THE EFFECT OF NUTRIENT ENRICHMENT ON STREAM PERIPHYTON GROWTH IN THE SOUTHERN COASTAL PLAIN OF GEORGIA: IMPLICATIONS FOR LOW DISSOLVED OXYGEN

by

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(Under the Direction of Catherine Pringle and George Vellidis)

ABSTRACT

Blackwater rivers are common throughout the Atlantic Coastal Plain and water quality is heavily influenced by the flat topography, sandy soils and floodplain swamp forests. In the southern coastal plain of Georgia, streams regularly violate dissolved oxygen (DO) standards established by the Georgia Department of Natural Resources. Total Maximum Daily Load (TMDL) management plans must be developed for watersheds that are drained by DO-impaired streams but previous studies suggest DO may be naturally low. At nine sites throughout the region, eighteen passive nutrient diffusion periphytometers were deployed to determine if algal growth was nutrient and/or light limited. Periphyton biomass for treatments in the sun, measured as chlorophyll *a*, was significantly ($p < 0.05$) greater than corresponding treatments in the shade and algal growth was nutrient-limited at several sites where DO concentrations were below regulatory standards. Factors other than algae may be responsible for low DO concentrations during summer.

INDEX WORDS: Periphyton, Periphytometer, Dissolved Oxygen, Nutrient Enrichment

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DEDICATION

For my mother, who encouraged her children to *aim and achieve*.

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CHAPTER 1

INTRODUCTION

Background

The Atlantic Coastal Plain physiographic province of the United States can be divided into two contrasting regions: the Upper and Lower Coastal Plain. While streams predominantly drain mineral soils in the Upper Coastal Plain, streams draining peat that originate in swamps, bogs and marshes are more common in the Lower Coastal Plain (Smock and Gilinsky 1992). Furthermore, streams in the Upper Coastal Plain typically have higher slopes than Lower Coastal Plain streams (Smock and Gilinsky 1992).

In Georgia, river systems that originate in the Lower Atlantic Coastal Plain include the Ochlockonee, Satilla, St. Mary's and Suwannee River basins (Figure 1.1). Rivers and streams in this region are termed 'blackwater' due to the high levels of dissolved organic matter (DOM) that causes deep water to appear black and shallow water to appear tea-colored (Wharton 1978). Blackwater river systems are common throughout the coastal plain and these systems are heavily influenced by the flat topography and typically sandy soils (Smock and Gilinsky 1992). Dissolved organic acids in blackwater streams, for example, originate from humic and fulvic acids leached from swamp soils that do not retain DOM leached from terrestrial vegetation (Beck et al. 1974; Meyer 1990). Floodplain swamp forests that predominate in the region therefore have a strong influence on the water chemistry of blackwater streams.

303(d) Lists

Section 303(d) of the 1972 Federal Water Pollution Control Act – now the Clean Water Act – requires states to list impaired water bodies, establish Total Maximum Daily Loads (TMDLs) for each pollutant when streams do not meet designated use standards, and allocate responsibility to sources for lowering pollutant loads (U.S. House 2001). A TMDL is the total of a specific pollutant that a waterbody can receive and still meet water quality standards.

Most of the Georgia coastal plain streams on the 2001 303(d) list are included because of dissolved oxygen (DO) violations. In the southern coastal plain of Georgia (Ochlockonee, Suwannee, Satilla, and St. Mary's River Basin Group), 61 of the 67 streams listed violated DO standards. The Georgia Department of Natural Resources requires a daily DO average of 5.0 mg/L for most designated uses and a minimum of 4.0 mg/L. Under the TMDL program, the state must develop and implement costly water quality management plans for watersheds that are drained by DO-impaired streams in order to bring them back into compliance. TMDL models suggest a 40% average reduction in total nitrogen and phosphorus loads would be needed to improve dissolved oxygen concentrations (GEPD 2000). Nutrient load reductions may not improve DO concentrations in Georgia's southern coastal plain streams if natural factors are primarily responsible, however.

Factors Affecting Dissolved Oxygen

DO is one of the most important measures of water quality. Instream species richness and diversity are directly related to DO levels and prolonged exposure to concentrations below 3 mg/L are lethal to most fish species (Bosch et al. 2002). Both natural and anthropogenic factors can reduce DO levels within streams. Due to minimal surface turbulence, reaeration rates – the movement of atmospheric oxygen into water – are depressed in slow-moving streams, oxygen solubility is reduced as temperatures increase and the balance between oxygen production and consumption is disrupted by nutrient discharges (Joyce et al. 1985; Bosch et al. 2002). Increased algal growth from elevated nutrient concentrations can cause instream DO concentrations to fluctuate throughout the day due to algal photosynthesis and respiration (Lee 2002). Streams with dense algal populations experience the greatest fluctuations, as DO can decrease by 2 mg/L for a few hours each day when algae respire (Lee 2002). Decomposition of decaying algae by aerobic bacteria further reduces DO concentrations.

After monitoring nine sites within the Piscola Creek watershed of the Georgia coastal plain however, Vellidis et al. (1999) obtained the lowest mean summertime DO values (6.4 mg/L) from a reference stream with minimal nutrient loads. The stream was fed by a cypress dome wetland that had relatively high levels of organic matter (forest litter) and small flow velocities (Vellidis et al. 1999). Similarly, Ice and Sugden (2003) found DO concentrations below 5.0 mg/L in the majority of least-impaired and reference forest streams they studied in the Louisiana coastal plain. Low DO concentrations, particularly during summer months, may therefore be a natural condition in many streams.

Objectives

This research is linked to a larger study designed to determine the natural range of DO concentrations in Georgia coastal plain streams. My specific objectives were to: (1) determine whether algal growth in coastal plain streams is nutrient-limited and (2) investigate how the nutrient-irradiance relationship affects periphyton within these heavily shaded streams. Algae require light for photosynthesis and if stream concentrations of elements such as nitrogen and phosphorus are low, growth is often limited by the element in least supply relative to physiological needs.

To satisfy these two objectives, relative algal growth rates in four different stream environments were measured using passive nutrient diffusion periphytometers: (1) saturated nutrient concentrations and low irradiance; (2) saturated nutrients and high irradiance; (3) low nutrients and low irradiance; and (4) low nutrients and high irradiance.

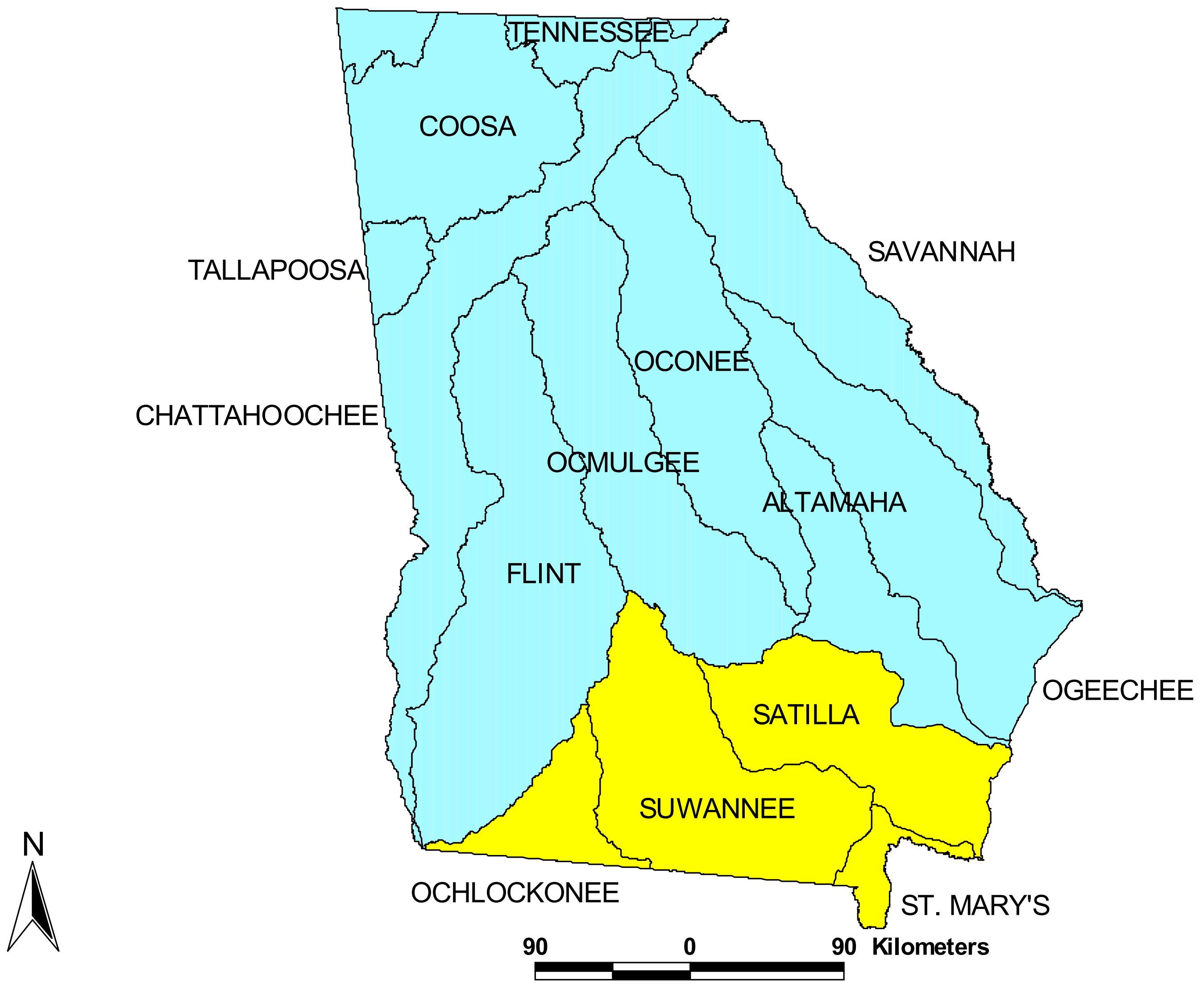


Figure 1.1. Georgia’s river basins. The four basins in the southern Coastal Plain are the Ochlockonee, Suwannee, Satilla and St. Mary’s.

CHAPTER 2

LITERATURE REVIEW

Background

Excessive inputs of phosphorus (P) and/or nitrogen (N) to various waters – streams, lakes, coastal areas etc. – can lead to eutrophication. Nutrient enrichment is a widespread problem in the U.S., and indeed throughout the world, as it affects the quality of domestic, industrial, agricultural and recreational water resources. Negative effects of eutrophication include increased phytoplankton and benthic algal biomass, decreased water transparency, dissolved oxygen (DO) depletion, extensive fish kills and increased incidence of toxic phytoplankton (Carpenter 1998). Additionally, planktonic and attached algae can produce tastes and odors in domestic water supplies (Lee 2002). Blooms of cyanobacteria caused by eutrophication in freshwater systems also contribute to the formation of trihalomethane during water treatment (Carpenter 1998).

For the Georgia coastal plain, surface-water quality problems include elevated nutrient concentrations and low DO levels (Berndt et al. 1996). Agriculture, ground-water/surface-water interactions, hydrogeology, and the southeastern U.S. climate are all factors that affect water quality in this area (Berndt et al. 1996). DO concentrations within coastal plain streams, for example, are negatively correlated with air and water temperatures and total organic carbon (Joyce et al. 1985). Most coastal plain streams flow through floodplain swamps and this also contributes to low DO levels (Benke and Meyer 1988). Within the Georgia coastal plain therefore, low DO concentrations can be caused by either a combination of factors or one dominant factor such as nutrient enrichment.

Nutrient Limitation and Biogeochemical Cycles

A general paradigm is that phosphorus usually limits algal and aquatic plant growth in freshwater systems while nitrogen limitation is common in marine systems (Hecky and Kilham 1988). There are exceptions to this however because in heavily disturbed areas such as those receiving large domestic and industrial wastewaters, neither element is limiting (Lee 2002). In this scenario, some studies have found that controlling anthropogenic inputs of P rather than N would be more cost-effective (e.g. Lee and Jones 1988). Evidence also suggests co-limitation of P and N for algae and vascular plants in freshwater systems (Rabalais 2002). Algal yields in some nutrient amendment studies have been higher for both nutrients together than for either P or N enrichment alone (Smith et al. 1999; Tank and Dodds 2003).

For marine systems, the concept of nutrient limitation by a single nutrient is also misleading. Excessive N and P inputs, for example, alter the biogeochemical cycle of silicon (Si) and this causes dissolved silicate limitation to occur more frequently (Rabalais 2002). Because algal growth can be affected by nutrient input ratios and biogeochemical processes, Howarth (1988) concluded that both N and P inputs to estuaries and coastal systems should be controlled to prevent eutrophication as many marine systems may actually be secondarily limited by P.

Conley (2000) outlined three aspects of N and P biogeochemistry that underscore differences between freshwater and marine nutrient limitation: (1) N denitrification losses, (2) N_2 fixation rates, and (3) regeneration of P in sediment. Unlike marine systems, N_2 fixation is common in freshwater systems and this allows N losses from denitrification to be recovered

(Howarth 1988). N thus develops as a limiting nutrient in marine systems because of its scarcity. Another key difference between both systems is the retention of P; freshwater systems retain P in the sediments through interactions with Fe but marine systems remineralize all deposited P and return it to the water column (Conley 2000). Seasonal differences in nutrient limitation for some estuarine systems can therefore be explained by the seasonal release of P from sediments. The process can be described as follows: warmer temperatures increase sulfate reduction rates, Fe cycling changes and both Fe-bound sulfate and Fe-associated P are released (Conley 2000). As a result, P concentration in the water column increases and this makes P limitation unlikely during summer.

Mulholland (1992) explored these processes in streams by studying factors regulating N and P concentrations. For example, biogeochemical cycles in upper soil horizons of forested watersheds reduce nutrient inputs to streams (Mulholland 1992). Differences in spatial and seasonal nutrient concentrations are caused by instream biological processes; nutrient uptake by microbes that decompose leaf litter can be significant (Mulholland 1992). Miltner and Rankin (1998) went further by investigating the relationship between primary nutrients and instream biotic integrity. Here, biotic integrity "refers to the extent to which a community has a species composition, diversity and functional organization comparable to that expected for the natural habitat of a region" (Miltner and Rankin 1998). Nutrient enrichment – especially increased P concentrations – was found to be negatively correlated to biotic integrity. Decreased relative abundance of top carnivores and insectivores, along with increased populations of tolerant or omnivorous fish species were all positively correlated to enrichment (Miltner and Rankin 1998). Interestingly, differences in the structure of the fish community as a result of enrichment were more pronounced than for the macroinvertebrate community. Scrapers were found to be highest in headwater streams that had elevated nutrient concentrations (Miltner and Rankin 1998). The increased algal biomass in these streams may explain higher populations of macroinvertebrates.

Bio-available forms of Nitrogen and Phosphorus

All forms of N and P entering surface waters are not available to stimulate algal growth. Eroding sediments (NH_4^+), organic matter (N and NH_4^+) and surface runoff (NO_3^-) provide the bulk of N entering freshwaters (Follett 2001). Typically, in developed U.S. watersheds, organic N constitutes 50% of total N (Sauer et al. 2001). Algae-accessible forms of N are nitrate and ammonia; organic N can also be made available through conversion to ammonia (Lee 2002). While total inorganic nitrogen ($NO_3 + NH_4$) concentrations below 100 µg/L may limit algal growth, streams with values above 400 µg/L are unlikely to be nitrogen limited (Horne and Goldman 1994).

For P, orthophosphate (PO_4^+) is the only form that can be assimilated by autotrophs (Correll 1998). P is lost from soils in both particulate – which is more dominant – and dissolved forms (Bennett et al. 2001). To support algal growth, some forms of particulate P are converted through mineralization reactions to soluble orthophosphate (Lee 2002) and the literature indicates that we can expect saturation of P for algal growth at concentrations between 3 – 25 µg/L (Bothwell 1985; Rosemond et al. 2002; Horner et al. 1983).

An increased possibility of P runoff to aquatic ecosystems now exists because of anthropogenic changes to the global P cycle. Animal manures and fertilization of agricultural crops are causing P accumulation in upland soils and this may increase the extent and severity of eutrophication throughout the world (Bennett et al. 2001). Additionally, because there is a lag time between P accumulation in soils and its eventual aquatic impact, "soil P accretion could lead to sudden and unanticipated changes in aquatic ecosystem productivity" (Bennett et al. 2001).

As nutrient loads increase, primary producers within ecosystems are the first to respond. Increased phytoplankton production increases turbidity and decreases light penetration through the water column. Consequently, the productivity and vertical distribution of other primary producers, such as attached algae and submersed macrophytes, may be affected (Skei et. al.2000). Studies also show that algae can in effect limit their further growth by shading themselves (Lee 2002).

Nutrient Enrichment Studies

Early research on nutrient enrichment assumed that rivers and streams were unaffected by excessive nutrient inputs (e.g. Hynes 1969). This argument derived from the belief that nutrient enrichment effects on algal growth were restricted by other physical, chemical, and biotic factors (Smith et al.1999). Rivers and streams were thought to be already nutrient saturated because "light limitation and short hydraulic residence times should restrict or prevent any potential algal responses to nutrient enrichment" (Smith et al. 1999). Furthermore, the response of primary and secondary consumers to nutrient enrichment – especially in complex temperate warmwater streams – can be indirect and unpredictable (Miltner and Rankin 1998).

Scientific evidence from numerous studies does, however, suggest that flowing waters are indeed affected by excess nutrients. For example, Huntsman (1948) fertilized an oligotrophic stream in Canada and found increased abundances of fish and aquatic organisms downstream. Elwood et al. (1981) observed a significant increase in benthic algal biomass, along with increased rates of detritus decomposition, after they used inorganic P to enrich an oligotrophic stream in Tennessee. Horner et al. (1990) investigated periphyton growth in laboratory stream channels and found that P concentration was a significant factor.

By utilizing the principle of passive diffusion, Matlock et al. (1998) designed a nutrient enrichment periphytometer to measure instream periphyton responses to elevated nutrient concentrations. Sampling units contained low density 1-L polyethylene bottles filled with nutrient solutions, bottle lids with 2.5 cm diameter holes, cellulose semi-permeable dialysis membranes and glass fiber filters. The dialysis membrane filters functioned as bio-filters and were placed across the bottle openings while the glass fiber filters provided artificial growth substrates and were placed above the membranes. Bottles were suspended in the stream channel for two weeks before glass fiber filters were collected and analyzed for chlorophyll *a* content. Matlock used this experimental technique to determine the limiting nutrient in an Oklahoma stream.

Dissolved Oxygen

Oxygen concentration in surface waters is a function of both oxygen inputs and outputs; therefore, factors such as aeration, photosynthesis, aerobic respiration and oxygen loss to the sediments are all important (Joyce et al. 1985). When excessive algal blooms decay, DO concentrations within surface waters are depleted due to “the biochemical oxygen demand of the algae, which exerts an oxygen demand in the water column and contributes to biotic and abiotic oxygen demand in the sediments” (Lee 2002). As organic carbon matter decays, aerobic bacteria deplete the available oxygen within the lower water column at a faster rate than oxygen diffusion from surface waters (Rabalais 2002). Therefore, hypoxic conditions will remain if oxygen consumption rates are greater than oxygen recharged to the system.

DO depletion does not occur solely during algal decomposition, however. During a single 24-hour cycle, algal photosynthesis increases instream oxygen concentrations during the day while algal respiration decreases DO at night (Lee 2002). This diurnal cycle of dissolved oxygen (Figure 2.1) is strongly influenced by the extent of algal growth; dense algal blooms will produce more extreme DO fluctuations within streams (Lee 2002). Fish and other aquatic organisms that depend on adequate DO concentrations are therefore adversely affected by explosive algal growth. Lee (2002) noted that growth rates of various aquatic species can be affected by DO concentrations below 5 mg/L. Furthermore, Hubbs et al. (1967) investigated the relationship between consistent DO cycles and activity patterns of killifish and found that individual oxygen consumption rates – especially at DO levels below 2 mg/L – were reduced as the available oxygen diminished. Higher fish activity during the day also corresponded to low DO concentrations recorded after dark (Hubbs et al.1967).

The relative importance of DO to fish was demonstrated by a study conducted by Alabaster (1959). By investigating the effect sewage effluent had on the instream distribution of both DO and fish, Alabaster (1959) found that fish can actually thrive in streams receiving undiluted sewage effluent provided that there is a high DO concentration. Significantly more fish were caught in traps where DO concentrations were high (Alabaster 1959).

Hypoxia in the Chesapeake Bay and the Gulf of Mexico

Two significant water bodies in the coastal U.S. that have been particularly affected by low DO concentrations are the Chesapeake Bay and the Gulf of Mexico. Both exhibit seasonal oxygen depletions due in part to nutrient enrichment. In fact, for both these waters, non-point source nutrient pollution from agriculture has been identified as the primary cause of eutrophication and its resultant effects (e.g. Staver and Brinsfield 2001; Ribaudo et al. 2001).

For the Chesapeake Bay, DO concentration in deep water begins to decrease during February and March as the water column undergoes increased stratification (Officer et al. 1984). Oxygen continues to decrease to near anoxic levels until September and October when less stratification occurs. The seasonal phytoplankton bloom, which occurs during midsummer, is apparently not directly associated with the development of anoxic conditions (Officer et al. 1984). Various data suggests that the oxygen demand – and hence, the anoxia – can be attributed to benthic respiration of organic matter from both the previous summer and fall (Officer et al. 1984). Because the reoxygenation rate will be lower than the benthic respiration rate, DO levels will decrease to zero during water column stratification. Therefore, the Chesapeake Bay anoxia is caused by two factors: benthic respiration and increased water column stratification during the summer. Of the two, benthic respiration appears to be the controlling factor. Nutrient inputs to Chesapeake Bay and annual plankton production have undergone historical increases while yearly variations of water column stratification have remained consistent (Officer et al. 1984).

In the northern Gulf of Mexico, agricultural nutrient loads from the Mississippi River Basin (MRB) have led to the development of the largest hypoxic zone in the Western Atlantic Ocean (Ribaudo et al. 2001). Because the Gulf accounts for approximately 25% of the total US continental shelf fishery (Mitch and Gosselink 2000), the hypoxia here is both a serious ecological and economic problem. The hypoxia is most severe in this region during summer but this is dependent on nutrient loading from the MRB (Mitch et al. 2001). Inflows from the Mississippi River increases the primary productivity of the upper waters and “phytoplankton and organic carbon from zooplankton sink to the bottom and utilize oxygen, either through respiration or decay" (Ribaudo et al. 2001). DO concentrations closer to the bottom therefore decrease to hypoxic or anoxic levels if mixing throughout the water column does not occur (Ribaudo et al. 2001).

Along with increased nutrients, global warming may result in an expansion of the hypoxic zone within the Gulf of Mexico. Increased atmospheric CO_2 concentrations could increase precipitation within the Mississippi River watershed and consequently, freshwater inputs to the Gulf would also increase (Justic et al. 1996). This scenario would produce a series of cascading events; water column stability, surface productivity, and global oxygen cycling would all be affected in the Gulf (Justic et al. 1996). Increased freshwater inputs are a concern because the level of hypoxia varies during dry and wet years. In 1988, record low discharges from the Mississippi River were observed and hypoxia in the Gulf was minimal; conversely, during the 1993 Great Flood, "the areal extent of hypoxia showed a twofold increase with respect to the 1985-1992 average" (Justic et al. 1996). Therefore, climate changes could actually enhance the hypoxic zone even if nutrient loads from the MRB remained constant.

Coastal Plain Streams

Dark-colored, low-gradient rivers that drain coastal plains are called blackwater rivers (Figure 2.2). These rivers are characterized by acidic water and relatively high levels of dissolved organic matter (DOM) (Berndt et al. 1996). For the Ogeechee River, which drains the Georgia coastal plain, DOM accounts for more than 96% of the total organic matter (Benke and Meyer 1988). Swamp forests that often border narrow floodplains of blackwater rivers contribute to the high levels of organic matter found in these systems (Berndt et al. 1996). For example, southeastern coastal plain streams in close proximity to heavily vegetated floodplains have increased contact with decomposing litterfall (Wharton 1978). The riparian forest therefore has a strong influence on the water chemistry of coastal plain streams.

Tan et al. (1990) studied the geochemistry of southeastern coastal plain streams and found that DO levels typically decline from winter to summer (Figure 2.3). DO can decrease due to a combination of factors such as increased microbial activity, low aeration rates and low streamflow (Tan et al. 1990). Low turbulence and low photosynthetic DO production – caused by shading throughout the year – combine to produce low reaeration rates in these streams (Joyce et al.1985). Also, the predominance of agriculture in areas such as the Little River watershed may increase the biological oxygen demand (BOD) of the streams through increased nutrient inputs.

The seasonally low DO concentrations found in coastal plain streams may not strictly be associated with agricultural nutrient loading however. Ice and Sugden (2003) found DO concentrations below the regulatory daily average (5.0 mg/L) in 80% of the minimally impacted Louisiana streams they studied. Within the Louisiana coastal plain, low gradient streams experience low flows and high temperatures during summer (Ice and Sugden 2003). Since Georgia coastal plain streams are exposed to similar natural conditions, the study therefore addresses the fundamental question of whether or not DO standards are even physically attainable for some southern streams during low summer flows. High organic loading, which leads to increased BOD, low summertime flows and high temperatures are all natural processes which can occur together to produce low DO levels (Ice and Sugden 2003). Other natural factors that might affect DO concentrations include stream discharge, type of channel bottom substrate and the extent of channel confinement (Ice and Sugden 2003).

High rainfall rates also affect stream water quality in the southeastern US. Annual rainfall in the Georgia coastal plain can be variable but precipitation is generally heaviest during spring and summer. Streamflow is closely linked to precipitation patterns and in the Little River watershed for example, streamflow as a percentage of rainfall is greatest from January to April (Sheridan 1997).

Water Quality Implications

Clearly, with ever increasing nutrient loads and the potential for the increased prevalence of eutrophication, controlling anthropogenic nutrient inputs to aquatic systems is essential. Bennett et al. (2001) concluded that the potential impacts of soil P accumulation could be reduced by: (1) controlling sources; and (2) increasing sinks. Sinks include riparian buffers, wetlands and detention basins (Bennett et al. 2001). However, these measures may be inadequate because of sediments present in eutrophic waters. Regardless of nutrient reductions from watersheds, sediments containing particulate N and P could maintain high algal biomass (Lee 2002). This phenomenon is more problematic in lakes, than streams, where sediments are constantly being transported downstream. The potential for recovery among various waters is consequently highly variable; typically, the eutrophic state persists and recovery is slow (Carpenter 1998). Long-term, dynamic approaches to combat the negative effects of eutrophication are therefore generally more reliable and effective.

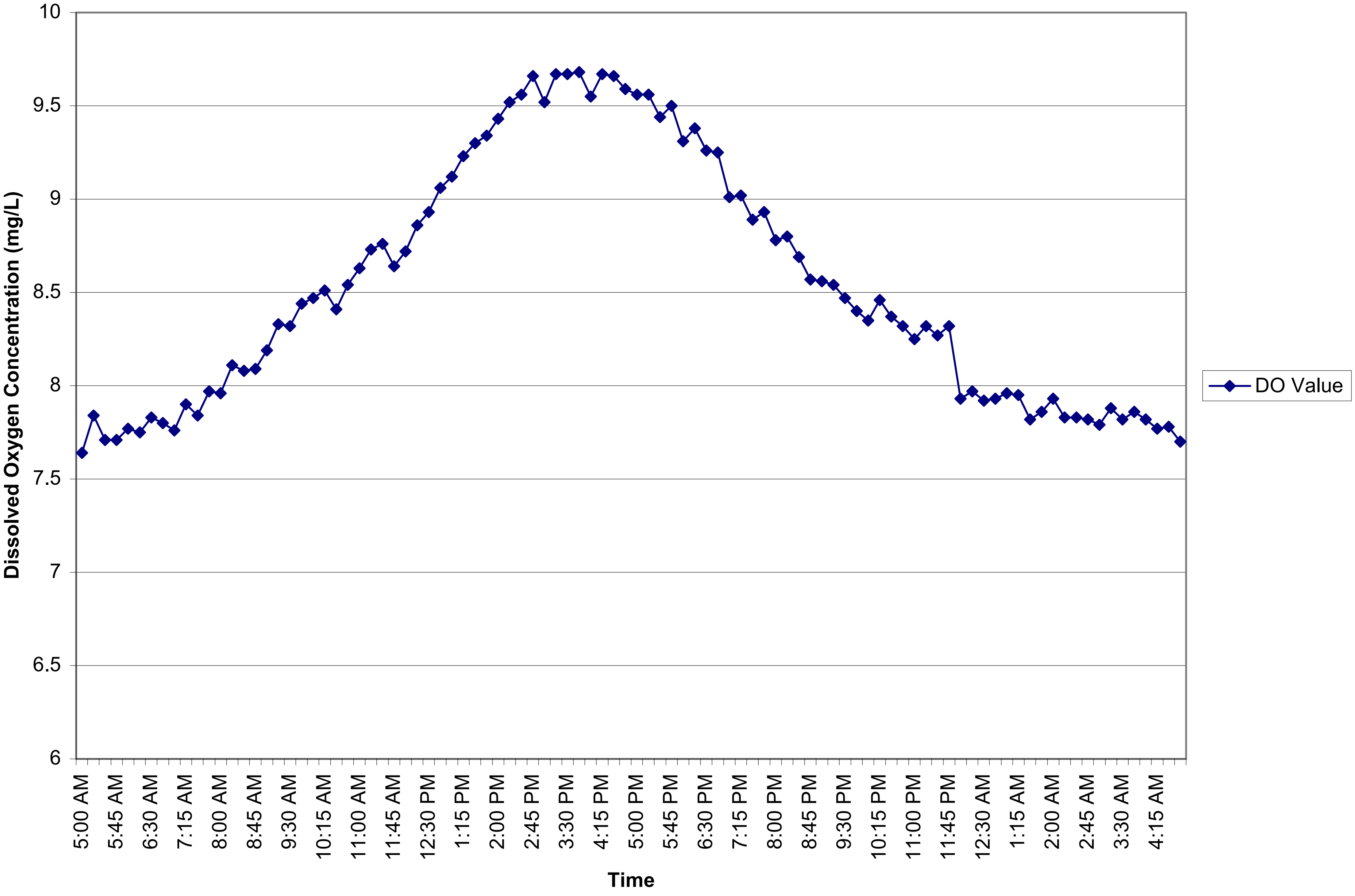


Figure 2.1. 24-hour cycle of dissolved oxygen concentrations at USDA-ARS Station N, Little River watershed. Concentrations are reported for February 1, 2004 to February 2, 2004.

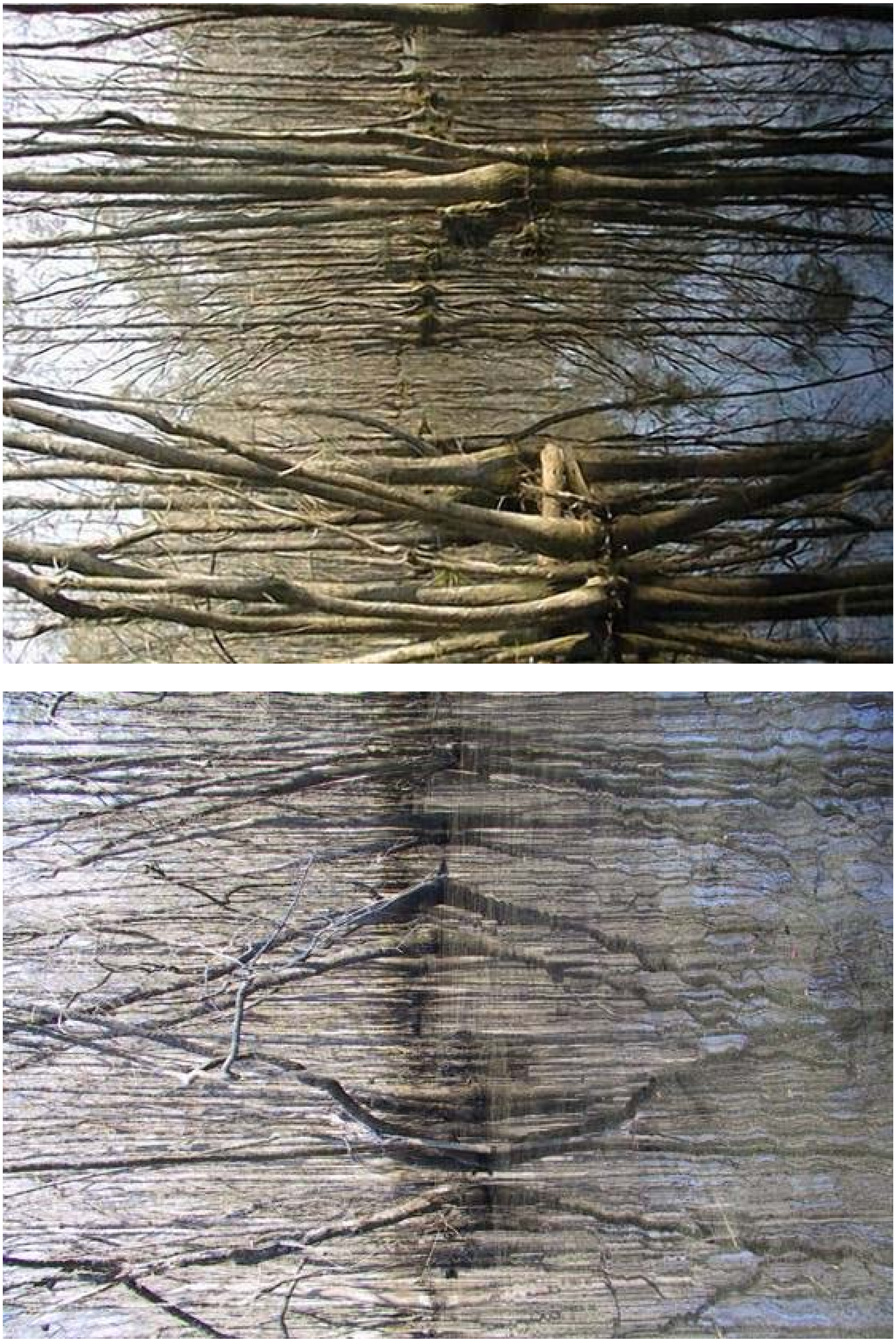


Figure 2.2. Blackwater streams in the Georgia coastal plain.

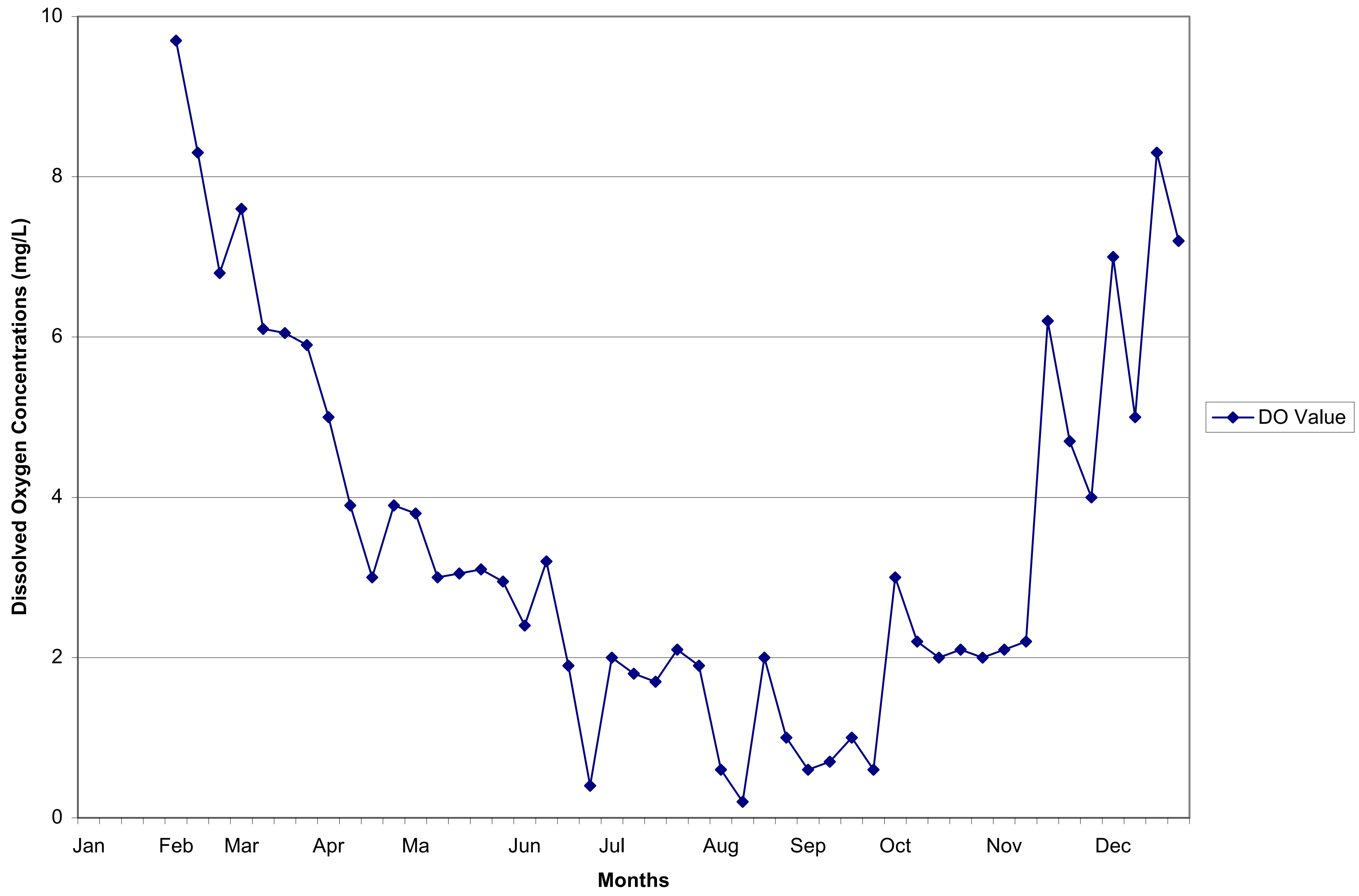


Figure 2.3. Dissolved oxygen concentrations at USDA-ARS Station B, Little River watershed 1979. Adapted from Joyce et al. (1985).

CHAPTER 3

PRELIMINARY EXPERIMENTS

Passive Nutrient Diffusion Periphytometers

Introduction

Several passive nutrient diffusion periphytometers were deployed between June 2003 and March 2004 to evaluate the experimental technique. Experiments were conducted in the Suwannee (Little River watershed; Figure 3.1) and Flint (Chickasawhatchee Creek watershed) River basins. The experimental technique – including nutrient reservoirs, nutrient concentrations and deployment length – was modified throughout these experiments to determine the suitability of periphytometers to both Georgia coastal plain streams and the fundamental research goal: to investigate the relationship between nutrients, algae and dissolved oxygen concentrations.

Experimental Technique

Matlock et al. (1998) designed the passive nutrient diffusion periphytometer to determine the limiting nutrient in an Oklahoma stream. Instream periphyton responses to elevated nutrient concentrations were assessed by sampling units that contained low density 1-L polyethylene bottles filled with nutrient solutions, bottle lids with 2.5 cm diameter holes, cellulose semi-permeable dialysis membranes and glass fiber filters. The dialysis membranes functioned as bio-filters and were placed across bottle openings while the glass fiber filters provided artificial growth substrates for algae and were placed above the membranes. For an individual bottle, the glass fiber filter and the dialysis membrane provided "a quiescent zone for passive diffusion of nutrients from the reservoir through the growth media to the stream" (Matlock et al. 1998). The control (deionized water) and each treatment – nitrate (NO_3), phosphate (PO_4) and nitrate-phosphate (NO_3-PO_4) – had six replicates and bottles were suspended in the stream channel on aluminum racks secured to the stream substrate by iron spikes. Periphytometers were deployed for two weeks before glass fiber filters were collected and analyzed for chlorophyll *a* content.

The periphytometer technique used in this study was modified from that described by Matlock et al. (1998). Each periphytometer frame was constructed with lawn fence wire (7.6 cm by 5 cm grid) cut in a 90 cm x 60 cm rectangle and attached by wire ties to 5 cm diameter schedule 40 PVC pipes (Figure 3.2). For a single frame, two PVC pipes (each 93 cm long) were connected by 90° elbows to a single 46 cm pipe at one end while 45° elbows were used to connect two 30 cm pipes at the other end. A 90° elbow was used to connect the two 30 cm pipes together to complete the frame. The 45° elbows produced a V-shape that turned the device into the flow.

Twenty plastic scintillation vials (20 mL, Fisherbrand catalog no. 03-337-23C) and six 250 mL bottles (Fisherbrand catalog no. 02-896-2D) were attached to the wire grid with black wire ties. Scintillation vials were arranged on the grid at the front end of the frame while 250 mL bottles were arranged at the opposite end. A 1.6 cm hole was drilled into each scintillation vial cap while 2.5 cm holes were drilled into 250 mL bottle caps. Durapore membrane filters (25 mm diameter, 0.45 µm pore size, Millipore catalog no. HVLP02500) and glass fiber filters (42.5 mm diameter; 1.5 µm pore size, Whatman 934-AH catalog no. 1827-105) were cut and placed across the top of each scintillation vial and 250 mL bottle, just inside the drilled caps. Glass fiber filters functioned as artificial growth substrates while membrane filters regulated diffusion of the nutrient solutions. Fiberglass insect screening, attached by rubber bands, was used to cover each individual bottle cap to protect glass fiber filters from grazers (Figure 3.2).

Preliminary Experiments

Laboratory Analyses

Stream water samples were taken when periphytometers were deployed and again when they were removed. These samples were analyzed for suspended solids, nitrate-N, ammonium-N, orthophosphate (soluble reactive phosphorus), chloride, dissolved organic carbon, and potassium using standard analytical techniques (APHA 2000). After removal from the streams, remaining solutions in 250 mL bottles and 20 mL scintillation vials were analyzed separately for nitrate and phosphate concentrations. Collected filters were stored in petri dishes, kept cool and transported to the lab for analysis. EPA Standard Method 10200H.3 (APHA 2000) was used to extract chlorophyll *a* from the filters and chlorophyll *a* content was determined by analysis on a Turner Designs TD 700 laboratory fluorometer. Chlorophyll *a* data for each sample was then expressed as µg/cm^2 by relating the mass of chlorophyll *a* extracted to the exposed surface area of 20 mL (1.7 cm^2) and 250 mL (3.3 cm^2) filters. Values for each filter in preliminary experiments are reported in Appendix A.

Experiments 1 and 2

Periphytometers were first deployed in the Little River watershed in Tift County, GA (Figure 3.1). At Site 1, a cross-section of the Little River main channel that was manually excavated 40 years ago for irrigation, two periphytometers were deployed midstream on June 27, 2003. All bottles on one frame were filled with deionized water and used as controls. The other periphytometer frame had bottles filled with a solution of 87.5 mg/L NO_3-N (using 632 mg/L KNO_3) and 10 mg/L PO_4-P (using 86 mg/L $Na_2HPO_4 \cdot 7H_2O$). This solution provided elevated nutrient concentrations to the artificial growth substrates. Each periphytometer frame was carefully placed in the stream with glass fiber filters perpendicular to the stream substrate and parallel to stream flow. To ensure stability, periphytometers were tied to trees at the V-shaped front and metal rods were placed just inside the frames at the back (Figure 3.2). Periphytometers were retrieved on July 2, 2003 after being deployed in the shade, under tree canopy cover, about 1 m apart.

On July 3, 2003, control and NO_3-PO_4 treatment replicates were used together and randomly arranged on the two frames used in experiment 1. Each frame therefore had three 250 mL bottles and ten 20 mL vials filled with the nutrient solution and three 250 mL bottles and ten 20 mL vials filled with deionized water. The 20 mL scintillation vials were arranged independently of the 250 mL bottles and both frames were deployed for five days in the same positions as the June 27th experiment.

Treatment means from both experiments were compared using the analysis of variance (ANOVA) procedure in Statistical Analysis Systems (SAS Institute, Cary, NC). Mean chlorophyll *a* values for control and treatment groups were low for both experiments but values for the July 3rd experiment were higher (Table 3.1). In the June 27th experiment, the mean chlorophyll *a* value for 250 mL control filters was significantly higher than 250 mL nutrient filters (Table 3.1). There were no significant differences among remaining treatment comparisons at $\alpha = 0.05$. For one frame in the July 3rd experiment, the mean chlorophyll *a* value for 250 mL nutrient filters was significantly higher than 20 mL nutrient filters (Table 3.1). Remaining treatment comparisons were not significantly different.

The 250 mL control filters in the June 27th experiment possibly had significantly higher chlorophyll *a* readings than the 250 mL nutrient filters because of differences in sunlight. The control frame was placed in the same position as Frame 2 from the July 3rd experiment and Frame 2 produced higher chlorophyll *a* values than Frame 1 (Table 3.1).

Experiment 3

Since chlorophyll *a* values were low for the first two experiments in the shade, the third experiment explored the potential effect of sunlight. Two periphytometers were deployed on July 11, 2003 near the western bank of Site 1; periphytometers deployed here, Site 2, were designated as either a control or nutrient frame. The third experiment was essentially the same as the first with only the location being different. Unlike Site 1, Site 2 had no flow and abundant sunshine. After five days, both frames were taken from the stream and half the glass fiber filters were removed from each periphytometer. Frames were returned to the stream for a further five days after quickly and carefully removing filters in the field. Overall, based on the ANOVA procedure, treatment means were significantly higher for Site 2 than Site 1. There were no significant differences between any treatment groups for filters removed after five or ten days (Figure 3.3).

Residual nutrient concentrations for both 250 mL bottles and 20 mL vials produced largely inconsistent results for the first three experiments (Table 3.3). As a result, remaining solutions in each 20 mL vial were considered individual samples in all subsequent experiments; a composite sample had been used in earlier experiments to represent a particular treatment (e.g. 20 mL NO_3-PO_4, 20 mL control). This new approach showed the individual variability among different treatment groups as well as consistent N: P molar ratios within 20 mL NO_3-PO_4 vials (Table 3.3).

Experiment 4

Beginning on September 1, 2003, only 20 mL scintillation vials were used in the experiments (Figure 3.4) because chlorophyll *a* values on 250 mL filters were not consistently greater than 20 mL filters. Nutrient treatments in the fourth experiment were also separated to produce three treatment groups: NO_3, PO_4 and NO_3-PO_4.

Two separate sites were compared as one periphytometer was deployed at Site 1 while the other was deployed at gaging Station B, a site monitored by the United States Department of Agriculture – Agricultural Research Service (USDA–ARS) on the main channel of the Little River in Tift County. This new location (Site 3; Figure 3.1) had both abundant sunshine and streamflow. Forty randomized 20 mL scintillation vials were attached to each frame with ten replicates each of deionized water, 87.5 mg/L NO_3-N (using 632 mg/L KNO_3), 10 mg/L PO_4-P (using 86 mg/L $Na_2HPO_4 \cdot 7H_2O$) and a combined nitrate-phosphate solution. Frames at both Site 1 and Site 3 were deployed for eleven days and treatment means were compared using the ANOVA procedure in SAS.

Unlike Site 1, periphytometers deployed at Site 3 were exposed to full sunlight and this translated into higher chlorophyll *a* values (Figure 3.3). Individual treatment means at both Site 1 and Site 3 were not significantly different but all treatment means from Site 3 were significantly greater than their corresponding treatments at Site 1 (Table 3.1).

Experiment 5

Results from earlier experiments indicated that solar radiation was a significant factor affecting algal growth on periphytometers. However, chlorophyll *a* values on 20 mL nutrient filters in the sun were not significantly different from control (deionized water) filters. The fifth experiment on October 17, 2003 investigated whether periphytometers were being deployed longer than necessary. Returning to Site 3 (Figure 3.5), two periphytometers were deployed 2 m apart in full sunlight and one frame was removed after three days while the other was removed after seven days.

After three days at Site 3, both control and PO_4 filters had significantly higher chlorophyll *a* mean values than NO_3 and NO_3-PO_4 filters (Table 3.1). Chlorophyll *a* mean values from control and PO_4 filters were not significantly different; NO_3 and NO_3-PO_4 filters were also not significantly different. After seven days, chlorophyll *a* mean values from control, PO_4 and NO_3-PO_4 filters were all significantly greater than NO_3 filters. Remaining treatment comparisons were not significantly different. Additionally, chlorophyll *a* mean values for treatments after three days were not significantly different from corresponding treatments after seven days (Table 3.1). At Site 3 therefore, algal colonization of glass fiber filters did not increase significantly from three to seven days.

Experiments 6 and 7

Results from the fifth experiment suggested that periphytometers needed to be deployed longer for the method to distinguish differential algal growth rates in response to nutrient availability. For the sixth and seventh experiments, several modifications were made: (1) periphytometers were deployed for fifteen days, (2) protective fiberglass screens on scintillation vial caps were removed and (3) PO_4 concentrations were increased. Fiberglass screens were removed because chlorophyll *a* values in earlier experiments were very low and the screens may have inhibited maximum algal growth on the filters. Since periphytometers were going to be deployed longer, PO_4 concentrations were increased to ensure continual enrichment of the filters throughout the experiments. Increased phosphate concentrations also produced the theoretical optimum molar N: P ratio for benthic algae (16: 1) (Redfield 1958) in NO_3-PO_4 20 mL vials.

Both experiments were conducted in the Chickasawhatchee Creek watershed in Baker County and were facilitated by the Jones Ecological Research Center in Newton, GA. Forty randomized 20 mL scintillation vials were attached to each frame, with ten replicates each of deionized water, 87.5 mg/L NO_3-N (using 632 mg/L KNO_3), 12 mg/L PO_4-P (using 103.8 mg/L $Na_2HPO_4{\cdot}7H_2O$) and a combined NO_3-PO_4 solution. Two periphytometers were deployed 2 m from the edge of the stream bank in the Chickasawhatchee Creek (Site 4) on March 11, 2004 (Figure 3.6). Frames were 1 m apart and both were exposed to full sunlight: because of the stream's current, one frame appeared to be in a higher flow position.

On March 17, 2004, two periphytometers were deployed at Site 5, an oligotrophic wetland area with no flow at the Jones Ecological Research Center (Figure 3.7). Nutrient treatment concentrations used in the Chickasawhatchee Creek experiment were also used here. Both periphytometers were only 1 m apart and were exposed to full sunlight.

In the Chickasawhatchee Creek, chlorophyll *a* values from the periphytometer exposed to stronger flow were log transformed prior to analysis to meet the ANOVA assumptions of normality and homogeneity of variances. The nonparametric Kruskal-Wallis test was used to test treatment effects at Site 5 (oligotrophic wetland) because transformations did not stabilize the variances. Multiple (separate-variance) t-tests were also performed on all possible pairwise comparisons of Site 5 treatment means. Tukey's multiple comparison procedure was used to determine which means were significantly different at $\alpha = 0.05$.

Chlorophyll *a* values from the Chickasawhatchee Creek experiment were dramatically higher than those obtained in previous experiments (Figure 3.3). The highest mean value obtained before this experiment for any treatment group was 1.21 $\mu g/cm^2$ for the 20 mL NO_3-PO_4 filters from the July 11, 2003 experiment (ten days). For one frame at Site 4, the mean chlorophyll *a* value for PO_4 filters was 8.48 $\mu g/cm^2$. The frame that experienced stronger flow (frame 2) produced higher chlorophyll *a* mean values than filters on the adjacent frame. PO_4 and NO_3-PO_4 filters from both frames were not significantly different but they were significantly higher than the corresponding control and NO_3 filters (Table 3.1). This experiment was the first without protective screens and eight filters were lost from the two frames. Grazers or the direct current velocity on the filters may have contributed to the lost filters.

Periphytometers at Site 5 were also deployed without protective screens on the vial caps and thirty six filters (out of eighty) were lost here; this site had no flow so grazers may be primarily responsible for the lost filters. Since almost half of the filters were lost, data from both frames were combined (Figure 3.3). The Kruskal-Wallis test, followed by Tukey's multiple comparison procedure, revealed significant treatment differences that were identical to results from the multiple t-tests. Mean chlorophyll *a* values for NO_3 (0.36 $\mu g/cm^2$) filters were significantly different from control (0.21 $\mu g/cm^2$) and PO_4 (0.22 $\mu g/cm^2$) filters while NO_3-PO_4 filters (2.10 $\mu g/cm^2$) were significantly greater than all other treatment groups (Table 3.1).

Conclusions

Results from these preliminary experiments indicated that 20 mL vials could be used in place of 250 mL bottles for nutrient enrichment research within Georgia coastal plain streams. After being left in the stream for ten days, 20 mL scintillation vials actually produced greater chlorophyll *a* readings than 250 mL bottles (Figure 3.3). Although no significant differences were found between mean chlorophyll *a* readings for 20 mL nutrient and control filters in the first five experiments, the data suggests that mean values were skewed because of extreme outliers. For example, the July 11th experiment (ten days) had one 20 mL control filter with a chlorophyll value of 0.047 $\mu g/cm^2$ while another had 2.224 $\mu g/cm^2$ (Appendix A). Without these two values, the mean chlorophyll *a* value for the 20 mL nutrient filters would be significantly higher than the 20 mL control filters.

Chlorophyll *a* data from the Jones Center experiments indicated that the protective fiberglass screens may have significantly affected filter colonization. Without the screens, chlorophyll *a* values increased and were consistent with ambient nutrient concentrations at both sites. Total inorganic nitrogen (NO_3-N + NH_4-N) concentrations above 400 μg/L are not expected to limit algal growth (Horne and Goldman 1994) and in the Chickasawhatchee Creek for example, greater chlorophyll *a* values on PO_4-enriched filters corresponded to ambient inorganic N levels (290.55 – 521.10 μg/L) (Figure 3.8). The longer deployment time (fifteen days) may have also have influenced these results but the eleven day experiment at Station B (Experiment 4) produced chlorophyll *a* values that were well below values from the Chickasawhatchee Creek experiment (Table 3.1). It is unlikely that Station B values would have been similar if the periphytometer remained in the water another four days. Periphyton colonized both the filters *and* the screens in the Little River experiments and this likely resulted in an underestimate of chlorophyll *a* which was only measured on the filters. Results from the Jones Center experiments however, suggests that the adapted periphytometers could be used in nutrient enrichment studies if an alternate technique was used to protect the glass fiber filters which did not provide a substrate for algal colonization.

Accordingly, in subsequent experiments, each periphytometer consisted of a primary and secondary frame (Figure 3.9). Each primary frame contained the basic materials for the experiments: 20 mL plastic scintillation vials filled with deionized water or nutrient solutions, drilled vial caps, glass fiber filters and membrane filters. When each periphytometer was deployed, the secondary frame was attached beneath the primary frame to protect the glass fiber filters from grazers and prevent floating debris from moving up through the frame and settling on top of the 20 mL vials – thus potentially shading the filters.

Secondary frames had the same dimensions as primary frames but were constructed with 3.8 cm diameter schedule 40 PVC pipes (Figure 3.9). On one side of the secondary frame, a fiberglass insect screen was taped along the exterior to provide a continuous cover. A small hole was made in the screen near to the front of the frame – at the base of the V-shape – to accommodate the metal rod used to anchor each periphytometer unit. High density foam weatherstrip (MD Building Products, 1.3 cm x 1.9 cm) was glued along the other side of the secondary frame with silicone gel. The weatherstrip provided more protection for glass fiber filters because it closed the gap between primary and secondary frames when they were attached together. The fiberglass screen on the secondary frame was approximately 2.5 cm below scintillation vials on the primary frame (Figure 3.10). Several holes were drilled into the secondary frame to allow wire ties to connect both frames together and to ensure that the secondary frame sank lower in the water; scintillation vials on the primary frame therefore remained just beneath the water surface.

Diffusion Rate

Introduction

Two separate lab experiments investigated whether the periphytometer experimental technique supplied adequate nutrient concentrations to promote algal growth. Both the rate of nutrient diffusion from the 20 mL vials and nutrient concentrations present in glass fiber filters were essential factors that had to be addressed. In both experiments, Durapore membrane filters (25 mm diameter, 0.45 µm pore size, Millipore catalog no. HVLP02500) and glass fiber filters (42.5 mm diameter; 1.5 µm pore size, Whatman 934-AH catalog no. 1827-105) were cut and placed across the top of each scintillation vial, just inside the drilled caps.

The first experiment was conducted over ten days with fiberglass screens attached to each vial cap while a second, fifteen day experiment did not include fiberglass screens. The second experiment investigated diffusion rates over a longer period and was conducted after removing fiberglass screens in the adapted periphytometers. Since these experiments were designed to simulate the stream environment, results can be extrapolated to give an indication of nutrient levels algae would be exposed to when periphytometers are deployed.

Ten Day Experiment

For the first experiment (2/20/2004 – 3/1/2004), a 1.06 m long trough was built with two separate 7.6 cm diameter schedule 40 PVC pipes – 40 cm and 66 cm long – connected by a 10.2 cm diameter pipe (Figures 3.11 & 3.12). The 40 cm pipe was connected to a spigot that provided an artificial current (tap water) to the device with a flow velocity of 0.05 m/s. Water was allowed to flow in and out of the trough by attaching uneven aluminum stands that placed the trough at an angle. The top half of the 66 cm long PVC pipe was removed and ten scintillation vials were attached by rubber bands to individual aluminum wires that were supported by small cuts in the PVC pipe. Each vial was filled with a combined nutrient solution: 87.5 mg/L NO_3-N and 10 mg/L PO_4-P (using 632 mg/L KNO_3 and 86 mg/L $Na_2HPO_4 \cdot 7H_2O$). Vials were arranged 2.5 cm apart and one vial was removed after each day of the ten-day experiment – starting with the vial farthest from the incoming water source. Using a pipette, water samples were collected each day close to the vial that was removed on the final day of the experiment. Both water samples and solutions in retrieved vials were analyzed for nutrients using standard colorimetric procedures (APHA 2000).

Nitrate and phosphate diffusion curves revealed similar exponential declines in nutrient concentrations over the length of the experiment with a slight peak (N: 8.81 mg/L, P: 3.35 mg/L) for the 20 mL vial removed after nine days (Table 3.4; Figure 3.13). The nitrate concentration within the final 20 mL vial removed was 2.15 mg/L while the phosphate concentration was 1.58 mg/L. Based on an exponential fit of the data, the coefficient of determination (R^2) for nitrate and phosphate concentrations was 0.92. The average nitrate concentration within the daily collected water samples was 0.022 mg/L and this includes a relatively extreme value of 0.222 mg/L. Without this extreme value, the average nitrate concentration for the remaining samples was 0.012 mg/L. Phosphate concentrations were generally higher than nitrate concentrations and had an average value of 0.183 mg/L (Table 3.4).

Fifteen Day Experiment

The second experiment ran for fifteen days (3/12/04 – 3/27/04) and included fifteen scintillation vials without fiberglass screens (Figure 3.14). The initial trough used for the first experiment was modified to accommodate five additional vials; a 90 cm long PVC pipe was used with the 40 cm pipe to create a longer trough. The nutrient solution used to fill each 20 mL vial in this experiment was also different: 87.5 mg/L NO_3-N and 12 mg/L PO_4-P (using 632 mg/L KNO_3 and 103.8 mg/L $Na_2HPO_4{\cdot}7H_2O$). As with the first experiment, one scintillation vial was removed after each day of the experiment and analyzed for remaining nutrient concentrations.

Water samples were not collected in this experiment but NO_3 and PO_4 concentrations within each individual glass fiber filter were calculated to verify nutrient levels available to periphyton. Filters were analyzed after scintillation vials were removed from the trough. Nutrient concentrations were extracted by homogenizing each filter in 10 mL of water and correcting for the water volume already present in the filters. An average water volume – 0.1451 mL – was used to correct concentration values; wet and dry weights from five glass fiber filters that were not used in the experiment were used to calculate the average water volume retained in the filters.

Nitrate and phosphate diffusion curves in the fifteen day experiment both produced similar exponential concentration declines but there were two sharp deviations (Table 3.5; Figure 3.13). The 20 mL vials removed on the fourth (N: 53.96 mg/L, P: 10.677 mg/L) and seventh (N: 38.69 mg/L, P: 9.19 mg/L) days of the experiment had nutrient concentrations that were well above expected values. An exponential fit for the nitrate and phosphate concentrations produced R^2 values of 0.90 and 0.89 respectively.

For glass fiber filters, corrected NO_3 concentrations underwent an exponential decline in a pattern that was similar to the 20 mL nutrient solutions; NO_3 concentration peaks within the vials were reflected in the glass fiber filters (Table 3.5). PO_4 concentrations in glass fiber filters did not exponentially decline however. Filters retrieved in the later stages of the experiment (after ten days) had similar PO_4 concentrations to filters retrieved early (first five days). Average corrected PO_4 concentrations within glass fiber filters for each five day interval of the experiment were as follows: 5.09 mg/L, 4.30 mg/L and 5.62 mg/L. PO_4 concentrations in glass fiber filters therefore did not decrease as concentrations within 20 mL vials decreased. In contrast, average corrected NO_3 concentrations for each five day period were: 19.74 mg/l, 9.99 mg/L and 6.84 mg/L.

Discussion and Conclusions

While not an exact replica of stream conditions, the artificial flow through the trough was designed to simulate flow conditions found in Georgia coastal plain streams. Flow velocity (0.05 m/s) was based on the measured velocity in streams at the time of the study. For periphytometers deployed in different streams therefore, remaining nutrient concentrations in 20 mL vials may be different but the way in which nutrients diffused from deployment to retrieval dates should be similar.

Deviations from expected nutrient concentrations in both the ten and fifteen day experiments can be caused by a variety of factors. Affected vials may have been placed at a slightly upward angle in the water and variability in membrane filters may have reduced nutrient diffusion rates. In both experiments, a total of twenty five vials were used and only three had higher than expected nutrient concentrations (Figure 3.13). Since nutrient diffusion in the majority of vials followed a relatively consistent pattern, nutrient concentrations within 20 mL vials on deployed periphytometers are expected to decline exponentially. Also, nitrate and phosphate concentrations within the final 20 mL vials removed in both experiments were still quite high (NO_3: 2.15 – 4.47 mg/L and PO_4: 1.58 – 3.09 mg/L) (Tables 3.4 & 3.5). Vials on deployed periphytometers should have enough nutrients to continually enrich glass fiber filters throughout the experiments.

Daily water samples were collected during the ten day experiment to estimate nutrient concentrations at the artificial growth substrates. However, because of the low nitrate values obtained and inflated phosphate concentrations due to phosphates present in the tap water, it became evident that this method would be inappropriate. Each glass fiber filter in the fifteen day experiment was therefore analyzed for nutrient content after removal from the trough. Nutrient concentrations in the filters were sufficient to promote differential algal growth and therefore, in unsaturated streams, control (deionized water) filters should have significantly lower algal colonization rates than nutrient-enriched filters. Conversely, algal growth on control and nutrient filters should not be significantly different in streams with saturated ambient concentrations. These two scenarios assume that nutrients and not another factor, such as light, are limiting algal growth.

The diffusion experiments suggested that the periphytometer technique – with 20 mL nutrient reservoirs, membrane filters and glass fiber filters – could be used in Georgia coastal plain stream nutrient enrichment studies. Algal growth on the glass fiber filters should not be hampered by nutrient availability. The 20 mL vials function as point sources of nutrients that enable deployed periphytometers to assess (1) whether algal growth in a stream is nutrient-limited and (2) what nutrient(s) is/are limiting.

Table 3.1. Summary chlorophyll *a* data for preliminary periphytometer experiments.

Deployment Date	**Bottle Size**	**Frame**	**Treatment**	**Mean (µg/cm^2)**	**SD***	**CV***
27-Jun-03	250 mL	2	N + P	0.00181	0.00037	0.20581
(Site 1 - 5 days)	250 mL	1	Control	0.00348	0.00088	0.25204
(Little River cross-section)	20 mL	2	N + P	0.00284	0.00126	0.44193
	20 mL	1	Control	0.00291	0.00126	0.43319
03-Jul-03	250 mL	1	N + P	0.00874	0.00073	0.08346
(Site 1 - 5 days)	250 mL	1	Control	0.00619	0.00141	0.22703
(Little River cross-section)	20 mL	1	N + P	0.00434	0.00095	0.21959
	20 mL	1	Control	0.00598	0.00232	0.21959
	250 mL	2	N + P	0.01077	0.00176	0.16371
	250 mL	2	Control	0.00658	0.00266	0.40392
	20 mL	2	N + P	0.00598	0.00140	0.23471
	20 mL	2	Control	0.00840	0.00359	0.42778
11-Jul-03	250 mL	2	N + P	0.23391	0.06878	0.29406
(Site 2 - 5 days)	250 mL	1	Control	0.20275	0.05766	0.28436
(Little River cross-section)	20 mL	2	N + P	0.22043	0.03584	0.16261
	20 mL	1	Control	0.19626	0.08717	0.44415
11-Jul-03	250 mL	2	N + P	0.74966	0.09871	0.13167
(Site 2 - 10 days)	250 mL	1	Control	0.40768	0.25793	0.63268
(Little River cross-section)	20 mL	2	N + P	1.20944	0.29816	0.24653
	20 mL	1	Control	0.79236	0.61813	0.78011
01-Sep-03	20 mL	1	Control	0.00375	0.00214	0.57129
(Site 1 - 11 days)	20 mL	1	N	0.00411	0.00338	0.82288
(Little River cross-section)	20 mL	1	P	0.00538	0.00240	0.44580
	20 mL	1	N + P	0.00382	0.00119	0.31058
01-Sep-03	20 mL	2	Control	0.11073	0.06719	0.60679
(Site 3 - 11 days)	20 mL	2	N	0.14417	0.08968	0.62206
(USDA-ARS Station B)	20 mL	2	P	0.16315	0.14050	0.86115
	20 mL	2	N + P	0.06801	0.08151	1.19846
17-Oct-03	20 mL	1	Control	0.06089	0.01008	0.16556
(Site 3 - 3 days)	20 mL	1	N	0.04138	0.01073	0.25928
(USDA-ARS Station B)	20 mL	1	P	0.06041	0.01587	0.26274
	20 mL	1	N + P	0.04386	0.01241	0.28291
17-Oct-03	20 mL	2	Control	0.05682	0.01283	0.22573
(Site 3 - 7 days)	20 mL	2	N	0.03264	0.01705	0.52231
(USDA-ARS Station B)	20 mL	2	P	0.08707	0.05571	0.63980
	20 mL	2	N + P	0.06371	0.02862	0.44930
11-Mar-04	20 mL	1	Control	2.40137	0.91099	0.37936
(Site 4 - 15 Days)	20 mL	1	N	2.81317	0.82702	0.29398
(Chickasawhatchee Creek)	20 mL	1	P	6.85639	1.34920	0.19678
	20 mL	1	N + P	7.98893	1.20055	0.15028

Table 3.1. Summary chlorophyll *a* data for preliminary periphytometer experiments (continued).

Deployment Date	Bottle Size	Frame	Treatment	Mean (µg/cm^2)	SD*	CV*
11-Mar-04	20 mL	2	Control	4.13948	0.97381	0.23525
(Site 4 - 15 Days)	20 mL	2	N	4.66648	0.46119	0.09883
(Chickasawhatchee Creek)	20 mL	2	P	8.48485	1.86721	0.22006
	20 mL	2	N + P	8.05568	3.31065	0.41097
17-Mar-04	20 mL	1 + 2	Control	0.21288	0.03162	0.14854
(Site 5 - 15 Days)**	20 mL	1 + 2	N	0.36437	0.09879	0.27112
(Oligotrophic wetland)	20 mL	1 + 2	P	0.22656	0.05182	0.22873
	20 mL	1 + 2	N + P	2.09617	0.45388	0.21653

*S.D. = Standard deviation and CV = Coefficient of variation.

**Thirty six (out of eighty) filters were lost in the periphytometer experiments at Site 5. Chlorophyll *a* data from both frames were combined for statistical analyses.

Table 3.2. Stream nutrient concentrations during preliminary periphytometer experiments.

Date*	Location	NO$_3$-N (ug/L)	NH$_4$-N (ug/L)	SRP (ug/L)	N:P Molar Ratio
27-Jun-03	Site 1 (Experiment 1)	215.20	170.40	1073.75	1.14
02-Jul-03	Site 1	236.60	23.85	56.60	8.63
03-Jul-03	Site 1 (Experiment 2)	145.90	40.05	7.50	57.99
08-Jul-03	Site 1	1131.35	997.35	21.55	324.70
11-Jul-03	Site 2 (Experiment 3)	-------	-------	-------	-------
16-Jul-03	Site 2	-------	-------	-------	-------
21-Jul-03	Site 2	-------	-------	-------	-------
01-Sep-03	Site 1 (Experiment 4)	132.50	60.15	19.55	26.62
12-Sep-03	Site 1	48.15	48.65	54.95	6.02
01-Sep-03	Site 3	78.30	40.20	15.30	21.71
12-Sep-03	Site 3	108.15	46.55	27.40	15.01
17-Oct-03	Site 3 (Experiment 5)	0.85	265.45	1067.35	1.31
20-Oct-03	Site 3	0.70	173.30	185.85	4.93
24-Oct-03	Site 3	0.00	81.95	35.35	12.24
11-Mar-04	Site 4 (Experiment 6)	247.85	47.35	18.15	34.69
12-Mar-04	Site 4	251.20	39.30	37.30	15.88
13-Mar-04	Site 4	267.30	29.50	32.35	17.47
14-Mar-04	Site 4	274.05	16.50	24.50	20.69
15-Mar-04	Site 4	291.30	22.95	55.65	10.20
16-Mar-04	Site 4	296.40	40.45	6.10	109.45
17-Mar-04	Site 4	318.75	42.85	4.75	150.43
18-Mar-04	Site 4	317.70	40.05	5.35	130.50
19-Mar-04	Site 4	318.40	27.05	0.00	-------
22-Mar-04	Site 4	358.55	41.00	24.55	31.19
23-Mar-04	Site 4	410.30	33.55	14.15	56.94
24-Mar-04	Site 4	432.10	38.20	5.55	155.62
25-Mar-04	Site 4	462.00	38.20	17.20	52.88
26-Mar-04	Site 4	491.90	29.20	1.10	825.30
17-Mar-04	Site 5 (Experiment 7)	4.80	44.25	4.65	51.81
19-Mar-04	Site 5	2.25	44.15	0.00	-------
22-Mar-04	Site 5	8.80	26.55	13.00	11.82
23-Mar-04	Site 5	11.30	32.10	0.00	-------
24-Mar-04	Site 5	10.85	34.75	5.85	34.19
25-Mar-04	Site 5	10.10	41.80	3.30	71.54
26-Mar-04	Site 5	9.85	55.05	3.55	86.09
29-Mar-04	Site 5	8.65	39.30	40.50	5.45
31-Mar-04	Site 5	10.10	42.35	12.85	18.60
01-Apr-04	Site 5	7.70	57.95	1.15	276.21

*Stream water samples were collected on deployment and retrieval dates at Sites 1 and 3. Samples were collected throughout the experiments at Sites 4 and 5.

Table 3.3. Residual concentrations in nitrate-phosphate nutrient reservoirs after preliminary periphytometer experiments.

Date Deployed	Location	Treatment	Nitrate (mg/L)	Phosphate (mg/L)	N:P Molar Ratio
27-Jun-03	Site 1*	250mL NP	48.27	14.54	5.09
(5 days)	(Experiment 1)	20mL NP	13.98	8.17	2.62
03-Jul-03	Site 1*	250mL NP	3.60	0.47	11.79
(5 days)	(Experiment 2)	20mL NP	0.07	2.84	0.04
		250mL NP	32.21	5.79	8.53
		20mL NP	0.10	2.39	0.07
11-Jul-03	Site 2*	250mL NP	39.27	5.74	10.49
(5 days)	(Experiment 3)	20mL NP	10.97	2.83	5.93
11-Jul-03	Site 2*	250mL NP	23.91	4.19	8.75
(10 days)	(Experiment 3)	20mL NP	3.48	1.29	4.12
01-Sep-03	Site 1	20mL NP	1.02	0.82	1.92
(11 days)	(Experiment 4)	20mL NP	2.05	1.27	2.47
		20mL NP	1.97	1.25	2.41
		20mL NP	2.05	1.29	2.44
		20mL NP	1.68	1.10	2.35
		20mL NP	1.19	0.88	2.08
		20mL NP	1.93	1.25	2.36
		20mL NP	1.93	1.30	2.28
		20mL NP	1.39	1.03	2.07
		20mL NP	1.25	0.99	1.95
01-Sep-03	Site 3	20mL NP	1.19	0.98	1.87
(11 days)	(Experiment 4)	20mL NP	0.98	0.98	1.54
		20mL NP	1.97	1.14	2.66
		20mL NP	0.95	0.87	1.67
		20mL NP	1.13	0.94	1.84
		20mL NP	0.38	0.21	2.74
		20mL NP	0.93	0.78	1.84
		20mL NP	0.87	0.91	1.45
		20mL NP	1.21	0.96	1.94
		20mL NP	1.05	0.86	1.88
17-Oct-03	Site 3	20mL NP	26.89	4.74	8.68
(3 days)	(Experiment 5)	20mL NP	29.57	5.20	8.72
		20mL NP	35.82	5.88	9.34
		20mL NP	25.45	4.77	8.17
		20mL NP	28.06	4.94	8.70
		20mL NP	26.44	4.52	8.96
		20mL NP	26.70	4.44	9.20
		20mL NP	23.18	3.93	9.04
		20mL NP	32.75	4.91	10.22
		20mL NP	25.94	4.34	9.15

Table 3.3. Residual concentrations in nitrate-phosphate nutrient reservoirs after preliminary periphytometer experiments (continued).

Date Deployed	Location	Treatment	Nitrate (mg/L)	Phosphate (mg/L)	N:P Molar Ratio
17-Oct-03	Site 3	20mL NP	11.38	3.22	5.42
(7 days)	(Experiment 5)	20mL NP	7.30	2.34	4.78
		20mL NP	6.67	2.28	4.49
		20mL NP	19.41	4.18	7.12
		20mL NP	9.87	2.86	5.29
		20mL NP	9.23	2.45	5.78
		20mL NP	7.74	2.45	4.85
		20mL NP	11.30	2.89	5.98
		20mL NP	8.41	2.51	5.15
		20mL NP	10.66	2.95	5.53
11-Mar-04	Site 4	20mL NP	0.00	0.07	0.01
	(Frame 1)	20mL NP	1.88	1.46	1.97
	(Experiment 6)	20mL NP	0.18	0.32	0.88
		20mL NP	0.63	0.78	1.23
		20mL NP	2.45	1.57	2.39
		20mL NP	0.00	0.27	0.02
		20mL NP	3.01	2.07	2.23
		20mL NP	1.82	1.62	1.73
		20mL NP	0.12	0.60	0.31
		20mL NP	0.58	0.66	1.34
11-Mar-04	Site 4	20mL NP	0.61	0.45	2.09
(15 days)	(Frame 2)	20mL NP	0.56	0.31	2.75
	(Experiment 6)	20mL NP	0.59	0.42	2.17
		20mL NP	0.74	0.57	1.99
		20mL NP	1.52	1.27	1.84
		20mL NP	0.29	0.33	1.36
		20mL NP	0.53	0.39	2.11
		20mL NP	0.01	0.03	0.42
		20mL NP	2.72	1.85	2.24
		20mL NP	1.01	1.02	1.52
17-Mar-04	Site 5	20mL NP	0.75	0.22	5.30
(15 days)	(Frame 1)	20mL NP	1.34	0.54	3.77
	(Experiment 7)	20mL NP	4.50	1.62	4.25
		20mL NP	1.35	0.70	2.95
		20mL NP	1.75	0.79	3.38
		20mL NP	0.02	0.04	0.67
		20mL NP	1.75	1.39	1.94
		20mL NP	0.00	0.03	0.18
		20mL NP	0.08	0.02	6.35
		20mL NP	0.72	0.01	75.46

Table 3.3. Residual concentrations in nitrate-phosphate nutrient reservoirs after preliminary periphytometer experiments (continued).

Date Deployed	**Location**	**Treatment**	**Nitrate (mg/L)**	**Phosphate (mg/L)**	**N:P Molar Ratio**
17-Mar-04	Site 5	20mL NP	0.16	0.38	0.65
(15 days)	(Frame 2)	20mL NP	0.28	0.37	1.17
	(Experiment 7)	20mL NP	0.59	0.34	2.68
		20mL NP	0.35	0.57	0.95
		20mL NP	0.36	0.75	0.74
		20mL NP	0.00	0.13	0.00
		20mL NP	0.00	0.01	0.00
		20mL NP	0.07	0.18	0.58
		20mL NP	0.36	0.68	0.82
		20mL NP	0.43	0.81	0.82

*Composite samples were collected separately for 250 mL and 20 mL reservoirs after the June 27th, July 3rd and July 11, 2003 experiments.

Table 3.4. Ten-day diffusion experiment data. Ten 20 mL vials were filled with a nitrate-phosphate solution and one vial was removed and analyzed after each day of the experiment.

Day*	Nitrate (mg/L)	Phosphate (mg/L)	Water Samples (mg/L)**	
			Nitrate	Phosphate
0	87.5000	10.0000	0.0048	0.1705
			0.0025	0.1783
1	81.5355	9.4209	0.0026	0.1851
			0.0035	0.1845
2	46.5129	7.3393	0.0015	0.1885
			0.0034	0.1890
3	37.8995	6.7748	0.0034	0.2013
			0.0007	0.1979
4	16.5941	4.4385	0.0024	0.1658
			0.0016	0.1816
5	14.2670	4.2404	0.0000	0.2067
			0.0000	0.2041
6	9.9456	3.5567	0.2217	0.0186
			0.2199	0.0104
7	6.1203	2.8697	0.0000	0.2224
			0.0000	0.2154
8	3.4179	2.0426	0.0100	0.2151
			0.0028	0.2166
9	8.8079	3.3481	0.0000	0.2164
			0.0000	0.2180
10	2.1493	1.5823	0.0000	0.2279
			0.0000	0.2164

*Experiment dates: February 20, 2004 - March 1, 2004.

**Daily water samples were collected close to the vial removed on the tenth day of the experiment.

Table 3.5. Fifteen-day diffusion experiment data. Fifteen 20 mL vials were filled with a nitrate-phosphate solution and one vial was removed and analyzed after each day of the experiment.

Day*	**Nitrate Concentrations (mg/L)**			**Phosphate Concentrations (mg/L)**		
	20 mL Vial	**Filter**	**Corrected Value****	**20 mL Vial**	**Filter**	**Corrected Value****
0	87.5000	--------	--------	12.0000	--------	--------
1	62.2181	0.2029	14.18	11.4673	0.0620	4.33
2	34.6800	0.4490	31.39	8.5388	0.1023	7.15
3	32.5452	0.2581	18.04	8.4889	0.0778	5.44
4	53.9549	0.3585	25.06	10.6773	0.0666	4.66
5	24.2329	0.1434	10.02	7.2390	0.0552	3.86
6	17.8943	0.2176	15.21	5.9576	0.0842	5.89
7	38.6860	0.2641	18.46	9.1893	0.0752	5.26
8	11.9195	0.1128	7.88	5.2489	0.0496	3.47
9	6.9157	0.0534	3.73	4.0222	0.0407	2.84
10	8.7947	0.0671	4.69	4.0845	0.0578	4.04
11	7.6400	0.0939	6.56	3.9549	0.0969	6.77
12	4.3232	0.1102	7.70	2.8714	0.0758	5.30
13	3.9200	0.0849	5.93	2.8501	0.0858	6.00
14	4.2100	0.0784	5.48	3.1416	0.0641	4.48
15	4.4694	0.1219	8.52	3.0921	0.0795	5.55

*Experiment dates: March 12, 2004 - March 27, 2004.

**Corrected value calculated by using the average water volume within the glass fiber filters, 0.1451 mL, and the volume of water used for extraction, 10 mL.

Figure 3.1. Sites used for preliminary experiments in the Little River watershed. Sites 1 and 2 were in a manually excavated cross-section of the Little River main channel. Site 3 was on the main channel at USDA-ARS Station B. Site 13 (Station N), in a tributary of the Little River (Heard Creek), was used in subsequent experiments.

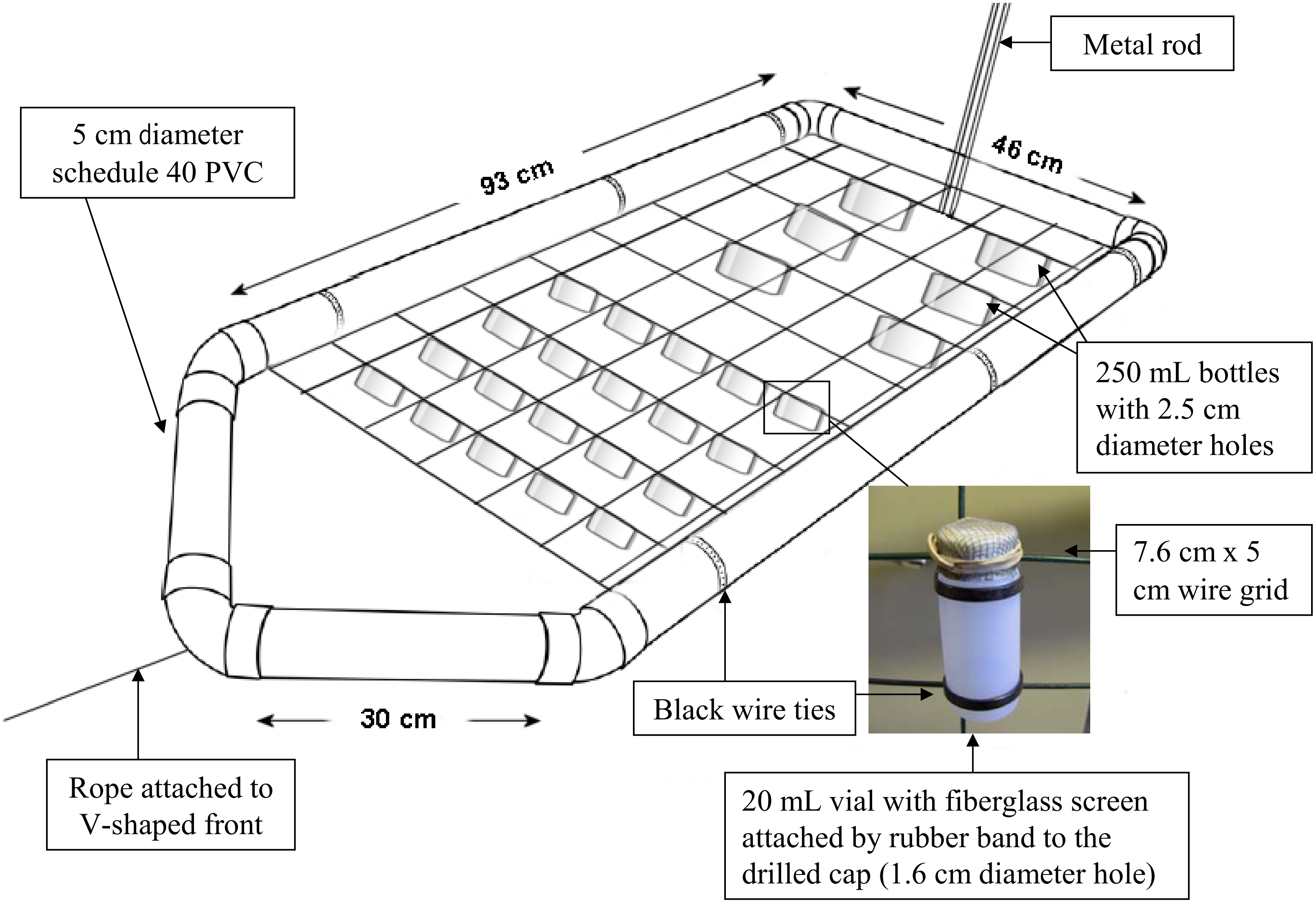


Figure 3.2. Periphytometer frame deployed for the first three preliminary experiments.

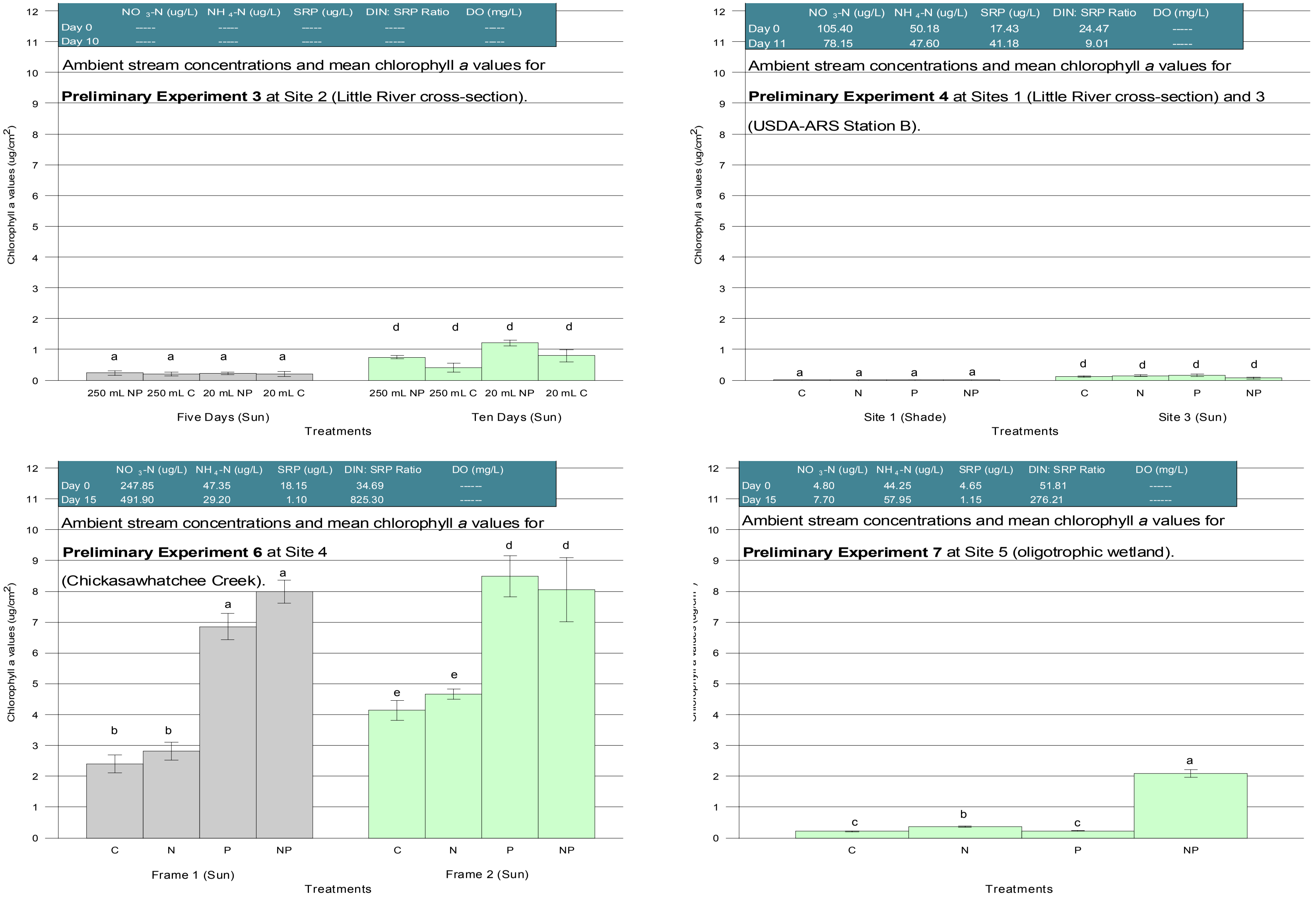


Figure 3.3. Summary chlorophyll *a* data for four preliminary experiments. Different letters within each category (multiple frames; shade or sun) represent treatment means that are significantly different at $\alpha = 0.05$. Error bars represent standard error. Chlorophyll *a* results from both frames at experiment 7 were combined due to lost filters.

Figure 3.4. Periphytometer frame deployed for September 1, 2003 and October 17, 2003 preliminary experiments. The forty 20 mL scintillation vials are submersed just beneath the water surface.

Figure 3.5. Periphytometers deployed at Site 3. Frames were deployed on October 17, 2003 in the main channel of the Little River (USDA-ARS Station B). One frame was retrieved on October 20, 2003 and the other on October 24, 2003.

Figure 3.6. Periphytometers deployed at Site 4. Frames were deployed on March 11, 2004 in Chickasawhatchee Creek and retrieved on March 26, 2004.

Figure 3.7. Periphytometers deployed at Site 5. Frames were deployed on March 17, 2004 and retrieved on April 1, 2004.

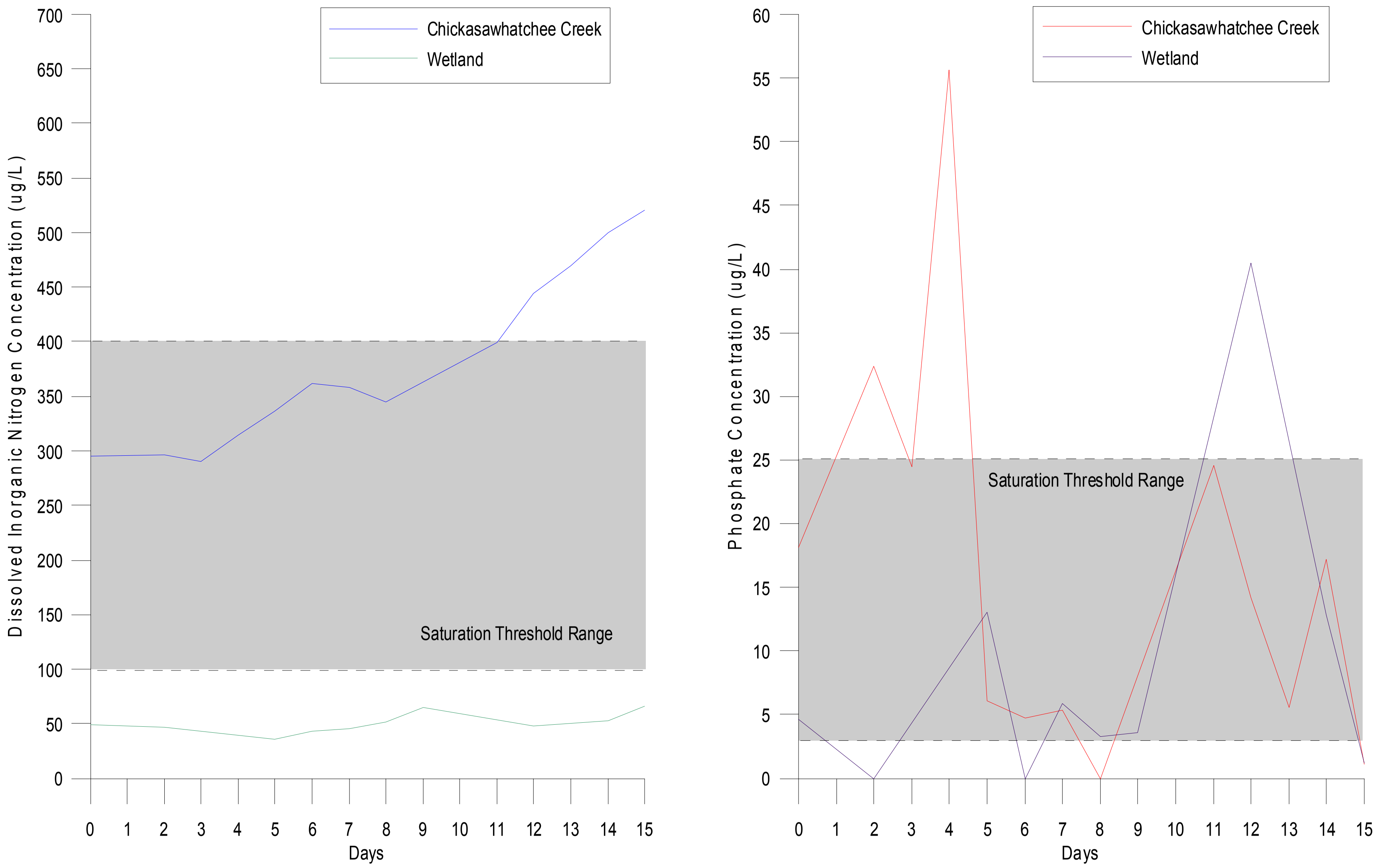


Figure 3.8. Stream nutrient concentrations during preliminary experiments at Sites 4 and 5. Two frames were deployed on March 11, 2004 in Chickasawhatchee Creek (Site 4) and retrieved on March 26, 2004. On March 17, 2004, two additional periphytometers were deployed in the wetland (Site 5) and retrieved on April, 1 2004. The shaded region on each graph is the range of reported nutrient saturation levels for algal growth.

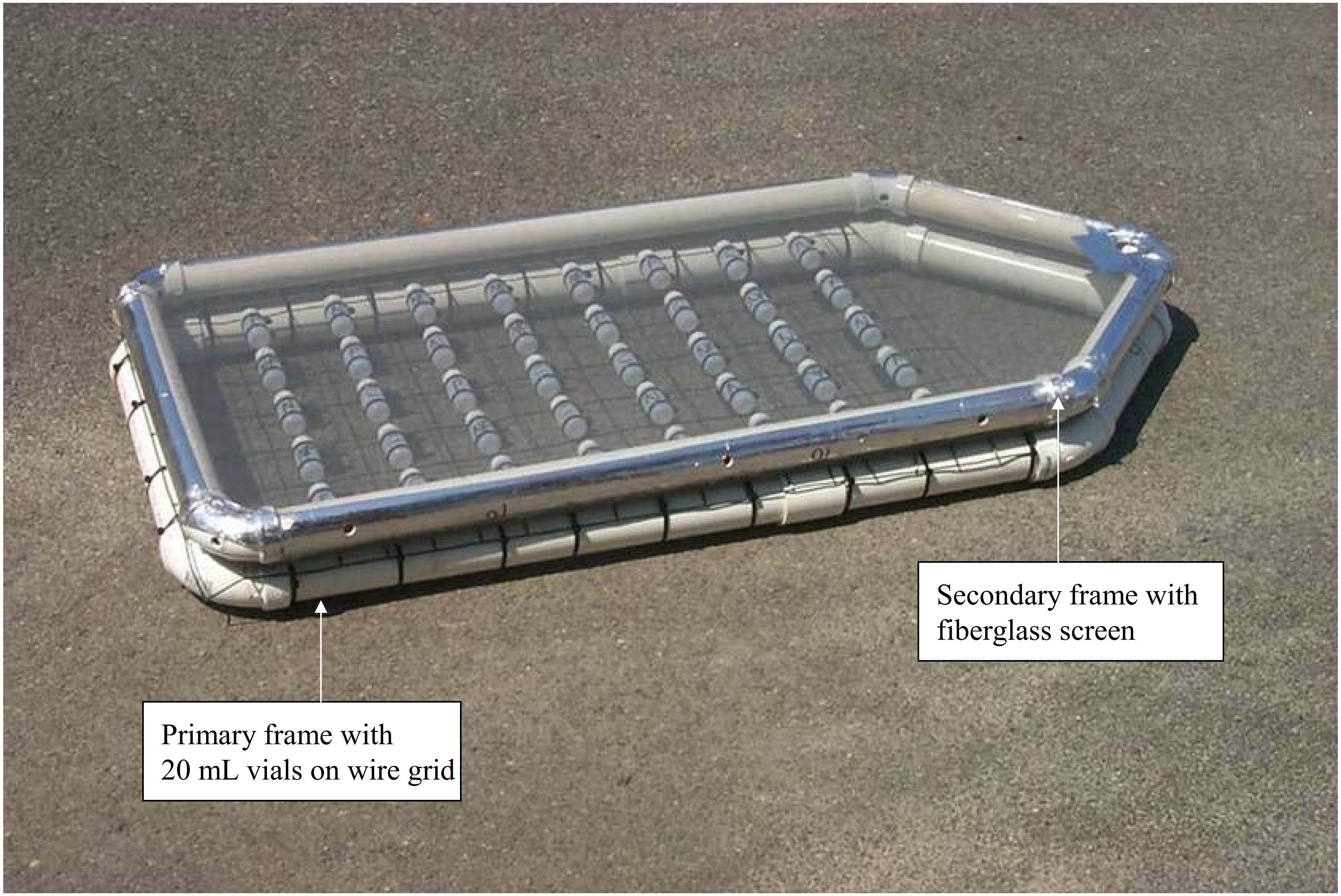


Figure 3.9. Periphytometer with a primary and secondary frame. When placed in the water, the secondary frame lies beneath the primary frame to protect the glass fiber filters. (The picture shows the frames inverted). Wire ties were used to attach the frames together.

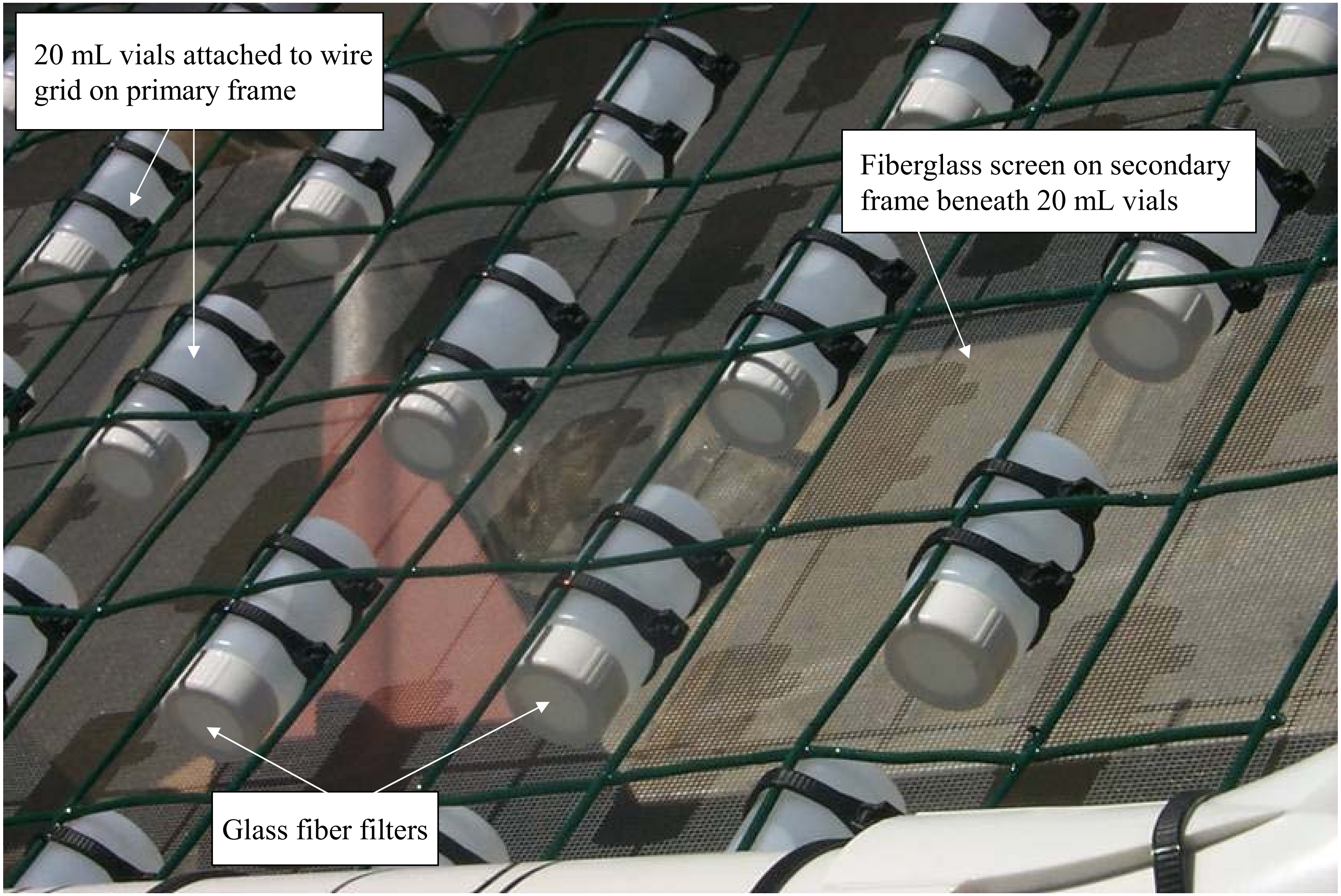


Figure 3.10. 20 mL vials on primary frame. The fiberglass screen on the secondary frame was approximately 2.5 cm below the scintillation vials on the primary frame.

Figure 3.11. Apparatus used for ten-day diffusion experiment.

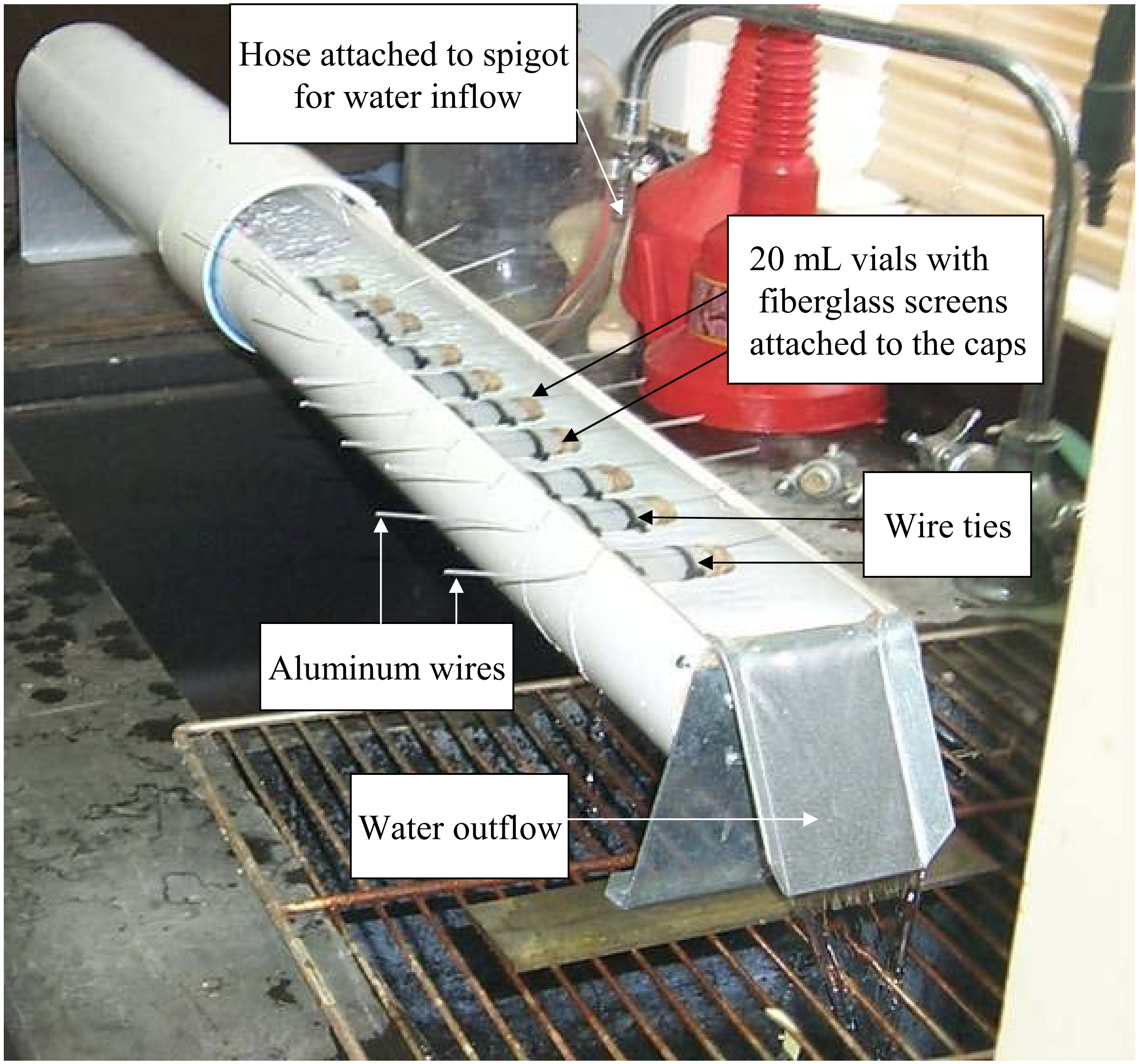


Figure 3.12. 20 ml vials in ten-day diffusion experiment.

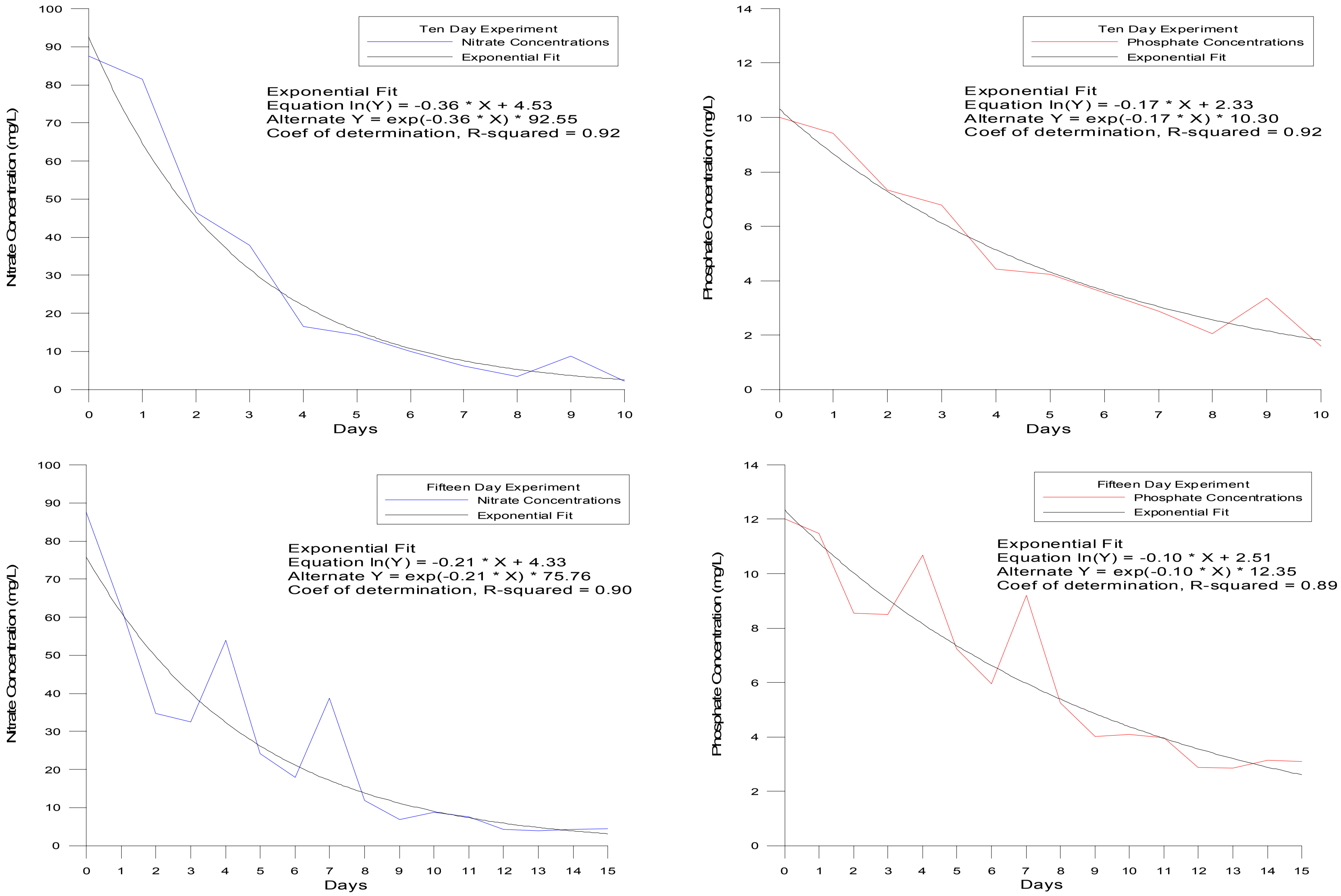


Figure 3.13. Scintillation vial residual nutrient concentrations in both diffusion experiments. For the ten-day experiment, ten 20 mL vials were filled with the nutrient solution (87.5 mg/L NO_3-N and 10 mg/L PO_4-P) and one vial was removed and analyzed after each day of the experiment. Fifteen vials were filled with 87.5 mg/L NO_3-N and 12 mg/L PO_4-P in the fifteen-day experiment.

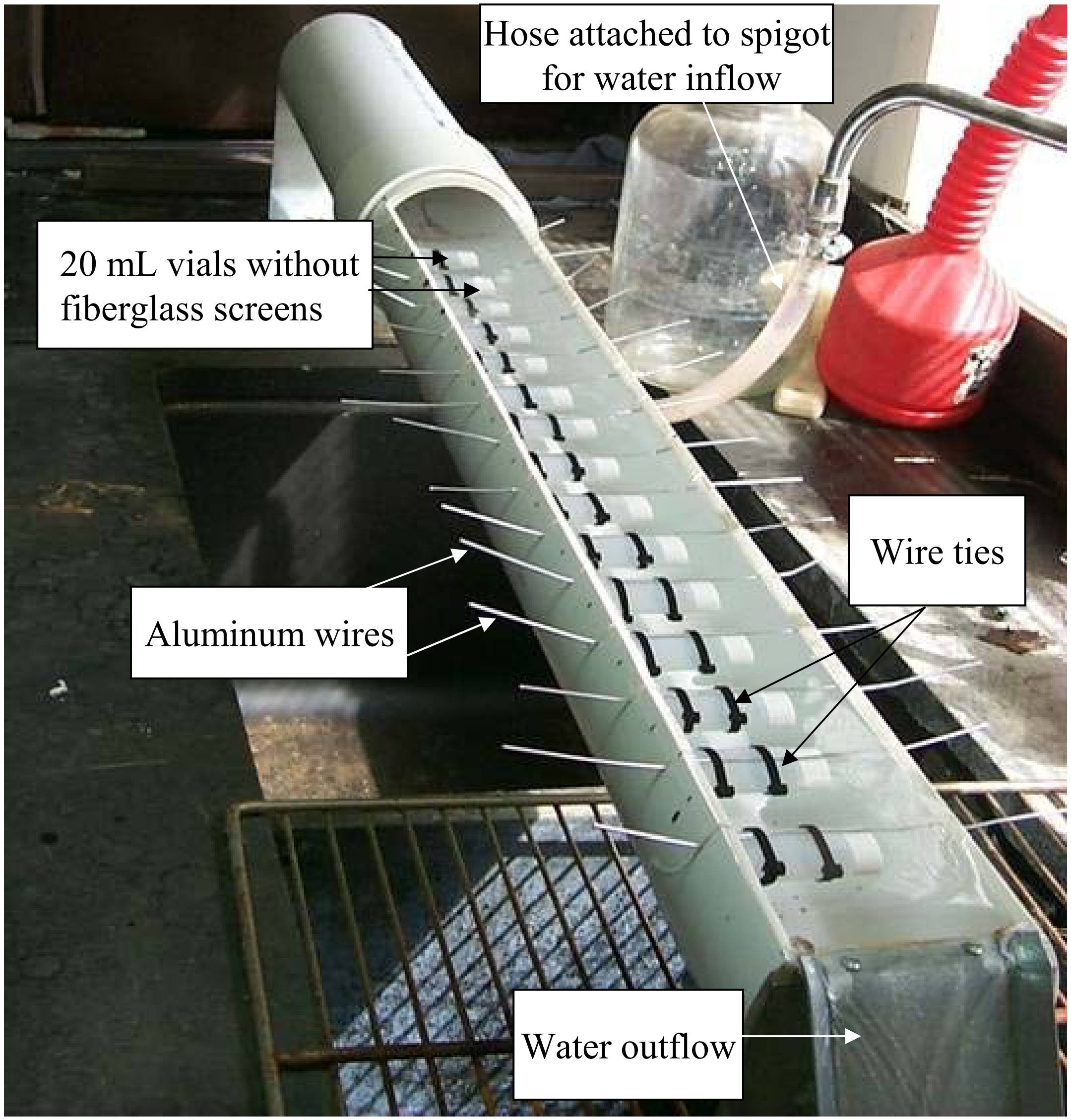


Figure 3.14. 20 ml vials in fifteen-day diffusion experiment.

CHAPTER 4

PERIPHYTON RESPONSE TO NUTRIENT ENRICHMENT: METHODS

Introduction

The current dissolved oxygen (DO) standard established by the Georgia Department of Natural Resources requires a daily average of 5.0 mg/L for most designated stream uses and a minimum of 4.0 mg/L. In the Georgia coastal plain (Ochlockonee, Suwannee, Satilla, and St. Mary's River Basins), 91% of streams on the 2001 303(d) list are included because of DO violations. Total Maximum Daily Load (TMDL) water quality management plans must be implemented for watersheds that are drained by these DO-impaired streams and the resultant economic consequences may be severe for people in surrounding communities. However, DO in Georgia coastal plain streams may be naturally low.

In heavily shaded blackwater streams, warm temperatures and low flows during summer as well as high organic carbon loads from the riparian vegetation may cause DO to decrease independently of anthropogenic influences. However, because slow moving streams with low DO concentrations are usually associated with excessive algal growth, the experiments described here measured algal response to nutrient enrichment in several Georgia coastal plain streams.

Study Sites

Eighteen passive nutrient diffusion periphytometers were deployed at nine sites throughout Georgia's southern coastal plain between April and June, 2004 (Figure 4.1). These sites were located within the Ocmulgee, Suwannee and Satilla River Basin groups and were categorized as predominantly forested, predominantly agricultural or mixed watersheds based on land use (Table 4.1; Figures 4.2 & 4.3). Two periphytometers were deployed at each site to determine if algal growth was nutrient-limited in these streams and to investigate how the nutrient-irradiance relationship affected periphyton. Periphytometers were deployed under tree canopy cover in the shade and in full sunlight as algal growth rates in four different stream environments were measured: (1) saturated nutrient concentrations and low irradiance; (2) saturated nutrients and high irradiance; (3) low nutrients and low irradiance; and (4) low nutrients and high irradiance.

Passive nutrient diffusion periphytometers

As described in the previous chapter, each periphytometer had a primary frame with forty 20 mL scintillation vials and a secondary frame that protected the glass fiber filters (Figures 3.9 & 3.10). Secondary frames, with fiberglass screens, were constructed with 3.8 cm diameter schedule 40 PVC pipes and fit perfectly under primary frames because both had the same dimensions. Vials were filled with deionized water or nutrient solutions and randomly attached by wire ties to the wire grid on each primary frame. A 1.6 cm hole was drilled into each scintillation vial cap and a glass fiber filter along with a Durapore membrane filter were placed across the top of each vial, just inside the cap. Glass fiber filters (42.5 mm diameter) were cut with a cork borer to fit scintillation vial caps. Membrane filters regulated diffusion of nutrient solutions while glass fiber filters functioned as artificial growth substrates for periphyton. There were ten replicate vials within each of the following four groups:

- Control - Deionized water
- Nitrate - 87.5 mg/L NO_3-N (using 632 mg/L KNO_3)
- Phosphate - 12 mg/L PO_4-P (using 103.8 mg/L $Na_2HPO_4 \cdot 7H_2O$)
- Nitrate-Phosphate - 87.5 mg/L NO_3-N and 12 mg/L PO_4-P

Periphytometer Deployment and Retrieval

Periphytometers were transported to each site with 20 mL vials already filled with deionized water or nutrient solutions and attached to primary frames. A 91 cm x 152 cm x 91 cm cooler packed with ice and built with wood sheathing and interior Styrofoam insulating sheets allowed periphytometers to be prepared in a laboratory and transported to sites ready for deployment (Figure 4.4). However, the cooler was designed to transport six primary frames only; secondary frames were attached at each site before deploying periphytometers.

Each periphytometer was carefully placed in the stream with glass fiber filters perpendicular to the stream substrate and parallel to stream flow. One metal rod was driven into the stream substrate at the front of each periphytometer and attached by rope and clamps. Metal rods allowed periphytometers to move with the current and adjust to fluctuating water levels but prevented frames from drifting downstream.

Periphytometers were removed from stream sites after fifteen days and primary frames (with 20 mL vials and colonized filters) were transported to the laboratory in the cooler. Upon removal from the streams, wire ties that connected primary and secondary frames were cut. Once back at the laboratory, glass fiber filters from each scintillation vial were then carefully removed under controlled conditions, sorted by treatment groups in petri dishes, covered in foil and frozen for at least twenty four hours.

Ocmulgee Basin

Broxton Rocks Preserve

On April 8, 2004, two periphytometers were deployed in Coffee County at the Broxton Rocks Preserve near Broxton, GA (Site 6). Located in the Ocmulgee River watershed (just north of the Satilla River Basin) and managed by the Nature Conservancy, this predominantly forested area was selected as a reference site because it had been historically free of anthropogenic disturbances. Because the experiments were conducted in early April, tree canopy cover had not yet fully developed and was patchy throughout the site. One periphytometer was deployed in Rocky Creek, a tributary of the Ocmulgee River, under the best available canopy cover in a stream reach approximately 2 m wide. The frame exposed to full sunlight was deployed 12 m downstream and about 3 m from a small waterfall area (Figure 4.5). With the exception of the Broxton Rocks site, all study sites were located on the public right-of-way where roads crossed selected streams/rivers

Suwannee Basin

Five Mile Creek

Two periphytometers were deployed in Five Mile Creek (Site 7) near Weber, GA in Berrien County on April 13, 2004. Located in a predominantly forested watershed within the Alapaha River watershed, Five Mile Creek flows from north to south and was on the 2001 303(d) list for dissolved oxygen violations. Periphytometers were deployed on opposite sides of State Route (SR) 64 with one frame 6 m south of the bridge under heavy canopy cover near the stream bank. The frame exposed to full sunlight was deployed 3 m north of the bridge (Figure

4.6). Both periphytometers were deployed under low flow conditions and there was no visible flow when periphytometers were retrieved.

Suwannoochee Creek

Six periphytometers were deployed on April 15, 2004 in the Suwannee River watershed. Two frames were deployed at each of three nested watersheds in the Suwannoochee Creek, another DO-impaired 303 (d) listed stream that flows north to south. The three selected sites were all predominantly forested and the first two periphytometers were deployed near DuPont, GA (Site 8) in Clinch County. The frame in the sun was deployed approximately 3 m south of the bridge on SR 38 and in the center of the stream channel while the shaded frame was deployed under tree canopy cover near the stream bank 8 m downstream (Figure 4.7).

The other two sites in the Suwannoochee Creek were located on the Clinch and Echols County borders. Approximately 20 km south of DuPont, two periphytometers were deployed on the southern side of the bridge on SR 187 near Fruitland, GA (Site 9). Frames were deployed 8 m apart and the frame exposed to full sunlight was in the center of the stream channel, 8 m south of the bridge; the shaded frame was deployed under tree canopy cover near the stream bank (Figure 4.8). The stream experienced low flow conditions on both periphytometer deployment and retrieval dates.

At the third site in the Suwannoochee Creek, approximately 37 km southeast of Fruitland near Fargo, GA (Site 10), two periphytometers were deployed in the center of the stream channel. One periphytometer was deployed 6 m north of the bridge on SR 94 and was exposed to full sunlight while the other frame was deployed 3 m upstream and had significant canopy cover overhead although it was in the center of the channel (Figure 4.9). Stream flow was low when periphytometers were deployed and retrieved.

Little River

Two periphytometers were deployed at each of two United States Department of Agriculture – Agricultural Research Service (USDA–ARS) gaging stations in Tift County, GA. These sites were located in the Little River watershed, an area with significant agricultural land use. The Little River flows from north to south and two periphytometers were deployed on May 21, 2004 at Station N (Site 13) in Heard Creek, a tributary of the Little River which flows in a southwesterly direction (Figure 3.1). One frame was deployed 2 m northeast of the bridge on Whiddon Mill Road and 0.6 m from a V-notch weir – this frame was exposed to the sun. The other frame was deployed in the main stream channel 6 m upstream and under heavy canopy cover (Figure 4.10). Low flow conditions were prevalent on deployment and retrieval dates as mean daily flow rates were 0.0272 and 0.0156 cubic meters per second (m^3/s) respectively (Appendix B).

On May 24, 2004, two periphytometers were deployed in the main channel of the Little River at Station B (Site 3). One periphytometer was deployed 3 m north of the bridge on Upper Ty Ty Road while the other frame was deployed 9 m upstream under heavy canopy cover (Figure 4.11). Stream flow was low when periphytometers were deployed (0.0008 m^3/s) but there was no flow when they were retrieved.

Satilla Basin

Little Satilla Creek

On April 26, 2004, four periphytometers were deployed in the Satilla River Basin. All four frames were deployed in Little Satilla Creek (Little Satilla River watershed) which was 303 (d) listed for DO-impairment. Little Satilla Creek flows in a southerly direction and the four frames were deployed in two nested watersheds that had no visible flow on periphytometer deployment and retrieval dates. First, two periphytometers were deployed in a watershed with mixed forest and agricultural land use near Screven, GA (Site 11). The frame exposed to the sun was deployed 3 m south of the bridge on County Road 390 (Nine Run Road) while the second periphytometer was deployed 5 m downstream, near the stream bank and under canopy cover (Figure 4.12).

Approximately 21 km north of Screven, two additional periphytometers were deployed at a predominantly forested site near Odum, GA (Site 12). The periphytometer in full sunlight was deployed 3 m south of the bridge on SR 27 and the second frame was deployed under tree canopy cover, 6 m downstream (Figure 4.13). During the experiments, some of the trees providing canopy cover to the periphytometer in the shade were cut (Figure 4.14) but the frame in the sun still had greater exposure to sunlight.

Physicochemical Analyses

Dissolved oxygen and temperature measurements were taken at each site with a DO meter (YSI 550) when periphytometers were deployed and again when they were retrieved. Using a LI-COR quantum sensor (LI-190SA), photosynthetically active radiation – close to each periphytometer in the shade and the sun – was measured in micromoles per second per square meter (μmol s^{-1} m^{-2}). Two stream water samples were collected at each site on deployment and retrieval dates: one sample close to the periphytometer in the shade and another for the frame in the sun. At Stations N and B in the Little River watershed however, stream water samples close to periphytometers in the sun were collected every other day. Because periphytometers were close to each other, it was assumed that the single sample represented both periphytometers at each site. Stream samples were analyzed for suspended solids, nitrate-N, ammonium-N, orthophosphate (soluble reactive phosphorus), chloride, potassium and dissolved organic carbon (DOC) using standard analytical techniques (APHA 2000). The pH values for stream samples were measured in the lab with a pH meter (Orion Model SA720). Residual solutions in 20 mL scintillation vials after stream removal were also analyzed for nitrate and phosphate concentrations using standard colorimetric techniques (APHA 2000).

Chlorophyll *a* Analyses

EPA Standard Method 10200H.3 was used to extract chlorophyll *a* from glass fiber filters (APHA 2000). Chlorophyll *a* content was determined by analysis on a Turner Designs TD 700 laboratory fluorometer. Chlorophyll *a* data for each sample was then expressed as μg/cm^2 by relating the mass of chlorophyll *a* extracted to the exposed surface area of glass fiber filters (1.7 cm^2).

Statistical Analyses

Stream Water Samples

Stream water sample variables from the nine study sites were compared using either an analysis of variance (ANOVA) or Kruskal-Wallis procedures in Statistical Analysis Systems

(SAS Institute, Cary, NC). The ANOVA procedure was used on raw data values when assumptions of normality and homogeneity of variances were met; only NO_3-N stream concentrations met these criteria. Both dissolved organic carbon and total suspended solids stream data were log transformed prior to analysis to meet the ANOVA assumptions. The non-parametric Kruskal-Wallis procedure was used to compare the remaining stream variables that could not meet the ANOVA assumptions. The null hypothesis for stream sample analyses was that there was no significant difference between sites. The alternative hypothesis was that at least one site was significantly different. If the analyses revealed significant differences, Tukey's multiple comparison procedure was used to determine which sites were significantly different at $\alpha = 0.05$.

Residual Concentrations

Linear regressions were used to determine whether residual treatment concentrations in 20 mL vials were significantly related to chlorophyll *a* values on glass fiber filters. For each treatment group (NO_3, PO_4 and NO_3-PO_4), mean chlorophyll *a* values from each site in the shade and sun were compared to corresponding mean residual nutrient concentrations. All PO_4 treatment vials in the sun, for example, were analyzed relative to their residual PO_4 concentrations to determine whether these concentrations were a significant predictor of chlorophyll *a* values.

Chlorophyll a Analyses

Treatment means, for individual periphytometers in the sun and shade at each site, were compared using the ANOVA procedure in SAS. Additionally, t-tests were used to compare treatment means in the shade at each site to their corresponding groups in the sun. Where necessary, chlorophyll *a* values were transformed prior to analysis to meet the ANOVA assumptions. Chlorophyll *a* values from both periphytometers at Site 6 (Broxton Rocks), as well as frames in the sun at Sites 13 (USDA-ARS Station N), 3 (USDA-ARS Station B), 11 (Screven) and 12 (Odum) were log transformed. Data from the periphytometer deployed in the shade at Odum were reciprocally transformed. The null hypothesis for chlorophyll *a* analyses was that there was no significant difference between treatments. The alternative hypothesis was that at least one treatment was significantly different. If the analyses revealed significant treatment effects, Tukey's multiple comparison procedure was used to determine which means were significantly different at $\alpha = 0.05$.

Table 4.1. Watershed data for the nine study sites.

Site Name	Coordinates	Basin	Watershed	12-Digit HUC*	Forest/wetland %*	Agriculture %
Broxton Rocks Preserve near Broxton, GA**	N 31°43’54.8” W 082°51’10.7”	Ocmulgee	Ocmulgee River	030701040804	95.00	5.00
Five Mile Creek near Weber, GA	N 31°14’16.3” W 083°07’49.8”	Suwannee	Alapaha River	031102020801	66.95	17.24
Suwannoochee Creek near DuPont,GA	N 30°59’09.5” W 082°52’46.9”	Suwannee	Suwannee River	031102010302	80.84	0.81
Suwannoochee Creek near Fruitland,GA	N 30°49’23.2” W 082°50’24.9”	Suwannee	Suwannee River	031102010303	73.07	0.24
Suwannoochee Creek near Fargo,GA	N 30°41’00.5” W 082°34’54.2”	Suwannee	Suwannee River	031102010305	82.00	0.16
Little River at USDA-ARS Station N in Tifton, GA	N 31°31’03” W 083°35’10”	Suwannee	Little River	031102040104	34.28	54.14
Little River at USDA-ARS Station B in Tifton, GA	N 31°28’53” W 083°35’03”	Suwannee	Little River	031102040105	34.33	41.07
Little Satilla Creek near Screven, GA	N 31°30’38.0” W 082°01’00.3”	Satilla	Little Satilla River	030702020404	50.59	28.63
Little Satilla Creek near Odum, GA	N 31°40’04.5” W 082°02’26.9”	Satilla	Little Satilla River	030702020402	56.23	24.87

*HUC = Hydrologic Unit Codes. Land use in the forest/wetland category includes deciduous, evergreen and mixed forests as well as forested and non-forested wetlands.

**The Broxton Rocks site was in an Ocmulgee watershed immediately northwest of the Satilla River basin. Based on recent aerial photographs, the Broxton Rocks watershed is greater than 90% forested.

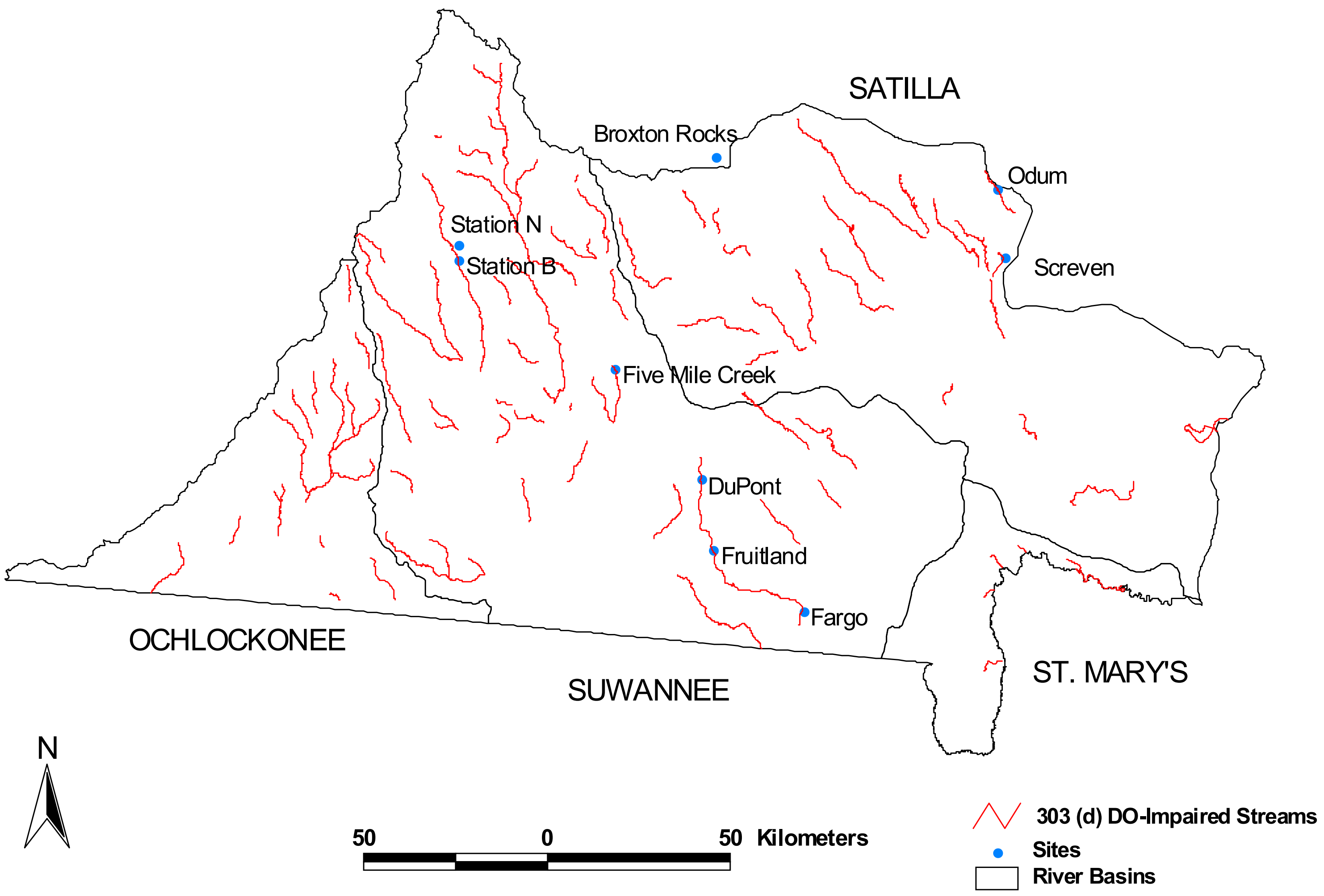


Figure 4.1. Study sites in the southern coastal plain of Georgia.

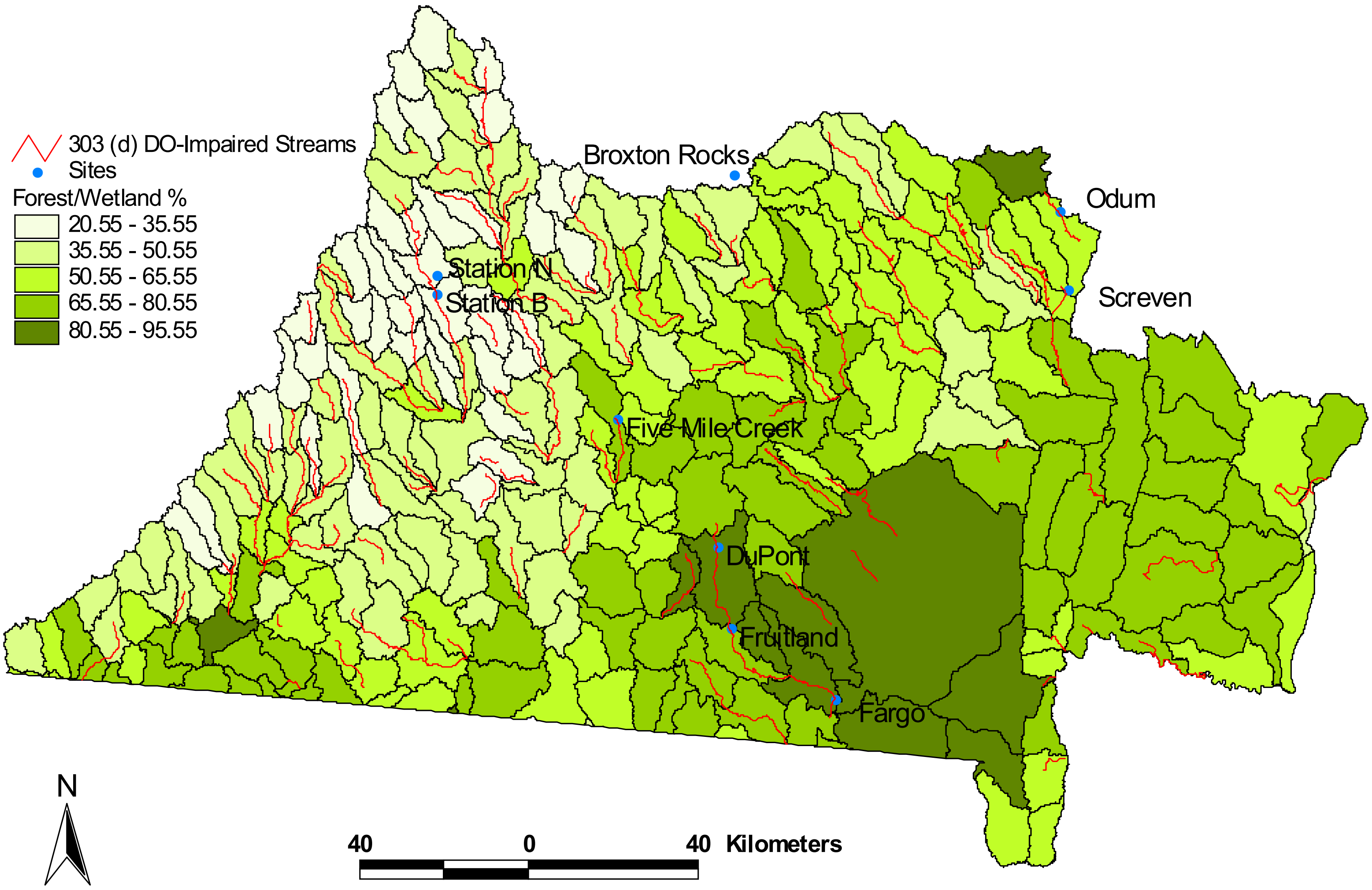


Figure 4.2. Dissolved oxygen impaired stream segments relative to forest and wetland cover in the southern coastal plain of Georgia.

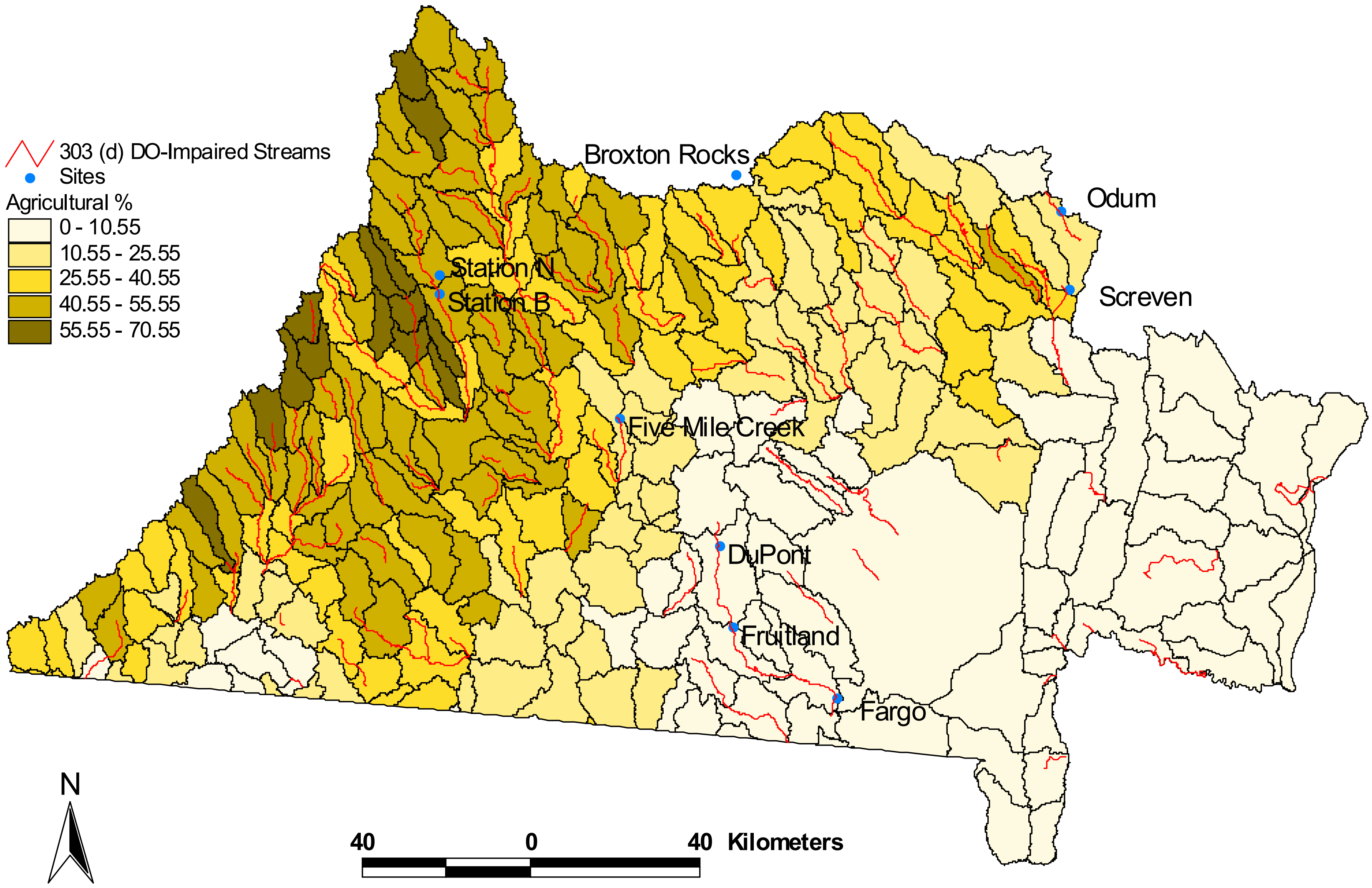


Figure 4.3. Dissolved oxygen impaired stream segments relative to agricultural land use in the southern coastal plain of Georgia.

Figure 4.4. Cooler used to transport periphytometers. The periphytometers were prepared in a laboratory, placed in the cooler and transported to sites ready for deployment. After stream removal, periphytometers were transported to the lab for analyses.

Figure 4.5. Periphytometers deployed at the Broxton Rocks Preserve (Broxton, GA). One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.6. Periphytometers deployed in Five Mile Creek (Weber, GA). One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.7. Periphytometers deployed in Suwannoochee Creek (DuPont, GA). One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.8. Periphytometers deployed in Suwannoochee Creek (Fruitland, GA). One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.9. Periphytometers deployed in Suwannoochee Creek (Fargo, GA). Photo was taken on April 30, 2004, the date the periphytometers were retrieved. Notice the slight angle for the periphytometer deployed in the sun.

Figure 4.10. Periphytometers deployed in the Little River at USDA-ARS Station N. One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.11. Periphytometers deployed in the Little River at USDA-ARS Station B. One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.12. Periphytometers deployed in Little Satilla Creek (Screven, GA). One frame was deployed in the shade (left) and the other in full sunlight (right).

Figure 4.13. Periphytometers deployed in Little Satilla Creek (Odum, GA) on April 26, 2004.

Figure 4.14. Periphytometers in Little Satilla Creek (Odum, GA) on May 11, 2004.

CHAPTER 5

RESULTS

Physicochemical Analyses

Dissolved Oxygen, Temperature, Irradiance and pH

Dissolved oxygen (DO) concentrations varied considerably among the nine study sites (Table 5.1; Figure 5.1(a)). The highest DO concentration at Broxton Rocks was 9.38 mg/L while Little River at Station B and Little Satilla Creek (Screven and Odum) all had DO concentrations below 1.00 mg/L on both deployment and retrieval dates; when periphytometers were retrieved from Odum, the DO concentration was 0.30 mg/L. Largest differences in DO concentrations between periphytometer deployment and retrieval dates were recorded for Broxton Rocks (9.38 mg/L to 4.68 mg/L) and Suwannoochee Creek at DuPont (3.41 mg/L to 5.68 mg/L), Fruitland (7.91 mg/L to 2.68 mg/L) and Fargo (6.70 mg/L to 2.97 mg/L).

Stream temperatures were lowest at Broxton Rocks. For all study sites, stream temperatures ranged between 15 - 24 °C, with a general increase in temperatures for later experiments (Table 5.1; Figure 5.1(a)). Except for Odum, where trees were cut during the experiment, photosynthetically active radiation (PAR) values in the shade were below 100 micromoles per second per square meter (µmol s^{-1} m^{-2}) at all sites (Table 5.2). PAR values in the sun were generally above 1000 µmol s^{-1} m^{-2}.

Average stream pH values at Station N (6.80) and Station B (6.95) were significantly higher than all other sites while Fruitland (4.10) and Fargo (4.07) had significantly lower pH values than every site except Five Mile Creek at Weber (4.23) (Table 5.1; Figure 5.1(a)).

Between deployment and retrieval dates, pH values did not change substantially at the study sites – the largest change was recorded at Broxton Rocks (5.35 to 6.33).

Stream Water Samples

NO_3-N and soluble reactive phosphorus (SRP) stream concentrations were significantly different at only a few sites (Table 5.1; Figure 5.1(a)). Station N ($\bar{x}$: 112.09 µg/L) had significantly higher NO_3-N concentrations than Broxton Rocks (16.59 µg/L) while Station B (6.63 µg/L) had significantly lower SRP concentrations than both Screven (53.49 µg/L) and Odum (34.50 µg/L). There were no other significant differences in NO_3-N and SRP concentrations among the nine sites. Except for DuPont and Station N, NO_3-N concentrations on deployment and retrieval dates were below 45 µg/L. Five Mile Creek, DuPont and Station B had the lowest SRP concentrations (0.00 µg/L – 21.85 µg/L) on periphytometer deployment and retrieval dates but values at the other sites may have been affected by transient concentration spikes. At Station N for example, samples were taken every other day and SRP stream concentrations fluctuated between 7.10 and 46.95 µg/L (Figure 5.2); this was also evident at Chickasawhatchee Creek (Figure 3.8). Rainfall may cause concentration spikes because sediments become disturbed and PO_4-P is released into the water column. Stream molar N: P ratios on deployment and retrieval dates are reported in Table 5.3.

NH_4-N concentrations at DuPont ($\bar{x}$: 289.4 µg/L), Fargo (388.68 µg/L) and Screven (576.33 µg/L) were significantly greater than Broxton Rocks (67.10 µg/L) (Table 5.1; Figure 5.1(b)). Additionally, NH_4-N concentrations at Screven were significantly greater than Station B ($\bar{x}$: 125.95 µg/L). There were no other significant differences in NH_4-N concentrations among the nine sites. However, the highest NH_4-N concentrations were recorded at Fruitland; from deployment to retrieval in the sun, NH_4-N concentrations increased from 63.50 µg/L to 1542.35 µg/L.

Mean potassium concentrations at Broxton Rocks (1.45 mg/L), Screven (2.05 mg/L), Odum (2.20 mg/L), Station B (2.31 mg/L) and Station N (1.80 mg/L) were not significantly different (Table 5.1; Figure 5.1(b)). Potassium concentrations at Five Mile Creek ($\bar{x}$: 0.47 mg/L), Fruitland (0.48 mg/L) and Fargo (0.30 mg/L) were significantly lower than every other site except DuPont (0.85 mg/L) and Broxton Rocks. Chloride concentrations at Odum ($\bar{x}$: 14.21 mg/L) were significantly greater than all sites except Station B (13.65 mg/L) (Figure 5.1(b)). Mean chloride concentrations at Station B were not significantly different from Screven (12.70 mg/L) either (Table 5.1). Five Mile Creek ($\bar{x}$: 7.95 mg/L), DuPont (7.81 mg/L), Fruitland (9.04 mg/L), and Fargo (8.66 mg/L) had chloride concentrations that were not significantly different; these values were lower than all other sites except Broxton Rocks.

Dissolved organic carbon (DOC) levels at Fruitland ($\bar{x}$: 55.46 mg/L) and Fargo (52.22 mg/L) were significantly greater than all other study sites except DuPont (Table 5.1; Figure 5.1(c)). DOC concentrations at Five Mile Creek ($\bar{x}$: 32.65 mg/L), DuPont (43.46 mg/L), Screven (32.23 mg/L) and Odum (34.54 mg/L) were not significantly different. Station B ($\bar{x}$: 14.93 mg/L), Broxton Rocks (18.57 mg/L) and Station N (13.76 mg/L) had significantly lower DOC concentrations than all other sites. Odum had the highest average total suspended solids (TSS) with a value of 31.32 mg/L (Figure 5.1(c)). Only Five Mile Creek ($\bar{x}$: 5.58 mg/L), Fargo (4.85 mg/L) and Station N (2.82 mg/L) had significantly lower mean TSS values, however.

Flow

Flow data for USDA-ARS Stations N and B during periphytometer experiments are reported in Appendix B. Flow was not measured at the remaining sites because low flow conditions prevalent on deployment and retrieval dates were below the operating range of our instruments (Table 5.4).

Residual Concentrations

After removing the 20 mL vials from streams, average NO_3 concentrations in NO_3 and NO_3-PO_4 treatment groups were between 0.09 and 11.17 mg/L (Tables 5.5 & 5.6; Appendix C). Residual PO_4 concentrations in the respective PO_4 treatment groups ranged from 0.23 to 3.72 mg/L. Regression analyses on (1) NO_3, (2) PO_4 and (3) NO_3-PO_4 treatment groups from all sites revealed that residual concentrations were not a significant predictor of chlorophyll *a* values for periphytometers deployed in the sun. For PO_4 and NO_3-PO_4 treatment groups in the shade however, residual nutrient concentrations were a significant predictor of chlorophyll *a* values.

Chlorophyll *a* Analyses

Ocmulgee Basin

Broxton Rocks Preserve

Chlorophyll *a* results from both periphytometers at Broxton Rocks mirrored each other (Tables 5.7 & 5.8; Figure 5.3(a)) and reflected an unsaturated stream nutrient environment. In the shade, chlorophyll *a* values for control ($\bar{x}$: 0.15 µg/cm^2) and NO_3 (0.21 µg/cm^2) glass fiber filters were not significantly different but both were significantly lower than PO_4 (0.45 µg/cm^2) filters. NO_3-PO_4 ($\bar{x}$: 1.45 µg/cm^2) filters produced significantly higher values than all other treatment groups (Appendix D). Chlorophyll *a* results from the periphytometer in the sun followed the same pattern (C: 0.22 μg/cm^2, NO_3: 0.23 μg/cm^2, PO_4: 0.65 μg/cm^2 and NO_3-PO_4: 1.74 μg/cm^2). Except for the NO_3 treatment groups, mean chlorophyll *a* values in the sun were significantly greater than corresponding treatment groups in the shade.

Suwannee Basin

Five Mile Creek

Treatment groups in the shade at Five Mile Creek were not significantly different (Table 5.7) but chlorophyll *a* values from the periphytometer in the sun suggested unsaturated stream nutrient concentrations. Control ($\bar{x}$: 1.85 μg/cm^2), NO_3 (1.95 μg/cm^2) and PO_4 ($\bar{x}$: 2.29 μg/cm^2) filters were not significantly different but all were significantly lower than NO_3-PO_4 ($\bar{x}$: 4.01 μg/cm^2) filters (Figure 5.3(a)). For this and all subsequent sites, mean chlorophyll *a* values for treatment groups in the sun were significantly greater than their corresponding groups in the shade.

Little River

The lowest chlorophyll *a* values in the study were obtained from periphytometers deployed in the shade at both USDA-ARS Stations N and B (Table 5.7). There were no significant differences between any of the treatment groups for the periphytometer in the shade at Station N (Figure 5.3(a)). PO_4 ($\bar{x}$: 5.54 μg/cm^2) and NO_3-PO_4 ($\bar{x}$: 6.93 μg/cm^2) filters in the sun were not significantly different but both were greater than control (0.55 μg/cm^2) and NO_3 (0.67 μg/cm^2) filters. Ambient stream inorganic nitrogen concentrations may have been saturated.

At Station B in the shade, PO_4 (0.04 µg/cm^2) and NO_3-PO_4 (0.04 µg/cm^2) filters were not significantly different but PO_4 filters were significantly greater than both control ($\bar{x}$: 0.03 µg/cm^2) and NO_3 (0.03 µg/cm^2) filters. Chlorophyll *a* values in the sun were consistent with unsaturated stream nutrient concentrations. Chlorophyll *a* values for NO_3-PO_4 ($\bar{x}$: 5.00 µg/cm^2) filters were significantly greater than all other treatment groups: control ($\bar{x}$: 1.11 µg/cm^2), NO_3 (1.48 µg/cm^2) and PO_4 (1.58 µg/cm^2).

Suwannoochee Creek

At DuPont, there were no significant differences between any of the treatment groups for either the periphytometer in the shade or the sun (Tables 5.7 & 5.8; Figure 5.3(b)). Control ($\bar{x}$: 0.22 µg/cm^2), NO_3 (0.29 µg/cm^2), PO_4 (0.24 µg/cm^2) and NO_3-PO_4 ($\bar{x}$: 0.32 µg/cm^2) filters in the shade at Fruitland were also not significantly different. In the sun, chlorophyll *a* values for NO_3 ($\bar{x}$: 2.21 µg/cm^2), PO_4 (2.32 µg/cm^2) and NO_3-PO_4 (2.36 µg/cm^2) filters were not significantly different but only PO_4 and NO_3-PO_4 filters were significantly greater than control (1.87 µg/cm^2) filters. Stream nutrient concentrations were low when periphytometers were deployed at Fruitland but increased at the end of the experiments. Treatment groups in the shade at Fargo were not significantly different (Table 5.7) and only PO_4 ($\bar{x}$: 1.07 µg/cm^2) and NO_3-PO_4 (0.52 µg/cm^2) filters in the sun were significantly different (Table 5.8; Figure 5.3(b)).

Satilla Basin

Little Satilla Creek

Treatment groups in the shade at Screven were not significantly different (Table 5.7; Figure 5.3(c)). Control ($\bar{x}$: 1.88 µg/cm^2), PO_4 (2.01 µg/cm^2) and NO_3-PO_4 (1.91 µg/cm^2) groups in the sun were also not significantly different. Chlorophyll *a* values for all three of these groups were significantly greater than NO_3 values ($\bar{x}$: 1.41 μg/cm^2), however, and this was consistent with saturated stream nutrient concentrations.

At Odum, some of the trees surrounding the periphytometer in the shade were cut down (Figure 4.14) and both frames produced chlorophyll *a* values that suggested an unsaturated stream nutrient environment. Chlorophyll *a* values for NO_3-PO_4 ($\bar{x}$: 0.41 μg/cm^2) filters in the shade were significantly greater than control ($\bar{x}$: 0.14 μg/cm^2) and PO_4 (0.15 μg/cm^2) filters but not NO_3 (0.21 μg/cm^2) filters (Table 5.7; Figure 5.3(c)). NO_3 (1.08 μg/cm^2) filters in the sun were significantly greater than both control (0.60 μg/cm^2) and PO_4 (0.66 μg/cm^2) filters but NO_3-PO_4 (2.81 μg/cm^2) filters were significantly greater than all other treatment groups.

Table 5.1. Stream variables on periphytometer deployment and retrieval dates.

Date*	Site Name	DO (mg/L)	Temp (°C)	pH	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	K (mg/L)	Cl (mg/L)	DOC (mg/L)	TSS (mg/L)
08-Apr	Broxton Rocks	8.78	15.93	5.62	16.60	55.95	34.10	1.60	7.01	17.35	-----
		9.38	15.67	5.35	16.45	34.30	7.85	1.20	6.91	15.84	-----
23-Apr	Broxton Rocks	5.22	17.42	6.42	22.85	130.40	7.30	1.40	6.49	19.39	12.00
		4.68	17.28	6.33	10.45	47.75	0.55	1.60	6.16	21.70	5.60
13-Apr	Five Mile Creek	2.50	19.00	4.21	32.85	86.45	13.90	0.60	7.15	35.01	3.84
				4.22	29.60	73.75	4.50	-----	7.25	-----	5.88
28-Apr	Five Mile Creek	1.70	17.40	4.24	20.05	270.05	20.55	0.40	8.83	30.58	6.40
				4.24	17.00	346.30	21.85	0.40	8.56	32.35	6.18
15-Apr	DuPont	3.41	18.00	4.26	18.80	173.40	13.55	0.40	7.94	38.42	3.22
				4.26	22.50	178.80	18.60	1.00	8.03	53.80	6.49
30-Apr	DuPont	5.68	19.60	4.58	111.85	424.75	18.05	1.00	8.02	41.20	12.67
				4.96	74.60	380.65	8.40	1.00	7.25	40.40	8.57
15-Apr	Fruitland	7.91	20.00	3.99	20.50	69.80	8.35	0.30	8.24	50.47	3.22
				4.08	21.25	63.50	5.25	0.20	7.72	45.91	4.04
30-Apr	Fruitland	2.68	20.40	4.15	29.20	1518.20	35.65	0.70	10.02	58.56	19.33
				4.17	30.60	1542.35	37.60	0.70	10.19	66.88	11.33
15-Apr	Fargo	6.70	16.80	4.08	25.65	369.75	21.45	0.30	8.35	52.91	0.78
				4.09	25.65	366.95	16.75	0.30	8.50	51.26	1.80
30-Apr	Fargo	2.97	20.20	4.08	30.70	420.25	39.85	0.30	9.08	49.39	14.67
				4.01	25.60	397.75	26.20	0.30	8.69	55.33	2.15
26-Apr	Screven	0.54	19.90	5.05	18.00	396.70	23.45	1.80	12.12	32.71	7.60
				5.14	24.70	431.95	25.95	1.40	12.48	30.77	8.40
11-May	Screven	0.42	20.80	5.68	29.20	727.20	72.05	2.60	13.08	33.35	6.29
				5.64	43.60	749.45	92.50	2.40	13.12	32.10	5.71
26-Apr	Odum	0.87	21.00	4.76	14.10	179.30	29.65	1.00	13.39	28.53	41.89
				4.75	20.45	222.85	49.20	2.00	13.73	36.17	25.40
11-May	Odum	0.30	22.00	5.09	27.80	134.55	32.70	3.30	14.73	37.89	34.00
				5.05	38.00	108.05	26.25	2.50	14.97	35.55	24.00

Table 5.1. Stream variables on periphytometer deployment and retrieval dates (continued).

Date*	Site Name	DO (mg/L)	Temp (°C)	pH	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	K (mg/L)	Cl (mg/L)	DOC (mg/L)	TSS (mg/L)
21-May	Station N	1.23	22.90	6.97	97.05	200.00	10.00	2.00	10.62	14.75	2.95
21-May	Station N			6.78	124.95	183.35	7.10	1.80	11.16	13.08	3.03
24-May	Station N			6.75	67.80	220.45	46.95	2.20	10.70	14.15	-----
26-May	Station N			6.93	80.95	341.90	9.20	2.20	10.61	16.86	-----
28-May	Station N			6.82	29.00	310.50	9.35	1.40	11.17	13.55	-----
01-Jun	Station N			6.83	28.00	640.75	24.20	1.80	12.58	13.77	-----
03-Jun	Station N			6.64	306.00	100.60	8.95	1.40	9.73	12.02	-----
05-Jun	Station N			6.67	113.10	170.00	36.75	1.80	10.86	12.15	4.28
05-Jun	Station N	2.19	21.80	6.83	162.00	118.60	15.50	1.60	11.08	13.54	1.00
24-May	Station B	0.35	22.60	6.88	28.85	240.00	0.00	2.80	13.42	18.02	9.07
24-May	Station B			6.99	29.20	230.90	6.80	3.00	13.66	17.84	5.67
26-May	Station B			7.24	27.45	56.40	0.00	2.80	13.49	15.70	-----
28-May	Station B			6.86	27.60	58.20	0.00	2.00	13.59	13.73	-----
01-Jun	Station B			7.19	26.95	82.55	17.00	1.40	13.44	12.90	-----
03-Jun	Station B			6.84	32.75	91.85	9.25	1.20	13.20	11.86	-----
05-Jun	Station B			6.69	23.85	133.35	1.10	2.00	13.27	14.14	-----
08-Jun	Station B			6.82	21.70	130.00	17.35	4.00	14.53	18.45	6.68
08-Jun	Station B	0.89	23.80	7.05	19.75	110.30	8.20	1.60	14.28	11.71	9.55

*Values in the shade are reported first for each date and site. Between deployment and retrieval dates at Stations N and B, water samples were collected near periphytometers in the sun.

Table 5.2. Irradiance measurements at the nine study sites.

Site Name*	**Shade (umol s^{-1} m^{-2})****	**Sun (umol s^{-1} m^{-2})****
Broxton Rocks Preserve (Broxton, GA)	85.30	1038.10
Five Mile Creek (Weber, GA)	87.50	1162.01
Suwannoochee Creek (DuPont, GA)	55.62	1662.10
Suwannoochee Creek (Fruitland, GA)	46.40	974.00
Suwannoochee Creek (Fargo, GA)	--------	--------
Little River at USDA-ARS Station N (Tifton, GA)	60.50	1354.10
Little River at USDA-ARS Station B (Tifton, GA)	20.70	1350.00
Little Satilla Creek (Screven, GA)	--------	--------
Little Satilla Creek (Odum, GA)	400.00	1950.00

* Irradiance was only measured once at each site, either on deployment or retrieval dates. At Fargo and Screven, overcast conditions prevented measurements on both dates. Irradiance levels in the shade at Odum were taken after trees had been cut during the experiment.

**Units in micromoles per second per square meter. 1 umol s^{-1} m^{-2} = 6.02 x 1017 photons = 1 microeinstein per second per square meter ($uEs^{-1}m^{-2}$).

Table 5.3. Stream molar N:P ratios on periphytometer deployment and retrieval dates. NO_2-N, NO_3-N, NH_4-N and SRP concentrations were used to compute the ratios.

		Day 0 N:P Ratio				Day 15 N:P Ratio		
Site Name	**Day 0**	**Shade**	**Sun**	**Combined**	**Day 15**	**Shade**	**Sun**	**Combined**
Broxton Rocks Preserve (Broxton, GA)	8-Apr-2004	9.41	26.27	**12.56**	23-Apr-2004	99.07	487.32	**126.12**
Five Mile Creek (Weber, GA)	13-Apr-2004	36.45	96.58	**51.15**	28-Apr-2004	70.85	84.84	**78.06**
Suwannoochee Creek (DuPont, GA)	15-Apr-2004	69.67	52.59	**59.77**	30-Apr-2004	133.69	252.77	**171.44**
Suwannoochee Creek (Fruitland, GA)	15-Apr-2004	47.88	70.04	**56.43**	30-Apr-2004	226.02	217.74	**221.74**
Suwannoochee Creek (Fargo, GA)	15-Apr-2004	92.81	117.97	**103.84**	30-Apr-2004	56.84	81.62	**66.66**
Little River at USDA-ARS Station N (Tifton, GA)	21-May-2004	120.43	163.26	**138.21**	5-Jun-2004	29.13	56.40	**37.21**
Little River at USDA-ARS Station B (Tifton, GA)	24-May-2004	N/A*	185.79	**378.57**	8-Jun-2004	41.46	74.68	**52.10**
Little Satilla Creek (Screven, GA)	26-Apr-2004	90.46	89.31	**89.86**	11-May-2004	53.89	43.48	**48.04**
Little Satilla Creek (Odum, GA)	26-Apr-2004	32.64	24.54	**27.59**	11-May-2004	23.02	23.94	**23.43**

* On this date, SRP concentration in the shade at USDA-ARS Station B was 0.00 ug/L.

Table 5.4. Relative flow on periphytometer deployment and retrieval dates.

Site Name	Deployment	Retrieval
Broxton Rocks Preserve (Broxton, GA)	low flow	low flow
Five Mile Creek (Weber, GA)	low flow	no visible flow
Suwannoochee Creek (DuPont, GA)	low flow	no visible flow
Suwannoochee Creek (Fruitland, GA)	low flow	low flow
Suwannoochee Creek (Fargo, GA)	low flow	low flow
Little River at USDA-ARS Station N (Tifton, GA)	0.0272 (m^3/s)	0.0156 (m^3/s)
Little River at USDA-ARS Station B (Tifton, GA)	0.0008 (m^3/s)	0.0000 (m^3/s)
Little Satilla Creek (Screven, GA)	no visible flow	no visible flow
Little Satilla Creek (Odum, GA)	no visible flow	no visible flow

* Flow measurements were available from USDA-ARS gaging Stations N and B. Flow data during the entire experiments at Stations N and B are reported in Appendix B.

Table 5.5. Average chlorophyll *a* values and residual nutrient concentrations in the shade.

Site	NO_3 Treatment Group		PO_4 Treatment Group		NO_3-PO_4 Treatment Group	
Broxton Rocks (Broxton, GA)	NO_3 (mg/L)	**4.24**	NO_3 (mg/L)	**0.00**	NO_3 (mg/L)	**5.24**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**3.29**	PO_4 (mg/L)	**2.70**
	Chl *a* (µg/cm^2)	**0.21**	Chl *a* (µg/cm^2)	**0.45**	Chl *a* (µg/cm^2)	**1.45**
Five Mile Creek (Weber, GA)	NO_3 (mg/L)	**1.15**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**1.34**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**2.18**	PO_4 (mg/L)	**1.19**
	Chl *a* (µg/cm^2)	**0.28**	Chl *a* (µg/cm^2)	**0.36**	Chl *a* (µg/cm^2)	**0.30**
Suwannoochee Creek (DuPont, GA)	NO_3 (mg/L)	**1.18**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**1.13**
	PO_4 (mg/L)	**0.02**	PO_4 (mg/L)	**1.07**	PO_4 (mg/L)	**1.18**
	Chl *a* (µg/cm^2)	**0.19**	Chl *a* (µg/cm^2)	**0.22**	Chl *a* (µg/cm^2)	**0.17**
Suwannoochee Creek (Fruitland, GA)	NO_3 (mg/L)	**2.98**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**2.00**
	PO_4 (mg/L)	**0.02**	PO_4 (mg/L)	**2.53**	PO_4 (mg/L)	**1.57**
	Chl *a* (µg/cm^2)	**0.29**	Chl *a* (µg/cm^2)	**0.24**	Chl *a* (µg/cm^2)	**0.32**
Suwannoochee Creek (Fargo, GA)	NO_3 (mg/L)	**0.72**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**0.76**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**1.17**	PO_4 (mg/L)	**0.96**
	Chl *a* (µg/cm^2)	**0.20**	Chl *a* (µg/cm^2)	**0.28**	Chl *a* (µg/cm^2)	**0.21**
Little River at USDA-ARS Station N (Tifton, GA)	NO_3 (mg/L)	**1.40**	NO_3 (mg/L)	**0.18**	NO_3 (mg/L)	**1.01**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**1.12**	PO_4 (mg/L)	**0.85**
	Chl *a* (µg/cm^2)	**0.04**	Chl *a* (µg/cm^2)	**0.05**	Chl *a* (µg/cm^2)	**0.04**
Little River at USDA-ARS Station B (Tifton, GA)	NO_3 (mg/L)	**0.77**	NO_3 (mg/L)	**0.05**	NO_3 (mg/L)	**0.62**
	PO_4 (mg/L)	**0.02**	PO_4 (mg/L)	**0.81**	PO_4 (mg/L)	**0.69**
	Chl *a* (µg/cm^2)	**0.03**	Chl *a* (µg/cm^2)	**0.04**	Chl *a* (µg/cm^2)	**0.04**
Little Satilla Creek (Screven, GA)	NO_3 (mg/L)	**1.16**	NO_3 (mg/L)	**0.03**	NO_3 (mg/L)	**0.97**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**1.65**	PO_4 (mg/L)	**0.98**
	Chl *a* (µg/cm^2)	**0.39**	Chl *a* (µg/cm^2)	**0.46**	Chl *a* (µg/cm^2)	**0.39**
Little Satilla Creek (Odum, GA)	NO_3 (mg/L)	**0.96**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**0.62**
	PO_4 (mg/L)	**0.01**	PO_4 (mg/L)	**1.34**	PO_4 (mg/L)	**0.83**
	Chl *a* (µg/cm^2)	**0.21**	Chl *a* (µg/cm^2)	**0.15**	Chl *a* (µg/cm^2)	**0.41**

Table 5.6. Average chlorophyll *a* values and residual nutrient concentrations in the sun.

Site	NO_3 Treatment Group		PO_4 Treatment Group		NO_3-PO_4 Treatment Group	
Broxton Rocks (Broxton, GA)	NO_3 (mg/L)	**3.64**	NO_3 (mg/L)	**0.00**	NO_3 (mg/L)	**6.42**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**3.70**	PO_4 (mg/L)	**3.14**
	Chl *a* (μg/cm^2)	**0.23**	Chl *a* (μg/cm^2)	**0.65**	Chl *a* (μg/cm^2)	**1.74**
Five Mile Creek (Weber, GA)	NO_3 (mg/L)	**1.39**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**4.00**
	PO_4 (mg/L)	**0.02**	PO_4 (mg/L)	**1.93**	PO_4 (mg/L)	**2.19**
	Chl *a* (μg/cm^2)	**1.95**	Chl *a* (μg/cm^2)	**2.29**	Chl *a* (μg/cm^2)	**4.01**
Suwannoochee Creek (DuPont, GA)	NO_3 (mg/L)	**1.30**	NO_3 (mg/L)	**0.01**	NO_3 (mg/L)	**1.34**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**1.44**	PO_4 (mg/L)	**1.21**
	Chl *a* (μg/cm^2)	**3.64**	Chl *a* (μg/cm^2)	**3.42**	Chl *a* (μg/cm^2)	**3.62**
Suwannoochee Creek (Fruitland, GA)	NO_3 (mg/L)	**6.42**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**11.17**
	PO_4 (mg/L)	**0.00**	PO_4 (mg/L)	**3.30**	PO_4 (mg/L)	**3.72**
	Chl *a* (μg/cm^2)	**2.21**	Chl *a* (μg/cm^2)	**2.32**	Chl *a* (μg/cm^2)	**2.36**
Suwannoochee Creek (Fargo, GA)	NO_3 (mg/L)	**0.68**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**0.69**
	PO_4 (mg/L)	**0.01**	PO_4 (mg/L)	**1.24**	PO_4 (mg/L)	**0.89**
	Chl *a* (μg/cm^2)	**0.72**	Chl *a* (μg/cm^2)	**1.07**	Chl *a* (μg/cm^2)	**0.52**
Little River at USDA-ARS Station N (Tifton, GA)	NO_3 (mg/L)	**1.00**	NO_3 (mg/L)	**0.03**	NO_3 (mg/L)	**0.09**
	PO_4 (mg/L)	**0.02**	PO_4 (mg/L)	**0.69**	PO_4 (mg/L)	**0.23**
	Chl *a* (μg/cm^2)	**0.67**	Chl *a* (μg/cm^2)	**5.54**	Chl *a* (μg/cm^2)	**6.93**
Little River at USDA-ARS Station B (Tifton, GA)	NO_3 (mg/L)	**1.01**	NO_3 (mg/L)	**0.05**	NO_3 (mg/L)	**8.92**
	PO_4 (mg/L)	**0.01**	PO_4 (mg/L)	**2.08**	PO_4 (mg/L)	**3.26**
	Chl *a* (μg/cm^2)	**1.48**	Chl *a* (μg/cm^2)	**1.58**	Chl *a* (μg/cm^2)	**5.00**
Little Satilla Creek (Screven, GA)	NO_3 (mg/L)	**0.91**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**0.86**
	PO_4 (mg/L)	**0.01**	PO_4 (mg/L)	**1.36**	PO_4 (mg/L)	**0.86**
	Chl *a* (μg/cm^2)	**1.41**	Chl *a* (μg/cm^2)	**2.01**	Chl *a* (μg/cm^2)	**1.91**
Little Satilla Creek (Odum, GA)	NO_3 (mg/L)	**0.51**	NO_3 (mg/L)	**0.02**	NO_3 (mg/L)	**0.13**
	PO_4 (mg/L)	**0.01**	PO_4 (mg/L)	**1.01**	PO_4 (mg/L)	**0.59**
	Chl *a* (μg/cm^2)	**1.08**	Chl *a* (μg/cm^2)	**0.66**	Chl *a* (μg/cm^2)	**2.81**

Table 5.7. Summary chlorophyll *a* data for periphytometers deployed in the shade.

	Treatment Groups				
Site	Control	NO_3-N	PO_4-P	NO_3-N + PO_4-P	Statistics
Broxton Rocks (Broxton, GA)	**0.15**	**0.21**	**0.45**	**1.45**	Mean (µg/cm^2)
	0.04	0.05	0.06	0.32	Standard Deviation
	0.30	0.25	0.15	0.22	Coefficient of Variation
Five Mile Creek (Weber, GA)	**0.27**	**0.28**	**0.36**	**0.30**	Mean (µg/cm^2)
	0.08	0.08	0.11	0.08	Standard Deviation
	0.28	0.27	0.32	0.28	Coefficient of Variation
Suwannoochee Creek (DuPont, GA)	**0.16**	**0.19**	**0.22**	**0.17**	Mean (µg/cm^2)
	0.05	0.04	0.15	0.04	Standard Deviation
	0.30	0.24	0.70	0.21	Coefficient of Variation
Suwannoochee Creek (Fruitland, GA)	**0.22**	**0.29**	**0.24**	**0.32**	Mean (µg/cm^2)
	0.06	0.10	0.07	0.08	Standard Deviation
	0.26	0.34	0.30	0.25	Coefficient of Variation
Suwannoochee Creek (Fargo, GA)	**0.33**	**0.20**	**0.28**	**0.21**	Mean (µg/cm^2)
	0.18	0.11	0.15	0.13	Standard Deviation
	0.54	0.57	0.52	0.61	Coefficient of Variation
Little River at USDA-ARS Station N (Tifton, GA)	**0.05**	**0.04**	**0.05**	**0.04**	Mean (µg/cm^2)
	0.02	0.01	0.02	0.01	Standard Deviation
	0.37	0.33	0.38	0.23	Coefficient of Variation
Little River at USDA-ARS Station B (Tifton, GA)	**0.03**	**0.03**	**0.04**	**0.04**	Mean (µg/cm^2)
	0.01	0.01	0.01	0.01	Standard Deviation
	0.25	0.20	0.20	0.18	Coefficient of Variation
Little Satilla Creek (Screven, GA)	**0.47**	**0.39**	**0.46**	**0.39**	Mean (µg/cm^2)
	0.15	0.19	0.19	0.06	Standard Deviation
	0.31	0.48	0.41	0.15	Coefficient of Variation
Little Satilla Creek (Odum, GA)	**0.14**	**0.21**	**0.15**	**0.41**	Mean (µg/cm^2)
	0.03	0.05	0.04	0.20	Standard Deviation
	0.22	0.23	0.28	0.49	Coefficient of Variation

Table 5.8. Summary chlorophyll *a* data for periphytometers deployed in the sun.

	Treatment Groups				
Site	**Control**	**NO_3-N**	**PO_4-P**	**NO_3-N + PO_4-P**	**Statistics**
Broxton Rocks (Broxton, GA)	**0.22**	**0.23**	**0.65**	**1.74**	Mean (µg/cm^2)
	0.03	0.03	0.07	0.13	Standard Deviation
	0.16	0.12	0.12	0.07	Coefficient of Variation
Five Mile Creek (Weber, GA)	**1.85**	**1.95**	**2.29**	**4.01**	Mean (µg/cm^2)
	0.46	0.41	0.35	0.33	Standard Deviation
	0.25	0.21	0.15	0.08	Coefficient of Variation
Suwannoochee Creek (DuPont, GA)	**3.54**	**3.64**	**3.42**	**3.62**	Mean (µg/cm^2)
	0.35	0.38	0.39	0.45	Standard Deviation
	0.10	0.10	0.11	0.13	Coefficient of Variation
Suwannoochee Creek (Fruitland, GA)	**1.87**	**2.21**	**2.32**	**2.36**	Mean (µg/cm^2)
	0.31	0.28	0.23	0.23	Standard Deviation
	0.17	0.13	0.10	0.10	Coefficient of Variation
Suwannoochee Creek (Fargo, GA)	**0.72**	**0.72**	**1.07**	**0.52**	Mean (µg/cm^2)
	0.29	0.44	0.48	0.21	Standard Deviation
	0.40	0.61	0.45	0.40	Coefficient of Variation
Little River at USDA-ARS Station N (Tifton, GA)	**0.55**	**0.67**	**5.54**	**6.93**	Mean (µg/cm^2)
	0.16	0.39	0.83	1.93	Standard Deviation
	0.29	0.58	0.15	0.28	Coefficient of Variation
Little River at USDA-ARS Station B (Tifton, GA)	**1.11**	**1.48**	**1.58**	**5.00**	Mean (µg/cm^2)
	0.50	0.64	0.55	1.15	Standard Deviation
	0.45	0.43	0.35	0.23	Coefficient of Variation
Little Satilla Creek (Screven, GA)	**1.88**	**1.41**	**2.01**	**1.91**	Mean (µg/cm^2)
	0.52	0.16	0.19	0.38	Standard Deviation
	0.28	0.12	0.10	0.20	Coefficient of Variation
Little Satilla Creek (Odum, GA)	**0.60**	**1.08**	**0.66**	**2.81**	Mean (µg/cm^2)
	0.15	0.33	0.16	0.65	Standard Deviation
	0.25	0.31	0.24	0.23	Coefficient of Variation

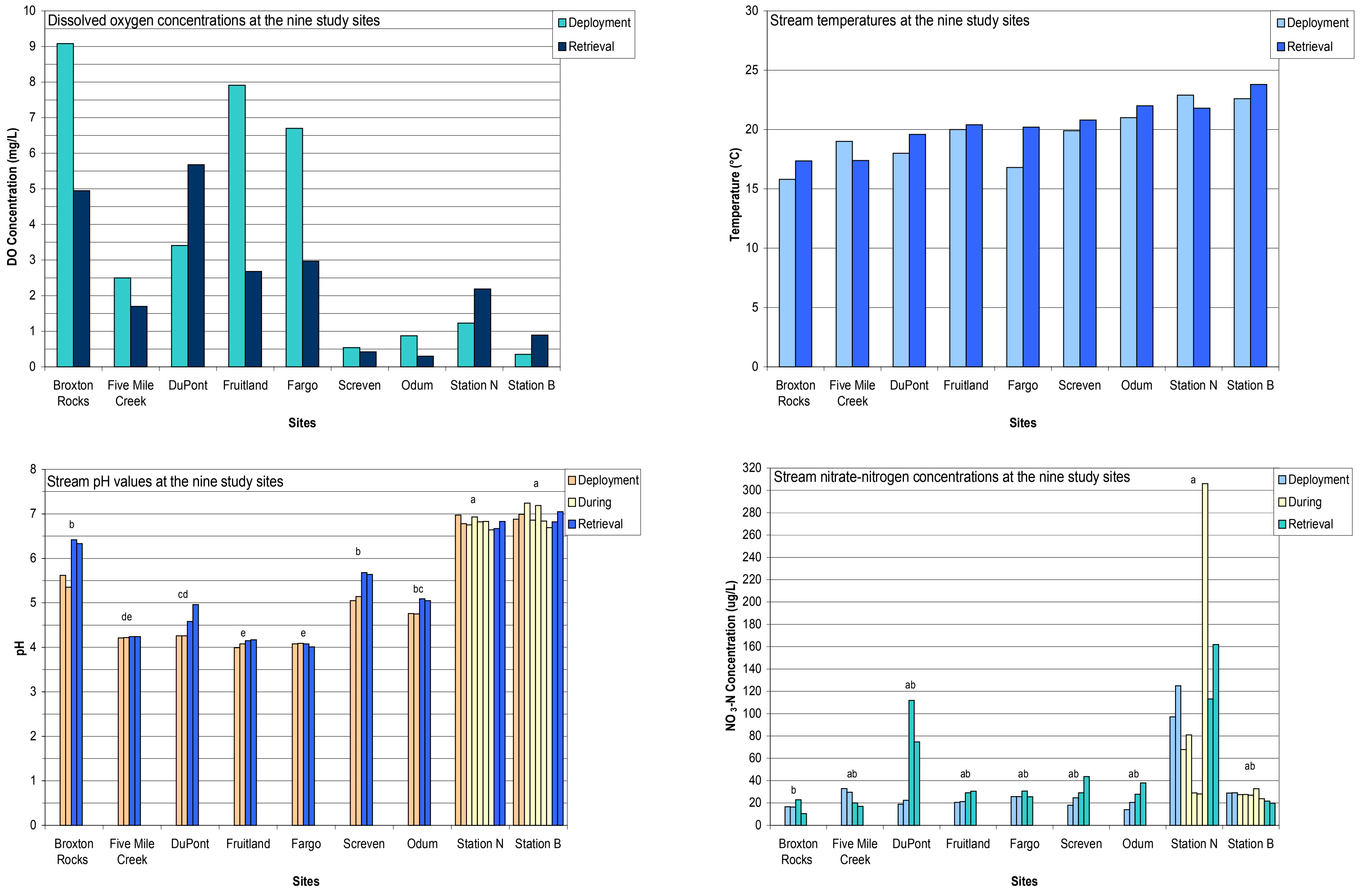


Figure 5.1(a). Stream variables at the nine study sites. For each site, stream concentrations on periphytometer deployment and retrieval dates were obtained from stream samples collected in the (1) shade and (2) sun. Stream samples throughout experiments at Stations N and B were collected close to frames in the sun. Sites with different letters are significantly different at α = 0.05.

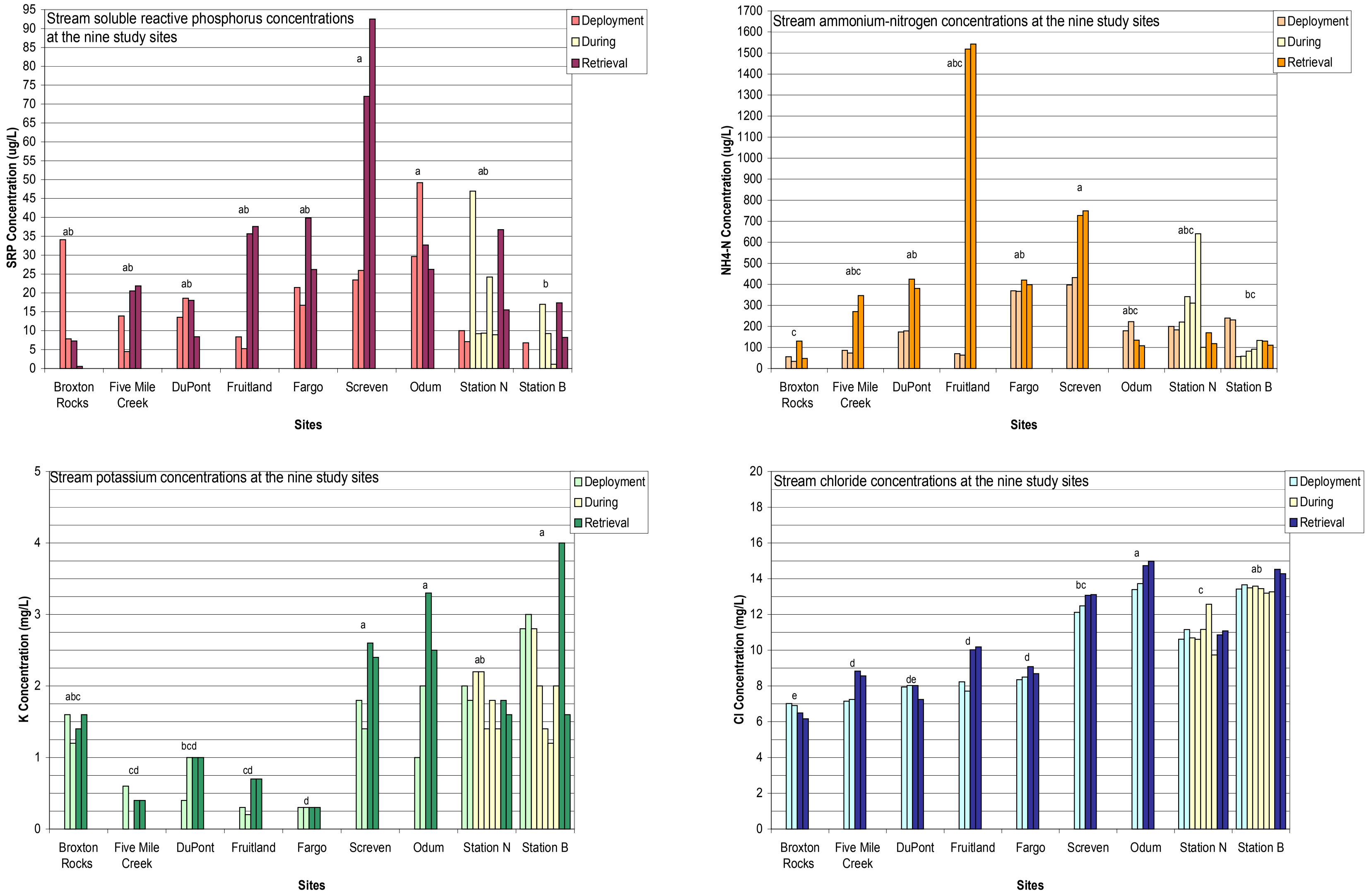


Figure 5.1(b). Stream variables at the nine study sites (continued). For each site, stream concentrations on periphytometer deployment and retrieval dates were obtained from stream samples collected in the (1) shade and (2) sun. Stream samples throughout experiments at Stations N and B were collected close to frames in the sun. Sites with different letters are significantly different at $\alpha = 0.05$.

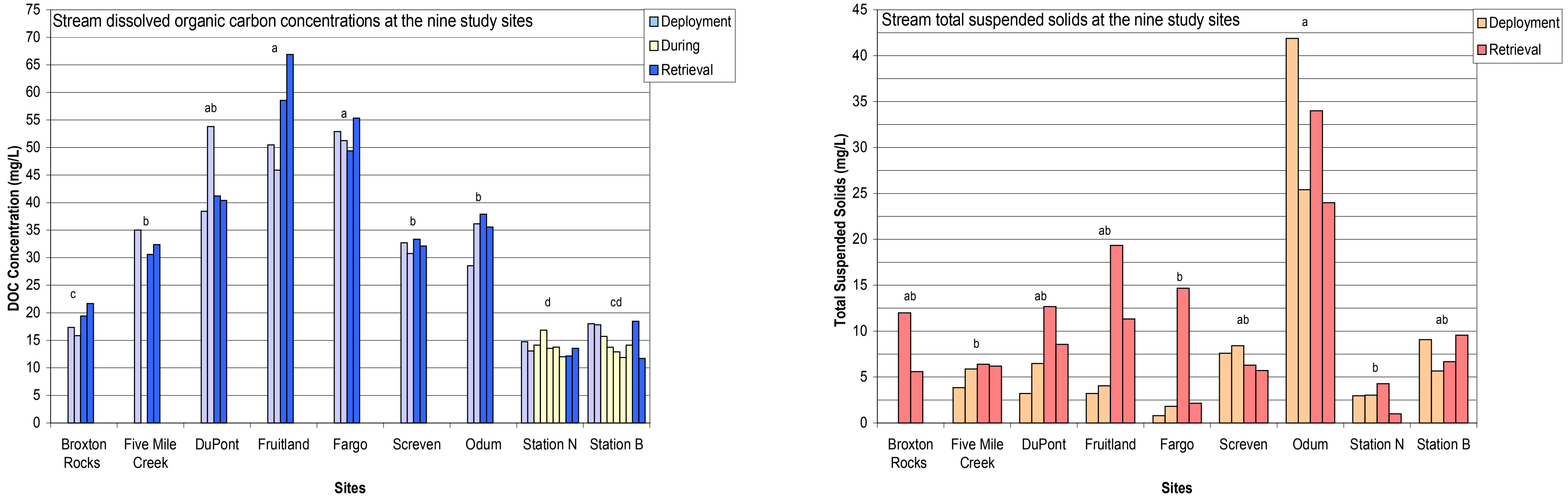


Figure 5.1(c). Stream variables at the nine study sites (continued). For each site, stream concentrations on periphytometer deployment and retrieval dates were obtained from stream samples collected in the (1) shade and (2) sun. Stream samples throughout experiments at Stations N and B were collected close to frames in the sun. Sites with different letters are significantly different at $\alpha = 0.05$.

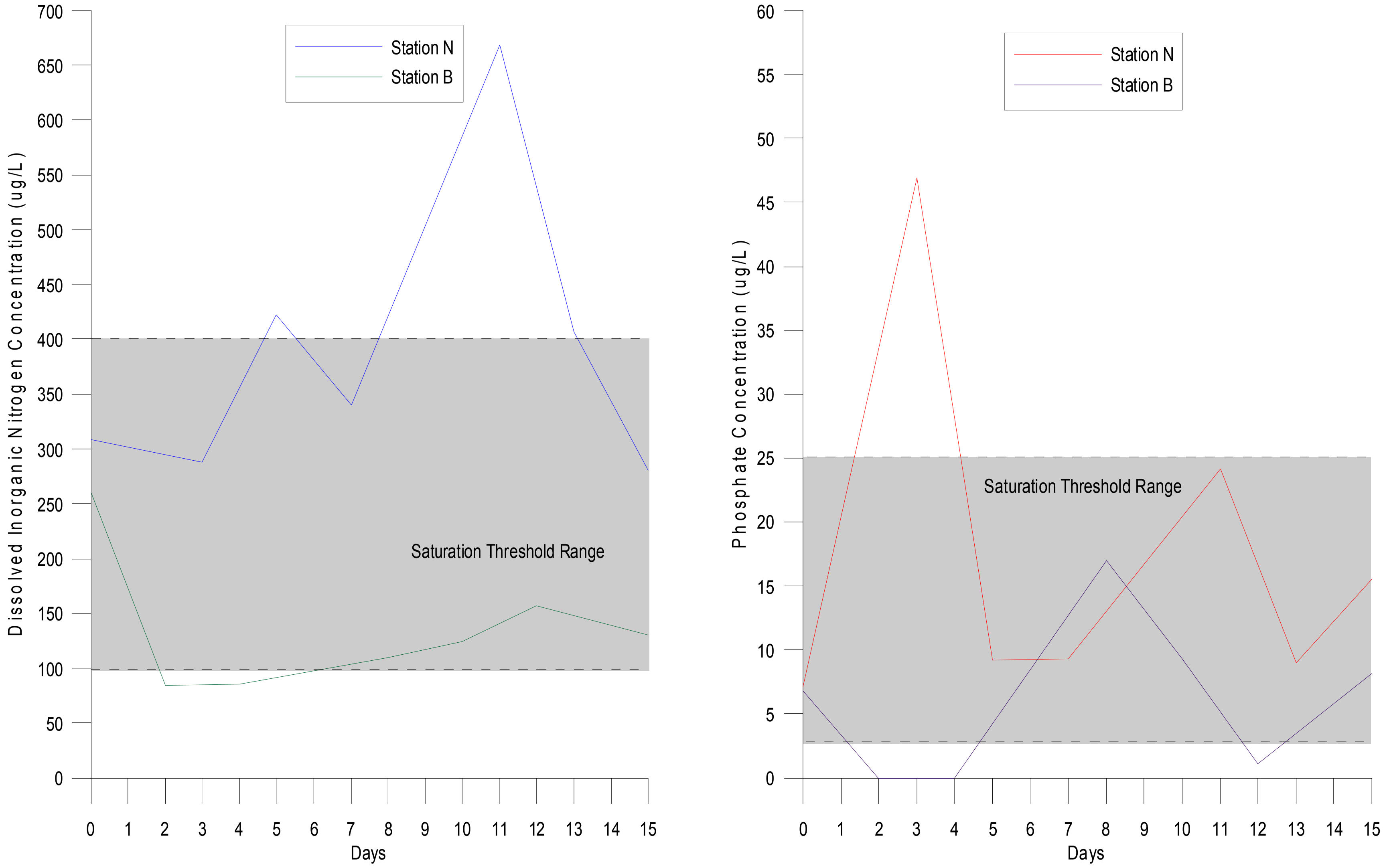
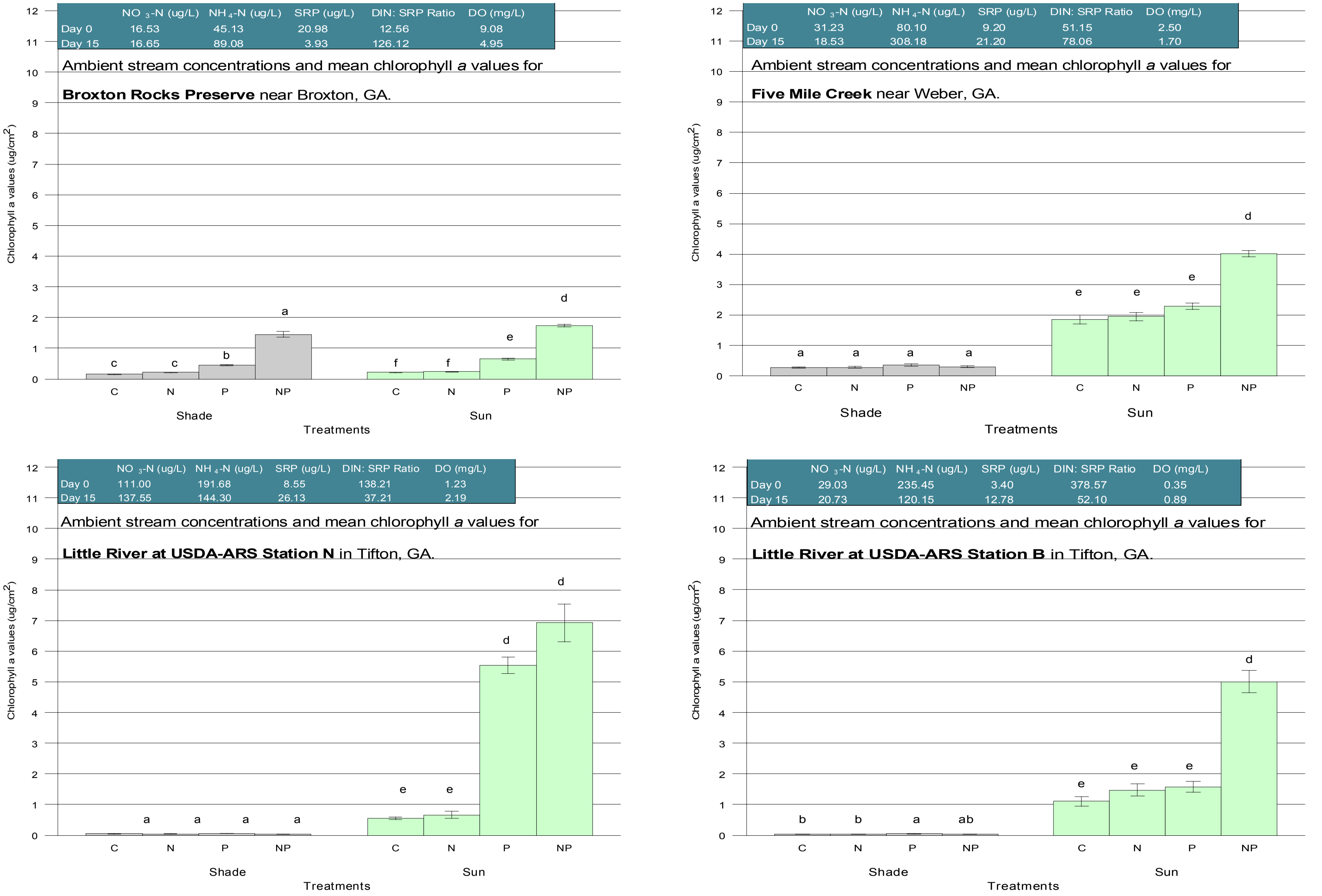


Figure 5.2. Stream nutrient concentrations at USDA-ARS Stations N and B during periphytometer experiments. At Station N, two periphytometers were deployed on May 21, 2004 and retrieved on June 5, 2004. Two additional periphytometers were deployed at Station B from May 24, 2004 to June 8, 2004. The shaded region on each graph is the range of reported nutrient saturation levels for algal growth.



Ambient stream concentrations and mean chlorophyll *a* values for **Broxton Rocks Preserve** near Broxton, GA.

	NO $_3$-N (ug/L)	NH $_4$-N (ug/L)	SRP (ug/L)	DIN: SRP Ratio	DO (mg/L)
Day 0	16.53	45.13	20.98	12.56	9.08
Day 15	16.65	89.08	3.93	126.12	4.95

Ambient stream concentrations and mean chlorophyll *a* values for **Five Mile Creek** near Weber, GA.

	NO $_3$-N (ug/L)	NH $_4$-N (ug/L)	SRP (ug/L)	DIN: SRP Ratio	DO (mg/L)
Day 0	31.23	80.10	9.20	51.15	2.50
Day 15	18.53	308.18	21.20	78.06	1.70

Ambient stream concentrations and mean chlorophyll *a* values for **Little River at USDA-ARS Station N** in Tifton, GA.

	NO $_3$-N (ug/L)	NH $_4$-N (ug/L)	SRP (ug/L)	DIN: SRP Ratio	DO (mg/L)
Day 0	111.00	191.68	8.55	138.21	1.23
Day 15	137.55	144.30	26.13	37.21	2.19

Ambient stream concentrations and mean chlorophyll *a* values for **Little River at USDA-ARS Station B** in Tifton, GA.

	NO $_3$-N (ug/L)	NH $_4$-N (ug/L)	SRP (ug/L)	DIN: SRP Ratio	DO (mg/L)
Day 0	29.03	235.45	3.40	378.57	0.35
Day 15	20.73	120.15	12.78	52.10	0.89

Figure 5.3 (a). Summary chlorophyll *a* data for the nine study sites. Different letters within each category (shade or sun) represent treatment means that are significantly different at $\alpha = 0.05$. Error bars represent standard error.

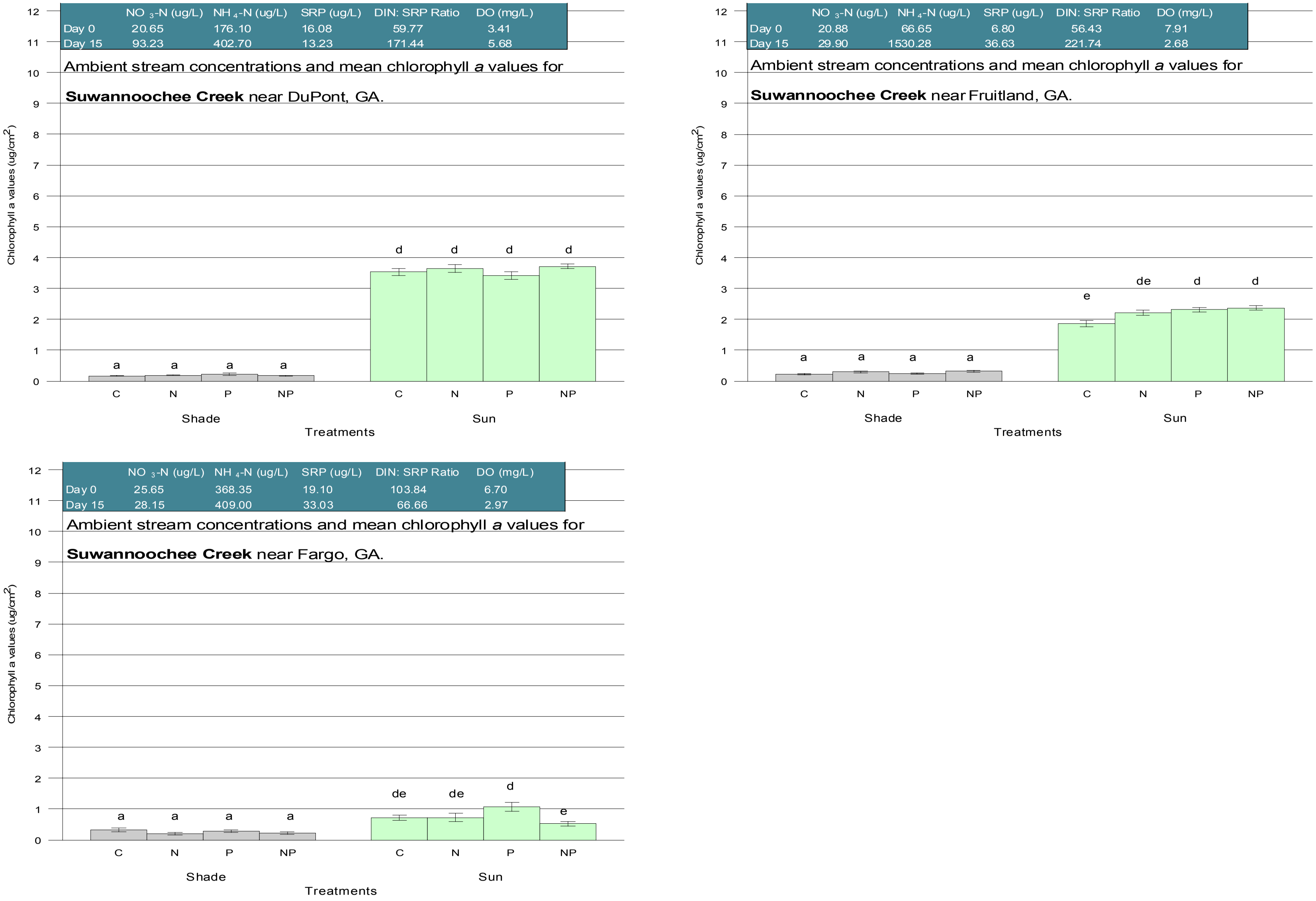


Figure 5.3 (b). Summary chlorophyll *a* data for the nine study sites (continued). Different letters within each category (shade or sun) represent treatment means that are significantly different at α = 0.05. Error bars represent standard error.

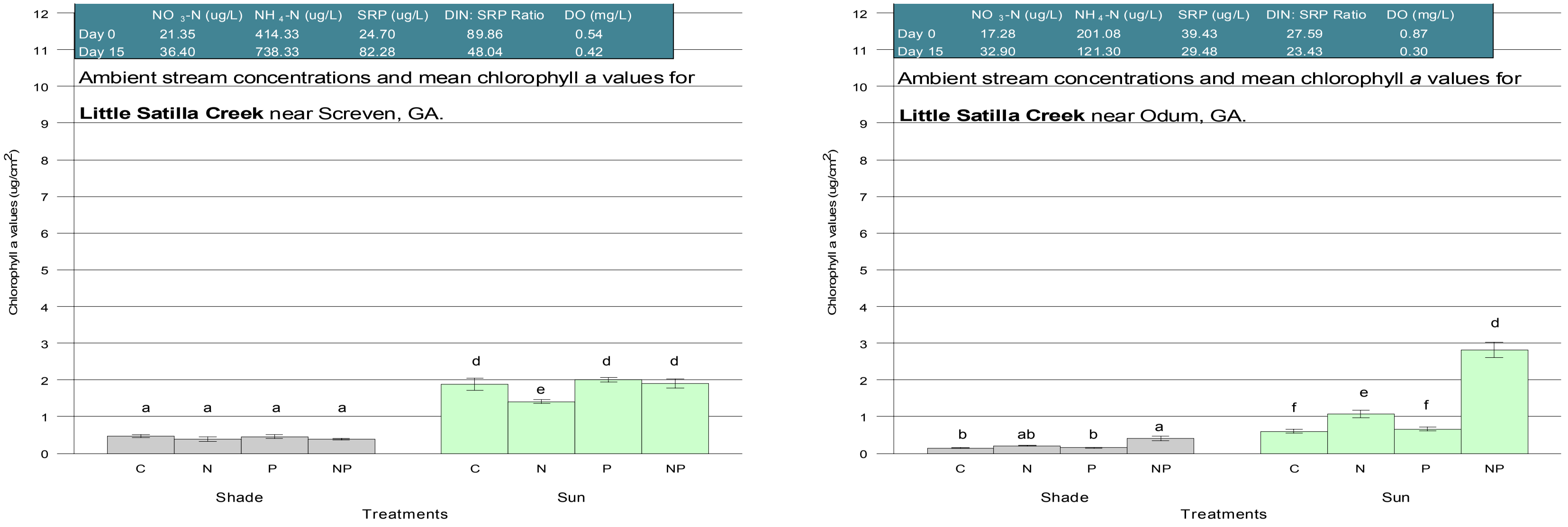


Figure 5.3 (c). Summary chlorophyll *a* data for the nine study sites (continued). Different letters within each category (shade or sun) represent treatment means that are significantly different at $\alpha = 0.05$. Error bars represent standard error.

CHAPTER 6

DISCUSSION

Blackwater systems in the southern coastal plain of Georgia are characterized by low dissolved oxygen (DO) concentrations (Meyer 1992), especially during the summer when DO concentrations can fall well below minimum regulatory levels (4.0 mg/L). DO concentrations in these systems are typically low during summer and autumn, but increase in winter and spring (Smock and Gilinsky 1992). Several factors such as low-flow conditions, decreased oxygen solubility in warmer water and increased microbial respiration may explain this seasonal pattern (Smock and Gilinsky 1992). Additionally, organic matter from the floodplain can increase sediment oxygen demand and high dissolved organic carbon (DOC) concentrations can promote bacterial growth and respiration (Meyer 1992). The focus of this study however, was on nutrient levels within these systems; specifically, on algal periphyton response to nutrients in streams which can potentially result in low DO levels.

Factors Affecting Relative Periphyton Growth

Light Availability

Light conditions clearly affected chlorophyll *a* production at the nine study sites. Because chlorophyll *a* levels for both treatments and controls were significantly greater in the sun, periphyton growth may be predominately light-limited in heavily shaded coastal plain streams. Light is “a prerequisite for a phototrophic existence” because it enables periphyton to utilize inorganic compounds (Hill 1996). Nutrients and irradiance are critical factors affecting primary productivity but nutrient limitation of algal growth generally occurs only above photo-saturation levels (Mosisch et al. 1999). Algal biomass in some streams can therefore be primarily limited by irradiance and secondarily limited by nutrients (Lowe et al. 1986; Rosemond 1994). Results from periphytometer experiments indicate that excess nutrients are unlikely to stimulate algal growth under low-light conditions in the Georgia coastal plain. Nutrient availability does appear to significantly affect primary productivity in lightly shaded areas however. Out of nine periphytometers deployed in relatively open areas, all but three – Little Satilla Creek near Screven and Suwannoochee Creek near DuPont and Fargo – had at least one treatment (NO_3, PO_4 or NO_3-PO_4) with chlorophyll *a* values significantly higher than the control. Experiments at both Broxton Rocks and Little Satilla Creek near Odum further demonstrated the relative importance of light. Both periphytometers in the shade at Broxton Rocks (incomplete canopy) and Odum (where trees were cut) were unintentionally exposed to higher irradiance levels and resultant chlorophyll *a* values reflected patterns observed in the sun (Figure 5.3 (a) & (c)).

DOC concentrations and total suspended solids (TSS) may also inhibit periphyton growth because of light attenuation. Riparian canopy cover can intercept up to 95% of the incident solar radiation in narrow stream channels and, as light penetrates the water, high DOC concentrations and suspended solids can scatter and absorb light (Hill 1996). Smock and Gilinsky (1992) noted that DOC in blackwater streams can approach 50 mg/L, while concentrations greater than 3 mg/L are rarely found in higher-gradient southeastern streams. Highest DOC concentrations in this study were found in Suwannoochee Creek, as all three sites (DuPont, Fruitland and Fargo) had values that approached or exceeded 50 mg/L (Table 5.1; Figure 5.1(c)). Due to the predominance of swamp-stream systems, the ratio of total dissolved inorganic to organic constituents in southeastern blackwater rivers is 1:1 as opposed to 10:1 in the average world river (Wharton 1978).

DOC concentrations and TSS were probably not a significant factor in this study, however. The 20 mL nutrient reservoirs on deployed periphytometers were just beneath the water surface so light attenuation probably did not affect algal growth on glass fiber filters. Furthermore, TSS values may be misleading because in some cases, stream water samples were taken after periphytometers were deployed; stream sediments may have been disturbed during the deployment process.

Nutrients

Nutrient Saturation of Algal Growth

Algal growth in streams can be nutrient-saturated within a range of concentrations. According to algal nutrient kinetics, periphyton nutrient uptake and growth rates peak at optimal nutrient concentrations (species-dependent) and beyond this point, subsequent nutrient inputs will not necessarily increase biomass (see Horne and Goldman 1994). Luxury consumption of P, for example, may result in a temporal separation of nutrient uptake and microbial growth (Borchardt 1996). Bothwell (1985) studied diatoms in British Columbia and found that soluble reactive phosphorus (SRP) saturation occurs between 3 - 4 μg/L while experiments conducted by Rosemond et al. (2002) in Costa Rican streams indicated SRP saturation of microbially-mediated decomposition between 7 – 13 μg/L. In another study utilizing indoor artificial streams, 25 μg/L SRP produced the maximum chlorophyll *a* biomass (Horner et al. 1983).

Nitrogen limitation of benthic algae has been reported at NO_3-N concentrations of 55 μg/L in Sycamore Creek, Arizona (Grimm and Fisher 1986) as well as 100 μg/L in Saline Creek, Missouri (Lohman et al. 1991). Most algal species can use either NH_4-N or NO_3-N as inorganic nitrogen sources but because ammonium can be used to synthesize amino acids directly, it is often preferred (Graham and Wilcox 2000; Allan 1995). Dissolved inorganic nitrogen concentrations (DIN: NO_3-N and NH_4-N) below 100 µg/L may limit algal growth but at concentrations above 400 µg/L, algal growth would not be N-limited (Horne and Goldman 1994).

Residual Concentrations in the Nutrient Reservoirs

Average NO_3 and PO_4 concentrations in the respective treatment vials were generally above "saturation" levels when periphytometers were retrieved (NO_3: 0.09 – 11.17 mg/L and PO_4: 0.23 – 3.72 mg/L; Tables 5.5 & 5.6) although the actual concentrations experienced by attached algae are unclear.

While individual algal cells may saturate at lower concentrations, biomass can continue to increase within the periphyton community because of differential cellular uptake rates (Allan 1995). Factors that may be responsible for variability in residual concentrations include: (1) porosity differences in membrane filters, (2) ambient stream nutrient concentrations, (3) differences in flow rates, and (4) relative periphyton growth on glass fiber filters at different sites.

Residual concentrations in 20 mL vials at the nine study sites were similar to results from preliminary periphytometer experiments (Table 3.3; Appendix C). A few scintillation vials in each treatment group usually contained relatively higher residual concentrations and this was also observed in both diffusion experiments (Tables 3.4 & 3.5). Membrane filters were used to regulate nutrient diffusion and differences in residual concentrations may have been caused by filter variability. The extent and potential influence of this variability is unclear, however, because membrane filters were not analyzed during the study.

Regarding ambient nutrient concentrations, streams with high NO_3-N and PO_4-P concentrations should theoretically experience lower nutrient diffusion rates from treatment vials, but concentrations in 20 mL vials at the start of the experiments were much greater than ambient nutrient concentrations at all sites. The diffusion gradient would have been greatest going from the 20 mL vials to the surrounding water and therefore it is unlikely stream nutrient concentrations affected residual concentrations in treatment vials.

Flow rates may influence the relative residual concentrations because higher current velocities will induce greater nutrient diffusion rates from 20 mL vials. A challenge in relating flow rates to residual concentrations in this study is that daily flow rates were not measured at all sites during the experiments. At USDA-ARS Stations N and B, where flow measurements were available, greater residual concentrations in treatment vials at Station B corresponded to lower current velocities (Table 5.4). Flow rates may therefore be negatively correlated to residual concentrations but, without constant measurements during experiments, it is not possible to accurately assess this relationship.

Excessive periphyton growth on glass fiber filters could also potentially reduce nutrient diffusion rates from 20 mL vials. However, linear regressions on chlorophyll *a* values and residual concentrations from periphytometers deployed in the sun revealed that there was not a significant relationship between these two variables. In the shade, although residual nutrient concentrations were significant for PO_4 and NO_3-PO_4 treatment groups, the relatively low chlorophyll *a* values likely influenced these results.

Although average residual nutrient concentrations in 20 mL vials were sufficient to sustain algal growth, results from both diffusion experiments suggested that, even if nutrient concentrations in the vials were depleted, glass fiber filters were likely to remain enriched relative to the surrounding water as long as ambient concentrations were low. Therefore, results from these nutrient enrichment experiments were unlikely to be significantly affected by the variability observed in residual concentrations.

Periphyton Response to Nutrient Enrichment

Periphyton biomass accrual at the nine study sites, measured as chlorophyll *a*, was similar to results obtained when the periphytometer technique was first used in the Upper Illinois River Basin (Matlock et al. 1998). After two weeks, mean chlorophyll *a* values in the original and subsequent experiments (Matlock et al. 1999a; Matlock et al. 1999b) were between 0.21 and 6.22 μg/cm^2 and several sites responded positively to nutrient enrichment. Additionally, chlorophyll *a* results from the present study corresponded well with data from other experiments using nutrient diffusing substrates (NDS). Tank and Dodds (2003) used glass fiber filters, 60 mL plastic containers and agar nutrient solutions to investigate nutrient-limited algal growth in ten streams across the U.S. and obtained chlorophyll *a* values between 0.10 and 13.20 μg/cm^2 after three weeks. In Canada, Corkum (1996) compared algal growth in forested and agricultural rivers using agar nutrient solutions as well and after five-six weeks, chlorophyll *a* values ranged from 0.20 to 9.50 μg/cm^2. Another study in several Australian streams allowed periphyton to colonize mesh-covered PVC jars containing agar nutrient solutions for seven weeks and chlorophyll *a* values were between 3.00 and 18.00 μg/cm^2 (Mosisch et al. 2001).

In the southeastern U.S, inorganic nutrient concentrations are generally low in undisturbed blackwater streams because: (1) the floodplains function as nutrient sinks; and (2) drainage basin soils are low in nutrients (Smock and Gilinsky 1992). Forested watersheds drained by low-DO streams were therefore favored in this study because potential nutrient limitation of periphyton growth would be clearly seen at these sites. Six of the nine study sites were in predominantly forested watersheds: Broxton Rocks, Five Mile Creek near Weber, Little Satilla Creek near Odum and Suwannoochee Creek near DuPont, Fruitland and Fargo (Table 4.1; Figure 4.2). The other three sites – Little Satilla Creek near Screven, Little River at USDA-ARS Stations N and B – all had strong agricultural influences but Screven was characterized as a mixed agricultural/forested site (Table 4.1; Figure 4.3). Selected sites consequently had varying ambient nutrient concentrations in addition to low DO concentrations.

Based on chlorophyll *a* data from periphytometer experiments, periphyton growth in the sun at Broxton Rocks, Little River at USDA-ARS Stations N and B, Five Mile Creek near Weber, Little Satilla Creek near Odum and Suwannoochee Creek near Fruitland was nutrient-limited (Table 6.1). Broxton Rocks was primarily limited by P and secondarily limited by N while algal growth at Station N was only P-limited. Maximum periphyton growth occurred on NO_3-PO_4 enriched filters at both sites indicating that ambient stream nutrient concentrations were below requirements for algal species in these streams. DIN concentrations at Broxton Rocks on periphytometer deployment (61.66 μg/L) and retrieval (105.73 μg/L) dates were lower than the average concentration throughout the Station N experiment (366.11 μg/L) and this may account for the secondary NO_3 effect at Broxton Rocks (Figure 5.3(a)).

Experimental results from Five Mile Creek and USDA-ARS Station B suggested that periphyton growth was co-limited by both N and P. For Five Mile Creek, the literature indicates that ambient DIN (111.33 µg/L and 326.71 µg/L) and SRP (9.20 µg/L and 21.20) concentrations could be below algal saturation levels (Horne and Goldman 1994; Horner et al. 1983). Stream nutrient concentrations throughout experiments at Station B (average DIN: 152.41 µg/L and SRP: 6.63 µg/L) were similar to Five Mile Creek (Table 5.1).

For all sites except Little Satilla Creek near Odum, stream DIN: SRP molar ratios (Table 5.3) on periphytometer deployment and retrieval dates suggested P-limitation of algal growth. N: P molar ratios below 16: 1 would theoretically lead to N limitation (Redfield 1958) but Allan (1995) noted that the shift from P to N limitation may actually occur anywhere from 10 - 30: 1. Nutrient ratios at Odum, the only site that was N-limited, were between 23: 1 and 27: 1; remaining sites all had much higher ratios (Table 5.3). For all nine sites, Odum had the second highest SRP concentrations (39.43 µg/L and 29.48 µg/L) and among the lowest DIN concentrations (218.36 µg/L and 154.20 µg/L). Odum was primarily limited by N but NO_3-PO_4 enriched filters produced the greatest periphyton biomass and this was consistent with previously published NDS experiments.

Tank and Dodds (2003) reviewed several NDS studies and found that co-limitation, or primary limitation by one nutrient and secondary limitation by another, was reported most frequently (41% of experiments). Liebig's Law of the Minimum – the single limiting nutrient paradigm – asserts that only one nutrient can limit plant growth at a particular time and this has been experimentally verified for algal monocultures (Tilman et al. 1982; Borchardt 1996). Multiple species algal communities may be limited by different nutrients because of species-specific nutrient requirements however. Francoeur (2001) conducted a meta-analysis of lotic nutrient amendment experiments and found that simultaneous stimulation of algal communities by separate additions of nutrients (e.g. N vs. P) was common. Periphytometer data from nutrient-limited sites in this study could therefore reflect “simultaneous limitation of different species in the same benthic algal community by different nutrients” (Francoeur 2001).

Based on stream nutrient ratios alone, chlorophyll *a* values for PO_4 and NO_3-PO_4 treatments should have been greater than controls at every site except Little Satilla Creek near Odum. However, stream ratios become irrelevant when ambient concentrations exceed growth-limiting levels for algae; cellular ratios are key (Borchardt 1996). Algal cellular ratios of N and P in Little Satilla Creek (Screven) and Suwannoochee Creek (DuPont and Fargo) – sites with high DIN: SRP ratios but no nutrient limitation – may have already been optimal for growth before the nutrient enrichment experiments.

Little Satilla Creek near Screven was characterized as a mixed agricultural/forested watershed and the high nutrient concentrations reported for this site (Table 5.1; Figure 5.3(c)) were not unexpected. Except for Suwannoochee Creek near DuPont and USDA-ARS Station N, NO_3-N values at Screven on periphytometer deployment and retrieval dates were in the same general range as the remaining sites (18 – 45 μg/L; Figure 5.1(a)). However, Screven had the highest overall SRP (23.45 – 92.50 μg/L) and the second highest NH_4-N (396.70 – 749.45 μg/L) concentrations. The high NH_4-N concentrations may explain why chlorophyll *a* values on control filters were higher than NO_3 filters: NH_4-N was saturated and there was no physiological advantage for periphyton in colonizing NO_3-N enriched filters. The periphyton community showed no evidence of nutrient-limited growth at Screven and this was consistent with an already saturated environment.

Suwannoochee Creek sites (DuPont, Fargo and Fruitland) were located in relatively secluded, forested areas and chlorophyll *a* results here were interesting. DIN concentrations at DuPont increased from the beginning (196.75 μg/L) to the end (495.93 μg/L) of the experiments while SRP concentrations declined (16.08 μg/L to 13.23 μg/L). There were no significant differences between any treatments at DuPont and furthermore, the average chlorophyll *a* value for control (3.50 μg/cm^2) filters in the sun was higher than every treatment group in the entire study except Five Mile Creek (NO_3-PO_4: 4.01 μg/cm^2), Station N (PO_4: 5.54 μg/cm^2, NO_3-PO_4: 6.93 μg/cm^2) and Station B (NO_3-PO_4: 5.00 μg/cm^2) (Figure 5.3 (a)). The especially high chlorophyll *a* values for control filters suggests that the periphyton community at DuPont may have been saturated by ambient stream concentrations.

At Fargo, the inconsistent chlorophyll *a* results in the sun may have been caused by the position of the periphytometer. The water level in the stream had dropped during the experiment and unfortunately the channel substrate had shifted the intended position of the apparatus; instead of being flat on the water surface, the periphytometer was at an angle (Figure 4.9). Because this was only observed on the retrieval date, the periphytometer may have been in that position for the majority of the experiment and the angle may have been more severe as well. Both the diffusion rate from the 20 mL vials and the subsequent periphyton response would have been affected by the position of the periphytometer. Therefore, results from this particular experiment will not be discussed further.

Periphyton growth at Fruitland was nutrient-limited in the sun but treatment means were similar. Stream DIN: SRP molar ratios (56.43 – 221.74) suggested P-limited algal growth and mean chlorophyll *a* values from PO_4 and NO_3-PO_4 filters were significantly greater than controls (Figure 5.3 (b)). Because NO_3 filters were not significantly different from any other treatment group however, results from this experiment are unclear. Toxicity may be a concern because of the high NH_4-N levels but in acidic streams, undissociated NH_4OH is converted to less harmful

NH_4+ and hydroxyl ions (OH^-) (Horne and Goldman 1994); average pH at Fruitland was 4.10 (Table 5.1).

Morin and Cattaneo (1992) analyzed several periphyton field studies and found that sampling designs used would only detect significant differences ($\alpha = 0.05$) in periphyton productivity if treatment means differed by at least a factor of two. Periphytometer results from Broxton Rocks, Station N, Station B, Five Mile Creek and Odum generally supported this analysis. Throughout the entire study however, low within-treatment variability for chlorophyll *a* values suggested smaller differences could be detected and this was indeed evident at both Fruitland and Screven (Figure 5.3 (b) & (c)).

Flow

Physiological processes within benthic algae, such as nutrient uptake and reproduction rates, are affected by current velocity (Allan 1995). Multiple factors control how benthic algae respond to current – optimum velocities are 0.05 m/s in some habitats while maximum algal growth occurs at 0.6 m/s in others (Stevenson 1996). Nutrients are continuously renewed in flowing waters but during the Little River (Stations N and B) experiments, minimal flows meant that normally high nutrient concentrations were low. Table 6.2 shows the mean daily flow rates and nutrient concentrations before and after experiments at Stations N and B. Flow measurements were available after experiments at Station N but nutrient concentrations were not; based on the pattern at Station B however, it is likely that there was a positive correlation between flow and nutrient concentrations at both sites. Because flow rates had begun to decrease before periphytometers were deployed and were even lower during the experiments (Appendix B), both sites were nutrient deficient. Despite Stations N and B being in agricultural watersheds, chlorophyll *a* values from both sites were consistent with actual stream concentrations during the experiments as both sites mimicked the nutrient characteristics of forested watersheds (Table 5.1).

Another issue with streamflow is that algal metabolism in streams with high nutrient concentrations is more likely to be positively affected by current (Stevenson 1996). Only three sites in this study could be characterized as streams with potentially high nutrient loads: Little River at USDA-ARS Stations N and B and Little Satilla Creek near Screven. Flow, if any, was minimal at these three sites but nutrient concentrations were relatively low at Stations N and B in comparison to Screven. Watershed characteristics such as hydrology and relative nutrient loads may account for this difference. Little Satilla Creek near Screven may simply have greater nutrient inputs than both gaging stations in the Little River and consequently, even with minimal flows, background concentrations remained excessive.

Table 6.1. Limiting nutrients for algal growth at the nine study sites. Chlorophyll *a* analyses from periphytometers deployed in the sun were used to determine limiting nutrients.

Site Name	**Limiting Nutrients***	**DO when Deployed (mg/L)****	**DO when Retrieved (mg/L)**
Broxton Rocks Preserve (Broxton, GA)	P/N	9.08	4.95
Five Mile Creek (Weber, GA)	NP	2.50	1.70
Suwannoochee Creek (DuPont, GA)	--------	3.41	5.68
Suwannoochee Creek (Fruitland, GA)	P	7.91	2.68
Suwannoochee Creek (Fargo, GA)	--------	6.70	2.97
Little River at USDA-ARS Station N (Tifton, GA)	P	1.23	2.19
Little River at USDA-ARS Station B (Tifton, GA)	NP	0.35	0.89
Little Satilla Creek (Screven, GA)	--------	0.54	0.42
Little Satilla Creek (Odum, GA)	N/P	0.87	0.30

*P/N : primarily phosphate limited, secondary nitrate limitation.
N/P : primarily nitrate limited, secondary phosphate limitation.
NP : co-limitation (nitrate + phosphate)

** DO = Dissolved Oxygen

Table 6.2. Nutrient concentrations and mean daily flow before and after experiments in the Little River at USDA-ARS Stations N and B (Tifton, GA).

Station	Date*	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	Mean Daily Flow (m^3/s)**
N	13-Feb-04	675.05	50.20	21.00	0.575
N	19-Feb-04	758.75	54.75	9.70	0.287
N	26-Feb-04	982.55	146.40	100.20	1.132
N	12-Mar-04	406.40	28.00	26.75	0.140
N	14-May-04	-------	-------	-------	0.032
N	26-Jun-04	-------	-------	-------	0.303
B	13-Feb-04	146.05	28.90	24.70	7.278
B	19-Feb-04	280.35	27.90	19.20	8.328
B	26-Feb-04	232.10	51.55	20.75	7.883
B	12-Mar-04	33.10	12.60	20.95	1.395
B	14-May-04	19.30	326.70	9.90	0.067
B	26-Jun-04	131.05	83.70	20.00	1.915

*Station N periphytometer experiments: May 21, 2004 - June 5, 2004.
Station B periphytometer experiments: May 24, 2004 - June 8, 2004.

**Flow measured in cubic meters per second (m^3/s).

CHAPTER 7

CONCLUSIONS

Georgia Coastal Plain Streams: Algae and Dissolved Oxygen

Algae can significantly decrease DO concentrations if conditions within the stream environment – light, nutrients, grazers etc. – are amenable to sustained population growth (Hill 1996; Borchardt 1996; Miltner and Rankin 1998). Within blackwater streams in the southern coastal plain of Georgia, however, multiple factors likely reduce the possibility of explosive algal growth.

For example, algal growth should not be nutrient-limited in streams with low DO concentrations if excessive algal growth is a significant factor in reducing DO. Algal blooms that eventually die and consume oxygen should already be in a nutrient saturated environment and providing additional nutrients should not stimulate differential algal growth. For sites with both low DO concentrations and nutrient deficiencies (Broxton Rocks, Five Mile Creek near Weber, Suwannoochee Creek near Fruitland, Little Satilla Creek near Odum and Little River at Stations N and B), prevailing conditions were not conducive to optimal algal growth. The potential to significantly lower DO concentrations should be greatest when algae are experiencing optimal growth conditions and if algae at these sites were in fact nutrient-limited, algal growth is unlikely to be the primary factor influencing DO violations.

The results from the experiments at Station N and Station B, although unexpected, demonstrated that benthic algae can be susceptible to seasonally low flows in southeastern blackwater streams. Both sites were located in nutrient-replete agricultural areas where critical factors such as irradiance, not nutrient deficiencies, would be expected to limit algal growth. However, minimal flow during periphytometer experiments reduced the supply of nutrients and algal growth *was* nutrient-limited. Both Stations N and B had extremely low DO concentrations yet the actual nutrient environment for benthic algae was poor. Even in areas with relatively high nutrient inputs, low flow conditions that are prevalent during summer can alter the overall nutrient resources available to benthic algae.

Additional characteristics of blackwater systems further compound the problem for benthic algae because canopy cover is greatest in summer and DOC concentrations are elevated in many streams. Although the three sites from Suwannoochee Creek (DuPont, Fruitland and Fargo) produced mixed results, relatively high DOC concentrations suggest that benthic algae would find it difficult to exploit potentially available resources. DOC concentrations may not have affected periphyton growth on glass fiber filters but algae growing in deeper water could be affected by the associated reduction in photosynthetic active radiation.

Study Limitations

Results from these experiments suggest that algae are not primarily responsible for seasonally low DO levels in this region. Our overall study has several limitations, however. First, specific algal taxa were not identified and actual species identification may provide more insight into the relationship between nutrients and periphyton. Studies conducted in nutrient-rich streams in the Virginia and North Carolina coastal plain have found that *Eunotia pectinalis* is a dominant species and it may be common throughout the Southeast because of its adaptation to acidic and low-conductivity streams (Smock and Gilinsky 1992). Comparing “indicator” algal species (e.g. *E. pectinalis*) at different study sites may have yielded information about the physiological requirements for algae in Georgia coastal plain streams. Another limitation of the study was that I only collected stream water samples on periphytometer deployment and retrieval dates (except at Stations N and B). However, many of the experiments were conducted simultaneously at remote sites and it was not possible to collect daily stream water samples. Daily flow measurements at all sites would have also increased the utility of flow data from Stations N and B because comparisons – periphyton growth, residual and stream nutrient concentrations etc. – could be made across all sites. Low flows would have been difficult to measure with available instrumentation, however.

Recommendations for Future Research

A more extensive project, addressing the aforementioned limitations within this study is recommended. Forested, agricultural and mixed watersheds within each of the four river basins in the southern coastal plain of Georgia – Ochlockonee, Suwannee, Satilla, and St. Mary's – should be targeted. A minimum of two watersheds per land use category and per basin would provide an extensive and rather powerful data set. Acquiring daily stream water samples and flow measurements at each site during the experiments would also help interpretation of algal response. Additionally, by identifying specific algal taxa colonizing filters at different sites and quantifying water column algae, complex stream interactions could be better understood.

Under section 303(d) of the Clean Water Act, Georgia is required to develop expensive, taxpayer-sponsored TMDL programs for each of the DO-impaired streams within the four southern coastal plain river basins. However, the DO regulatory standard may not actually be physically attainable in these streams during summer. Since we have low DO in some nutrient-poor streams where algae are nutrient-limited, our results suggest factors other than algae are responsible for seasonally low DO concentrations. A comprehensive study specifically addressing the effect of algae on DO levels would be helpful in eliminating algae as the cause of low DO in coastal plain streams and this could lead to their eventual removal from Georgia's 303(d) list. Delisting is usually reserved for streams that have undergone major improvements in water quality but in this scenario, delisting would be the proper course of action because streams in the southern coastal plain of Georgia may not have actually been impaired.

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APPENDIX A

CHLOROPHYLL A DATA FOR PRELIMINARY EXPERIMENTS

Table A-1. Chlorophyll *a* values for periphytometer experiment in the shade at Site 1. The frames were deployed on June 27, 2003 and retrieved on July 2, 2003.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S1-L627NP-1	1.97	0.00230	S1-L627C-1	2.55	0.00298
S1-L627NP-2	1.06	0.00124	S1-L627C-2	2.97	0.00347
S1-L627NP-3	1.48	0.00173	S1-L627C-3	3.41	0.00399
S1-L627NP-4	1.24	0.00145	S1-L627C-4	2.84	0.00332
S1-L627NP-5	1.80	0.00211	S1-L627C-5	1.82	0.00213
S1-L627NP-6	1.71	0.00200	S1-L627C-6	4.26	0.00498
Mean		0.00181			0.00348
Standard Deviation		0.00037			0.00088
Coefficient of Variation		0.20581			0.25204

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S1-S627NP-1	0.27	0.00119	S1-S627C-1	0.48	0.00211
S1-S627NP-2	0.46	0.00203	S1-S627C-2	0.76	0.00335
S1-S627NP-3	0.69	0.00304	S1-S627C-3	0.96	0.00423
S1-S627NP-4	0.38	0.00167	S1-S627C-4	0.78	0.00344
S1-S627NP-5	0.55	0.00242	S1-S627C-5	1.69	0.00744
S1-S627NP-6	0.72	0.00317	S1-S627C-6	0.52	0.00229
S1-S627NP-7	0.39	0.00172	S1-S627C-7	0.49	0.00216
S1-S627NP-8	0.66	0.00291	S1-S627C-8	0.81	0.00357
S1-S627NP-9	1.14	0.00502	S1-S627C-9	0.43	0.00189
S1-S627NP-10	0.82	0.00361	S1-S627C-10	0.47	0.00207
S1-S627NP-11	0.37	0.00163	S1-S627C-11	0.53	0.00233
S1-S627NP-12	0.41	0.00181	S1-S627C-12	0.66	0.00291
S1-S627NP-13	1.35	0.00595	S1-S627C-13	0.59	0.00260
S1-S627NP-14	0.52	0.00229	S1-S627C-14	0.44	0.00194
S1-S627NP-15	0.39	0.00172	S1-S627C-15	0.45	0.00198
S1-S627NP-16			S1-S627C-16	0.69	0.00304
S1-S627NP-17	1.04	0.00458	S1-S627C-17	0.56	0.00247
S1-S627NP-18	0.76	0.00335	S1-S627C-18	0.89	0.00392
S1-S627NP-19	0.49	0.00216	S1-S627C-19	0.35	0.00154
S1-S627NP-20	0.84	0.00370	S1-S627C-20	0.68	0.00300
Mean		0.00284			0.00291
Standard Deviation		0.00126			0.00126
Coefficient of Variation		0.44193			0.43319

*S1-L627NP = 250 mL nitrate-phosphate filter from June 27, 2003 experiment at Site 1.
S1-L627C = 250 mL control filter
S1-S627NP = 20 mL nitrate-phosphate filter
S1-S627C = 20 mL control filter

Table A-2. Chlorophyll *a* values for periphytometer experiment in the shade at Site 1. The frames were deployed on July 3, 2003 and retrieved on July 8, 2003.

Frame 1

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S1-L703NP-1	8.30	0.00971	S1-L703C-1	6.93	0.00811
S1-L703NP-4	6.79	0.00794	S1-L703C-2	4.89	0.00572
S1-L703NP-5	7.34	0.00858	S1-L703C-4	4.07	0.00476
Mean		0.00874			0.00619
Standard Deviation		0.00073			0.00141
Coefficient of Variation		0.08346			0.22703
S1-S703NP-1	0.63	0.00278	S1-S703C-1	1.73	0.00762
S1-S703NP-2	1.13	0.00498	S1-S703C-2	0.73	0.00322
S1-S703NP-3	1.28	0.00564	S1-S703C-3	2.10	0.00925
S1-S703NP-4	0.92	0.00405	S1-S703C-4	1.56	0.00687
S1-S703NP-5	0.88	0.00388	S1-S703C-5	1.40	0.00617
S1-S703NP-11	1.38	0.00608	S1-S703C-11	0.71	0.00313
S1-S703NP-12	1.02	0.00449	S1-S703C-12	1.15	0.00507
S1-S703NP-13	0.93	0.00410	S1-S703C-13	0.72	0.00317
S1-S703NP-14	0.93	0.00410	S1-S703C-14	1.25	0.00551
S1-S703NP-15	0.75	0.00330	S1-S703C-15	2.23	0.00982
Mean		0.00434			0.00598
Standard Deviation		0.00095			0.00232
Coefficient of Variation		0.21959			0.21959

Frame 2

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S1-L703NP-2	9.12	0.01067	S1-L703C-3	8.40	0.00982
S1-L703NP-3	7.41	0.00867	S1-L703C-5	5.66	0.00662
S1-L703NP-6	11.10	0.01298	S1-L703C-6	2.83	0.00331
Mean		0.01077			0.00658
Standard Deviation		0.00176			0.00266
Coefficient of Variation		0.16371			0.40392
S1-S703NP-6	1.47	0.00648	S1-S703C-6	1.78	0.00784
S1-S703NP-7	0.90	0.00396	S1-S703C-7	2.04	0.00899
S1-S703NP-8	1.15	0.00507	S1-S703C-8	1.46	0.00643
S1-S703NP-9	1.30	0.00573	S1-S703C-9	1.46	0.00643
S1-S703NP-10	0.87	0.00383	S1-S703C-10	2.06	0.00907
S1-S703NP-16	1.89	0.00833	S1-S703C-16	1.98	0.00872
S1-S703NP-17	1.42	0.00626	S1-S703C-17	1.68	0.00740
S1-S703NP-18	1.22	0.00537	S1-S703C-18	1.57	0.00692
S1-S703NP-19	1.69	0.00744	S1-S703C-19	0.89	0.00392
S1-S703NP-20	1.66	0.00731	S1-S703C-20	4.14	0.01824
Mean		0.00598			0.00840
Standard Deviation		0.00140			0.00359
Coefficient of Variation		0.23471			0.42778

Table A-3. Chlorophyll *a* values for periphytometer experiment in the sun at Site 2. These filters were retrieved after five days in the stream (July 11, 2003 - July 16, 2003).

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S2-L711NP-1	177.90	0.20807	S2-L711C-1	141.90	0.16596
S2-L711NP-2	280.48	0.32805	S2-L711C-2	242.96	0.28416
S2-L711NP-3	141.60	0.16561	S2-L711C-3	135.20	0.15813
Mean		0.23391			0.20275
Standard Deviation		0.06878			0.05766
Coefficient of Variation		0.29406			0.28436

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S2-S711NP-1	37.76	0.16634	S2-S711C-1	37.04	0.16317
S2-S711NP-2	56.51	0.24894	S2-S711C-2	28.73	0.12656
S2-S711NP-3	37.21	0.16392	S2-S711C-3	48.83	0.21511
S2-S711NP-4	55.58	0.24485	S2-S711C-4	22.87	0.10075
S2-S711NP-5	53.25	0.23458	S2-S711C-5	40.51	0.17846
S2-S711NP-6	53.19	0.23432	S2-S711C-6	42.67	0.18797
S2-S711NP-7	60.43	0.26621	S2-S711C-7	25.02	0.11022
S2-S711NP-8	46.37	0.20427	S2-S711C-8	38.38	0.16907
S2-S711NP-9			S2-S711C-9	86.36	0.38044
S2-S711NP-10			S2-S711C-10	75.09	0.33079
Mean		0.22043			0.19626
Standard Deviation		0.03584			0.08717
Coefficient of Variation		0.16261			0.44415

*S2-L711NP = 250 mL nitrate-phosphate filter from July 11, 2003 experiment at Site 2.
S2-L711C = 250 mL control filter
S2-S711NP = 20 mL nitrate-phosphate filter
S2-S711C = 20 mL control filter

Table A-4. Chlorophyll *a* values for periphytometer experiment in the sun at Site 2. These filters were retrieved after ten days in the stream (July 11, 2003 - July 21, 2003).

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S2-L711NP-4	522.64	0.61127	S2-L711C-4	660.40	0.77240
S2-L711NP-5	686.56	0.80299	S2-L711C-5	188.00	0.21988
S2-L711NP-6	713.68	0.83471	S2-L711C-6	197.30	0.23076
Mean		0.74966			0.40768
Standard Deviation		0.09871			0.25793
Coefficient of Variation		0.13167			0.63268

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S2-S711NP-11	212.60	0.93656	S2-S711C-11	190.00	0.83700
S2-S711NP-12	348.24	1.53410	S2-S711C-12	504.80	2.22379
S2-S711NP-13	253.36	1.11612	S2-S711C-13	106.45	0.46894
S2-S711NP-14	273.36	1.20423	S2-S711C-14	207.70	0.91498
S2-S711NP-15	354.00	1.55947	S2-S711C-15	123.20	0.54273
S2-S711NP-16	278.56	1.22714	S2-S711C-16	155.00	0.68282
S2-S711NP-17	275.76	1.21480	S2-S711C-17	78.43	0.34551
S2-S711NP-18	185.30	0.81630	S2-S711C-18	353.20	1.55595
S2-S711NP-19	178.00	0.78414	S2-S711C-19	69.17	0.30471
S2-S711NP-20	386.24	1.70150	S2-S711C-20	10.70	0.04714
Mean		1.20944			0.79236
Standard Deviation		0.29816			0.61813
Coefficient of Variation		0.24653			0.78011

*S2-L711NP = 250 mL nitrate-phosphate filter from July 11, 2003 experiment at Site 2.
S2-L711C = 250 mL control filter
S2-S711NP = 20 mL nitrate-phosphate filter
S2-S711C = 20 mL control filter

Table A-5. Chlorophyll *a* values for periphytometer experiment in the shade at Site 1. The frame was deployed on September 1, 2003 and retrieved on September 12, 2003.

Filter*	**Chl a - μg/L**	**Chl a - μg/cm^2**	**Filter**	**Chl a - μg/L**	**Chl a - μg/cm^2**
S1-901C-1	1.75	0.00771	S1-901N-1	0.59	0.00260
S1-901C-2	1.74	0.00767	S1-901N-2	0.51	0.00225
S1-901C-3	0.51	0.00225	S1-901N-3	0.32	0.00141
S1-901C-4	0.99	0.00436	S1-901N-4	1.01	0.00445
S1-901C-5	0.49	0.00216	S1-901N-5	2.92	0.01286
S1-901C-6	0.44	0.00194	S1-901N-6	1.70	0.00749
S1-901C-7	0.53	0.00233	S1-901N-7	0.29	0.00128
S1-901C-8	0.39	0.00172	S1-901N-8	0.60	0.00264
S1-901C-9	0.94	0.00414	S1-901N-9	0.84	0.00370
S1-901C-10	0.74	0.00326	S1-901N-10	0.55	0.00242
Mean		0.00375			0.00411
Standard Deviation		0.00214			0.00338
Coefficient of Variation		0.57129			0.82288

Filter	**Chl a - μg/L**	**Chl a - μg/cm^2**	**Filter**	**Chl a - μg/L**	**Chl a - μg/cm^2**
S1-901P-1	0.71	0.00313	S1-901NP-1	1.11	0.00489
S1-901P-2	1.04	0.00458	S1-901NP-2	0.90	0.00396
S1-901P-3	0.82	0.00361	S1-901NP-3	0.87	0.00383
S1-901P-4	0.59	0.00260	S1-901NP-4	1.01	0.00445
S1-901P-5	0.95	0.00419	S1-901NP-5	1.47	0.00648
S1-901P-6	1.57	0.00692	S1-901NP-6	0.47	0.00207
S1-901P-7	0.90	0.00396	S1-901NP-7	0.60	0.00264
S1-901P-8	1.83	0.00806	S1-901NP-8	0.78	0.00344
S1-901P-9	1.40	0.00617	S1-901NP-9	0.81	0.00357
S1-901P-10	2.41	0.01062	S1-901NP-10	0.66	0.00291
Mean		0.00538			0.00382
Standard Deviation		0.00240			0.00119
Coefficient of Variation		0.44580			0.31058

*S1-901C = Control filter from September 1, 2003 experiment at Site 1.
S1-901N = Nitrate filter
S1-901P = Phosphate filter
S1-901NP = Nitrate-phosphate filter

Table A-6. Chlorophyll *a* values for periphytometer experiment in the sun at Site 3. The frame was deployed on September 1, 2003 and retrieved on September 12, 2003.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-912C-1	12.04	0.05304	S3-912N-1	53.78	0.23692
S3-912C-2	47.58	0.20960	S3-912N-2	4.50	0.01982
S3-912C-3	30.43	0.13405	S3-912N-3	2.95	0.01300
S3-912C-4	36.60	0.16123	S3-912N-4	9.14	0.04026
S3-912C-5	41.66	0.18352	S3-912N-5	46.88	0.20652
S3-912C-6	12.47	0.05493	S3-912N-6	46.48	0.20476
S3-912C-7	2.76	0.01216	S3-912N-7	22.85	0.10066
S3-912C-8	32.48	0.14308	S3-912N-8	41.67	0.18357
S3-912C-9	3.67	0.01617	S3-912N-9	62.38	0.27480
S3-912C-10	31.66	0.13947	S3-912N-10	36.64	0.16141
Mean		0.11073			0.14417
Standard Deviation		0.06719			0.08968
Coefficient of Variation		0.60679			0.62206

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-912P-1	35.10	0.15463	S3-912NP-1	3.67	0.01617
S3-912P-2	61.80	0.27225	S3-912NP-2	67.84	0.29885
S3-912P-3	5.05	0.02225	S3-912NP-3	3.34	0.01471
S3-912P-4	2.80	0.01233	S3-912NP-4	8.57	0.03775
S3-912P-5	93.07	0.41000	S3-912NP-5	16.71	0.07361
S3-912P-6	4.00	0.01762	S3-912NP-6	19.63	0.08648
S3-912P-7	82.43	0.36313	S3-912NP-7	1.62	0.00714
S3-912P-8	5.05	0.02225	S3-912NP-8	12.39	0.05458
S3-912P-9	43.73	0.19264	S3-912NP-9	4.26	0.01877
S3-912P-10	37.33	0.16445	S3-912NP-10	16.35	0.07203
Mean		0.16315			0.06801
Standard Deviation		0.14050			0.08151
Coefficient of Variation		0.86115			1.19846

*S3-901C = Control filter from September 1, 2003 experiment at Site 3.
S3-901N = Nitrate filter
S3-901P = Phosphate filter
S3-901NP = Nitrate-phosphate filter

Table A-7. Chlorophyll *a* values for periphytometer experiment in the sun at Site 3. The frame was deployed on October 17, 2003 and retrieved on October 20, 2003.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-1017C-1	12.66	0.05577	S3-1017N-1	10.60	0.04670
S3-1017C-2	12.28	0.05410	S3-1017N-2	8.15	0.03590
S3-1017C-3	18.85	0.08304	S3-1017N-3	9.22	0.04062
S3-1017C-4	15.07	0.06639	S3-1017N-4	10.21	0.04498
S3-1017C-5	13.56	0.05974	S3-1017N-5	7.24	0.03189
S3-1017C-6	9.87	0.04348	S3-1017N-6	15.51	0.06833
S3-1017C-7	13.71	0.06040	S3-1017N-7	7.27	0.03203
S3-1017C-8	14.55	0.06410	S3-1017N-8	10.51	0.04630
S3-1017C-9	15.51	0.06833	S3-1017N-9	8.48	0.03736
S3-1017C-10	12.17	0.05361	S3-1017N-10	6.75	0.02974
Mean		0.06089			0.04138
Standard Deviation		0.01008			0.01073
Coefficient of Variation		0.16556			0.25928

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-1017P-1	7.08	0.03119	S3-1017NP-1	9.20	0.04053
S3-1017P-2	20.65	0.09097	S3-1017NP-2	8.77	0.03863
S3-1017P-3	12.62	0.05559	S3-1017NP-3	7.89	0.03476
S3-1017P-4	9.90	0.04361	S3-1017NP-4	9.47	0.04172
S3-1017P-5	15.67	0.06903	S3-1017NP-5	9.93	0.04374
S3-1017P-6	15.37	0.06771	S3-1017NP-6	6.50	0.02863
S3-1017P-7	12.83	0.05652	S3-1017NP-7	8.32	0.03665
S3-1017P-8	15.34	0.06758	S3-1017NP-8	13.61	0.05996
S3-1017P-9	11.39	0.05018	S3-1017NP-9	16.62	0.07322
S3-1017P-10	16.27	0.07167	S3-1017NP-10	9.26	0.04079
Mean		0.06041			0.04386
Standard Deviation		0.01587			0.01241
Coefficient of Variation		0.26274			0.28291

*S3-1017C = Control filter from October 17, 2003 experiment at Site 3.
S3-1017N = Nitrate filter
S3-1017P = Phosphate filter
S3-1017NP = Nitrate-phosphate filter

Table A-8. Chlorophyll *a* values for periphytometer experiment in the sun at Site 3. The frame was deployed on October 17, 2003 and retrieved on October 24, 2003.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-1024C-1	11.90	0.05242	S3-1024N-1	3.95	0.01740
S3-1024C-2	15.05	0.06630	S3-1024N-2	5.64	0.02485
S3-1024C-3	14.47	0.06374	S3-1024N-3	4.45	0.01960
S3-1024C-4	11.37	0.05009	S3-1024N-4	8.70	0.03833
S3-1024C-5	16.60	0.07313	S3-1024N-5	9.66	0.04256
S3-1024C-6	15.15	0.06674	S3-1024N-6	17.33	0.07634
S3-1024C-7	11.31	0.04982	S3-1024N-7	5.46	0.02405
S3-1024C-8	6.86	0.03022	S3-1024N-8	9.24	0.04070
S3-1024C-9	10.27	0.04524	S3-1024N-9	5.21	0.02295
S3-1024C-10	16.01	0.07053	S3-1024N-10	4.45	0.01960
Mean		0.05682			0.03264
Standard Deviation		0.01283			0.01705
Coefficient of Variation		0.22573			0.52231

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-1024P-1	15.87	0.06991	S3-1024NP-1	6.54	0.02881
S3-1024P-2	9.90	0.04361	S3-1024NP-2	9.37	0.04128
S3-1024P-3	26.25	0.11564	S3-1024NP-3	11.46	0.05048
S3-1024P-4	39.78	0.17524	S3-1024NP-4	16.89	0.07441
S3-1024P-5	8.08	0.03559	S3-1024NP-5	15.40	0.06784
S3-1024P-6	13.30	0.05859	S3-1024NP-6	23.10	0.10176
S3-1024P-7	8.81	0.03881	S3-1024NP-7	15.43	0.06797
S3-1024P-8	11.73	0.05167	S3-1024NP-8	27.98	0.12326
S3-1024P-9	18.12	0.07982	S3-1024NP-9	10.74	0.04731
S3-1024P-10	45.81	0.20181	S3-1024NP-10	7.71	0.03396
Mean		0.08707			0.06371
Standard Deviation		0.05571			0.02862
Coefficient of Variation		0.63980			0.44930

*S3-1017C = Control filter from October 17, 2003 experiment at Site 3.
S3-1017N = Nitrate filter
S3-1017P = Phosphate filter
S3-1017NP = Nitrate-phosphate filter

Table A-9. Chlorophyll *a* values for periphytometer experiment in the sun at Site 4. The frame was deployed on March 11, 2004 and retrieved on March 26, 2004.

Frame 1

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S4-311C-1	329.68	1.45233	S4-311N-1	669.84	2.95084
S4-311C-2	621.52	2.73797	S4-311N-2	1067.20	4.70132
S4-311C-3	647.60	2.85286	S4-311N-3	618.80	2.72599
S4-311C-4	676.88	2.98185	S4-311N-4		
S4-311C-5	377.28	1.66203	S4-311N-5	669.04	2.94731
S4-311C-6	368.48	1.62326	S4-311N-6		
S4-311C-7	423.12	1.86396	S4-311N-7	424.64	1.87066
S4-311C-8	1030.40	4.53921	S4-311N-8	524.88	2.31225
S4-311C-9	363.04	1.59930	S4-311N-9	683.44	3.01075
S4-311C-10	613.12	2.70097	S4-311N-10	450.88	1.98626
Mean		2.40137			2.81317
Standard Deviation		0.91099			0.82702
Coefficient of Variation		0.37936			0.29398

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S4-311P-1	1496.64	6.59313	S4-311NP-1	1441.28	6.34925
S4-311P-2	1384.00	6.09692	S4-311NP-2	2214.40	9.75507
S4-311P-3	1792.00	7.89427	S4-311NP-3	1884.80	8.30308
S4-311P-4	1883.20	8.29604	S4-311NP-4	1646.40	7.25286
S4-311P-5	1383.04	6.09269	S4-311NP-5	1758.40	7.74626
S4-311P-6	2169.60	9.55771	S4-311NP-6	1849.60	8.14802
S4-311P-7	1329.28	5.85586	S4-311NP-7	1487.84	6.55436
S4-311P-8	1267.84	5.58520	S4-311NP-8	2104.00	9.26872
S4-311P-9	1138.40	5.01498	S4-311NP-9	2196.80	9.67753
S4-311P-10	1720.00	7.57709	S4-311NP-10	1551.36	6.83419
Mean		6.85639			7.98893
Standard Deviation		1.34920			1.20055
Coefficient of Variation		0.19678			0.15028

*S4-311C = Control filter from March 11, 2004 experiment at Site 4.
S4-311N = Nitrate filter
S4-311P = Phosphate filter
S4-311NP = Nitrate-phosphate filter

Table A-10. Chlorophyll *a* values for periphytometer experiment in the sun at Site 4. The frame was deployed on March 11, 2004 and retrieved on March 26, 2004.

Frame 2

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S4-311C-11	971.68	4.28053	S4-311N-11	1049.60	4.62379
S4-311C-12	901.44	3.97110	S4-311N-12	913.60	4.02467
S4-311C-13	906.72	3.99436	S4-311N-13	1049.76	4.62449
S4-311C-14	1036.48	4.56599	S4-311N-14		
S4-311C-15	1366.56	6.02009	S4-311N-15	1105.76	4.87119
S4-311C-16	509.76	2.24564	S4-311N-16	1254.40	5.52599
S4-311C-17	952.80	4.19736	S4-311N-17	1098.88	4.84088
S4-311C-18			S4-311N-18	943.04	4.15436
S4-311C-19	736.48	3.24441	S4-311N-19		
S4-311C-20	1075.04	4.73586	S4-311N-20		
Mean		4.13948			4.66648
Standard Deviation		0.97381			0.46119
Coefficient of Variation		0.23525			0.09883

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S4-311P-11	1464.96	6.45357	S4-311NP-11	725.92	3.19789
S4-311P-12	1572.80	6.92863	S4-311NP-12	865.28	3.81181
S4-311P-13	1229.92	5.41815	S4-311NP-13	1980.80	8.72599
S4-311P-14	2310.40	10.17797	S4-311NP-14	3148.80	13.87137
S4-311P-15	2468.80	10.87577	S4-311NP-15	2078.40	9.15595
S4-311P-16	1928.00	8.49339	S4-311NP-16	3001.60	13.22291
S4-311P-17			S4-311NP-17	1416.48	6.24000
S4-311P-18			S4-311NP-18	1483.52	6.53533
S4-311P-19	2172.80	9.57181	S4-311NP-19	1729.60	7.61938
S4-311P-20	2260.80	9.95947	S4-311NP-20	1856.00	8.17621
Mean		8.48485			8.05568
Standard Deviation		1.86721			3.31065
Coefficient of Variation		0.22006			0.41097

*S4-311C = Control filter from March 11, 2004 experiment at Site 4.
S4-311N = Nitrate filter
S4-311P = Phosphate filter
S4-311NP = Nitrate-phosphate filter

Table A-11. Chlorophyll *a* values for periphytometer experiment in the sun at Site 5. The frame was deployed on March 17, 2004 and retrieved on April 1, 2004.

Frame 1

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S5-317C-1			S5-317N-1		
S5-317C-2			S5-317N-2	117.30	0.51674
S5-317C-3			S5-317N-3	49.34	0.21736
S5-317C-4			S5-317N-4	90.70	0.39956
S5-317C-5			S5-317N-5	54.49	0.24004
S5-317C-6	57.30	0.25242	S5-317N-6	70.79	0.31185
S5-317C-7			S5-317N-7	85.92	0.37850
S5-317C-8	26.92	0.20241	S5-317N-8		
S5-317C-9	47.68	0.21004	S5-317N-9	111.70	0.49207
S5-317C-10			S5-317N-10	58.85	0.25925
Mean		0.22162			0.35192
Standard Deviation		0.02200			0.10642
Coefficient of Variation		0.09927			0.30239

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S5-317P-1			S5-317NP-1	626.08	2.75806
S5-317P-2			S5-317NP-2	365.92	1.61198
S5-317P-3	78.96	0.34784	S5-317NP-3	368.48	1.62326
S5-317P-4			S5-317NP-4	584.48	2.57480
S5-317P-5	49.80	0.21938	S5-317NP-5	438.56	1.93198
S5-317P-6	56.41	0.24850	S5-317NP-6		
S5-317P-7			S5-317NP-7	478.08	2.10608
S5-317P-8	42.22	0.18599	S5-317NP-8		
S5-317P-9	68.09	0.29996	S5-317NP-9	526.56	2.31965
S5-317P-10	51.94	0.22881	S5-317NP-10	482.08	2.12370
Mean		0.25508			2.13119
Standard Deviation		0.05385			0.38620
Coefficient of Variation		0.21111			0.18121

*S5-317C = Control filter from March 17, 2004 experiment at Site 5.
S5-317N = Nitrate filter
S5-317P = Phosphate filter
S5-317NP = Nitrate-phosphate filter

Table A-12. Chlorophyll *a* values for periphytometer experiment in the sun at Site 5. The frame was deployed on March 17, 2004 and retrieved on April 1, 2004.

Frame 2

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S5-317C-11			S5-317N-11	95.96	0.42273
S5-317C-12			S5-317N-12		
S5-317C-13			S5-317N-13		
S5-317C-14			S5-317N-14		
S5-317C-15	59.79	0.26339	S5-317N-15	69.70	0.30705
S5-317C-16	47.43	0.20894	S5-317N-16	112.70	0.49648
S5-317C-17	41.67	0.18357	S5-317N-17		
S5-317C-18	38.45	0.16938	S5-317N-18		
S5-317C-19			S5-317N-19	44.00	0.33083
S5-317C-20			S5-317N-20		
Mean		0.20632			0.38927
Standard Deviation		0.03587			0.07548
Coefficient of Variation		0.17385			0.19390

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S5-317P-11	45.23	0.19925	S5-317NP-11	536.52	2.36352
S5-317P-12	37.04	0.16317	S5-317NP-12	517.92	2.28159
S5-317P-13			S5-317NP-13		
S5-317P-14			S5-317NP-14		
S5-317P-15	42.07	0.18533	S5-317NP-15	283.84	1.25040
S5-317P-16			S5-317NP-16		
S5-317P-17			S5-317NP-17	440.80	1.94185
S5-317P-18	47.84	0.21075	S5-317NP-18		
S5-317P-19	46.12	0.20317	S5-317NP-19	649.76	2.86238
S5-317P-20			S5-317NP-20	362.56	1.59718
Mean		0.19233			2.04949
Standard Deviation		0.01676			0.52726
Coefficient of Variation		0.08712			0.25726

*S5-317C = Control filter from March 17, 2004 experiment at Site 5.
S5-317N = Nitrate filter
S5-317P = Phosphate filter
S5-317NP = Nitrate-phosphate filter

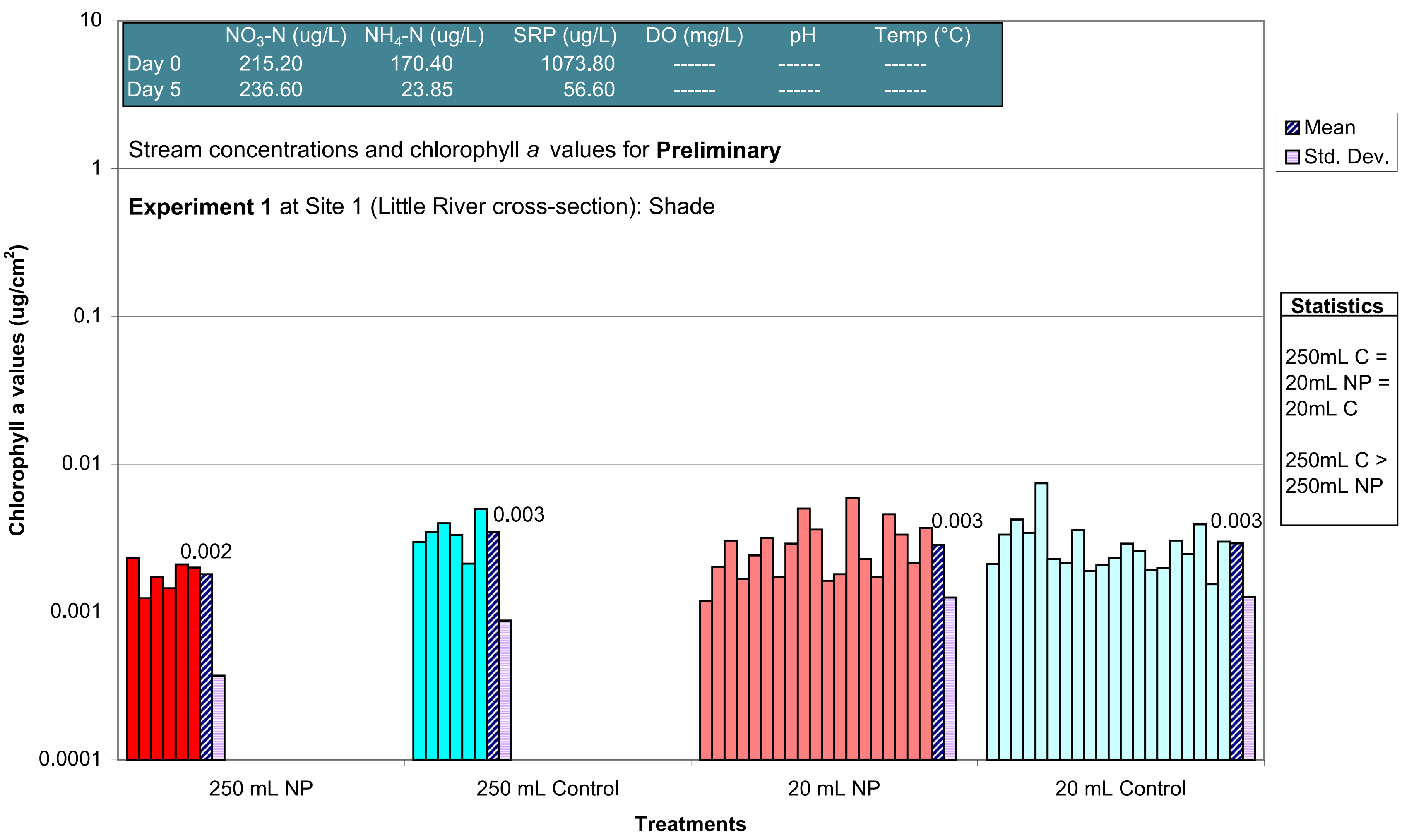


Figure A-1. Chlorophyll *a* values for June 27, 2003 preliminary experiment at Site 1. Two periphytometer frames were deployed in the shade and removed on July 2, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 250 mL bottles and 20 mL scintillation vials filled with N-P solutions and deionized water. Dissolved oxygen, pH and stream temperatures were not measured.

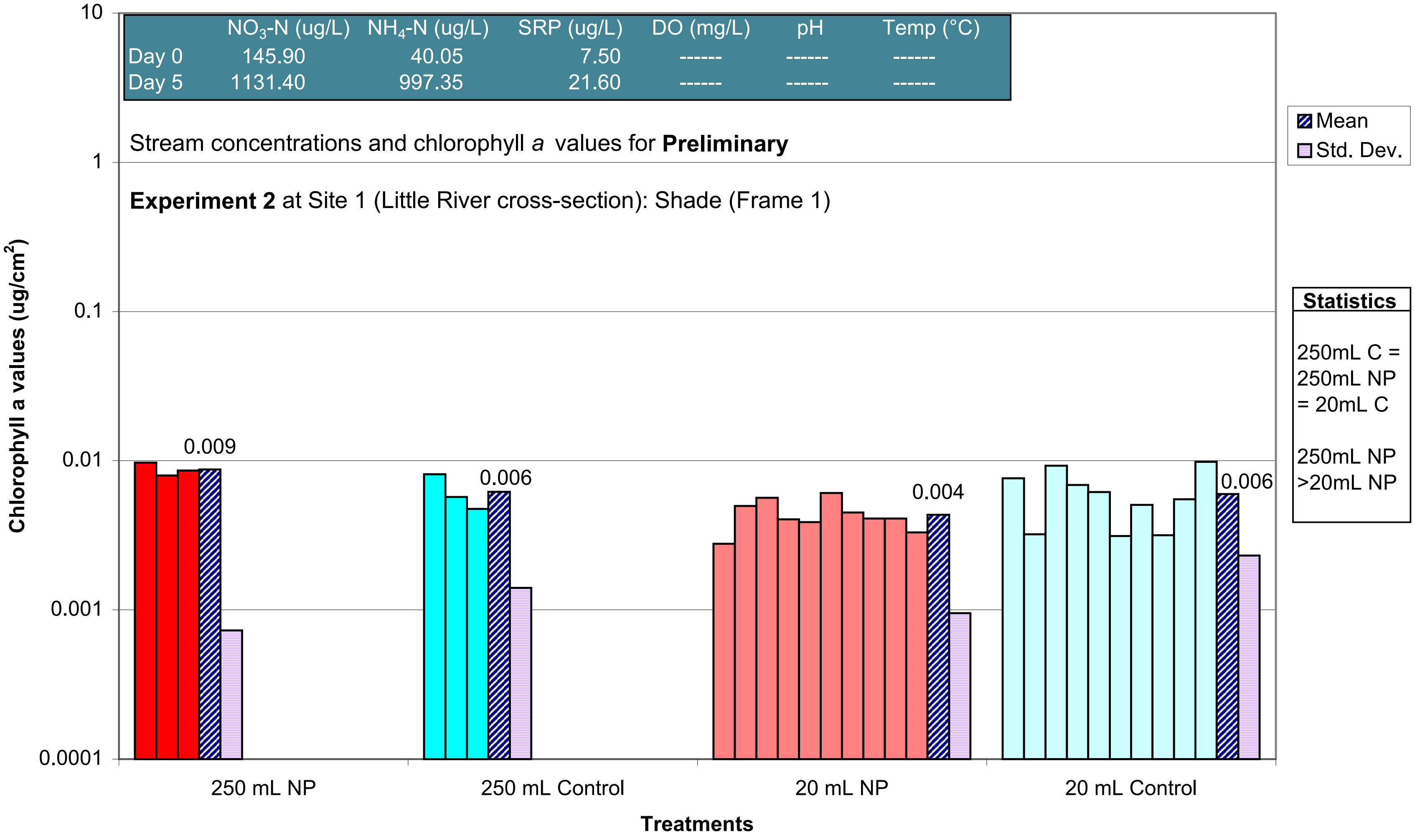


Figure A-2. Chlorophyll *a* values for July 3, 2003 preliminary experiment at Site 1 (frame 1). The periphytometer was deployed in the shade and removed on July 8, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 250 mL bottles and 20 mL scintillation vials filled with N-P solutions and deionized water. Dissolved oxygen, pH and stream temperatures were not measured.

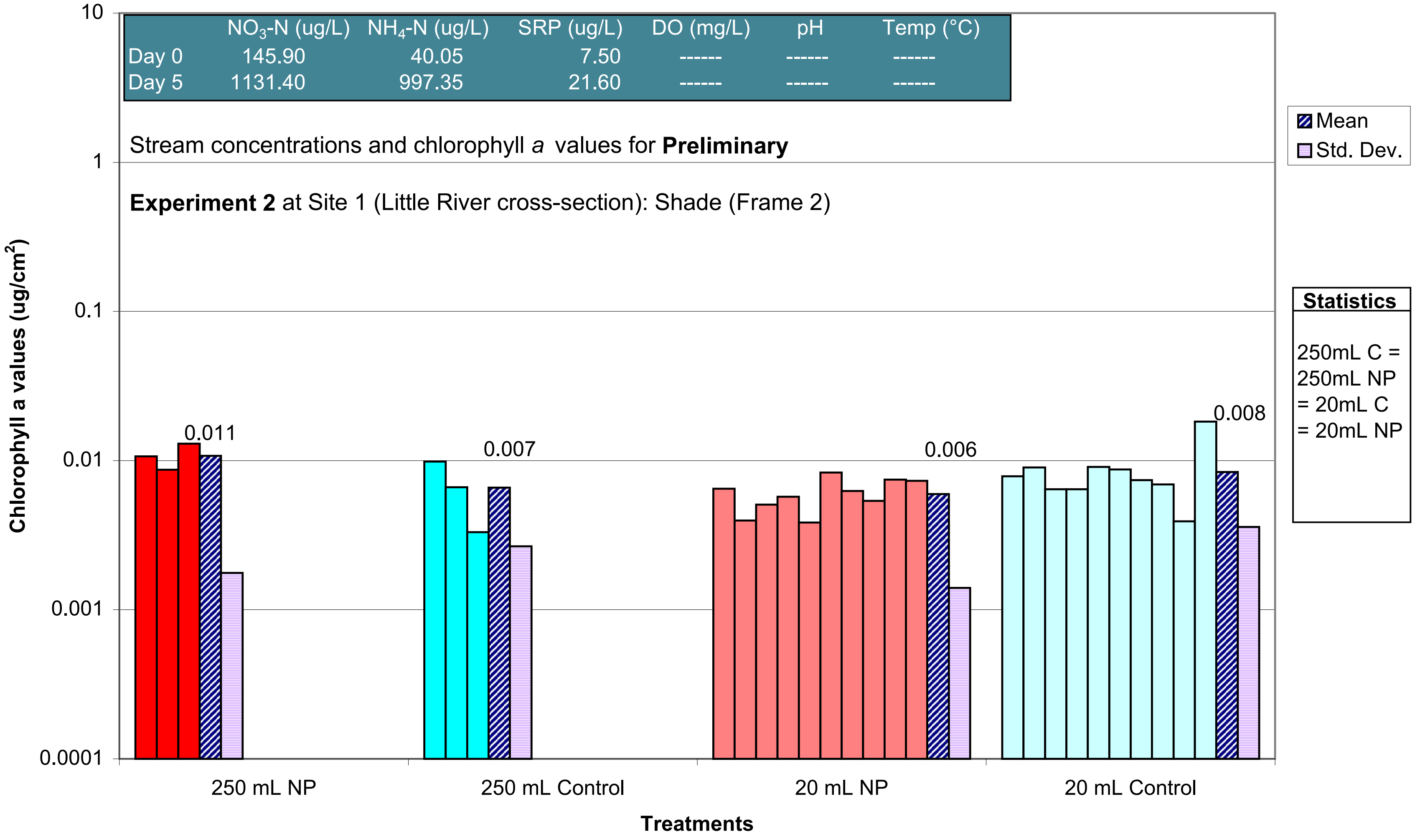
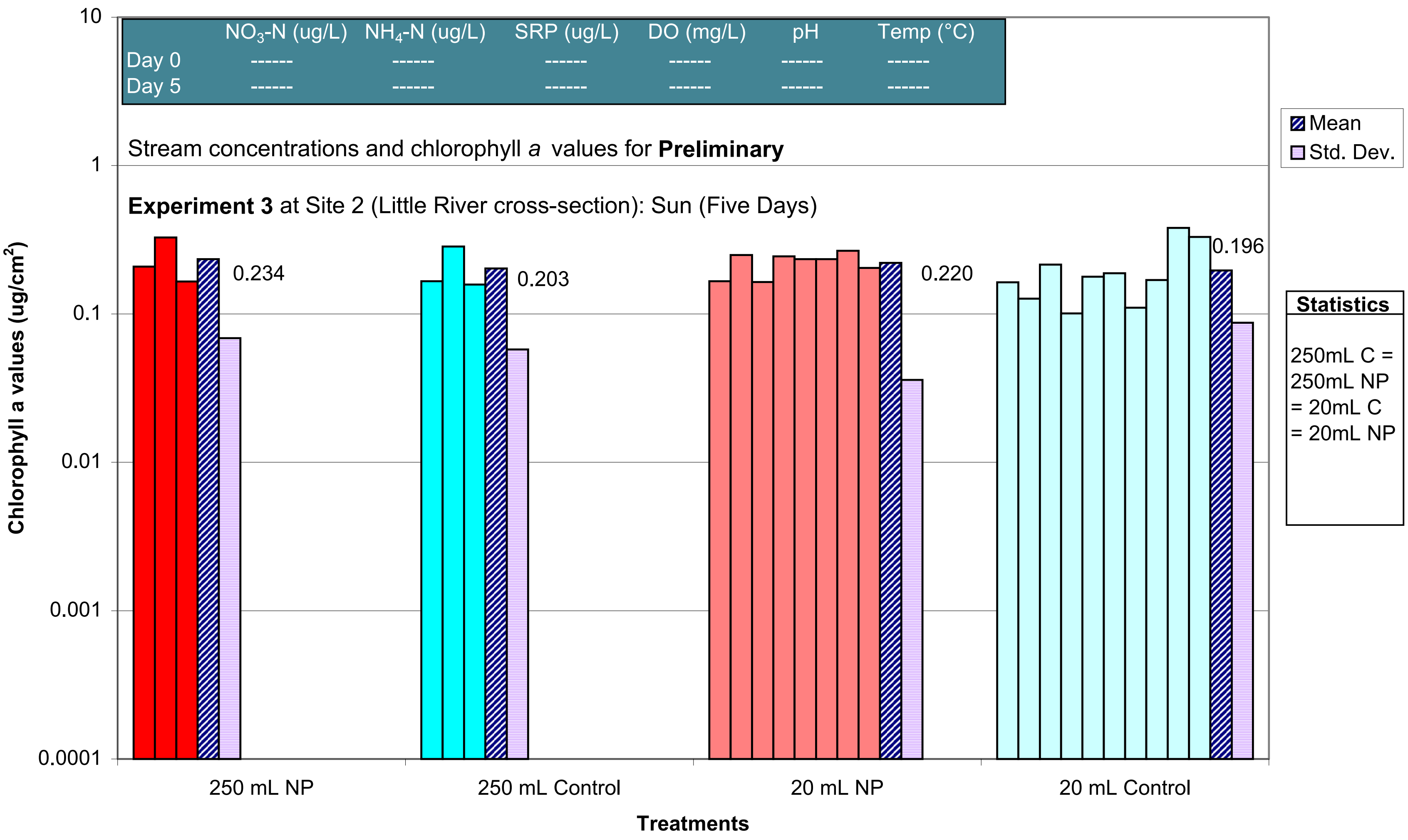


Figure A-3. Chlorophyll *a* values for July 3, 2003 preliminary experiment at Site 1 (frame 2). The periphytometer was deployed in the shade and removed on July 8, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 250 mL bottles and 20 mL scintillation vials filled with N-P solutions and deionized water. Dissolved oxygen, pH and stream temperatures were not measured.



	NO$_3$-N (ug/L)	NH$_4$-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	------	------	------	------	------	------
Day 5	------	------	------	------	------	------

Stream concentrations and chlorophyll *a* values for **Preliminary**

Experiment 3 at Site 2 (Little River cross-section): Sun (Five Days)

Statistics

250mL C = 250mL NP = 20mL C = 20mL NP

Figure A-4. Chlorophyll *a* values for July 11, 2003 preliminary experiment at Site 2 (five days). Two periphytometer frames were deployed in the sun and half the glass fiber filters from both frames were removed on July 16, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing filters retrieved from 250 mL bottles and 20 mL scintillation vials filled with N-P solutions and deionized water.

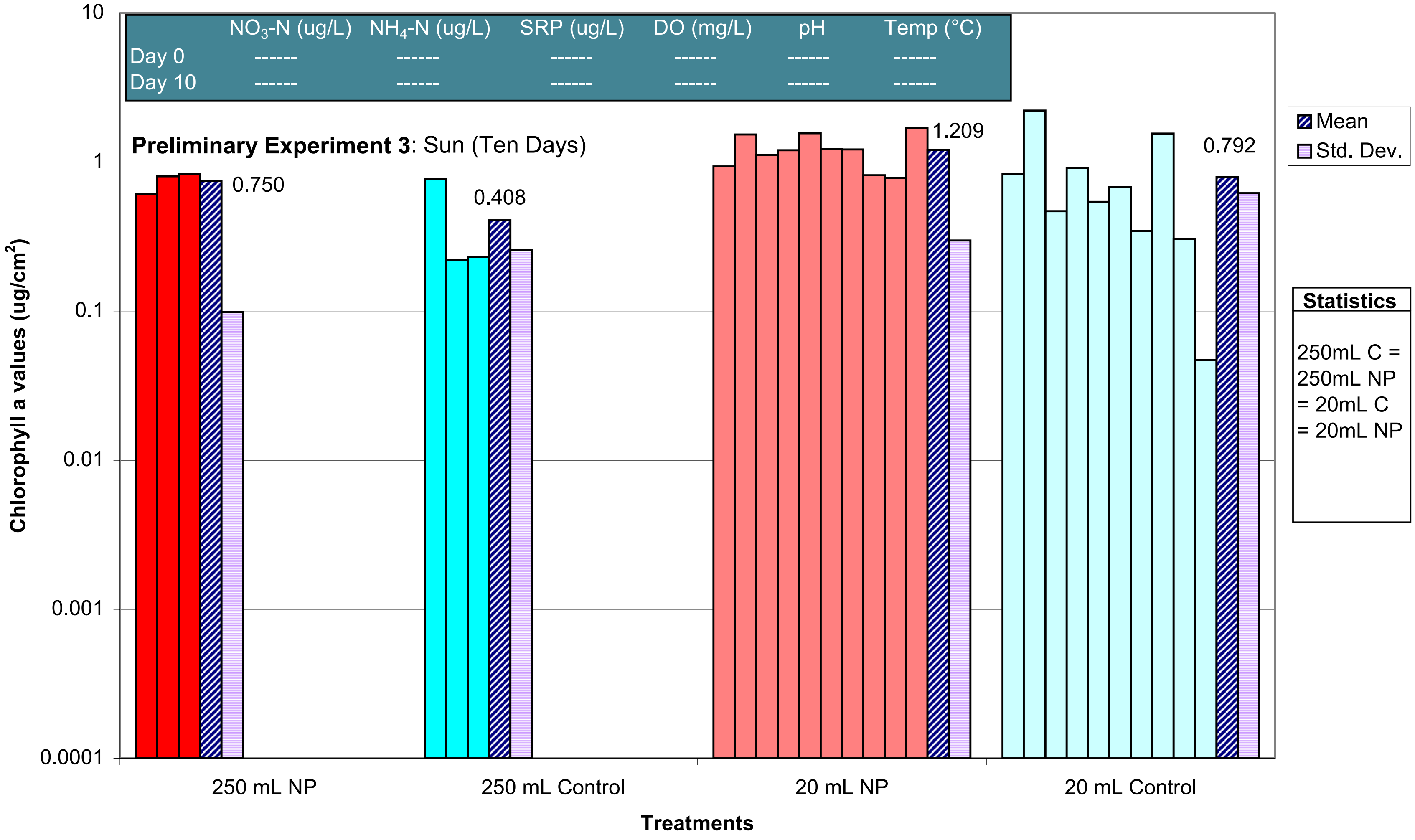


Figure A-5. Chlorophyll *a* values for July 11, 2003 preliminary experiment at Site 2 (ten days). Two periphytometer frames were deployed in the sun and half the glass fiber filters from both frames were removed on July 21, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing filters retrieved from 250 mL bottles and 20 mL scintillation vials filled with N-P solutions and deionized water.

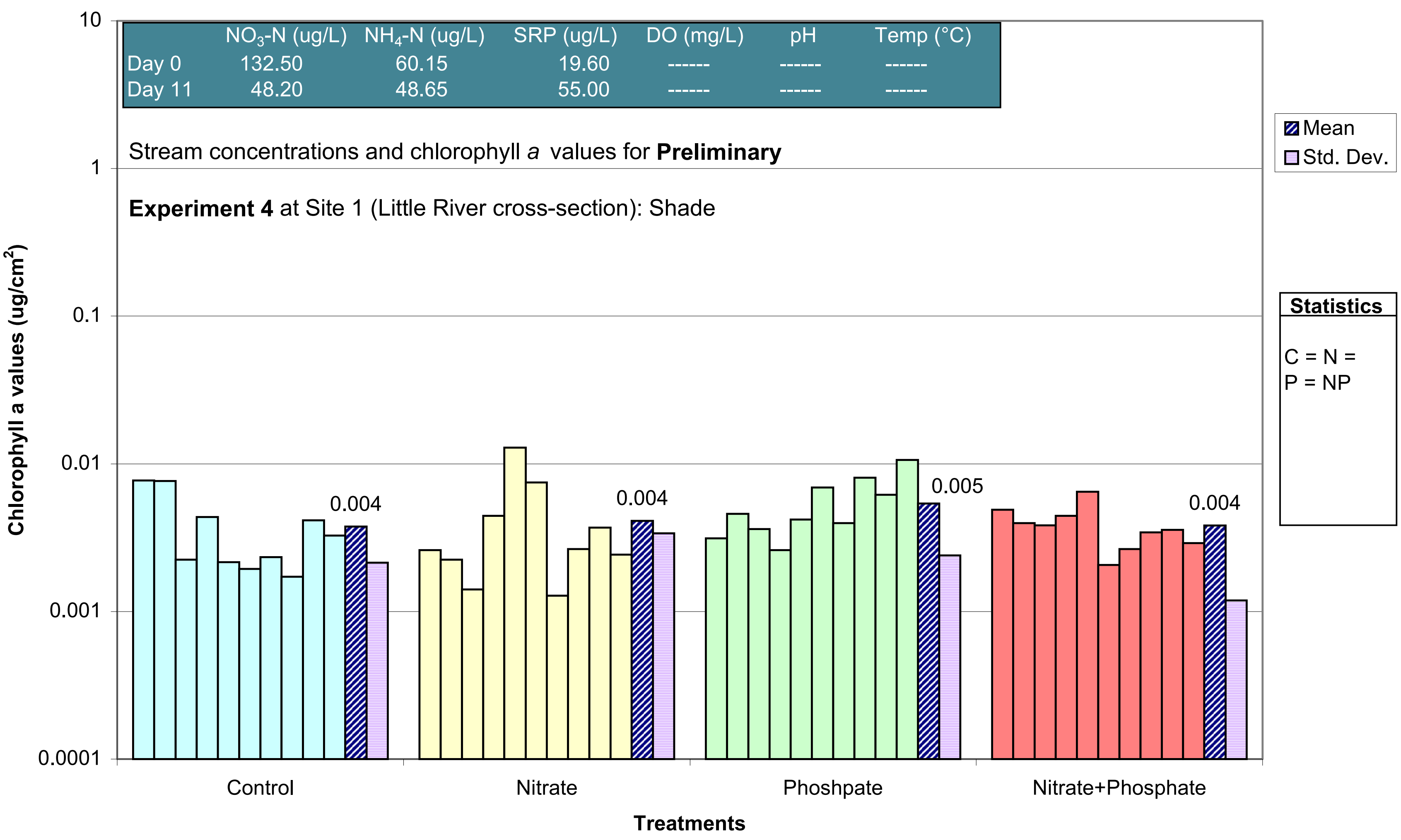


Figure A-6. Chlorophyll *a* values for September 1, 2003 preliminary experiment at Site 1. The periphytometer was deployed in the shade and removed on September 11, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen, pH and stream temperatures were not measured.

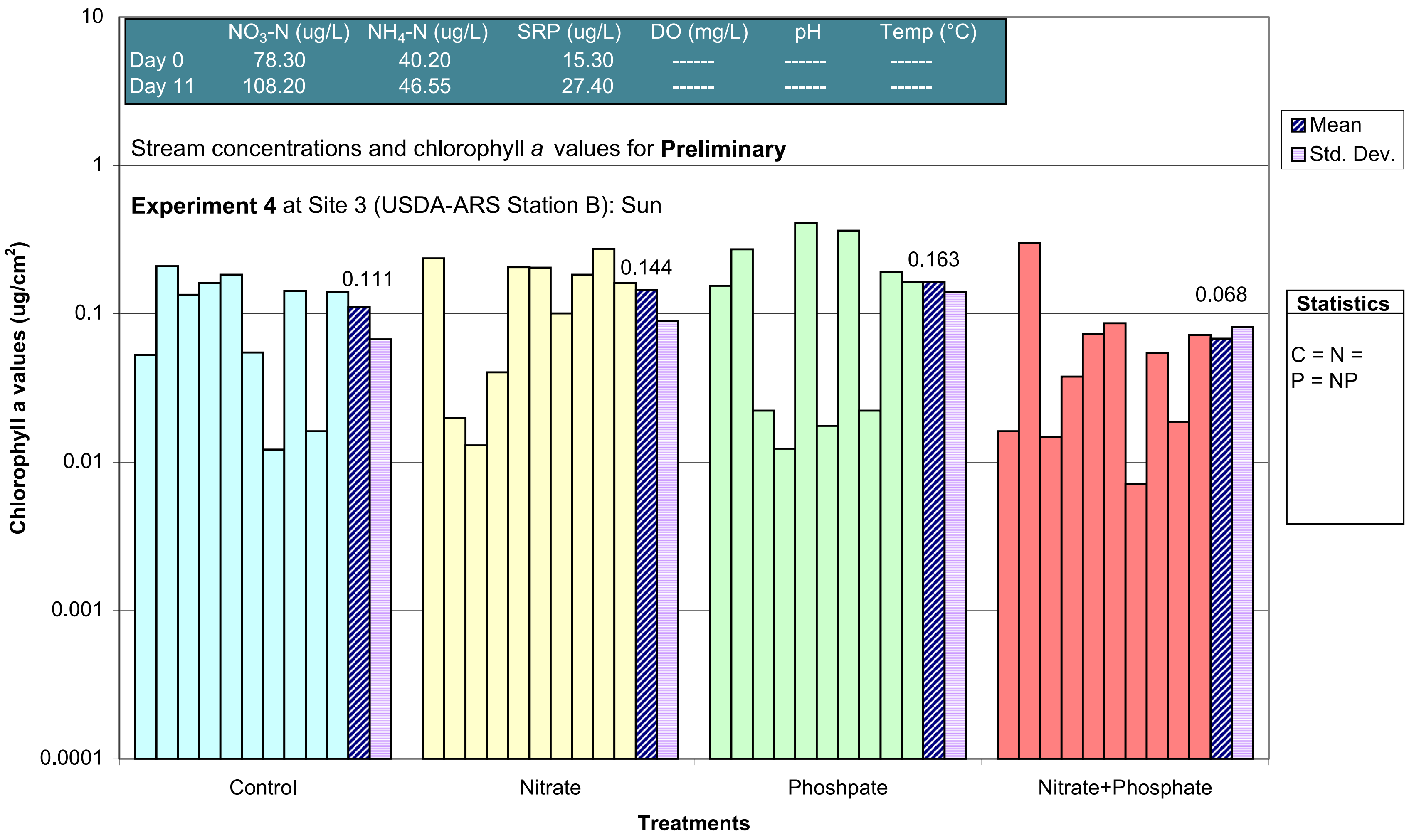


Figure A-7. Chlorophyll *a* values for September 1, 2003 preliminary experiment at Site 3. The periphytometer was deployed in the sun and removed on September 11, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen, pH and stream temperatures were not measured.

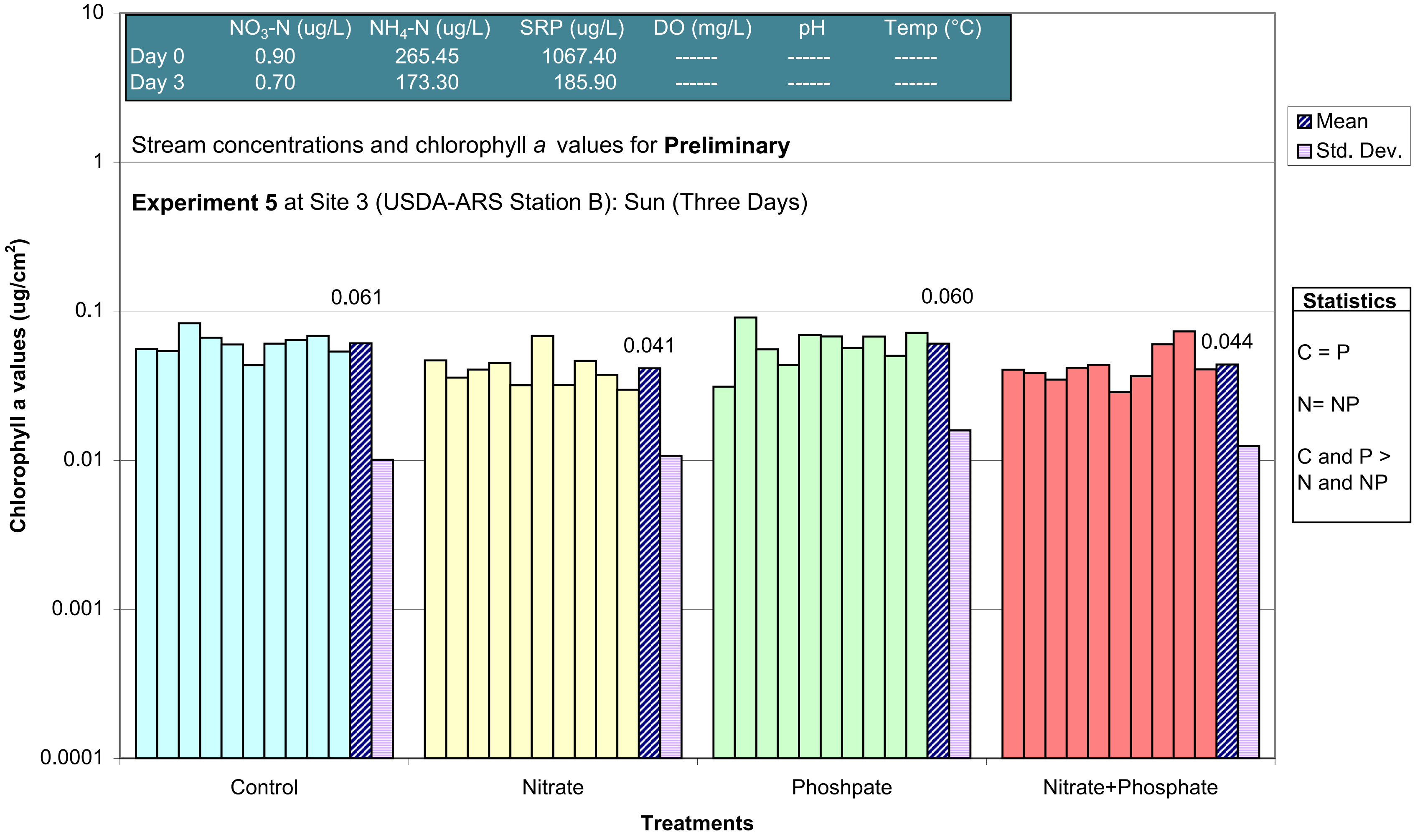
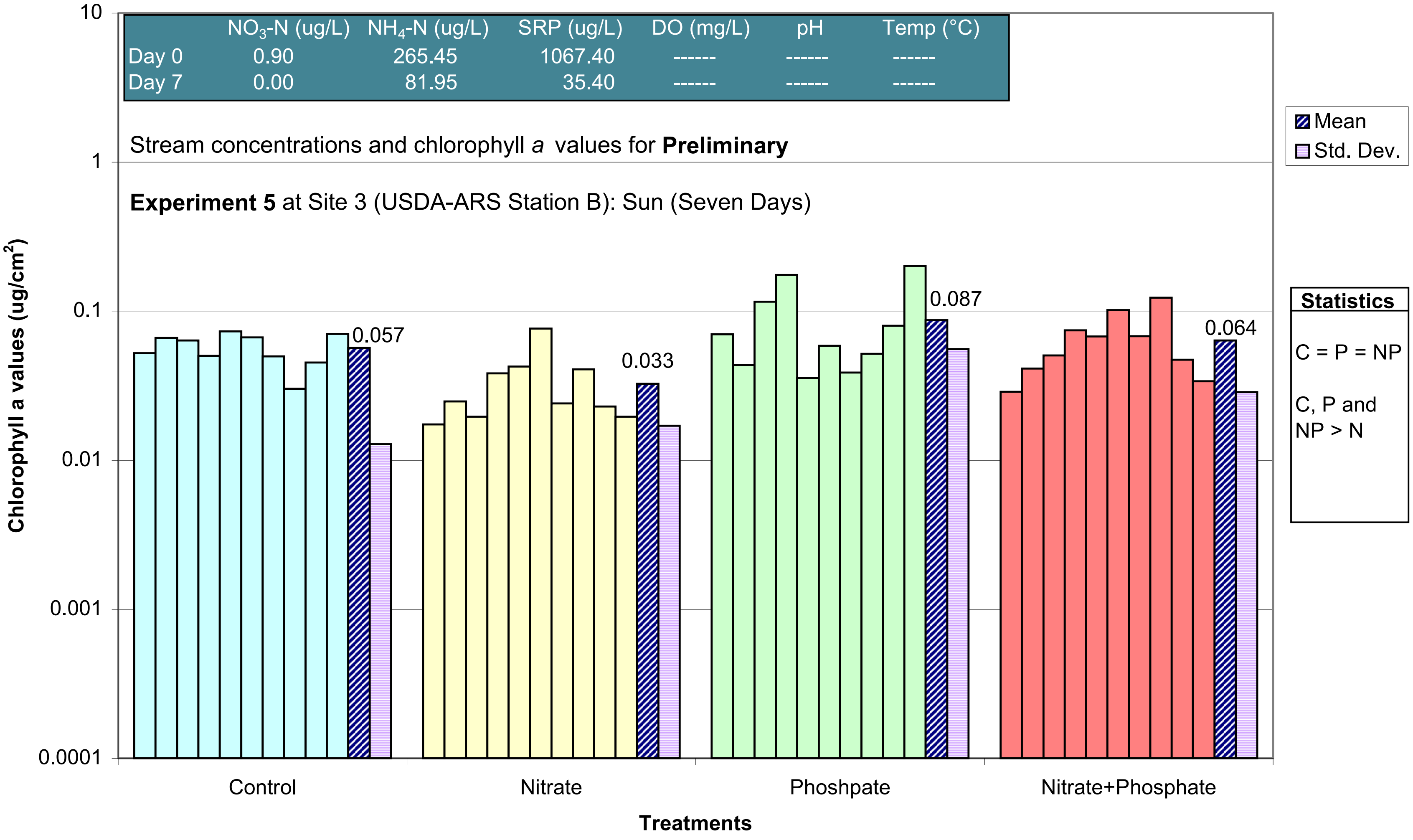
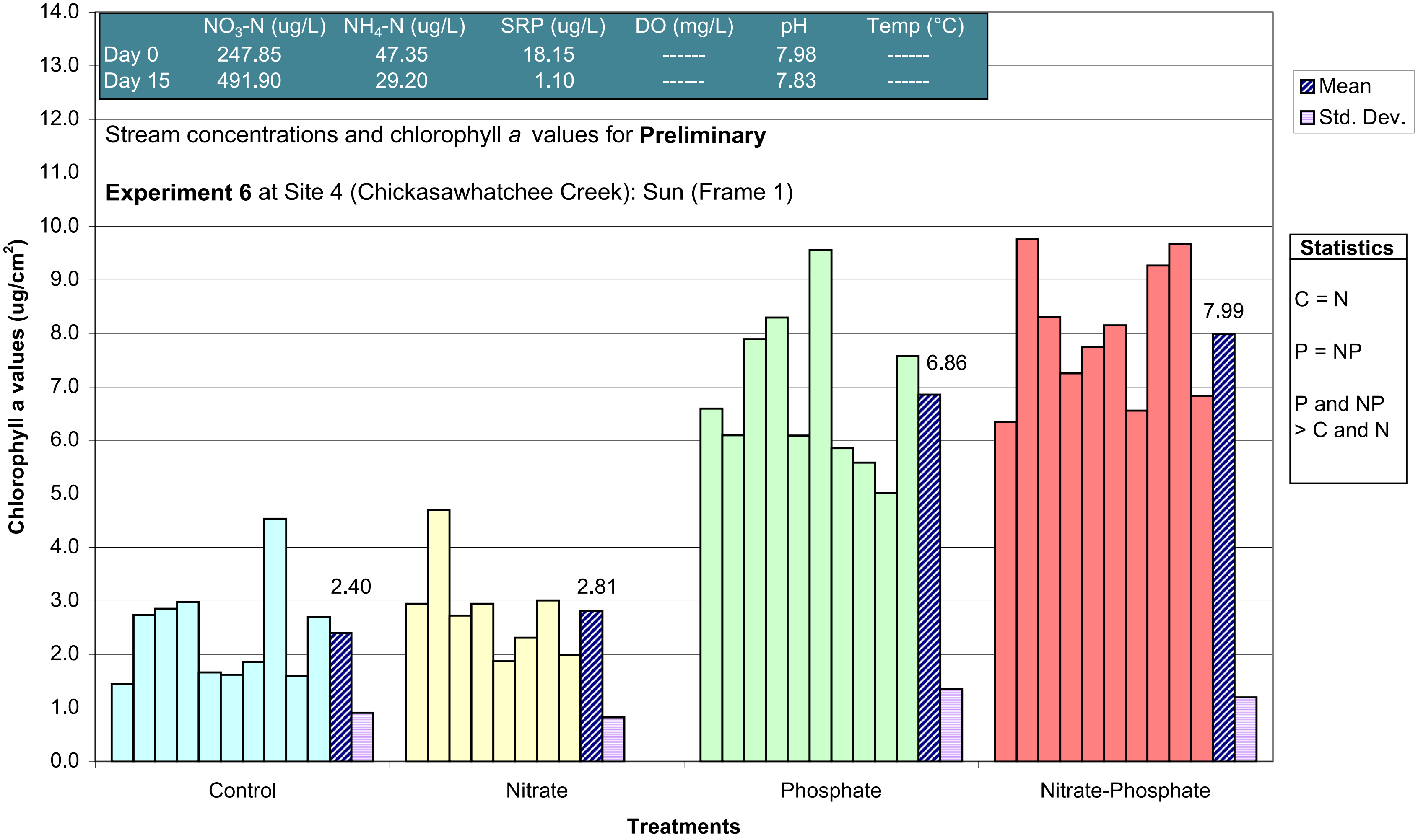


Figure A-8. Chlorophyll *a* values for October 17, 2003 preliminary experiment at Site 3 (three days). The periphytometer was deployed in the sun and removed on October 20, 2003. Chlorophyll *a* values ($\mu g/cm^2$) were obtained after analyzing the glass fiber filters retrieved from the 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen, pH and stream temperatures were not measured.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	0.90	265.45	1067.40	------	------	------
Day 7	0.00	81.95	35.40	------	------	------

Figure A-9. Chlorophyll *a* values for October 17, 2003 preliminary experiment at Site 3 (seven days). The periphytometer was deployed in the sun and removed on October 24, 2003. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen, pH and stream temperatures were not measured.

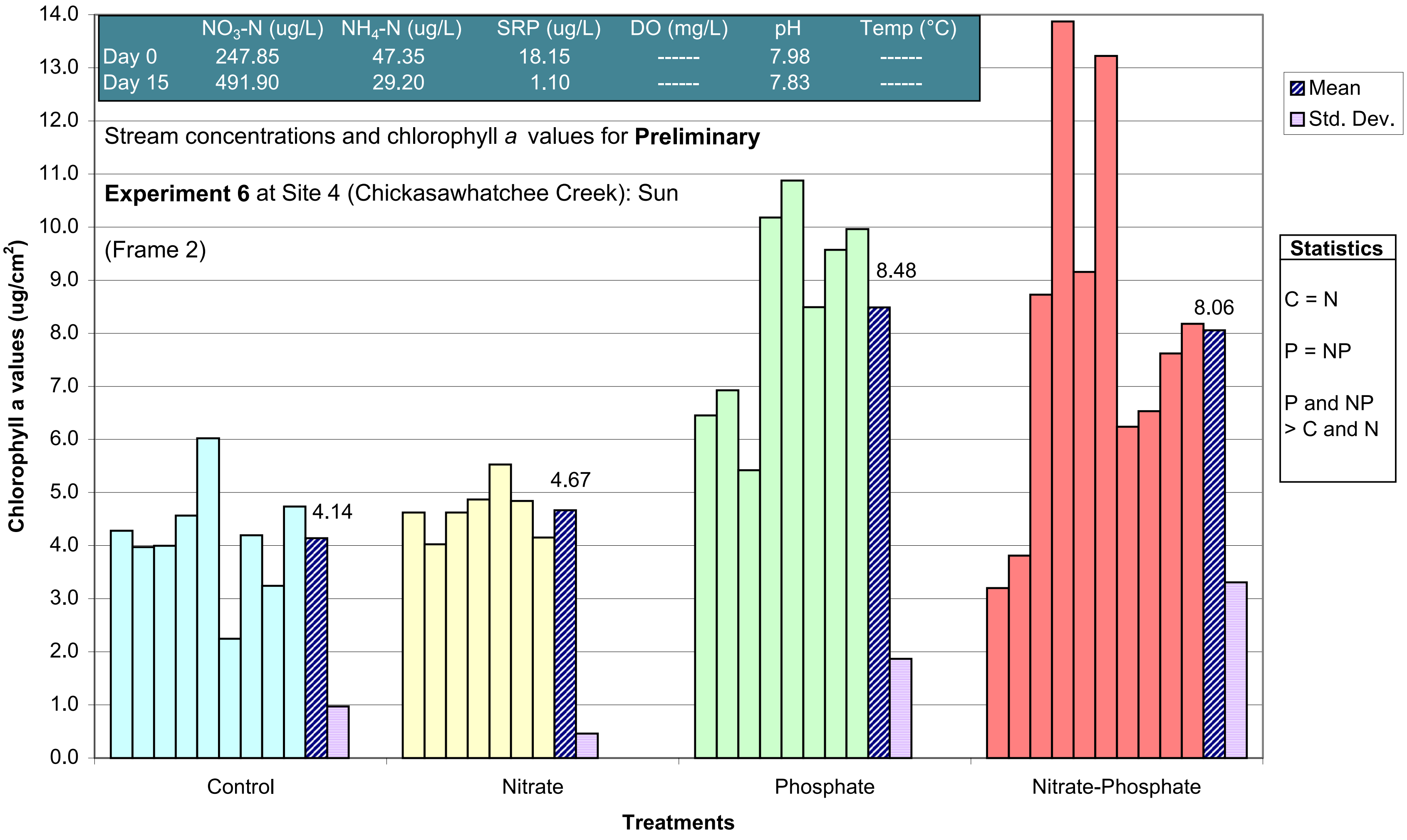


	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	247.85	47.35	18.15	------	7.98	------
Day 15	491.90	29.20	1.10	------	7.83	------

Stream concentrations and chlorophyll *a* values for **Preliminary**

Experiment 6 at Site 4 (Chickasawhatchee Creek): Sun (Frame 1)

Figure A-10. Chlorophyll *a* values for March 11, 2004 preliminary experiment at Site 4 (frame 1). The periphytometer was deployed in the sun and removed on March 26, 2004. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen and stream temperatures were not measured.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	247.85	47.35	18.15	------	7.98	------
Day 15	491.90	29.20	1.10	------	7.83	------

Figure A-11. Chlorophyll *a* values for March 11, 2004 preliminary experiment at Site 4 (frame 2). The periphytometer was deployed in the sun and removed on March 26, 2004. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen and stream temperatures were not measured.

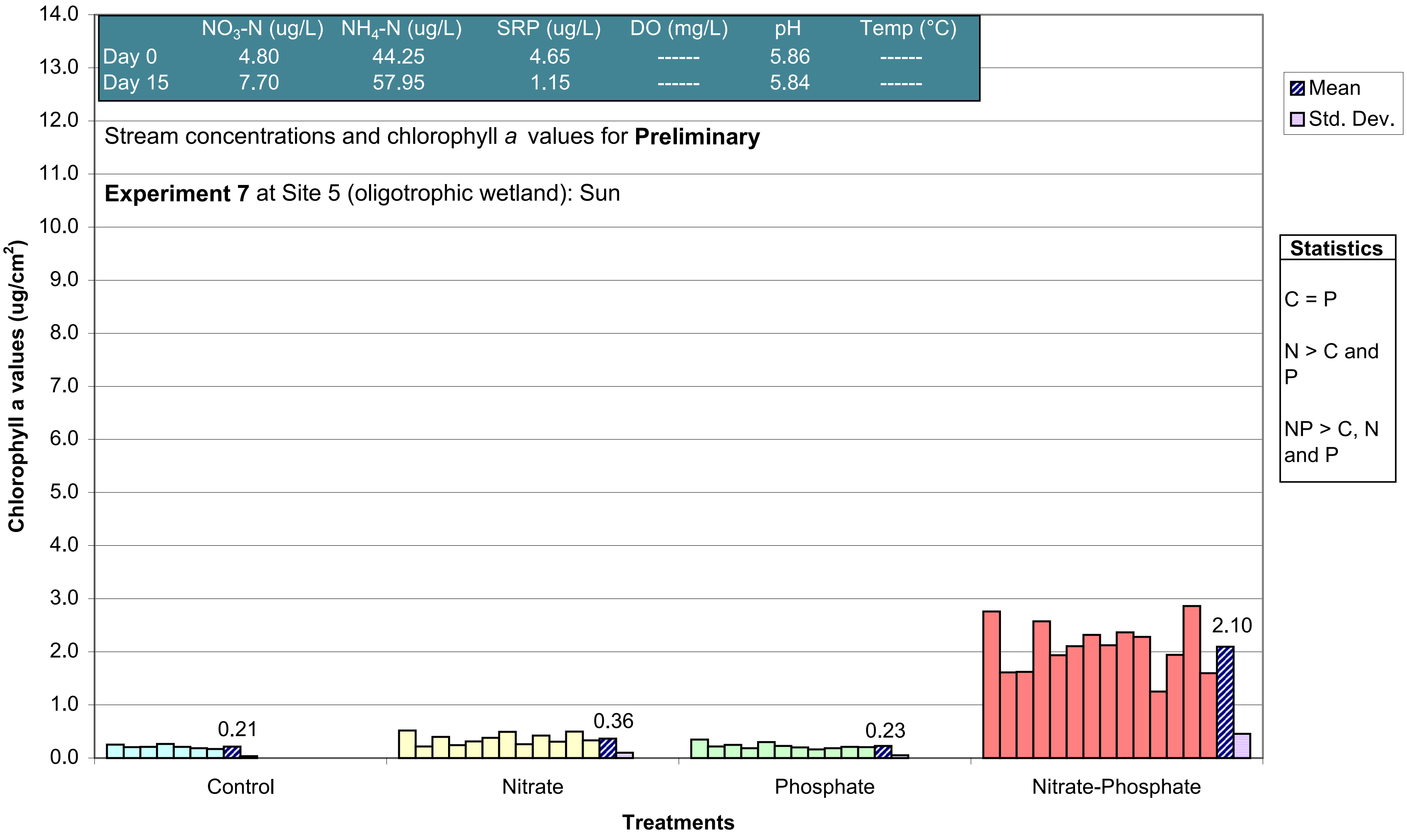


Figure A-12. Chlorophyll *a* values for March 17, 2004 preliminary experiment at Site 5 (2 frames combined). Two periphytometers were deployed in the sun and removed on April 1, 2004. Chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water. Dissolved oxygen and stream temperatures were not measured.

APPENDIX B

FLOW DATA

Table B-1. Flow data at USDA-ARS Station N during periphytometer experiment (May 21, 2004 - June 5, 2004). Flow measured in cubic meters per second.

Station	Year	Month	Day	Mean Daily Flow (m^3/s)	Max Instantaneous Discharge (m^3/s)	Min Instantaneous Discharge (m^3/s)
N	2004	5	21	0.0272	0.0297	0.0204
N	2004	5	22	0.0184	0.0204	0.0144
N	2004	5	23	0.0127	0.0144	0.0099
N	2004	5	24	0.0088	0.0099	0.0062
N	2004	5	25	0.0059	0.0074	0.0034
N	2004	5	26	0.0020	0.0034	0.0003
N	2004	5	27	0.0000	0.0003	0.0000
N	2004	5	28	0.0000	0.0000	0.0000
N	2004	5	29	0.0000	0.0000	0.0000
N	2004	5	30	0.0000	0.0000	0.0000
N	2004	5	31	0.0000	0.0000	0.0000
N	2004	6	1	0.0000	0.0000	0.0000
N	2004	6	2	0.0000	0.0000	0.0000
N	2004	6	3	0.0127	0.0272	0.0000
N	2004	6	4	0.0246	0.0297	0.0161
N	2004	6	5	0.0156	0.0181	0.0099

Table B-2. Flow data at USDA-ARS Station B during periphytometer experiment (May 24, 2004 - June 8, 2004). Flow measured in cubic meters per second.

Station	Year	Month	Day	Mean Daily Flow (m^3/s)	Max Instantaneous Discharge (m^3/s)	Min Instantaneous Discharge (m^3/s)
B	2004	5	24	0.0008	0.0272	0.0006
B	2004	5	25	0.0003	0.0184	0.0000
B	2004	5	26	0.0000	0.0127	0.0000
B	2004	5	27	0.0000	0.0088	0.0000
B	2004	5	28	0.0000	0.0059	0.0000
B	2004	5	29	0.0000	0.0020	0.0000
B	2004	5	30	0.0000	0.0000	0.0000
B	2004	5	31	0.0000	0.0000	0.0000
B	2004	6	1	0.0000	0.0000	0.0000
B	2004	6	2	0.0000	0.0000	0.0000
B	2004	6	3	0.0000	0.0000	0.0000
B	2004	6	4	0.0000	0.0000	0.0000
B	2004	6	5	0.0000	0.0000	0.0000
B	2004	6	6	0.0000	0.0127	0.0000
B	2004	6	7	0.0000	0.0246	0.0000
B	2004	6	8	0.0000	0.0156	0.0000

APPENDIX C

RESIDUAL NUTRIENT CONCENTRATIONS

Table C-1. Residual nutrient concentrations in 20 mL vials at the Broxton Rocks Preserve (Broxton, GA; Site 6). Periphytometers were deployed on April 8, 2004 and retrieved on April 23, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO$_3$-N**	**PO$_4$-P**		**NO$_3$-N**	**PO$_4$-P**	**20 mL Vial**
S6-408C-1	0.02635	0.00685	Control	0.00975	0.01830	S6-408C-11
S6-408C-2	0.01145	0.00015		0.01150	0.01485	S6-408C-12
S6-408C-3	0.01125	0.00000		0.01025	0.00645	S6-408C-13
S6-408C-4	0.01530	0.00000		0.01060	0.00315	S6-408C-14
S6-408C-5	0.01055	0.00000		0.00890	0.00055	S6-408C-15
S6-408C-6	0.01275	0.00445		0.00900	0.01220	S6-408C-16
S6-408C-7	0.02130	0.00000		0.00920	0.00325	S6-408C-17
S6-408C-8	0.01290	0.00000		0.00625	0.00120	S6-408C-18
S6-408C-9	0.01195	0.00000		0.00860	0.00000	S6-408C-19
S6-408C-10	0.01870	0.00000		0.00980	0.00865	S6-408C-20
S6-408N-1	5.74685	0.00000	Nitrate	1.61000	0.00145	S6-408N-11
S6-408N-2	3.96550	0.00000		3.87205	0.00000	S6-408N-12
S6-408N-3	6.62775	0.01125		1.06645	0.00510	S6-408N-13
S6-408N-4	2.65945	0.00120		5.29850	0.00000	S6-408N-14
S6-408N-5	6.02730	0.00000		6.76285	0.00620	S6-408N-15
S6-408N-6	11.19295	0.00000		0.75290	0.00000	S6-408N-16
S6-408N-7	1.58150	0.00000		5.61360	0.00000	S6-408N-17
S6-408N-8	1.88500	0.01025		3.05625	0.00000	S6-408N-18
S6-408N-9	0.86710	0.00000		3.78930	0.00900	S6-408N-19
S6-408N-10	1.81975	0.00000		4.53305	0.00000	S6-408N-20
S6-408P-1	0.00450	5.15195	Phosphate	0.00100	6.03245	S6-408P-11
S6-408P-2	0.00795	3.26305		0.00000	2.25025	S6-408P-12
S6-408P-3	0.00960	3.30540		0.00000	6.18090	S6-408P-13
S6-408P-4	0.00640	2.44865		0.00000	3.89545	S6-408P-14
S6-408P-5	0.00795	4.64575		0.00000	2.52730	S6-408P-15
S6-408P-6	0.00000	2.55025		0.00000	0.73805	S6-408P-16
S6-408P-7	0.00000	1.75095		0.00000	1.44075	S6-408P-17
S6-408P-8	0.00000	3.51135		0.00000	4.47490	S6-408P-18
S6-408P-9	0.00235	2.53450		0.00000	5.55745	S6-408P-19
S6-408P-10	0.00210	3.70280		0.00000	3.87055	S6-408P-20
S6-408NP-1	1.50925	1.28340	Nitrate-Phosphate	6.64085	3.59500	S6-408NP-11
S6-408NP-2	5.18785	2.83090		14.79590	5.36675	S6-408NP-12
S6-408NP-3	1.88775	1.60365		4.02905	2.76495	S6-408NP-13
S6-408NP-4	3.84915	2.37745		8.50970	4.09000	S6-408NP-14
S6-408NP-5	0.97035	1.13165		2.53735	2.15935	S6-408NP-15
S6-408NP-6	6.04975	3.21760		4.48950	2.95870	S6-408NP-16
S6-408NP-7	16.67050	5.59035		1.09840	1.28780	S6-408NP-17
S6-408NP-8	4.78150	2.86095		1.14185	1.36750	S6-408NP-18
S6-408NP-9	4.45195	2.64900		18.88290	6.06405	S6-408NP-19
S6-408NP-10	6.99890	3.44905		2.02305	1.78920	S6-408NP-20

Table C-2. Residual nutrient concentrations in 20 mL vials at Five Mile Creek (Weber, GA; Site 7). Periphytometers were deployed on April 13, 2004 and retrieved on April 28, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S7-413C-1	0.01780	0.00715	Control	0.01795	0.00385	S7-413C-11
S7-413C-2	0.01790	0.02205		0.01940	0.00325	S7-413C-12
S7-413C-3	0.01705	0.00000		0.01980	0.00370	S7-413C-13
S7-413C-4	0.01760	0.00000		0.01795	0.00465	S7-413C-14
S7-413C-5	0.01780	0.03790		0.02015	0.00265	S7-413C-15
S7-413C-6	0.01945	0.00095		0.01920	0.01220	S7-413C-16
S7-413C-7	0.02085	0.01035		0.01955	0.00775	S7-413C-17
S7-413C-8	0.02005	0.00835		0.01765	0.00750	S7-413C-18
S7-413C-9	0.01930	0.00000		0.01910	0.00765	S7-413C-19
S7-413C-10	0.02155	0.00000		0.01860	0.00680	S7-413C-20
S7-413N-1	1.15975	0.00365	Nitrate	3.12440	0.01710	S7-413N-11
S7-413N-2	1.11185	0.00000		0.98015	0.01090	S7-413N-12
S7-413N-3	1.16870	0.00000		0.47230	0.00940	S7-413N-13
S7-413N-4	2.07705	0.00000		2.54730	0.01195	S7-413N-14
S7-413N-5	0.05030	0.00685		1.45235	0.01100	S7-413N-15
S7-413N-6	1.12775	0.01070		0.67315	0.02330	S7-413N-16
S7-413N-7	2.34765	0.00000		0.61580	0.01595	S7-413N-17
S7-413N-8	0.77385	0.00000		1.14775	0.01500	S7-413N-18
S7-413N-9	0.80315	0.00000		1.13205	0.01675	S7-413N-19
S7-413N-10	0.86675	0.00870		1.79595	0.04330	S7-413N-20
S7-413P-1	0.01350	2.83140	Phosphate	0.01550	1.56205	S7-413P-11
S7-413P-2	0.01405	1.96850		0.01350	1.44680	S7-413P-12
S7-413P-3	0.01435	2.67375		0.01290	4.18490	S7-413P-13
S7-413P-4	0.01450	1.88040		0.01380	1.83890	S7-413P-14
S7-413P-5	0.01515	1.86605		0.01365	2.11920	S7-413P-15
S7-413P-6	0.01655	2.60795		0.01625	0.64915	S7-413P-16
S7-413P-7	0.01535	2.29735		0.01415	1.80960	S7-413P-17
S7-413P-8	0.01640	1.57355		0.01620	3.12865	S7-413P-18
S7-413P-9	0.01650	2.21755		0.01640	0.83415	S7-413P-19
S7-413P-10	0.03030	1.87435		0.01500	1.74315	S7-413P-20
S7-413NP-1	0.99195	1.01655	Nitrate-Phosphate	0.54130	0.70210	S7-413NP-11
S7-413NP-2	1.47055	1.29200		0.42675	0.71235	S7-413NP-12
S7-413NP-3	1.38050	1.16095		5.71830	2.89920	S7-413NP-13
S7-413NP-4	1.28510	1.12220		4.74945	2.71625	S7-413NP-14
S7-413NP-5	1.94955	1.52880		1.48010	1.15005	S7-413NP-15
S7-413NP-6	0.99430	0.96445		4.25895	2.33585	S7-413NP-16
S7-413NP-7	1.24565	1.13290		7.92910	3.52980	S7-413NP-17
S7-413NP-8	0.97435	0.99505		6.82150	3.61795	S7-413NP-18
S7-413NP-9	1.68625	1.35750		5.30525	2.65830	S7-413NP-19
S7-413NP-10	1.46490	1.30515		2.75505	1.58315	S7-413NP-20

Table C-3. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (DuPont, GA; Site 8). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S8-415C-1	0.01375	0.02750	Control	0.02045	0.01510	S8-415C-11
S8-415C-2	0.01465	0.02185		0.02135	0.00540	S8-415C-12
S8-415C-3	0.01225	0.00000		0.02125	0.00375	S8-415C-13
S8-415C-4	0.01310	0.00700		0.01815	0.00270	S8-415C-14
S8-415C-5	0.01245	0.01515		0.02320	0.00175	S8-415C-15
S8-415C-6	0.01445	0.01155		0.02530	0.00955	S8-415C-16
S8-415C-7	0.01180	0.00740		0.02555	0.00600	S8-415C-17
S8-415C-8	0.02190	0.03735		0.02620	0.00000	S8-415C-18
S8-415C-9	0.02165	0.02790		0.02460	0.09645	S8-415C-19
S8-415C-10	0.02040	0.02305		0.02750	0.02680	S8-415C-20
S8-415N-1	1.39490	0.01460	Nitrate	1.29235	0.00000	S8-415N-11
S8-415N-2	1.63510	0.01300		0.95745	0.00000	S8-415N-12
S8-415N-3	1.10530	0.02240		2.50505	0.00000	S8-415N-13
S8-415N-4	0.87360	0.01485		1.81030	0.00000	S8-415N-14
S8-415N-5	0.87730	0.01625		1.25100	0.00000	S8-415N-15
S8-415N-6	0.86705	0.04735		1.12770	0.00000	S8-415N-16
S8-415N-7	0.87745	0.00825		0.99910	0.00000	S8-415N-17
S8-415N-8	1.25260	0.00525		1.65805	0.00000	S8-415N-18
S8-415N-9	2.05275	0.00395		0.74795	0.00000	S8-415N-19
S8-415N-10	0.82790	0.01150		0.60500	0.00000	S8-415N-20
S8-415P-1	0.01840	1.47185	Phosphate	0.01225	1.46680	S8-415P-11
S8-415P-2	0.01835	0.94195		0.00980	0.99030	S8-415P-12
S8-415P-3	0.01400	1.17255		0.00935	1.99980	S8-415P-13
S8-415P-4	0.01400	0.90675		0.00825	1.65000	S8-415P-14
S8-415P-5	0.01905	1.04410		0.00820	0.98320	S8-415P-15
S8-415P-6	0.01880	0.91790		0.00995	1.90000	S8-415P-16
S8-415P-7	0.01650	0.80350		0.01145	0.92730	S8-415P-17
S8-415P-8	0.01910	0.99555		0.01235	1.66010	S8-415P-18
S8-415P-9	0.01515	1.27555		0.01125	0.63520	S8-415P-19
S8-415P-10	0.01500	1.16315		0.01100	2.15560	S8-415P-20
S8-415NP-1	1.47625	1.37190	Nitrate-Phosphate	1.29135	1.18865	S8-415NP-11
S8-415NP-2	1.14735	1.19285		1.02700	1.12935	S8-415NP-12
S8-415NP-3	1.41290	1.33925		1.08900	1.11605	S8-415NP-13
S8-415NP-4	0.79250	0.98075		1.08860	1.13575	S8-415NP-14
S8-415NP-5	1.03785	1.14195		2.83850	1.77925	S8-415NP-15
S8-415NP-6	1.08585	1.15665		0.70450	0.84475	S8-415NP-16
S8-415NP-7	0.78940	0.94715		1.48625	1.32355	S8-415NP-17
S8-415NP-8	1.73240	1.55495		0.56830	0.76695	S8-415NP-18
S8-415NP-9	0.75475	0.96005		2.09205	1.60695	S8-415NP-19
S8-415NP-10	1.04680	1.13130		1.19215	1.17570	S8-415NP-20

Table C-4. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (Fruitland, GA; Site 9). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S9-415C-1	0.02635	0.05320	Control	0.01845	0.00705	S9-415C-11
S9-415C-2	0.02155	0.03070		0.01520	0.00000	S9-415C-12
S9-415C-3	0.02140	0.02665		0.01665	0.00000	S9-415C-13
S9-415C-4	0.02080	0.02525		0.01650	0.00000	S9-415C-14
S9-415C-5	0.01995	0.02065		0.01515	0.00000	S9-415C-15
S9-415C-6	0.02010	0.01790		0.02370	0.00130	S9-415C-16
S9-415C-7	0.02000	0.02810		0.02365	0.00000	S9-415C-17
S9-415C-8	0.02085	0.01740		0.02355	0.00000	S9-415C-18
S9-415C-9	0.02030	0.01860		0.02520	0.00000	S9-415C-19
S9-415C-10	0.02070	0.01220		0.02615	0.00000	S9-415C-20
S9-415N-1	1.49640	0.01505	Nitrate	3.06755	0.00000	S9-415N-11
S9-415N-2	1.98495	0.01955		8.45695	0.00000	S9-415N-12
S9-415N-3	1.21945	0.01415		8.34925	0.00000	S9-415N-13
S9-415N-4	1.64185	0.02215		9.10420	0.00000	S9-415N-14
S9-415N-5	1.10050	0.01470		6.90605	0.00000	S9-415N-15
S9-415N-6	7.03710	0.01345		3.90790	0.00130	S9-415N-16
S9-415N-7	7.71665	0.01470		9.09440	0.00000	S9-415N-17
S9-415N-8	2.89750	0.01275		11.35310	0.00000	S9-415N-18
S9-415N-9	1.87945	0.01715		2.03710	0.00000	S9-415N-19
S9-415N-10	2.85275	0.01245		1.96780	0.00000	S9-415N-20
S9-415P-1	0.02365	3.43950	Phosphate	0.01990	1.65155	S9-415P-11
S9-415P-2	0.02300	3.52415		0.01995	4.27940	S9-415P-12
S9-415P-3	0.02420	1.29060		0.02135	6.84115	S9-415P-13
S9-415P-4	0.02340	1.95905		0.01945	7.05405	S9-415P-14
S9-415P-5	0.02210	3.78965		0.02095	4.27590	S9-415P-15
S9-415P-6	0.02275	2.17870		0.02115	1.94105	S9-415P-16
S9-415P-7	0.02270	2.09010		0.02015	2.20535	S9-415P-17
S9-415P-8	0.02305	1.99880		0.02105	2.23325	S9-415P-18
S9-415P-9	0.02300	3.50590		0.02130	0.80120	S9-415P-19
S9-415P-10	0.02245	1.54935		0.02190	1.72170	S9-415P-20
S9-415NP-1	0.88730	0.97220	Nitrate-Phosphate	3.91075	2.16450	S9-415NP-11
S9-415NP-2	1.40345	1.28440		34.51825	5.90745	S9-415NP-12
S9-415NP-3	1.90200	1.53190		3.20130	1.90355	S9-415NP-13
S9-415NP-4	1.51640	1.36430		9.09055	4.56130	S9-415NP-14
S9-415NP-5	1.09245	1.09640		12.93670	4.61220	S9-415NP-15
S9-415NP-6	1.30310	1.23325		4.85135	2.74950	S9-415NP-16
S9-415NP-7	1.76620	1.99425		10.79275	4.08700	S9-415NP-17
S9-415NP-8	1.56580	1.36480		2.04480	1.48645	S9-415NP-18
S9-415NP-9	5.48160	2.95635		21.62430	5.69180	S9-415NP-19
S9-415NP-10	3.09820	1.85710		8.71665	4.00260	S9-415NP-20

Table C-5. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (Fargo, GA; Site 10). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S10-415C-1	0.02345	0.03175		0.02010	0.04245	S10-415C-11
S10-415C-2	0.02170	0.02865		0.02020	0.01905	S10-415C-12
S10-415C-3	0.02265	0.01815		0.01905	0.00285	S10-415C-13
S10-415C-4	0.02320	0.01705		0.02115	0.00000	S10-415C-14
S10-415C-5	0.02245	0.01540	Control	0.01890	0.00000	S10-415C-15
S10-415C-6						S10-415C-16
S10-415C-7	0.02170	0.01485		0.02045	0.03225	S10-415C-17
S10-415C-8	0.02105	0.05565		0.02095	0.01725	S10-415C-18
S10-415C-9	0.01795	0.00750		0.02265	0.00860	S10-415C-19
S10-415C-10	0.01805	0.00115		0.02125	0.01680	S10-415C-20
S10-415N-1	1.04090	0.00000		0.61785	0.01730	S10-415N-11
S10-415N-2	0.69665	0.01760		0.67415	0.00780	S10-415N-12
S10-415N-3	0.65545	0.00000		0.39400	0.00580	S10-415N-13
S10-415N-4	0.79355	0.00000		0.81585	0.00690	S10-415N-14
S10-415N-5	0.71840	0.00000	Nitrate	0.59795	0.00160	S10-415N-15
S10-415N-6	0.41655	0.00000		0.93665	0.00465	S10-415N-16
S10-415N-7	0.44815	0.00860		0.47175	0.02925	S10-415N-17
S10-415N-8	0.59355	0.00000		0.82155	0.00575	S10-415N-18
S10-415N-9	1.23620	0.00000		0.97970	0.00000	S10-415N-19
S10-415N-10	0.59670	0.00000		0.51290	0.00000	S10-415N-20
S10-415P-1	0.01975	1.10505		0.02210	1.05125	S10-415P-11
S10-415P-2	0.01930	1.28055		0.02335	0.99565	S10-415P-12
S10-415P-3	0.01700	1.02355		0.02320	1.11450	S10-415P-13
S10-415P-4	0.01695	1.48255		0.02210	1.14975	S10-415P-14
S10-415P-5	0.01655	1.07095	Phosphate	0.02325	0.92805	S10-415P-15
S10-415P-6	0.02110	1.20305		0.02395	1.70925	S10-415P-16
S10-415P-7	0.02155	0.85770		0.03320	1.16775	S10-415P-17
S10-415P-8	0.02180	1.22420		0.02340	1.09655	S10-415P-18
S10-415P-9	0.02060	1.27675		0.02410	1.75880	S10-415P-19
S10-415P-10	0.02050	1.13285		0.02450	1.44880	S10-415P-20
S10-415NP-1	0.84420	1.02450		0.48470	0.72400	S10-415NP-11
S10-415NP-2	0.74385	0.95840		0.39485	0.68225	S10-415NP-12
S10-415NP-3	1.11985	1.25870		0.74865	0.97520	S10-415NP-13
S10-415NP-4	0.63900	0.89025		0.54250	0.77315	S10-415NP-14
S10-415NP-5	0.62155	0.88530	Nitrate-Phosphate	1.55205	1.37465	S10-415NP-15
S10-415NP-6	1.44565	1.36290		1.09335	1.21110	S10-415NP-16
S10-415NP-7	0.53755	0.81175		0.46845	0.74555	S10-415NP-17
S10-415NP-8	0.54960	0.81055		0.73840	0.98635	S10-415NP-18
S10-415NP-9				0.39505	0.70270	S10-415NP-19
S10-415NP-10	0.33375	0.59730		0.48095	0.75225	S10-415NP-20

Table C-6. Residual nutrient concentrations in 20 mL vials at USDA-ARS Station N, Little River (Tifton, GA; Site 13). Periphytometers were deployed on May 21, 2004 and retrieved on June 5, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S13-521C-1	0.19635	0.01675	Control	0.13735	0.03215	S13-521C-11
S13-521C-2	0.18805	0.03595		0.12240	0.02760	S13-521C-12
S13-521C-3	0.19135	0.00065		0.12000	0.01315	S13-521C-13
S13-521C-4	0.18330	0.00000		0.11560	0.00895	S13-521C-14
S13-521C-5	0.18755	0.00000		0.09330	0.02960	S13-521C-15
S13-521C-6	0.18950	0.01305		0.08240	0.01680	S13-521C-16
S13-521C-7	0.18500	0.00000		0.09655	0.01115	S13-521C-17
S13-521C-8	0.18225	0.00000		0.08755	0.03355	S13-521C-18
S13-521C-9	0.19430	0.00000		0.08910	0.02220	S13-521C-19
S13-521C-10	0.18895	0.00000		0.09095	0.00890	S13-521C-20
S13-521N-1	1.54190	0.00620	Nitrate	0.60120	0.00475	S13-521N-11
S13-521N-2	1.31065	0.01455		1.64890	0.00735	S13-521N-12
S13-521N-3	1.36365	0.00000		0.73325	0.00545	S13-521N-13
S13-521N-4	1.29550	0.00000		0.71865	0.03360	S13-521N-14
S13-521N-5	1.12695	0.00495		0.93455	0.01055	S13-521N-15
S13-521N-6	0.74060	0.00000		1.99960	0.02640	S13-521N-16
S13-521N-7	1.88275	0.00000		0.66835	0.02540	S13-521N-17
S13-521N-8	1.75695	0.00000		0.61140	0.02510	S13-521N-18
S13-521N-9	1.95650	0.00000		1.08255	0.00340	S13-521N-19
S13-521N-10	1.02180	0.00935		0.96010	0.00320	S13-521N-20
S13-521P-1	0.20735	0.66620	Phosphate	0.02835	0.40520	S13-521P-11
S13-521P-2	0.19285	1.17995		0.02850	0.71585	S13-521P-12
S13-521P-3	0.17730	1.03705		0.03040	1.06715	S13-521P-13
S13-521P-4	0.17885	1.15560		0.02940	0.72690	S13-521P-14
S13-521P-5	0.18470	0.80505		0.02935	0.73600	S13-521P-15
S13-521P-6	0.16265	1.23080		0.03895	0.55305	S13-521P-16
S13-521P-7	0.17000	1.40495		0.03635	0.37340	S13-521P-17
S13-521P-8	0.20355	0.92205		0.03675	1.27895	S13-521P-18
S13-521P-9	0.16665	0.85695		0.03620	0.51105	S13-521P-19
S13-521P-10	0.15005	1.90045		0.03725	0.50175	S13-521P-20
S13-521NP-1	0.86845	0.77180	Nitrate-Phosphate	0.06155	0.07495	S13-521NP-11
S13-521NP-2	1.13485	0.93750		0.28005	0.55830	S13-521NP-12
S13-521NP-3	1.90810	1.39225		0.05885	0.38730	S13-521NP-13
S13-521NP-4	1.12545	0.94370		0.10515	0.45225	S13-521NP-14
S13-521NP-5	0.91465	0.78775		0.03655	0.25825	S13-521NP-15
S13-521NP-6	0.70695	0.69185		0.04940	0.03075	S13-521NP-16
S13-521NP-7	0.78645	0.71485		0.17745	0.23510	S13-521NP-17
S13-521NP-8	0.90600	0.76525		0.05130	0.04420	S13-521NP-18
S13-521NP-9	0.70345	0.63375		0.04130	0.03075	S13-521NP-19
S13-521NP-10	1.00250	0.88855		0.07045	0.25090	S13-521NP-20

Table C-7. Residual nutrient concentrations in 20 mL vials at USDA-ARS Station B, Little River (Tifton, GA; Site 3). Periphytometers were deployed on May 24, 2004 and retrieved on June 8, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S3-524C-1	0.04450	0.01185	Control	0.03600	0.01195	S3-524C-11
S3-524C-2	0.04430	0.00000		0.03455	0.00000	S3-524C-12
S3-524C-3	0.03825	0.00000		0.03685	0.00000	S3-524C-13
S3-524C-4	0.04020	0.00000		0.03560	0.02835	S3-524C-14
S3-524C-5	0.04045	0.00000		0.03335	0.00000	S3-524C-15
S3-524C-6	0.04315	0.01560		0.03950	0.00595	S3-524C-16
S3-524C-7	0.04055	0.00000		0.04125	0.00220	S3-524C-17
S3-524C-8	0.03810	0.00000		0.03845	0.01230	S3-524C-18
S3-524C-9	0.04015	0.00000		0.02440	0.01800	S3-524C-19
S3-524C-10	0.02745	0.01365		0.02620	0.00425	S3-524C-20
S3-524N-1	1.22525	0.00755	Nitrate	1.15370	0.01890	S3-524N-11
S3-524N-2	1.52155	0.00735		0.31180	0.00000	S3-524N-12
S3-524N-3	1.20900	0.02195		0.95310	0.01415	S3-524N-13
S3-524N-4	0.61345	0.01860		0.69365	0.00165	S3-524N-14
S3-524N-5	0.48330	0.00940		1.06395	0.00000	S3-524N-15
S3-524N-6	0.27020	0.00060		1.00710	0.00000	S3-524N-16
S3-524N-7	0.35260	0.00345		0.76470	0.00000	S3-524N-17
S3-524N-8	1.20315	0.00000		0.61105	0.02700	S3-524N-18
S3-524N-9	0.37475	0.04170		1.32435	0.00805	S3-524N-19
S3-524N-10	0.46165	0.03745		2.21140	0.00040	S3-524N-20
S3-524P-1	0.03960	1.16185	Phosphate	0.04320	0.75715	S3-524P-11
S3-524P-2	0.06365	0.80280		0.04590	0.69835	S3-524P-12
S3-524P-3	0.04330	0.79690		0.04595	1.79330	S3-524P-13
S3-524P-4	0.04890	0.87755		0.04585	2.35970	S3-524P-14
S3-524P-5	0.04785	1.06430		0.04400	1.98515	S3-524P-15
S3-524P-6	0.03640	0.50610		0.04975	0.98750	S3-524P-16
S3-524P-7	0.06425	0.56160		0.04590	1.07025	S3-524P-17
S3-524P-8	0.04260	0.84970		0.05240	0.74455	S3-524P-18
S3-524P-9	0.04760	0.85595		0.04245	9.07340	S3-524P-19
S3-524P-10	0.04100	0.64970		0.05180	1.27670	S3-524P-20
S3-524NP-1	0.76000	0.76535	Nitrate-Phosphate	1.67765	1.28900	S3-524NP-11
S3-524NP-2	1.15710	0.99710		7.41050	2.96245	S3-524NP-12
S3-524NP-3	0.44190	0.54425		0.19055	0.94560	S3-524NP-13
S3-524NP-4	0.34785	0.49470		10.68760	3.57680	S3-524NP-14
S3-524NP-5	0.29655	0.43645		11.87855	4.10100	S3-524NP-15
S3-524NP-6	0.83030	0.86525		6.12725	3.85765	S3-524NP-16
S3-524NP-7	0.46720	0.63155		15.94395	4.70990	S3-524NP-17
S3-524NP-8	0.83155	0.84980		16.74135	4.70970	S3-524NP-18
S3-524NP-9	0.45890	0.59360		9.62885	3.21605	S3-524NP-19
S3-524NP-10	0.64635	0.75095				S3-524NP-20

Table C-8. Residual nutrient concentrations in 20 mL vials at Little Satilla Creek (Screven, GA; Site 11). Periphytometers were deployed on April 26, 2004 and retrieved on May 11, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S11-426C-1	0.03140	0.02305	Control	0.01710	0.01595	S11-426C-11
S11-426C-2	0.02960	0.00540		0.01970	0.00200	S11-426C-12
S11-426C-3	0.02900	0.00000		0.01625	0.00000	S11-426C-13
S11-426C-4	0.03170	0.00000		0.01735	0.00035	S11-426C-14
S11-426C-5	0.03080	0.01855		0.01420	0.00175	S11-426C-15
S11-426C-6	0.02940	0.00000		0.01610	0.01715	S11-426C-16
S11-426C-7	0.03150	0.00000		0.01590	0.00125	S11-426C-17
S11-426C-8	0.03050	0.00000		0.01790	0.00340	S11-426C-18
S11-426C-9	0.03060	0.00235		0.02125	0.00000	S11-426C-19
S11-426C-10	0.03110	0.00000		0.01385	0.00000	S11-426C-20
S11-426N-1	0.66765	0.00000	Nitrate	1.24700	0.02535	S11-426N-11
S11-426N-2	0.69525	0.00000		0.75335	0.00640	S11-426N-12
S11-426N-3	1.29010	0.00000		0.67540	0.00000	S11-426N-13
S11-426N-4	1.53085	0.00000		1.28700	0.00000	S11-426N-14
S11-426N-5	0.98370	0.00000		0.95100	0.01235	S11-426N-15
S11-426N-6	1.49725	0.00000		0.74065	0.00000	S11-426N-16
S11-426N-7	1.27310	0.01830		0.62065	0.00000	S11-426N-17
S11-426N-8	1.28650	0.01190		1.10910	0.00000	S11-426N-18
S11-426N-9	1.23275	0.00000		0.76400	0.00000	S11-426N-19
S11-426N-10	1.11730	0.00000		0.99670	0.00975	S11-426N-20
S11-426P-1	0.02585	1.57970	Phosphate	0.00945	1.44480	S11-426P-11
S11-426P-2	0.02440	1.51775		0.01060	0.89770	S11-426P-12
S11-426P-3	0.02470	1.81380		0.02260	1.54245	S11-426P-13
S11-426P-4	0.02430	1.44180		0.02295	1.46810	S11-426P-14
S11-426P-5	0.02445	2.00730		0.02325	1.34830	S11-426P-15
S11-426P-6	0.02465	1.83760		0.02415	0.98100	S11-426P-16
S11-426P-7	0.02505	1.73510		0.02320	1.61360	S11-426P-17
S11-426P-8	0.02510	1.50655		0.02435	1.30525	S11-426P-18
S11-426P-9	0.02505	1.52340		0.02315	1.17475	S11-426P-19
S11-426P-10	0.02410	1.55050		0.03285	1.77980	S11-426P-20
S11-426NP-1	1.10320	1.07705	Nitrate-Phosphate	1.19670	1.05965	S11-426NP-11
S11-426NP-2	0.80385	0.87045		1.29910	1.06585	S11-426NP-12
S11-426NP-3	0.59800	0.71905		0.54815	0.71045	S11-426NP-13
S11-426NP-4	1.18170	1.09560		0.69115	0.81335	S11-426NP-14
S11-426NP-5	1.19550	1.10855		0.72905	0.81180	S11-426NP-15
S11-426NP-6	1.03265	1.02210		0.57245	0.62595	S11-426NP-16
S11-426NP-7	0.83460	0.90040		0.64905	0.72820	S11-426NP-17
S11-426NP-8	0.78790	0.87820		0.86670	0.87705	S11-426NP-18
S11-426NP-9	0.79040	0.88445		1.10315	1.01040	S11-426NP-19
S11-426NP-10	1.34075	1.19515		0.96680	0.84755	S11-426NP-20

Table C-9. Residual nutrient concentrations in 20 mL vials at Little Satilla Creek (Odum, GA; Site 12). Periphytometers were deployed on April 26, 2004 and retrieved on May 11, 2004.

	Shade (mg/L)		**Treatment**	**Sun (mg/L)**		
20 mL Vial	**NO_3-N**	**PO_4-P**		**NO_3-N**	**PO_4-P**	**20 mL Vial**
S12-426C-1	0.01925	0.02740	Control	0.01685	0.03170	S12-426C-11
S12-426C-2	0.01770	0.01090		0.01665	0.01820	S12-426C-12
S12-426C-3	0.01775	0.00055		0.01760	0.01670	S12-426C-13
S12-426C-4	0.01580	0.00000		0.01640	0.01570	S12-426C-14
S12-426C-5	0.01715	0.00000		0.01915	0.01575	S12-426C-15
S12-426C-6	0.01740	0.02260		0.01810	0.01635	S12-426C-16
S12-426C-7	0.01810	0.00000		0.02160	0.02495	S12-426C-17
S12-426C-8	0.01715	0.00000		0.01965	0.01115	S12-426C-18
S12-426C-9	0.01785	0.00000		0.01745	0.00725	S12-426C-19
S12-426C-10	0.01610	0.00000		0.02150	0.02290	S12-426C-20
S12-426N-1	0.75565	0.01770	Nitrate	0.61700	0.01165	S12-426N-11
S12-426N-2	1.18955	0.00435		0.54180	0.00500	S12-426N-12
S12-426N-3	0.86850	0.00145		0.38775	0.00545	S12-426N-13
S12-426N-4	0.67645	0.00000		0.34335	0.00275	S12-426N-14
S12-426N-5	1.24705	0.00000		0.24965	0.01525	S12-426N-15
S12-426N-6	1.36610	0.01225		0.31650	0.00415	S12-426N-16
S12-426N-7	0.62325	0.00000		0.71690	0.00070	S12-426N-17
S12-426N-8	1.35770	0.00000		0.37095	0.00000	S12-426N-18
S12-426N-9	0.78080	0.00000		0.75070	0.00000	S12-426N-19
S12-426N-10	0.77315	0.01905		0.82725	0.01505	S12-426N-20
S12-426P-1	0.02005	1.09680	Phosphate	0.01990	0.83985	S12-426P-11
S12-426P-2	0.02030	1.56800		0.01605	0.79580	S12-426P-12
S12-426P-3	0.01965	1.49625		0.02110	0.94630	S12-426P-13
S12-426P-4	0.02025	1.36860		0.02085	1.22595	S12-426P-14
S12-426P-5	0.01970	1.32530		0.01985	1.15635	S12-426P-15
S12-426P-6	0.02025	1.16775		0.01830	1.06710	S12-426P-16
S12-426P-7	0.02165	1.27045		0.01920	0.95450	S12-426P-17
S12-426P-8	0.02155	1.42085		0.01895	1.13080	S12-426P-18
S12-426P-9	0.02275	1.38480		0.01730	1.03635	S12-426P-19
S12-426P-10	0.02290	1.25935		0.01695	0.96585	S12-426P-20
S12-426NP-1	1.07220	1.08540	Nitrate-Phosphate	0.10980	0.53640	S12-426NP-11
S12-426NP-2	0.30645	0.54380		0.01740	0.44170	S12-426NP-12
S12-426NP-3	0.90010	0.96850		0.01745	0.57260	S12-426NP-13
S12-426NP-4	0.55910	0.81800		0.68115	0.93320	S12-426NP-14
S12-426NP-5	0.38440	0.65895		0.01625	0.34580	S12-426NP-15
S12-426NP-6	0.69830	0.91675		0.02055	0.53620	S12-426NP-16
S12-426NP-7	0.23745	0.78240		0.01690	0.51755	S12-426NP-17
S12-426NP-8	0.79245	0.93995		0.34480	0.77540	S12-426NP-18
S12-426NP-9	0.70190	0.86085		0.01595	0.57095	S12-426NP-19
S12-426NP-10	0.51490	0.70955		0.05050	0.62570	S12-426NP-20

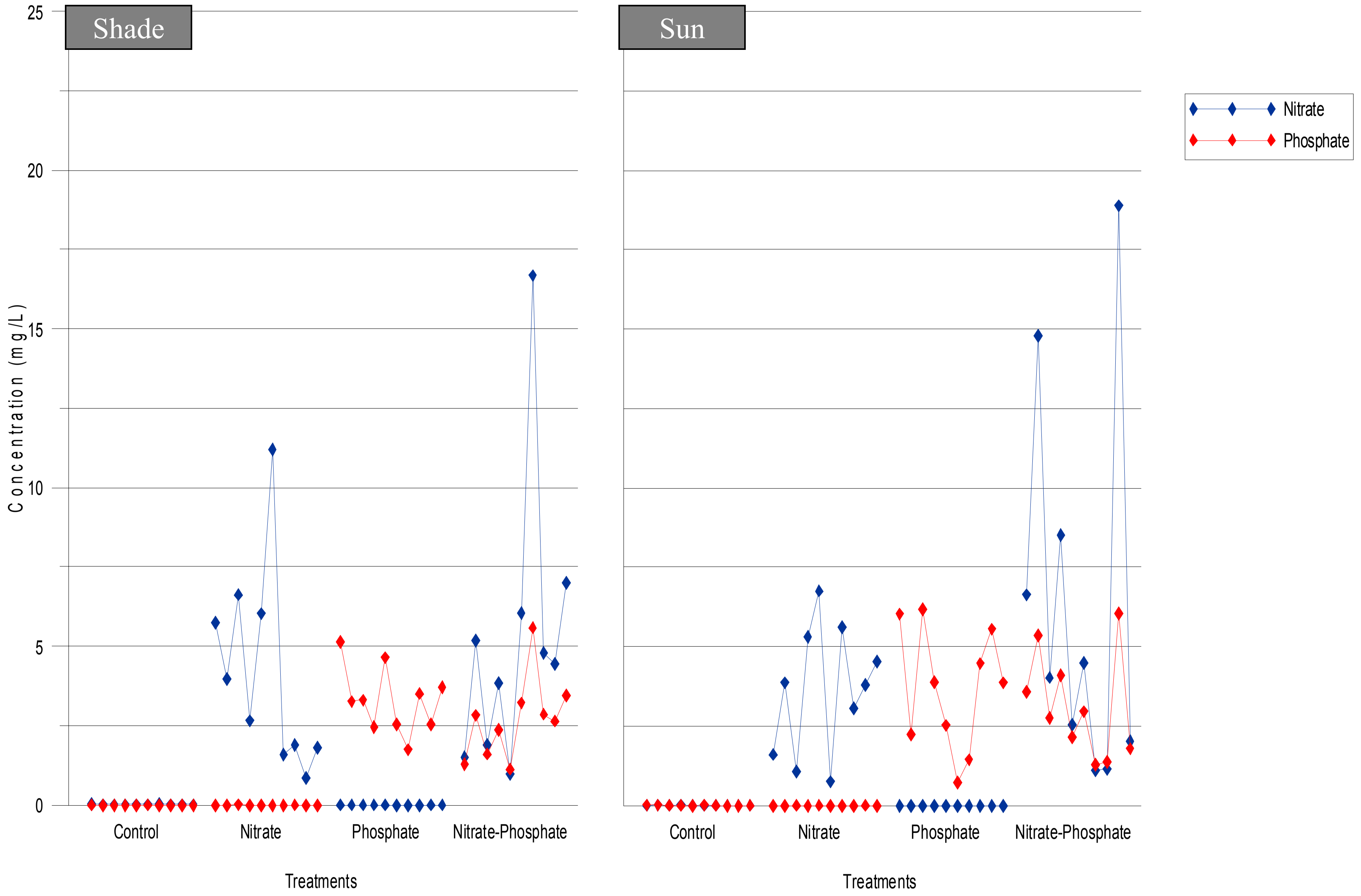


Figure C-1. Residual nutrient concentrations in 20 mL vials at the Broxton Rocks Preserve (Broxton, GA). Periphytometers were deployed on April 8, 2004 and retrieved on April 23, 2004.

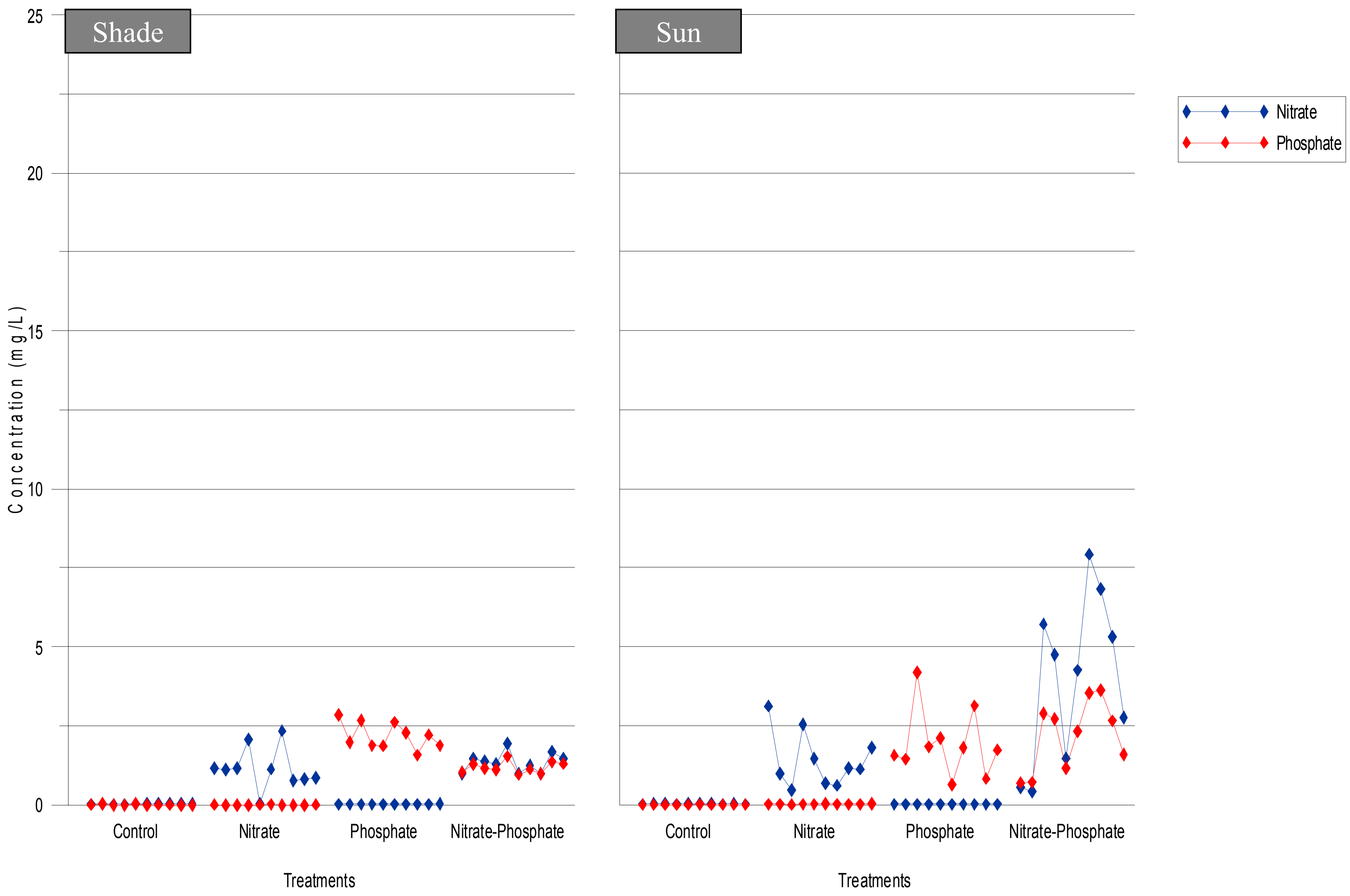


Figure C-2. Residual nutrient concentrations in 20 mL vials at Five Mile Creek (Weber, GA). Periphytometers were deployed on April 13, 2004 and retrieved on April 28, 2004.

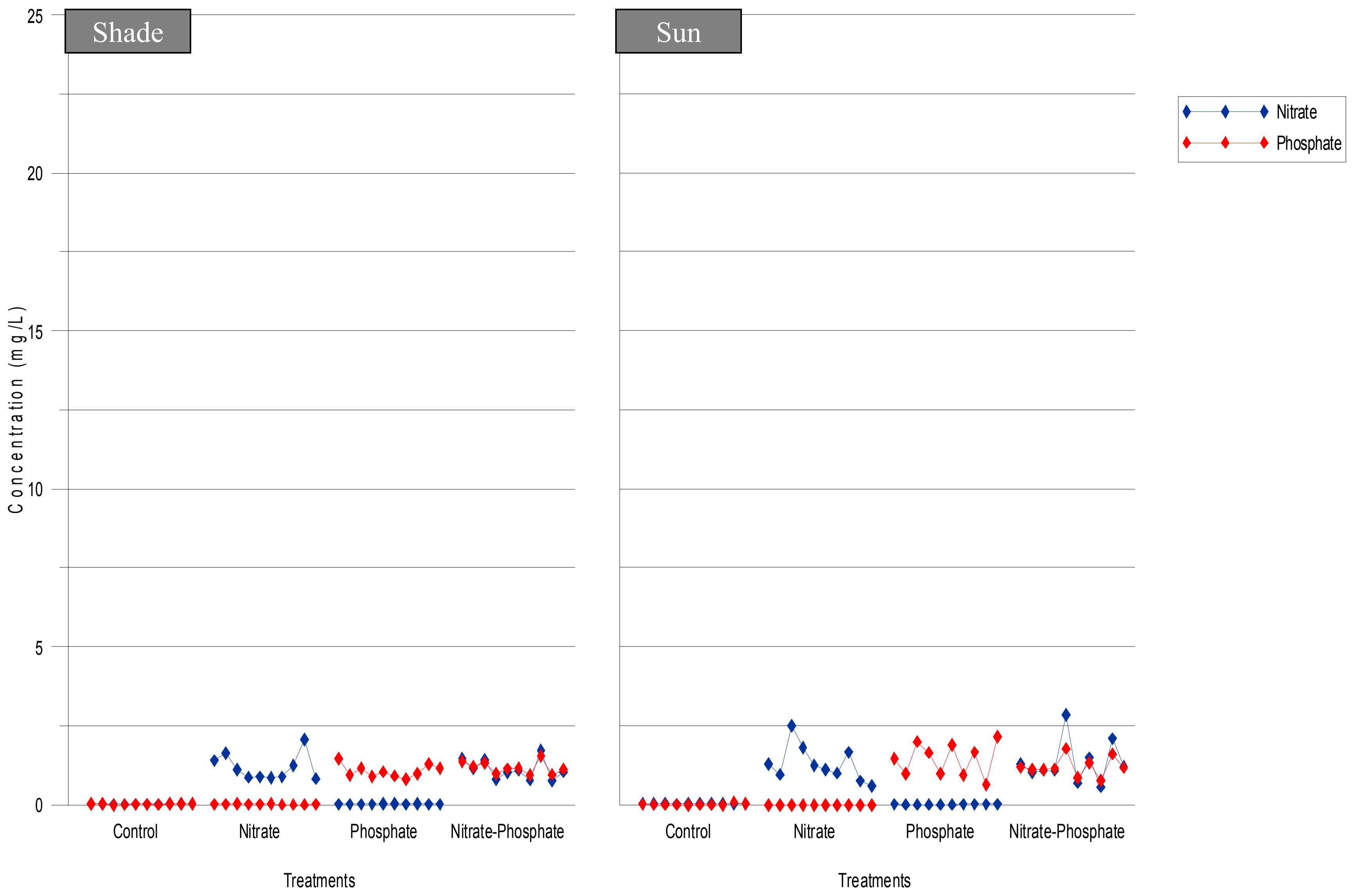


Figure C-3. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (DuPont, GA). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

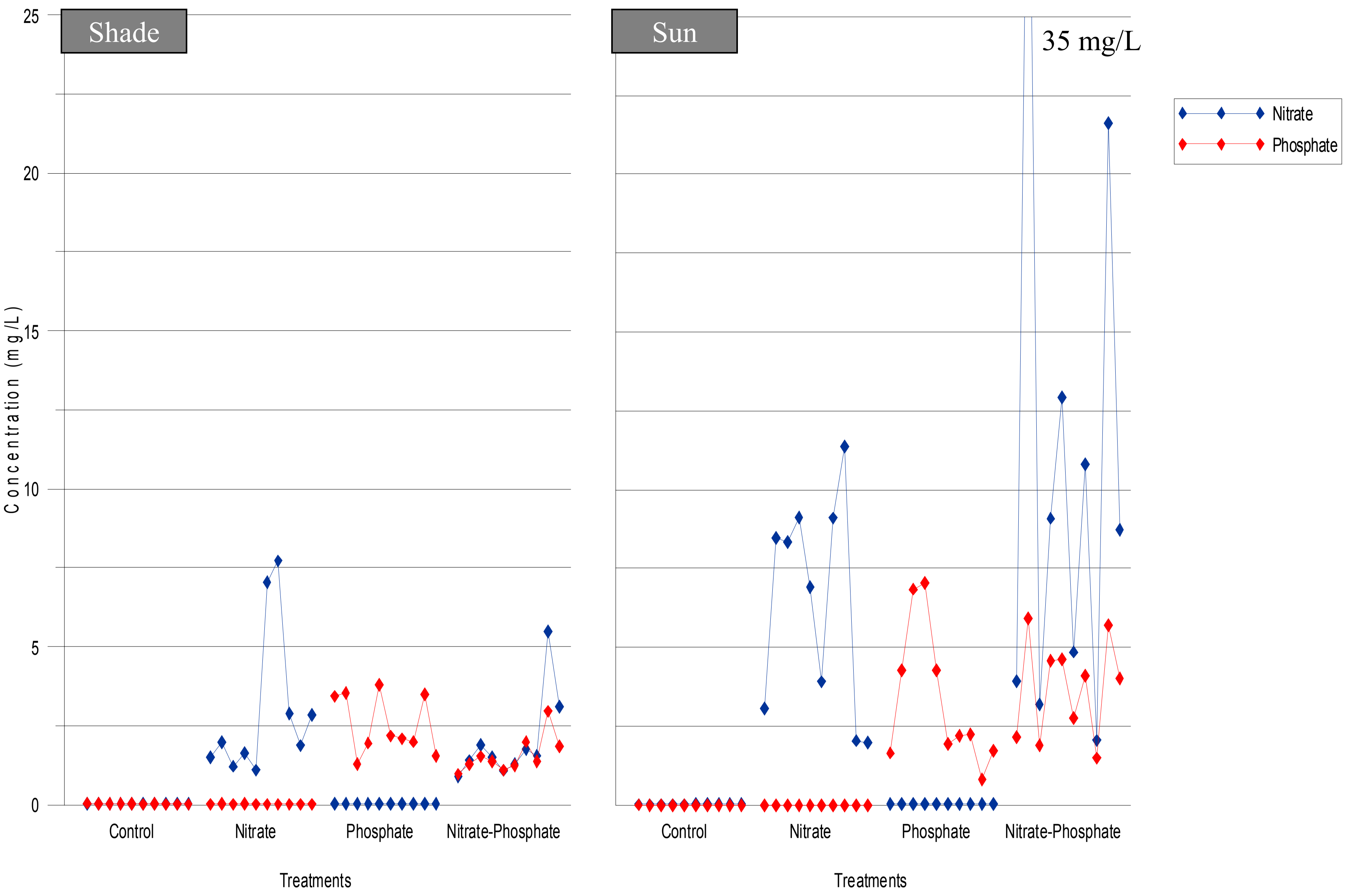


Figure C-4. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (Fruitland, GA). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

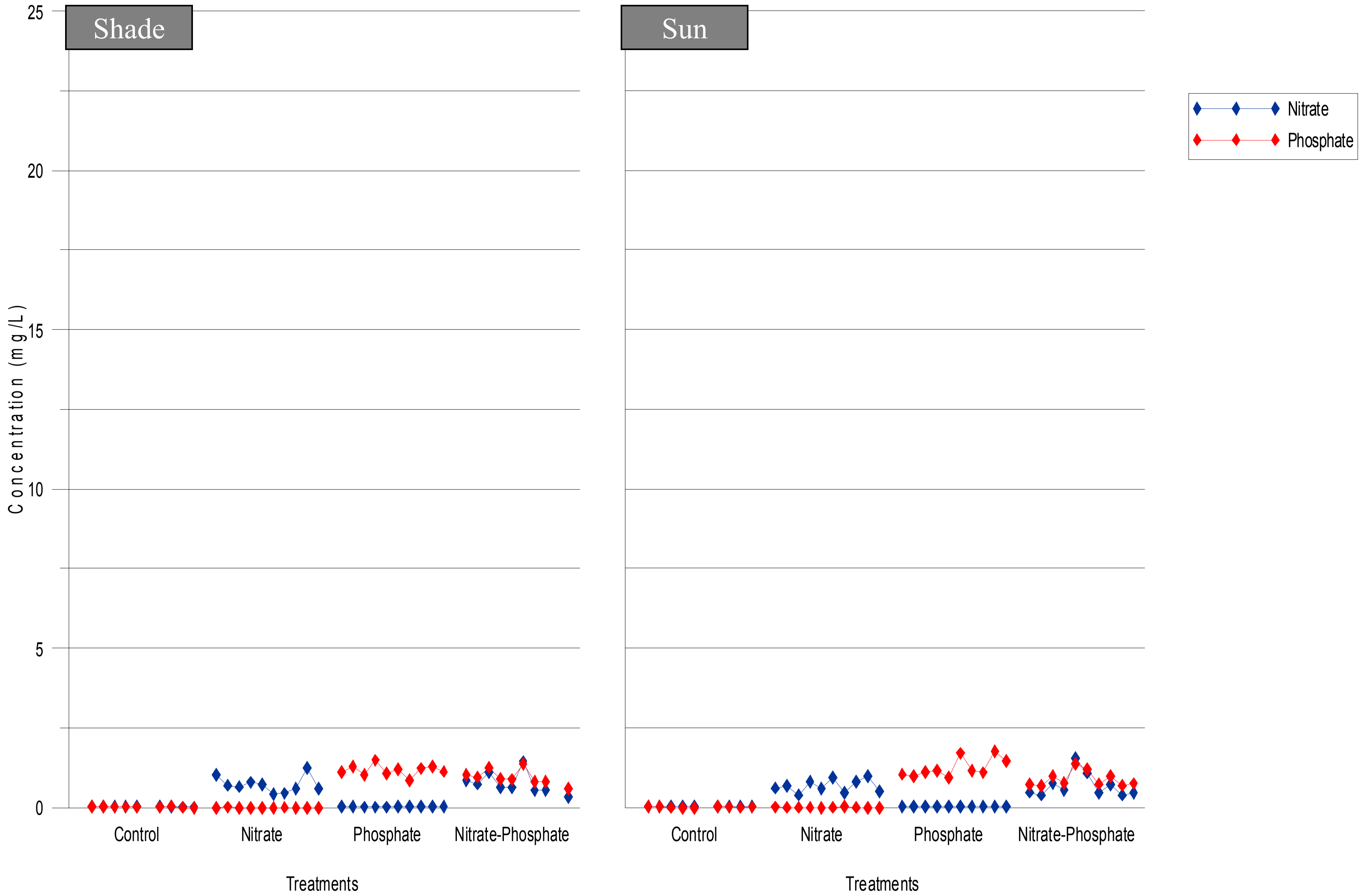


Figure C-5. Residual nutrient concentrations in 20 mL vials at Suwannoochee Creek (Fargo, GA). Periphytometers were deployed on April 15, 2004 and retrieved on April 30, 2004.

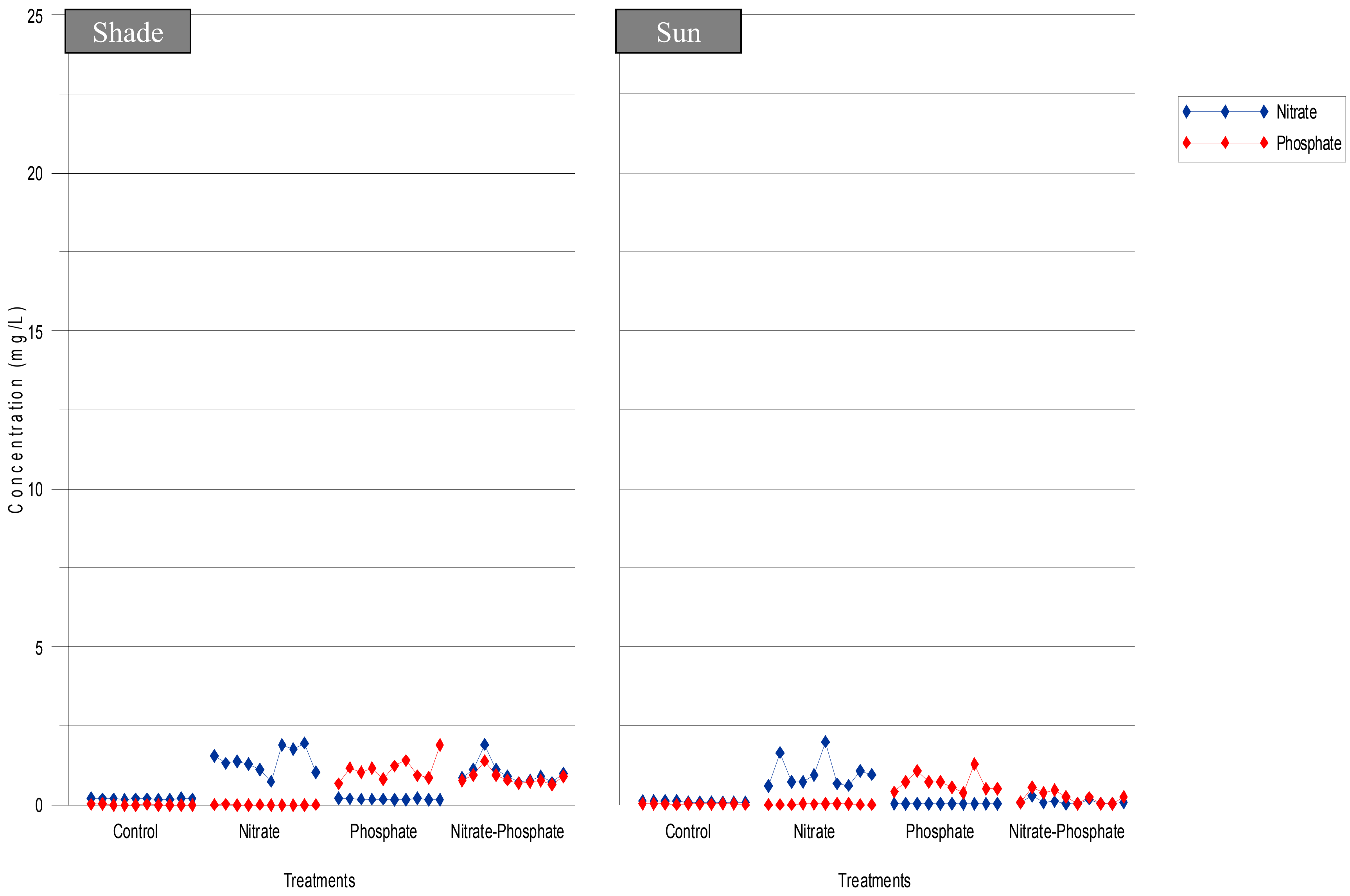


Figure C-6. Residual nutrient concentrations in 20 mL vials at USDA-ARS Station N, Little River (Tifton, GA). Periphytometers were deployed on May 21, 2004 and retrieved on June 5, 2004.

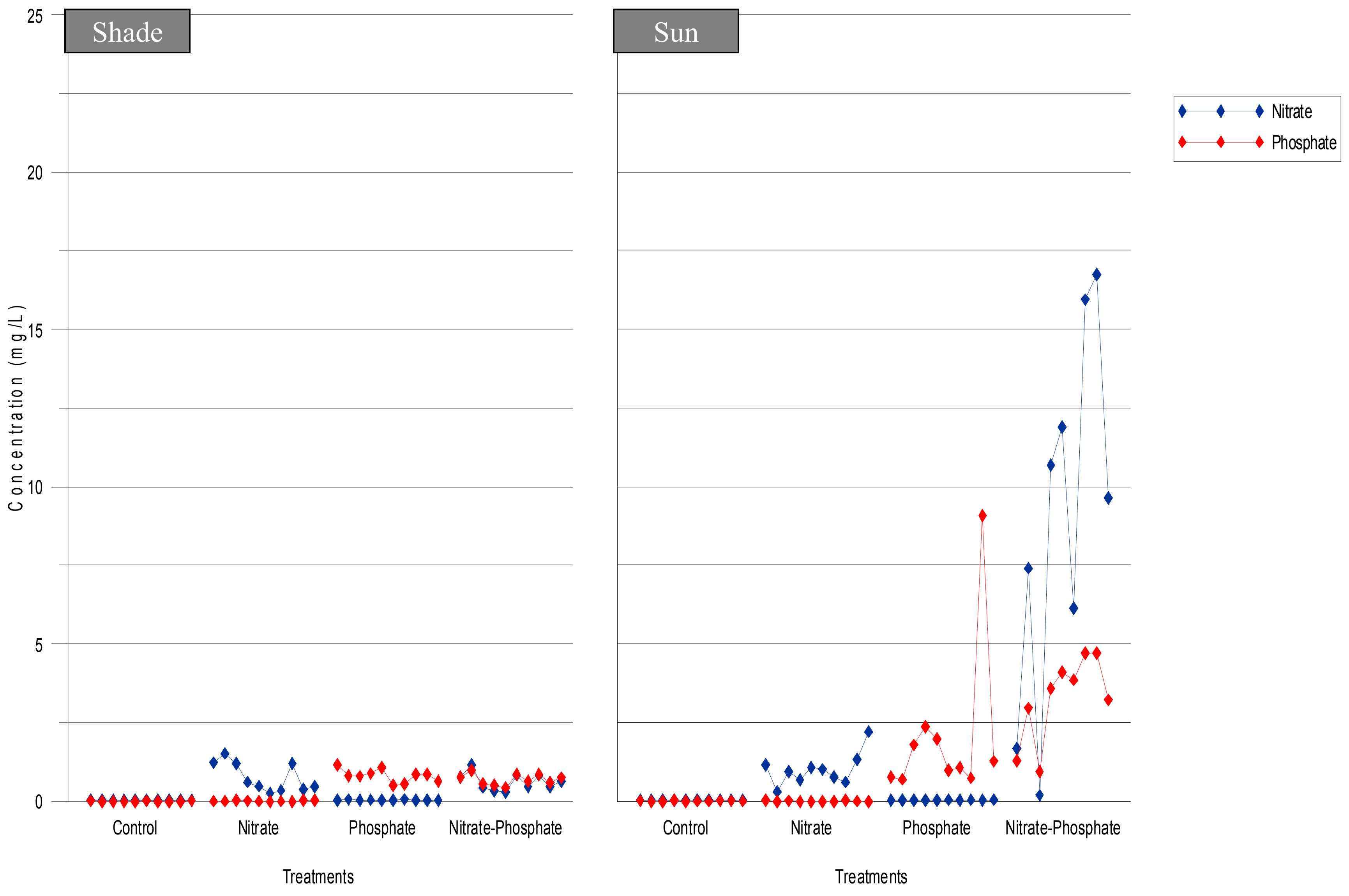


Figure C-7. Residual nutrient concentrations in 20 mL vials at USDA-ARS Station B, Little River (Tifton, GA). Periphytometers were deployed on May 24, 2004 and retrieved on June 8, 2004.

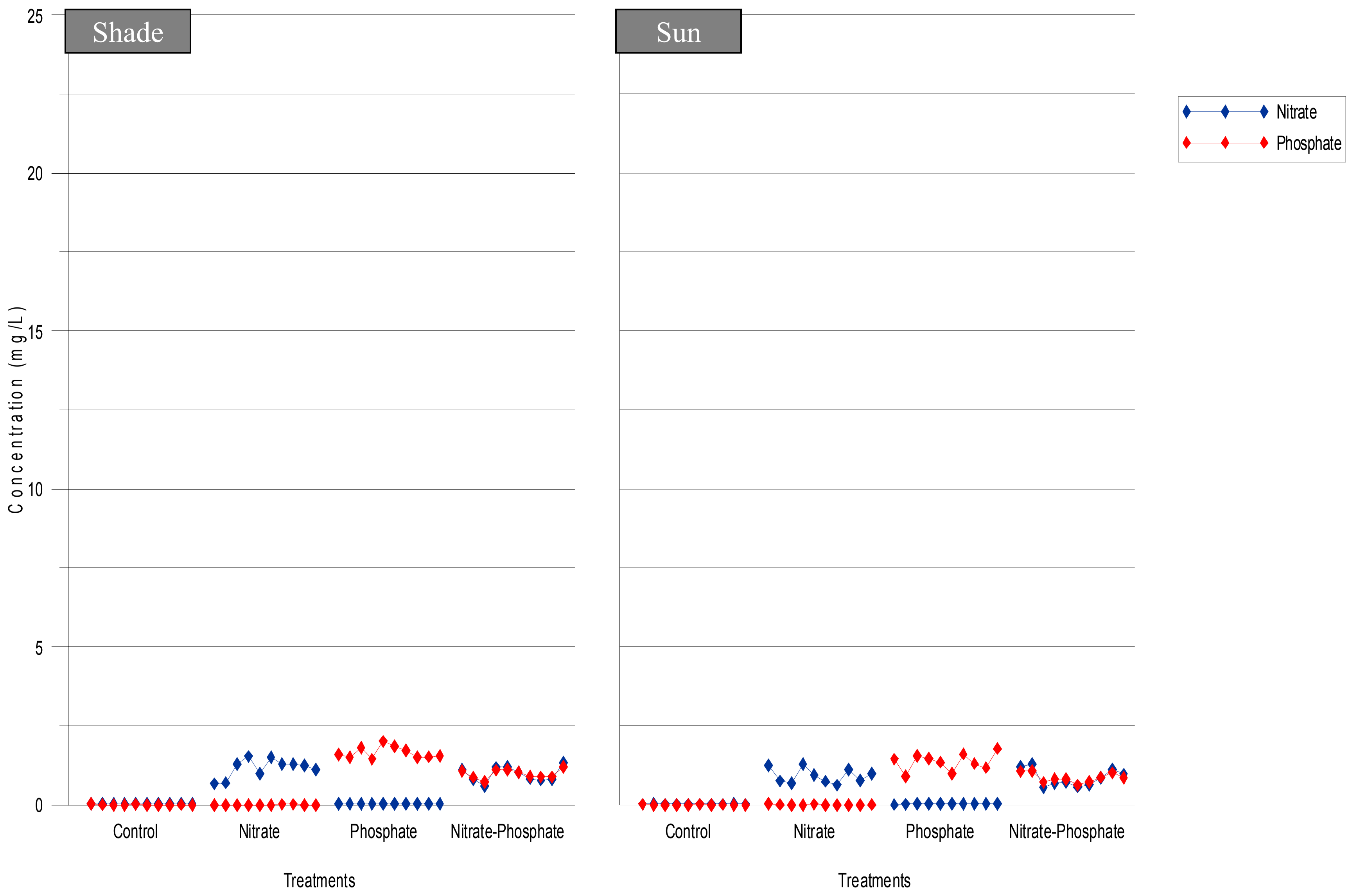


Figure C-8. Residual nutrient concentrations in 20 mL vials at Little Satilla Creek (Screven, GA). Periphytometers were deployed on April 26, 2004 and retrieved on May 11, 2004.

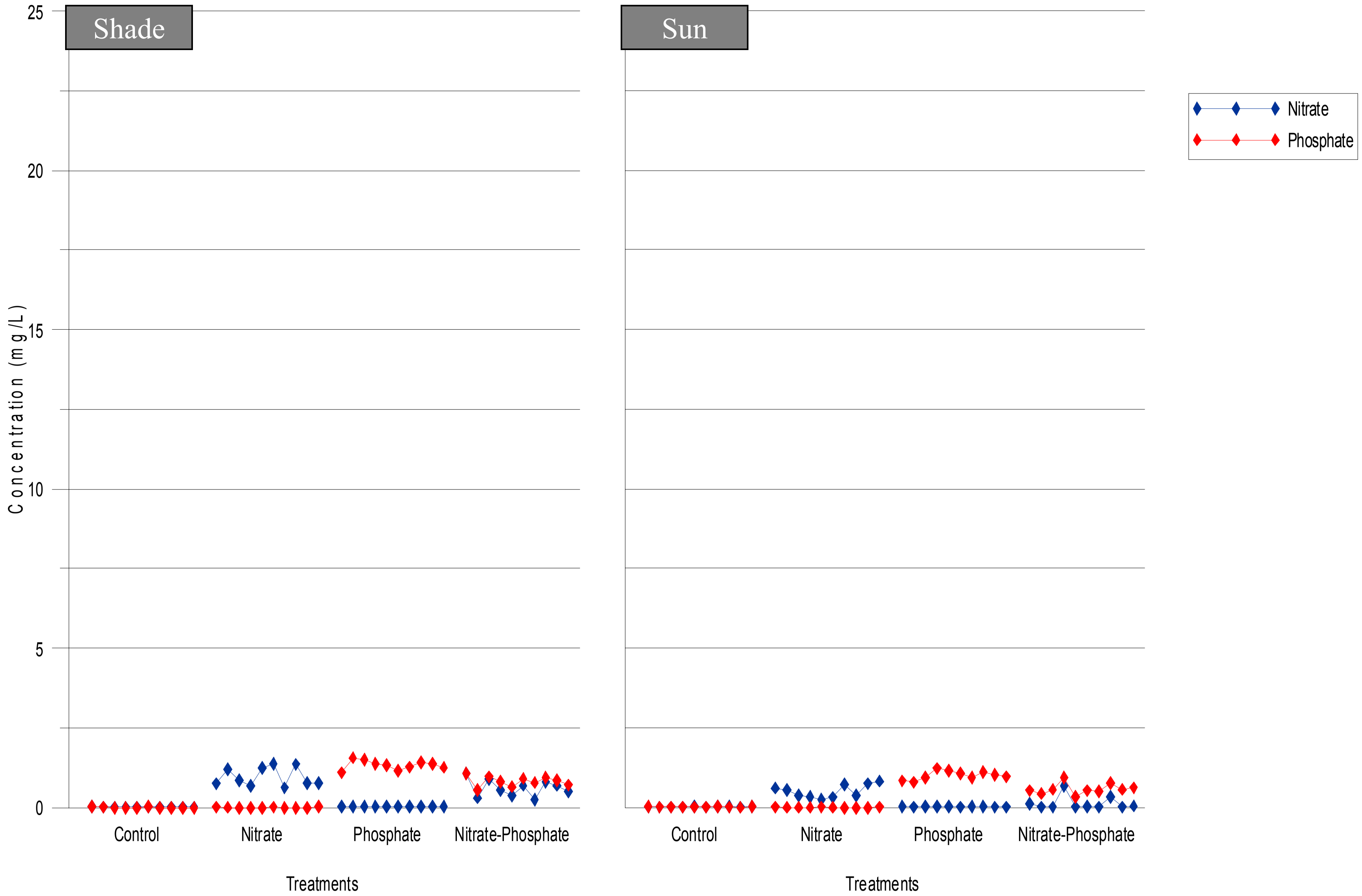


Figure C-9. Residual nutrient concentrations in 20 mL vials at Little Satilla Creek (Odum, GA). Periphytometers were deployed on April 26, 2004 and retrieved on May 11, 2004.

APPENDIX D

CHLOROPHYLL A DATA

Table D-1. Chlorophyll *a* values for periphytometer experiment in the shade at Broxton Rocks (Site 6). The frame was deployed on April 8, 2004 and retrieved on April 23, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S6-408C-1	60.57	0.26683	S6-408N-1	73.97	0.32586
S6-408C-2	40.02	0.17630	S6-408N-2	55.88	0.24617
S6-408C-3	22.36	0.09850	S6-408N-3	37.89	0.16692
S6-408C-4	25.44	0.11207	S6-408N-4	43.65	0.19229
S6-408C-5	34.02	0.14987	S6-408N-5	48.07	0.21176
S6-408C-6	31.74	0.13982	S6-408N-6	37.69	0.16604
S6-408C-7	31.80	0.14009	S6-408N-7	60.65	0.26718
S6-408C-8	26.63	0.11731	S6-408N-8	36.08	0.15894
S6-408C-9	32.49	0.14313	S6-408N-9	41.17	0.18137
S6-408C-10	29.41	0.12956	S6-408N-10	40.41	0.17802
Mean		0.14735			0.20945
Standard Deviation		0.04483			0.05153
Coefficient of Variation		0.30424			0.24602

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S6-408P-1	120.90	0.53260	S6-408NP-1	234.08	1.03119
S6-408P-2	107.30	0.47269	S6-408NP-2	328.64	1.44775
S6-408P-3	114.30	0.50352	S6-408NP-3	218.56	0.96282
S6-408P-4	85.91	0.37846	S6-408NP-4	329.76	1.45269
S6-408P-5	112.20	0.49427	S6-408NP-5	323.20	1.42379
S6-408P-6	106.70	0.47004	S6-408NP-6	348.80	1.53656
S6-408P-7	70.68	0.31137	S6-408NP-7	286.56	1.26238
S6-408P-8	87.08	0.38361	S6-408NP-8	412.16	1.81568
S6-408P-9	98.71	0.43485	S6-408NP-9	342.08	1.50696
S6-408P-10	106.71	0.47009	S6-408NP-10	472.80	2.08282
Mean		0.44515			1.45226
Standard Deviation		0.06458			0.31520
Coefficient of Variation		0.14508			0.21704

*S6-408C = Control filter from April 8, 2004 experiment at Site 6.
S6-408N = Nitrate filter
S6-408P = Phosphate filter
S6-408NP = Nitrate-phosphate filter

Table D-2. Chlorophyll *a* values for periphytometer experiment in the sun at Broxton Rocks (Site 6). The frame was deployed on April 8, 2004 and retrieved on April 23, 2004.

Filter*	Chl a - µg/L	Chl a - µg/cm^2	Filter	Chl a - µg/L	Chl a - µg/cm^2
S6-408C-11	67.67	0.29811	S6-408N-11	53.96	0.23771
S6-408C-12	45.19	0.19907	S6-408N-12	60.20	0.26520
S6-408C-13	36.61	0.16128	S6-408N-13	46.54	0.20502
S6-408C-14	50.52	0.22256	S6-408N-14	50.52	0.22256
S6-408C-15	50.06	0.22053	S6-408N-15	48.97	0.21573
S6-408C-16	50.69	0.22330	S6-408N-16	53.72	0.23665
S6-408C-17	52.63	0.23185	S6-408N-17	38.94	0.17154
S6-408C-18	53.45	0.23546	S6-408N-18	56.31	0.24806
S6-408C-19	46.24	0.20370	S6-408N-19	59.76	0.26326
S6-408C-20	41.51	0.18286	S6-408N-20	56.63	0.24947
Mean		0.21787			0.23152
Standard Deviation		0.03462			0.02726
Coefficient of Variation		0.15889			0.11775

Filter	Chl a - µg/L	Chl a - µg/cm^2	Filter	Chl a - µg/L	Chl a - µg/cm^2
S6-408P-11	183.65	0.80903	S6-408NP-11	454.88	2.00388
S6-408P-12	149.11	0.65687	S6-408NP-12	376.32	1.65780
S6-408P-13	158.20	0.69692	S6-408NP-13	380.80	1.67753
S6-408P-14	156.40	0.68899	S6-408NP-14	414.40	1.82555
S6-408P-15	128.80	0.56740	S6-408NP-15	391.52	1.72476
S6-408P-16	141.74	0.62441	S6-408NP-16	360.16	1.58661
S6-408P-17	148.27	0.65317	S6-408NP-17	405.28	1.78537
S6-408P-18	151.00	0.66520	S6-408NP-18	401.28	1.76775
S6-408P-19	131.20	0.57797	S6-408NP-19	418.40	1.84317
S6-408P-20	120.70	0.53172	S6-408NP-20	351.36	1.54784
Mean		0.64717			1.74203
Standard Deviation		0.07475			0.12717
Coefficient of Variation		0.11550			0.07300

*S6-408C = Control filter from April 8, 2004 experiment at Site 6.
S6-408N = Nitrate filter
S6-408P = Phosphate filter
S6-408NP = Nitrate-phosphate filter

Table D-3. Chlorophyll *a* values for periphytometer experiment in the shade at Five Mile Creek (Site 7). The frame was deployed on April 13, 2004 and retrieved on April 28, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S7-413C-1	70.38	0.31004	S7-413N-1	83.54	0.36802
S7-413C-2	48.85	0.21520	S7-413N-2	74.33	0.32744
S7-413C-3	35.30	0.15551	S7-413N-3	69.86	0.30775
S7-413C-4	50.31	0.22163	S7-413N-4	66.00	0.29075
S7-413C-5	75.37	0.33203	S7-413N-5	94.76	0.41744
S7-413C-6	67.03	0.29529	S7-413N-6	43.45	0.19141
S7-413C-7	96.96	0.42714	S7-413N-7	54.01	0.23793
S7-413C-8	58.02	0.25559	S7-413N-8	71.03	0.31291
S7-413C-9	40.59	0.17881	S7-413N-9	44.61	0.19652
S7-413C-10	66.38	0.29242	S7-413N-10	41.29	0.18189
Mean		0.26837			0.28321
Standard Deviation		0.07631			0.07548
Coefficient of Variation		0.28435			0.26651

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S7-413P-1	53.96	0.23771	S7-413NP-1	83.00	0.36564
S7-413P-2	92.90	0.40925	S7-413NP-2	56.32	0.24811
S7-413P-3	85.97	0.37872	S7-413NP-3	66.89	0.29467
S7-413P-4	70.59	0.31097	S7-413NP-4	99.52	0.43841
S7-413P-5	55.91	0.24630	S7-413NP-5	76.00	0.33480
S7-413P-6	134.80	0.59383	S7-413NP-6	39.17	0.17256
S7-413P-7	59.41	0.26172	S7-413NP-7	68.31	0.30093
S7-413P-8	100.80	0.44405	S7-413NP-8	96.74	0.42617
S7-413P-9	99.03	0.43626	S7-413NP-9	47.99	0.21141
S7-413P-10	53.49	0.23564	S7-413NP-10	53.83	0.23714
Mean		0.35544			0.30298
Standard Deviation		0.11204			0.08442
Coefficient of Variation		0.31522			0.27864

*S7-413C = Control filter from April 13, 2004 experiment at Site 7.
S7-413N = Nitrate filter
S7-413P = Phosphate filter
S7-413NP = Nitrate-phosphate filter

Table D-4. Chlorophyll *a* values for periphytometer experiment in the sun at Five Mile Creek (Site 7). The frame was deployed on April 13, 2004 and retrieved on April 28, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S7-413C-11	483.68	2.13075	S7-413N-11	668.32	2.94414
S7-413C-12	467.04	2.05744	S7-413N-12	506.08	2.22943
S7-413C-13	531.20	2.34009	S7-413N-13	479.04	2.11031
S7-413C-14	358.24	1.57815	S7-413N-14	481.44	2.12088
S7-413C-15	618.56	2.72493	S7-413N-15	351.20	1.54714
S7-413C-16	296.16	1.30467	S7-413N-16	401.44	1.76846
S7-413C-17	397.92	1.75295	S7-413N-17	345.44	1.52176
S7-413C-18	250.56	1.10379	S7-413N-18	350.08	1.54220
S7-413C-19	355.68	1.56687	S7-413N-19	420.96	1.85445
S7-413C-20	437.60	1.92775	S7-413N-20	418.56	1.84388
Mean		1.84874			1.94826
Standard Deviation		0.46382			0.41068
Coefficient of Variation		0.25088			0.21079

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S7-413P-11	663.04	2.92088	S7-413NP-11	976.64	4.30238
S7-413P-12	656.32	2.89128	S7-413NP-12	1095.04	4.82396
S7-413P-13	466.72	2.05604	S7-413NP-13	888.64	3.91471
S7-413P-14	449.76	1.98132	S7-413NP-14	838.24	3.69269
S7-413P-15	480.32	2.11595	S7-413NP-15	879.52	3.87454
S7-413P-16	584.64	2.57551	S7-413NP-16	931.20	4.10220
S7-413P-17	455.36	2.00599	S7-413NP-17	866.56	3.81744
S7-413P-18	479.84	2.11383	S7-413NP-18	912.96	4.02185
S7-413P-19	523.68	2.30696	S7-413NP-19	812.80	3.58062
S7-413P-20	443.84	1.95524	S7-413NP-20	903.84	3.98167
Mean		2.29230			4.01121
Standard Deviation		0.35290			0.33272
Coefficient of Variation		0.15395			0.08295

*S7-413C = Control filter from April 13, 2004 experiment at Site 7.
S7-413N = Nitrate filter
S7-413P = Phosphate filter
S7-413NP = Nitrate-phosphate filter

Table D-5. Chlorophyll *a* values for periphytometer experiment in the shade at DuPont (Site 8). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S8-415C-1	33.98	0.14969	S8-415N-1	38.87	0.17123
S8-415C-2	27.90	0.12291	S8-415N-2	31.56	0.13903
S8-415C-3	27.87	0.12278	S8-415N-3	35.21	0.15511
S8-415C-4	25.32	0.11154	S8-415N-4	50.28	0.22150
S8-415C-5	32.52	0.14326	S8-415N-5	46.61	0.20533
S8-415C-6	42.91	0.18903	S8-415N-6	33.23	0.14639
S8-415C-7	40.15	0.17687	S8-415N-7	31.77	0.13996
S8-415C-8	35.96	0.15841	S8-415N-8	50.45	0.22225
S8-415C-9	40.05	0.17643	S8-415N-9	37.42	0.16485
S8-415C-10	66.32	0.29216	S8-415N-10	64.60	0.28458
Mean		0.16431			0.18502
Standard Deviation		0.04917			0.04491
Coefficient of Variation		0.29925			0.24274

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S8-415P-1	15.65	0.06894	S8-415NP-1	31.75	0.13987
S8-415P-2	19.77	0.12193	S8-415NP-2	28.09	0.12374
S8-415P-3	24.89	0.10965	S8-415NP-3	37.82	0.16661
S8-415P-4	33.24	0.14643	S8-415NP-4	42.83	0.18868
S8-415P-5	38.19	0.16824	S8-415NP-5	32.41	0.14278
S8-415P-6	48.43	0.21335	S8-415NP-6	30.75	0.13546
S8-415P-7	61.03	0.26885	S8-415NP-7	42.99	0.18938
S8-415P-8	31.76	0.13991	S8-415NP-8	44.56	0.19630
S8-415P-9	139.90	0.61630	S8-415NP-9	35.80	0.15771
S8-415P-10	68.97	0.30383	S8-415NP-10	57.09	0.25150
Mean		0.21574			0.16920
Standard Deviation		0.15015			0.03633
Coefficient of Variation		0.69597			0.21469

*S8-415C = Control filter from April 15, 2004 experiment at Site 8.
S8-415N = Nitrate filter
S8-415P = Phosphate filter
S8-415NP = Nitrate-phosphate filter

Table D-6. Chlorophyll *a* values for periphytometer experiment in the sun at DuPont (Site 8). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S8-415C-11	740.80	3.26344	S8-415N-11	731.84	3.22396
S8-415C-12	805.92	3.55031	S8-415N-12	1019.84	4.49269
S8-415C-13	788.48	3.47348	S8-415N-13	910.24	4.00987
S8-415C-14	721.76	3.17956	S8-415N-14	834.88	3.67789
S8-415C-15	962.08	4.23824	S8-415N-15	863.68	3.80476
S8-415C-16	820.00	3.61233	S8-415N-16	793.76	3.49674
S8-415C-17	933.60	4.11278	S8-415N-17	812.80	3.58062
S8-415C-18	794.40	3.49956	S8-415N-18	837.44	3.68916
S8-415C-19	715.52	3.15207	S8-415N-19	760.00	3.34802
S8-415C-20	749.28	3.30079	S8-415N-20	708.32	3.12035
Mean		3.53826			3.64441
Standard Deviation		0.35229			0.38041
Coefficient of Variation		0.09957			0.10438

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S8-415P-11	817.12	3.59965	S8-415NP-11	850.40	3.74626
S8-415P-12	670.24	2.95260	S8-415NP-12	865.76	3.81392
S8-415P-13	783.04	3.44952	S8-415NP-13	792.48	3.49110
S8-415P-14	767.84	3.38256	S8-415NP-14	886.08	3.90344
S8-415P-15	892.64	3.93233	S8-415NP-15	965.92	4.25515
S8-415P-16	900.64	3.96758	S8-415NP-16	829.60	3.65463
S8-415P-17	803.04	3.53762	S8-415NP-17	815.36	3.59189
S8-415P-18	787.84	3.47066	S8-415NP-18	870.88	3.83648
S8-415P-19	760.00	3.34802	S8-415NP-19	796.00	3.50661
S8-415P-20	590.08	2.59947	S8-415NP-20	549.76	2.42185
Mean		3.42400			3.62213
Standard Deviation		0.38859			0.45290
Coefficient of Variation		0.11349			0.12504

*S8-415C = Control filter from April 15, 2004 experiment at Site 8.
S8-415N = Nitrate filter
S8-415P = Phosphate filter
S8-415NP = Nitrate-phosphate filter

Table D-7. Chlorophyll *a* values for periphytometer experiment in the shade at Fruitland (Site 9). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm²**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm²**
S9-415C-1	37.87	0.16683	S9-415N-1	40.40	0.17797
S9-415C-2	21.27	0.09370	S9-415N-2	27.96	0.12317
S9-415C-3	53.04	0.23366	S9-415N-3	83.61	0.36833
S9-415C-4	60.97	0.26859	S9-415N-4	60.12	0.26485
S9-415C-5	52.39	0.23079	S9-415N-5	59.87	0.26374
S9-415C-6	71.03	0.31291	S9-415N-6	113.90	0.50176
S9-415C-7	56.44	0.24863	S9-415N-7	82.00	0.36123
S9-415C-8	44.30	0.19515	S9-415N-8	70.57	0.31088
S9-415C-9	46.19	0.20348	S9-415N-9	69.93	0.30806
S9-415C-10	61.42	0.27057	S9-415N-10	60.32	0.26573
Mean		0.22243			0.29457
Standard Deviation		0.05855			0.09945
Coefficient of Variation		0.26324			0.33760

Filter	**Chl a - µg/L**	**Chl a - µg/cm²**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm²**
S9-415P-1	26.46	0.11656	S9-415NP-1	30.04	0.13233
S9-415P-2	29.74	0.13101	S9-415NP-2	66.34	0.29225
S9-415P-3	37.74	0.16626	S9-415NP-3	96.95	0.42709
S9-415P-4	73.41	0.32339	S9-415NP-4	81.50	0.35903
S9-415P-5	68.32	0.30097	S9-415NP-5	74.35	0.32753
S9-415P-6	68.55	0.30198	S9-415NP-6	85.68	0.37744
S9-415P-7	52.20	0.22996	S9-415NP-7	89.51	0.39432
S9-415P-8	68.87	0.30339	S9-415NP-8	72.48	0.31930
S9-415P-9	66.84	0.29445	S9-415NP-9	61.52	0.27101
S9-415P-10	59.65	0.26278	S9-415NP-10	58.36	0.25709
Mean		0.24307			0.31574
Standard Deviation		0.07387			0.08002
Coefficient of Variation		0.30392			0.25345

*S9-415C = Control filter from April 15, 2004 experiment at Site 9.
S9-415N = Nitrate filter
S9-415P = Phosphate filter
S9-415NP = Nitrate-phosphate filter

Table D-8. Chlorophyll *a* values for periphytometer experiment in the sun at Fruitland (Site 9). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S9-415C-11			S9-415N-11	544.96	2.40070
S9-415C-12	518.56	2.28441	S9-415N-12	503.84	2.21956
S9-415C-13	447.20	1.97004	S9-415N-13	545.44	2.40282
S9-415C-14	309.92	1.36529	S9-415N-14	552.16	2.43242
S9-415C-15	448.32	1.97498	S9-415N-15	331.52	1.46044
S9-415C-16	480.96	2.11877	S9-415N-16	505.92	2.22872
S9-415C-17	399.04	1.75789	S9-415N-17	474.56	2.09057
S9-415C-18	483.84	2.13145	S9-415N-18	511.68	2.25410
S9-415C-19	299.84	1.32088	S9-415N-19	485.76	2.13991
S9-415C-20	429.76	1.89322	S9-415N-20	560.32	2.46837
Mean		1.86855			2.20976
Standard Deviation		0.31488			0.27806
Coefficient of Variation		0.16852			0.12583

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S9-415P-11	550.24	2.42396	S9-415NP-11	569.44	2.50855
S9-415P-12	533.28	2.34925	S9-415NP-12	611.68	2.69463
S9-415P-13	545.12	2.40141	S9-415NP-13	442.72	1.95031
S9-415P-14	610.56	2.68969	S9-415NP-14	491.84	2.16670
S9-415P-15	599.52	2.64106	S9-415NP-15	551.04	2.42749
S9-415P-16	484.32	2.13357	S9-415NP-16	549.44	2.42044
S9-415P-17	420.64	1.85304	S9-415NP-17	523.20	2.30485
S9-415P-18	507.36	2.23507	S9-415NP-18	468.96	2.06590
S9-415P-19	500.48	2.20476	S9-415NP-19	604.00	2.66079
S9-415P-20	507.68	2.23648	S9-415NP-20	552.64	2.43454
Mean		2.31683			2.36342
Standard Deviation		0.23200			0.23085
Coefficient of Variation		0.10014			0.09768

*S9-415C = Control filter from April 15, 2004 experiment at Site 9.
S9-415N = Nitrate filter
S9-415P = Phosphate filter
S9-415NP = Nitrate-phosphate filter

Table D-9. Chlorophyll *a* values for periphytometer experiment in the shade at Fargo (Site 10). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S10-415C-1	43.85	0.19317	S10-415N-1	13.26	0.05841
S10-415C-2	81.11	0.35731	S10-415N-2	13.01	0.05731
S10-415C-3	56.09	0.24709	S10-415N-3	39.20	0.17269
S10-415C-4	53.43	0.23537	S10-415N-4	58.12	0.25604
S10-415C-5	35.37	0.15581	S10-415N-5	19.57	0.08621
S10-415C-6	73.52	0.32388	S10-415N-6	24.88	0.10960
S10-415C-7	85.64	0.37727	S10-415N-7	69.57	0.30648
S10-415C-8	186.08	0.81974	S10-415N-8	87.99	0.38762
S10-415C-9	64.52	0.28423	S10-415N-9	57.84	0.25480
S10-415C-10	66.27	0.29194	S10-415N-10	72.63	0.31996
Mean		0.32858			0.20091
Standard Deviation		0.17643			0.11373
Coefficient of Variation		0.53694			0.56605

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S10-415P-1	22.00	0.09692	S10-415NP-1	20.59	0.09070
S10-415P-2	18.18	0.08009	S10-415NP-2	13.90	0.06123
S10-415P-3	91.80	0.40441	S10-415NP-3	19.50	0.08590
S10-415P-4	117.40	0.51718	S10-415NP-4	99.01	0.43617
S10-415P-5	58.19	0.25634	S10-415NP-5	30.38	0.13383
S10-415P-6	71.03	0.31291	S10-415NP-6	92.70	0.40837
S10-415P-7	29.18	0.12855	S10-415NP-7	79.10	0.34846
S10-415P-8	78.09	0.34401	S10-415NP-8	39.22	0.17278
S10-415P-9	51.57	0.22718	S10-415NP-9	40.69	0.17925
S10-415P-10	109.00	0.48018	S10-415NP-10	51.81	0.22824
Mean		0.28478			0.21449
Standard Deviation		0.14715			0.13027
Coefficient of Variation		0.51672			0.60733

*S10-415C = Control filter from April 15, 2004 experiment at Site 10.
S10-415N = Nitrate filter
S10-415P = Phosphate filter
S10-415NP = Nitrate-phosphate filter

Table D-10. Chlorophyll *a* values for periphytometer experiment in the sun at Fargo (Site 10). The frame was deployed on April 15, 2004 and retrieved on April 30, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S10-415C-11	101.20	0.44581	S10-415N-11	223.00	0.98238
S10-415C-12	216.16	0.95225	S10-415N-12	214.00	0.94273
S10-415C-13	57.46	0.25311	S10-415N-13	98.24	0.43278
S10-415C-14	105.09	0.46294	S10-415N-14	84.53	0.37238
S10-415C-15	236.96	1.04388	S10-415N-15	197.60	0.87048
S10-415C-16	151.50	0.66740	S10-415N-16	116.80	0.51454
S10-415C-17	271.04	1.19401	S10-415N-17	79.08	0.34837
S10-415C-18	214.72	0.94590	S10-415N-18	86.03	0.37899
S10-415C-19	147.98	0.65191	S10-415N-19	418.08	1.84176
S10-415C-20	126.30	0.55639	S10-415N-20	122.70	0.54053
Mean		0.71736			0.72249
Standard Deviation		0.28773			0.43949
Coefficient of Variation		0.40110			0.60830

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S10-415P-11	194.90	0.85859	S10-415NP-11	96.70	0.42599
S10-415P-12	149.30	0.65771	S10-415NP-12	108.94	0.47991
S10-415P-13	336.64	1.48300	S10-415NP-13	49.33	0.21731
S10-415P-14	207.53	0.91423	S10-415NP-14	93.04	0.40987
S10-415P-15	390.56	1.72053	S10-415NP-15	97.31	0.42868
S10-415P-16	177.30	0.78106	S10-415NP-16	167.40	0.73744
S10-415P-17	137.76	0.60687	S10-415NP-17	142.70	0.62863
S10-415P-18	179.90	0.79251	S10-415NP-18	145.70	0.64185
S10-415P-19	186.50	0.82159	S10-415NP-19	65.75	0.28965
S10-415P-20	478.72	2.10890	S10-415NP-20	218.40	0.96211
Mean		1.07450			0.52215
Standard Deviation		0.48461			0.21094
Coefficient of Variation		0.45101			0.40398

*S10-415C = Control filter from April 15, 2004 experiment at Site 10.
S10-415N = Nitrate filter
S10-415P = Phosphate filter
S10-415NP = Nitrate-phosphate filter

Table D-11. Chlorophyll *a* values for periphytometer experiment in the shade at USDA-ARS Station N (Site 13). The frame was deployed on May 21, 2004 and retrieved on June 5, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S13-521C-1	6.69	0.02947	S13-521N-1	6.72	0.02960
S13-521C-2	5.65	0.02488	S13-521N-2	11.01	0.04850
S13-521C-3	8.71	0.03837	S13-521N-3	7.30	0.03216
S13-521C-4	7.57	0.03335	S13-521N-4	4.57	0.02013
S13-521C-5	11.55	0.05088	S13-521N-5	8.67	0.03819
S13-521C-6	11.15	0.04912	S13-521N-6	14.92	0.06573
S13-521C-7	9.82	0.04326	S13-521N-7	6.03	0.02656
S13-521C-8	14.22	0.06264	S13-521N-8	13.08	0.05762
S13-521C-9	19.10	0.08414	S13-521N-9	11.36	0.05004
S13-521C-10	15.58	0.06863	S13-521N-10	11.16	0.04916
Mean		0.04847			0.04177
Standard Deviation		0.01778			0.01395
Coefficient of Variation		0.36679			0.33398

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S13-521P-1	6.98	0.03075	S13-521NP-1	6.53	0.02877
S13-521P-2	6.17	0.02718	S13-521NP-2	6.43	0.02833
S13-521P-3	10.68	0.04705	S13-521NP-3	8.90	0.03921
S13-521P-4	7.74	0.03410	S13-521NP-4	9.21	0.04057
S13-521P-5	12.13	0.05344	S13-521NP-5	7.13	0.03141
S13-521P-6	16.77	0.07388	S13-521NP-6	8.16	0.03595
S13-521P-7	13.42	0.05912	S13-521NP-7	10.77	0.04744
S13-521P-8	10.28	0.04529	S13-521NP-8	13.78	0.06070
S13-521P-9	13.42	0.05912	S13-521NP-9	9.43	0.04152
S13-521P-10	21.75	0.09581	S13-521NP-10	9.71	0.04278
Mean		0.05257			0.03967
Standard Deviation		0.01989			0.00920
Coefficient of Variation		0.37834			0.23197

*S13-521C = Control filter from May 21, 2004 experiment at Site 13.
S13-521N = Nitrate filter
S13-521P = Phosphate filter
S13-521NP = Nitrate-phosphate filter

Table D-12. Chlorophyll *a* values for periphytometer experiment in the sun at USDA-ARS Station N (Site 13). The frame was deployed on May 21, 2004 and retrieved on June 5, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S13-521C-11	147.70	0.65066	S13-521N-11	130.30	0.57401
S13-521C-12	136.10	0.59956	S13-521N-12	108.30	0.47709
S13-521C-13	82.90	0.36520	S13-521N-13	409.76	1.80511
S13-521C-14	57.59	0.25370	S13-521N-14	122.40	0.53921
S13-521C-15	142.70	0.62863	S13-521N-15	123.90	0.54581
S13-521C-16	95.00	0.41850	S13-521N-16	129.60	0.57093
S13-521C-17	129.60	0.57093	S13-521N-17	105.30	0.46388
S13-521C-18	141.00	0.62115	S13-521N-18	116.00	0.51101
S13-521C-19	130.80	0.57621	S13-521N-19	105.20	0.46344
S13-521C-20	192.40	0.84758	S13-521N-20	162.10	0.71410
Mean		0.55321			0.66646
Standard Deviation		0.15895			0.38594
Coefficient of Variation		0.28732			0.57909

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S13-521P-11	1139.20	5.01850	S13-521NP-11	684.32	3.01463
S13-521P-12	1035.20	4.56035	S13-521NP-12	1479.20	6.51630
S13-521P-13	1180.16	5.19894	S13-521NP-13	1234.24	5.43718
S13-521P-14	1398.40	6.16035	S13-521NP-14	1636.80	7.21057
S13-521P-15	1544.64	6.80458	S13-521NP-15	1673.60	7.37269
S13-521P-16	1033.28	4.55189	S13-521NP-16	2398.40	10.56564
S13-521P-17	1414.24	6.23013	S13-521NP-17	1843.20	8.11982
S13-521P-18	1343.20	5.91718	S13-521NP-18	1310.08	5.77128
S13-521P-19	1020.16	4.49410	S13-521NP-19	1483.84	6.53674
S13-521P-20	1462.40	6.44229	S13-521NP-20	1982.40	8.73304
Mean		5.53783			6.92779
Standard Deviation		0.82673			1.93355
Coefficient of Variation		0.14929			0.27910

*S13-521C = Control filter from May 21, 2004 experiment at Site 13.
S13-521N = Nitrate filter
S13-521P = Phosphate filter
S13-521NP = Nitrate-phosphate filter

Table D-13. Chlorophyll *a* values for periphytometer experiment in the shade at USDA-ARS Station B (Site 3). The frame was deployed on May 24, 2004 and retrieved on June 8, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-524C-1	5.81	0.02561	S3-524N-1	5.01	0.02205
S3-524C-2	6.53	0.02877	S3-524N-2	5.41	0.02384
S3-524C-3	4.79	0.02108	S3-524N-3	9.48	0.04174
S3-524C-4	5.63	0.02480	S3-524N-4	6.48	0.02855
S3-524C-5	10.79	0.04753	S3-524N-5	8.78	0.03868
S3-524C-6	9.53	0.04198	S3-524N-6	6.57	0.02893
S3-524C-7	7.43	0.03273	S3-524N-7	8.20	0.03612
S3-524C-8	10.36	0.04564	S3-524N-8	7.25	0.03195
S3-524C-9	8.06	0.03551	S3-524N-9	8.76	0.03857
S3-524C-10	8.70	0.03831	S3-524N-10	6.76	0.02978
Mean		0.03420			0.03202
Standard Deviation		0.00868			0.00626
Coefficient of Variation		0.25385			0.19539

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-524P-1	6.21	0.02734	S3-524NP-1	5.36	0.02361
S3-524P-2	8.27	0.03643	S3-524NP-2	7.28	0.03207
S3-524P-3	8.11	0.03573	S3-524NP-3	6.48	0.02854
S3-524P-4	12.19	0.05370	S3-524NP-4	8.15	0.03590
S3-524P-5	9.37	0.04127	S3-524NP-5	9.13	0.04020
S3-524P-6	12.73	0.05608	S3-524NP-6	10.68	0.04705
S3-524P-7	9.60	0.04229	S3-524NP-7	8.92	0.03930
S3-524P-8	11.98	0.05278	S3-524NP-8	8.38	0.03692
S3-524P-9	9.99	0.04400	S3-524NP-9	8.70	0.03830
S3-524P-10	12.13	0.05344	S3-524NP-10	9.36	0.04122
Mean		0.04431			0.03631
Standard Deviation		0.00905			0.00638
Coefficient of Variation		0.20422			0.17582

*S3-524C = Control filter from May 24, 2004 experiment at Site 3.
S3-524N = Nitrate filter
S3-524P = Phosphate filter
S3-524NP = Nitrate-phosphate filter

Table D-14. Chlorophyll *a* values for periphytometer experiment in the sun at USDA-ARS Station B (Site 3). The frame was deployed on May 24, 2004 and retrieved on June 8, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-524C-11	356.48	1.57040	S3-524N-11	280.96	1.23771
S3-524C-12	319.20	1.40617	S3-524N-12	467.68	2.06026
S3-524C-13	93.62	0.41242	S3-524N-13	259.52	1.14326
S3-524C-14	311.52	1.37233	S3-524N-14	394.72	1.73885
S3-524C-15	108.10	0.47621	S3-524N-15	150.80	0.66432
S3-524C-16	272.96	1.20247	S3-524N-16	625.60	2.75595
S3-524C-17	141.50	0.62335	S3-524N-17	161.80	0.71278
S3-524C-18	142.00	0.62555	S3-524N-18	478.88	2.10960
S3-524C-19	424.48	1.86996	S3-524N-19	278.72	1.22784
S3-524C-20	350.56	1.54432	S3-524N-20	252.96	1.11436
Mean		1.11032			1.47649
Standard Deviation		0.50030			0.63650
Coefficient of Variation		0.45060			0.43109

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S3-524P-11	242.40	1.06784	S3-524NP-11	1124.96	4.95577
S3-524P-12	283.68	1.24969	S3-524NP-12	972.00	4.28194
S3-524P-13	446.24	1.96581	S3-524NP-13	1365.12	6.01374
S3-524P-14	157.00	0.69163	S3-524NP-14	1672.00	7.36564
S3-524P-15	355.84	1.56758	S3-524NP-15	1279.52	5.63665
S3-524P-16	510.08	2.24705	S3-524NP-16	882.56	3.88793
S3-524P-17	564.48	2.48670	S3-524NP-17	967.36	4.26150
S3-524P-18	443.04	1.95172	S3-524NP-18	1339.68	5.90167
S3-524P-19	340.16	1.49850	S3-524NP-19	759.52	3.34590
S3-524P-20	237.44	1.04599	S3-524NP-20	991.52	4.36793
Mean		1.57725			5.00187
Standard Deviation		0.54832			1.15228
Coefficient of Variation		0.34764			0.23037

*S3-524C = Control filter from May 24, 2004 experiment at Site 3.
S3-524N = Nitrate filter
S3-524P = Phosphate filter
S3-524NP = Nitrate-phosphate filter

Table D-15. Chlorophyll *a* values for periphytometer experiment in the shade at Screven (Site 11). The frame was deployed on April 26, 2004 and retrieved on May 11, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S11-426C-1	32.10	0.14141	S11-426N-1	35.00	0.15419
S11-426C-2	97.83	0.43097	S11-426N-2	24.25	0.10683
S11-426C-3	143.80	0.63348	S11-426N-3	31.36	0.13815
S11-426C-4	109.70	0.48326	S11-426N-4	133.60	0.58855
S11-426C-5	106.50	0.46916	S11-426N-5	110.50	0.48678
S11-426C-6	116.70	0.51410	S11-426N-6	112.00	0.49339
S11-426C-7	74.29	0.32727	S11-426N-7	118.90	0.52379
S11-426C-8	117.50	0.51762	S11-426N-8	148.40	0.65374
S11-426C-9	125.30	0.55198	S11-426N-9	87.95	0.38744
S11-426C-10	153.80	0.67753	S11-426N-10	79.27	0.34921
Mean		0.47468			0.38821
Standard Deviation		0.14510			0.18649
Coefficient of Variation		0.30569			0.48040

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S11-426P-1	45.32	0.19965	S11-426NP-1	68.24	0.30062
S11-426P-2	42.36	0.18661	S11-426NP-2	86.60	0.38150
S11-426P-3	52.01	0.22912	S11-426NP-3	72.22	0.31815
S11-426P-4	100.50	0.44273	S11-426NP-4	91.51	0.40313
S11-426P-5	134.80	0.59383	S11-426NP-5	107.90	0.47533
S11-426P-6	133.50	0.58811	S11-426NP-6	86.15	0.37952
S11-426P-7	102.60	0.45198	S11-426NP-7	93.08	0.41004
S11-426P-8	108.40	0.47753	S11-426NP-8	89.16	0.39278
S11-426P-9	164.30	0.72379	S11-426NP-9	73.11	0.32207
S11-426P-10	153.10	0.67445	S11-426NP-10	110.82	0.48819
Mean		0.45678			0.38713
Standard Deviation		0.18609			0.05947
Coefficient of Variation		0.40739			0.15363

*S11-426C = Control filter from April 26, 2004 experiment at Site 11.
S11-426N = Nitrate filter
S11-426P = Phosphate filter
S11-426NP = Nitrate-phosphate filter

Table D-16. Chlorophyll *a* values for periphytometer experiment in the sun at Screven (Site 11). The frame was deployed on April 26, 2004 and retrieved on May 11, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S11-426C-11	676.80	2.98150	S11-426N-11	246.72	1.08687
S11-426C-12	307.84	1.35612	S11-426N-12	387.68	1.70784
S11-426C-13	513.12	2.26044	S11-426N-13	299.68	1.32018
S11-426C-14	344.48	1.51753	S11-426N-14	324.48	1.42943
S11-426C-15	378.24	1.66626	S11-426N-15	363.84	1.60282
S11-426C-16	286.08	1.26026	S11-426N-16	342.56	1.50907
S11-426C-17	450.08	1.98273	S11-426N-17	310.72	1.36881
S11-426C-18	393.28	1.73251	S11-426N-18	314.56	1.38573
S11-426C-19	566.88	2.49727	S11-426N-19	306.56	1.35048
S11-426C-20	358.40	1.57885	S11-426N-20	296.48	1.30608
Mean		1.88335			1.40673
Standard Deviation		0.51938			0.16281
Coefficient of Variation		0.27577			0.11574

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S11-426P-11	441.92	1.94678	S11-426NP-11	465.92	2.05251
S11-426P-12	486.88	2.14485	S11-426NP-12	459.68	2.02502
S11-426P-13	508.64	2.24070	S11-426NP-13	383.04	1.68740
S11-426P-14	470.72	2.07366	S11-426NP-14	396.96	1.74872
S11-426P-15	404.16	1.78044	S11-426NP-15	333.60	1.46960
S11-426P-16	410.40	1.80793	S11-426NP-16	278.56	1.22714
S11-426P-17	489.76	2.15753	S11-426NP-17	424.96	1.87207
S11-426P-18	429.44	1.89181	S11-426NP-18	494.88	2.18009
S11-426P-19	524.32	2.30978	S11-426NP-19	599.20	2.63965
S11-426P-20	394.08	1.73604	S11-426NP-20	497.44	2.19137
Mean		2.00895			1.90936
Standard Deviation		0.19330			0.38148
Coefficient of Variation		0.09622			0.19980

*S11-426C = Control filter from April 26, 2004 experiment at Site 11.
S11-426N = Nitrate filter
S11-426P = Phosphate filter
S11-426NP = Nitrate-phosphate filter

Table D-17. Chlorophyll *a* values for periphytometer experiment in the shade at Odum (Site 12). The frame was deployed on April 26, 2004 and retrieved on May 11, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S12-426C-1	25.82	0.11374	S12-426N-1	40.81	0.17978
S12-426C-2	32.98	0.14529	S12-426N-2	44.52	0.19612
S12-426C-3	28.41	0.12515	S12-426N-3	26.26	0.11568
S12-426C-4	27.80	0.12247	S12-426N-4	62.33	0.27458
S12-426C-5	26.92	0.11859	S12-426N-5	53.02	0.23357
S12-426C-6	20.45	0.09009	S12-426N-6	46.01	0.20269
S12-426C-7	30.62	0.13489	S12-426N-7	47.19	0.20789
S12-426C-8	36.63	0.16137	S12-426N-8	53.89	0.23740
S12-426C-9	46.23	0.20366	S12-426N-9	33.37	0.14700
S12-426C-10	37.46	0.16502	S12-426N-10	58.08	0.25586
Mean		0.13803			0.20506
Standard Deviation		0.03052			0.04622
Coefficient of Variation		0.22114			0.22540

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S12-426P-1	30.27	0.13335	S12-426NP-1	15.94	0.07022
S12-426P-2	37.04	0.16317	S12-426NP-2	133.00	0.58590
S12-426P-3	44.93	0.19793	S12-426NP-3	57.16	0.25181
S12-426P-4	34.84	0.15348	S12-426NP-4	160.00	0.70485
S12-426P-5	37.12	0.16352	S12-426NP-5	72.64	0.32000
S12-426P-6	25.76	0.11348	S12-426NP-6	98.75	0.43502
S12-426P-7	52.50	0.23128	S12-426NP-7	161.30	0.71057
S12-426P-8	35.53	0.15652	S12-426NP-8	104.20	0.45903
S12-426P-9	18.99	0.08366	S12-426NP-9	53.28	0.23471
S12-426P-10	22.44	0.09885	S12-426NP-10	69.52	0.30626
Mean		0.14952			0.40784
Standard Deviation		0.04236			0.20032
Coefficient of Variation		0.28327			0.49117

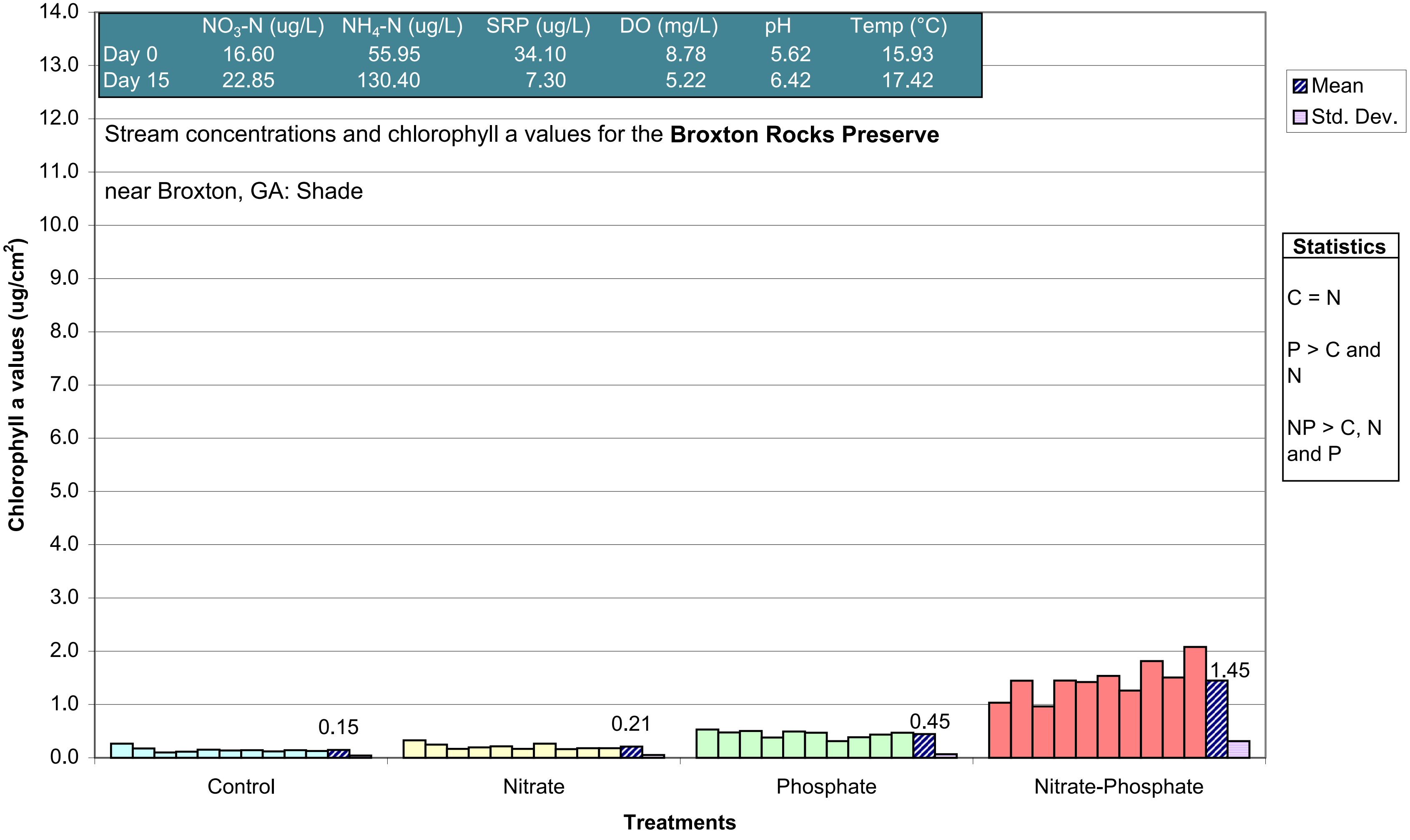
*S12-426C = Control filter from April 26, 2004 experiment at Site 12.
S12-426N = Nitrate filter
S12-426P = Phosphate filter
S12-426NP = Nitrate-phosphate filter

Table D-18. Chlorophyll *a* values for periphytometer experiment in the sun at Odum (Site 12). The frame was deployed on April 26, 2004 and retrieved on May 11, 2004.

Filter*	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S12-426C-11	119.00	0.52423	S12-426N-11	195.40	0.86079
S12-426C-12	155.80	0.68634	S12-426N-12	217.30	0.95727
S12-426C-13	150.00	0.66079	S12-426N-13	387.84	1.70855
S12-426C-14	191.60	0.84405	S12-426N-14	170.40	0.75066
S12-426C-15	146.00	0.64317	S12-426N-15	175.60	0.77357
S12-426C-16	174.00	0.76652	S12-426N-16	296.48	1.30608
S12-426C-17	102.40	0.45110	S12-426N-17	176.20	0.77621
S12-426C-18	145.20	0.63965	S12-426N-18	300.16	1.32229
S12-426C-19	106.60	0.46960	S12-426N-19	192.30	0.84714
S12-426C-20	74.80	0.32952	S12-426N-20	338.72	1.49216
Mean		0.60150			1.07947
Standard Deviation		0.14830			0.32966
Coefficient of Variation		0.24655			0.30539

Filter	**Chl a - µg/L**	**Chl a - µg/cm^2**	**Filter**	**Chl a - µg/L**	**Chl a - µg/cm^2**
S12-426P-11	139.70	0.61542	S12-426NP-11	821.92	3.62079
S12-426P-12	203.00	0.89427	S12-426NP-12	739.84	3.25921
S12-426P-13	153.20	0.67489	S12-426NP-13	710.08	3.12811
S12-426P-14	114.20	0.50308	S12-426NP-14	813.76	3.58485
S12-426P-15	102.20	0.45022	S12-426NP-15	369.12	1.62608
S12-426P-16	166.10	0.73172	S12-426NP-16	627.84	2.76581
S12-426P-17	173.40	0.76388	S12-426NP-17	441.76	1.94608
S12-426P-18	210.80	0.92863	S12-426NP-18	753.60	3.31982
S12-426P-19	111.80	0.49251	S12-426NP-19	540.80	2.38238
S12-426P-20	124.70	0.54934	S12-426NP-20	560.64	2.46978
Mean		0.66040			2.81029
Standard Deviation		0.15941			0.65340
Coefficient of Variation		0.24139			0.23250

*S12-426C = Control filter from April 26, 2004 experiment at Site 12.
S12-426N = Nitrate filter
S12-426P = Phosphate filter
S12-426NP = Nitrate-phosphate filter



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	16.60	55.95	34.10	8.78	5.62	15.93
Day 15	22.85	130.40	7.30	5.22	6.42	17.42

Stream concentrations and chlorophyll a values for the **Broxton Rocks Preserve**

near Broxton, GA: Shade

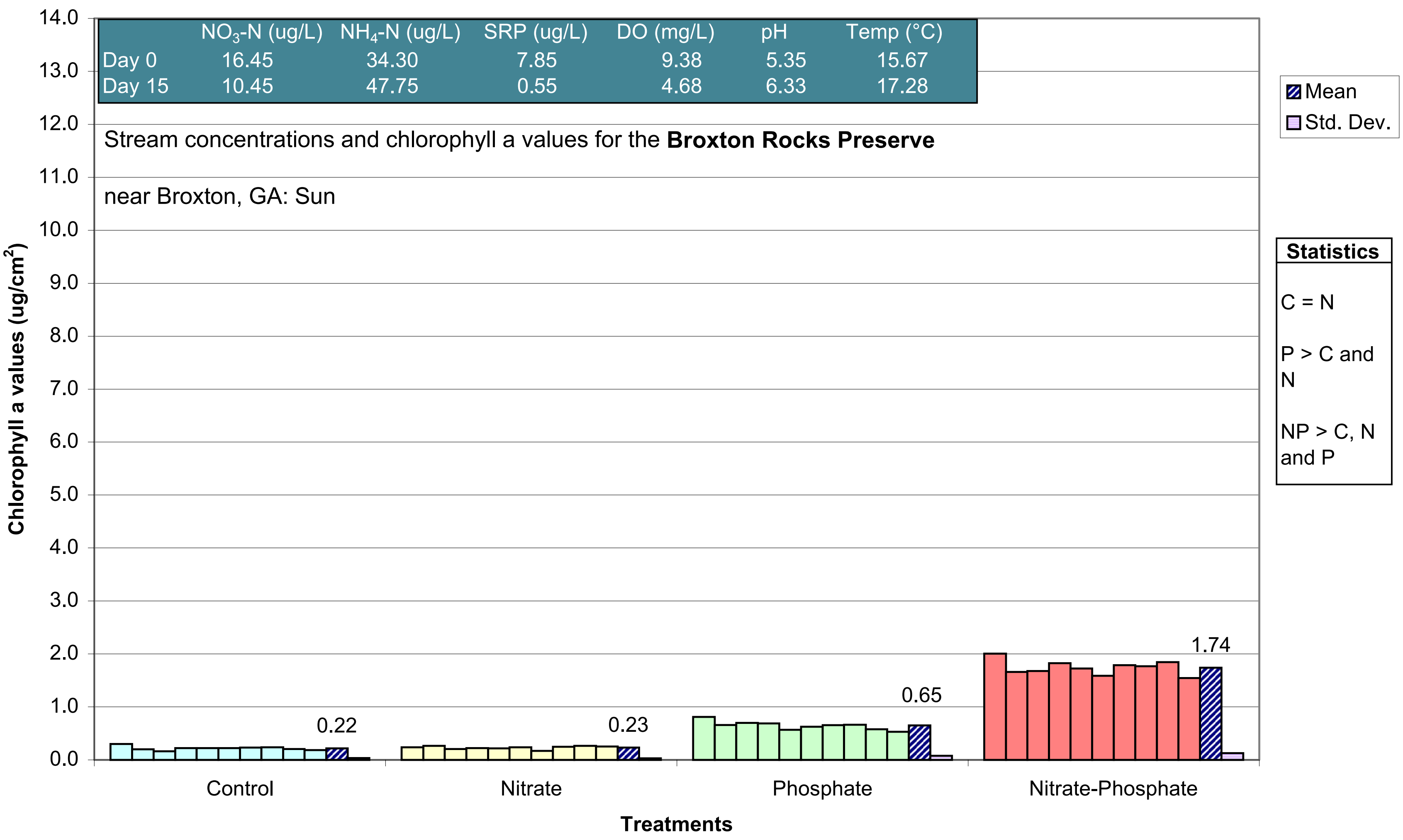
Statistics

C = N

P > C and N

NP > C, N and P

Figure D-1. Chlorophyll *a* values for April 8, 2004 experiment at the Broxton Rocks Preserve near Broxton, GA (shade). The periphytometer was removed on April 23, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	16.45	34.30	7.85	9.38	5.35	15.67
Day 15	10.45	47.75	0.55	4.68	6.33	17.28

Stream concentrations and chlorophyll a values for the **Broxton Rocks Preserve**

near Broxton, GA: Sun

Statistics

C = N

P > C and N

NP > C, N and P

Figure D-2. Chlorophyll *a* values for April 8, 2004 experiment at the Broxton Rocks Preserve near Broxton, GA (sun). The periphytometer was removed on April 23, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.

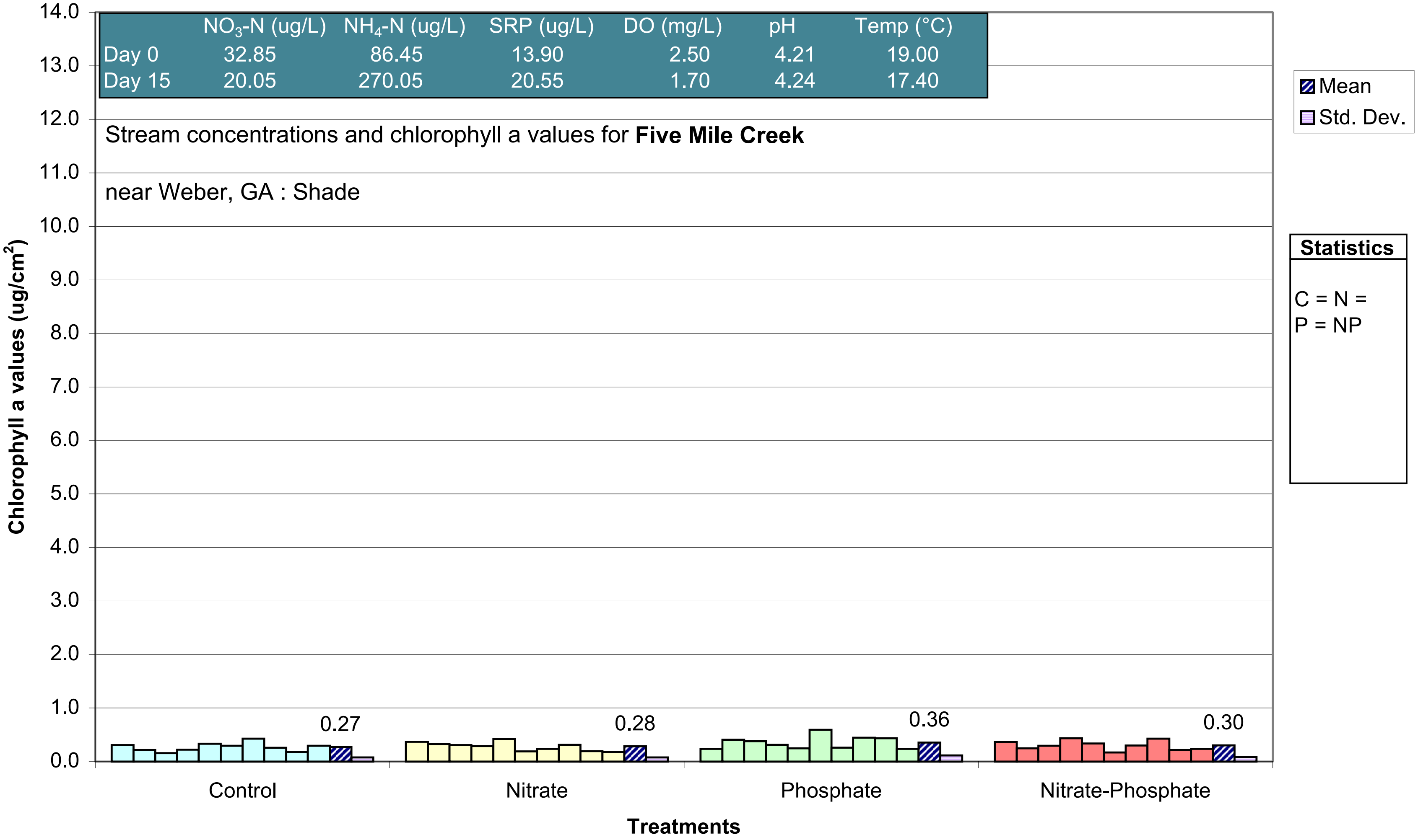
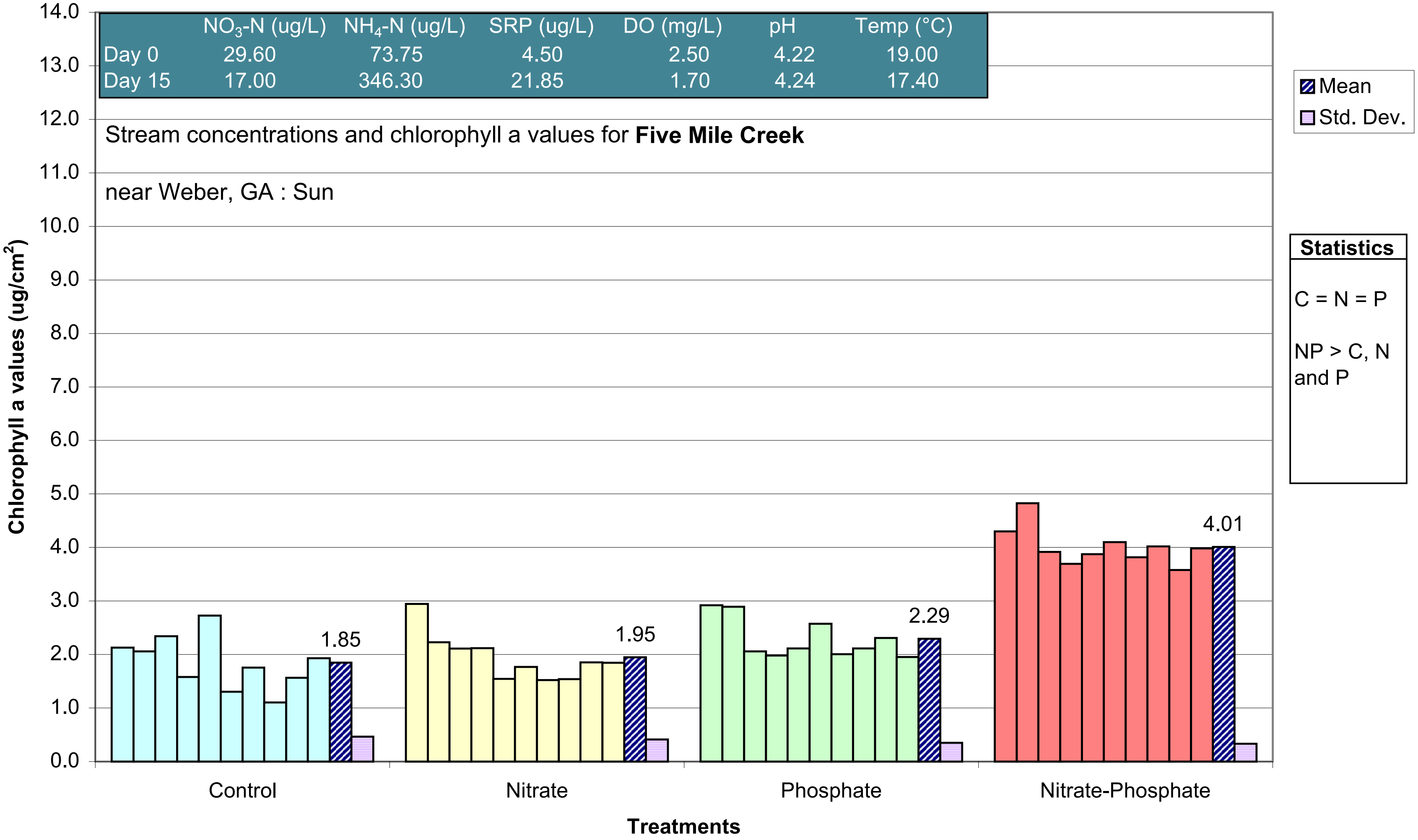


Figure D-3. Chlorophyll *a* values for April 13, 2004 experiment in Five Mile Creek near Weber, GA (shade). The periphytometer was removed on April 28, 2004 and chlorophyll *a* values (μg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	29.60	73.75	4.50	2.50	4.22	19.00
Day 15	17.00	346.30	21.85	1.70	4.24	17.40

Figure D-4. Chlorophyll *a* values for April 13, 2004 experiment in Five Mile Creek near Weber, GA (sun). The periphytometer was removed on April 28, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.

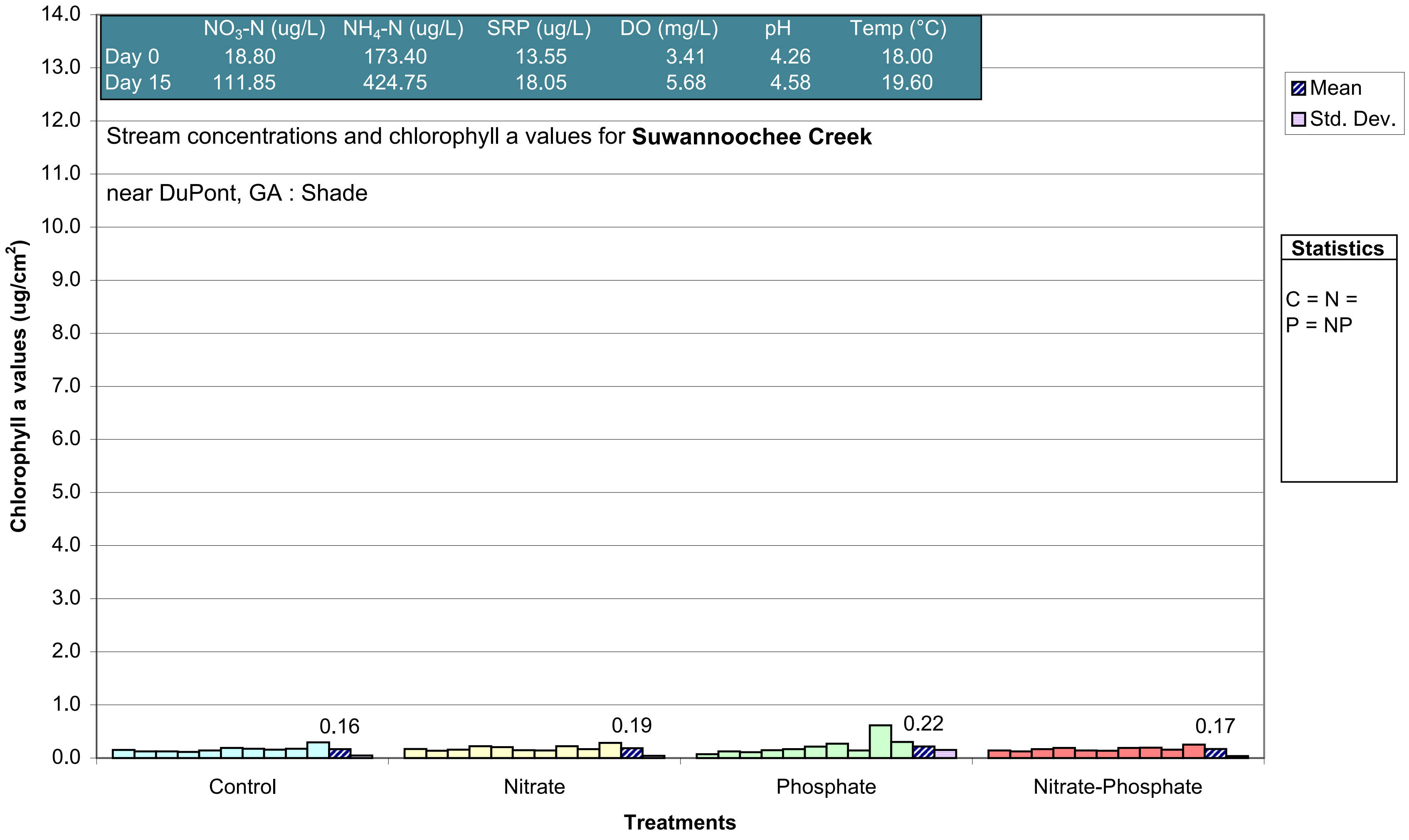
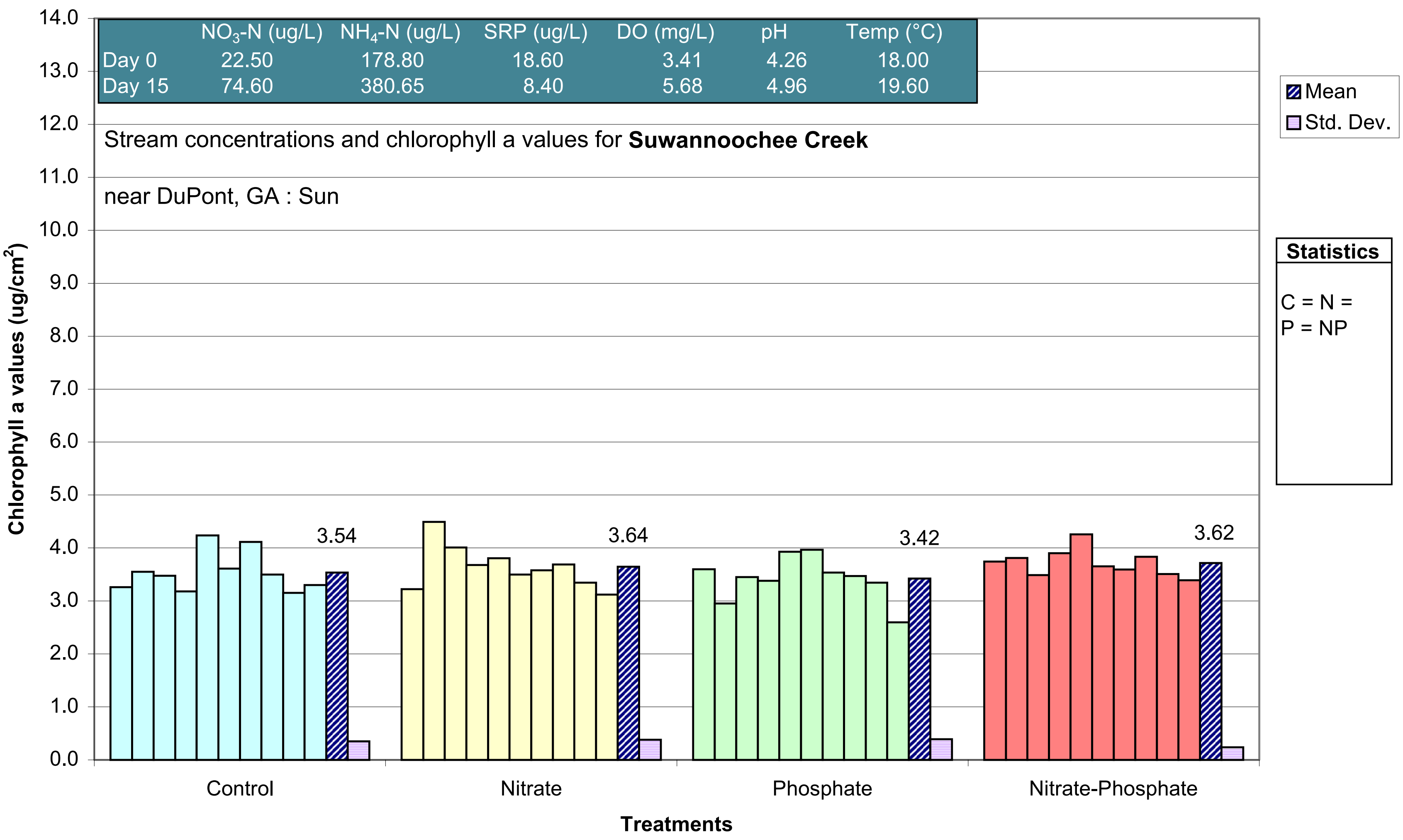
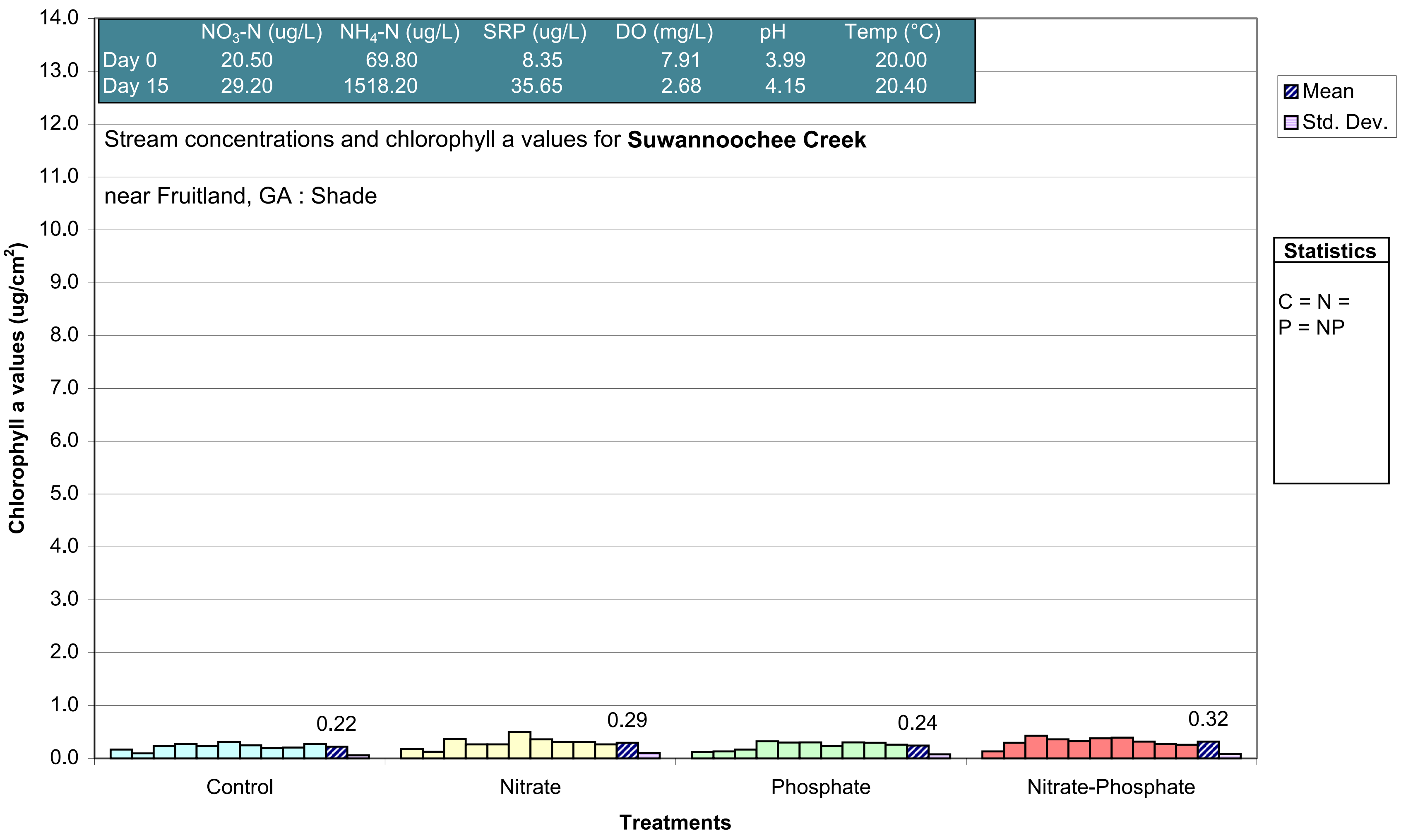


Figure D-5. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near DuPont, GA (shade). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values ($\mu g/cm^2$) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	22.50	178.80	18.60	3.41	4.26	18.00
Day 15	74.60	380.65	8.40	5.68	4.96	19.60

Figure D-6. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near DuPont, GA (sun). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	20.50	69.80	8.35	7.91	3.99	20.00
Day 15	29.20	1518.20	35.65	2.68	4.15	20.40

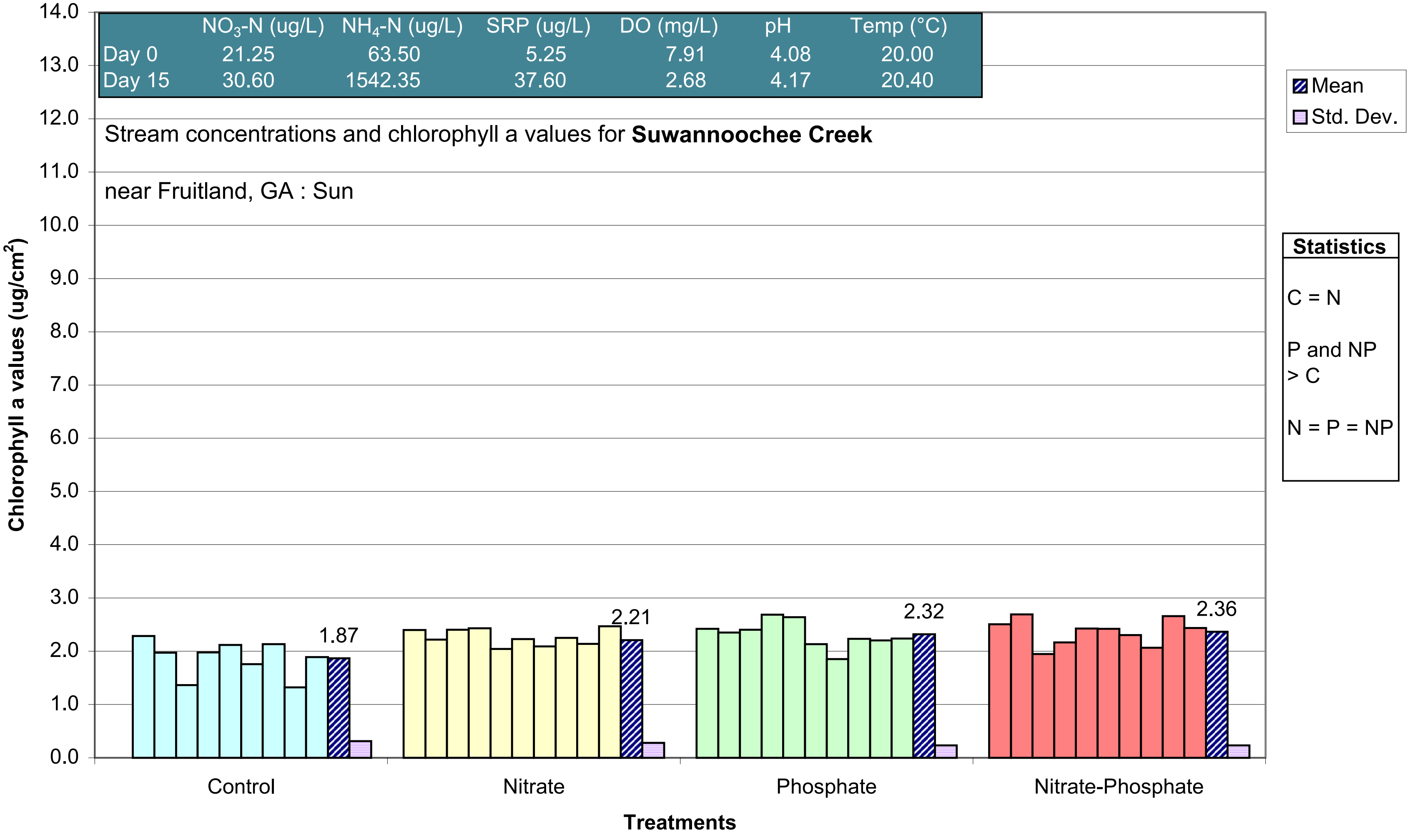
Stream concentrations and chlorophyll a values for **Suwannoochee Creek**

near Fruitland, GA : Shade

Statistics

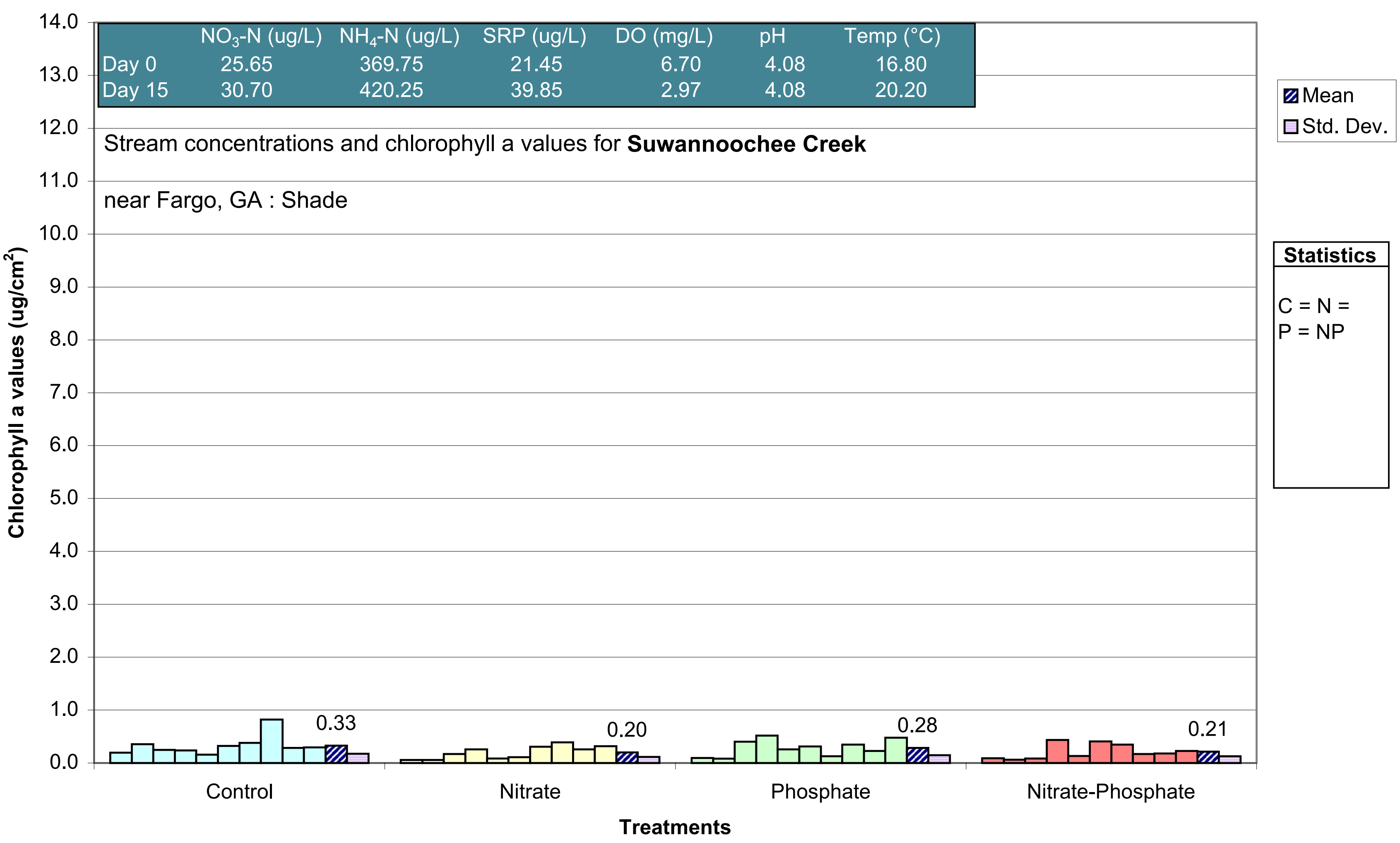
C = N =
P = NP

Figure D-7. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near Fruitland, GA (shade). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



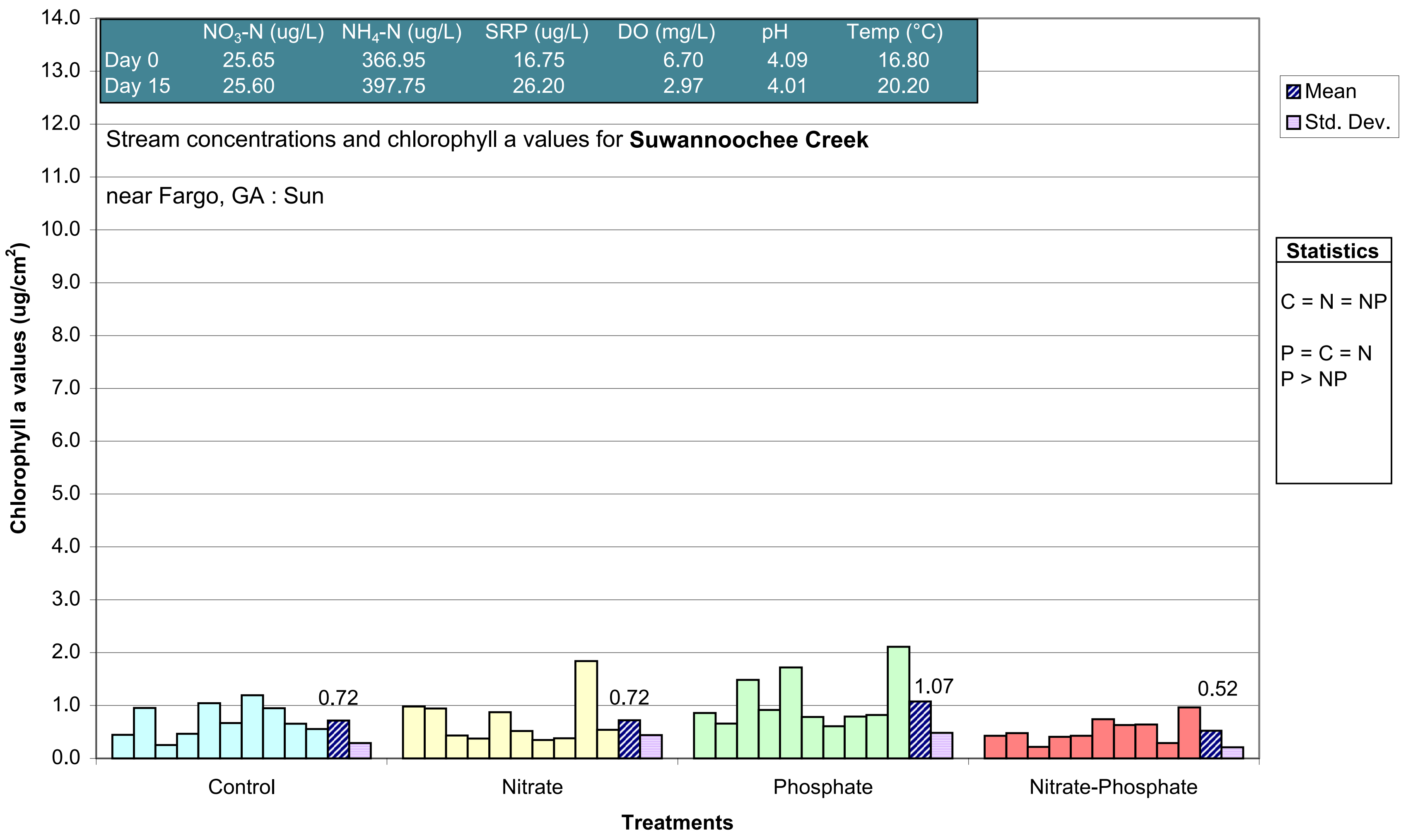
	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	21.25	63.50	5.25	7.91	4.08	20.00
Day 15	30.60	1542.35	37.60	2.68	4.17	20.40

Figure D-8. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near Fruitland, GA (sun). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



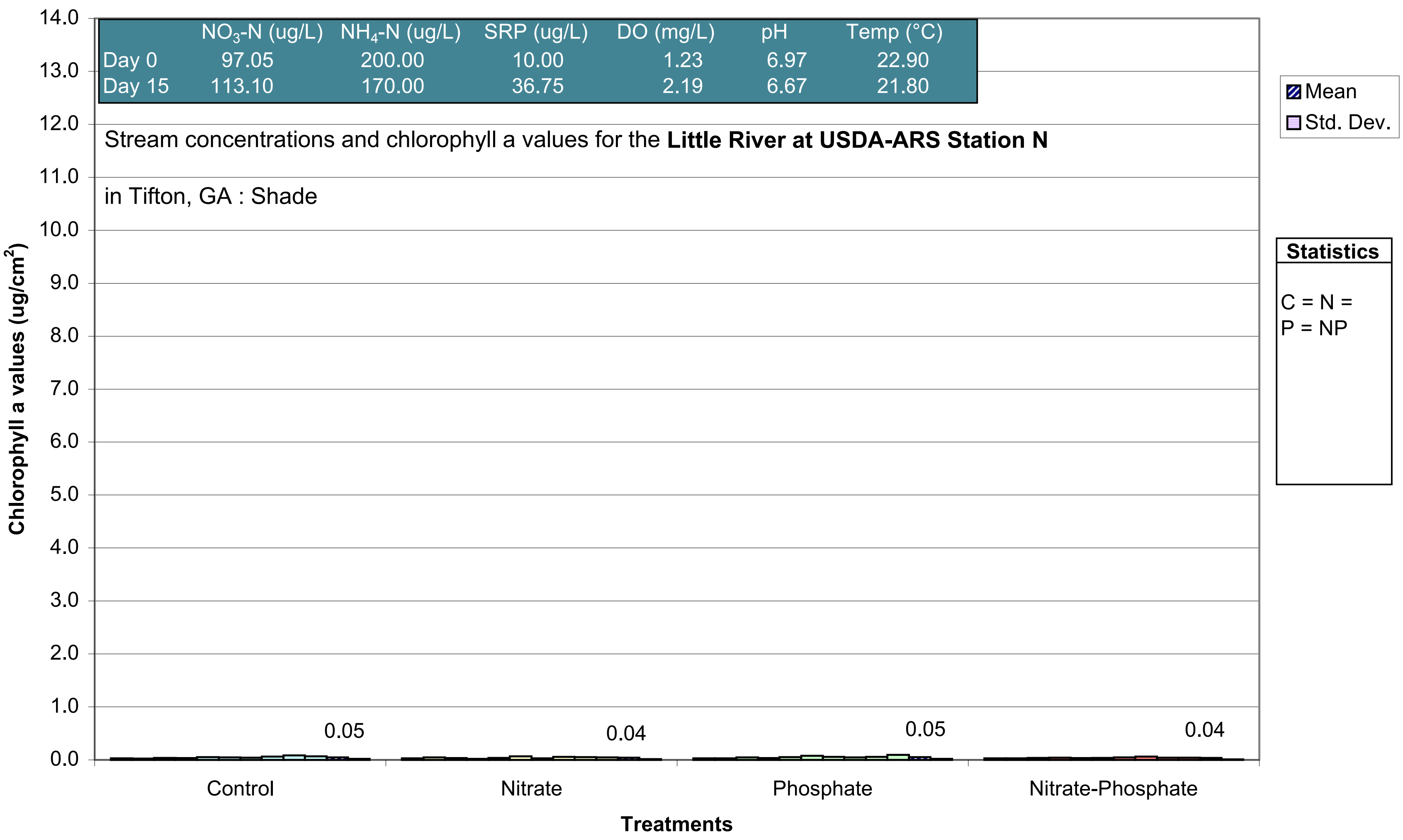
	NO$_3$-N (ug/L)	NH$_4$-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	25.65	369.75	21.45	6.70	4.08	16.80
Day 15	30.70	420.25	39.85	2.97	4.08	20.20

Figure D-9. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near Fargo, GA (shade). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	25.65	366.95	16.75	6.70	4.09	16.80
Day 15	25.60	397.75	26.20	2.97	4.01	20.20

Figure D-10. Chlorophyll *a* values for April 15, 2004 experiment in Suwannoochee Creek near Fargo, GA (sun). The periphytometer was removed on April 30, 2004 and chlorophyll *a* values ($\mu g/cm^2$) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	97.05	200.00	10.00	1.23	6.97	22.90
Day 15	113.10	170.00	36.75	2.19	6.67	21.80

Figure D-11. Chlorophyll *a* values for May 21, 2004 experiment in the Little River at USDA-ARS Station N (shade). The periphytometer was removed on June 5, 2004 and chlorophyll *a* values (μg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.

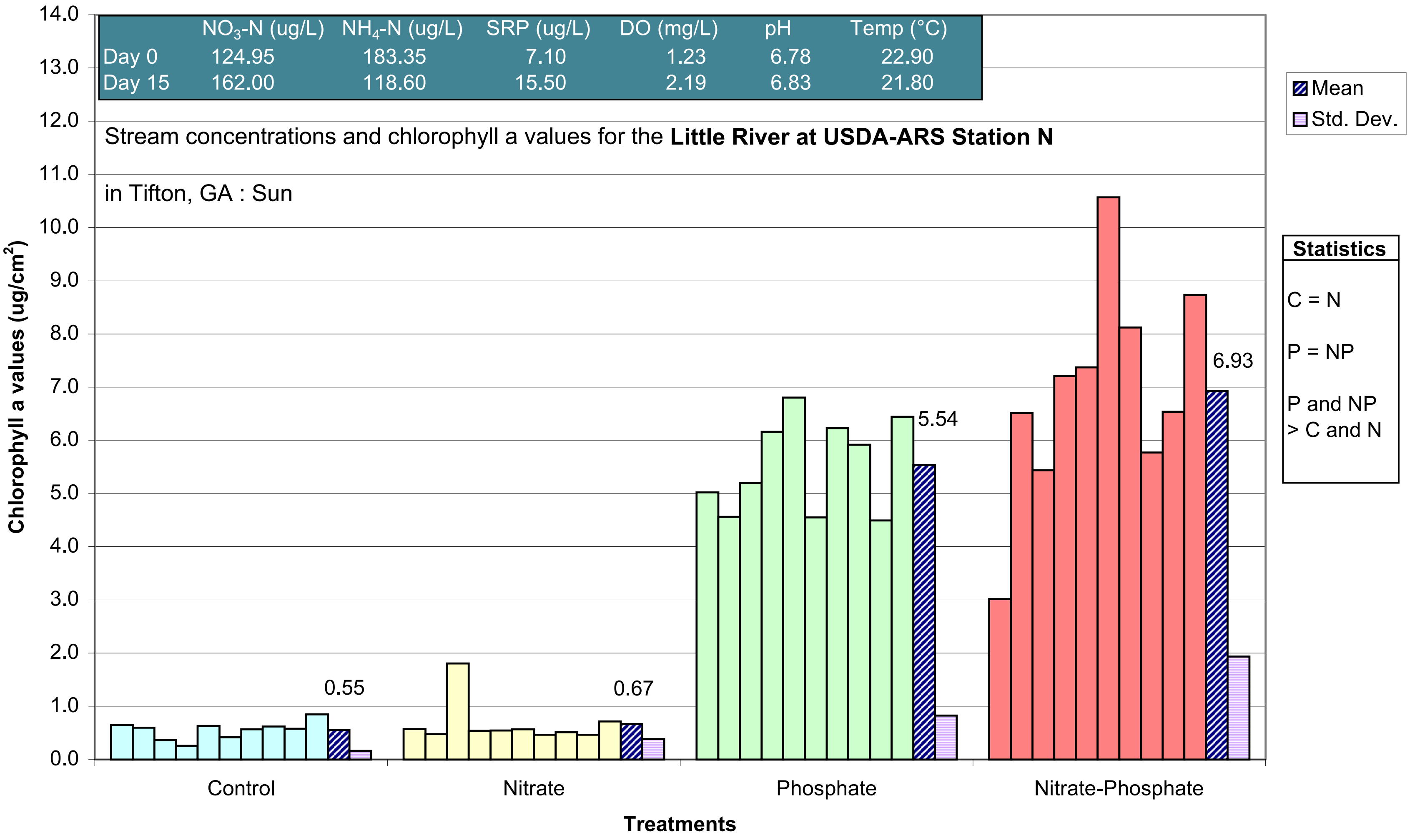
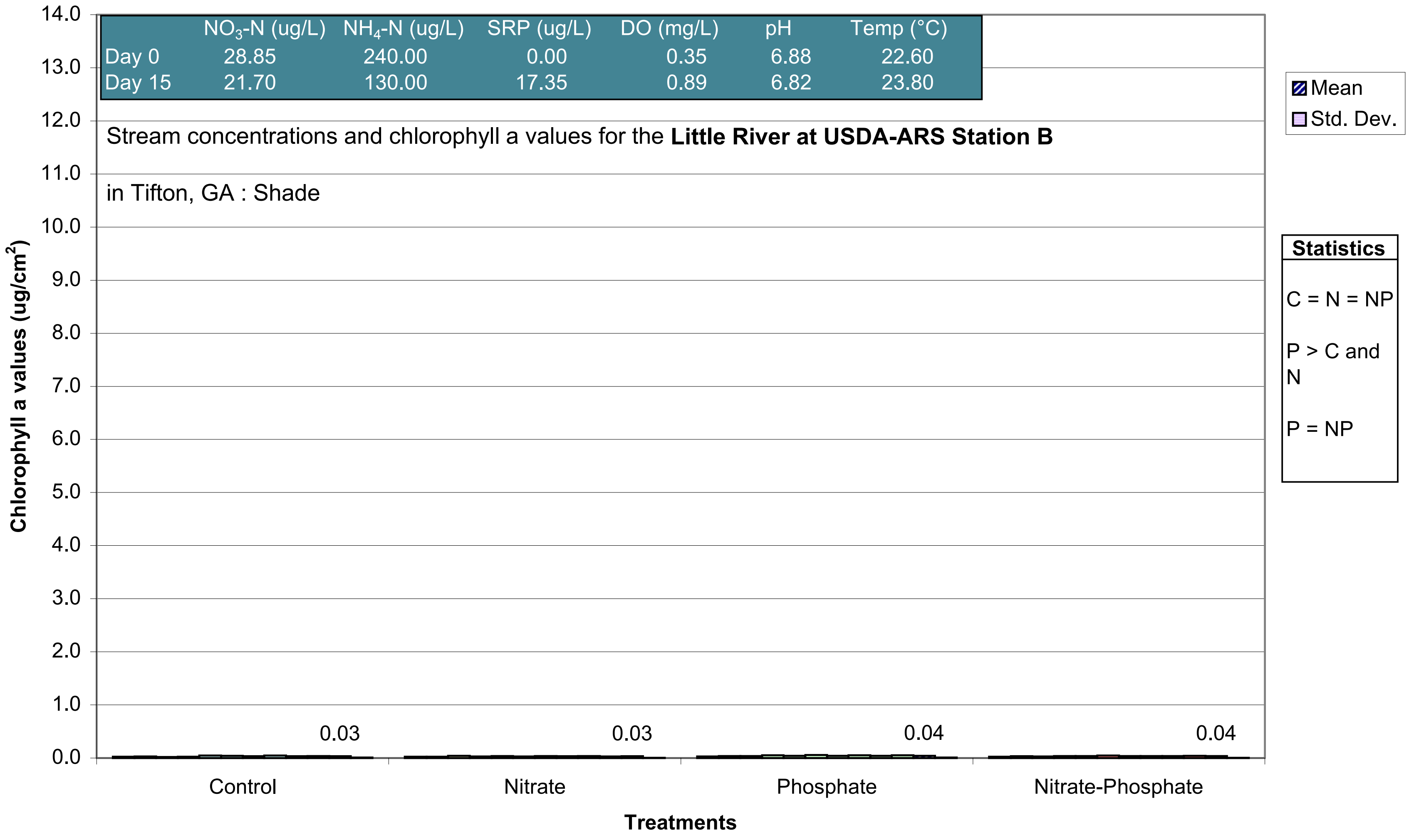


Figure D-12. Chlorophyll *a* values for May 21, 2004 experiment in the Little River at USDA-ARS Station N (sun). The periphytometer was removed on June 5, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO$_3$-N (ug/L)	NH$_4$-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	28.85	240.00	0.00	0.35	6.88	22.60
Day 15	21.70	130.00	17.35	0.89	6.82	23.80

Stream concentrations and chlorophyll a values for the **Little River at USDA-ARS Station B**

in Tifton, GA : Shade

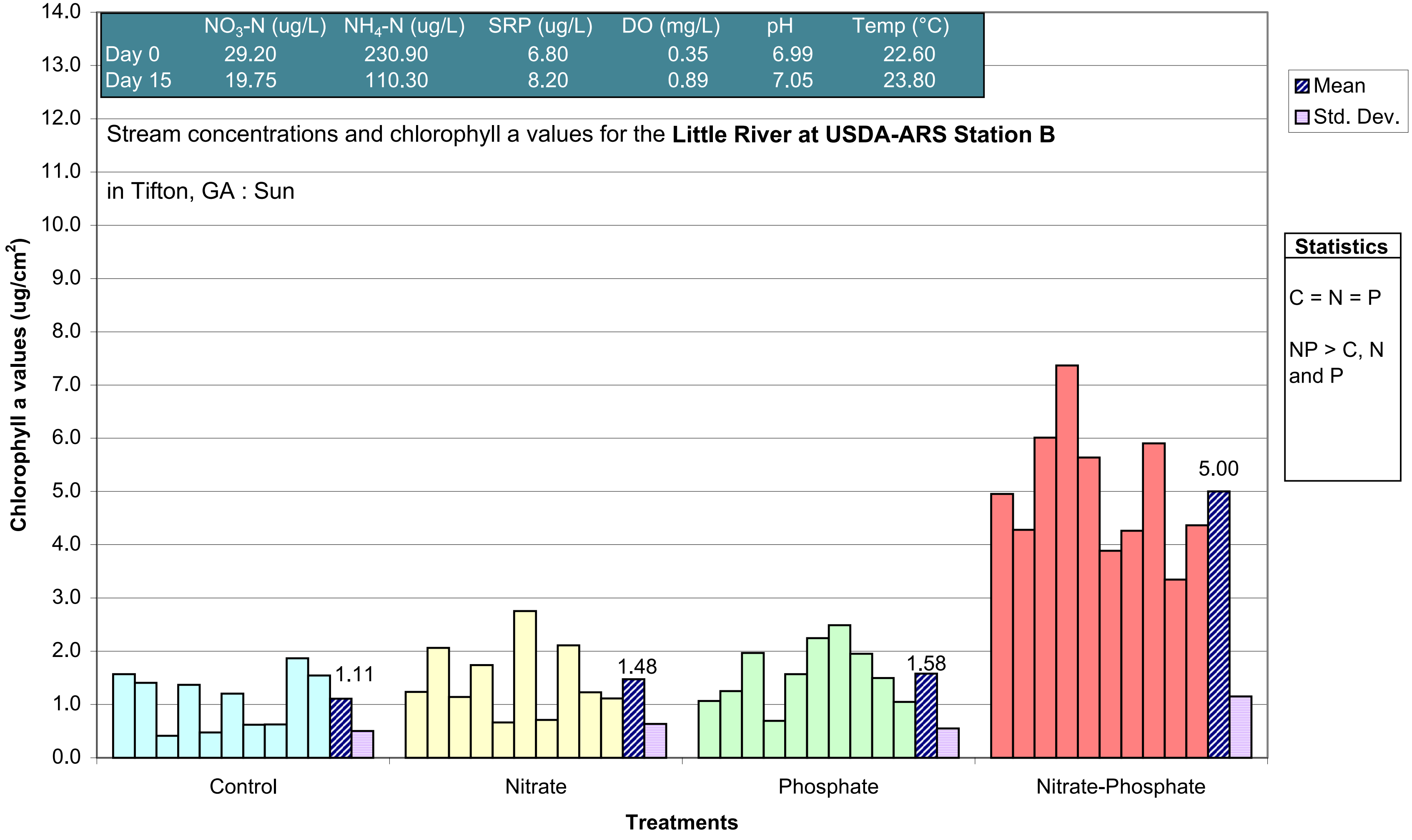
Statistics

C = N = NP

P > C and N

P = NP

Figure D-13. Chlorophyll *a* values for May 24, 2004 experiment in the Little River at USDA-ARS Station B (shade). The periphytometer was removed on June 8, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	29.20	230.90	6.80	0.35	6.99	22.60
Day 15	19.75	110.30	8.20	0.89	7.05	23.80

Stream concentrations and chlorophyll a values for the **Little River at USDA-ARS Station B**

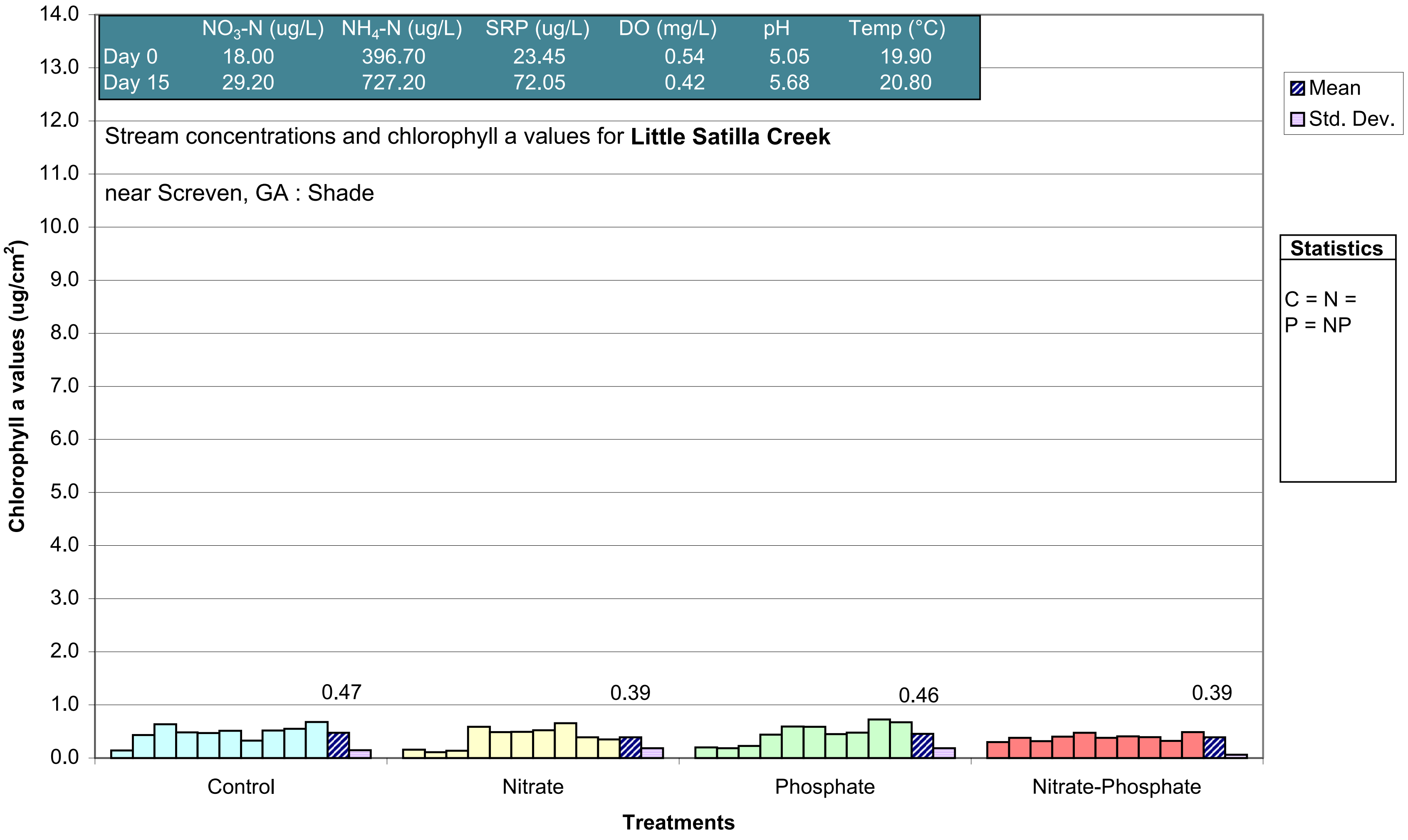
in Tifton, GA : Sun

Statistics

C = N = P

NP > C, N and P

Figure D-14. Chlorophyll *a* values for May 24, 2004 experiment in the Little River at USDA-ARS Station B (sun). The periphytometer was removed on June 8, 2004 and chlorophyll *a* values (μg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	18.00	396.70	23.45	0.54	5.05	19.90
Day 15	29.20	727.20	72.05	0.42	5.68	20.80

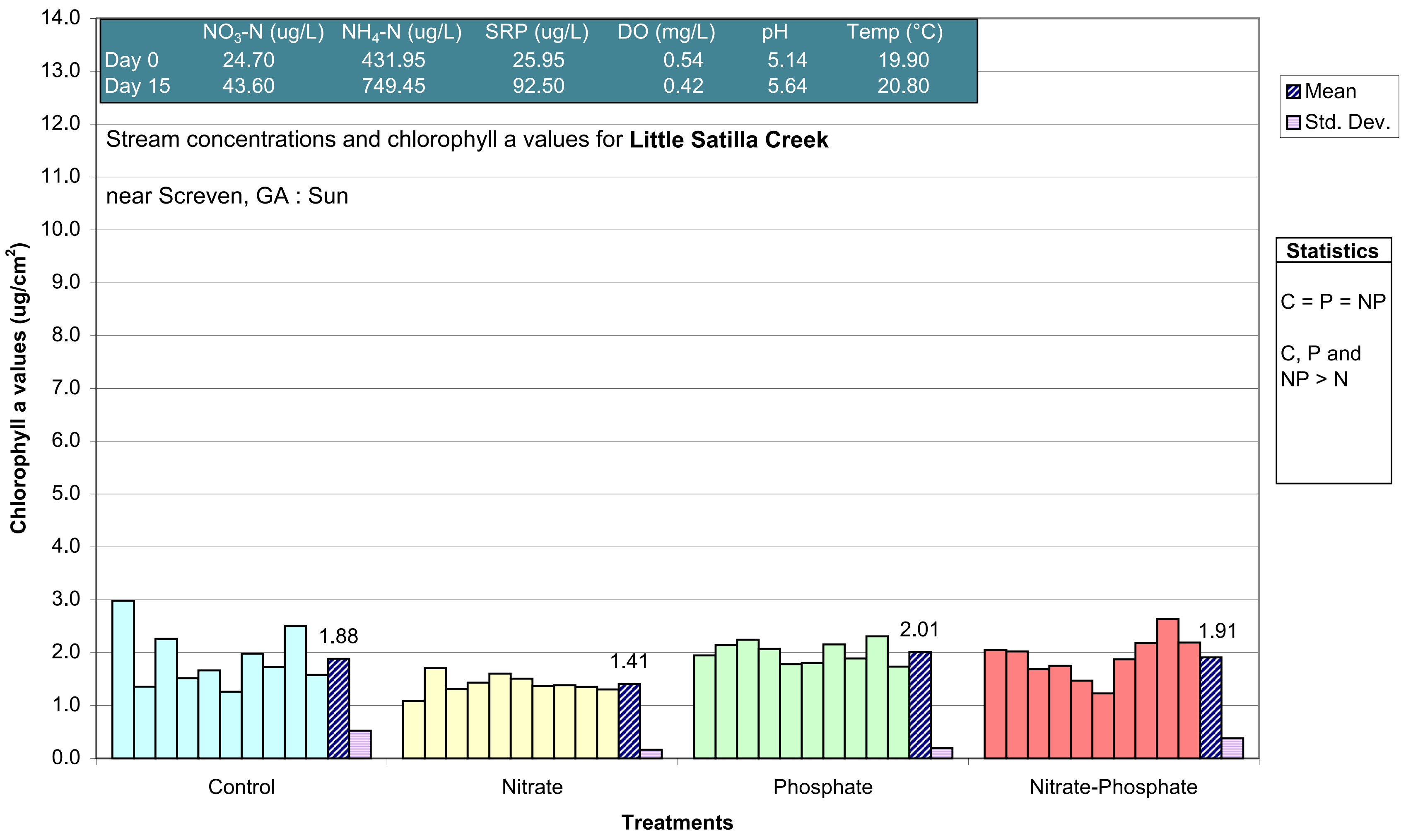
Stream concentrations and chlorophyll a values for **Little Satilla Creek**

near Screven, GA : Shade

Statistics

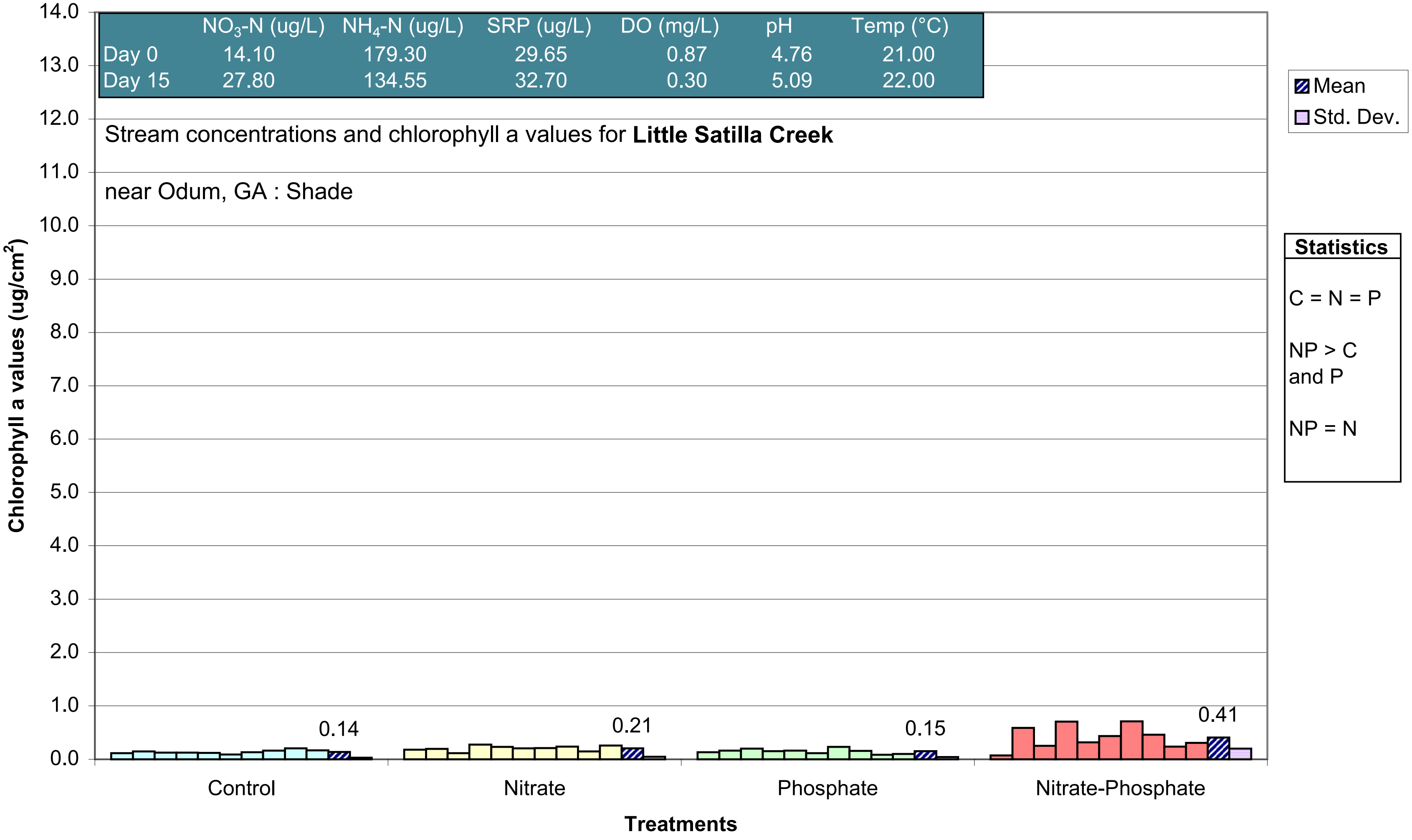
C = N =
P = NP

Figure D-15. Chlorophyll *a* values for April 26, 2004 experiment in Little Satilla Creek near Screven, GA (shade). The periphytometer was removed on May 11, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



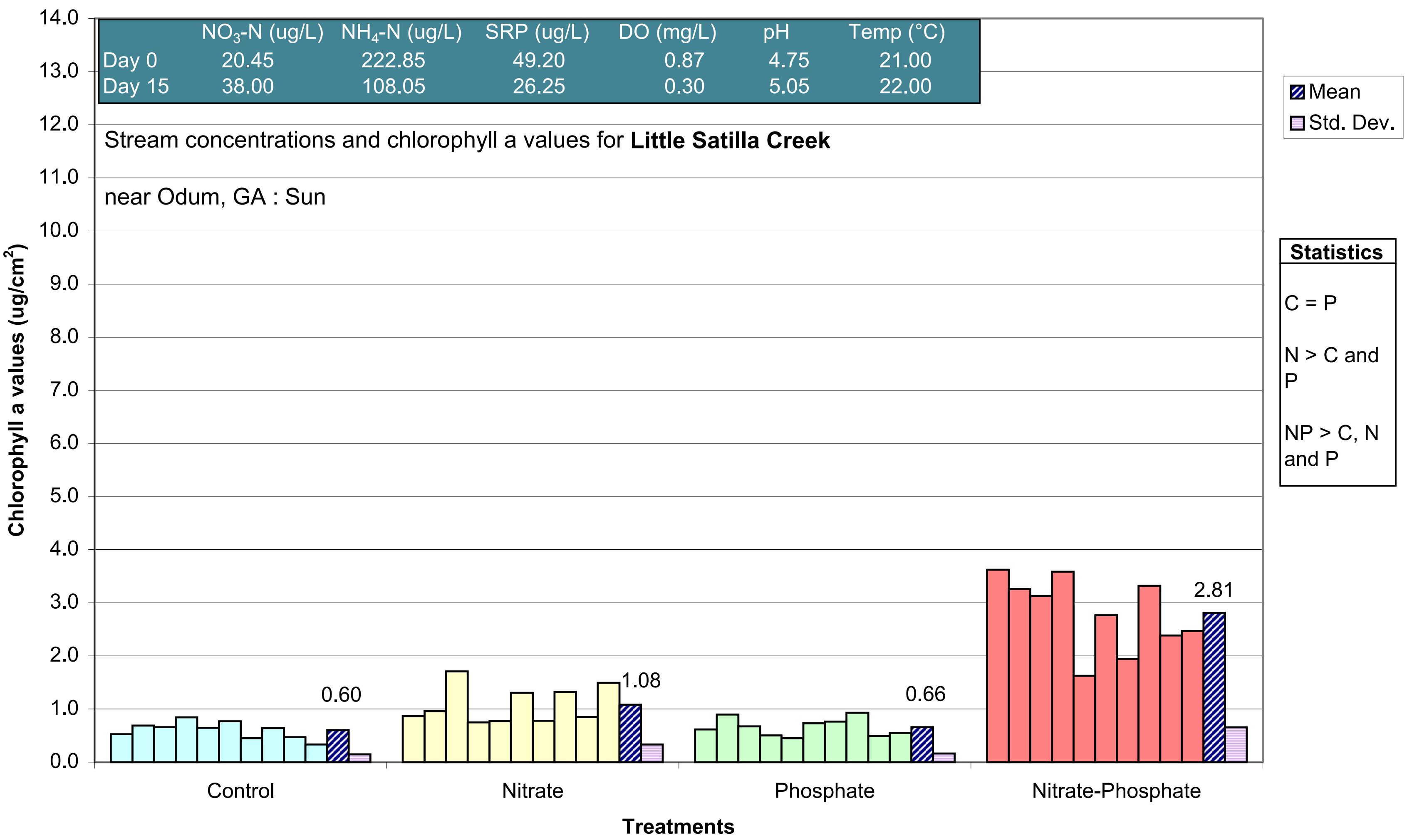
	NO$_3$-N (ug/L)	NH$_4$-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	24.70	431.95	25.95	0.54	5.14	19.90
Day 15	43.60	749.45	92.50	0.42	5.64	20.80

Figure D-16. Chlorophyll *a* values for April 26, 2004 experiment in Little Satilla Creek near Screven, GA (sun). The periphytometer was removed on May 11, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	14.10	179.30	29.65	0.87	4.76	21.00
Day 15	27.80	134.55	32.70	0.30	5.09	22.00

Figure D-17. Chlorophyll *a* values for April 26, 2004 experiment in Little Satilla Creek near Odum, GA (shade). The periphytometer was removed on May 11, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.



	NO_3-N (ug/L)	NH_4-N (ug/L)	SRP (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	20.45	222.85	49.20	0.87	4.75	21.00
Day 15	38.00	108.05	26.25	0.30	5.05	22.00

Figure D-18. Chlorophyll *a* values for April 26, 2004 experiment in Little Satilla Creek near Odum, GA (sun). The periphytometer was removed on May 11, 2004 and chlorophyll *a* values (µg/cm^2) were obtained after analyzing glass fiber filters retrieved from 20 mL scintillation vials filled with nutrient solutions or deionized water.