dickeii v. *maximum* West & West												X				
S. dickeii v. *rhomboidium* W.& G.S. West								X							X	X
S. gladiosum Turner																X
S. leptocladum Nordstedt											X					
S. leptocladum v. *sinuatum* Wolle[a]																
S. manfeldtii v. *fluminense* Schumacher	X		X	X		X		X	X	X	X	X	X	X	X	X
S. megacanthum Lundell									X	X	X	X				X
S. ophiura v. *cambricum* (Lund) W. & W.						X					X				X	
S. orbiculare Ralfs								X								X
S. paradoxum Meyen				X	X					X	X	X	X	X		X
S. paradoxum v. *cingulum* W. & W.										X	X	X	X	X	X	X
S. paradoxum v. *parvum* W. West				X				X	X	X	X	X	X	X	X	X
S. pentacerum (Wolle) G. M. Smith								X			X	X		X	X	X
S. protectum v *planktonicum* G.M. Smith																X
S. subcruciatum Cook & Wille	X		X	X	X	X		X	X	X	X	X	X	X	X	X
S. tetracerum Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. turgescens de Not.											X		X		X	X
S. vestitum Ralfs								X	X				X	X		
S. spp. Meyen[a]																
Stichococcus scopulinus Hazen								X								
S. spp. Nageli													X			
Stigeoclonium spp. Kutzing							X						X			
Tetraedron arthrodesmiforme (W.) Wol.								X	X		X	X		X		
T. asymmetricum Prescott															X	
T. bifurcatum (Wille) Lagerheim															X	
T. bifurcatum v. *minor* Prescott		X														
T. caudatum (Corda) Hansgirg		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. caudatum v. *longispinum*															X	
T. limneticum Borge													X			X
T. lobulatum (Naegeli) Hansgirg						X								X		
T. lobulatum v. *crassum* Prescott										X			X			
T. minmum (Braun) Hansgirg	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
T. muticum (Braun) Hansgirg	X	X		X										X	X	
T. obesum (W & W) Wille *ex* Brunnthaler		X												X	X	X
T. pentaedricum West & West											X	X	X			X
T. planktonicum G. M. Smith				X		X		X	X	X	X	X	X	X	X	
T. regulare Kutzing												X				
T. regulare v. *bifurcatum* Wille				X												
T. regulare v. *incus* Teiling												X				

Table 3-4. (Continued). Page 6 of 12

	Years															
TAXON	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
T. trigonum (Nageli) Hansgirg		X	X	X		X	X	X	X	X	X	X	X	X	X	X
T. trigonum v. *gracile* (Reinsch) DeToni		X				X				X		X		X		
T. spp. Kutzing[a]																
Tetrallantos lagerheimii Teiling							X		X	X			X			X
Tetraspora lamellose Prescott						X										
T. spp. Link[a]																
Tetrastrum heteracanthum (Nor.) Chod.								X		X	X			X		
T. staurogeniforme (Schroeder) Lemm.									X					X		
Tomaculum catenatum Whitford															X	
Treubaria setigerum (Archer) G. M. Sm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Westella botryoides (W. & W.) Wilde.				X		X				X	X	X	X	X		X
W. linearis G. M. Smith				X		X			X	X	X	X	X			X
Xanthidium antiloparium.v. floridense Sc. & Gron.											X					
X. cristatatum v. *uncinatum* Breb.								X		X	X	X	X	X	X	X
X. spp. Ehrenberg								X								
Class: Bacillariophyceae																
Achnanthes lanceolata Brebisson								X			X					
A. microcephala Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Bory		X								X						
Amphiprora ornate Bailey								X								
Amphora ovalis Kutzing												X				
Anomoeoneis vitrea (Grunow) Ross	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Pfitzer[a]																
Asterionella formosa Hassall	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Attheya zachariasi J. Brun	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cocconeis placentula Ehrenberg				X	X				X				X	X		X
C. spp. Ehrenberg[a]																
Cyclotella comta (Ehrenberg) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. glomerata Bachmann	X	X	X	X	X				X	X	X	X	X	X	X	X
C. meneghiniana Kutzing	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
C. pseudostelligera Hustedt[a]																
C. stelligera Cleve & Grunow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Kutzing[a]																
Cymbella affinis Kutzing						X			X							
C. gracilis (Rabenhorst) Cleve									X	X						
C. minuta (Bliesch & Rabn.) Reim.	X	X		X	X			X	X	X	X	X	X	X	X	X
C. naviculiformis Auersw. *ex* Heib.													X			
C. tumida (Brebison) van Huerck															X	
C. turgida (Gregory) Cleve															X	
C. spp. Agardh[a]																
Denticula elegans Kutzing								X		X			X	X	X	X
D. elegans v. *crassa* (Naegeli) Hustedt														X		
D. thermalis Kutzing				X				X			X				X	
Diploneis ellyptica (Kutzing) Cleve										X						
D. marginestriata Hustedt													X			
D. ovalis (Hilse) Cleve										X						
D. puella (Schum.) Cleve										X				X		

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

	Years															
Taxon	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
D. spp. Ehrenberg[a]																
Eunotia flexuosa v. *eurycephala* Grun.					X											
E. zasuminensis (Cab.) Koerner	X	X	X	X	X	X		X	X	X	X	X	X	X		X
Fragillaria. construens (Ehrenberg) Grun.									X							X
F. crotonensis Kitton	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
F. virescens Ralfs																X
Frustulia rhomboides (Ehr.) de Toni									X							
F. rhomboides v. *saxonica* (Rabh.) de T.									X							
Gomphonema angustatum (Kutz.) Rabh.								X								
G. gracile (Her.) Van Huerk													X		X	X
G. parvulum Kutz.								X	X			X	X			X
G. spp. Agardh[a]																
Melosira ambigua (Grunow) O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. distans (Ehrenberg) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. granulata (Ehrenberg) Ralfs											X		X		X	
M. granulata v. *angustissima* O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. italica (Ehrenberg) Kutzing[a]																
M. italica v. *tennuissima* (Grun.) O. Mull.												X			X	X
M. varians Agardh				X							X	X	X	X	X	X
M. spp. Agardh		X			X		X	X	X	X	X	X	X	X	X	X
Meridion circulare Agardh								X								
Navicula bacillum Ehrenberg																X
N. cryptocephala Kutzing		X	X					X						X		
N. exigua (Gregory) O. Muller	X							X		X						
N. exigua v. *capitata* Patrick		X											X			
N. radiosa Kutzing									X		X				X	
N. radiosa v. *tenella* (Breb.) Grun.									X	X		X	X	X		X
N. subtilissima Cleve	X					X			X		X	X	X		X	
N. spp. Bory										X					X	X
Nitzschia acicularis W. Smith		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. agnita Hustedt	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. communis Rabenhorst												X				
N. holsatica Hustedt	X		X	X	X	X	X	X	X	X	X	X	X	X	X	
N. kutzingiana Hilse										X	X		X	X	X	
N. linearis W. Smith						X					X		X			
N. palea (Kutzing) W. Smith	X	X	X	X				X		X	X	X	X	X	X	X
N. sublinearis Hustedt		X		X			X	X				X			X	
N. thermalis Kutzing														X		
N. spp. Hassall								X			X		X			
Pinnularia biceps Gregory											X					
P. subcaptiata Gregory																X
P. mesolepta (Her.) W. Smith													X			
P. spp. Ehrenberg								X			X		X			X
Rhizosolenia spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Skeletonema potemos (Weber) Hilse	X	X		X	X	X		X	X		X	X	X	X	X	
Stephanodiscus astraea (Her.) Grunow											X		X		X	
S. spp. Ehrenberg	X	X	X	X					X	X	X	X	X		X	
Surirella angustata Kutz.									X							

Table 3-4. (Continued).

	Years															
Taxon	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
S. linearis W. Smith																X
S. linearis v. *constricta* (Her.) Gro.				X									X		X	
S. tenuis Mayer											X					
Synedra actinastroides Lemmerman[a]																
S. acus Kutzing			X	X		X		X	X	X	X	X	X	X	X	X
S. amphicephala Kutzing												X	X			
S. delicatissima Lewis[a]																
S. filiformis v. *exilis* Cleve-Euler				X		X	X	X	X	X	X	X	X	X	X	X
S. planktonica Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. rumpens Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. rumpens v. *fragilarioides* Grunow[a]																
S. rumpens v. *scotica* Grunow															X	
S. ulna (Nitzsch) Ehrenberg	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
S. spp. Ehrenberg[a]																
Tabellaria fenestrata (Lyngb) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. flocculosa (Roth.) Kutzing						X				X			X	X	X	
Class: Chrysophyceae																
Aulomonas purdyii Lackey	X	X	X	X	X		X	X		X	X	X	X	X	X	
Bicoeca petiolatum (Stien) Pringsheim		X	X													
Calycomonas pascheri (Van Goor) Lund	X					X			X							
Centritractus belanophorus Lemm.											X					
Chromulina nebulosa Pascher												X		X	X	X
C. spp. Chien.				X				X	X	X		X		X	X	
Chrysococcus rufescens Klebs									X							
Chrysosphaerella solitaria Lauterb.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Codomonas annulata Lackey		X	X	X	X	X	X		X	X	X	X	X	X	X	
Dinobryon acuminatum Ruttner													X		X	
D. bavaricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. cylindricum Imhof		X		X				X	X		X	X	X	X	X	X
D. divergens Imhof	X	X			X			X	X	X	X	X	X	X	X	X
D. pediforme (Lemm.) Syein.												X			X	
D. sertularia Ehrenberg	X					X		X	X	X	X	X		X	X	
D. sociale Ehrenberg														X		X
D. spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Domatomococcus cylindricum Lackey				X	X				X						X	
Erkinia subaequicilliata Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Kephyrion campanuliforme Conrad									X							
K. littorale Lund				X				X	X	X	X	X	X	X	X	X
K. petasatum Conrad									X							
K. rubi-claustri Conrad								X	X	X	X	X	X	X	X	X
K. skujae Ettl[a]																
K. valkanovii Conrad											X	X				
K. spp. Pascher	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mallomonas acaroides Perty											X	X	X		X	
M. akrokomos (Naumann) Krieger				X	X	X			X		X	X	X	X	X	X
M. allantoides Perty												X		X		
M. allorgii (Defl.) Conrad									X							

Table 3-4. (Continued).

Taxon	Years															
	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
M. alpina Pascher				X		X										
M. caudata Conrad	X				X	X	X	X	X		X	X	X		X	X
M. globosa Schiller				X		X	X	X	X	X	X	X	X	X	X	X
M. producta Iwanoff						X		X	X		X		X	X	X	X
M. pseudocoronata Prescott	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. tonsurata Teiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Perty						X							X			
Ochromonas granularis Doflein				X	X	X	X	X	X	X	X	X	X	X	X	
O. mutabilis Klebs						X						X	X			
O. spp. Wyss	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pseudokephyrion concinum (Schill.) Sch.											X			X		
P. schilleri Conrad				X	X		X	X	X		X			X		X
P. tintinabulum Conrad				X												
P. spp. Pascher									X		X	X		X		X
Rhizochrisis polymorpha Naumann					X	X	X	X	X	X	X	X	X	X	X	X
R. spp. Pascher															X	
Salpingoeca frequentissima (Zach.) Lem.				X	X	X			X		X					
Stelexomonas dichotoma Lackey	X	X	X	X		X		X	X		X	X	X	X	X	X
Stokesiella epipyxis Pascher			X	X	X							X		X	X	X
Synura sphagnicola Korschikov										X						
S. spinosa Korschikov	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
S. uvella Ehrenberg							X					X		X	X	
S. spp. Ehrenberg[a]																
Uroglenopsis americana (Caulk.) Lemm.	X	X	X		X											
Class: Haptophyceae																
Chrysochromulina parva Lackey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Class: Xanthophyceae																
Characiopsis acuta Pascher								X			X	X	X	X	X	X
C. cylindrica (Lambert) Lemm.													X	X		
C. dubia Pascher	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Dichotomococcus curvata Korschikov[a]																
Ophiocytium capitatum v. *longisp.* (M) L.									X	X	X	X	X	X	X	
Stipitococcus vas Pascher									X							
Class: Cryptophyceae																
Cryptomonas erosa Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. erosa v. *reflexa* Marsson				X	X	X	X	X	X	X	X	X	X	X	X	X
C. gracilia Skuja						X										
C. marsonii Skuja									X				X	X	X	X
C. obovata Skuja									X		X	X		X	X	
C. ovata Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. phaseolus Skuja																
C. reflexa Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Ehrenberg													X		X	

Table 3-4. (Continued).

	Years															
Taxon	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Rhodomonas minuta Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Class: Myxophyceae																
Agmenellum quadriduplicatum Brebisson	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. thermale Drouet and Daily									X						X	X
Anabaena catenula (Kutzing) Born.			X	X											X	X
Anabaena circinalis (Kutz.) Rabenhorst															X	X
A. inaequalis (Kutzing) Born.						X							X		X	
A. scheremetievi Elenkin			X	X	X		X					X	X		X	
A. wisconsinense Prescott	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. spp. Bory		X			X		X	X		X		X	X	X	X	
Anacystis incerta (Lemm.) Druet & Daily				X		X	X									
A. spp. Meneghini[a]																
Aphanocaspsa delicatissima West & West																X
A. rivularis (Carm.) Raben.														X		
A. spp. Nageli																X
Chroococcus dispersus (Keissl.) Lemm.				X		X							X	X		X
C. giganteous W. West												X				
C. limneticus Lemmermann			X	X	X	X	X	X	X		X	X	X	X	X	X
C. minor Kutzing								X	X		X	X	X	X	X	X
C. turgidus (Kutz.) Lemmermann[a]																
C. spp. Nageli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Coelosphaerium kuetzingiana Nageli[a]																
C. neagleanum Unger												X	X			
Dactylococcopsis irregularis Hansgirg									X	X	X		X		X	
D. musicola Hustedt													X			
D. raphidiopsis Hansgirg													X			
D. rupestris Hansgirg						X										
D. smithii Chodat and Chodat			X	X		X			X	X	X	X	X		X	X
D. spp. Hansgirg						X										
Gomphospaeria lacustris Chodat											X					
Lyngbya contorta Lemmermann[a]																
L. limnetica Lemmermann[a]																
L. ochracea (Kutzing) Thuret						X		X		X	X			X		X
L. subtilis W. West[a]																
L. tenue Agardh										X				X	X	X
L. spp. Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X			X
Merismopedia tenuissima Lemmermann				X												
Microcystis aeruginosa Kutzing	X	X		X	X	X	X			X	X	X	X	X	X	X
Oscillatoria amoena (Kutz.) Gomont										X						
O. amphibia Agardh								X	X	X		X	X			
O. geminata Meneghini	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. limnetica Lemmermann	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
O. splendida Greville	X	X		X				X								
O. subtilissima Kutz.						X	X	X	X	X	X	X	X	X	X	X
O. spp. Vaucher							X		X				X		X	
Phormidium angustissimum West & West																
P. spp. Kutzing																
Raphidiopsis curvata Fritsch & Rich	X	X	X	X	X	X		X		X			X	X		X

Table 3-4. (Continued).

Years

Taxon	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
R. mediterranea Skuja					X											
R. spp. Fritsch & Rich													X			
Rhabdoderma sigmoidea Schm. & Laut.[a]																
Spirulina subsala Oersted								X						X	X	
Synecococcus lineare (Sch. & Lt.) Kom.	X	X		X	X	X	X		X	X						X
Class: Euglenophyceae																
Euglena acus Ehrenberg					X					X	X				X	X
E. deses Ehrenberg											X	X			X	
E. fusca (Klebs). Lemmermann														X		
E. minuta Prescott						X		X		X	X		X	X	X	X
E. polymorpha Dangeard		X					X	X		X	X			X	X	X
E. proxima Dangeard									X	X	X	X			X	
E. texta (Duj.) Hubn.														X		
E. spp. Ehrenberg	X	X		X	X		X			X	X	X	X	X	X	X
Lepocinclus acicularis France												X				
L. acuta Prescott										X					X	
L. fusiformis Lemmermann														X		X
L. glabra Drezepolski									X							
L. ovum. (Ehr.) Lemm.						X				X			X	X	X	X
L. ovum. v. *palatina* Lemmermann															X	
L. sphagnophila Lemmermann														X		
L. spp. Perty				X												X
Phacus acuminatus Stokes															X	
P. cuvicauda Swirenko						X										
P. longicauda (Her.) Dujardin						X							X			X
P. orbicularis Hubner											X				X	
P. tortus (Lemm.) Skvortzow[a]																
P. triquter Playfair										X						
P. spp. Dujardin[a]																
Trachelomonas abrupta (Swir.) Deflandre												X				
T. abrupta v. *minor* Deflan.											X	X				
T. acanthostoma (Stk.) Defl.							X			X	X	X	X	X	X	X
T. charkowiensis v *affine* (Skv.) Deflandre																X
T. ensifera Daday									X				X			
T. euchlora (Ehrenberg) Lemmermann														X		
T. hispida (Perty) Stein	X				X		X	X	X	X	X		X	X	X	X
T. hispida v *coronate* Lemm. ex Defland.																X
T. lemmermanii v. *acuminata* Deflandre											X		X			
T. pulcherrima Playfair														X		
T. pulcherrima v. *minor* Playfair										X						
T. varians (Lemm.) Deflandre													X			
T. volvocina Ehrenberg	X				X		X		X	X	X		X	X	X	X
T. spp. Ehrenberg																X
Class: Dinophyceae																
Ceratium hirundinella (OFM) Schrank	X		X	X	X	X									X	

Years

Taxon	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
C. hirundinella v. *brachyceras* (Day.) Est.											X			X	X	X
Glenodinium borgei (Lemm.) Schiller		X												X	X	X
G. gymnodinium Penard			X							X		X	X	X		X
G. palustre (Lemm.) Schiller													X			
G. penardiforme (Linde.) Schiller					X	X				X		X	X	X	X	X
G. quadridens (Stein) Schiller												X	X			
G. spp. (Ehrenberg) Stein[a]																
Gymnodinium aeruginosum Stein				X	X	X			X	X	X		X		X	X
G. neglectum (Schilling) Lindemann														X		
G. spp. (Stein) Kofoid & Swezy	X		X	X		X	X	X	X	X	X	X	X		X	X
Peridinium aciculiferum Lemmermann														X		
P. bipes v *travectum* (Ehr.) Lefevre																X
P. cinctum (Muller) Ehrenberg								X				X				
P. godlewskii Wolzynska														X		X
P. inconspicuum Lemmermann	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. intermedium Playfair				X	X	X	X	X	X	X	X	X	X	X	X	
P. limbatum (Stokes) Lemm.											X		X		X	
P. pusillum (Lenard) Lemmermann	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
P. quadridens Stein														X		
P. umbonatum Stein[a]																
P. willei Huitfeld-Kass										X	X	X		X	X	X
P. wisconsinense Eddy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Ehrenberg															X	
Class: Chloromonadophyceae																
Gonyostomum depresseum Lauterborne	X			X	X			X	X	X	X	X	X	X	X	X
G. semen (Ehrenberg) Diesing														X		
G. spp. Diesing																

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[a]= taxa found during 1987 - 94 only.

Table 3-5. Dominant classes, their most abundant species, and their percent composition (in parentheses) at Lake Norman locations during each sampling period of 2010.

Location	February	June
2.0	Cryptophyceae (64.5) *Rhodomonas minuta* (52.8)	Bacillariophyceae (77.0) *Fragillaria crotonensis* (32.8)
5.0	Cryptophyceae (68.2) *R. minuta* (57.5)	Bacillariophyceae (60.3) *Melosira distans* (37.0)
9.5	Cryptophyceae (73.7) *R. minuta* (64.8)	Bacillariophyceae (47.7) *M. distans* (26.9)
11.0	Cryptophyceae (64.8) *R. minuta* (63.0)	Bacillariophyceae (60.6) *M. distans* (32.2)
15.9	Cryptophyceae (73.7) *R. minuta* (70.2)	Bacillariophyceae (74.0) *F. crotonensis*
	August	November
2.0	Chlorophyceae (64.0) *Cosmarium asphearosphorum* v. *strigosum* (32.5)	Bacillariophyceae (59.9) *Melosira ambigua* (39.7)
5.0	Chlorophyceae (75.6) *C. asphear.* v *strig.* (28.6)	Bacillariophyceae (50.6) *M. ambigua* (22.4)
9.5	Chlorophyceae (74.0) *C. asphear.* v *strig.* (27.7)	Bacillariophyceae (47.5) *M. ambigua* (14.1)
11.0	Chlorophyceae (68.0) *C. asphear.* v *strig.* (29.7)	Bacillariophyceae (56.2) *M. ambigua* (28.5)
15.9	Chlorophyceae (61.4) *C. asphear.* v *strig.* (26.4)	Bacillariophyceae (63.3) *M. ambigua* (27.3)

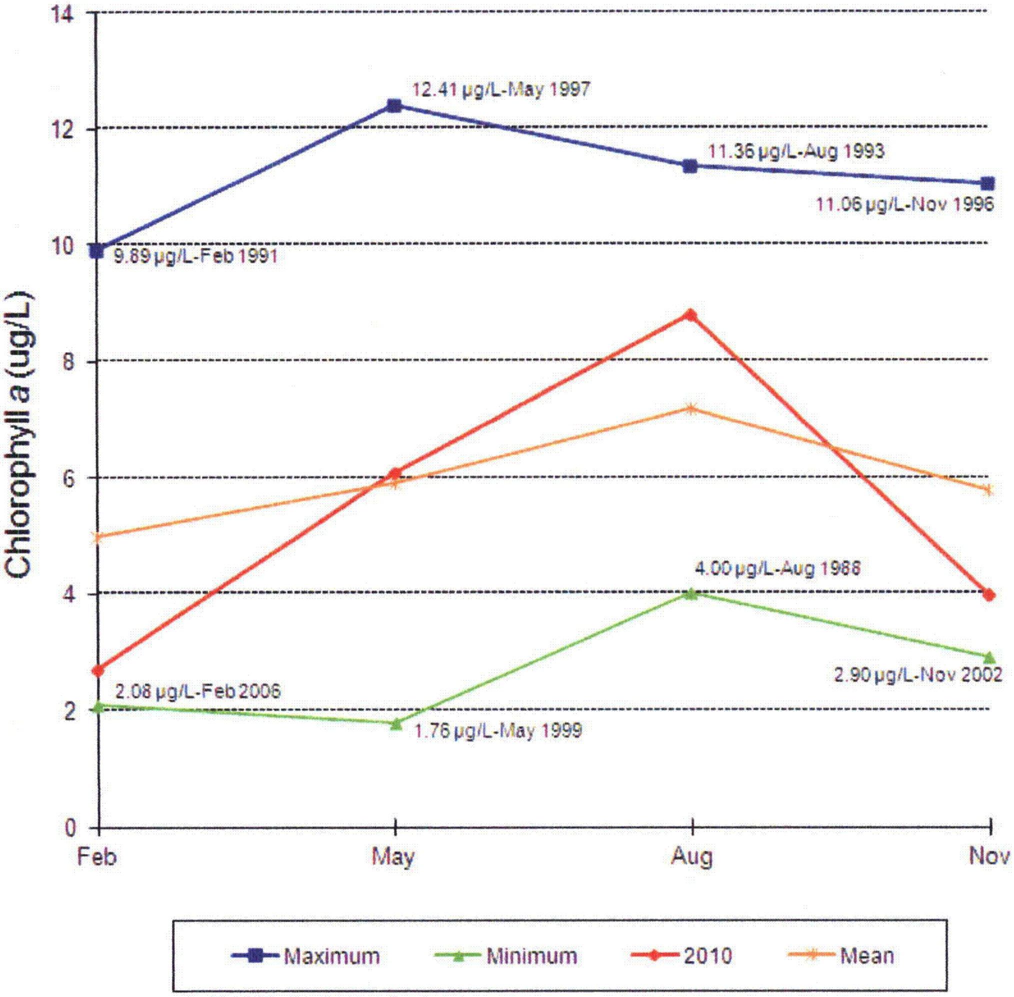

Figure 3-1. Lake Norman phytoplankton chlorophyll *a* seasonal maximum and minimum lake-wide means since August 1987 compared with the long-term seasonal lake-wide means and lake-wide means for 2010 (Note: sampling during the spring period of 2010 was delayed until early June due to scheduling conflicts).

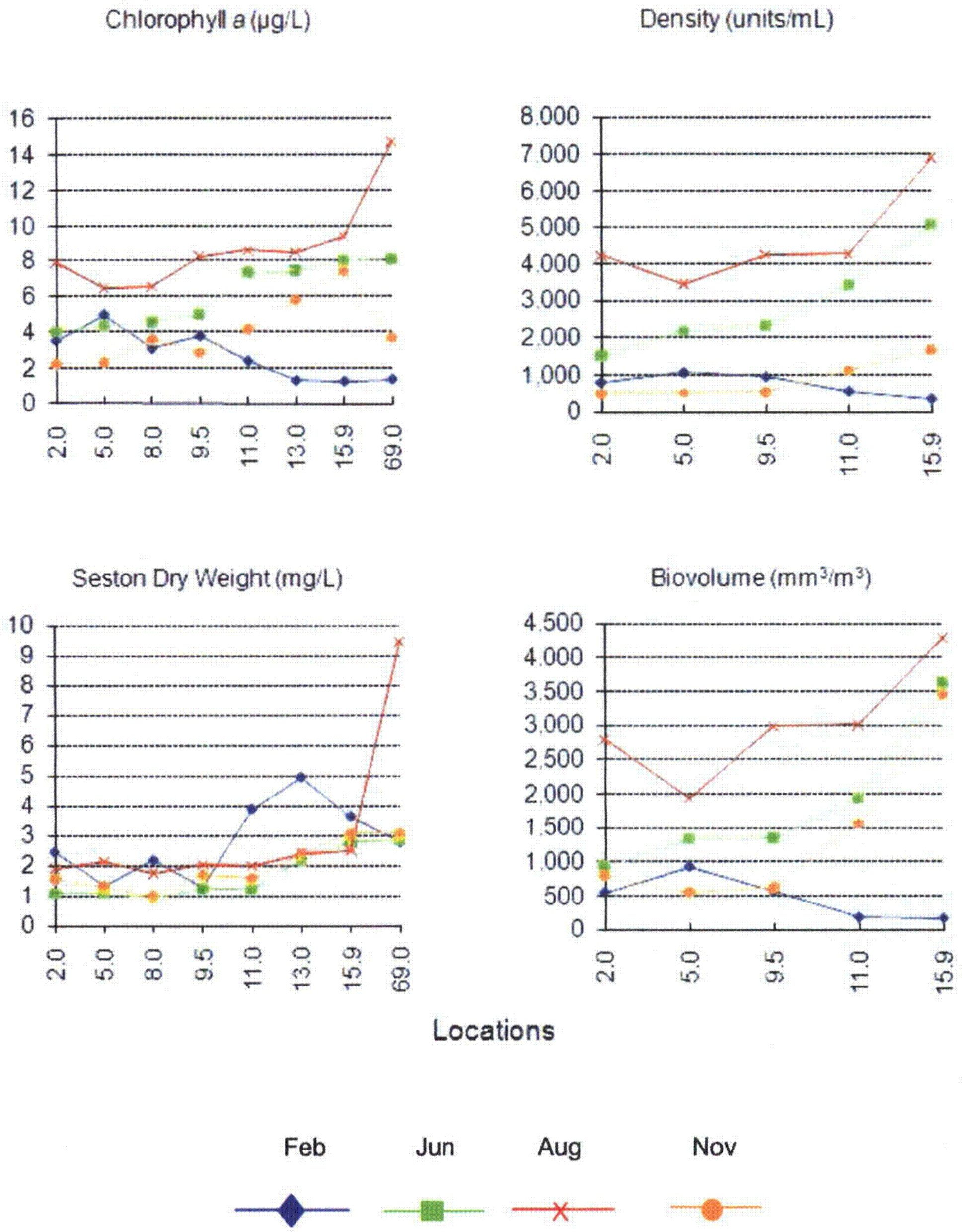

Figure 3-2. Phytoplankton chlorophyll *a*, densities, biovolumes, and seston weights at locations in Lake Norman in February, early June, August, and November 2010.

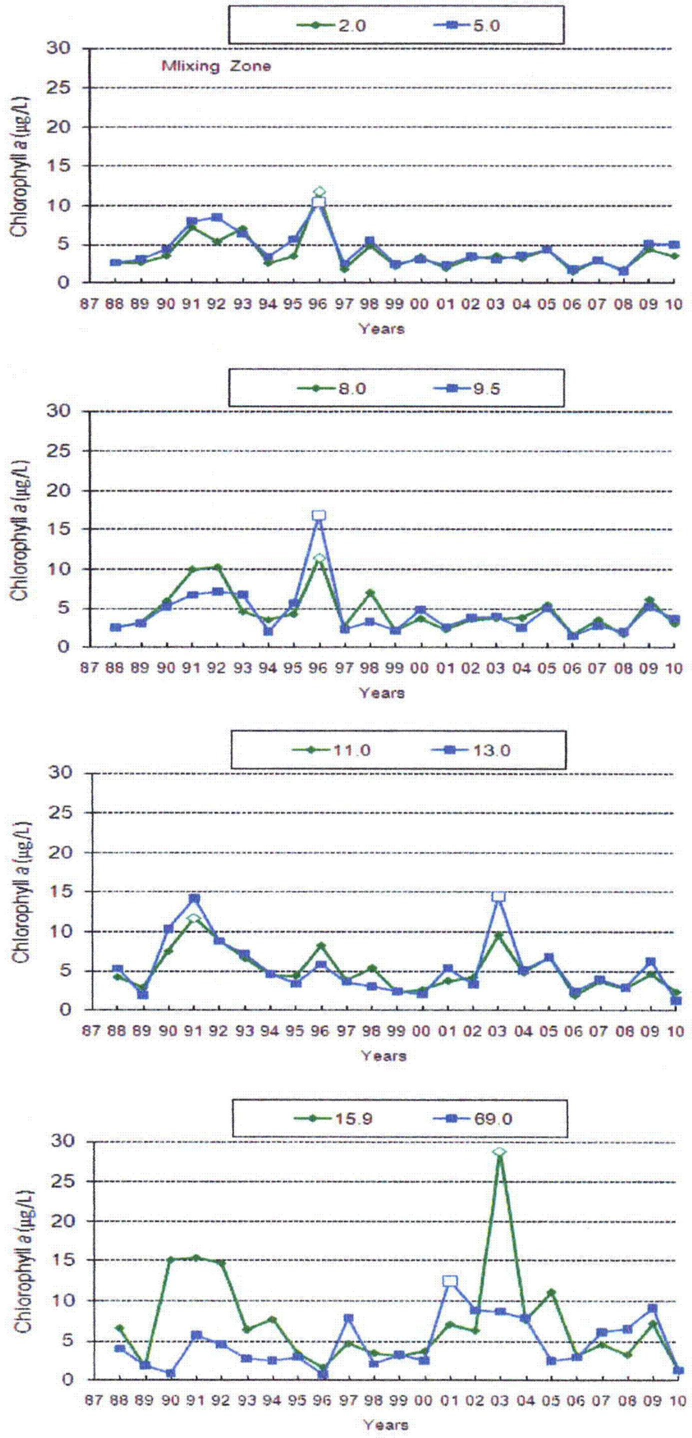

Figure 3-3. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from February 1988 – 2010 (Note: clear data points represent long-term maxima).

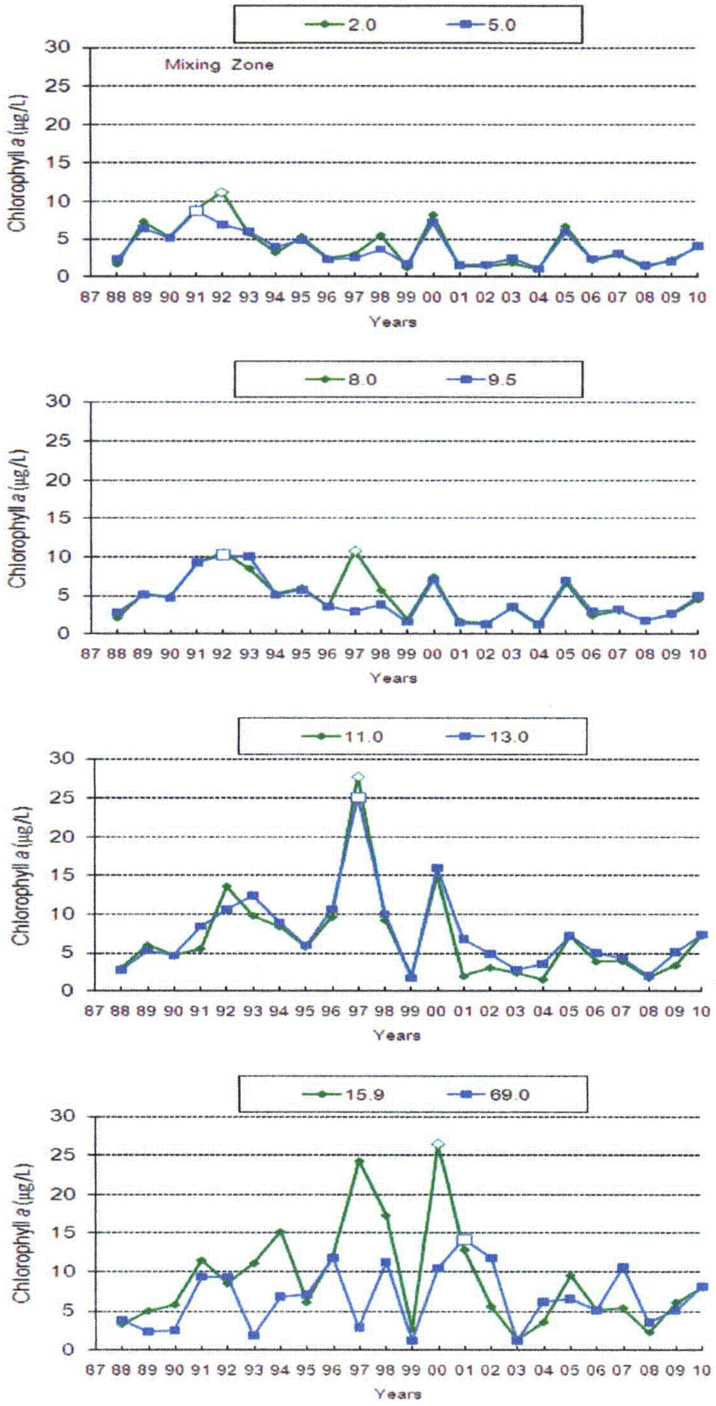

Figure 3-4. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman from May 1988 – 2010 (Note: in 2010, spring sampling was conducted in early June, and clear data points represent long-term maxima).

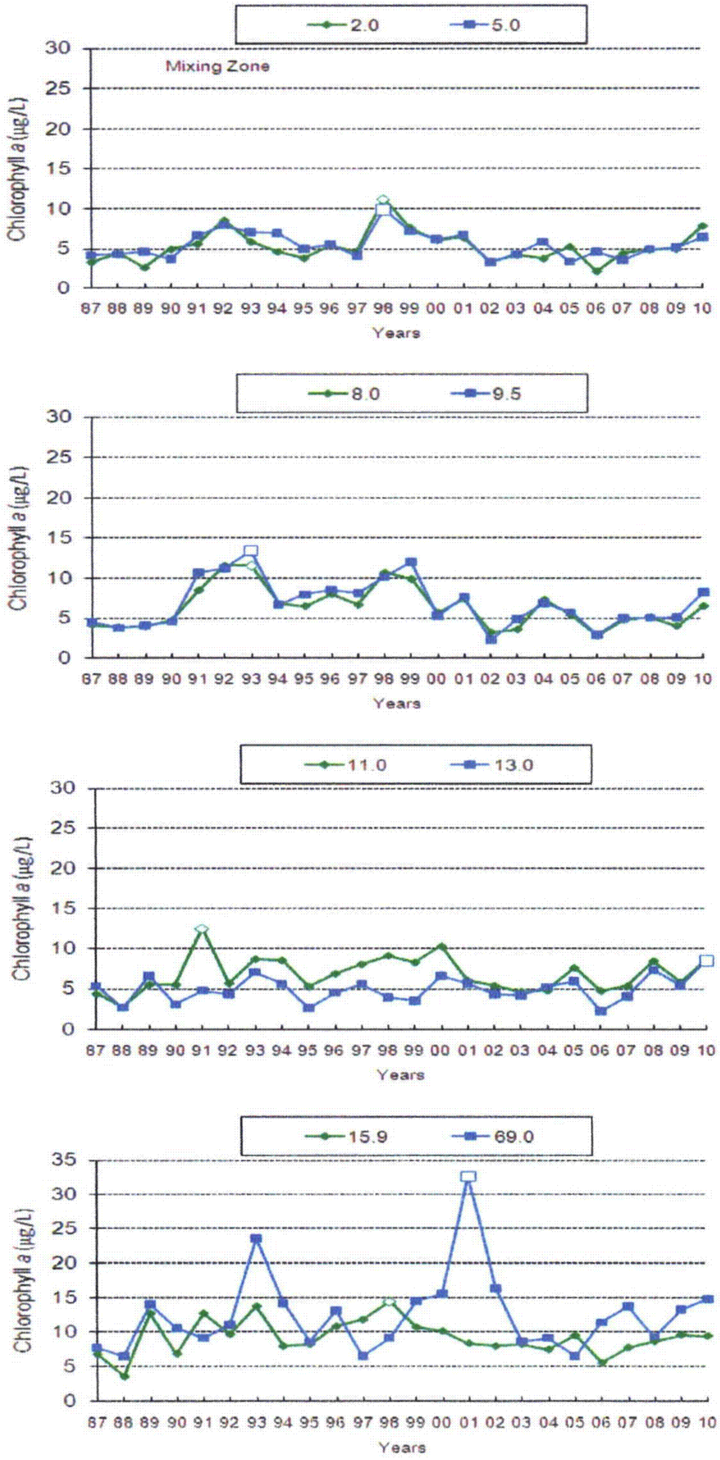

Figure 3-5. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during August 1987 – 2010 (Note: change in axis for 15.9 and 69.0, and that clear data points represent long-term maxima).

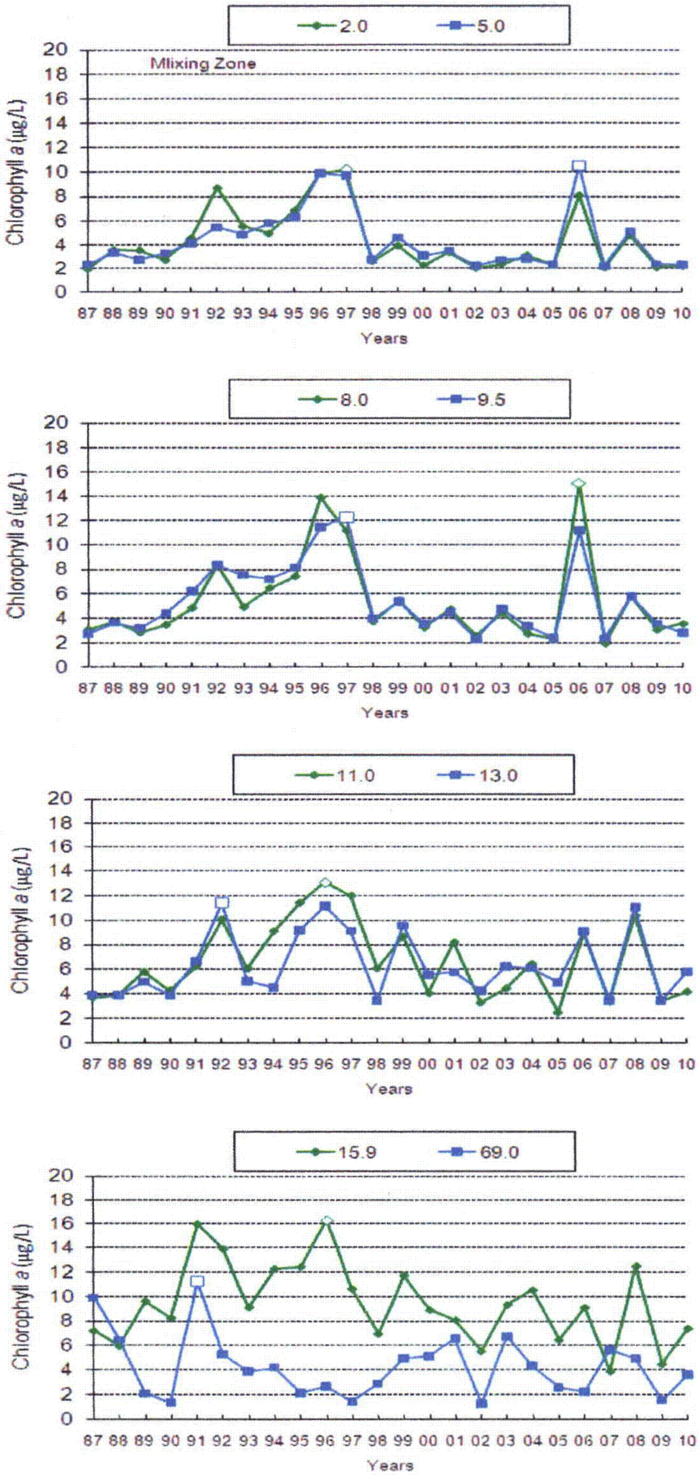

Figure 3-6. Phytoplankton mean chlorophyll *a* concentrations by location for samples collected in Lake Norman during November 1987 – 2010 (Note: change in axis, and that clear data points represent long-term maxima).

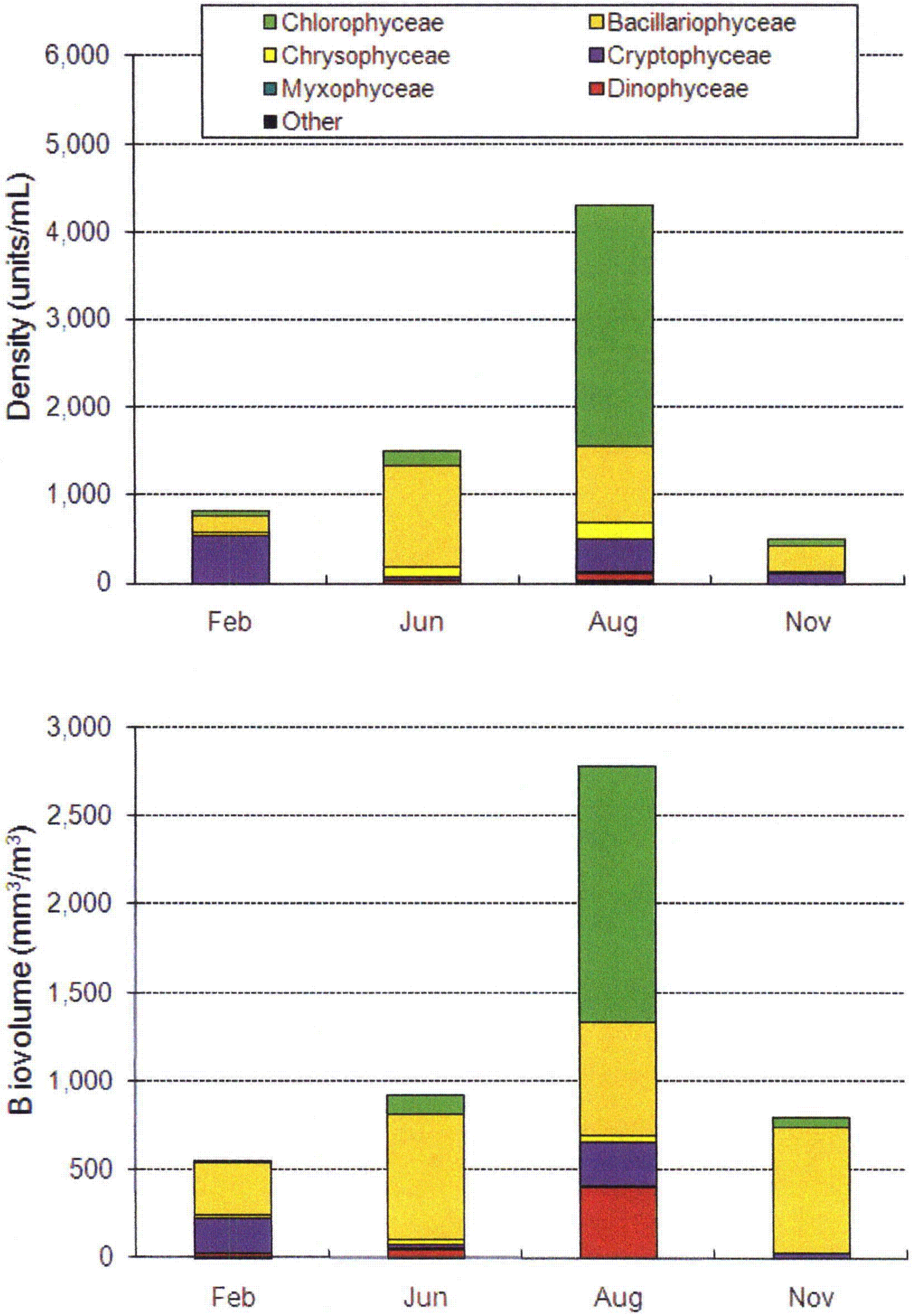

Figure 3-7. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 2.0 in Lake Norman during 2010.

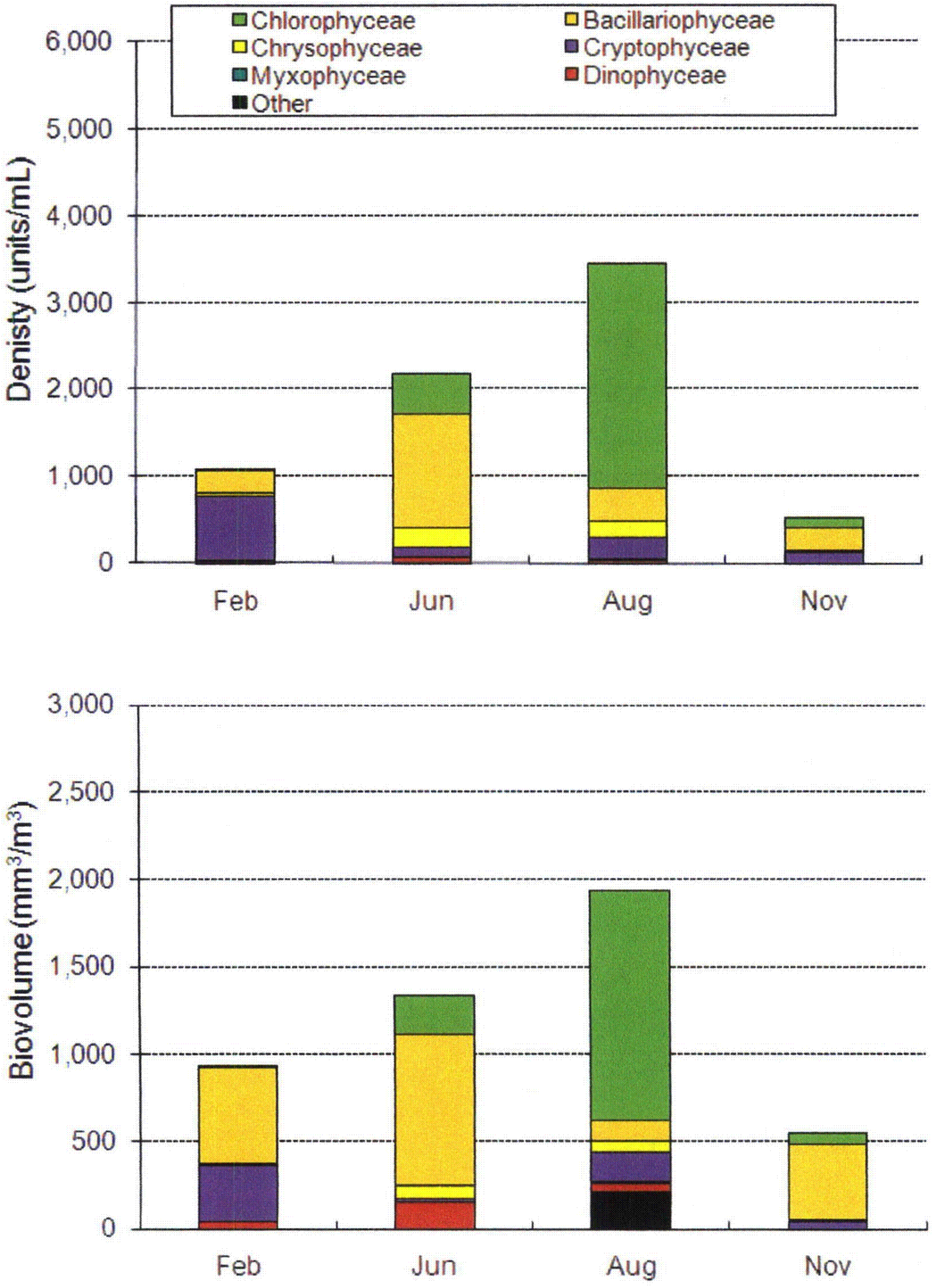

Figure 3-8. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 5.0 in Lake Norman during 2010.

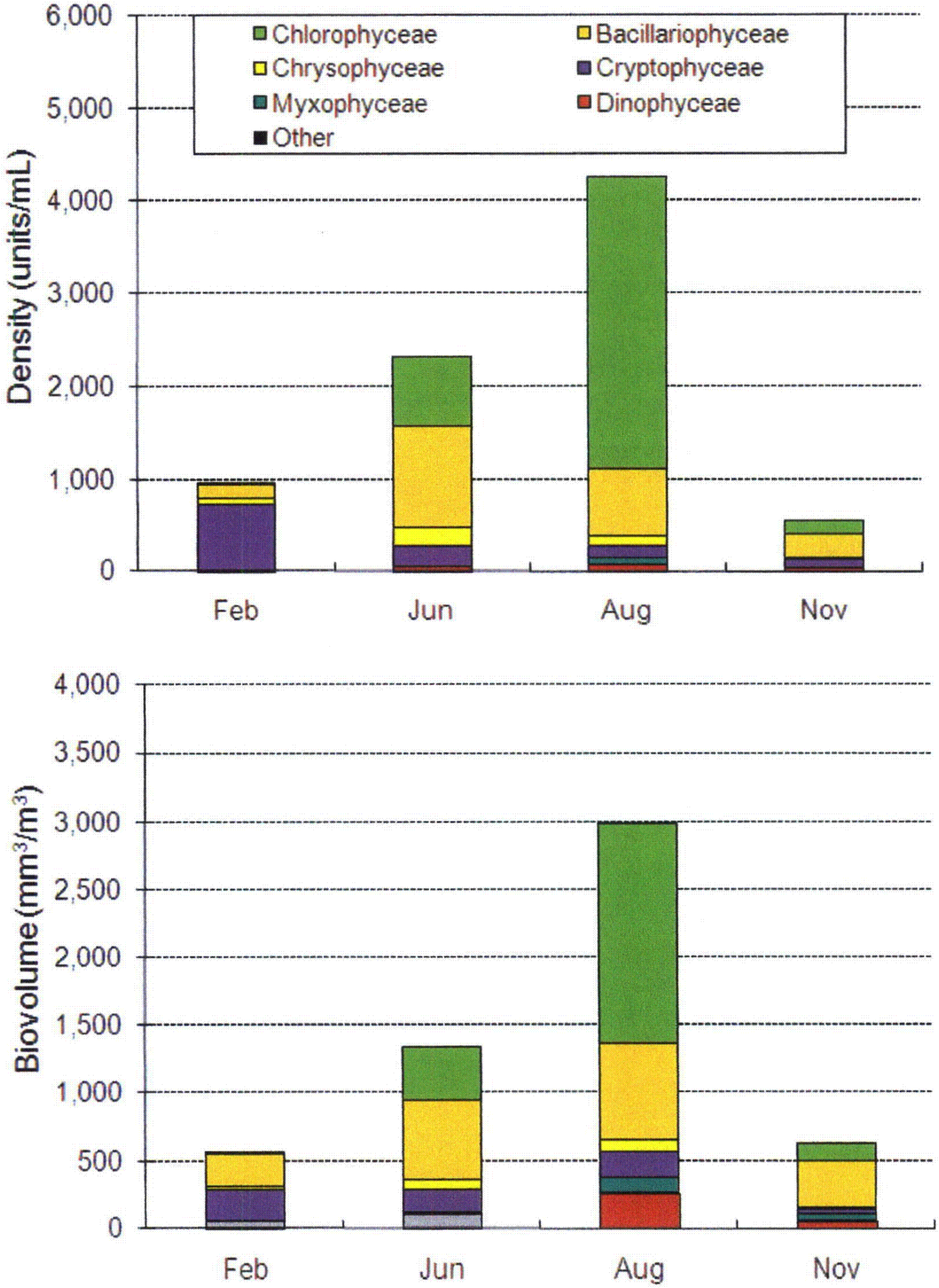

Figure 3-9. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 9.5 in Lake Norman during 2010.

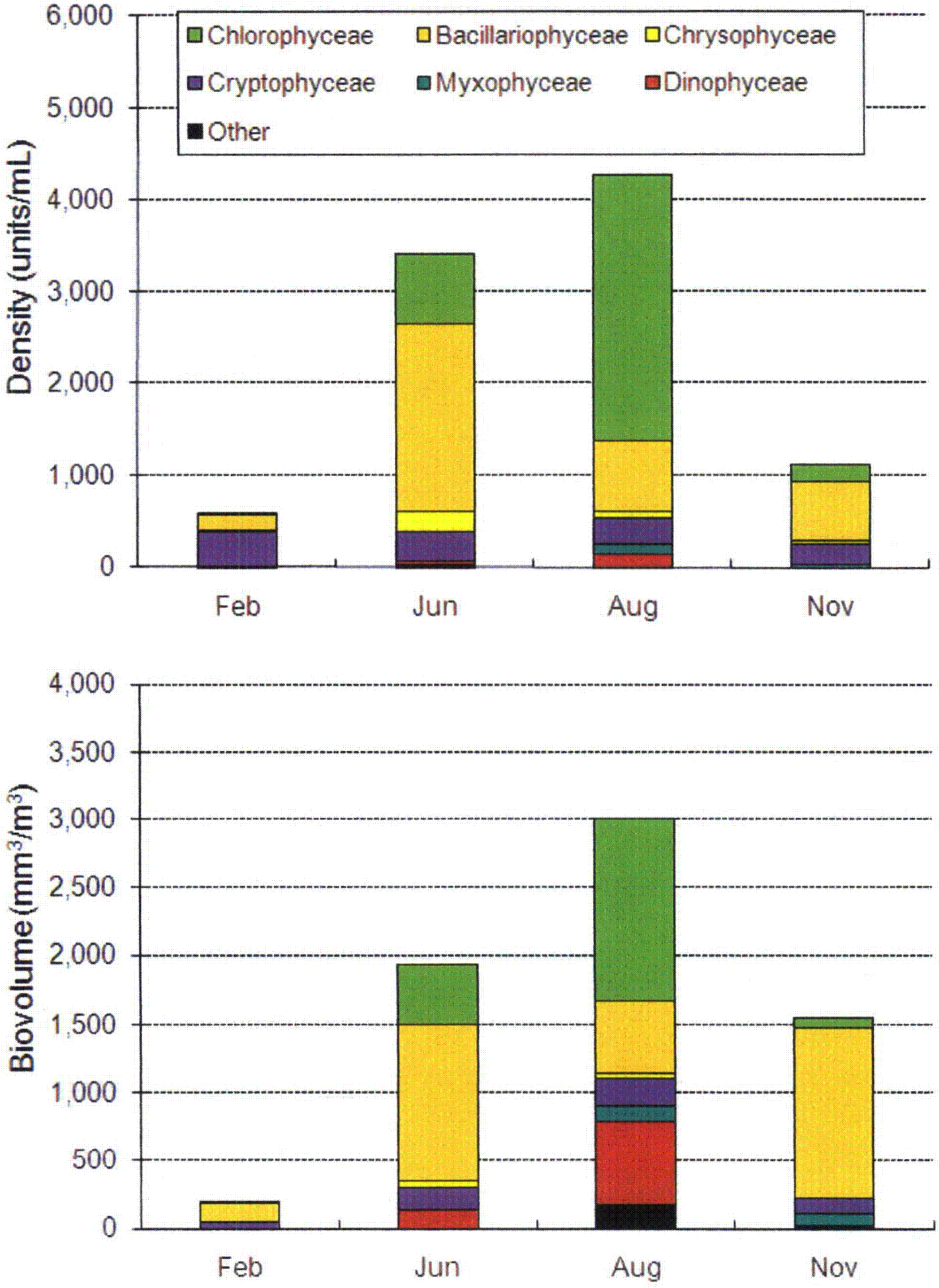

Figure 3-10. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 11.0 in Lake Norman during 2010.

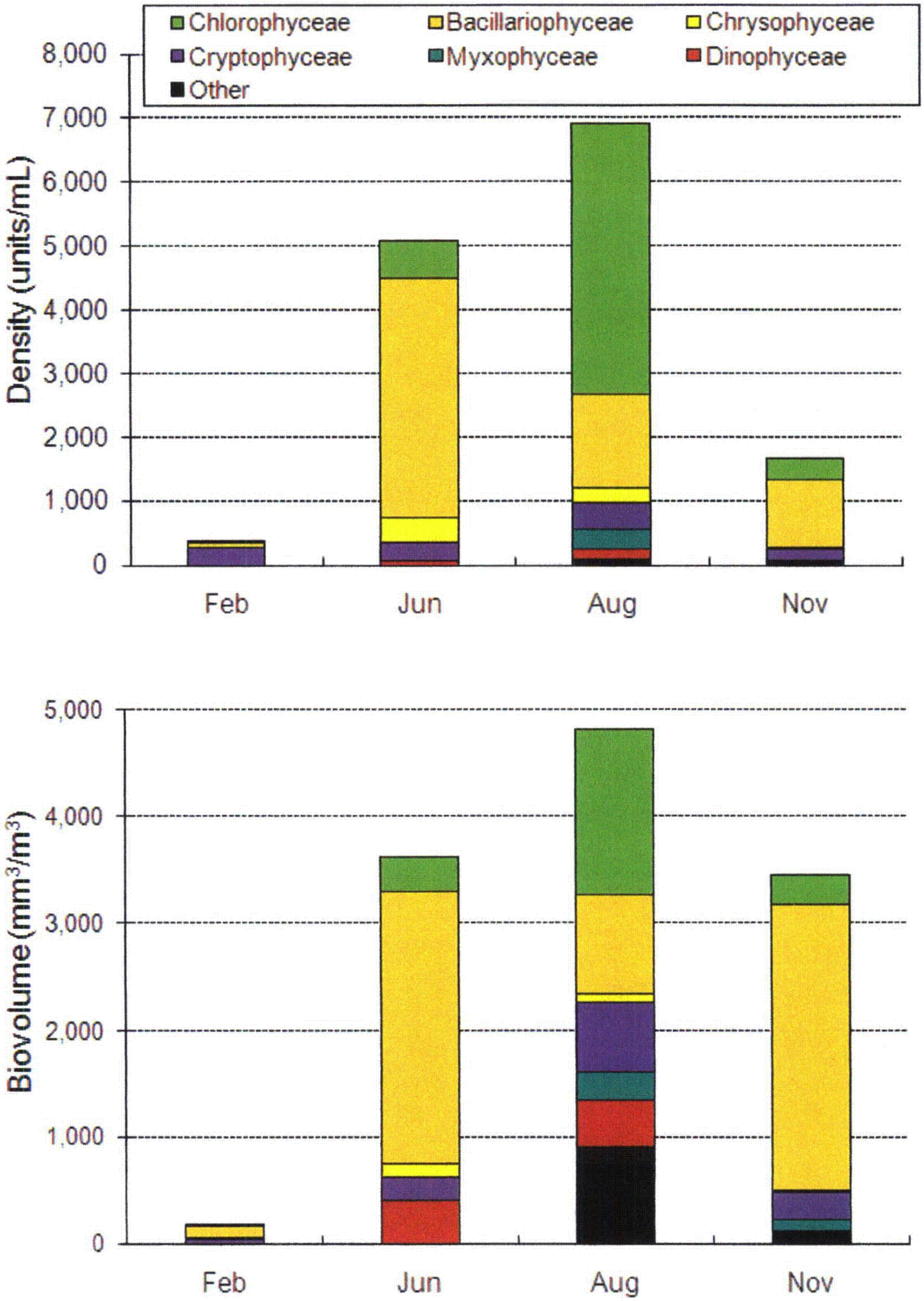

Figure 3-11. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 15.9 in Lake Norman during 2010.

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 2010 with historical data collected during the period 1987 – 2009.

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 (early June), summer (August), and fall (November) 2010. 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 2010 were compared with corresponding data from quarterly monitoring begun in August 1987.

RESULTS AND DISCUSSION

Total Abundance

Epilimnetic zooplankton densities ranged from a low of 19,157/m^3 at Location 2.0 in November, to a high of 187,170/m^3 at Location 15.9 in early June. During 2010, there was a certain amount of variability in annual maxima among Lake Norman locations. The annual epilimnetic maxima were recorded from Locations 2.0, 11.0, and 15.9 in the spring, while Locations 5.0 and 9.5 demonstrated their peak annual densities in the winter (Table 4-1; Figures 4-1 and 4-2). The lowest epilimnetic densities occurred at Locations 2.0, 9.5, and 11.0 in the fall. The annual minima at Locations 5.0 and 15.9 occurred in the summer and winter, respectively. 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 2010).

Whole-column densities ranged from a low of 17,197/m^3 at Location 2.0 in November to 127,975/m^3 at Location 9.5 in February. Maximum densities in 2010 whole-column samples were observed at Locations 2.0 and 9.5 in the winter, and at Locations 5.0, 11.0, and 15.9 in the spring. The seasonal whole-column minima at Locations 2.0, 5.0, and 9.5 occurred in the fall, while minima at Locations 11.0 and 15.9 were observed in the winter (Table 4-1 and Figure 4-1).

During 2010, 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 2010). 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.

Zooplankton distributions varied spatially and seasonally in 2010. During most seasons, average densities were generally variable but mixing zone densities were generally lowest in Fall (Table 4-1; Figures 4-1 and 4-2). In most previous years of the program, background locations had higher mean densities than mixing zone locations (Duke Energy 2010; Figures 4-3 through 4-6).

Epilimnetic zooplankton densities during all seasons of 2010 were all within historical ranges (Figures 4-3 through 4-6). The highest winter densities recorded from Locations 2.0 and 11.0 occurred in 1996, while the winter maximum at Location 9.5 was recorded in 1995 (Figure 4-3). The winter maximum from Location 5.0 occurred in 2004, while the long-term winter maximum from Location 15.9 occurred in 2009. Long-term maximum densities for spring were observed at Locations 2.0 and 5.0 in 2005, while the highest spring values from Locations 11.0 and 15.9 occurred in 2002. The highest spring peak at Location 9.5 was observed in 2005 (Figure 4-4). Long-term summer maxima occurred in 1988 at Locations 2.0, 5.0, and 11.0, while summer maxima at Locations 9.5 and 15.9 occurred in 2007 and 2003, respectively (Figure 4-5). Long-term maxima for the fall occurred at Locations 2.0, 9.5, and 11.0 in 2006. The long-term fall maximum at Location 5.0 occurred in 2009, while Location 15.9 demonstrated its fall maximum in 1996 (Figure 4-6).

Year-to-year fluctuations of densities in the mixing zone during the winter have occasionally been quite striking, particularly between 1991 and 1997. From 1998 to 2003, year-to-year fluctuations in the mixing zone were less apparent. Since 2004, some higher annual fluctuations were apparent. Densities at both mixing zone locations were higher during the winter of 2010 than during the winter of 2009. From 1990 to 2003, the densities at mixing zone locations in the spring, summer, and fall demonstrated moderate degrees of year-to-year variability, and the extended trend at mixing zone locations in the spring had been a gradual, long-term increase through 2005. During the spring of 2006, zooplankton densities in the mixing zone declined sharply, as compared to 2005, but were well within earlier historical ranges. During the spring of 2007, mixing zone locations demonstrated increases followed by sharp declines to the long-term minima at both locations in 2008. In the spring of 2009 and 2010 densities continued to increase. From 1989 to 2008, year-to-year fluctuations in the mixing zone during the summer were comparatively low, with the exception of a sharp increase in density at Location 5.0 in 2007. This was followed by a decline in 2008 and then increases in 2009. During the summer of 2010, the density at Location 2.0 increased from the previous year, while a sharp decline was observed at Location 5.0. During fall periods of 1989 – 2008, mixing zone densities showed minimal fluctuations in the low range with the exceptions of 2006 and 2009 when values at both locations increased sharply. In fact, the long-term fall peak at Location 5.0 was observed in 2009. During 2010, densities at mixing zone locations declined dramatically and were in the low historical range. The background locations continue to exhibit considerable year-to-year variability in all seasons. Background locations demonstrated lower densities in 2010 than in 2009 (Figures 4-3 through 4-6).

Community Composition

One hundred and twenty-four zooplankton taxa have been identified since the Lake Norman Maintenance Monitoring Program began in August 1987 (Table 4-2). Fourty-eight taxa were identified during 2010, as compared to 53 recorded for 2009 (Duke Energy 2009). One new taxon, the rotifer *Brachionus angulosa* was added to the taxa list in 2010.

During 2010, rotifers were dominant in nearly two-thirds of the samples (Table 4-1). Copepods were dominant in both epilimnetic and whole-column samples at Location 9.5 in the spring of 2010, and were dominant in the whole-column sample from Location 2.0 during the summer. Copepods dominated epilimnetic and whole-column samples at Location 5.0 during the summer. In the fall of 2010, copepods were dominant at all but Location 15.9. Rotifers were the dominant forms in most samples collected during the winter, spring, and summer of 2010, but were only dominant at Location 15.9 in the fall. Cladocerans, typically the least abundant forms, were dominant in the whole-column sample from Location 15.9 in the summer of 2010 (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 2009, rotifers declined in relative abundances in both the epilimnetic and whole-column samples of the mixing zone during 2010 and their percent of compositions were within historical ranges (Figure 4-7). At background locations rotifer relative abundances showed somewhat more moderate decreases in epilimnetic and whole-column samples since 2009 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 2010. Adult copepods seldom comprised more than 7% of the copepod densities at any location. In order of seasonal importance, *Epishura* and *Cyclops* were most common among winter samples, while *Epishura* and *Tropocyclops* were important among spring samples. *Tropocyclops* was most important among summer assemblages, especially in whole-column samples. During the fall period, *Tropocyclops* and *Epishura* were important constituents in most samples. Those taxa which demonstrated occasional importance were *Diaptomus*, and *Mesocyclops*. Similar patterns of copepod taxonomic distributions were observed in previous years (Duke Energy 2010).

Copepods tended to be more abundant among background locations than among mixing zone locations during 2010. Copepods peaked in the mixing zone during winter and at background locations in the spring. During most past years, peaks from both areas were observed in the spring (Duke Energy 2010).

Cladocera

Bosmina was the most abundant cladoceran observed in 2010 samples, as has been the case in most previous studies (Duke Energy 2010 and Hamme 1982). *Bosmina* often comprised greater than 5% of the total zooplankton densities in both epilimnetic and whole-column samples (Table 4-3). *Bosminopsis* was important among cladocerans in the summer when it dominated cladoceran populations at all but one location and was the dominant zooplankter in the whole-column at Location 15.9. *Diaphanosoma* was the dominant cladoceran in three spring samples and one summer sample. Similar patterns of cladoceran dominance have been observed in past years (Duke Energy 2010).

Long-term seasonal trends of cladoceran densities were variable. During 2008, maximum densities in the mixing zone occurred in the winter, while peaks at background locations were observed in the spring (Figure 4-10). From 1990 to 1993, and in 2009, peak densities occurred in the winter, while in 1994, 1995, 1997, 2000, 2004, 2005, and 2007 maxima were recorded in the spring (Figure 4-10). During 1996 and 2002, peak cladoceran densities occurred in the spring in the mixing zone, and in the summer among background locations, while in 1999 they peaked in the mixing zone during the summer and among background locations in the fall. Maximum cladoceran densities in 1998 occurred in the summer. In 2001, maximum cladoceran densities in the mixing zone occurred in the fall, while background locations showed peaks in the winter. During 2003, maximum densities in the mixing zone occurred in the fall, while peaks among background locations were observed in the summer. During 2010, peak cladoceran densities were recorded in the summer from both the mixing zone and among background locations. Spatially, cladocerans were well distributed among most locations (Table 4-1 and Figure 4-2).

Rotifera

Polyarthra was the most abundant rotifer at all locations in the fall of 2010 (Table 4-3). *Kellicotia* dominated rotifer populations during the spring, while *Asplanchna* dominated most winter populations. *Keratella* was dominant in five summer samples and *Trichocerca* was the most abundant rotifer in four 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 2010 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 2010, peak rotifer densities were observed at both mixing zone and background locations in the spring.

FUTURE STUDIES

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

SUMMARY

During 2010, seasonal maximum densities among zooplankton assemblages varied considerably and no consistent seasonal trends were observed. Maxima occurred in spring and winter, 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 2010. Spatial trends of zooplankton populations were generally similar to those of the phytoplankton, with increasing densities from downlake to uplake during all seasons but winter. From around 1997 through 2005, a year-to-year trend of increasing zooplankton densities was observed among mixing zone locations in the spring. Densities at these locations declined sharply in 2006, followed by an increase in 2007. The densities showed a decline in 2008, followed by increases in 2009 and 2010. In most cases, densities in 2010 were lower than in 2009. Long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations. Epilimnetic zooplankton densities were within ranges of those observed in previous years.

One hundred and twenty-four zooplankton taxa have been recorded from Lake Norman since the Program began in 1987. Fourty-eight taxa were identified in 2010, as compared to 53 in 2009. One new taxon, the rotifer *Brachionus angulosa* was added to the taxa list in 2010.

Rotifers were dominant in nearly two-thirds of all samples; however, their overall relative abundances declined since 2009 in epilimnetic and whole-column samples from mixing zone and background locations. Overall, relative abundance of copepods in 2010 increased over 2009. The relative abundance of all microcrustaceans (copepods and cladocerans) increased throughout the lake in 2010 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, Diaptomus,* and *Mesocyclops* 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 occasionally important among spring and summer populations. The most abundant rotifers observed in 2010, as in many previous years, were *Polyarthra, Kellicotia,* and *Asplanchna.* *Keratella* and *Trichocerca* were also occasionally important among rotifer populations.

Lake Norman continues to support a highly diverse and longitudinally variable zooplankton community. No impacts of plant operations were observed.

Table 4-1. Total zooplankton densities (No. X 1000/m^3), densities of major zooplankton taxonomic groups, and percent composition (in parentheses) of major taxa in the epilimnion and whole column net tow samples collected from Lake Norman in winter (February), spring (June), summer (August), and fall (November) 2010.

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
2/19/2010	Epilimnion	Copepoda	24.21	16.17	65.59	28.94	5.85
			(33.2)	(21.7)	(45.2)	(43.7)	(23.3)
		Cladocera	5.21	5.26	33.07	3.07	0.94
			(7.1)	(7.1)	(22.8)	(4.6)	(3.7)
		Rotifera	43.49	52.97	46.60	34.19	18.31
			(59.6)	(71.2)	(32.1)	(51.6)	(73.0)
		Total	72.91	74.40	145.26	66.20	25.10
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	31 m	19 m	21 m	25 m	21 m
		Copepoda	19.00	13.43	59.03	20.56	7.50
			(29.6)	(24.5)	(46.1)	(39.8)	(37.0)
		Cladocera	5.61	10.12	21.31	2.92	1.16
			(8.7)	(18.4)	(16.6)	(5.6)	(5.7)
		Rotifera	39.55	31.35	47.63	28.24	11.59
			(61.7)	(57.1)	(37.3)	(54.6)	(57.3)
		Total	64.16	57.90	127.97	51.72	20.25

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
6/10/2010	Epilimnion	Copepoda	25.34	15.23	14.60	31.79	48.23
			(25.8)	(23.1)	(33.2)	(28.2)	(26.0)
		Cladocera	10.29	4.66	4.31	12.54	19.64
			(10.5)	(7.1)	(9.8)	(11.2)	(10.6)
		Rotifera	62.52	45.93	25.08	68.26	117.30
			(63.7)	(69.8)	(57.0)	(60.6)	(63.4)
		Total	96.15	65.82	43.99	112.59	185.17
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	20 m	21 m	25 m	19 m
		Copepoda	23.98	30.18	16.90	32.99	28.44
			(43.0)	(44.5)	(40.3)	(39.7)	(31.7)
		Cladocera	9.69	4.66	5.08	8.03	14.91
			(17.4)	(6.9)	(12.1)	(9.7)	(16.6)
		Rotifera	22.13	32.97	19.98	42.01	46.31
			(39.6)	(48.6)	(47.6)	(50.6)	(51.7)
		Total	55.80	67.81	41.96	83.03	89.66

Table 4-1. (Continued).

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
8/23/2010	Epilimnion	Copepoda	8.19	11.40	9.72	17.57	23.45
			(12.9)	(37.3)	(11.8)	(16.6)	(30.2)
		Cladocera	11.51	8.89	18.17	42.29	25.35
			(18.1)	(29.1)	(22.0)	(39.9)	(32.6)
		Rotifera	43.94	10.25	54.70	46.26	28.87
			(69.0)	(33.6)	(66.2)	(43.5)	(37.2)
		Total	63.64	30.54	82.59	106.12	77.67
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	17 m	20 m	24 m	20 m
		Copepoda	12.81	20.11	22.57	18.85	29.15
			(43.3)	(56.4)	(31.2)	(34.3)	(34.2)
		Cladocera	1.62	5.22	13.30	17.02	30.62
			(5.5)	(14.7)	(18.4)	(31.0)	(36.0)
		Rotifera	15.13	10.29	36.38	19.04	25.19
			(51.2)	(28.9)	(50.4)	(34.7)	(29.6)
		Total	29.56	35.62	72.25	54.91	85.14 [a]

			Locations				
Sample Date	**Sample Type**	**Taxa**	**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
11/11/2010	Epilimnion	Copepoda	13.11	18.38	16.74	37.15	25.61
			(68.4)	(59.3)	(55.1)	(56.9)	(23.5)
		Cladocera	3.08	6.49	8.25	5.62	5.66
			(16.1)	(20.9)	(27.1)	(8.6)	(5.2)
		Rotifera	2.97	6.14	5.42	22.56	77.69
			(15.5)	(19.8)	(17.8)	(34.5)	(71.3)
		Total	19.16	31.01	30.41	65.33	108.96
	Whole-column		**2.0**	**5.0**	**9.5**	**11.0**	**15.9**
		Depth	30 m	18 m	20 m	25 m	21m
		Copepoda	11.80	12.28	15.56	31.78	20.61
			(68.6)	(57.0)	(63.4)	(56.0)	(29.4)
		Cladocera	4.17	6.20	5.29	5.39	5.00
			(24.3)	(28.7)	(21.6)	(9.5)	(7.1)
		Rotifera	1.22	3.07	3.68	19.54	44.48
			(7.1)	(14.3)	(15.0)	(34.5)	(63.5)
		Total	17.19	21.54	24.53	56.71	70.09

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[a] = *Chaoborus* (167/m^3, 0.2%)

Table 4-2. Zooplankton taxa identified from samples collected quarterly on Lake Norman from 1987 – 2010.

Taxon	87-95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
Copepoda																
Cyclops thomasi Forbes	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. vernalis Fischer		X														
C. spp. O. F. Muller	X	X	X	X			X	X	X						X	X
Diaptomus birgei Marsh	X					X										
D. mississippiensis Marsh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. pallidus Herick	X	X	X		X				X		X					
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					X		
Paracyclops limbricatus v. *poppei*											X					
Tropocyclops prasinus (Fischer)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. spp. (Fischer)	X	X	X				X	X		X		X	X	X	X	X
Cladocera																
Alona spp.Baird		X	X										X		X	
Alonella spp. (Birge)	X				X											
Bosmina longirostris (O. F. M.)	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
B. spp. Baird	X	X	X	X		X	X	X								
Bosminopsis dietersi Richard	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceriodaphnia dubia																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	X
Chydorus spp. Leach	X	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
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
D. pulicaria Sars		X	X													
D. retrocurva Forbes		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
D. spp. Fischer	X	X	X	X		X	X	X	X	X						

Table 4-2. (Continued).

Taxon	87-95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
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
H. gibberum Zaddach	X		X	X												
H. spp. Stingelin	X	X	X			X	X	X	X						X	
Ilyocryptus sordidus (Lieven)	X															
I. spinifer Herrick					X											
I. spp. Sars	X			X		X								X		
Latona setifera (O.F. Muller)	X															
Leptodora kindtii (Focke)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leydigia acanthoceroides (Fis.)										X						
L. spp. Freyberg	X	X	X						X	X			X	X		
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 calyciflorus											X					
Brachionus angulosa																X
Brachionus 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												X
Chromogaster ovalis (Berg.)			X	X	X		X				X	X	X	X	X	
C. spp. Lauterborne	X	X														
Collotheca balatonica Harring		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
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
C. spp. Hlava	X	X	X				X		X							
Conochilus unicornis (Rouss.)	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Hlava	X	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
G. spp. Imhof	X	X	X	X			X									
Hexarthra mira Hudson			X	X	X	X		X				X	X	X	X	X
H. spp. Schmada	X	X	X				X									

Table 4-2. (Continued).

Taxon	87-93	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
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
K. spp. Rousselet	X	X	X				X	X	X	X	X				X	
Keratella americana Carlin													X			
K. cochlearis Raderorgan					X	X				X			X	X	X	X
K. quadrata																X
K. taurocephala Myers			X		X					X	X		X	X		
K. spp. Bory de St. Vincent	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Lecane luna O. F. Muller														X		
Lecane spp. Nitzsch	X		X	X		X		X	X		X	X				X
Macrochaetus subquadratus P.			X	X												
M. spp. Perty	X	X			X	X		X			X					
Monommata spp. Bartsch												X			X	
Monostyla stenroosi (Meiss.)	X															
M. spp. Ehrenberg	X	X		X					X							X
Notholca spp. Gosse	X	X		X												
Platyias patulus Harring								X								
Ploesoma hudsonii Brauer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. truncatum (Levander)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Herrick	X	X		X			X								X	X
Polyarthra euryptera (Weir.)	X			X						X		X	X			
P. major Burckhart			X		X	X		X	X	X	X	X	X	X	X	X
P. vulgaris Carlin	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
P. spp. Ehrenberg	X	X	X					X	X						X	
Synchaeta spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichocerca capucina (Weir.)	X	X	X	X				X								
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
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	X										
Insecta																
Chaoborus spp. Lichtenstein	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 2010.

Locations	Winter	Spring	Summer	Fall
		Copepoda:	**Epilimnion**	
2.0	*Epishura* (1.6)	*Diaptomus* (2.3)	*Diaptomus* (1.9)[b]	*Mesocyclops* (2.5)
5.0	No adults present	*Epishura* (1.1)[b]	*Cyclops* (1.0)	*Diapomus* (4.5)
9.5	*Epishura* (3.6)	*Epishura* (1.4)[b]	No adults present	*Tropocyclops* (6.6)[b]
11.0	*Cyclops* (1.3)	*Tropocyclops* (2.0)	*Mesocyclops* (1.6)[b]	*Tropocyclops* (4.4)
15.9	*Cyclops* (12.8)[b]	*Epishura* (13.0)	*Tropocyclops* (1.9)[b]	*Tropocyclops* (16.1)
		Copepoda:	**Whole-column**	
2.0	*Tropocyclops* (3.3)	*Tropocyclops* (0.6)	*Tropocyclops* (5.9)	*Tropocyclops* (3.0)
5.0	*Epishura* (2.8)[b]	*Mesocyclops* (1.2)[b]	*Tropocyclops* (15.1)[c]	*Epishura* (2.5)
9.5	*Eopishura* (1.9)	*Epishura* (2.8)	*Tropocyclops* (2.9)	*Epishura* (12.3)
11.0	*Diaptomus* (2.4)	*Diaptomus* (3.5)	*Tropocyclops* (10.9)	*Epishura* (4.3)
15.9	*Cyclops* (1.6)[b]	*Tropocyclops* (4.8)	*Tropocyclops* (8.6)	*Tropocyclops* (1.6)
		Cladocera:	**Epilimnion**	
2.0	*Bosmina* (96.2)	*Bosmina* (67.7)	*Bosminopsis* (88.9)	*Bosmina* (69.0)
5.0	*Bosmina* (100.0)	*Bosmina* (75.9)	*Bosminopsis* (54.6)	*Bosmina* (72.9)
9.5	*Bosmina* (86.6)	*Bosmina* (77.4)	*Bosminopsis* (86.1)	*Bosmina* (89.2)
11.0	*Bosmina* (88.5)	*Bosmina* (62.4)	*Bosminopsis* (98.4)	*Bosmina* (87.3)
15.9	*Bosmina* (100.0)	*Diaphanosoma* (44.0)	*Bosminopsis* (91.0)	*Bosmina* (67.8)
		Cladocera:	**Whole-column**	
2.0	*Bosmina* (97.4)	*Bosmina* (50.1)	*Diaphanosoma* (92.1)	*Bosmina* (62.1)
5.0	*Bosmina* (64.7)	*Bosmina* (64.5)	*Bosminopsis* (80.0)	*Bosmina* (73.6)
9.5	*Bosmina* (89.3)	*Bosmina* (48.8)	*Bosminopsis* (84.6)	*Bosmina* (89.6)
11.0	*Bosmina* (95.2)	*Diaphanosoma* (57.5)	*Bosminopsis* (79.0)	*Bosmina* (87.8)
15.9	*Bosmina* (100.0)	*Diaphanosoma* (58.8)	*Bosminopsis* (75.5)	*Bosmina* (74.0)

Table 4-3. (Continued).

Locations	Winter	Spring	Summer	Fall
		Rotifera:	**Epilimnion**	
2.0	*Asplanchna* (48.4)	*Kellicotia* (72.2)	*Conochilus* (63.4)	*Polyarthra* (84.2)
5.0	*Asplanchna* (43.2)	*Kellicottia* (37.8)	*Keratella* (48.6)	*Polyarthra* (91.7)
9.5	*Asplanchna* (89.5)	*Kellicotia* (28.0)	*Trichocerca* (45.7)	*Polyarthra* (76.5)
11.0	*Asplanchna* (47.0)	*Kellicotia* (36.8)	*Trichocera* (41.4)	*Polyarthra* (70.2)
15.9	*Polyarthra* (49.5)	*Kellicotia* (30.1)	*Keratella* (26.7)	*Polyarthra* (56.8)
		Rotifera:	**Whole-column**	
2.0	*Asplanchna* (42.3)	*Kellicotia* (68.3)	*Keratella* (31.8)	*Polyarthra* (70.6)
5.0	*Asplanchna* (37.0)	*Kellicotia* (34.0)	*Keratella* (36.9)	*Polyarthra* (73.6)
9.5	*Asplanchna* (76.5)	*Kellicotia* (23.1)	*Trichocerca* (39.6)	*Polyarthra* (73.9)
11.0	*Keratella* (25.5)	*Kellicotia* (36.3)	*Trichocerca* (26.2)	*Polyarthra* (74.9)
15.9	*Polyarthra* (42.4)	*Kellicotia* (28.9)	*Keratella* (28.4)	*Polyarthraa* (47.0)

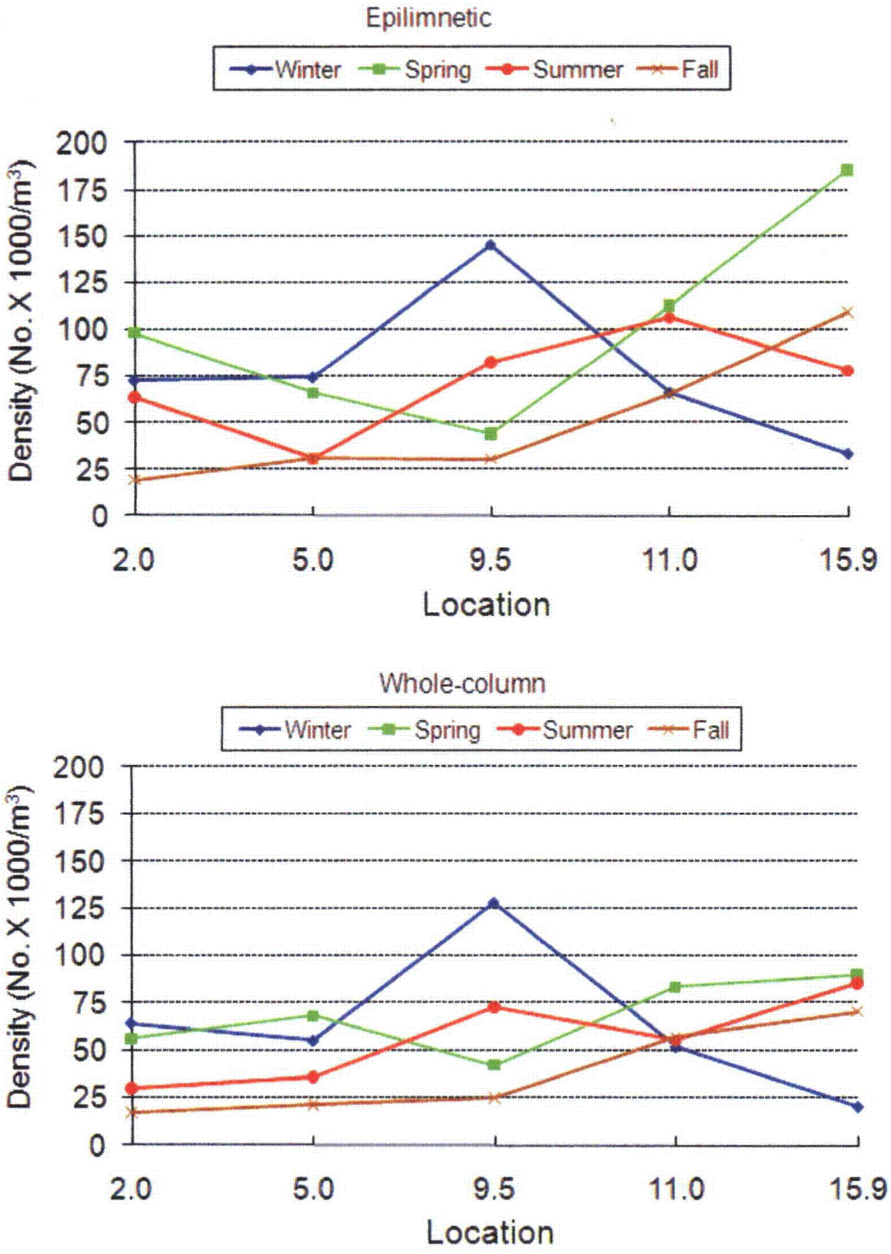


Figure 4-1. Total zooplankton density by location for samples collected in Lake Norman in 2010.

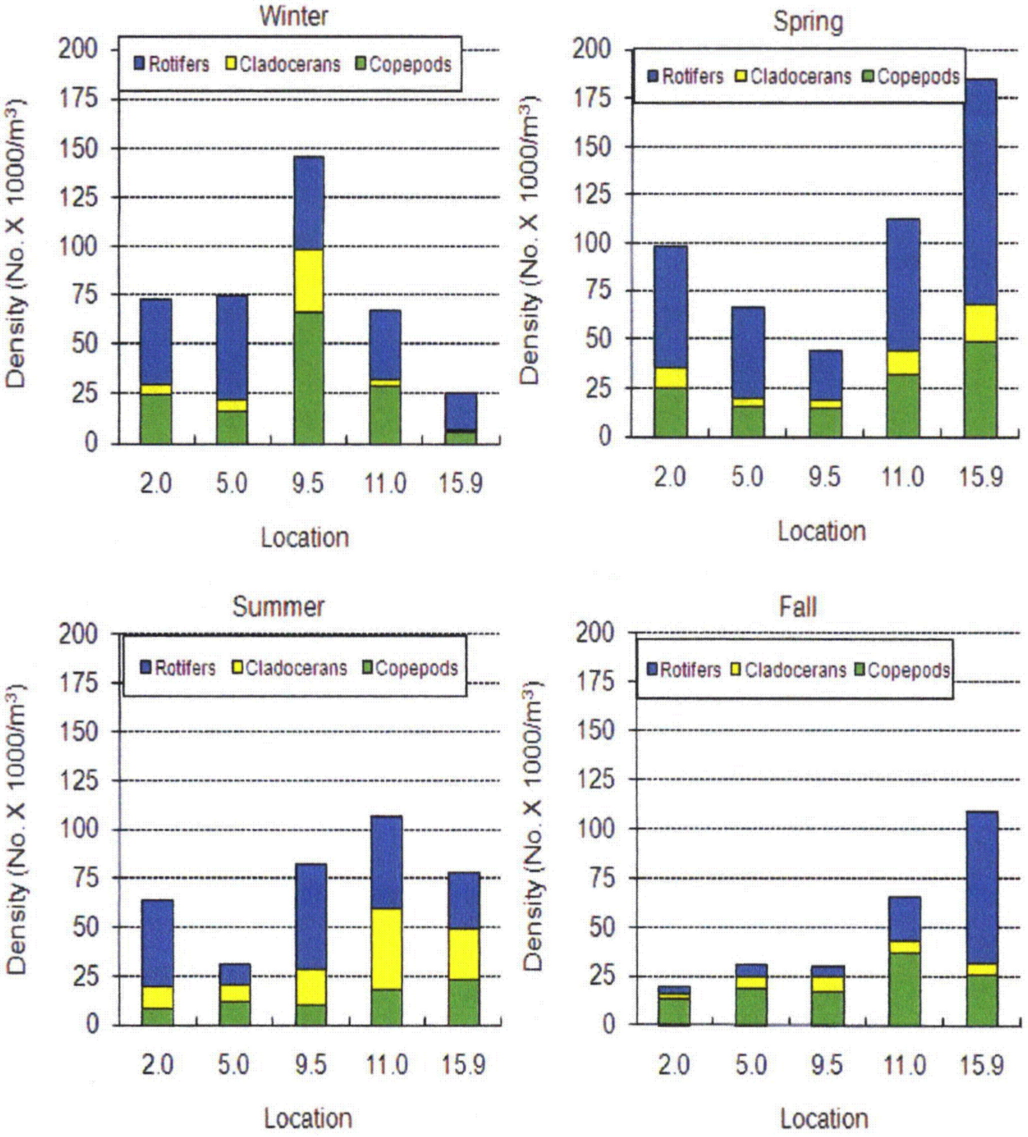
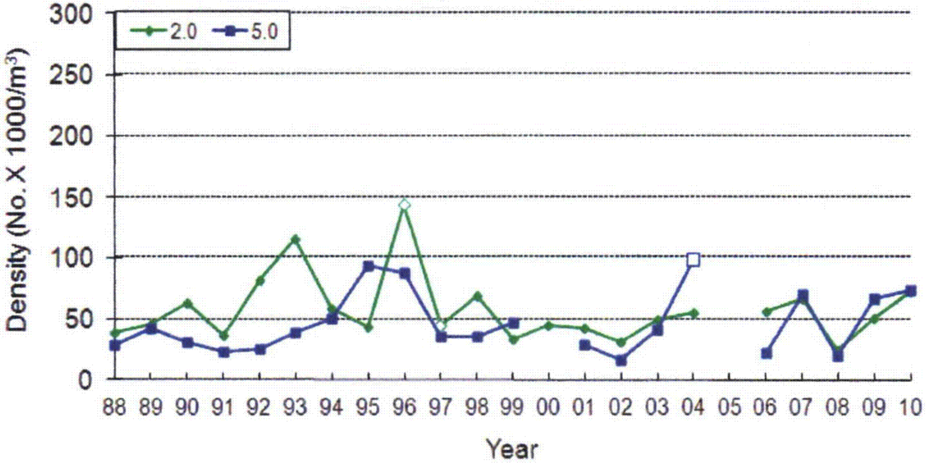


Figure 4-2. Zooplankton community composition by sample period and location for epilimnetic samples collected in Lake Norman in 2010.

Winter

Mixing Zone Locations



Background Locations

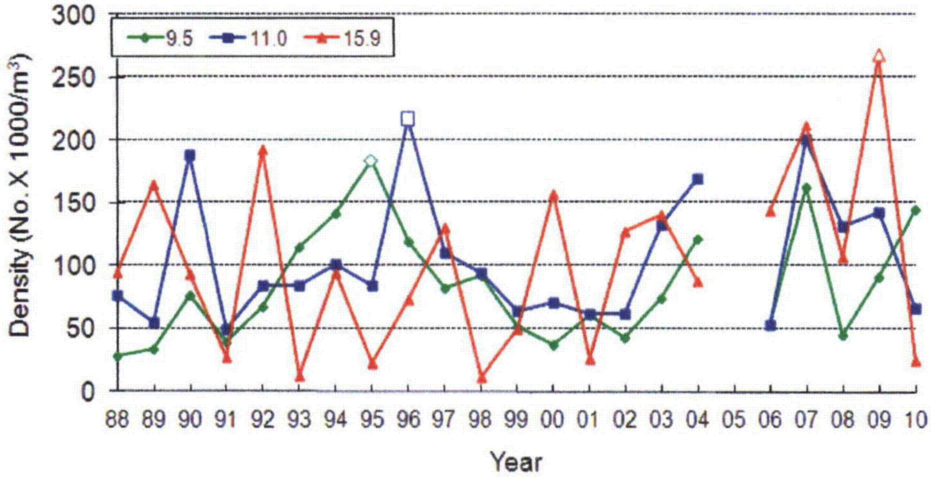
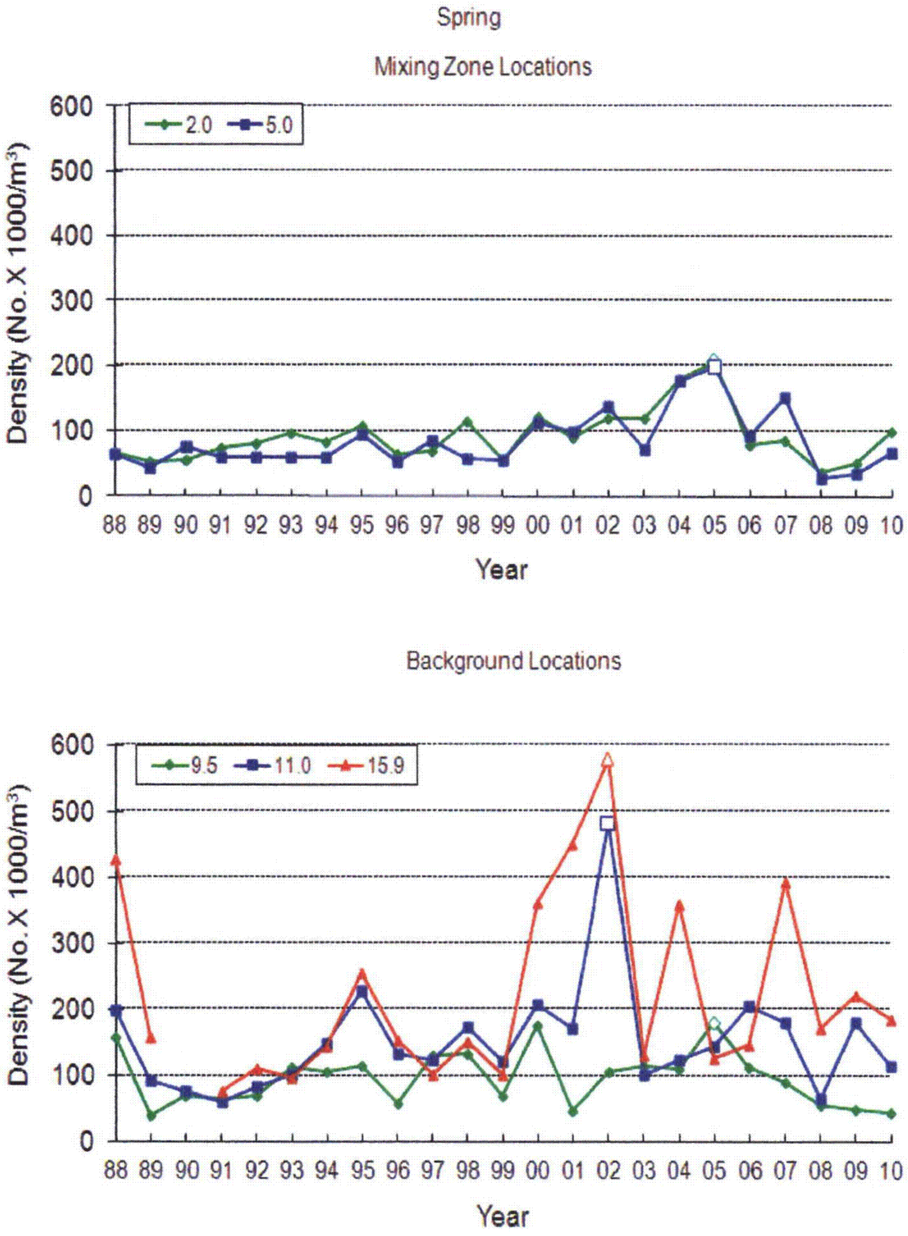


Figure 4-3. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the winter periods of 1988 – 2010 (clear data points represent long-term maxima).


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 – 2010 (clear data points represent long-term maxima).

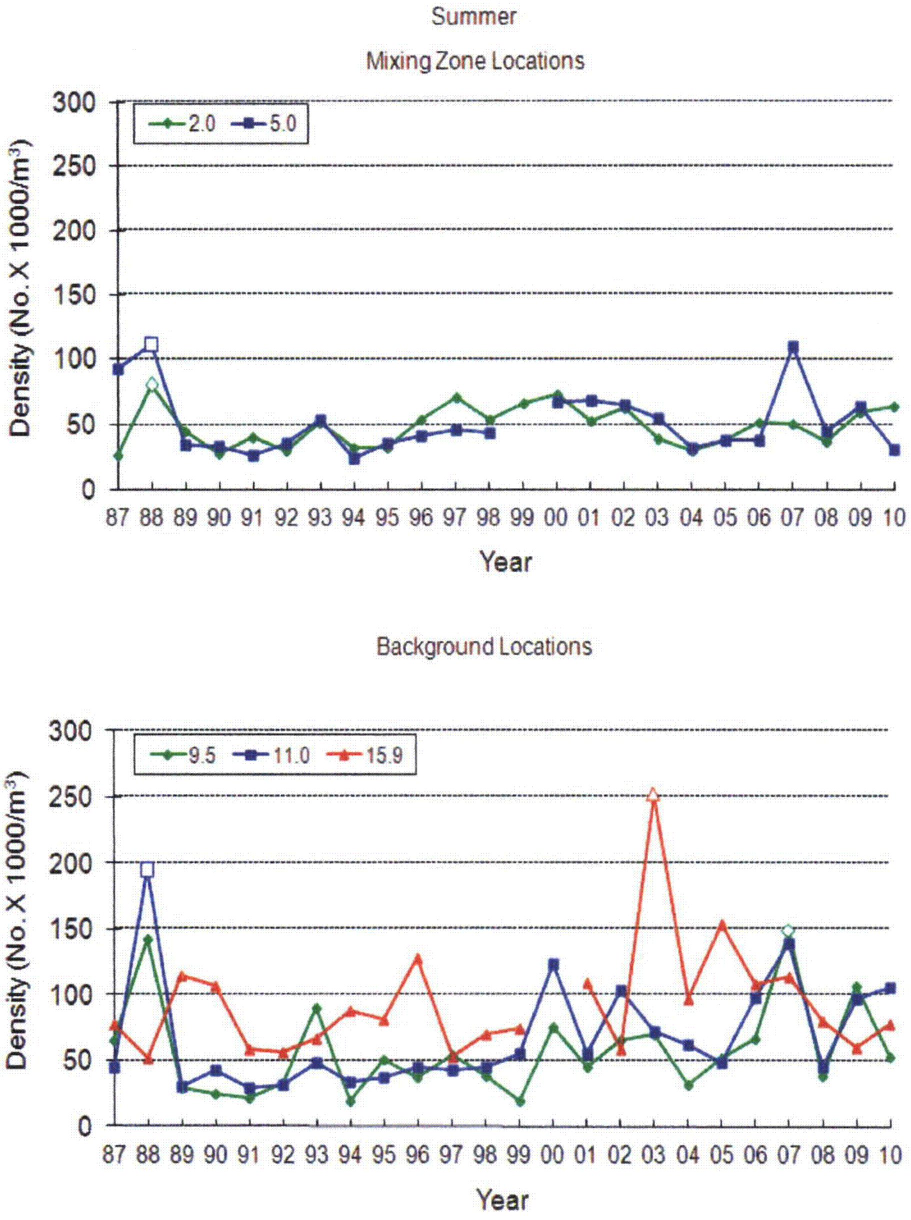
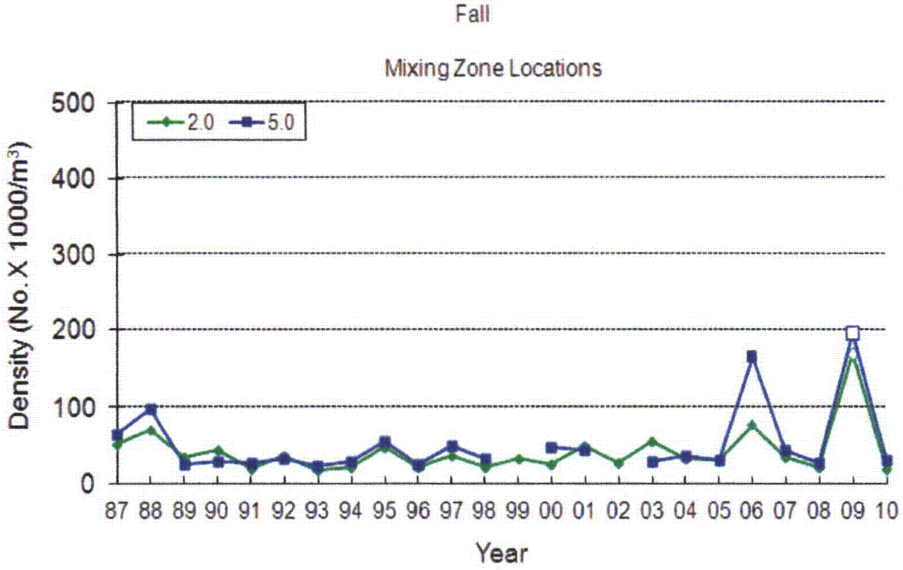


Figure 4-5. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the summer periods of 1987 – 2010 (clear data points represent long-term maxima).


Fall

Mixing Zone Locations

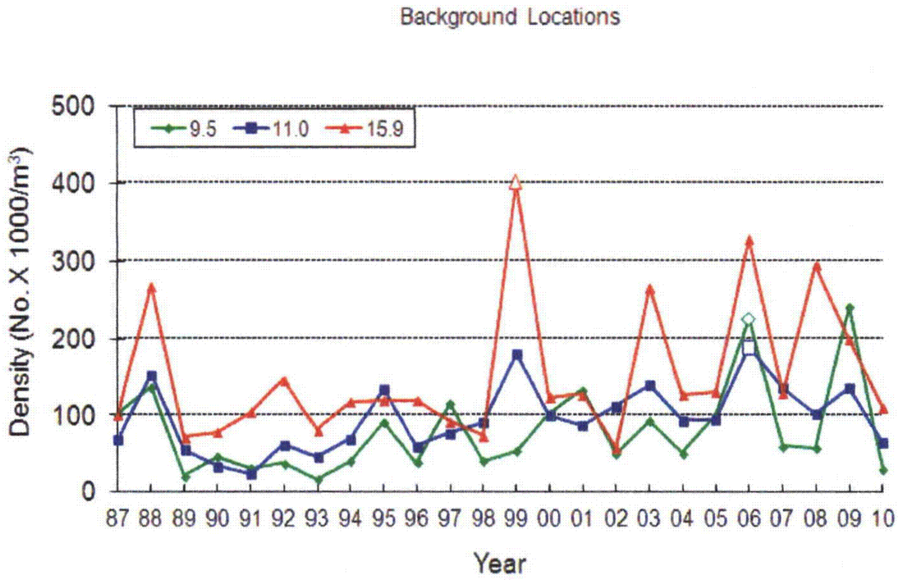
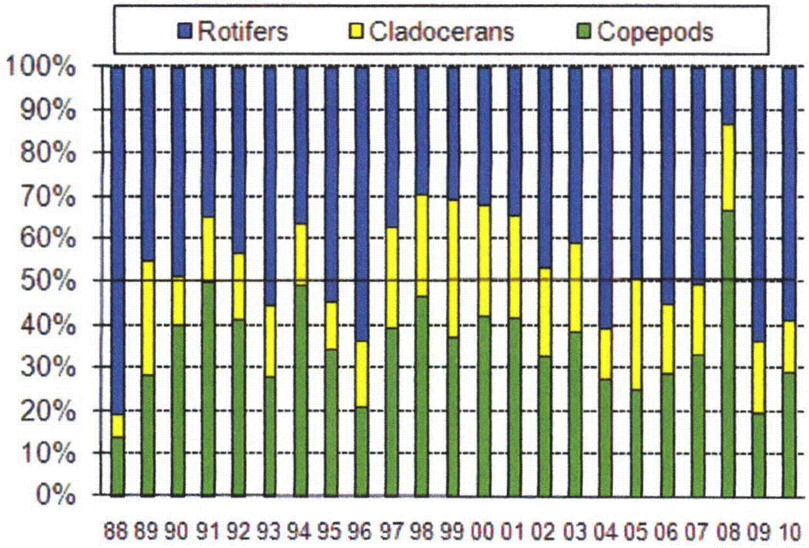

Background Locations

Figure 4-6. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the fall periods of 1987 – 2010 (clear data points represent seasonal maxima).

Mixing Zone: Epilimnion



Mixing Zone: Whole-column

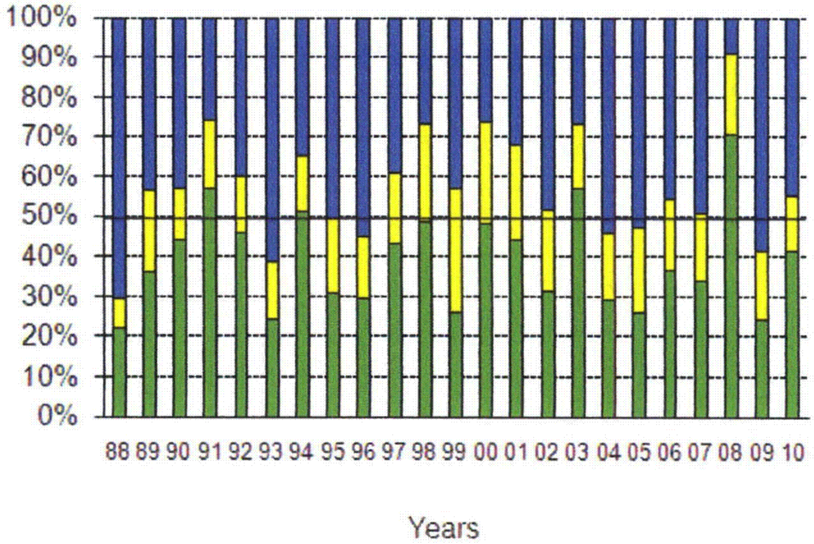


Figure 4-7. Annual percent composition of major zooplankton taxonomic groups from mixing zone locations (Locations 2.0 and 5.0 combined) during 1988 – 2010 (Note: does not include Location 5.0 in the fall of 2002 or winter samples from 2005).

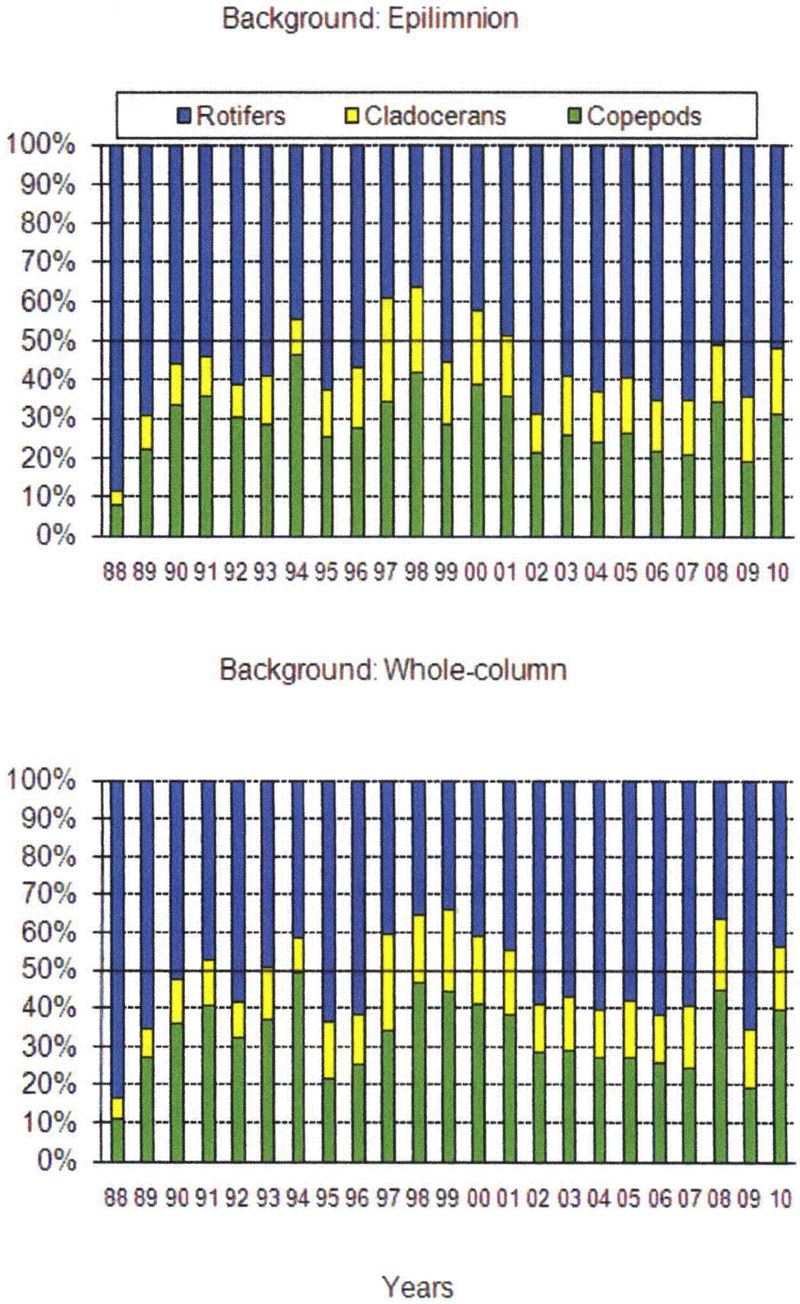


Figure 4-8. Annual percent composition of major zooplankton taxonomic groups from background locations (Locations 9.5, 11.0, and 15.9 combined) during 1988 – 2010 (Note: does not include winter samples from 2005).

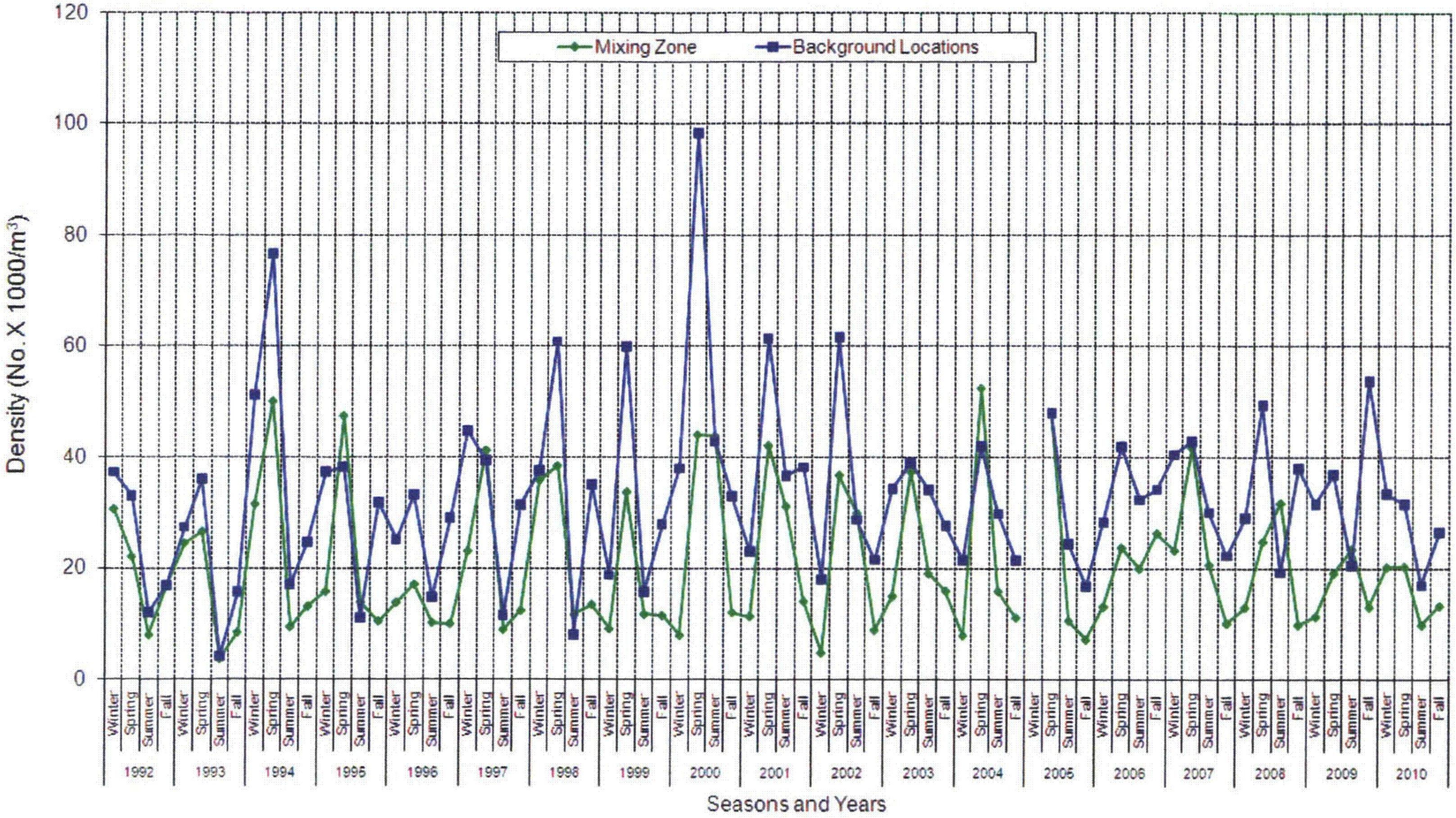


Figure 4-9. Copepod densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2010 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

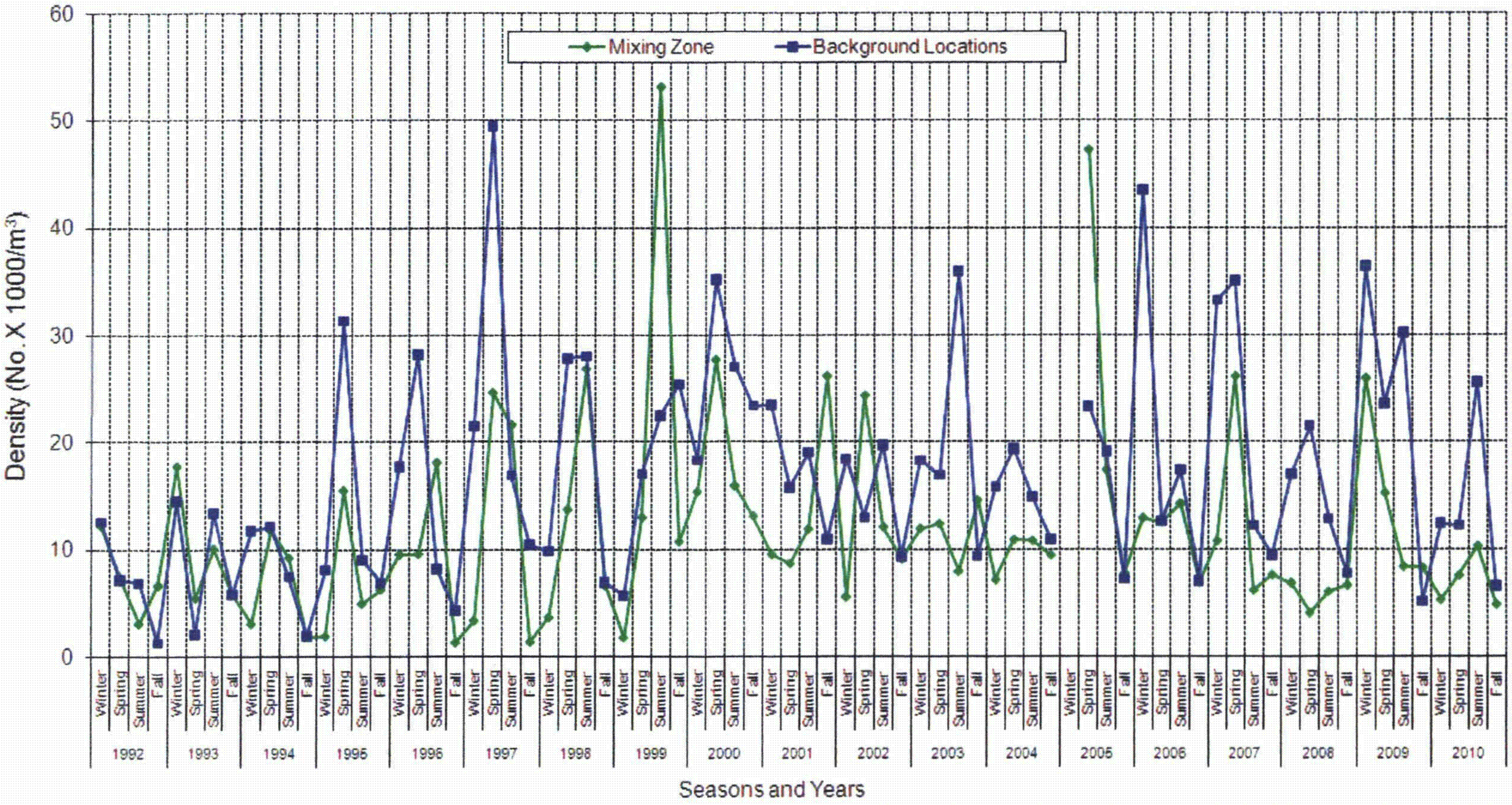


Figure 4-10. Cladoceran densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2010 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

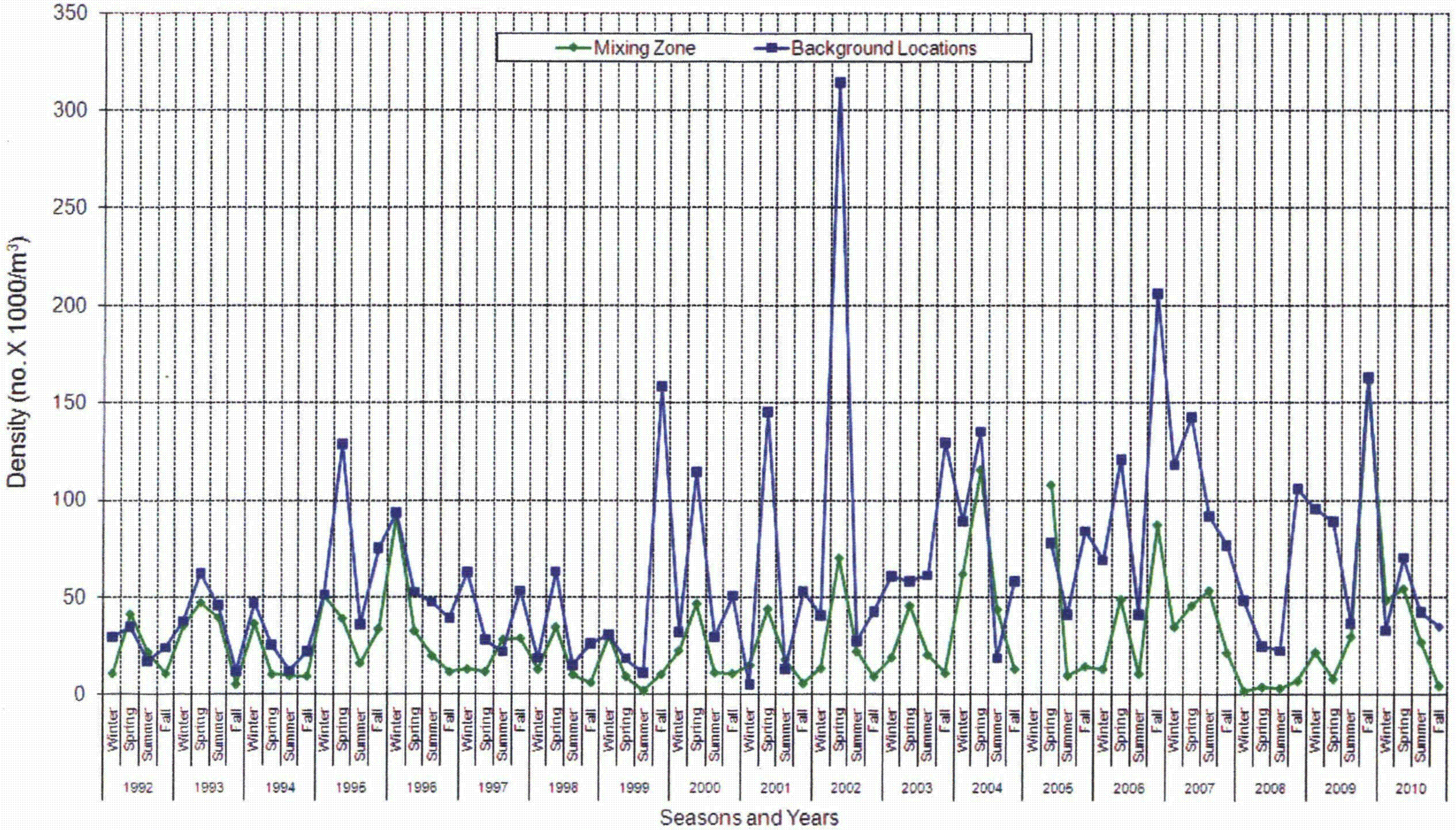


Figure 4-11. Rotifer densities during each season of each year among epilimnetic samples collected in Lake Norman from 1990 – 2010 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

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 (DE) personnel monitored specific fish population parameters in Lake Norman during 2010. The components of this program were:

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

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 spotted bass and largemouth bass, where total length (TL, mm) and weight (g) were obtained for each individual collected. Catch per unit effort (number of individuals/3,000 m and kg/3,000 m) and the number of species were calculated for each sampling area. Sagittal otoliths were removed from all black bass $\geq$ 125 mm and sectioned for age determination (Devries and Frie 1996). Black bass $<$ 125 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 $\geq$150 mm long, using the formula $W_r = (W/W_s) \times 100$, where W = weight of the individual fish (g) and W_s = length-specific mean weight (g) for a fish as predicted by a weight-length equation for each species (Anderson and Neumann 1996). Growth rates (age 2 to 6 years) were compared between species and among areas with analysis of variance ($\alpha = 0.05$) and Tukey's pairwise comparison (Analytical Software 2008).

Fall ElectrofishingYoung-of-Year Bass Survey

An electrofishing survey was conducted in November at the same three areas (MSS, REF, MNS) as the spring survey and consisted of five 300-m shoreline transects at each area. Again, shallow flats where the boat could not access within 3 to 4 m of the shoreline were excluded. Stunned black bass were collected by two netters, identified to species, and individually measured and weighed. 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 weekly during July and August to specifically search for dead or dying striped bass in Zones 1 to 4. All observed dead striped bass were collected and a subsample (n = 145) of individual TL was measured prior to disposal.

Striped Bass Netting Survey

Striped bass were collected for age, growth, and condition determinations in December by DE and NCWRC personnel. 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 total lengths and weights 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. An annual mobile hydroacoustic survey of the lake was conducted in mid-September with multiplexing, side- and down-looking transducers to detect surface-oriented fish and deeper fish (from 2.0 m depth to the bottom), respectively.

Annual purse seine samples were also collected in mid-September from the 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 2010 electrofishing resulted in the collection of 6,626 individuals (26 species and two centrarchid hybrid complexes) weighing 353.87 kg at average water temperatures ranging from 18.9 to 19.5 °C (Table 5-1). Bluegill *Lepomis macrochirus* dominated samples numerically while spotted bass dominated samples gravimetrically. The survey consisted of 1,518 individuals (17 species and two centrarchid hybrid complexes) in the MSS area, 2,317 fish (19 species and two centrarchid hybrid complexes) in the REF area, and 2,791 individuals (18 species and two hybrid centrarchid complexes) in the MNS area (Figure 5-2). There is no apparent temporal trend in the number of individuals collected within or among areas since 1993.

Total biomass of fish in 2010 was 150.47 kg in the MSS area, 118.38 kg in the REF area, and 85.02 kg in the MNS area, following the spatial trend of previous years. 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 5-3) and, in 2010, were most abundant in the REF area, intermediate in the MSS area, and least abundant in the MNS area. Spotted bass biomass showed the same spatial heterogeneity trend as overall biomass and was highest in the MSS area, intermediate in the REF area, and lowest in the MNS area. In 2010, 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 72.5 for fish 200 to 249 mm in the MNS area to 86.2 for fish ≥ 450 mm also in the MNS area (Figure 5-5a). Overall, spotted bass (≥ 150 mm) mean W_r values were highest in the MSS area (78.8), intermediate in the REF area (78.1), lowest in the MNS area (76.5), and within the range of observed historical values (71.4 to 82.3) (Duke Power unpublished data, 2004a, and 2005; Duke Energy 2006, 2007, 2008, 2009, and 2010).

The number of individuals and biomass of largemouth bass from all areas in 2010 were low and similar to 2006 – 2009 data, signifying a downward trend (Figure 5-6a and b). As in most years, 2010 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 69.1 for a single fish 200 to 249 mm in the MNS area to 100.5 for a single fish ≥ 450 mm in the REF 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 REF area (89.4), intermediate in the MSS areas (86.6), and lowest in the MNS area (80.2), and within the range of observed historical values (76.0 to 89.9; Duke Power unpublished data, 2004a, 2005; Duke Energy 2006, 2007, 2008, 2009, 2010).

Largemouth bass numbers in 2010 were inadequate for growth rate comparisons with spotted bass or with previous years of largemouth bass data (Tables 5-2 and 5-3). Spotted bass in 2010 showed a higher mean TL at all ages in the MNS area, although the highest mean TL by age varied among areas in previous years. Spotted bass growth for all areas was fastest through age 3 and slowed with increasing age. Although the largemouth bass population parameters have decreased sharply since the introduction of spotted bass, a causal effect, although likely, is indeterminate due to possible confounding effects of other introduced species, including alewife *Alosa pseudoharengus* and white perch *Morone americana* (Kohler and Ney 1980 and Madenjian et al. 2000).

Fall Electrofishing Young-of-Year Black Bass Survey

Fall 2010 electrofishing resulted in the collection of 118 spotted, 15 largemouth, and 1 hybrid black bass young-of-year (< 150 mm), showing an overall decrease in the number of young-of-year black bass compared to 2008 – 2009 (Figure 5-7). As in 2005 – 2009, young-of-year black bass numbers were highest in the MSS area.

Summer Striped Bass Mortality Surveys

In 2010, a total of 6,996 dead striped bass were collected, representing the largest recorded die-off of this Lake Norman sport fish species. Striped bass TL varied (448-685 mm) with a mean of 579 mm. Most fish were collected from Zone 1 during July and August surveys (Figure 5-8). Although many mortalities (n = 280) from July 14 to 24 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), numbers were indeterminate. Fish mortalities thereafter were associated with the elimination of preferred striped bass habitat in the hypolimnion, corresponding with that time period between July 19 and July 26 when the last remaining pocket of preferred striped bass habitat disappeared (see

Chapter 2 including Figure 2-11). That time interval can be narrowed further as additional water quality profiles at Location 1.0 (Figure 2-1) on July 21, 22, and 23 (Duke Energy, unpublished data) measured maximal hypolimnetic DO concentrations > 2.0 mg/L while the profile on July 26 (maximal hypolimnetic DO concentrations = 1.8 mg/L) was the first < 2.0 mg/L. 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 occurred in 1983 (163), 2004 (2,609), and 2009 (362).

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 5-5). 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 (n = 105) collected in mid to late December 2010 ranged in TL from 274 to 660 mm and were dominated by age 1 and 2 fish (Figure 5-9). Striped bass growth was fastest through age 4 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 (90.2) and declined thereafter. Mean W_r was 86.1 for all striped bass in 2010, slightly above the range of observed historical values (78.5 to 85.8). However, the predominance of age 1 and 2 striped bass collected in 2010 diminishes the value of this comparison. Growth in 2010 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, and 2010).

The December striped bass gillnetting also yielded 145 catfish. Blue catfish *Ictalurus furcatus* (117) dominated the catch and ranged in length from 324 to 755 mm. Flathead catfish *Pylodictis olivaris* (17) and channel catfish *I. punctatus* (11) were less numerous and ranged in length from 382 to 703 mm and 272 to 524 mm, respectively.

Fall Hydroacoustics and Purse Seine Surveys

Mean forage fish densities in the six zones of Lake Norman ranged from 1,448 (Zone 1) to 8,697 (Zones 5 and 6) fish/ha in September 2010 (Table 5-4). 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 2010 was approximately 53.0 million fish, the second lowest population estimate 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 2010 (95.4%), similar to surveys since 1993 (Table 5-6). The modal length class of threadfin shad collected in 2010 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 – 2010 (range = 1.7 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 2010. Spring electrofishing indicated that 17 to 19 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 2010 were generally similar to those noted annually since 1993. Collections were numerically and gravimetrically dominated by centrarchids. Largemouth bass number of individuals was the lowest recorded since sampling began in 1993, although biomass increased slightly from 2009. Spotted bass, adults and young-of-year, number of individuals and biomass continue to increase, 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 2010, striped bass mortalities (6,996) during summer stratification were the highest number ever collected, ranging in TL from 448 to 685 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, and 2010), 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 number of this stocked sport fish species. It should be noted that preferred striped bass habitat has never existed in Lake Norman since summer 1983.

Winter mean W_r (86.1) of striped bass was slightly higher than in previous years although dominated by age 1 and 2 fish. Hydroacoustic sampling estimated a forage fish population of approximately 53.0 million in 2010, the second lowest estimate since surveys began in 1997. Alewife percent composition in fall purse seine surveys was 4.3% 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, and 2010). 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, March/April 2010.

		MSS		REF		MNS		Total	
Scientific Name	Common Name	No.	Kg	No.	Kg	No.	Kg	No.	Kg
Lepisosteidae									
Lepisosteus osseus	Longnose gar			1	1.92			1	1.92
Clupeidae									
Alosa pseudoharengus	Alewife			1	0.01			1	0.01
Dorosoma cepedianum	Gizzard shad	15	5.71	29	14.10	7	3.81	51	23.62
Dorosoma petenense	Threadfin shad			6	0.09	6	0.05	12	0.14
Cyprinidae									
Cyprinella chloristia	Greenfin shiner			20	0.05	7	0.02	27	0.07
Cyprinella nivea	Whitefin shiner			2	0.01	2	0.01	4	0.02
Cyprinus carpio	Common carp	11	29.21	4	8.65	4	12.67	19	50.53
Notemigonus crysoleucas	Golden shiner	1	0.01					1	0.01
Notropis hudsonius	Spottail shiner					26	0.27	26	0.27
Catostomidae									
Carpiodes cyprinus	Quillback	1	1.17			1	1.13	2	2.30
Moxostoma rupiscartes	Striped jumprock	1	0.02					1	0.02
Ictaluridae									
Ameiurus nebulosus	Brown bullhead			1	0.30			1	0.30
Ictalurus punctatus	Channel catfish	7	2.56	11	3.78	2	0.96	20	7.30
Pylodictis olivaris	Flathead catfish	3	0.19	12	0.70	10	0.81	25	1.70
Moronidae									
Morone americana	White perch	10	1.67			11	0.57	21	2.25
Morone saxatilis	Striped bass	2	2.81	1	1.96			3	4.77
Centrarchidae									
Lepomis auritus	Redbreast sunfish	80	2.12	240	4.64	439	7.63	759	14.39
Lepomis cyanellus	Green sunfish	54	1.19	295	3.89	4	0.11	353	5.19
Lepomis gulosus	Warmouth	7	0.08	39	0.71	76	0.93	122	1.72
Lepomis hybrid	Hybrid sunfish	26	0.77	63	1.50	82	2.12	171	4.38
Lepomis macrochirus	Bluegill	893	13.73	1,245	17.54	1,873	20.46	4,011	51.73
Lepomis microlophus	Redear sunfish	109	10.21	65	5.45	45	4.84	219	20.49
Micropterus punctulatus	Spotted bass	224	47.03	254	41.27	179	19.99	657	108.30
Micropterus salmoides	Largemouth bass	45	22.73	18	8.92	12	6.48	75	38.14
Micropterus hybrid	Hybrid black bass	28	9.24	8	2.23	4	2.16	40	13.63
Pomoxis nigromaculatus	Black crappie			2	0.67			2	0.67
Percidae									
Etheostoma olmstedi	Tessellated darter					1	0.00	1	0.00
Perca flavescens	Yellow perch	1	0.01					1	0.01
Total		1,518	150.47	2,317	118.38	2,791	85.02	6,626	353.87
Total No. Species		17		19		18			
Mean Water Temperature (° C)		18.9		19.1		19.5			

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, March/April 2010.

		Age (years)									
Taxa	Area	1	2	3	4	5	6	7	8	9	12
Spotted bass	MSS	170	236	344	386	412	432		441		
	REF	133	230	342	381	404	433	444	435		
	MNS	174	259	350	391	422		496			
	Mean TL (mm)	**159**	**242**	**345**	**386**	**413**	**432**	**470**			
Largemouth bass	MSS	197	293	361	361	426	431	338	363	419	451
	REF	172	298	348		414		524	435		
	MNS	193	232		400	405	435				
	Mean TL (mm)	**187**	**274**	**354**	**380**	**415**	**433**	**431**	**399**	**419**	

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 2010, 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	197	293	361	361
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	172	298	348	-
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	193	232	-	400

[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

Table 5-4. Lake Norman forage fish densities (No./ha) and population estimates from September 2010 hydroacoustic survey.

Zone	No./ha	Population estimate
1	1,448	3,302,712
2	3,480	10,724,201
3	4,214	14,560,639
4	1,564	1,925,433
5	8,697	18,316,501
6	8,697[a]	4,157,307
Lakewide total		52,986,793
95% CI		47,964,444 – 58,009,141

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

Table 5-5. Number of individuals (No.), percent composition of forage fish, and threadfin shad modal TL class collected from purse seine surveys in Lake Norman during late summer/fall, 1993 – 2010.

		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

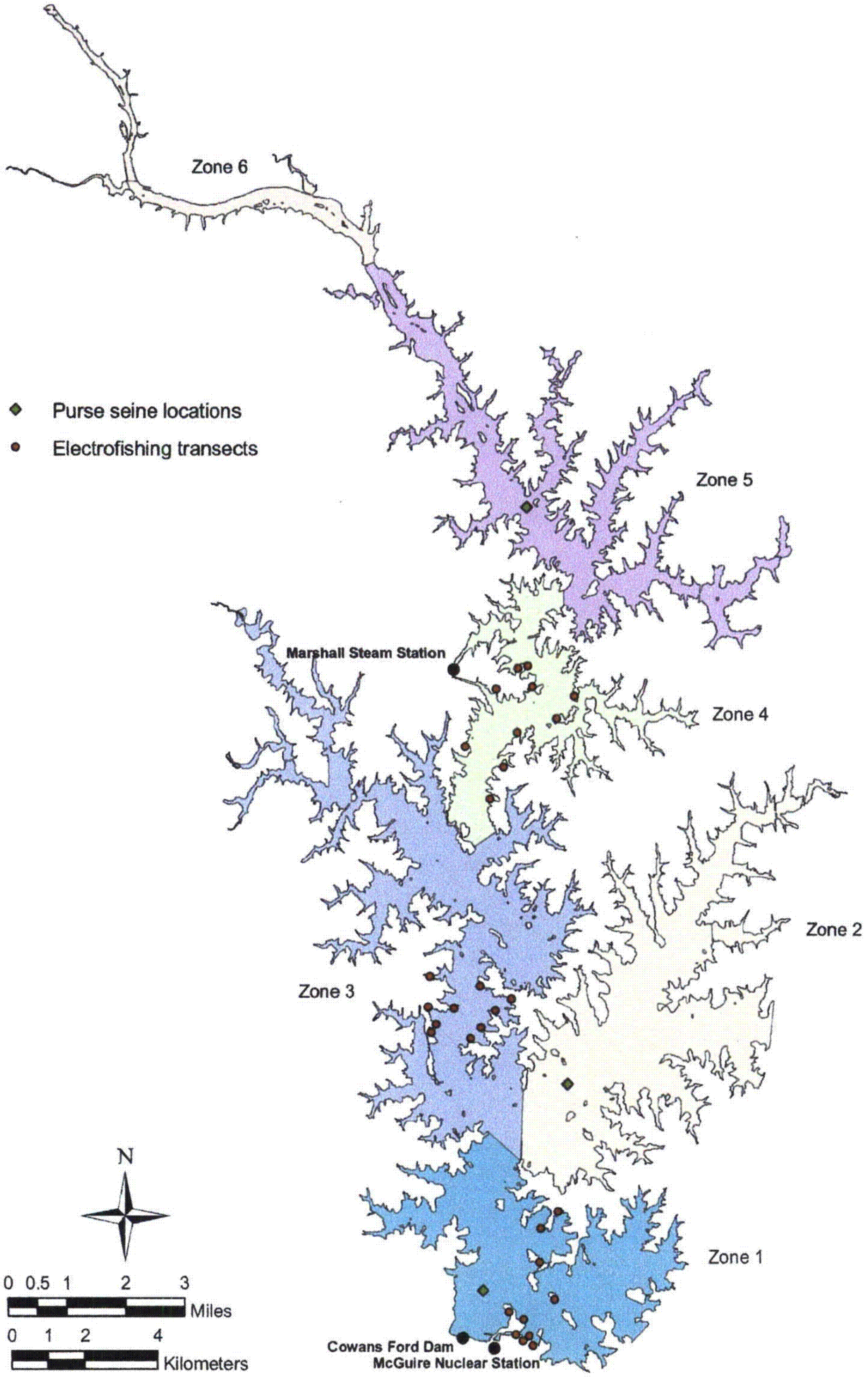


Figure 5-1. Sampling locations and zones associated with fishery assessments in Lake Norman.

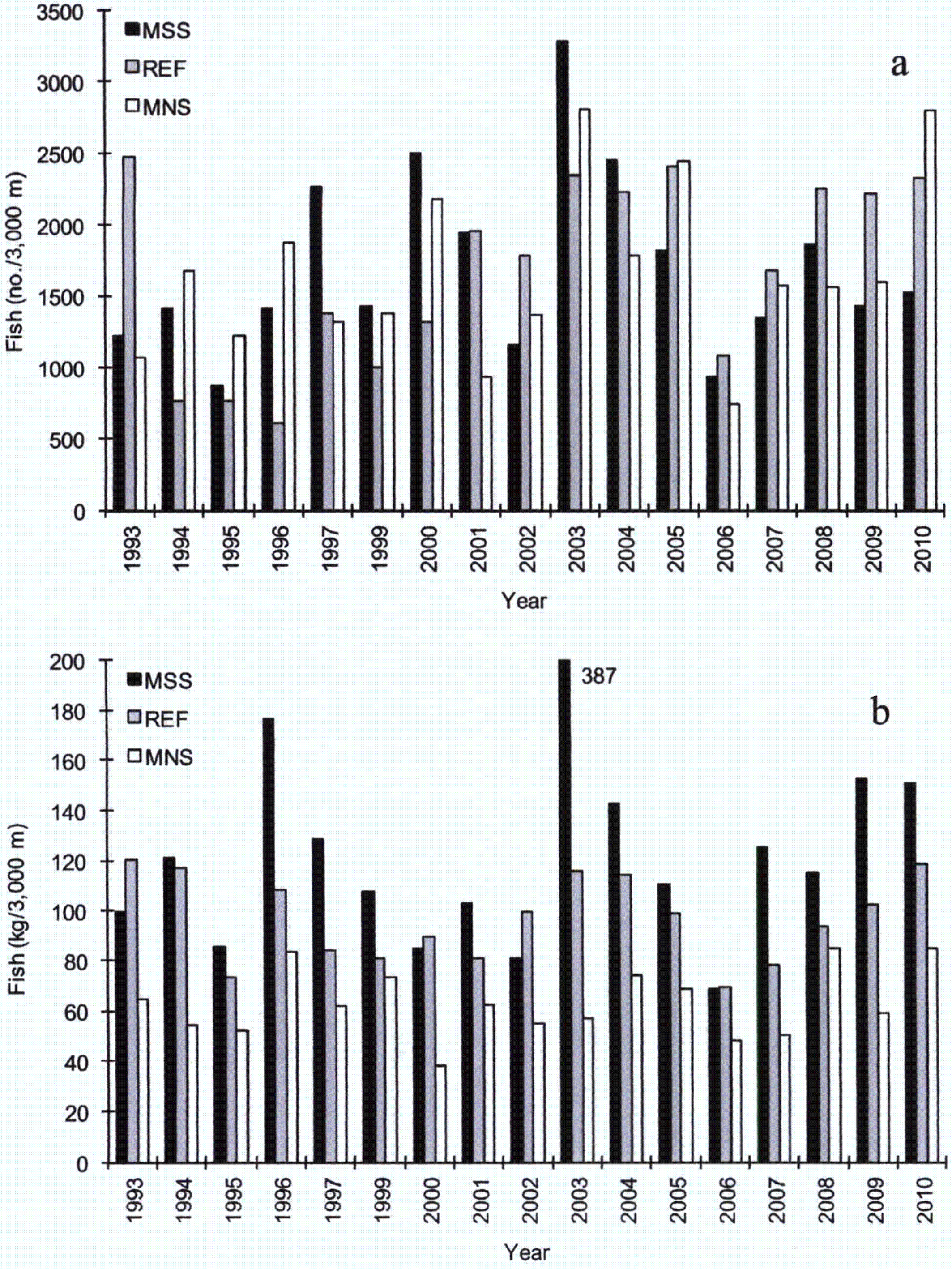
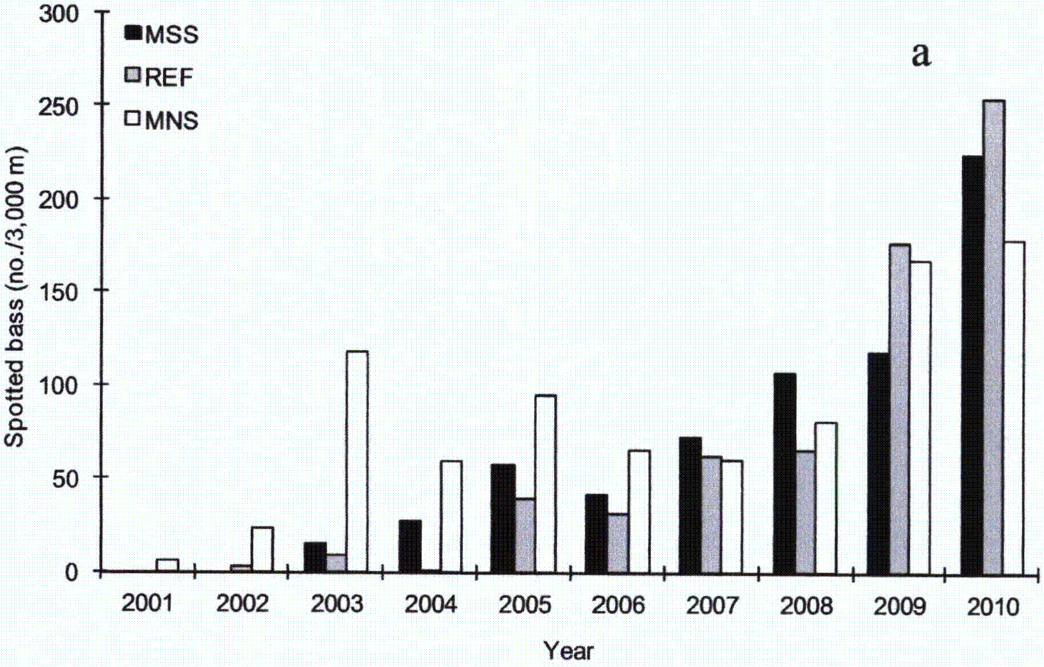


Figure 5-2. Number of individuals (a) and biomass (b) of fish collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2010.



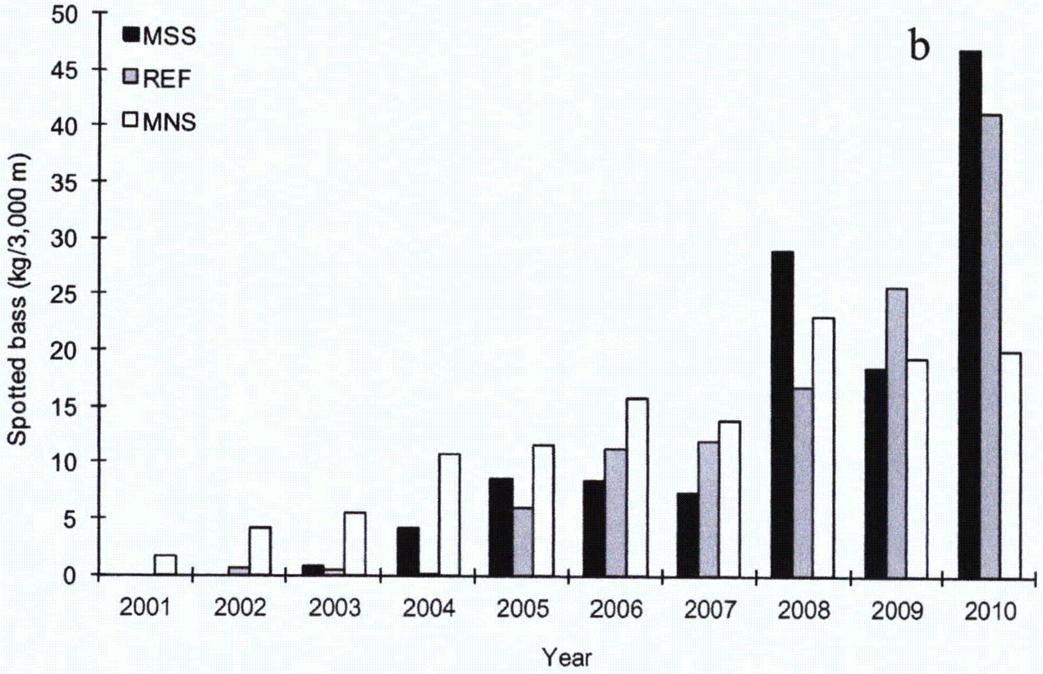


Figure 5-3. Number of individuals (a) and biomass (b) of spotted bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 2001 – 2010.

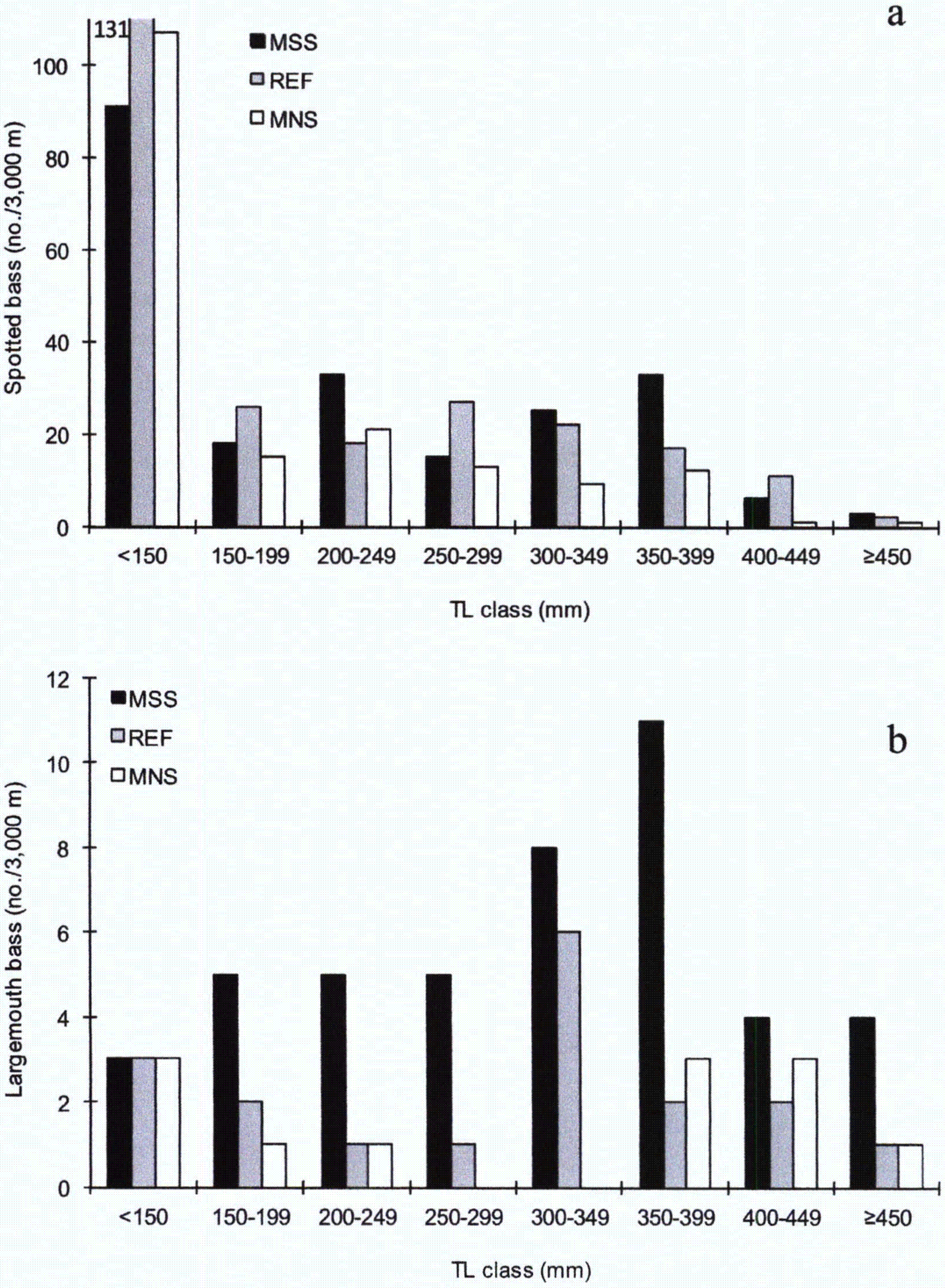


Figure 5-4. Size distributions of spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2010.

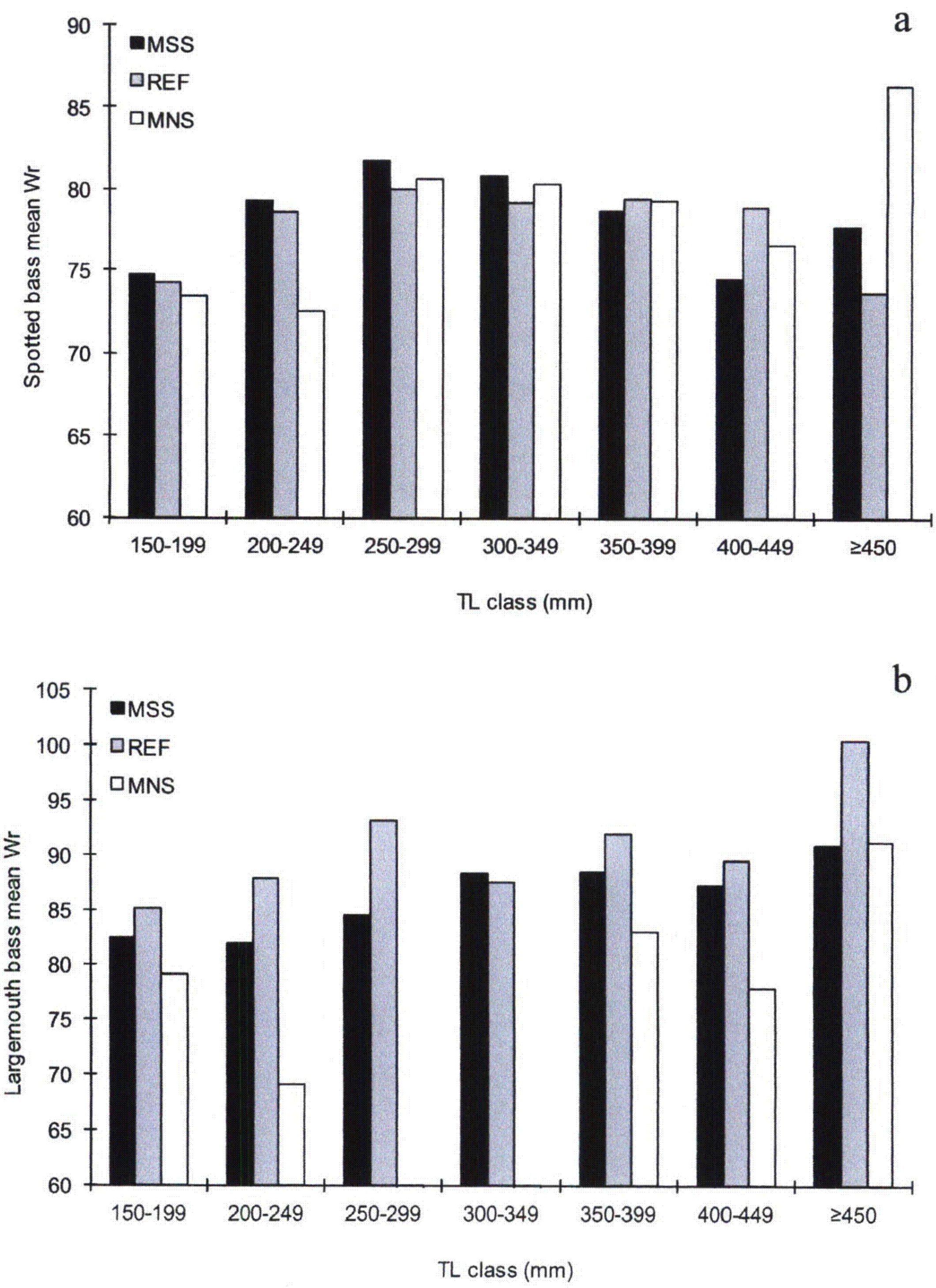


Figure 5-5. Condition (Wr) for spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, April 2010.

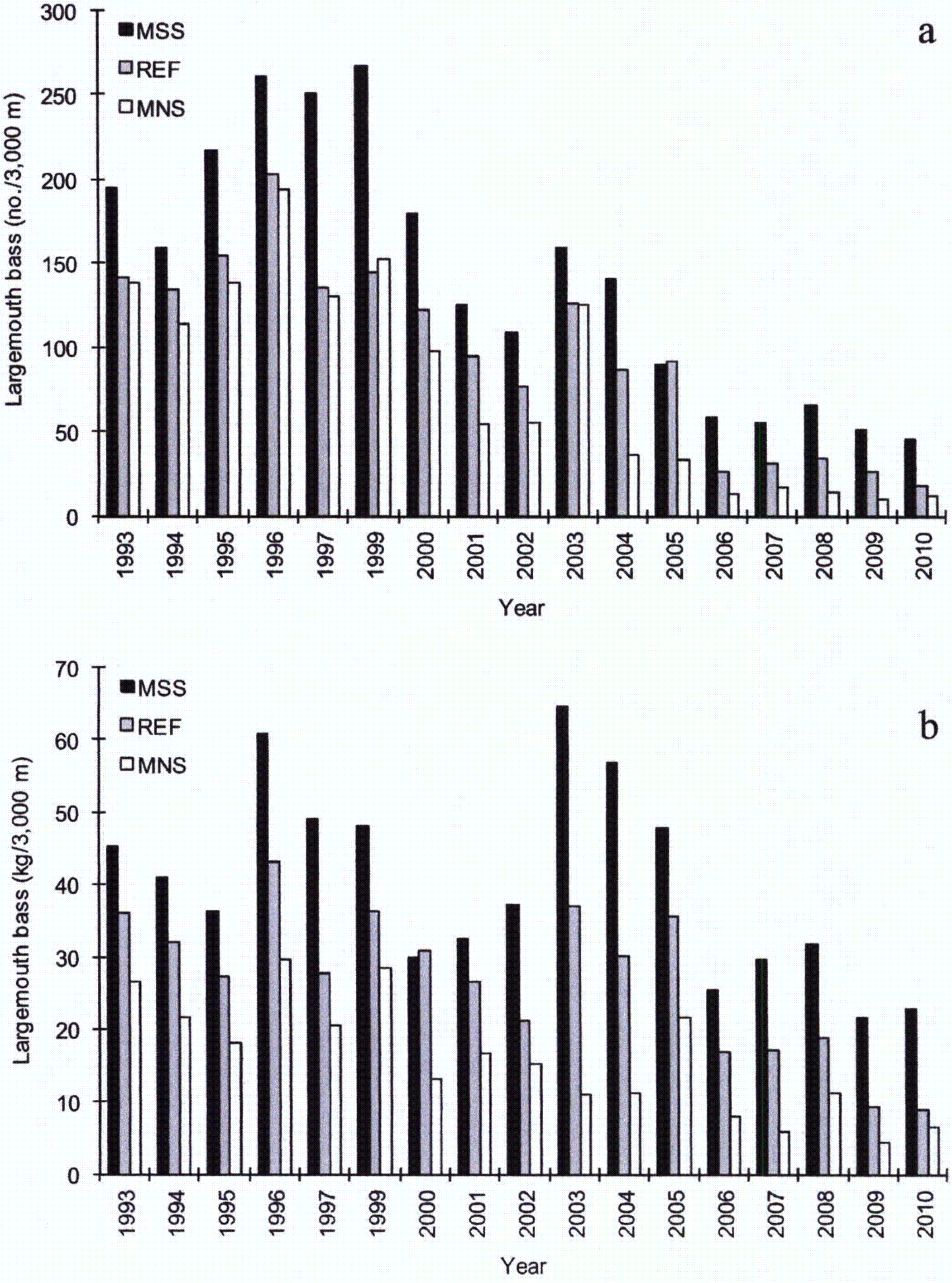


Figure 5-6. Number of individuals (a) and biomass (b) of largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, March/April 1993 – 1997 and 1999 – 2010.

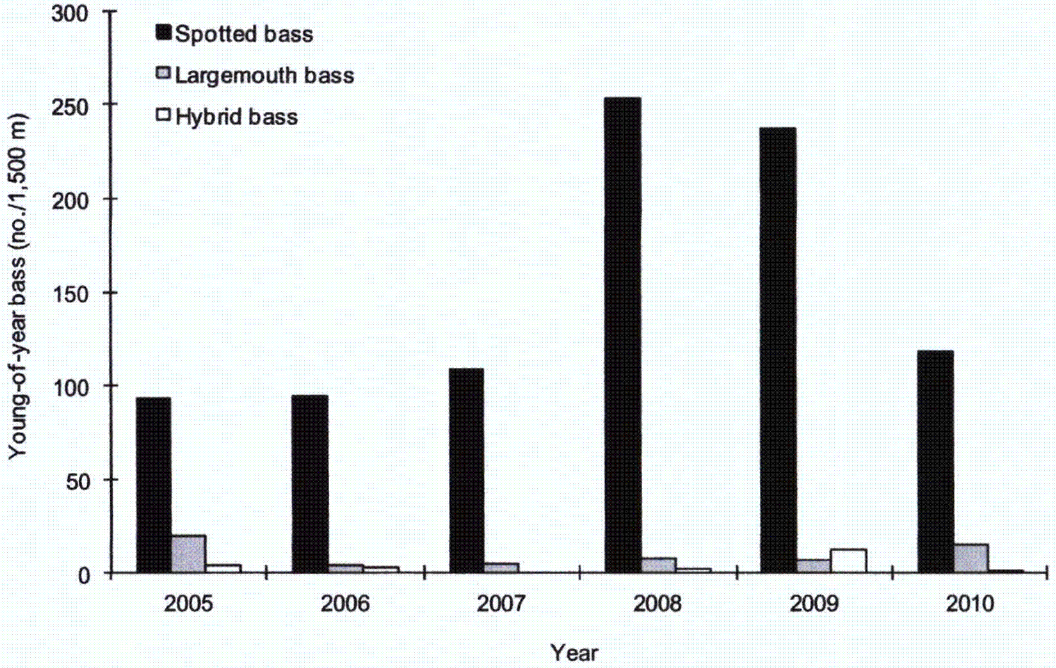


Figure 5-7. Number of young-of-year black bass (< 150 mm) collected from electrofishing five 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, November 2005 – 2010.

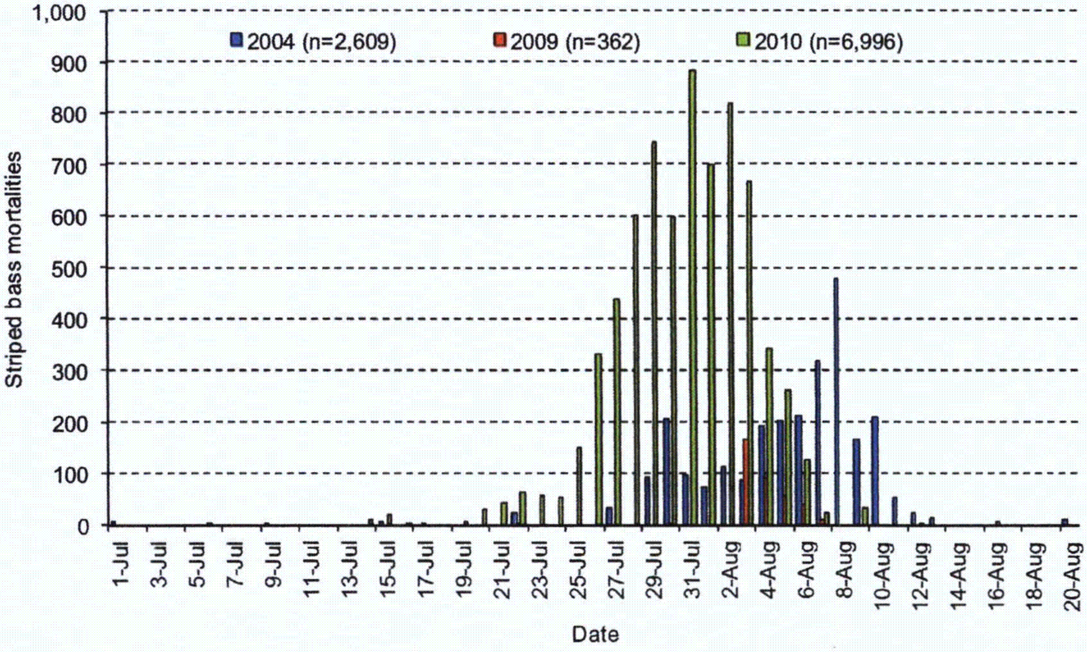


Figure 5-8. Number of striped bass mortalities by date in July/August 2004, 2009, and 2010.

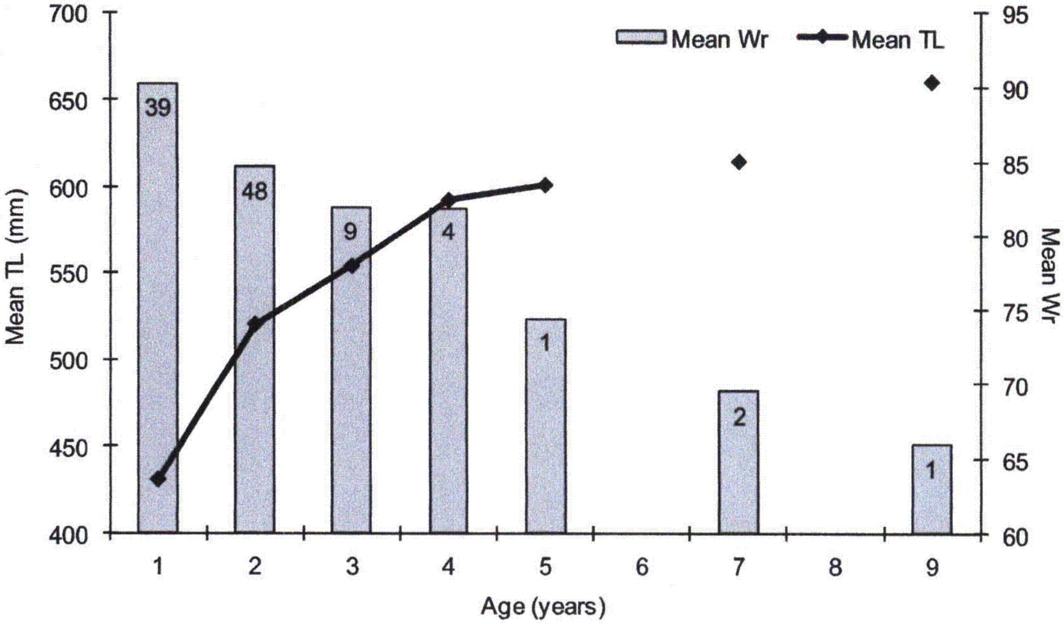


Figure 5-9. Mean TL and condition (Wr) by age of striped bass collected in Lake Norman, December 2010. Numbers of fish by age are inside bars.

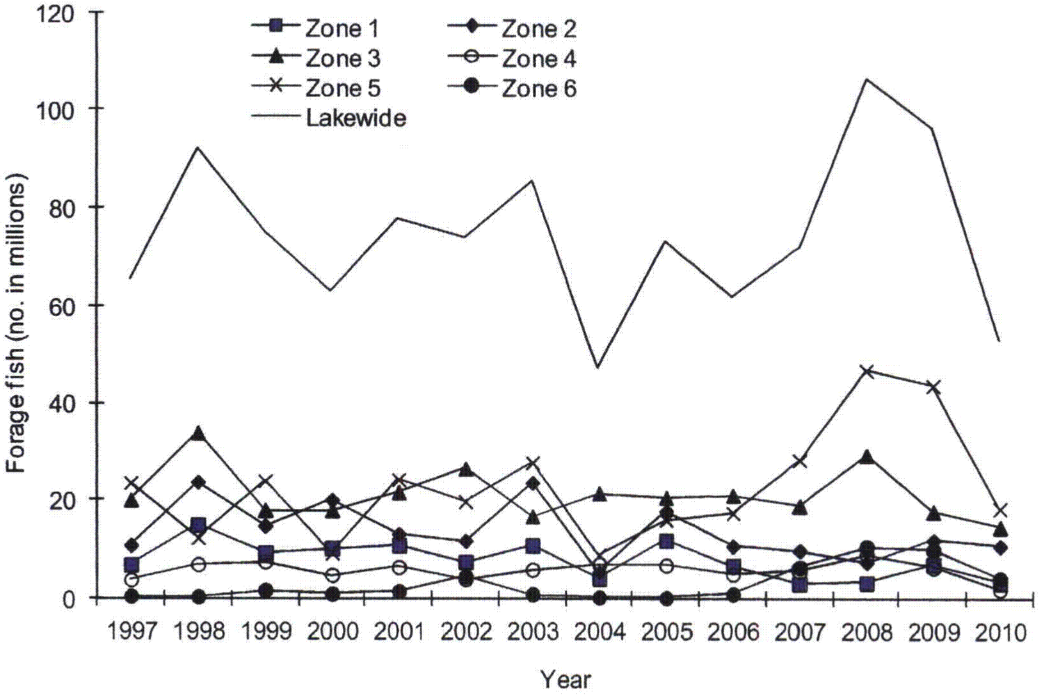


Figure 5-10. Zonal and lake-wide population estimates of pelagic forage fish in Lake Norman, September 1997 – 2010.

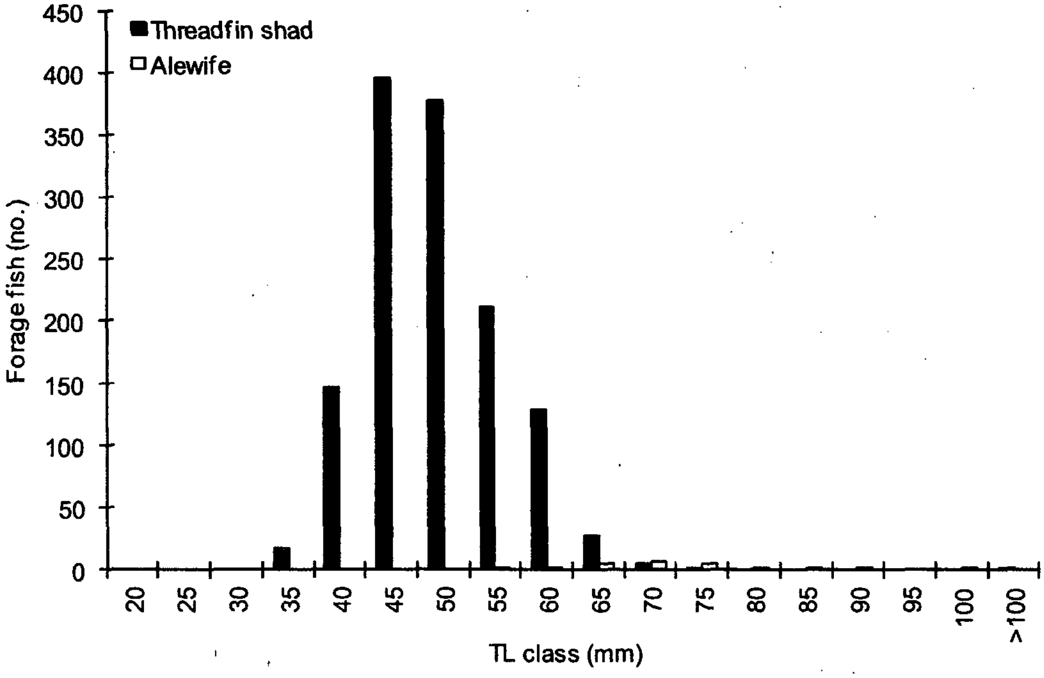


Figure 5-11. Number of individuals and size distribution of threadfin shad and alewife collected from purse seine surveys in Lake Norman, September 2010.

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