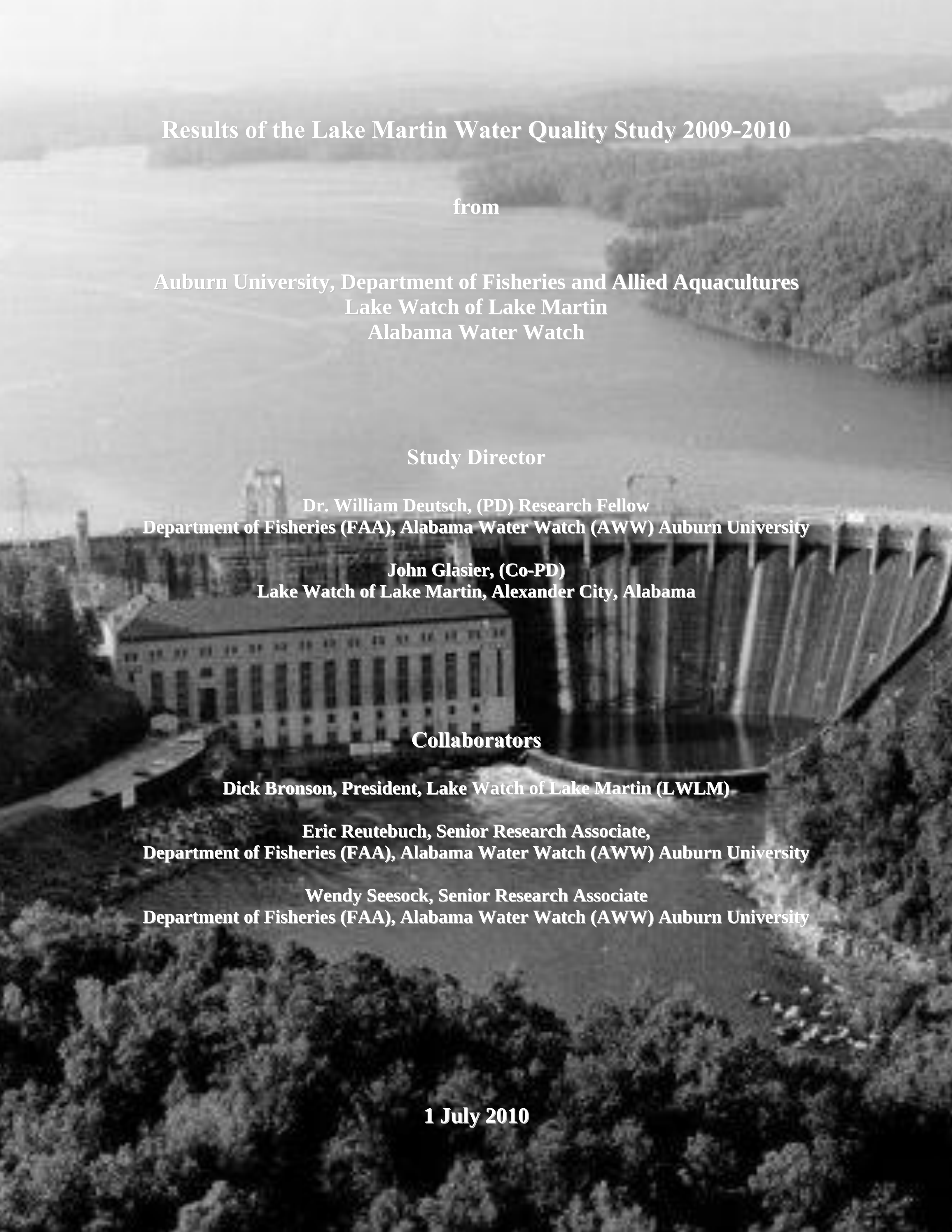

Results of the Lake Martin Water Quality Study 2009-2010

from

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I. STUDY DESCRIPTION

A. INTRODUCTION

Goals and Objectives

The overall goal of the study was to provide baseline water quality/nutrient data for Lake Martin, particularly in areas where historic sampling efforts have not been as intensive as mainstream sampling, which could be used by Alabama Power in its relicensing of the Martin Hydroelectric Project. Additional tributary embayment sampling was emphasized, but historic mainstream sites were included for comparison and trophic state value. The initial plan was to sample beginning in April 2009 and continue through October 2009. However, additional sampling during the winter months was deemed beneficial in light of above normal rainfall during the growing season and the resultant high water levels in the lake. This provided a year long study which included the winter months on the reservoir. Little historic data exist for comparison during this time of year. Collection of adequate baseline data which included the winter months was thought to be helpful in evaluating potential rule curve or operation changes for Lake Martin that may be implemented as a result of relicensing. These research activities resulted in this comprehensive assessment of nutrient concentrations and trophic state in both tributary embayments and mainstream reservoir sites. The effort to quantify nutrient inputs in Lake Martin, using Standard Methods of field and laboratory analyses in collaboration with citizen volunteers, had wide support. This study built upon earlier partnerships developed during the Tallapoosa River Watershed Project (TWP) which assessed nutrient impacts and land use and compared low-tech and high-tech methods of sampling (Reutebuch et al 2005).

Need for the Study

Nutrient and sediment loading of surface waters from both point and nonpoint sources have been identified as major problems in the United States, and agricultural activities were reported to be responsible for more than 60% of surface water pollution (EPA 1990). Addressing nutrient and sediment pollutants in Alabama via research and public education is especially important because these pollutants are increasing problems in many areas. Surface water pollutants of special concern in Alabama are nonpoint sources of organic enrichment and siltation from poultry operations, forest clear cuts and livestock operations (ADEM 1994).

Because of the relative importance of nonpoint sources of pollution, pollution abatement has shifted to a watershed management approach (Browne 1981). The Alabama Department of Environmental Management (ADEM) has developed a watershed management strategy (McIndoe 1996) as a means of dealing with these nonpoint sources of pollution. ADEM has also been in the process of adopting nutrient standards for reservoirs throughout the state in an effort to limit these sources of pollution. Standards are set for mainstream sections of public reservoirs in the state and data exists primarily at these locations, unless water quality problems exist on a particular tributary or its watershed. ADEM established chlorophyll *a* standards for Lake Martin at three locations in May 2002. During the current FERC relicensing process some operational changes have been proposed for the lake, such as a higher winter rule curve and/or longer "full-pool" season (see Martin Study Plan 12A). As part of that relicensing process, additional water quality/nutrient data was needed from tributary embayments to address questions relating to potential changes in project operations and their possible impact on current water quality and nutrient levels in Lake Martin.

Lake Martin is located on the Tallapoosa River in east-central Alabama and is the largest reservoir in the Tallapoosa Basin (Appendix Figure 1). It is typical of southeastern hydropower reservoirs in terms of hydrology, lake morphometry, and operation. The Tallapoosa River originates in west Georgia, about 30 miles west of metro-Atlanta, and flows southwest through Alabama to join the Coosa River near the state capital, Montgomery. According to ADEM (2003) the potential for nutrient enrichment is the primary water quality threat to Lake Martin in the Tallapoosa River Watershed. Sources and relative amounts of nutrients entering the watershed are poorly understood. Data indicate that from the mid 1980's there has been a trend of increasing eutrophication in the upper portion of Lake Martin. Results of a 2004 Auburn University (AU) study also indicated that this trend of upstream eutrophication is generally continuing, which may be explained in part by a decline in forest land and an increase in urban, barren and agricultural lands in the upper and middle Tallapoosa watersheds (Reutebuch et al 2007). More recent data collected during the drought of 2007 indicated that the lake trophic state declined, dropping into the mesotrophic range upstream and into the oligotrophic category at the most downstream site (ADEM 2008). Regardless of meteorological conditions, the watershed is expected to continue to experience rapid population growth and development because of its importance for tourism, water recreation and commercial real estate development.

Mainstream inflows from the upper reaches of the watershed and smaller tributary inflows from subwatersheds contiguous to the lake are the principal delivery means for nonpoint source nutrients. Tributary embayments around the lake comprise complex lake morphologies that are differentially influenced by nutrient loading and the contingent physical, chemical, and biological conditions for eutrophication. Chlorophyll *a* concentrations are an important indicator of the effects of nutrients, as well as the lake trophic state; AU data (unpublished) and the results of the 2007-2008 Rule Curve Variance (APCO) water quality study indicate that chlorophyll *a* values often remained high during winter months under certain conditions.

B. OBJECTIVES

Research Objective

To provide baseline water quality data by using Standard Methods (APHA 1998) to assess nutrient dynamics in Lake Martin at historic mainstem sites as well as tributary embayment locations. (Appendix Figure 1)

C. MATERIALS AND METHODS

Research

AU coordinated research conducted by university personnel with citizen study partners, Lake Watch of Lake Martin (LWLM), and Lake Martin Home Owners/Boat Owners Association (HOBOs) who provided boat transportation to sites on the lake. AU/AWW conducted water sampling and analyses according to Standard Methods. A map and list of station locations are presented in the Appendix Figure 1 and Table 1, respectively. Variables and methods utilized are located in Appendix Table 2. The sixteen stations on Lake Martin were sampled for nutrients, sediments and chlorophyll *a*. Sample stations were distributed among major embayments as well as along the mainstream of the reservoir. Samples were collected monthly at mid-channel locations: at 16 stations during the growing season (April-October 2009) and at 8 stations during the winter season (November 2009-March 2010). At each lake and embayment sampling station, temperature, dissolved oxygen and pH were measured *in situ* at the surface (0.5 m), and temperature and dissolved oxygen were also measured at a depth of 5 ft or approximately at ADEM regulatory depth of 1.5 m. Secchi disk visibility was measured and the photic zone depth (1% incident light) was determined through the calculated relationships of Secchi depth, station and date from historic Lake Martin data. A submersible electric pump and hose apparatus was raised and lowered throughout the photic zone and water was collected in plastic containers onboard boat. Aliquots of this composite sample were poured into Nalgene® bottles (some containing preservative for total phosphorus analyses) and stored on ice in the dark during transport to laboratory facilities at AU. Water quality variables measured from collected samples included corrected chlorophyll *a*, total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), turbidity, total suspended solids (TSS), total alkalinity, total hardness and specific conductance. . The Trophic State Index (Carlson 1977) was calculated using mean corrected chlorophyll *a* values for the 2004 and 2009 growing seasons. Samples were split with Alabama Power on the first sample date as part of QA/QC procedures.

D. RESULTS AND DISCUSSION

Water quality and quantity are both affected by meteorological conditions. Weather data for the 2004-2005 and the 2009-2010 study periods are shown in Appendix Table 3. Temperatures during the 2004 growing season were average, while temperatures during 2009-2010 were lower than normal, particularly during the winter months. During 2004 rainfall amounts were lower than normal from April through July and higher than normal during August and September. Mean monthly rainfall during the growing season of 2009 was much higher than normal with the exception of the months of April and June. Yearly totals were about average during 2004 and above average for 2009-2010. Higher than normal rainfall measured during the 2009 growing season led to additional sampling at selected stations during the winter season. Total solar radiation values measured during the two study periods were similar.

In situ growing season 2009

Growing season mean *in situ* values are presented in Appendix Table 4. Water temperature (mean values measured at 5 ft.) during the growing season ranged from a low of 26.0° C at both stations 15 (Coley Creek) and 16 (Tallapoosa River above Coley Creek), to a high of 27.8° C at station 12 (Elkahatchee Creek below Abbott Hwy Bridge). Mean temperatures measured at 0.5 m ranged from 26.5° C at station 3 (Big Kowaliga Creek at Castaway Island), to a high of 28.5° C at stations 12 and 14 (mainstream at Hwy 280 bridge).

Mean values for dissolved oxygen (Appendix Figure 2), also measured at 5 ft, ranged from a low of 7.2 mg/l at station 5 (Blue Creek at Stillwaters Marina) to a high of 9.0 mg/l at station 15. No values below 5 mg/l were recorded at any station during the study.

Values for pH measured at the surface (0.5m) ranged from lows of 6.6 at stations 1(Big Kowaliga at Cedar Point) and 2 (Little Kowaliga Creek at Nero's Point) to a high of 8.0 mg/l at station 15. Higher pH values were likely the result of the effluent from a waste water treatment plant (WWTP) and phytoplankton production in this embayment during the growing season.

Penetration of light into the water column is important as phytoplankton require adequate light for photosynthesis. Phytoplankton, abiogenic turbidity and dissolved substances in the water affect light penetration. Secchi visibility (Appendix Figure 3) is an indicator of water transparency and the availability of light for phytoplankton/oxygen production. Secchi measurements varied most dramatically across the range of stations sampled in Lake Martin. Mean values ranged from a low of 1.3 m at the most riverine sample site, station 16 , to a high of 5.4 m at station 3the lowest site on the Kowaliga arm of the reservoir. Stations 3 and 4 (dam forebay) were very similar throughout the study and values for visibility showed little difference. Photic zone, the depth to which 1% of incident radiation is detectable and available for production exhibited the same pattern as the secchi determinations. The shallowest photic zone occurred at station 16 and the deepest at station 3.

Water quality growing season 2009

Water quality values measured during the growing season are presented in Appendix Table 5. Total alkalinity is a measure of the buffering capacity of water and is expressed as $CaCO_3$ equivalent. Values ranged from 13.0 mg/l $CaCO_3$ at station 2 to a high of 18.5 mg/l $CaCO_3$ at station 8 (Sandy Creek at Smith's Landing). Values were similar across stations; however, as values for alkalinity are typically low in the Tallapoosa River Basin, the slightly elevated values at station 8 and also at station 15 likely reflected the influence of a WWTP on the respective watersheds.

Total hardness is a measure of calcium and magnesium (as well as other divalent ions) in water expressed as $CaCO_3$. Hardness values across all stations were low, ranging from 10.8 mg/l $CaCO_3$ at station 10 (Mainstream at Bay Pine Island) to 14.1 mg/l $CaCO_3$ at station 8.

Mean nutrient values across stations were variable and apparently more indicative of the different activities on these subwatersheds. Total nitrogen (TN) values ranged from 149 µg/l at station 2 to a high of 596 µg/l at station 15. Soluble reactive phosphorus (SRP) is the most biologically available form of phosphorus and usually does not occur in large amounts in a reservoir unless there is a continuing source of the nutrient. Unpolluted waters generally have less than 10 µg/l SRP (Lind 1985) and phytoplankton and bacteria can deplete available SRP when concentrations are low. Mean values for SRP were low at most stations and ranged from 0.0 µg/l at stations 1-4 and 11(Dennis Creek Embayment) to a high of 0.6 µg/l at stations 9 (Manoy Creek Embayment) and 15. Total phosphorus (TP) values ranged from 6.0 µg/l at stations 2-4 to a high of 52 µg/l at station 15 (Appendix Figure 4).

Turbidity values measured during the growing season were relatively low for most stations given the amount of rain that occurred during this time period. Values ranged from a low of 1.2 NTUs at stations 3 and 4 to a high of 9.5 NTUs at station 16. Higher turbidities were expected at station 16 as it is the uppermost station and the most riverine in nature. High turbidities can reduce productivity in an otherwise suitable or nutrient rich environment as the turbidity can block the light necessary for expression of these nutrients in the form of phytoplankton biomass.

Specific conductance is a measure of the capacity of water to conduct a current. It is an indicator of dissolved solids in water, and thus often an indicator of pollutants. Values measured during the growing season were similar at all stations, not exceeding 60 µS/cm at any station on any date. Mean values ranged from 43.3 µS/cm at station11 to 49.7 µS/cm at station 13.

Total suspended solids (TSS) can include both living and dead organic matter as well as inorganic particles. Values for TSS measured during the growing season were low (Appendix Figure 5). However those stations with high turbidities typically had higher TSS values. Values for TSS did not exactly mirror stations with high turbidities as station 15 had higher mean TSS compared to station 16 which had higher mean turbidity. Phytoplankton biomass could have been a component of the higher mean value measured at station 15. Values for TSS ranged from lows of 1.0 mg/l at stations 3 and 4 to a high of 8.1 mg/l at station 15.

Corrected chlorophyll *a* was selected as one of the criteria for estimating primary production in response to nutrient loading within a water body (EPA 1998). These values are among the most important indicators of lake trophic condition and have been used as standard lake nutrient criteria for Lake Martin since 2002 (ADEM 2005). A standard corrected chlorophyll *a* value of 5.0 µg/l or lower measured monthly (photic zone composite) at the deepest point mid channel April through October at the dam forebay (station 4), or immediately upstream of Blue Creek (station 6) or above the Hwy 63 bridge at Kowaliga (between stations 1 and 3) determines whether the reservoir is meeting its use criteria.

Mean chlorophyll *a* values measured during the 2009 growing season ranged from 1.5 µg/l at station 3 to 20.0 µg/l at station 15 (Appendix Figure 6). Most elevated chlorophyll *a* values occurred in the embayments, however a mean value of 7.5 µg/l was calculated from station 14, the mainstem station downstream of embayment station 15. The highest chlorophyll *a* concentrations measured during the 2009 growing season were from Coley Creek (station 15).

In situ winter season 2009-2010

Water temperature (mean values measured at 5 ft.) during the winter season ranged from a low of 10.6° C at station 16, to a high of 11.8° C at station 8 (Appendix Table 6). Water temperatures measured at the surface (0.5 m) were similar, with means ranging from a low of 10.6° C at station 16 to a high of 11.9° C at stations 8, 13 (Elkahatchee Creek Embayment below Sugar Creek) and 15.

Mean values for dissolved oxygen, also measured at 5 ft, ranged from a low of 9.5 mg/l at station 15 to 10.4 mg/l at station 16. Dissolved oxygen is usually higher in winter months and not generally an issue of concern. No values below 8 mg/l were recorded at any of the eight stations during the winter sampling. Higher dissolved oxygen values accompanied a drop in temperature as the cooler water actually “holds” more of the gas.

Values measured for pH varied little during the winter season. The upper portion of Sandy Creek (station 8) had the lowest mean value (6.3) while Station 16 had the highest (6.8). As expected the surface (0.5 m) was usually well mixed during the winter season and would not be expected to exhibit strong differences.

Secchi measurements during the winter season decreased dramatically across the range of eight stations sampled in Lake Martin. This decline reflected the impact of abiogenic turbidity from the watershed and likely from exposed shoreline erosion during the rainy winter season. Values ranged from a low of 0.7 m at stations 13 and 14 to a high of 2.2 m at station 4. Photic zone depth ranged from a low of 1.8 m at stations 13 and 14 and reached 5.6 m at the dam forebay (station 4) during the winter.

Water quality winter season 2009-2010

Water quality values measured during the winter season at the eight stations appear in Appendix Table 6. Total alkalinity varied little from growing season values with the lowest mean value measured at station 14 (12.1 mg/l $CaCO_3$) and the highest at station 15 (16.9 mg/l $CaCO_3$). Hardness also was relatively unchanged ranging from 10.3 mg/l $CaCO_3$ at station 14 to 15.3 mg/l $CaCO_3$ at station 15 during this time period.

Nutrient values did exhibit some distinct seasonal differences. Total nitrogen (TN) measured at each of the eight stations was consistently higher than the growing season values, from 1.3 to almost 2 times higher. Highest values were measured at station 15 (891 µg/l) and lowest at station 4 (374 µg/l).

Soluble reactive phosphorus (SRP) was measurable at all stations sampled during the winter season when it had not been detectable during the growing season at stations 1-4 and 11. Values ranged from 0.8 µg/l at station 9 to 12.8 µg/l at station 15. This form of phosphorus would support phytoplankton growth even during the winter months. Its presence contributed to elevated chlorophyll *a* values measured at some stations sampled during the winter season. Total phosphorus (TP) was also elevated above levels measured during the growing season, ranging from 15.0 µg/l at station 4 to 60.4 µg/l at station 13. Sugar Creek received effluent from the Alex City WWTP until June 2001, when the effluent was diverted from Sugar Creek to a mainstream diffuser located mid-channel just upstream of Elkahatchee and Dennis Creeks (CH2M Hill 2003). Additional sampling may be required to determine if the excess phosphorus was from continuing impacts of the WWTP or other sources.Elevated rainfall amounts, reduced shoreline vegetation and lowered lake levels likely contributed to the higher turbidity measured during the winter months. Lowest mean values measured were at station 4 (7.2 NTUs) and the highest at station14 (41.2 NTUs).

Mean values measured for specific conductance were lower during the winter months compared to growing season values with the exception of station 15. Specific conductance ranged from a low of 36.8 µS/cm at station 14 to a high of 59.7 µS/cm at station 15 during the winter months. .

Mean values for total suspended solids increased during the winter season. Station means followed the same pattern as turbidity with lowest values occurring at station 4 (2.5 mg/l) and highest at station 14 (29.1 mg/l).

Corrected chlorophyll *a* concentrations were highest during the winter season at stations 13 and 15. Mean values for those embayment stations were 4.1 and 3.9 µg/l respectively. The nutrient concentrations and environmental conditions in these embayments were more than adequate for phytoplankton production. Lowest mean value occurred at station 16 (0.6 µg/l) where constant flows were not as conducive to phytoplankton production, though the nutrients were present.

Statistical analysis of 2009 growing season data

Station means were tested using a Tukey's test at $\alpha = 0.05$ in order to discover differences among stations during the study (Cody and Smith 1997). Certain variables were selected as being of primary interest and relevant to proposed operational changes in the reservoir.

Dissolved oxygen at 0.5 m, secchi visibility, TP, corrected chlorophyll *a* and TSS were compared among stations to determine if any differences existed along the upstream to downstream gradient, among embayments and between embayments and mainstream stations. Results appear in the Appendix Tables 7-12.

Mean values for dissolved oxygen at all stations at 0.5m and 5.0 ft. were analyzed (Appendix Tables 7-8). Dissolved oxygen measured at the regulatory depth of 5 ft. resulted in no significant differences among stations. However some statistical differences were evident when mean DO concentrations at 0.5 m were compared. Differences were not great and were possibly more a result of sampling time than actual differences among stations. Surface levels of water bodies are subject to more wind and wave action and can be affected by photoinhibition, all or some of which may explain the results of the statistical analyses.

Mean Secchi visibility was tested among stations during 2009 and statistical differences existed from upstream to downstream and between embayments and mainstream stations (Appendix Table 9). Stations nearest the dam (3 and 4) were significantly clearer ($p < 0.05$) than other Kowaliga stations (1 and 2) upstream of the dam. Downstream stations were significantly clearer that the upstream or more riverine stations (15 and 16).

Analysis of TSS among stations mirrored the Secchi results with upstream stations (15 and 16) having significantly higher TSS values. While stations 15 and 16 were not significantly different from each other, their TSS values probably came from two different sources. TSS values at station 15 could have included phytoplankton biomass as well as sediment while means measured from station 16 likely contained primarily sediment. However both occurred in amounts high enough to set them apart from other stations. Results of statistical analyses for TSS across all stations appear in Appendix Table 10.

Results of TP analyses among stations demonstrated that station 15 was different from all other sampled stations probably due to the constant source of nutrients entering this embayment from the Coley Creek WWTP. Stations varied from upstream to downstream with upstream stations (both embayment and mainstream) having higher phosphorus values. However they showed little statistical differences among stations, and there seemed to be no strong pattern between embayments and mainstream stations. Appendix Table 11 includes results of statistical analyses for all stations for TP during the 2009 growing season.

Corrected chlorophyll *a* analyses indicated that station 15 was significantly different (higher) from other stations, as expected and that station 13 was significantly higher than all other stations with the exception of station 14. Station 13 is the most upstream portion of Elkahatchee Creek which had received effluent from the Alex City WWTP until June 2001 and also exhibited high levels of TP during the 2009 growing season as well. Values from statistical analyses appear in the Appendix Table 12.

In situ growing season 2004

Water temperatures (mean values measured at 0.5 m) during the 2004 growing season ranged from a low of 25.0° C at station 3, to a high of 27.3° C at station 13 (Appendix Table 13). Mean values for dissolved oxygen also measured at 0.5 m ranged from a low of 7.6 mg/l at station 2 to a high of 9.5 mg/l at station 15. No values below 5 mg/l were recorded at any station during the 2004 study. Values for pH were measured at the surface (0.5 m) and means ranged from lows of 6.9 at stations 2, 3 and 5 to a high of 7.6 at station 15.

Secchi visibility ranged from a low of 1.2 m at station 15 to a high of 5.0 m at station 3. Photic zone depth ranged from 1.4 m (sunlight extending to the bottom in shallow Coley Creek embayment station 15) to 11.4 m at station 3.

Water quality growing season 2004 vs. 2009 statistical comparison

Data collected during the Tallapoosa Watershed Project (2004-2006) on Lake Martin are presented in Appendix Table 13. Figures 2-6 (Appendix) show comparisons between 2004 and 2009 growing seasons for dissolved oxygen (0.5m), Secchi visibility, TP, TSS and corrected chlorophyll *a*. These data were also selected for statistical comparison and details are presented in the Appendix figures.

Statistical differences in dissolved oxygen concentrations (mg/l) at 0.5 m were detected at half of the stations when 2004 and 2009 data were compared. Those stations which were not significantly different between these two growing seasons were 1, 9, 13, 14, and 15 (Appendix Figure 2). Values were significantly higher during 2009 at stations 2 and 3, while values at stations 5, 7, 8, and 10-12 were significantly higher in 2004. As discussed earlier, the differences may reflect time of sampling and weather conditions rather than actual differences in conditions at these stations.

No statistical differences in Secchi visibility measured at each station occurred between the 2004 and 2009 growing seasons (Appendix Figure 3). Though rainfall amounts differed between the two growing seasons it was apparently not enough to significantly impact the visibility.

Results of comparison of mean TP values at each station between 2004 and 2009 growing seasons indicated that there were no significant differences. This was surprising in view of the difference in rainfall amounts between the two years. Total phosphorus values were slightly higher at most stations during 2009, but not enough to be significant (Appendix Figure 4.)

There were only two stations where mean TSS was significantly different between 2004 and 2009. Both stations 7 (Sandy Creek near mainstream) and 13 (Elkahatchee Creek below Sugar Creek confluence) are embayment stations. MeanTSS values measured at these two stations in 2009 were significantly higher than those measured during the 2004 growing season (Appendix Figure 5).

Comparison of values for corrected chlorophyll *a* concentrations during the 2004 and 2009 growing seasons appear in Appendix Figure 6. The only statistical differences evident between the two growing seasons occurred at stations 1 and 2, where corrected chlorophyll *a* was higher during 2009. Values were low at these upper locations on the Kowaliga arm of the reservoir but differences were apparently enough to be detected in the analysis between years.

Comparison of 2009-2010 growing season vs winter season

Values for dissolved oxygen measured at 5 ft. were higher at all stations during the winter season compared to growing season values (Appendix Figure 7). Differences were significant at all stations with the exception of stations 13 and 15, the stations with the highest chlorophyll *a* concentrations.

Secchi visibilities measured during the winter season were statistically different (lower) from growing season means at all stations with the exception of station 15 (Appendix Figure 8). This was expected as higher turbidities and sediment loads affect visibility and are more common during the winter rainy season. While secchi visibilities were lower at station 15 during the winter, the difference was not significant. As Coley Creek (station 15) is a relatively narrow and shallow tributary embayment, it appeared to be affected less by season and more by the WWTP effluent.

Total phosphorus (TP) values were much higher at most stations during the winter months compared to the growing season (Appendix Figure 9). Station 15 was the exception to that as mean TP values were almost identical between the two seasons. Though differences at each station were great between seasons, none were significantly different.

While chlorophyll production occurred at all stations sampled during the winter months, the most dramatic examples of winter season production occurred at stations 13 and 15 (Appendix Figure 10). Winter season values at stations 13 and 15 exceeded mean chlorophyll *a* values measured during the growing season at stations 1-8. Differences were significant between seasons at stations 8, 13, 14, 15 and 16. There were no significant differences between seasons at stations 4, 9 and 11, though chlorophyll *a* values were greater at all stations during the growing season.

Total suspended solids (TSS) were also dramatically higher during the winter than the growing season at all stations, except station 15 (Appendix Figure 11). Though TSS values were higher in the winter, station 4, the dam forebay, was the only location where a significant difference occurred between seasons.

Trophic State Comparison

The Trophic State Index (TSI) increased at all stations during the 2009 growing season when compared to 2004 except at station 10 (Appendix Figure 12). Values were not tested for significance but a trend was evident when compared to values calculated for 2004. Most values in the lower end of the reservoir (stations 1-6) fell within the oligotrophic range during both years however stations 7-12 moved into the mesotrophic range for both growing seasons. TSI values above 50 moved stations 13, 14 (2009) and 15 into the eutrophic range. Station 16 had a TSI in the mesotrophic range for 2009 only.

E. CONCLUSIONS

Lake Martin exhibited differences in water quality from upstream to downstream with Coley Creek often being the only statistically different site throughout the 2009-2010 study. However most variables tested were not determined to be significantly different among stations during the growing season. In addition to the impacts from Coley Creek, the contribution from the river upstream also affected downstream locations and this was particularly evident at station 14, the mainstream location at the 280 highway bridge. Elkahatchee Creek embayment (station 13) expressed the results of nutrient enrichment and was significantly different from other stations in the amounts of total phosphorus and chlorophyll *a* measured. The Kowaliga arm of the reservoir (stations 1-4) was the clearest and most nutrient poor during the growing season.

There were very few differences evident between the 2004 and 2009 growing seasons. The significant differences were only evident in dissolved oxygen measured at the surface (0.5 m) and this could have been a function of sampling time, wind action and/or photoinhibition in this surface layer. Total suspended solids were significantly higher during 2009 at stations 7 and 13, (both embayment stations) and the differences were likely a result of the higher rainfall amounts recorded during 2009. There were significant differences measured in corrected chlorophyll *a* concentrations from only 2 stations. Though values measured at stations 1 and 2 were low, they were significantly higher in 2009 when compared with the 2004 data. Trophic State Index values calculated for both years indicated an increasing trend in trophic state at most all stations between 2004 and 2009 though significant differences were not detected. TSI values indicated that the Kowaliga arm and lower part of the reservoir were in the oligotrophic range. This portion of Lake Martin with low nutrient and sediment impacts may be more susceptible to change than other parts of the reservoir.

Differences between the growing season and winter season of 2009 confirmed that nutrient loading during the winter was much higher. There was also phytoplankton production at all stations sampled during the winter season. Though the chlorophyll *a* values measured during the winter at each station were not higher than growing season means for the same station, some stations had chlorophyll values that exceeded growing season means at other stations. Stations 9, 11, 13 and 15 all had winter season means that exceeded mean values measured during the growing season at stations 1-6. These stations (9, 11, 13 and 15) were all embayment stations and were responding to the available nutrients, quieter waters, and perhaps slightly higher mean temperatures that some embayments provided.

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III. APPENDIX

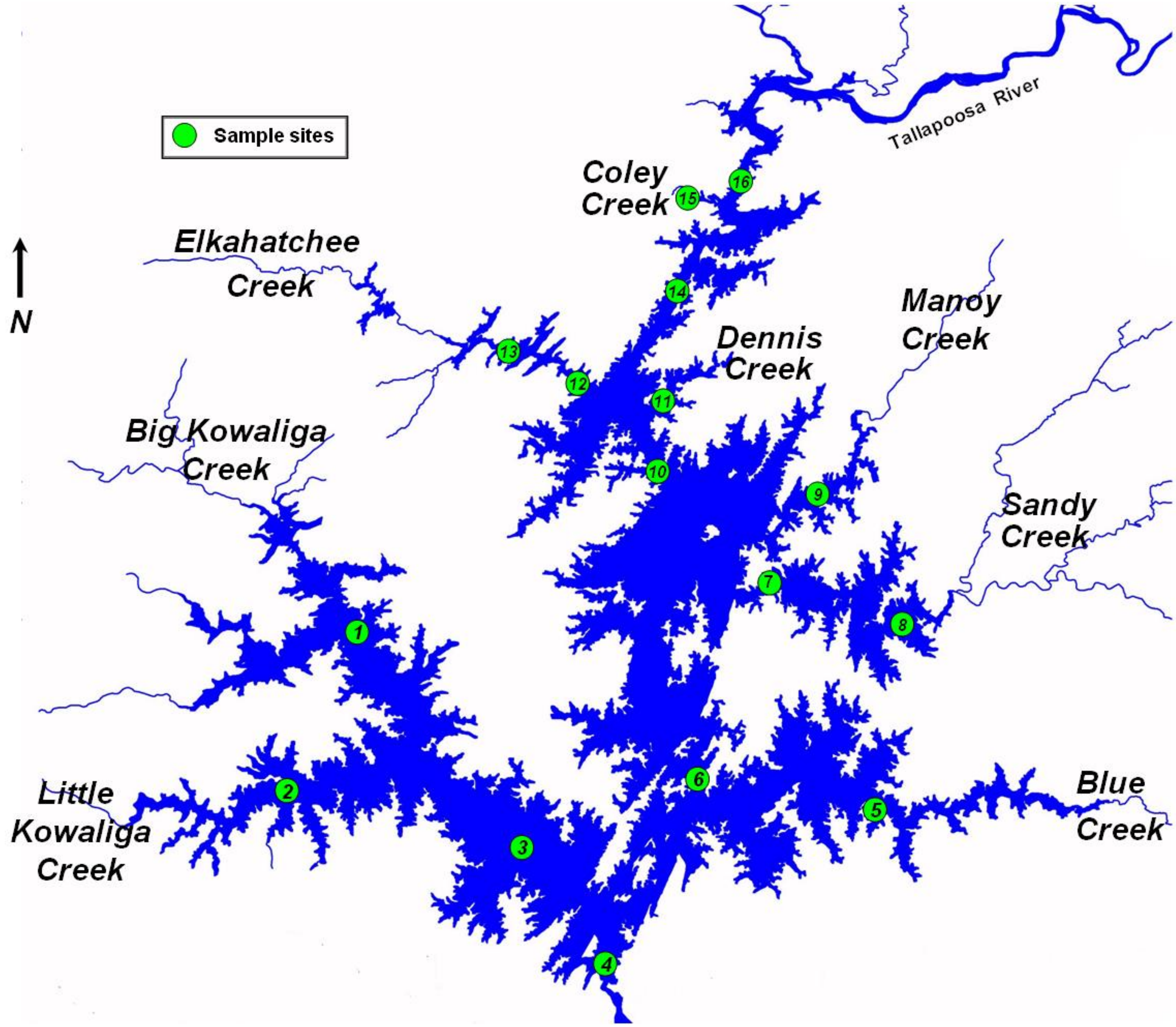

Figure 1. Water quality sampling locations on Lake Martin (April 2009-March 2010).

Table 1. Location of 16 sampling stations on Lake Martin.

Sample Site	Location	Latitude	Longitude
1	BIG KOWALIGA CREEK @ CEDAR POINT	32.79167	-85.99250
2	LITTLE KOWALIGA CREEK @ NERO'S POINT	32.73833	-86.01194
3	BIG KOWALIGA CREEK @ CASTAWAY ISLAND	32.72000	-85.93917
4	TALLAPOOSA RIVER MARTIN DAM FOREBAY	32.68647	-85.91070
5	BLUE CREEK @ STILLWATERS MARINA	32.73465	-85.82030
6	TALLAPOOSA RIVER UPSTREAM OF BLUE CREEK	32.73437	-85.88740
7	SANDY CREEK 1 MILE UPSTREAM OF MAINSTREAM (ADEM SITE 10)	32.80415	85.85423
8	SANDY CREEK @ SMITH LANDING	32.79250	-85.81750
9	MANOY CREEK EMBAYMENT (ADEM SITE 9)	32.83389	-85.84140
10	MAINSTREAM @ BAY PINE ISLAND	32.83917	-85.89000
11	DENNIS CREEK EMBAYMENT	32.86112	-85.89643
12	ELKAHATCHEE CREEK BELOW ABBOTT HIGHWAY BRIDGE	32.87122	-85.91787
13	ELKHATACHEE CREEK ½ MILE BELOW SUGAR CREEK CONFLUENCE (ADEM SITE 8)	32.87806	-85.94360
14	MAINSTREAM @ HIGHWAY 280 BRIDGE	32.90022	-85.88747
15	COLEY CREEK EMBAYMENT (ADEM SITE 7-slightly moved)	32.92760	-85.88000
16	TALLAPOOSA RIVER UPSTREAM OF COLEY CREEK	32.93361	-85.86690

Table 2. Analytical methods for measuring water quality variables.

Variable	Method	Reference
In Situ		
Temperature	thermister	APHA 1998
Dissolved oxygen	membrane electrode	APHA 1998
Visibility	Secchi disk	Lind 1985
Euphotic zone determination	Secchi disk and historical data	Lind 1985
Laboratory Analyses		
Chlorophyll *a* (corrected)	spectrophotometric	APHA 1998
Total phosphorus	persulfate digestion followed by ascorbic acid method	APHA 1998
Soluble reactive phosphorus	ascorbic acid method	APHA 1998
Total Nitrogen	Persulfate digestion followed by ultraviolet spectrophotometry	APHA 1998
Turbidity	Nephelometric	APHA 1998
Total suspended solids	vacuum filtration	APHA 1998
Total alkalinity	potentiometric titration	APHA 1998
Total Hardness	EDTA titration	APHA 1998
pH	glass electrode	APHA 1998

Table 3. Meteorological conditions in the vicinity of Lake Martin during 2004-2005 and 2009-2010.

	2004-2005					2009-2010				
Month	Temperature[1] (°C)	DFN[2] (°C)	Rainfall[3] (cm)	DFN[2] (cm)	Solar Radiation[4] (langleys)	Temperature[1] (°C)	DFN[2] (°C)	Rainfall[3] (cm)	DFN[2] (cm)	Solar Radiation[4] (langleys)
April	14.8	-2.3	4.04	-8.86	470.1	15.2	-1.9	11.13	-1.77	430.6
May	21.5	+0.5	5.33	-4.17	488.0	21.3	+0.3	20.09	+10.59	348.3
June	24.1	+1.9	9.40	-1.9	416.3	25.8	+3.6	6.65	-4.65	527.2
July	25.6	-0.4	9.55	-4.05	488.7	25.4	-0.6	17.37	+3.77	509.7
August	23.7	-1.8	16.59	+6.8	447.8	24.4	+1.1	12.04	+2.24	418.2
September	22.3	-0.6	20.04	+9.94	345.3	21.7	-0.7	26.26	+16.16	327.1
October	18.6	+1.2	5.05	-1.85	248.8	15.4	-2.0	21.92	+15.02	249.8
November	13.4	+0.9	19.13	+8.33	204.8	9.0	-3.5	13.56	+2.76	245.3
December	5.2	-3.0	6.60	-7.70	191.8	5.2	-3.0	29.24	+14.94	155.1
January	7.3	+1.0	6.91	-5.79	196.5	2.3	-4.0	14.12	+1.42	226.3
February	9.2	+0.6	12.65	-1.85	227.3	3.0	-5.6	9.35	-5.15	269.1
March	10.4	-1.8	22.25	+5.25	318.8	8.8	-3.4	10.95	-6.05	328.6
TOTAL			**137.54**					**192.68**		

[1] Temperature at Camp Hill, Alabama
[2] DFN = Departure from normal
[3] Rainfall at Lake Martin Dam
[4] Solar Radiation at Auburn University

Table 4. Growing season mean (range) *in situ* values of temperature, dissolved oxygen, pH, Secchi and photic zone measured at each sampling station on Lake Martin, 2009.

Variable	**Stations**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Temp (° C) @ 0.5 m	26.6 (23-31)	26.8 (23-30)	26.5 (21-29)	26.7 (20-30)	26.8 (21-31)	26.9 (23-31)	27.3 (24-31)	27.6 (24-31)	28.0 (24-32)	28.2 (24-32)	28.2 (24-32)	28.5 (24-32)	28.3 (24-32)	28.5 (24-32)	28.2 (21-33)	27.4 (21-32)
Temp (° C) at 5 ft	26.9 (23-30)	27.0 (23-30)	26.5 (21-30)	26.6 (20-30)	27.7 (24-30)	26.9 (22-31)	27.2 (23-31)	27.4 (23-31)	27.6 (24-31)	27.5 (24-31)	27.6 (24-31)	27.8 (24-31)	27.7 (24-31)	27.5 (23-32)	26.0 (20-31)	26.0 (20-31)
DO @ 5 ft (mg/l)	8.1 (7-9)	8.1 (7-9)	8.2 (7-9)	7.4 (6-9)	7.2 (6-8)	7.4 (6-8)	7.4 (6-9)	7.5 (7-9)	7.5 (5-9)	7.8 (6-9)	7.8 (6-9)	7.8 (7-9)	8.3 (7-10)	8.1 (7-9)	9.0 (7-10)	7.6 (7-8)
pH @ 0.5 m	6.6 (6-7)	6.6 (6-7)	6.7 (6-8)	7.0 (7-8)	6.8 (7-7)	6.9 (7-7)	7.1 (7-8)	7.3 (7-8)	7.3 (7-8)	7.4 (7-8)	7.6 (7-8)	7.6 (7-8)	7.9 (8-8)	7.4 (7-8)	8.0 (8-9)	7.1 (7-8)
Secchi (m)	4.3 (4-5)	4.4 (4-5)	5.4 (4-6)	5.3 (4-6)	3.4 (3-4)	4.1 (4-5)	3.6 (3-4)	2.6 (2-4)	3.1 (3-3)	3.2 (3-3)	2.7 (3-3)	2.5 (2-3)	2.1 (2-3)	2.0 (2-3)	1.4 (1-2)	1.3 (1-2)
Photic zone (m)	10.9 (10-12)	10.9 (9-12)	13.5 (11-16)	13.2 (11-16)	8.6 (6-11)	10.3 (9-12)	8.9 (6-11)	6.6 (5-9)	7.8 (7-9)	8.0 (7-9)	6.8 (6-8)	6.3 (5-7)	5.1 (4-7)	4.9 (4-7)	3.4 (2-4)	3.2 (2-4)

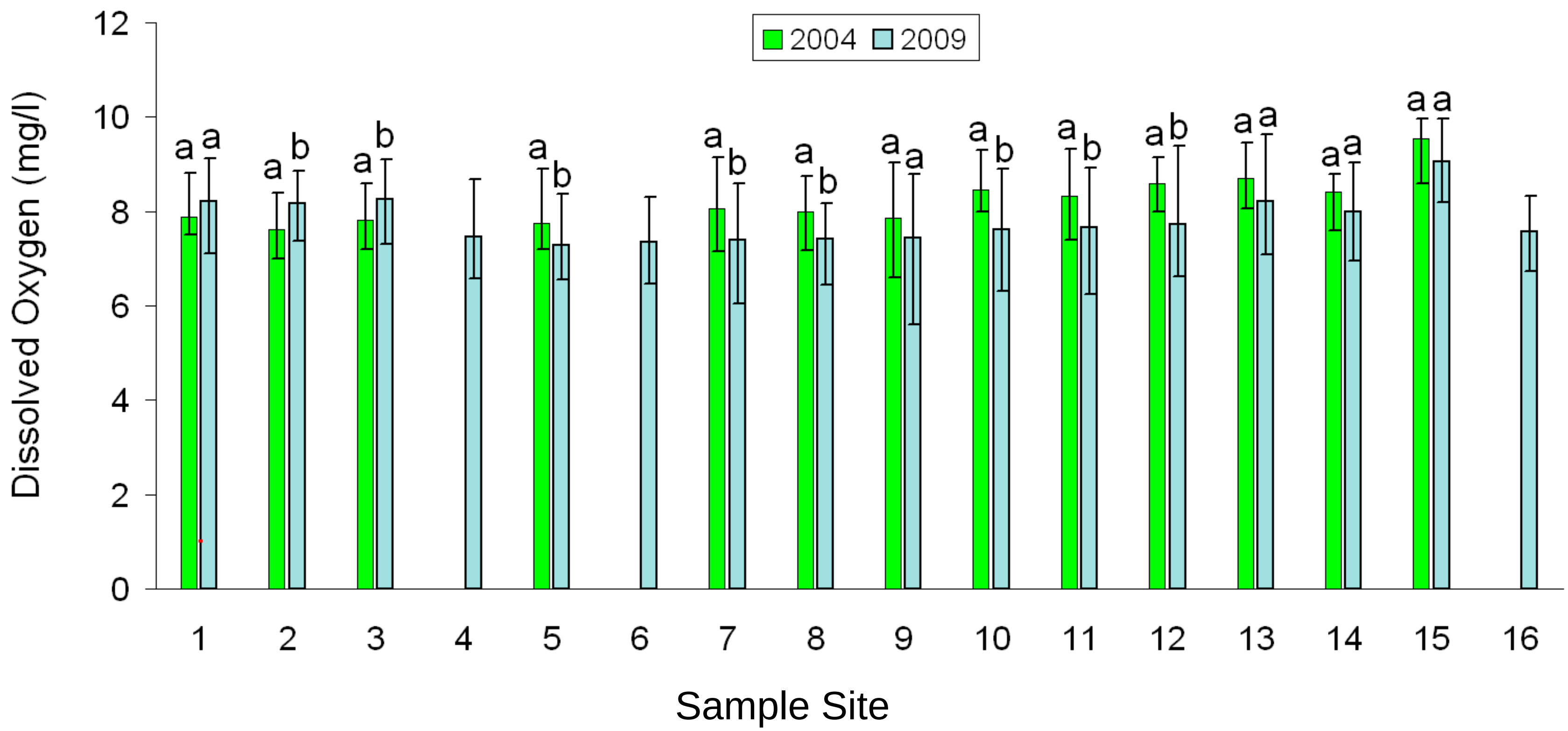

Figure 2. Dissolved oxygen (mg/L) means and ranges measured at a depth of 0.5 meters at 16 sampling locations on Lake Martin during the growing season (April-October) of 2004 and 2009. Means subtended by different letters are significantly different ($\alpha = 0.05$).

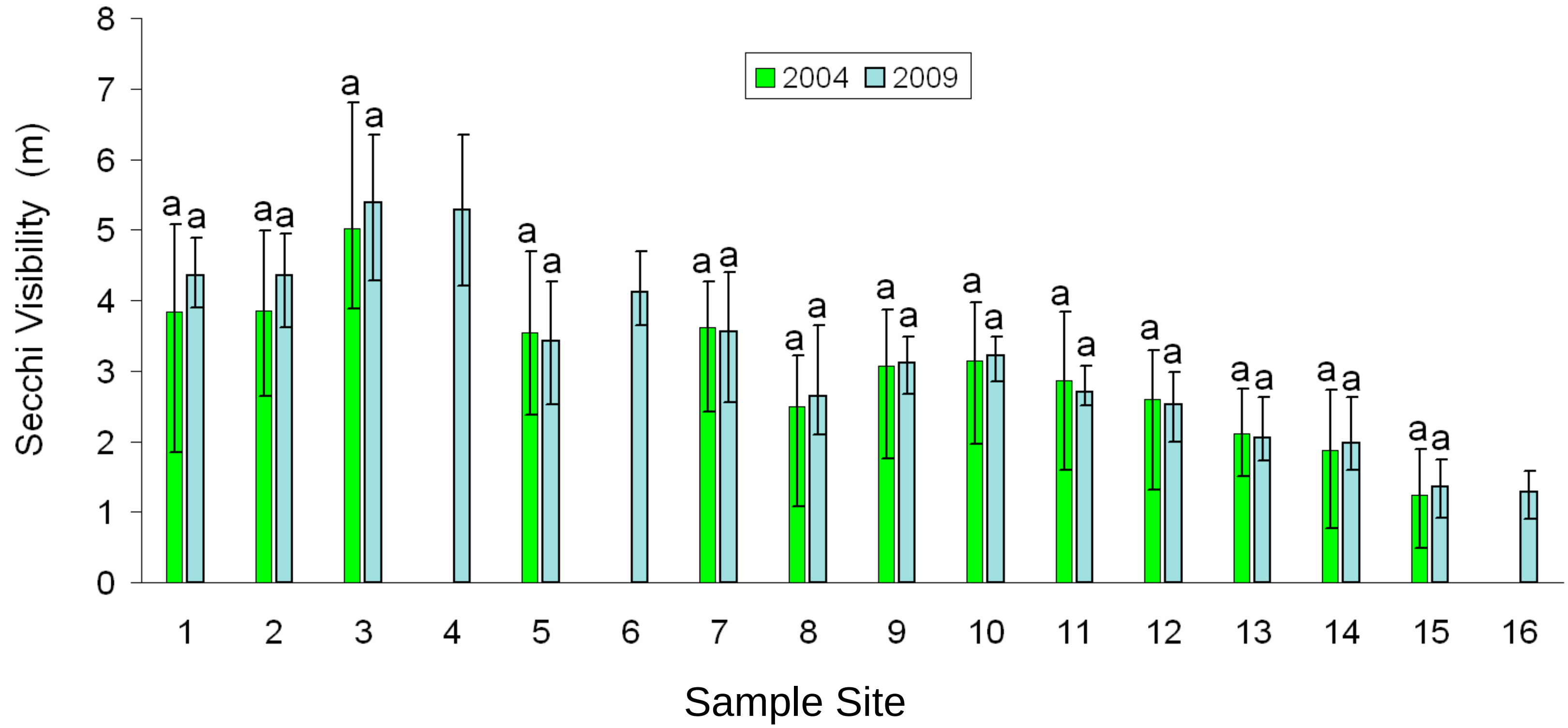

Figure 3. Secchi visibility (m) means and ranges measured at 6 sampling locations on Lake Martin during the growing season (April-October) of 2004 and 2009. Means subtended by different letters are significantly different ($\alpha = 0.05$).

Table 5. Growing season (April-October 2009) mean (range) values of total alkalinity (T. Alk), hardness, total nitrogen (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), turbidity, specific conductance, total suspended solids (TSS) and corrected chlorophyll *a* (CChlor a) measured at each station on Lake Martin, 2009.

Variable	**Stations**															
	1	**2**	**3**	**4**	**5**	**6**	7	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
T. Alk (mg/l $CaCO_3$)	15.25 (13-21)	13.0 (10-16)	14.0 (10-19)	15.2 (13-18)	15.4 (11-24)	13.2 (13-15)	14.6 (12-25)	18.5 (15-24)	14.9 (13-20)	13.8 (11-19)	15.2 (13-20)	15.0 (12-22)	16.4 (14-18)	15.4 (13-19)	16.0 (11-21)	14.2 (10-18)
Hardness (mg/l $CaCO_3$)	11.1 (10-12)	11.2 (11-12)	11.4 (11-12)	11.9 (11-14)	12.2 (12-13)	11.3 (11-12)	11.7 (11-13)	14.1 (13.2-15.3)	11.6 (10-12)	10.8 (9-12)	11.3 (10-12)	11.3 (10-12)	13.0 (10-14)	11.2 (8-12)	13.1 (11-15)	11.9 (10-13)
TN (µg/l)	198 (148-253	149 (0-220)	194 (118-234)	205 (135-269)	207 (141-259)	210 (165-276)	246 (202-301)	282 (206-378)	223 (96-348)	247 (96-406)	258 (117-408)	293 (152-419)	350 (221-416)	335 (188-435)	596 (449-749)	421 (351-528)
SRP (µg/l)	0	0	0	0	0.1 (0-.1)	0.3 (0-2)	0.3 (0-1)	0.4 (0-1)	0.6 (0-2)	0.1 (0-1)	0	0.2 (0-2)	0.1 (0-1)	0.1 (0-1)	0.6 (0-2)	0.3 (0-1)
TP (µg/l)	8 (5-13)	6 (4-8)	6 (4-10)	6 (3-8)	8 (5-11)	8 (4-10)	10 (6-14)	12 (8-14)	11 (8-14)	12 (10-16)	14 (11-20)	17 (14-21)	24 (18-31)	20 (15-29)	52 (34-75)	24 (19-29)
Turbidity (NTU)	1.7 (1-2)	1.6 (1-2)	1.2 (1-2)	1.2 (1-2)	2.6 (2-4)	1.6 (1-2)	2.2 (1-4)	4.4 (3-6)	2.1 (2-4)	2.2 (2-3)	2.6 (2-3)	2.9 (2-5)	3.9 (3-5)	4.6 (4-7)	7.6 (3-15)	9.5 (5-17)
Specific Conductance (µS/cm)	45.7 (44-48)	45.8 (44-48)	45 (44-47)	44.1 (43-46)	45.4 (44-46)	43.9 (43-46)	44.3 (42-49)	46.2 (43-49)	44.2 (42-46)	43.5 (41-45)	43.3 (41-46)	44.7 (43-46)	49.7 (47-55)	43.6 (42-45)	49.5 (43-56)	44.1 (41-48)
TSS (mg/l)	1.4 (1-2)	1.4 (1-2)	1.0 (1-1)	1.0 (1-1)	1.8 (1-2)	1.3 (1-2)	1.8 (2-2)	2.9 (2-4)	2.1 (2-3)	2.1 (2-2)	2.4 (2-3)	2.9 (2-4)	4.1 (4-5)	4.1 (3-5)	8.1 (4-13)	6.7 (5-10)
CChlor a (µg/l)	1.88 (1-2)	1.6 (1-2)	1.5 (1-3)	1.6 (0-3)	1.8 (1-4)	2.0 (0-3)	3.2 (2-5)	3.4 (2-5)	4.4 (2-6)	4.0 (2-5)	4.6 (3-7)	5.7 (4-8)	10.2 (8-13)	7.5 (4-17)	20.0 (10-31)	4.1 (1-8)

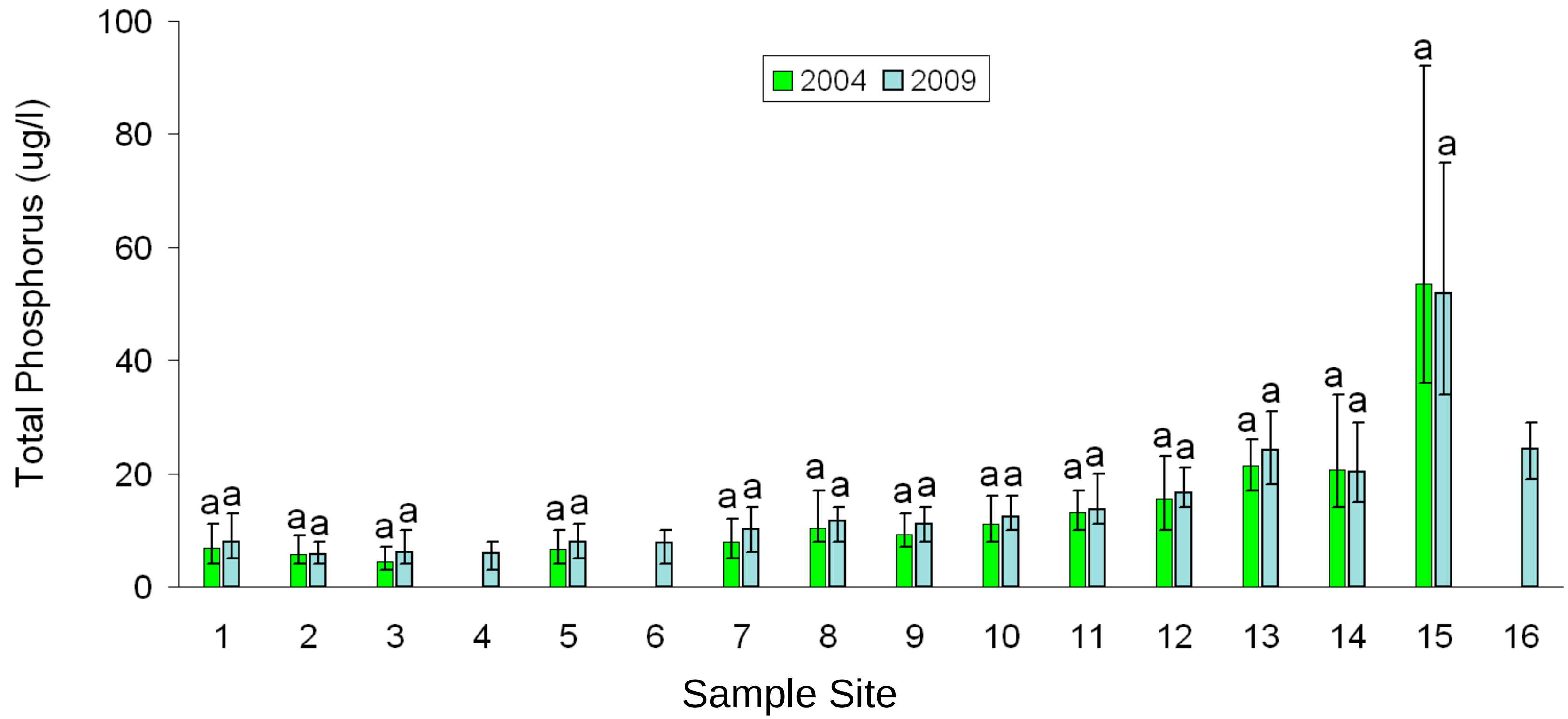

Figure 4. Total phosphorus means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) of 2004 and 2009. Means subtended by different letters are significantly different ($\alpha = 0.05$).

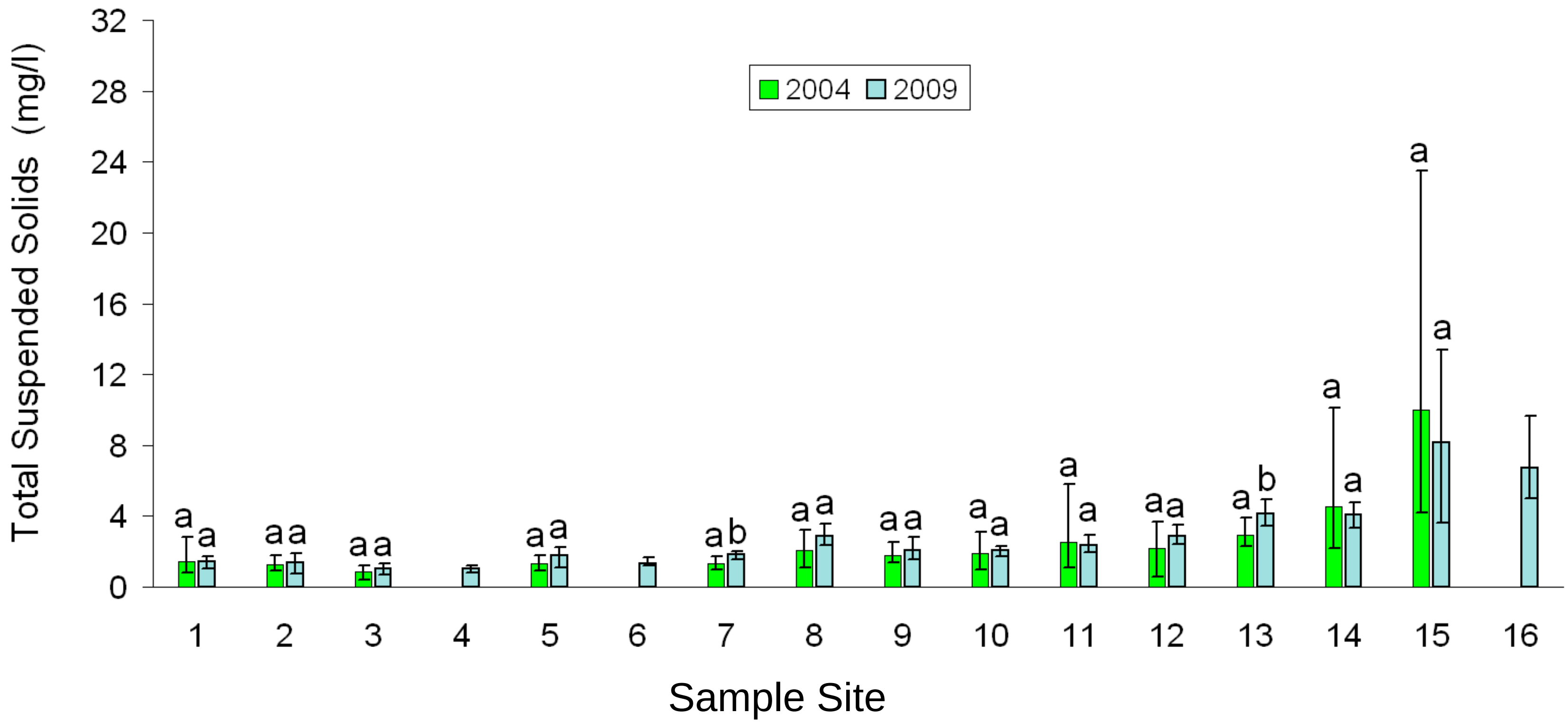

Figure 5. Total suspended solids means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) of 2004 and 2009. Means subtended by different letters are significantly different ($\alpha = 0.05$).

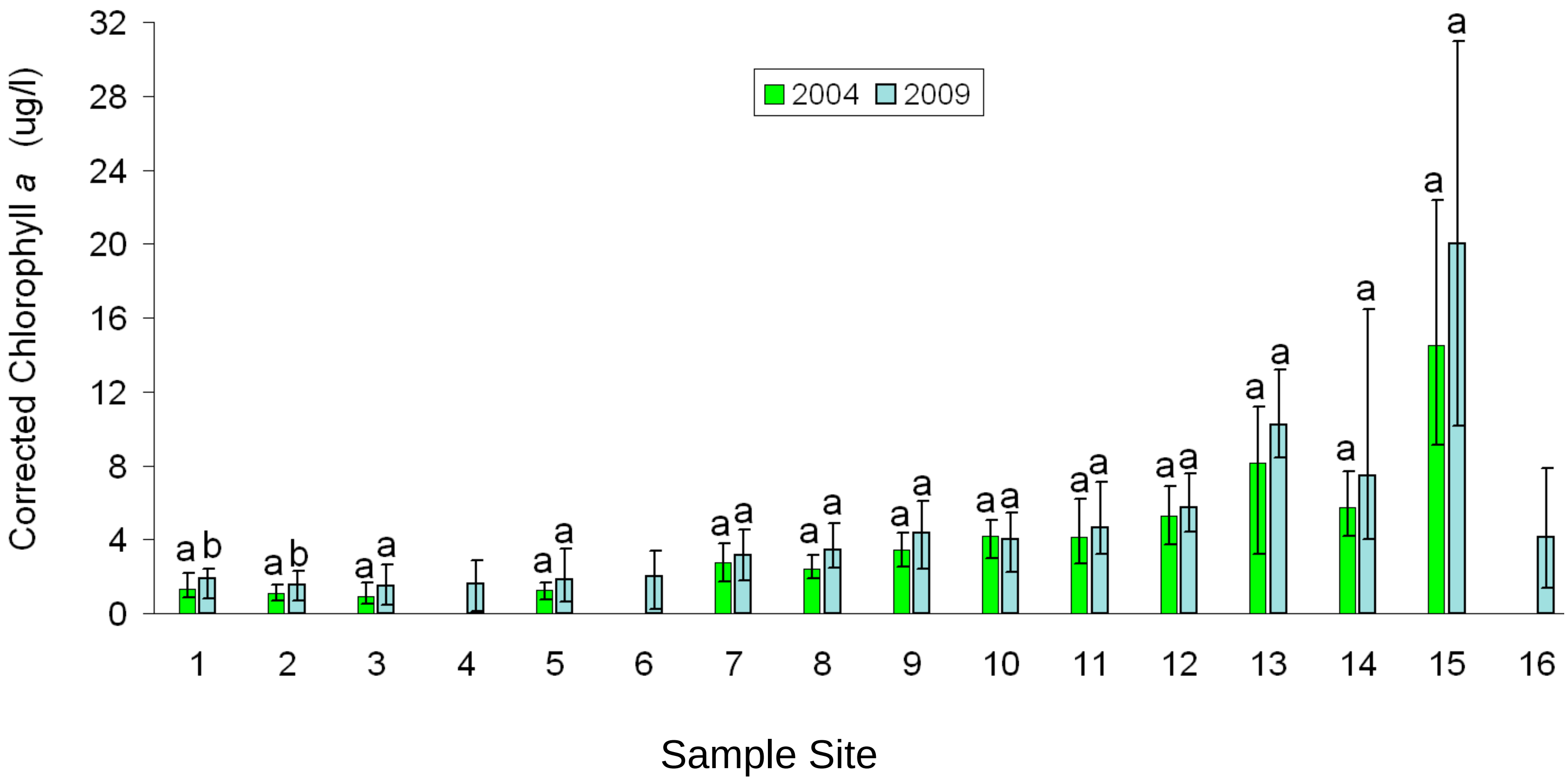

Figure 6. Corrected chlorophyll *a* means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) of 2004 and 2009. Means subtended by different letters are significantly different ($\alpha = 0.05$).

Table 6. Winter season (November 2009-March 2010) mean (range) values for *in situ* values of temperature, dissolved oxygen, pH, Secchi and photic zone; and total alkalinity, hardness, total nitrogen (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), turbidity, specific conductance, total suspended solids (TSS), and corrected chlorophyll *a* (CChlor a) measured at each station on Lake Martin, 2009-2010.

Variable	Stations							
	4	**8**	**9**	**11**	**13**	**14**	**15**	**16**
Temp (° C) @ 0.5 m	11.5 (7-18)	11.9 (8-17)	11.6 (8-17)	11.7 (8-17)	11.9 (7-16)	11.1 (8-15)	11.9 (9-15)	10.6 (7-14)
Temp (° C) @ 5 ft	11.5 (7-18)	11.8 (7-17)	11.6 (8-17)	11.6 (7-17)	11.7 (7-16)	11.0 (8-15)	11.3 (8-14)	10.6 (7-14)
DO @ 5 ft (mg/l)	10.0 (8-11)	9.8 (8-12)	9.8 (8-11)	10.0 (8-11)	9.6 (8-12)	10.1 (8-12)	9.5 (8-12)	10.4 (9-12)
pH @ 0.5 m	6.5 (6-7)	6.3 (6-8)	6.4 (6-8)	6.4 (6-8)	6.4 (6-7)	6.4 (6-7)	6.6 (6-8)	6.8 (6-7)
Secchi (m)	2.2 (1-3)	0.8 (0-2)	1.5 (1-2)	1.0 (0-2)	0.7 (0-1)	0.7 (0-1)	1.1 (1-2)	0.9 (1-1)
Photic zone (m)	5.6 (4-8)	1.9 (0-4)	3.7 (2-6)	2.6 (1-6)	1.8 (1-3)	1.8 (0-3)	2.6 (2-4)	2.2 (2-3)
Total. Alkalinity (mg/l $CaCO_3$)	13.9 (9-20)	14.3 (10-20)	14.5 (10-18)	13.9 (8-20)	13.5 (11-15)	12.1 (8-18)	16.9 (13-20)	12.5 (9-15)
Hardness (mg/l $CaCO_3$)	10.6 (10-11)	11.7 (10-13)	11.4 (11-12)	10.4 (9-11)	11.4 (10-13)	10.3 (10-11)	15.3 (12-18)	10.7 (10-12)
TN (µg/l)	374 (206-551)	518 (348-698)	397 (272-525)	499 (371-629)	562 (373-815)	631 (373-984)	891 (752-1033)	581 (476-727)
SRP (µg/l)	1.6 (0-5)	1.2 (0-3)	0.8 (0-2)	2.0 (0-4)	3.4 (1-5)	3.0 (1-5)	12.8 (7-22)	3.5 (1-6)
TP (µg/l)	15.0 (6-24)	40.2 (13-87)	20.4 (10-37)	37.4 (15-59)	60.4 (30-131)	57.4 (22-149)	53.0 (47-58)	34.3 (21-44)
Turbidity (NTU)	7.2 (2-11)	39.8 (8-100)	9.6 (4-16)	20.1 (5-35)	37.7 (12-100)	41.2 (10-140)	13.3 (6-19)	17.2 (11-21)
Specific conductance (µS/cm)	40.2 (37-44)	38.0 (34-43)	41.4 (39-43)	37.5 (31-43)	39.9 (31-48)	36.8 (28-43)	59.7 (47-66)	39.0 (36-43)
TSS (mg/l)	2.5 (1-4)	19.7 (4-55)	5.5 (3-10)	12.7 (4-24)	22.1 (7-61)	29.1 (6-106)	9.6 (4-14)	13.1 (8-22)
CChlor a (µg/l)	1.2 (1-3)	1.2 (1-3)	3.6 (1-11)	2.8 (0-6)	4.1 (1-9)	1.1 (0-2)	3.9 (0-13)	0.6 (0-1)

Table 7. Tukey's Studentized Range Test for dissolved oxygen measured at 0.5 meters at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	STA
	A	9.0529	7	15
	A			
B	A	8.2629	7	3
B	A			
B	A	8.2129	7	13
B	A			
B	A	8.2043	7	1
B	A			
B	A	8.1700	7	2
B	A			
B	A	7.9957	7	14
B	A			
B	A	7.7343	7	12
B	A			
B	A	7.6600	7	11
B	A			
B	A	7.6157	7	10
B	A			
B	A	7.5814	7	16
B	A			
B	A	7.4557	7	4
B				
B		7.4414	7	9
B				
B		7.4186	7	8
B				
B		7.3900	7	7
B				
B		7.3600	7	6
B				
B		7.2786	7	5

Table 8. Tukey's Studentized Range Test for dissolved oxygen measured at five feet at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	STA
A	8.9657	7	15
A	8.3186	7	13
A	8.2214	7	3
A	8.1329	7	14
A	8.1157	7	1
A	8.1157	7	2
A	7.7757	7	12
A	7.7657	7	11
A	7.7557	7	10
A	7.6386	7	16
A	7.5471	7	8
A	7.5029	7	9
A	7.4443	7	4
A	7.4057	7	7
A	7.3843	7	6
A	7.2357	7	5

Table 9. Tukey's Studentized Range Test for Secchi visibility measured at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping			Mean	N	STA
	A		5.3929	7	3
	A				
	A		5.2786	7	4
	B		4.3579	7	2
	B				
	B		4.3493	7	1
	B				
C	B		4.1129	7	6
C	B				
C	B	D	3.5586	7	7
C		D			
C	E	D	3.4286	7	5
	E	D			
F	E	D	3.2150	7	10
F	E	D			
F	E	D	3.1114	7	9
F	E				
F	E	G	2.7050	7	11
F	E	G			
F	E	G	2.6464	7	8
F		G			
F		G	2.5250	7	12
		G			
	H	G	2.0529	7	13
	H	G			
	H	G	1.9707	7	14
	H				
	H		1.3521	7	15
	H				
	H		1.2857	7	16

Table 10. Tukey's Studentized Range Test for total suspended solids measured from a photic zone composite at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping			Mean	N	STA
	A		8.1414	7	15
	A				
	A		6.7452	7	16
	B		4.1469	7	13
	B				
C	B		4.0803	7	14
C	B				
C	B	D	2.8729	7	8
C	B	D			
C	B	D	2.8658	7	12
C	B	D			
C	B	D	2.3519	7	11
C		D			
C		D	2.0847	7	10
		D			
		D	2.0731	7	9
		D			
		D	1.8233	7	7
		D			
		D	1.7930	7	5
		D			
		D	1.4393	7	1
		D			
		D	1.3734	7	2
		D			
		D	1.3432	7	6
		D			
		D	1.0283	7	3
		D			
		D	1.0243	7	4

Table 11. Tukey's Studentized Range Test for total phosphorus measured from a photic zone composite at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping			Mean	N	STA
	A		0.051857	7	15
	B		0.024286	7	16
	B				
	B		0.024143	7	13
	B				
C	B		0.020286	7	14
C	B				
C	B	D	0.016571	7	12
C		D			
C	E	D	0.013714	7	11
C	E	D			
C	E	D	0.012286	7	10
C	E	D			
C	E	D	0.011714	7	8
	E	D			
	E	D	0.011000	7	9
	E	D			
	E	D	0.010143	7	7
	E	D			
	E	D	0.008000	7	1
	E				
	E		0.007857	7	5
	E				
	E		0.007714	7	6
	E				
	E		0.006000	7	3
	E				
	E		0.005857	7	4
	E				
	E		0.005714	7	2

Table 12. Tukey's Studentized Range Test for chlorophyll *a* measured from a photic zone composite at 16 sites during the growing season (April-October) on Lake Martin in 2009. Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	STA
	A	20.038	7	15
	B	10.215	7	13
	B			
C	B	7.475	7	14
C				
C	D	5.723	7	12
C	D			
C	D	4.636	7	11
C	D			
C	D	4.374	7	9
C	D			
C	D	4.102	7	16
C	D			
C	D	4.010	7	10
C	D			
C	D	3.432	7	8
	D			
	D	3.159	7	7
	D			
	D	2.001	7	6
	D			
	D	1.884	7	1
	D			
	D	1.808	7	5
	D			
	D	1.614	7	4
	D			
	D	1.565	7	2
	D			
	D	1.511	7	3

Table 13. Growing season (April-October 2004) mean (range) values of *in situ* values of temperature, dissolved oxygen, pH, Secchi visibility and photic zone; and total alkalinity, hardness, total nitrogen (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), turbidity, specific conductance, total suspended solids (TSS) and corrected chlorophyll *a* (CChlor a) measured at each station on Lake Martin, 2004.

Variable	Stations												
	1	2	3	5	7	8	9	10	11	12	13	14	15
Temp (° C) @ 0.5 m	25.3 (16-29)	25.3 (16-29)	25.0 (16-30)	26.1 (18-31)	26.3 (18-31)	26.2 (19-30)	26.6 (20-31)	26.5 (19-31)	26.6 (18-31)	27.1 (19-31)	27.3 (19-31)	26.9 (21-31)	26.4 (18-30)
DO @ 0.5 m (mg/l)	7.9 (8-9)	7.6 (7-8)	7.8 (7-9)	7.8 (7-9)	8.0 (7-9)	8.0 (7-9)	7.9 (7-9)	8.5 (8-9)	8.3 (7-9)	8.6 (8-9)	8.7 (8-9)	8.4 (8-9)	9.5 (9-10)
pH @ 0.5 m	7.0 (7-7)	6.9 (7-7)	6.9 (7-7)	6.9 (7-7)	7.0 (7-8)	7.1 (7-8)	7.0 (7-8)	7.2 (7-8)	7.1 (7-8)	7.2 (7-8)	7.4 (7-8)	7.2 (7-8)	7.6 (7-9)
Secchi (m)	3.8 (2-5)	3.9 (3-5)	5.0 (4-7)	3.5 (2-5)	3.6 (2-4)	2.5 (1-3)	3.1 (2-4)	3.1 (2-4)	2.9 (2-4)	2.6 (1-3)	2.1 (2-3)	1.9 (1-3)	1.2 (0-2)
Photic zone (m)	9.7 (5-12)	9.8 (7-13)	11.4 (9-14)	8.6 (5-11)	8.3 (5-10)	5.7 (3-7)	7.6 (5-9)	7.4 (5-10)	6.5 (3-8)	6.4 (4-8)	5.1 (4-6)	4.3 (2-6)	1.4 (1-2)
T. Alk (mg/l $CaCO_3$)	12.89 (11-15)	11.89 (11-13)	12.32 (11-14)	13.79 (13-15)	13.07 (12-15	17.29 (16-19)	13.04 (13-14)	13.07 (12-15)	12.79 (12-14)	13.68 (13-15)	16.46 (15-19)	12.89 (12-15)	14.32 (13-17
Hardness (mg/l $CaCO_3$)	10.2 (9-11)	10.4 (8-11)	10.6 (10-11)	11.5 (11-12)	15.2 (15-15)	15.9 (13-18)	16.10 (16-16)	14.0 (14-14)	10.9 (10-12)	10.5 (9-11)	18.5 (19-19)	19.0 (19-19)	18.2 (18-18)
TN (µg/l)	216 (125-330)	208 (110-280)	174 (124-240)	183 (116-233)	467 (137-1634)	295 (182-416)	453 (70-1791)	459 (100-1811)	491 163-1766)	510 (116-1943)	596 (219-1833)	611 (296-1749)	820 (389-1939)
SRP (µg/l)	1.4 (0-5)	0.9 (0-2)	0.3 (0-1)	1.1 (0-2)	0.9 (0-2)	1.3 (0-3)	1.4 (1-2)	0.7 (0-1)	1.3 (0-2)	0.9 (0-2)	0.9 (0-2)	0.9 (0-2)	1.7 (0-4)
TP (µg/l)	7 (4-11)	6 (4-9)	4 (3-7)	7 (4-10)	8 (5-12)	10 (8-17)	9 (7-13)	11 (8-16)	13 (10-17)	16 (10-23)	21 (17-26)	21 (14-34)	53 (36-92)
Turbidity (NTU)	2.3 (1-5)	2.2 (1-4)	1.5 (1-3)	2.4 (1-4)	1.9 (1-4)	4.7 (2-12)	2.6 (2-5)	2.6 (2-5)	3.1 (2-6)	3.0 (2-6)	3.5 (2-7)	7.5 (2-18)	13.5 (6-36)
Specific Conductance (µS/cm)	42.3 (34-46)	38.7 (21-45)	40.6 (29-46)	44.2 (35-48)	47.1 (45-50)	50.8 (49-52)	47.1 (44-50)	45.8 (43-50)	44.8 (42-48)	45.6 (43-49)	50.8 (48-54)	42.9 (42-45)	50.0 (47-57)
TSS (mg/l)	1.4 (1-3)	1.3 (1-2)	0.8 (0-1)	1.3 (1-2)	1.4 (1-2)	2.1 (1-3)	1.8 (1-3)	1.9 (1-3)	2.5 (1-6)	2.2 (1-4)	3.0 (2-4)	4.6 (2-10)	10.0 (4-24)
CChlor a (µg/l)	1.31 (1-2)	1.09 (1-2)	0.95 (0-2)	1.52 (1-3)	2.73 (2-4)	2.43 (2-3)	3.45 (3-4)	4.20 (3-5)	4.15 (3-6)	5.3 (4-7)	8.16 (3-11)	5.75 (4-8)	14.52 (9-22)

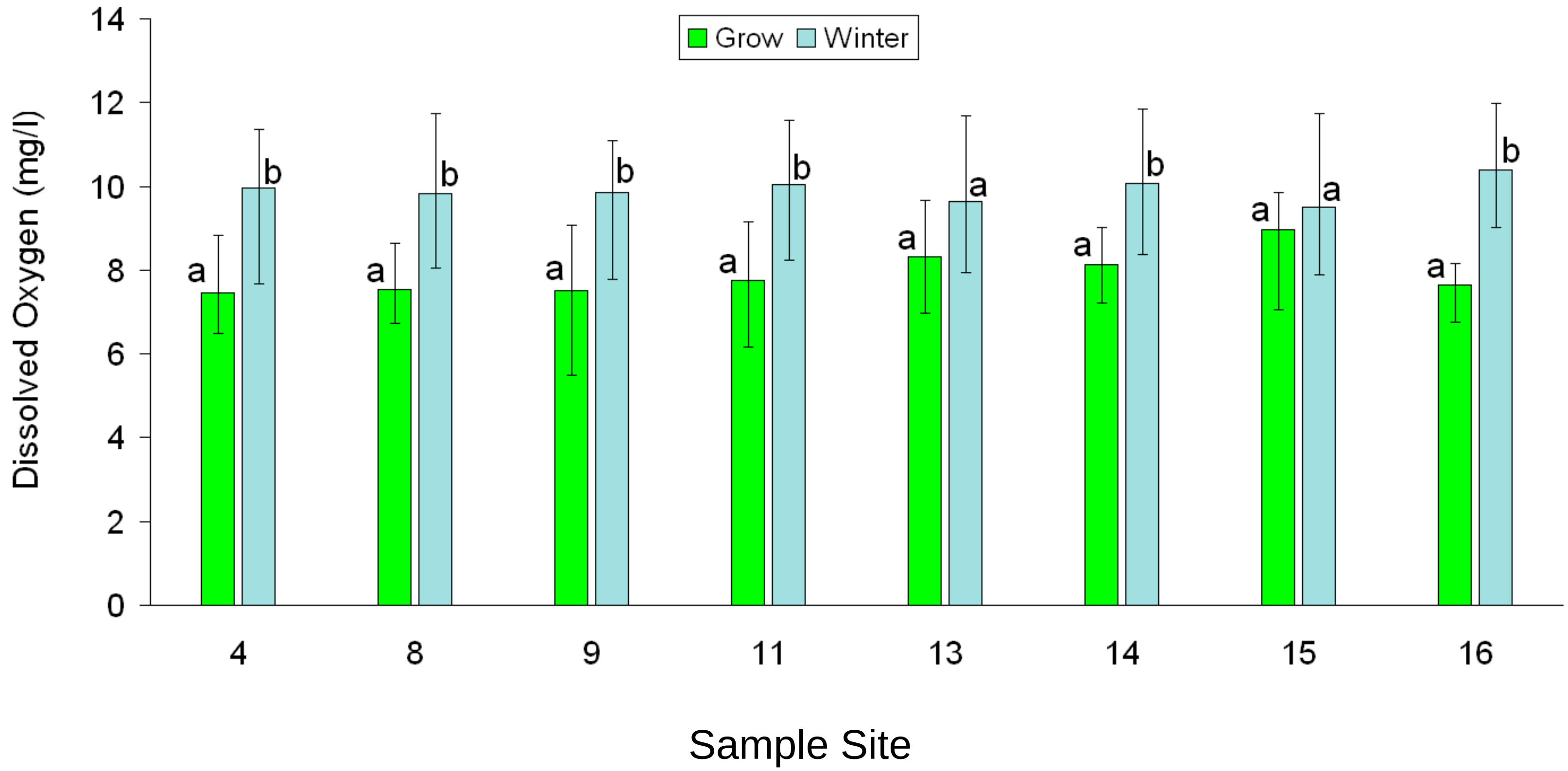

Figure 7. Dissolved oxygen means and ranges measured from ranges measured at a depth of five feet at 16 sampling locations on Lake Martin during the growing season (April-October) and the winter (November-March) of 2009-2010. Means subtended by different letters are significantly different ($\alpha = 0.05$).

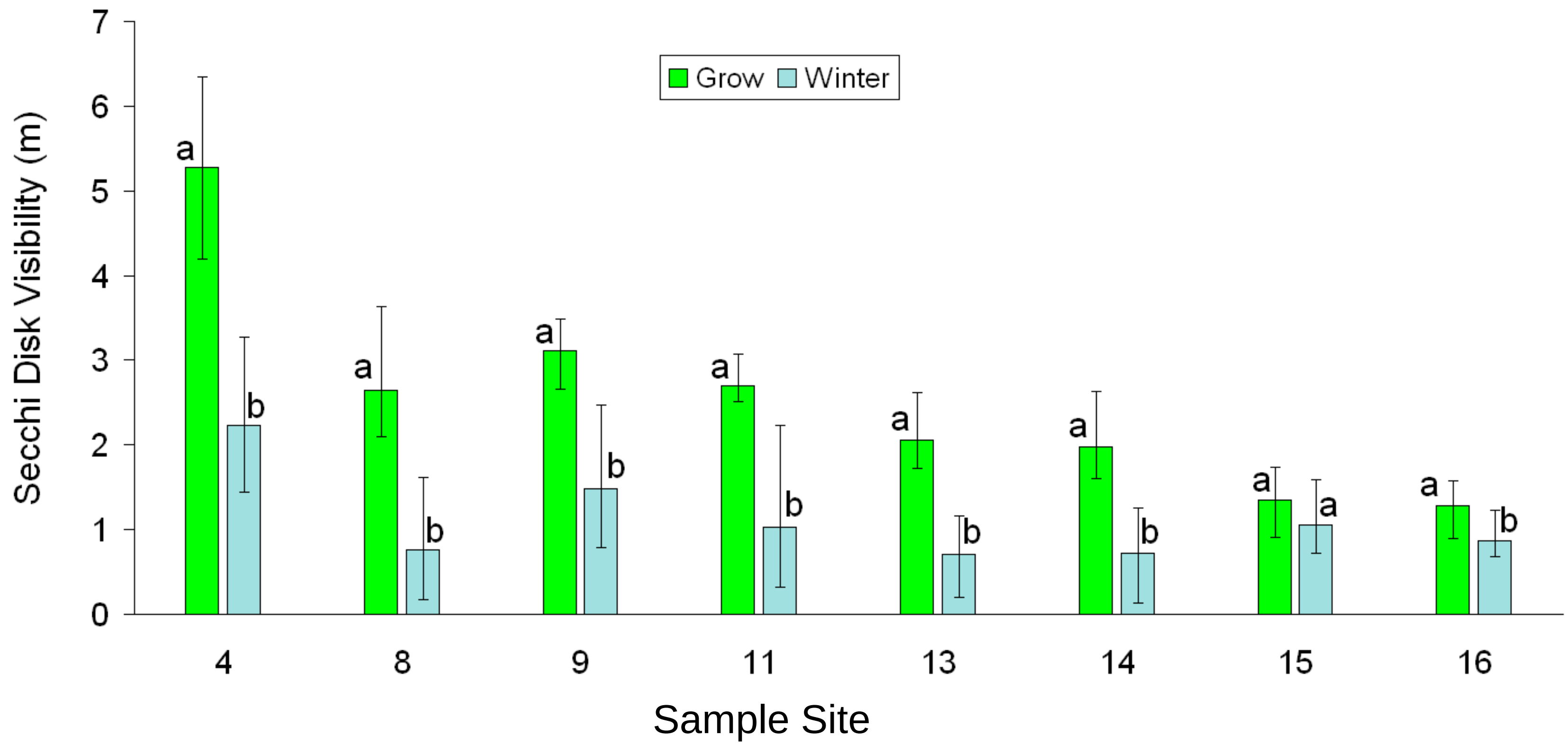

Figure 8. Secchi visibility means and ranges measured at 16 sampling locations on Lake Martin during the growing season (April-October) and the winter (November-March) of 2009-2010. Means subtended by different letters are significantly different ($\alpha = 0.05$).

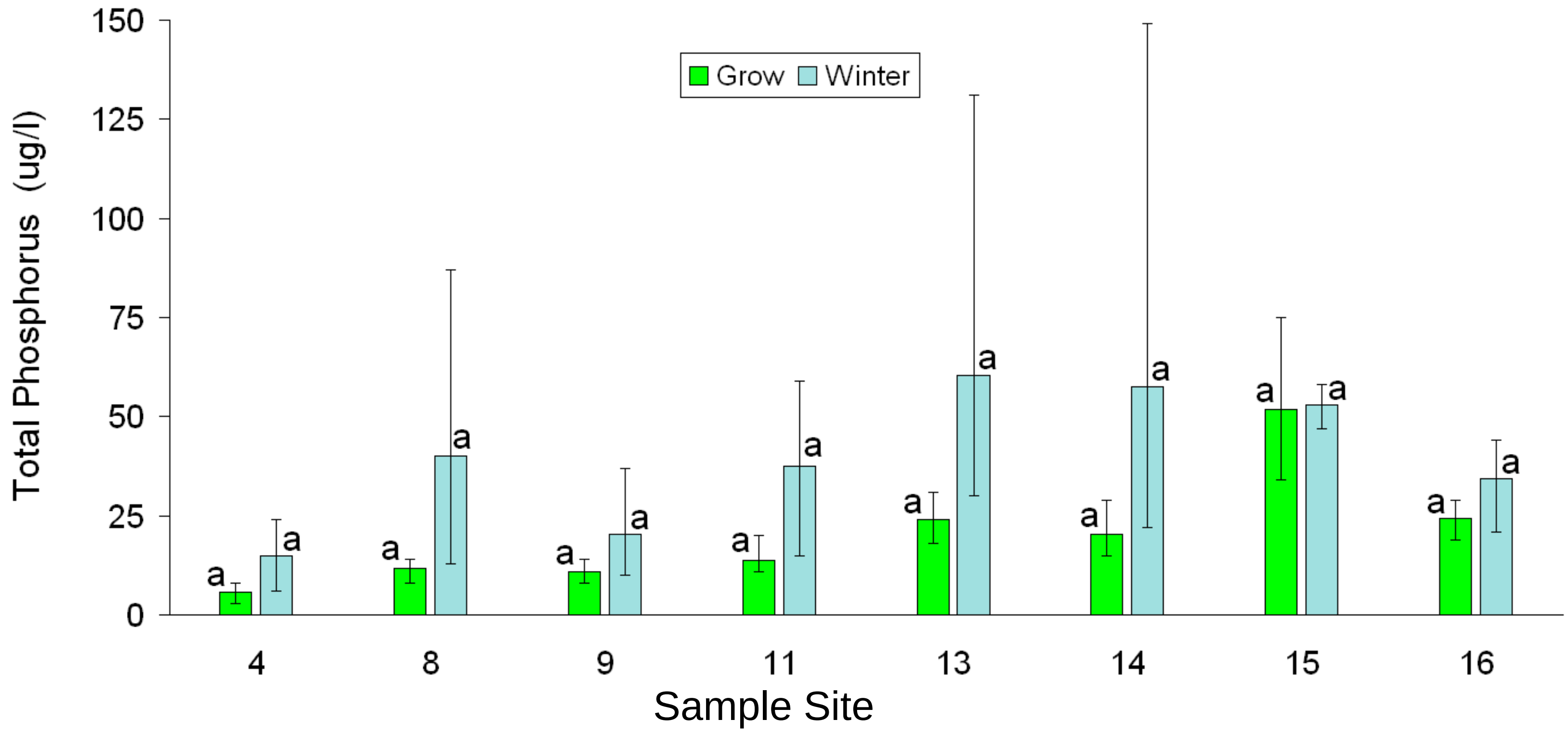

Figure 9. Total phosphorus means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) and the winter (November-March) of 2009-2010. Means subtended by different letters are significantly different (α = 0.05).

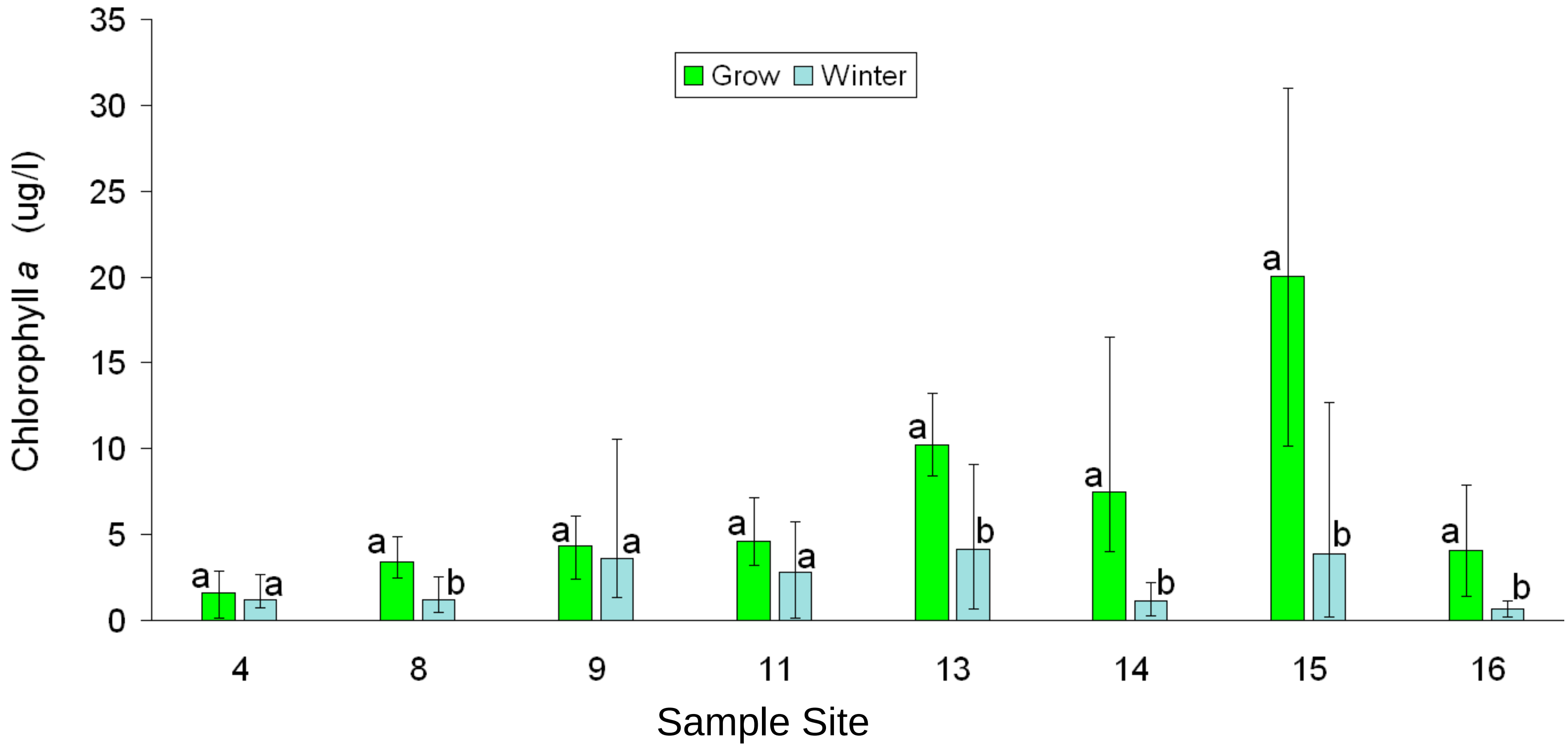

Figure 10. Corrected chlorophyll *a* means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) and the winter (November-March) of 2009-2010. Means subtended by different letters are significantly different ($\alpha = 0.05$).

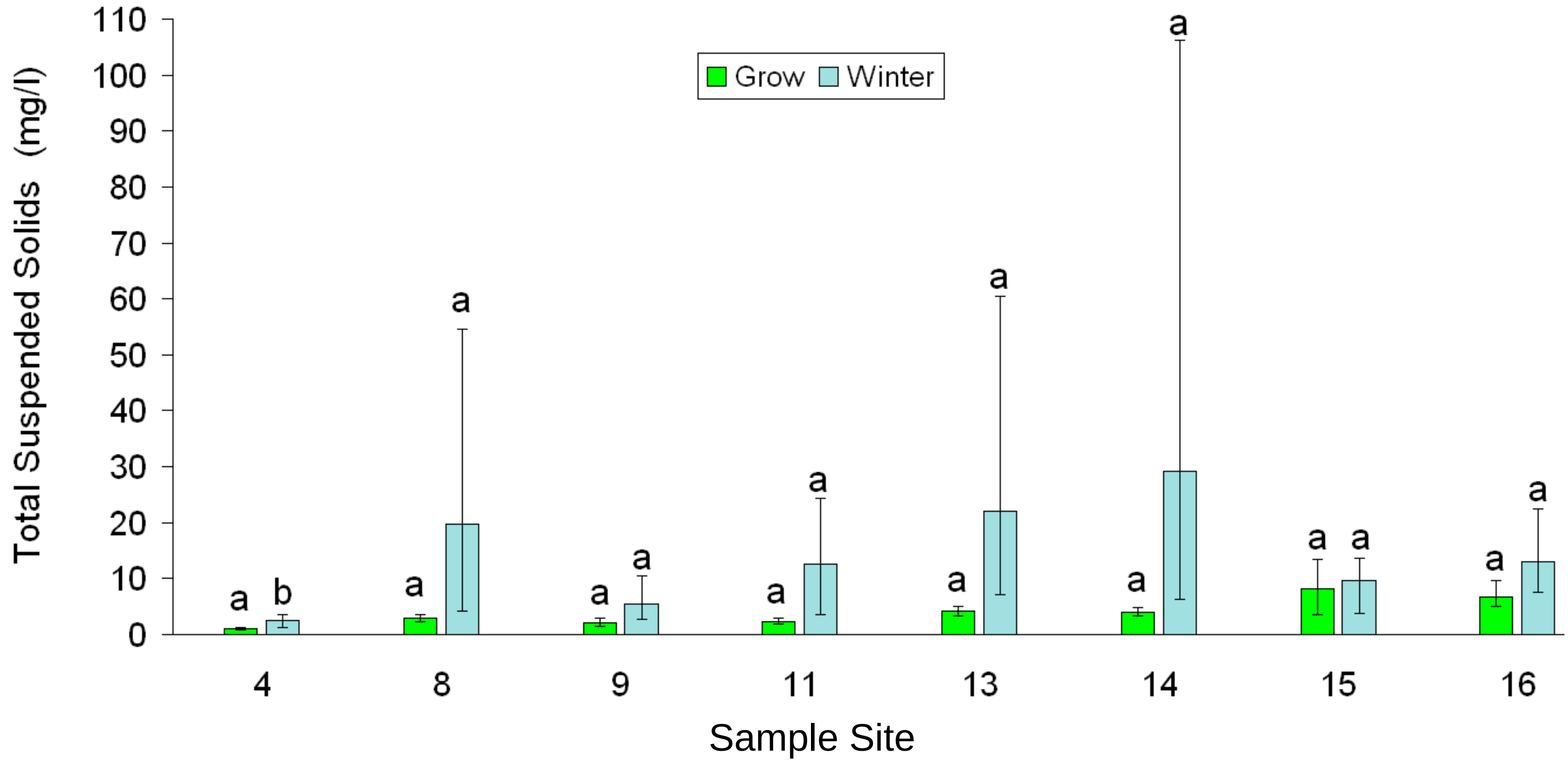

Figure 11. Total suspended solids means and ranges measured from a photic zone composite at 16 sampling locations on Lake Martin during the growing season (April-October) and the winter (November-March) of 2009-2010. Means subtended by different letters are significantly different ($\alpha = 0.05$).

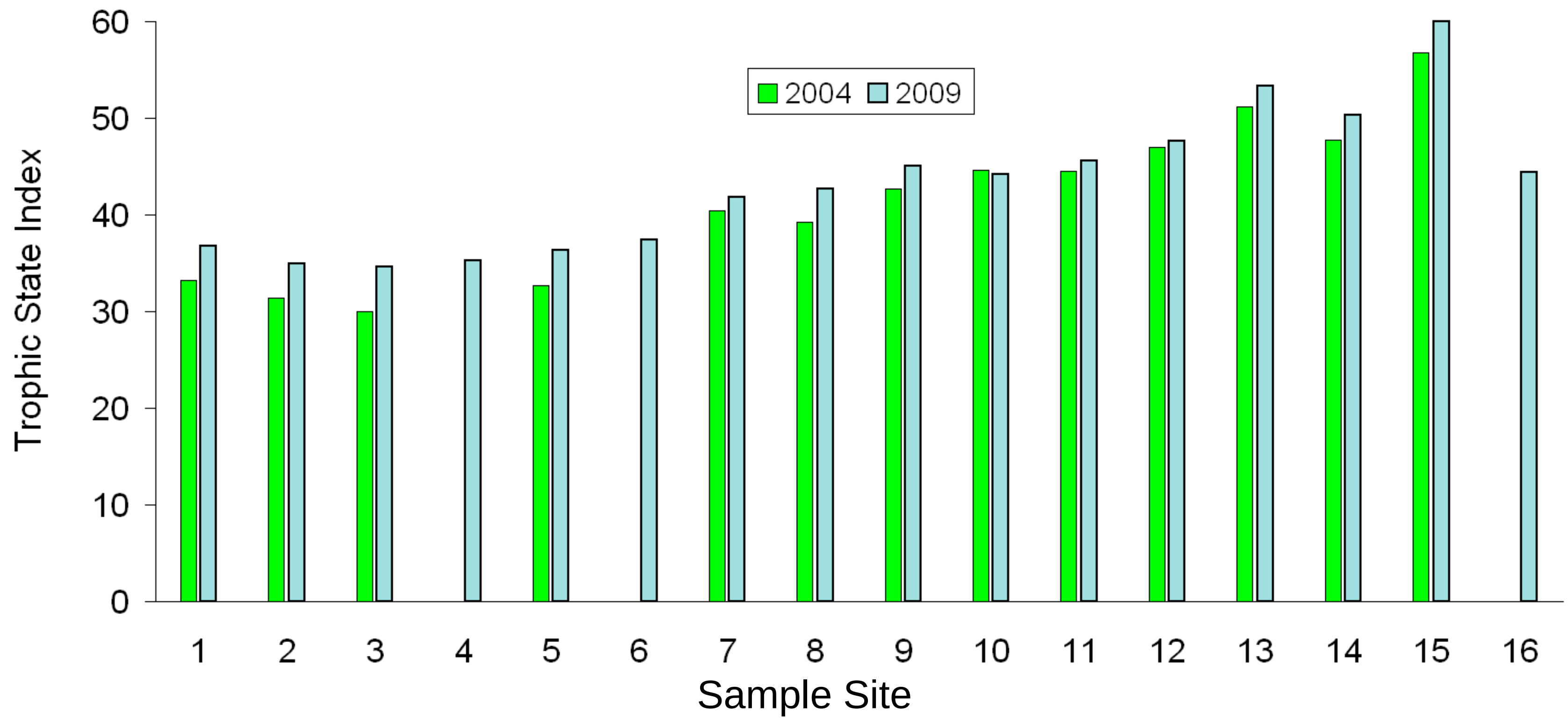

Figure 12. Trophic state index calculated from chlorophyll *a* concentrations at 16 sampling locations on Lake Martin during the growing season (April-October).