THE RELATIONSHIP BETWEEN NUTRIENT LIMITATION AND PHYTOPLANKTON COMMUNITY STRUCTURE IN TENKILLER FERRY LAKE

By

SHANON HARAUGHTY

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Kansas State University

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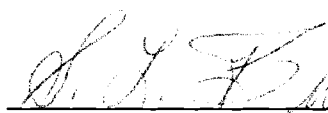

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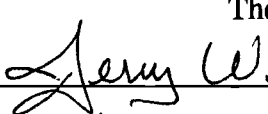

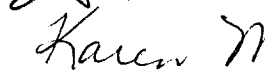

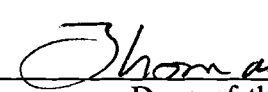

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PREFACE

Degradation of water bodies is an extensive problem. Combined with natural ontogeny of lakes and reservoirs, cultural eutrophication poses a significant threat to this nation's water resources. The deleterious impacts of these processes affect both abiotic and biotic components of aquatic systems, often with unfortunate results. Because these components are closely associated, it is imperative that both abiotic and biotic factors be considered in methods of restitution. In accordance, whether a system is driven by "top-down" or "bottom-up" mechanisms of population control, it is important to monitor primary producers and the environmental factors which affect them. This study addresses these issues in Tenkiller Ferry Lake.

The interactions between primary producers and the aquatic environment have been researched extensively in the lab and predictable results are well established. Although certain trends in succession of dominant genera have been identified in the field, variable conditions generate more speculation since results are often site specific. This study should provide insights into these interactions and appropriate management strategies for optimal use of Tenkiller Ferry Lake.

I gratefully acknowledge the assistance in the forms of financial support, expert advice and additional field work provided by the personnel of the OSU-Water Quality Research Lab. I especially thank Drs. S.L. Burks and J.L. Wilhm for their guidance, financial assistance, and provision of an excellent working environment in which to pursue this study. Their expertise in this field has been an invaluable asset.

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with phytoplankton identification. I express my gratitude to my fellow graduate students, in particular Noble Jobe and Greg Kloxin, for the support and friendship they provided towards the completion of this project and throughout my tenure at OSU. The value of these alliances is beyond measure. Finally, I thank my parents, John and Norma Haraughty, and my Grandmother, Dr. Edith Haraughty, for their love and support; I owe all that I am to these people.

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CHAPTER I

INTRODUCTION

Wetzel (1983) defined eutrophication as a natural aging process of water bodies in which overall concentrations of nutrients increase; resulting in increased productivity, structural simplification of biotic components, and reduced stability of the system. The rate at which this process occurs often is increased by anthropogenic activities which introduce excess nutrients into the watershed through agricultural activities, deforestation, municipal and industrial sewage, and other products of urban development (Raman 1985). Resultant productivity frequently is manifested as phytoplanktonic blooms which produce undesirable effects on water quality.

Highly productive phytoplankton communities have a profound impact on several water quality parameters. Removal of carbon dioxide from the water column during photosynthesis results in higher pH values and shifts alkalinity from bicarbonate to carbonate forms and from carbonate to hydroxide forms (Sawyer and McCarty 1978). High photosynthetic rates during the day produce increased dissolved oxygen in the water column and corresponding oxygen consumption rates during nocturnal respiration. The diel oxygen cycle often results in fish kills (Lingeman et al. 1975). Increased algal biomass and subsequent decomposition contributes to anoxia in stratified water bodies (Wetzel 1983).

Higher phytoplanktonic productivity increases turbidity through light absorption by algal cells and increased dissolved organic matter, resulting in reduced clarity and "greener" water which is aesthetically displeasing (Sand-Jensen and Borum 1991).

Excessive phytoplankton growth often results in taste and odor problems in both water and fish flesh and release of toxic ammonia, nitrite, and hydrogen sulfide levels (Young et al. 1988; Smith 1988).

Despite the harmful impacts, phytoplankton are essential to lentic communities in their role as primary producers (Sand-Jensen and Borum 1991), so elimination is not an appropriate goal. However, because of deleterious effects, monitoring and perhaps control of phytoplanktonic communities in water bodies where conditions are favorable for excessive algal productivity is imperative. Since phytoplankton communities are potentially limited by a wide variety of factors including temperature, light intensity and periodicity, water currents, mixing depth, available nutrients, and invertebrate grazers, growth limiting factors may differ among similar systems lending to the complexity of community dynamics (Brown 1983, Brylinsky and Mann 1973). In addition, phytoplankton communities exhibit notable annual trends (Margalef 1963). Thus, monitoring community dynamics may not insure against damage unless causal factors are identified to explain changes in phytoplanktonic communities.

Reservoirs offer the limnologist an unusual opportunity to study phytoplankton ecology. Fluctuations in water level and turbidity often preclude the establishment of periphyton and rooted macrophytes, which are often dominant in lakes, thus emphasizing contribution of planktonic algae to total primary production (Thornton et al. 1990). Brown (1983) stated that reservoirs and long lakes exhibit longitudinal gradients in turbidity as a result of settling of suspended solids. Indeed, reservoirs uniquely combine some of the characteristics of longitudinal flow and importance of allochthonous inputs from lotic sources with lentic characteristics of depth, stratification, and nominal current velocities.

Thornton et al. (1990) divided most reservoirs into three zones based on their

physical and biological processes. The riverine zone is a lotic-like well-mixed system with relatively high nutrient concentrations from allochthonous sources. However, turbidity limits primary productivity in this zone. Anoxic conditions are rarely a problem due to shallow depths and well-mixed waters, though allochthonous organic matter may create significant oxygen demands. The transition zone occurs where current velocities slow and suspended particles settle. Increased light penetration combined with relatively high nutrient concentrations transported from the riverine zone enable phytoplanktonic communities to flourish. Thermal stratification may begin in some segments of this section due to greater depths and inadequate mixing, leading to anoxic conditions and more eutrophic systems. Finally, as dilution continues and depth increases, the reservoir becomes most like a lentic system. Standing crop of the lacustrine zone is almost exclusively autochthonous and a stable stratification is likely to occur during summer, with corresponding reductions in nutrient availability. This section exhibits the lowest concentrations of turbidity, nutrient, and chlorophyll *a* with corresponding increases in clarity.

Tizler et al. (1991) claimed researchers generally consider algal communities to be limited by a single factor, usually nutrients. In the case of a limiting nutrient, the spring maximum controls phytoplankton assemblage dynamics for the remainder of the growing season (Vollenweider cf. Tizler et al. 1991). Limitation by a single factor seems reasonable for systems which are relatively closed to allochthonous inputs, such as natural lakes, but is less plausible when considering reservoirs.

Due to the longitudinal heterogeneity in reservoirs, different factors might limit phytoplanktonic productivity. Thus, manipulation of a single limiting factor in the riverine zone may not benefit the lacustrine zone .

The purpose of this study was to examine the relationship between longitudinal and temporal variation in environmental factors, especially nutrients, and plankton

populations in Tenkiller Ferry Lake, Oklahoma. Specific objectives include the following:

1) Determining specific nutrient limitation relative to spatial and temporal trends in Tenkiller Ferry Lake using algal assays.
2) Relate this limitation to assumed planktonic community structure.

The null hypotheses are as follows:

H_o: nutrient limitation as determined by algal assays is not related to community structure.

H_o: no longitudinal trend in nutrient limitation exists in Tenkiller Ferry Lake.

CHAPTER II

LITERATURE REVIEW

Limitation of Phytoplankton Productivity

Definition and Misconceptions

Considerable dissention exists among limnologists and phycologists on the exact definition of a growth limiting factor. Whether a limiting factor curbs the rate of phytoplankton growth or phytoplankton biomass is controversial. Gibson (1971) gave three definitions for phytoplankton growth limitation. First, "an organism is limited when it is not growing as fast as it is theoretically able to", second, "a factor is said to be limiting when it is in such short supply that no growth is possible", and finally, "a factor is not limiting if, when it is increased, no effect on growth is observed". Given the first view, that environmental conditions are rarely as optimal *in situ* as they are in the laboratory, it is likely that organisms are often in this state of limitation. The final view is applied in most laboratory assays that identify nutrient limitation by comparing the growth of algae in untreated lake water to that in lake water spiked with nutrient additions (Miller et al. 1978).

Reynolds (1984) discussed two views of algal limitation. The first, Leibig's Law of the Minimum, governs Gibson's third definition, assuming that growth rate is independent of nutrient concentration until it becomes absolutely limiting (Figure 1). Growth will proceed at the maximum rate until the substrate concentration is depleted to a certain point, at which time growth rate will precipitously decline, and

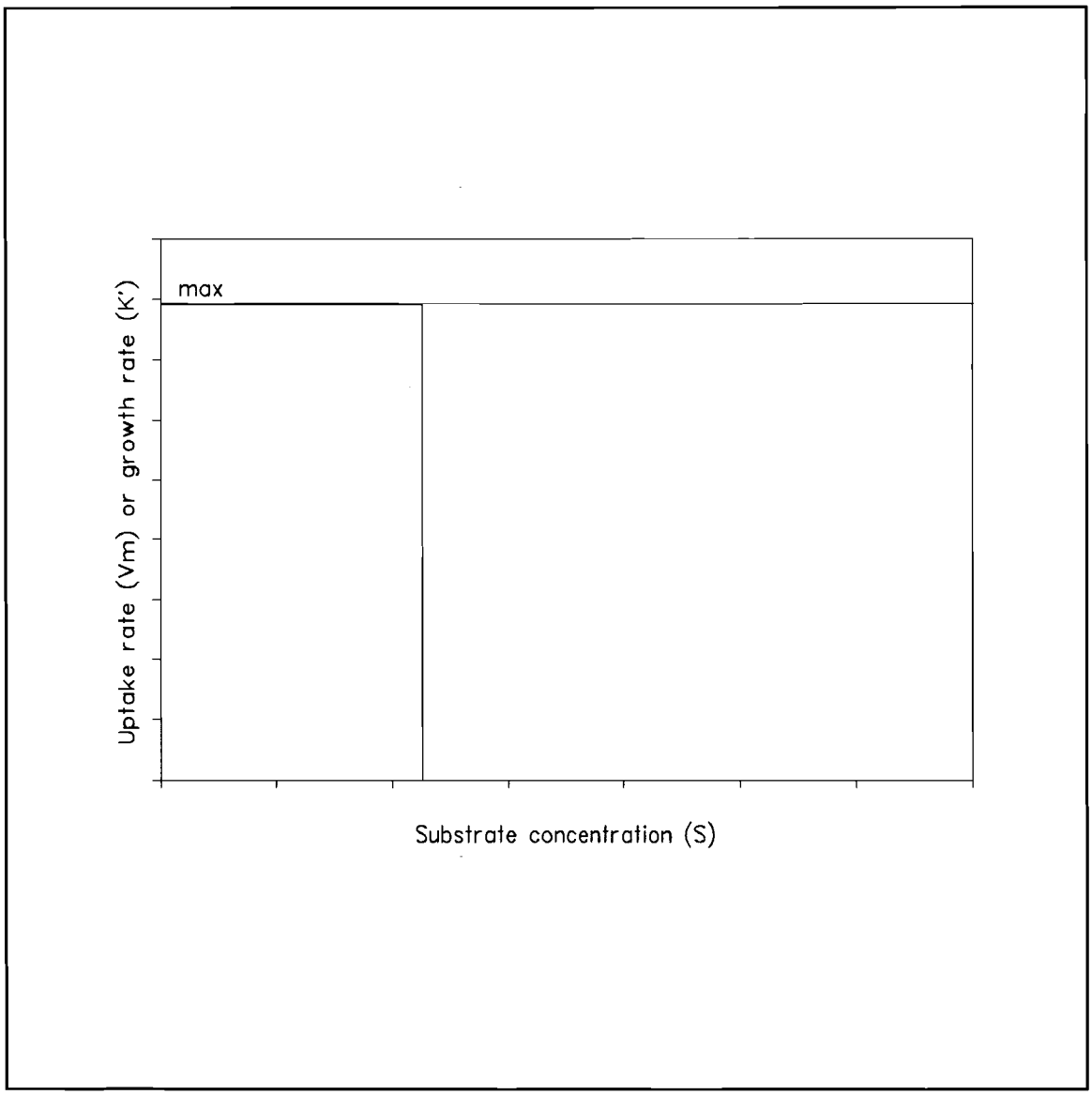

Figure 1. Leibig's Law of the Minimum (from Reynolds 1984).

population becomes limited. Because few of the available dissolved nutrients are ever present in water in the concentrations that must be maintained in the cell, cells must accumulate and store the required nutrients. Growth cannot exceed the capacity of the environment to supply the nutrient which is first exhausted. Therefore, the species which has the largest stored reserves of the limiting nutrient would be most

successful. Comprehension becomes difficult when considering this explanation as to why various species of phytoplankton could be limited by different concentrations of the assorted nutrients when minimum cell contents of macronutrients are similar among the freshwater phytoplankton, excluding silica content of diatoms. This similarity might suggest the improbability that phytoplankton assemblages could be impacted directly by the law of the minimum. Yet, species respond differently to nutrient availability which serves to direct seasonal succession in many systems (Hutchinson 1967).

The second explanation of nutrient limitation discussed by Reynolds (1984) concerns the capacity of certain phytoplankton to store excess nutrients for later use. Unlike the previous definition, growth rate is directly related to nutrient concentration (Figure 2). Growth rate is controlled by availability of the limiting nutrient such that the greater the deficit, the slower the growth rate. Species able to cache nutrients for later use are least impacted during periods of low ambient concentrations. This has been demonstrated by application of Michaelis-Menton kinetics described by the Monod equation (cf. Ahlgren 1988). Droop (1973) developed this model further to include the nutrients actually available to the cell externally and internally in the relationship to growth rate.

Harris (1986) disagreed with Reynolds' second definition, remarking on the error in assuming a relationship between concentration of nutrient and growth rate. He suggested that this idea resulted from batch culture work, which are inappropriate tests to make that type of inference because the initial concentration of nutrient is the entire available supply. To determine whether a substance is limiting, simple measurement of ambient levels of that substance is insufficient, the rate of turnover must also be considered.

One source of this debate over the definition of phytoplankton limitation may be

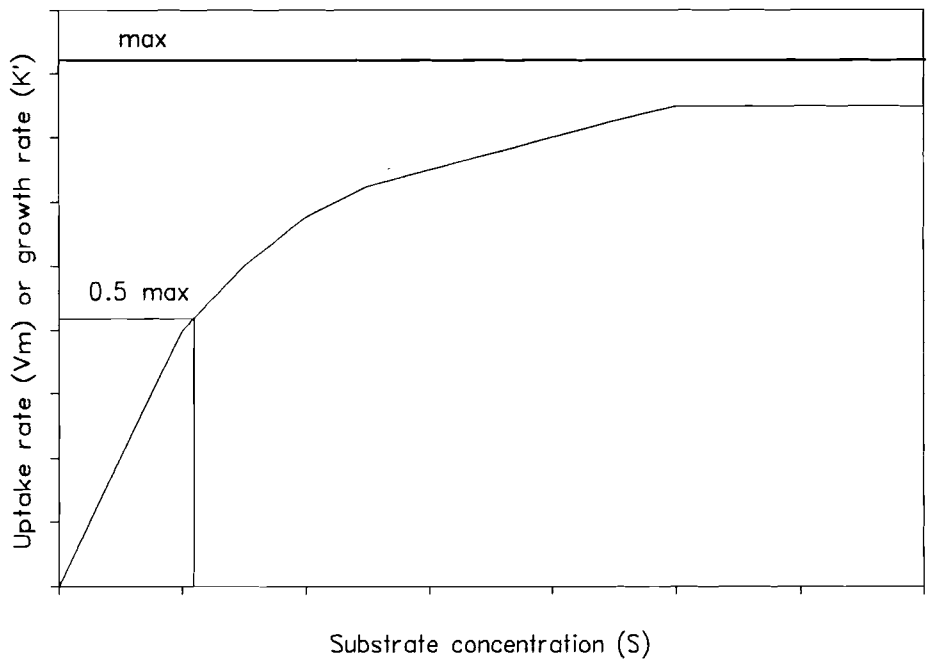

Figure 2. Michaelis-Menten Kinetics (from Reynolds 1984).

the differences in dynamics of limiting factors in water bodies of varying trophic status. The mechanisms of limitation differ between phytoplankton in oligotrophic oceans and those in eutrophic sewage ponds. The divergence is not concerned merely with which factors limit growth, for often the same nutrient is limiting under oligotrophic and eutrophic conditions (Schindler 1977), but is relevant to why such

factors are limiting. For this reason, it is imperative to consider abiotic and biotic mechanisms of control specific to a system before assumptions are made regarding which factors regulate its primary productivity.

Causal Factors

Pearsall is considered to be the first to make a clear hypothesis relating chemical composition of water to the abundance, composition, and distribution of phytoplankton (Reynolds 1984). He related diatom increases to higher levels of silica, Chrysophyta (golden-brown algae) abundances to low silica levels and low nitrogen to phosphorus ratios, and increases in Cyanophyta (blue-green algae) to concentrations of organic nitrogen. Potential catalysts of algal blooms and the phenomenon of phytoplankton succession have been explored extensively and growth limiting factors have been determined to differ greatly among systems.

Light availability, as related to photoperiod and intensity, and effects on algal productivity has been well documented (Lund 1949, Reynolds 1973, Laws and Bannister 1980). Brown (1983) related algal productivity to turbidity and light attenuation. Turbidity is the presence of suspended solids which reduce light transmission by scattering or absorption, whereas light attenuation is the process by which light intensity becomes reduced as it travels from above the surface into the water column (Lind 1985). Brown (1983) related variability in algal productivity to the stochasticity of reservoir turbidity. Temperature variation effects on algal physiology and metabolism and optimum temperature ranges for cell growth have been established for most phytoplankton (Eppley 1972, Goldman and Carpenter 1974, Reynolds 1984). Water currents created by wind mixing and longitudinal flow have been related to cell growth (Margalef 1978, Harris 1986).

Studies have indicated that phytoplankton productivity can also be limited by

zooplankton grazing (Shapiro and Wright 1984, Lehman and Sandgren 1990, Sondergaard et al. 1990). The impact of nutrient regeneration/recycling by zooplankton on community structure has also been demonstrated (Lehman 1980, Moegenburg and Vanni 1991). Elser et al. (1988) illustrated zooplankton-mediated shifts among nitrogen- and phosphorus- limited phytoplankton communities. As a result of these findings, numerous studies have explored the use of population manipulation of planktivorous fish to control phytoplankton standing crops (Meijer et al. 1990, Reimann et al. 1990).

Phytoplankton growth limitation also has been demonstrated to be a consequence of nutrient dynamics (Lund 1949, Hutchinson 1957, Vanni and Tempte 1990). Nutrient availability (Hutchinson 1967, Fuhs et al. 1972), nutrient content of algal cells (Droop 1974), and cellular macronutrient ratios (Rhee and Gotham 1980) have all been related to algal growth rate. Of the elements that comprise algal cell tissue, 11 (C, O, H, N, P, S, K, Mg, Ca, Na, and Cl) are classified as macronutrients and 9 (Fe, Mn, Cu, Zn, B, Si, Mo, V, and Co) as micronutrients based on their percentage of ash-free dry-weight, in reference to the amounts required by cells for normal function (Reynolds 1984). The macronutrients nitrogen, phosphorus, carbon and the micronutrient silica are considered most likely to be limiting because large amounts are required by cells relative to ambient concentrations (Vollenweider 1968, Schindler 1971, 1977; Schelske and Stoermer 1972). Redfield (1958) documented the ratio of macronutrients (carbon, nitrogen, and phosphorus) contained in algal cells. Many researchers believe the same ratio (approximately 15 nitrogen : 1 phosphorus) of nutrients to be required for cell growth (Gibson 1971). Various investigators have examined the effects of micronutrient deprivation on phytoplankton growth and determined that micronutrients are no less important to algal ecology, simply that their ecological role in regulating species composition and abundance is less well

understood than that of macronutrients (Reynolds 1984).

Algal biomass in lakes frequently is considered to be primarily phosphorus-limited or will develop phosphorus limitation if homeostatic conditions are reached (Schindler 1977). Yet, it has become evident repeatedly that dissolved inorganic nitrogen also plays a role with phosphorus (Rhee 1974, Groeger and Kimmel 1988, Vanni and Temte 1990). Therefore, the dynamics of both nutrient classes must be explored to understand their effects on regulating productivity within lakes.

Phosphorus Dynamics. Phosphorus is essential for growth and function of algae as a component of genetic code in nucleic acids and high energy chemical bonds in adenosine triphosphate (Ahlgren 1988). It occurs in rocks mainly as calcium phosphates and calcium apatites in the $CaOP_2O_5H_2O$ system (Gray 1982). Dissolved phosphorus in lake water comes mainly from weathering of these rocks. The concentration fluctuates widely (between 0.1 and 1000 ug P l^{-1}) and seasonally with trends in weathering and biological transformation (Reynolds 1984). Phosphorus usually occurs in water in the oxidized state either in forms of inorganic orthophosphate ions (PO_4^{-3}) or in organic compounds (Reynolds 1984). Of the forms of phosphorus, only a few are considered ecologically significant. Polyphosphates or condensed phosphates are used as a means of corrosion control and calcium carbonate stabilization in softened waters to eliminate the need for recarbonation (Sawyer and McCarty 1978), and in detergents as water conditioners and builders. Condensed phosphates hydrolyze readily to orthophosphates (Gray 1982). Rigler cited dissolved orthophosphates as the main source of phosphorus available to phytoplankton (cf. Reynolds 1984). The forms commonly measured are total phosphorus (TP), which represents both organic and inorganic phosphorus, and soluble reactive phosphorus (SRP) or orthophosphate ($o\text{-}PO_4^{3-}P$) (Lind 1985). Many phytoplankton species also can use dissolved organic phosphorus sources through the use of alkaline

phosphotases, a process which further complicates the determination of algal-available phosphorus (Reynolds 1984). The potential for hydrolysis of polyphosphates and organic phosphates to orthophosphate may cause significant fluctuations (usually over estimation) in SRP and is one reason TP is frequently used rather than SRP as a measure of eutrophication (Wetzel and Likens 1979).

Thornton et al. (1990) described several processes that affect phosphorus dynamics in a reservoir. These include internal and external loadings, sedimentation, flow, mixing, and discharge. Concentrations in the reservoir result from watershed-wide activities which affect phosphorus transport such as agriculture, urbanization and industrialization, lake basin rock weathering, and internal nutrient recycling. Internal recycling of phosphorus occurs by various pathways including decomposition of organic matter, sediment release and recycling by zooplankton. These pathways all produce forms of phosphorus which are rapidly assimilated by phytoplankton (Moegenburg and Vanni 1991, Tizler et al. 1991).

Most important in this consideration of phosphorus dynamics is the positive correlation between phosphorus concentrations in lakes and annual primary productivity as measured in grams of carbon assimilated. Vollenweider (cf. Wetzel 1983) demonstrated this principle in his study of natural lakes in America and Europe. Positive correlations also have been identified between phosphorus concentrations and productivity as measured by chlorophyll *a* concentrations (Sakamoto 1966, Dillon and Rigler 1974).

Nitrogen Dynamics. Nitrogen is assimilated by algae primarily as a component of amino acids and proteins. Eppley and Thomas (1969) believed nitrogen to be the nutrient most likely responsible for limiting the size and growth rate of phytoplankton standing crop in marine systems, particularly coastal communities. Several commonly occurring forms of nitrogen potentially are available to algae including nitrate, nitrite,

ammonium ions, and certain dissolved organic nitrogenous compounds such as urea and free amino acids and peptides (Reynolds 1984). In addition, several species of Cyanophyta (blue-green algae) and some heterotrophic bacteria are able to fix dissolved molecular nitrogen (N_2) into ammonium in cells for conversion to amino acids (Lee 1989). This process is dependent upon anoxic conditions, as oxygen inhibits the function of the nitrogen-fixing enzyme nitrogenase, and 90% of nitrogenase activity occurs in specialized cells known as heterocysts, though non-heterocystous Cyanophyta are known to fix nitrogen through filamentous aggregation into dense clusters (Reynolds 1984). Hutchinson determined that nitrates are the dominant form of dissolved inorganic nitrogen in oligotrophic waters (cf. Harris 1986).

The resulting cycle of nitrogen dynamics is complex (Figure 3). Large amounts of nitrogen are oxidized to N_2O_5 which combines with water to form HNO_3 which is carried to the earth by rainfall (Sawyer and McCarty 1978). Inorganic nitrates are extremely soluble and may be abundant (one or two orders of magnitude higher in waters receiving substantial inputs of leachates from agricultural soils, ground water, or treated sewage effluent (Reynolds 1984). As a result of these rapid turnover rates in soils, groundwater, and lakes, nitrogen is generally abundant compared to phosphorus (Harris 1986). Ammonium may be oxidized by bacteria to nitrate through a process known as nitrification (Sawyer and McCarty 1978). Under anoxic conditions, nitrate may be reduced to ammonium by ammonification and nitrite, a product of bacterial reduction of nitrate (Harris 1986). Ammonium primarily originates from bacterial degradation of organic matter and from animal excrements. Collapse of algal blooms and destratification thus may result in temporarily elevated surface levels (Reynolds 1984). As a result of these processes, nitrite and ammonium may become abundant in eutrophic waters (Harris 1986).

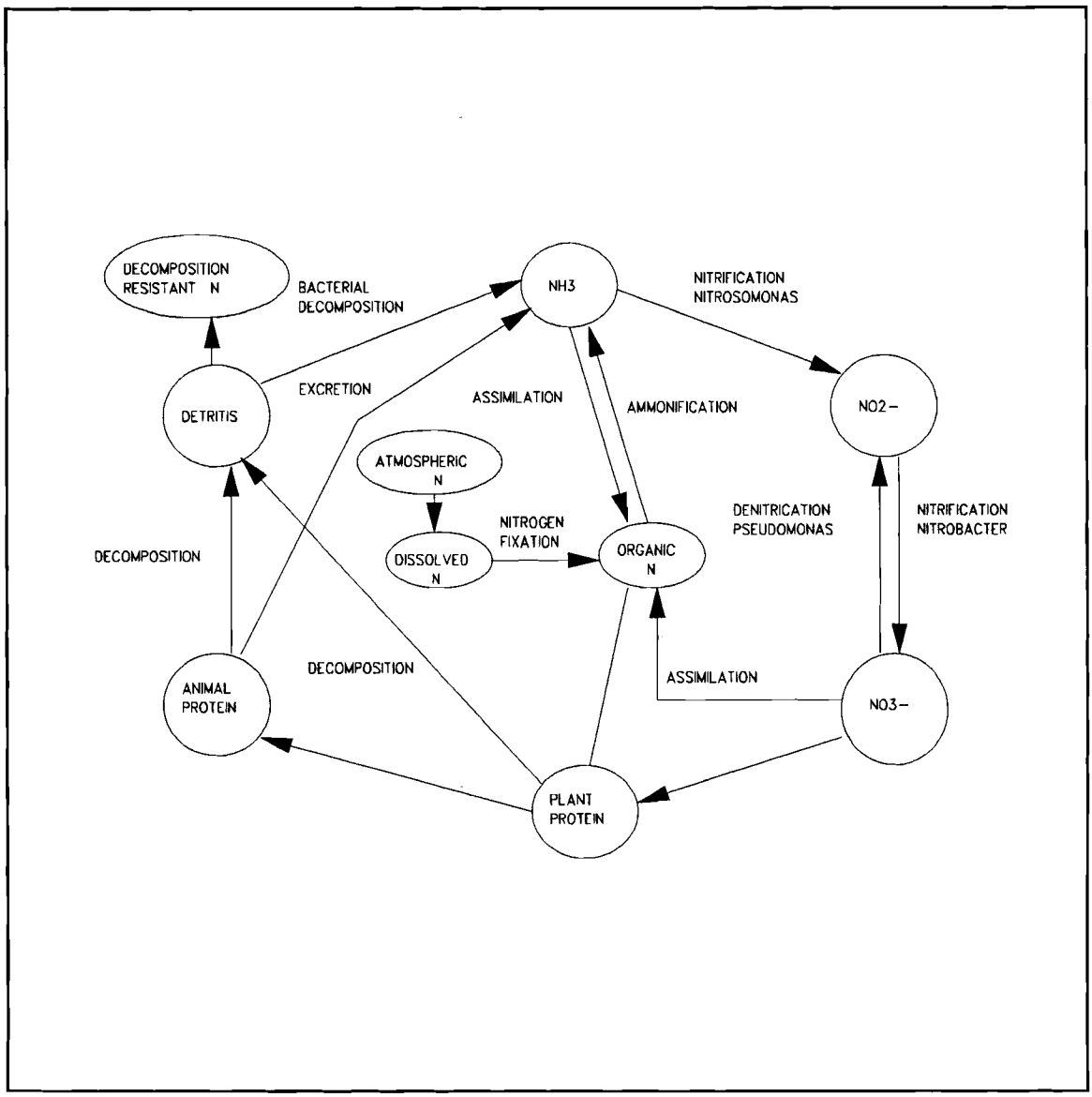

Figure 3. Nitrogen Cycle (modified from Sawyer and McCarty 1978).

Carbon Limitation. Schindler (1977) and Harris (1986) dismissed the idea that carbon limitation was important in controlling eutrophication in some lakes. The results of laboratory batch culture experiments where phytoplankton were stimulated by the addition of carbon but not other macronutrients could not be repeated in whole-lake experiments, indicating that the laboratory results may have been misleading.

Schindler offered two explanations for the inadequacy of bottle assays to predict carbon limitation: experimental closed containers greatly reduced water turbulence and interaction with the atmosphere, and proportion of alkalinity supplied by hydroxyl ions has been found to influence carbon infiltration into lake water. Harris (1986) concluded that dissolved inorganic carbon never limits lake biomass, but may effect species composition and photosynthesis. Yet, Shapiro (cf. Siegfried 1984) cited carbon limitation as a possible explanation for the dominance of blue-green algae in Lake George NY, indicating continued division in the scientific community over the importance of carbon limitation.

Reynolds (1984) described the carbon cycle which elucidates the reasoning behind Schindler's explanations for the misrepresentations by the bottle tests (Figure 4). Photosynthetic activity can cause carbon depletion by using dissolved carbon dioxide (CO_2) more rapidly than it is replenished from the atmosphere. Since pH is influenced by inorganic carbon equilibria (Figure 5), this depletion leads to an increase in pH as the equilibrium shifts from dissolved CO_2 and bicarbonate (HCO_3^-) to carbonate ions (CO_3^{2-}). The resulting conditions, e.g. lower available carbon and higher pH, may reduce the rate of photosynthesis. This potential for limitation by carbon becomes important when conducting laboratory tests and interpreting their results.

Techniques for Assessing Nutrient Limitation

A number of different methods have been developed to determine which nutrient is limiting cell growth, ranging from field tests to laboratory bioassays. Lin and Schelske (1981) subdivided laboratory methods into two groups: addition of nutrients to filtered water with inoculated laboratory cultured species, and addition of nutrients to water samples containing natural phytoplankton assemblages. In selecting the most

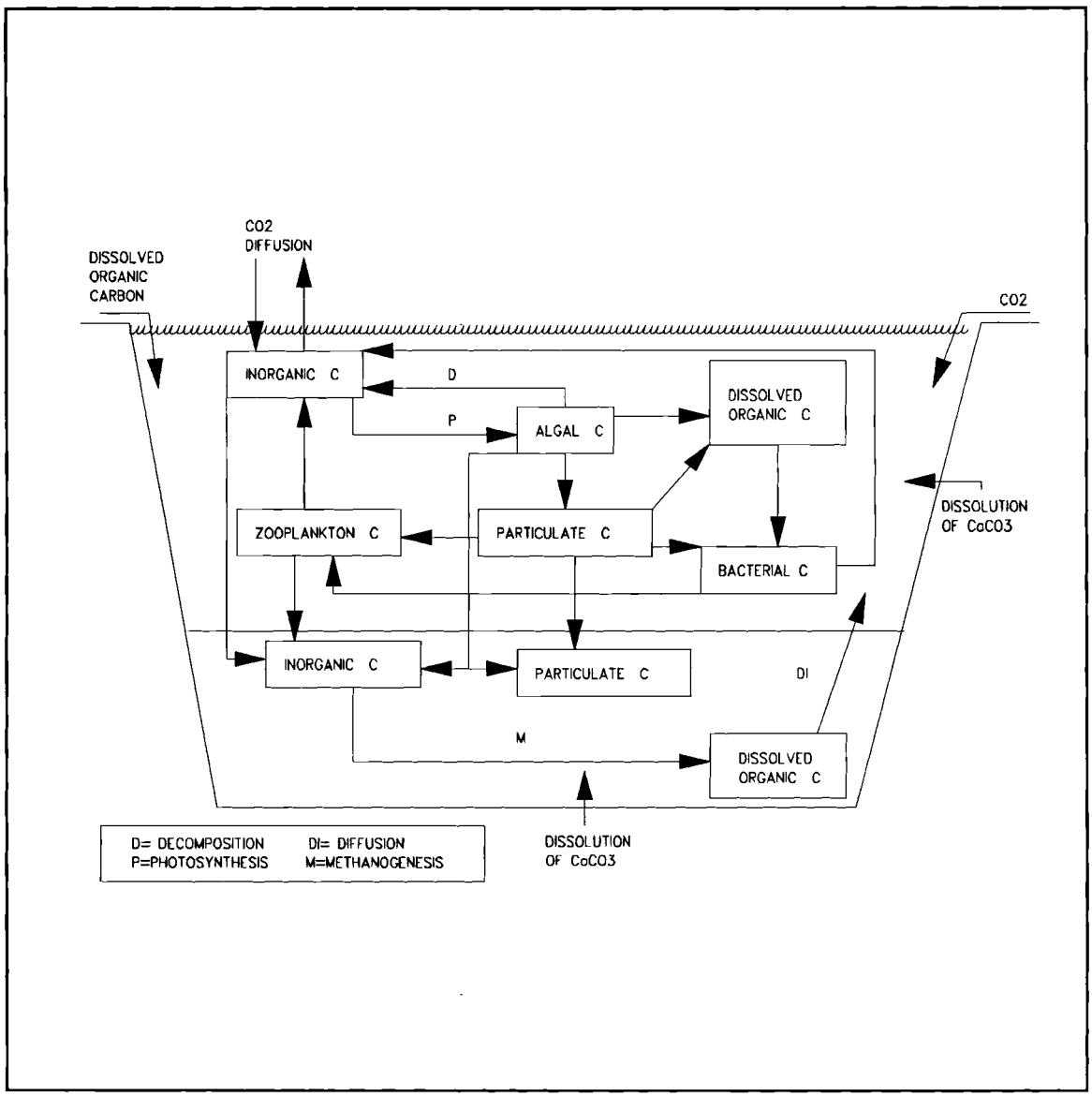

Figure 4. Carbon Cycle in Natural Waters (modified from Wetzel 1983).

appropriate method for a particular study, a researcher must consider the inherent strengths and weaknesses of available methods. Often it is advisable to use more than one type of method to combine the strong points and diminish the inadequacies of each technique.

Field Studies. The primary advantage of a field study is its element of realism.

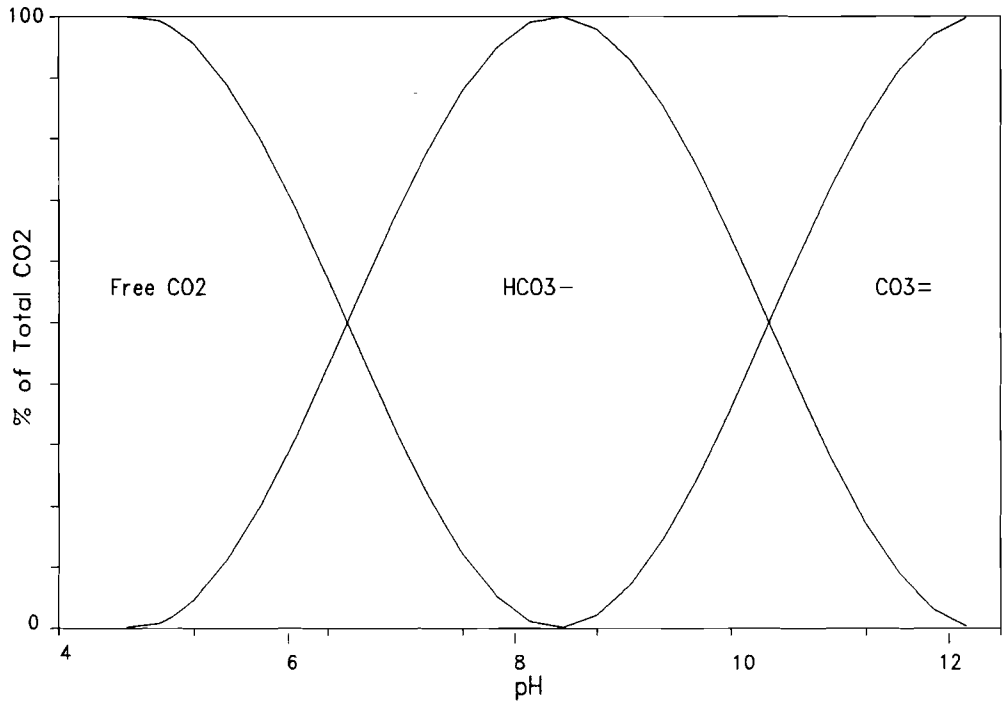

Figure 5. Relation Between pH and Inorganic Carbon Species (from Wetzel 1983).

Results are specific to location in that they incorporate spatial and temporal variation in environmental conditions such as rain, sunlight, temperature, and wind. These studies may address biotic variability by incorporating indigenous plankton assemblages. Use of phytoplankton from the natural community rather than laboratory monocultures has implications to succession as opposed to mere changes in

biomass (Schelske 1984). Field studies can incorporate biotic impacts on phytoplankton communities as well as abiotic impacts. Dawidowicz (1990) and Moegenburg and Vanni (1991) used *in situ* experiments to demonstrate effects of zooplankton on natural assemblages of phytoplankton productivity and community structure.

Baker (1984) listed several disadvantages to field methods, including: highly variable results, requiring extensive sampling, and often resulting in no measurable effect; results represent only a brief period of time and conditions; and quality assurance/quality control procedures are not well developed. Schelske (1984) added that enclosures for field algal assays affect patterns of irradiance and turbulence and thus temperature, light, nutrient dynamics, and turbulence are not the same as for phytoplankton in the rest of the water body. An enclosure large enough to reduce these effects is usually cost-prohibitive unless used for long-term studies. Another problem with field studies is the susceptibility of materials left in the field to damage from environmental elements and humans. Limnocorrals are apt to be damaged by wind or by curious weekend lake users, resulting in significant data loss unless the corrals are under constant supervision or in a restricted area.

Laboratory Assays. Laboratory assays may be less realistic in their representation of natural phytoplanktonic environments, but often yield more reliable results. Baker (1984) acknowledged several advantages to laboratory tests including: responses are amenable to extrapolation to natural conditions; results are an integrated measure of bioavailability, rather than concentrations; and results are interpreted easily and quality assurance/quality control measures are more robust. Chang et al. (1992) stated that unlike natural communities, batch culture yields are based on initial nutrient spikes, which may be greatly reduced by the termination of the experiment. However, the ability to control physical variables such as light and temperature makes

the interpretation of results less ambiguous than those of field studies. In addition, the standardization of laboratory assays allows for repeatability, both within and among laboratories.

The literature on experimental design of algal assays is divided on whether use of natural phytoplankton assemblages or laboratory monocultures is preferred. Chang et al. (1992) stated that although natural assemblages more accurately represent the algal community, shifts in species composition often occur in long-term experiments, adding uncertainty which can be avoided using a monoculture. In addition, this shift in species composition which occurs in the laboratory, may be entirely different from the one which would occur under similar test conditions *in situ*. Lin and Schelske (1981) considered seasonal succession of phytoplankton communities too important to overlook through use of a monoculture.

Succession of Phytoplankton Communities

Paradox of the Plankton

Hutchinson (1961) commented on the relatively large number of algal species which coexist within apparently uniform water conditions. He termed this phenomenon the 'paradox of the plankton' as it seems to contradict the principle of competitive exclusion which would prohibit two or more species from occupying the same ecological niche (Hardin 1960). Hutchinson (1961) suggested that since phytoplankton habitat is highly patchy (spatially and temporally) due to seasonal trends in physico-chemical conditions, the principle of competitive exclusion could be accommodated.

Tilman (1977) offered an alternative to Hutchinson's theory, citing that several species may coexist providing that they are each limited by a different factor. It has also been demonstrated that variations in availability of a limiting factor increase

species diversity (Sommer 1984), which effectively unites the two theories defining the paradox of the plankton. The same spatial and temporal variations in physico-chemical conditions and the limitation by different factors which allow several different species to coexist, also result in seasonal shifts in phytoplankton assemblages which are termed seasonal succession.

Relation of Species Composition to Nutrient Limitation

As a consequence of the differential abilities of phytoplankton to compete for and use nutrients, certain forms are able to dominate under circumstances of nutrient limitation. Lehman et al. (1975) reported that chrysophytes have the lowest minimum requirements and a high storage capacity (Lee 1989) for nitrogen and phosphorus. Under more oligotrophic conditions, where lower concentrations of nutrients are available, these species are typically dominant. Chlorophytes and cyanophytes, which typically dominate in eutrophic systems have comparatively high minimum requirements of nitrogen and phosphorus. However, chlorophytes and cyanophytes have the highest maximum growth rates of the algae (Lehmen et al. 1975) and thus are able to out-compete chrysophytes when nutrients are more abundant.

Even when nutrients are plentiful, availability can limit growth and lead to dominance of certain genera over others. Blue-green algae have several advantages in eutrophic systems. In addition to low grazing susceptibility and increased buoyancy, many species of Cyanophyta are able to fix atmospheric nitrogen, and thus are often dominant in situations where nitrogen is the limiting nutrient (deNoyelles and O'Brien 1978). Shapiro (1973) suggested that blue-greens may become dominant when carbon is limiting due to their aptitude for attaining carbon dioxide in low concentrations at high pH. Chlorophytes are more competitive than other algae when phosphorus becomes limiting in eutrophic conditions due to their differential ability to procure and

store phosphorus (Schindler 1977). In conclusion, Cyanophyta are expected to dominate under nitrogen-limiting eutrophic conditions while Chlorophyta will dominate under phosphorus limitation. Co-dominance by Cyanophyta and Chlorophyta occurs in circumstances of dual limitation. These differences in the degree to which algae are impacted by limitation are driven by season and result in seasonal succession.

Seasonal Succession: Explanation and Misinterpretations

Reynolds (1984) summarized seasonal succession as seasonal changes in phytoplankton composition and abundance during which mean specific population densities fluctuate through 6-9 orders of magnitude, or the equivalent of 20 to 30 cell divisions. These temporal variations occur on a scale of weeks or months which means that environmental conditions such as temperature and day length are likely to affect succession. South and Whittick (1987) noted that phytoplankton assemblages exhibit horizontal patchiness in abundance and species composition resulting from differences in physico-chemical conditions in the water column. In essence, this patchiness varies spatially and temporally with elastic boundaries of algal assemblages resulting in seasonal patterns of species succession. These seasonal patterns are fairly repeatable from one year to the next and are similar among lakes of the same trophic status (Reynolds 1984, Sommer et al. 1986).

Margalef (1978) determined that seasonal succession was marked by a general trend of dominance from smaller to larger species. Diatoms, which are heavily grazed, dominate spring blooms. As grazing impacts increase, dominance shifts to larger dinoflagellates and green flagellates in summer. Autumn often has a second bloom of diatoms as surface waters cool and mixing makes nutrients from the hypolimnion available. Lewis (1978) observed similar patterns of direction of

dominance shifts, from unflagellated to flagellated organisms and from smaller to larger forms.

Spatial and temporal variability of biotic and abiotic factors in many water bodies induces difficulty in the classification of a specific trophic status, but seasonal succession of algal communities can be used as a general index of trophic status (Rott 1984, Rosas et al. 1993). Rosas et al. (1993) defined the trophic status of a lake as a measure of the means by which biota respond to changes in physical and chemical conditions. Numerous studies have related trophic state to nutrient loading rates and established models to estimate lake response to particular nutrient loadings and management strategies (i.e., Shannon and Brezonik 1972). Use of phytoplankton succession patterns may provide more useful trophic indices as it measures combined effects of nutrient loadings, hydraulics, and environmental conditions specific to a certain water body and assigns a value which more accurately depicts the dynamics of the system than mere chemical or chlorophyll *a* concentrations, which more accurately depicts the dynamics of the system (Carlson 1977). This approach to trophic classification is amenable to Lindeman's (1942) trophic-dynamic approach to ecology in which the lake is considered as the primary body of interest, as all lesser communities are dependent upon it. By focusing concern on phytoplankton community dynamics, a researcher encompasses all the parameters which impact them.

The ability to classify a water body based on its trophic state is a valuable tool for scientists and managers. The ontogeny of lakes generally is believed to progress from oligotrophic to eutrophic conditions, though many case studies have shown reductions in primary productivity over time (Wetzel 1983). Recent investigations have revealed the ability of anthropogenic activities to expedite this process. As a result of this acceleration, often termed cultural eutrophication, limnologists are increasingly

concerned with establishing standardized methods to measure and define the trophic status of water bodies.

Carlson (1977) defined an index for classification of lake trophic status based on Secchi disk transparency, chlorophyll *a*, and total phosphorus. This was based on a scale of zero to 100 with a 10 unit change considered significant. Other studies base trophic classification on one or two of the above parameters. Trifonova (1989) based his classifications on multiple parameters, including Secchi depth, biomass, chlorophyll *a*, and total phosphorus content (Figure 6).

Alteration of normal successional patterns is often interpreted as a warning of increasing eutrophication (Raschke 1993). Numerous studies have related phytoplanktonic community succession in lakes of varying trophic status and identified trophic specific patterns of succession. In addition, many species are identified as indicators of certain trophic conditions based on the trophic conditions in which they consistently dominate plankton assemblages (Figure 7).

Succession Under Oligotrophic Conditions. According to Rott (1984), no clear successional pattern was observable under ultra-oligotrophic conditions; small Chrysophyceae and net plankton are present year-round. Trifonova (1989) described oligotrophic lakes as having poor phytoplankton, predominated by Chrysophyta and cold-water dinoflagellates with only one spring biomass bloom in the annual succession. Summer assemblages usually were dominated by small diatoms, chrysophytes and chlorococcales (small, coccoid green algae), with a small increase in late summer biomass due to chlorococcales blooms and small numbers of dinoflagellates (*Ceratium*) followed by a sharp decline. These results were agreeable to those compiled by Rott (1984), who cited spring communities as dominated by small, pennate diatoms, followed by small, centric diatoms in early summer and an assemblage dominated by *Ceratium* and *Peridinium* in late summer. Duarte et al.

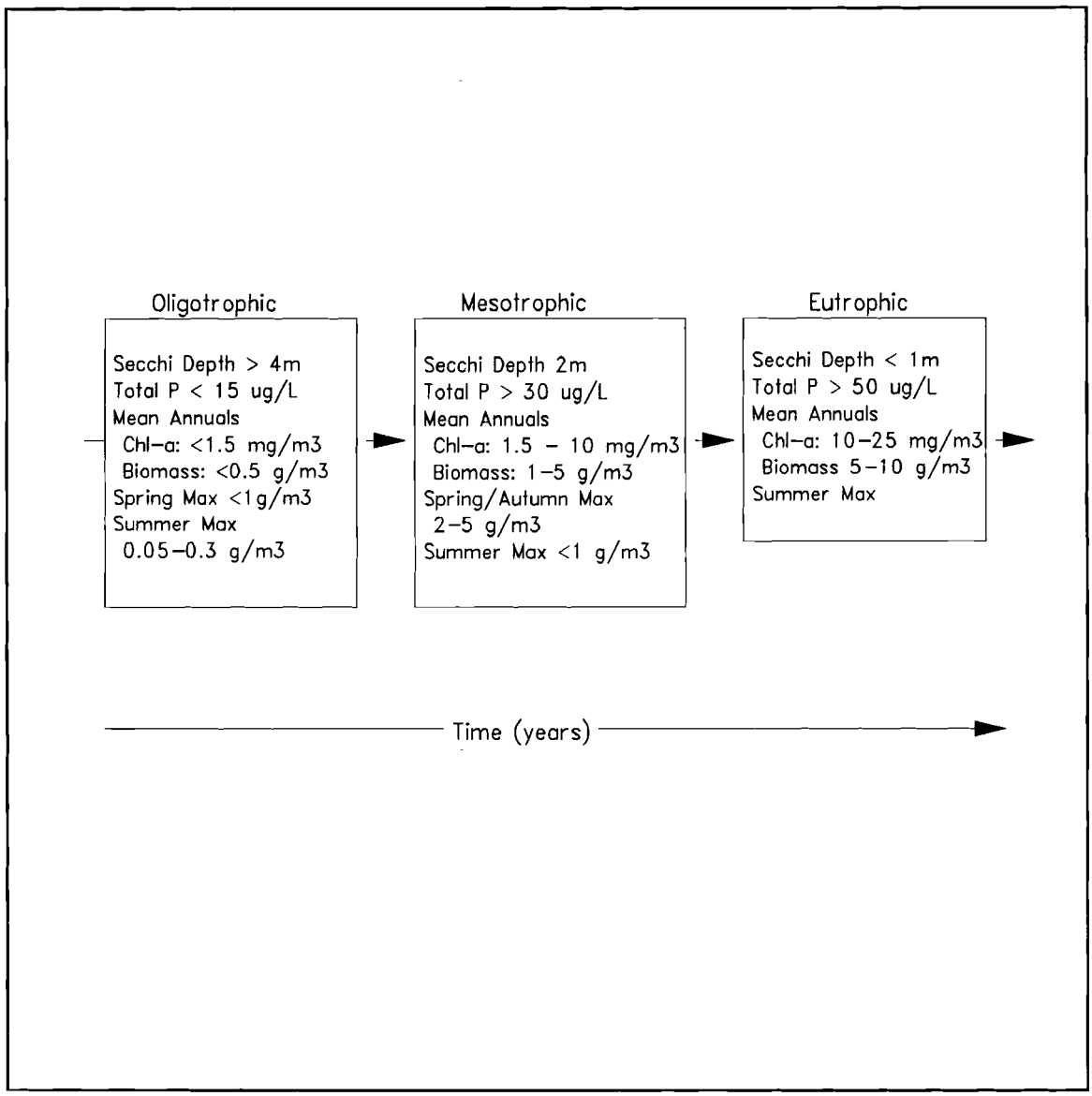

Figure 6. Parameter Bounds in Trophic State Succession (Trifonova 1989).

(1992) found the dominant genera in oligotrophic Florida lakes to be green algae.

Mesotrophic Seasonal Succession. Mesotrophic bodies of water typically exhibit a spring bloom of small chrysophytes which moves toward small centric diatoms and/or small, coccoid green algae in early summer. Late summer is characterized by *Ceratium-Peridinium* assemblages or specific cyanophytes, followed by fall blooms

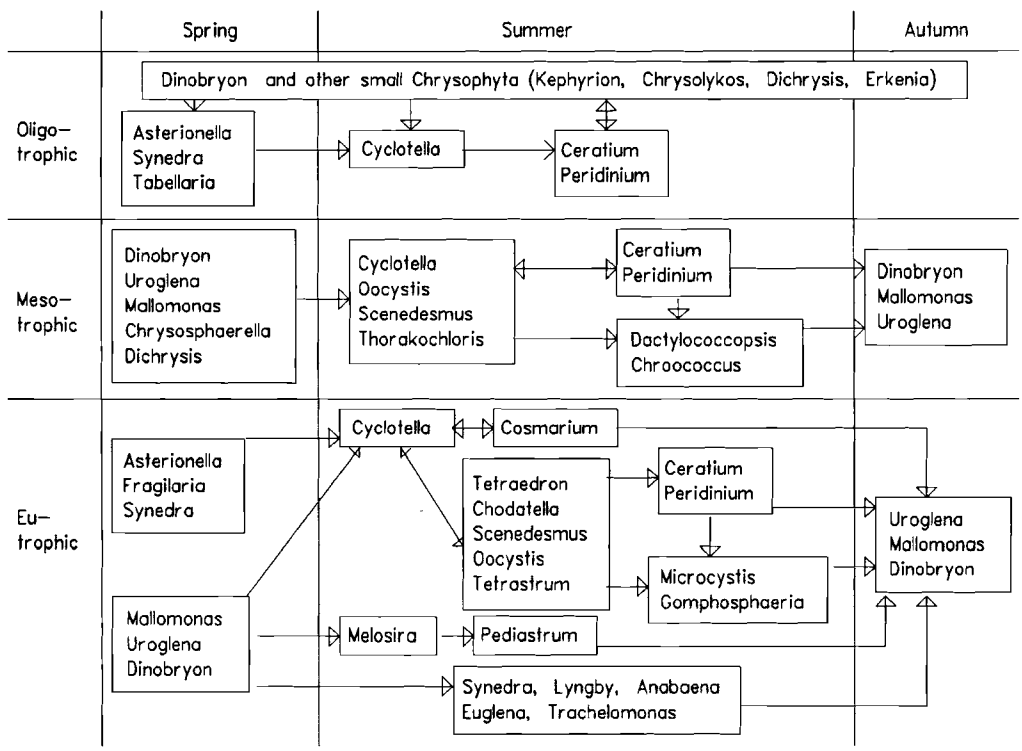

Figure 7. Trophic Specific Succession (from Rott 1984).

dominated by Chrysophyta (Rott 1984). Happey-wood (cf. Rosas et al. 1993) proposed *Ankistrodesmus, Chlorella, Oocystis, Cryptomonas, Rhodomonas, Oscillatoria, Anabaena, Aphanizomenon,* and *Microcystis* to be characteristic of mesotrophic conditions. Trifonova (1989) characterized mesotrophic succession as spring and autumn peaks of diatoms (*Melosira*) or Chrysophytes (*Dinobryon*). Rapid declines in

biomass occur in late spring, followed by a short, clear water phase after which a summer peak of diatoms, dinoflagellates (*Ceratium*), and cyanophytes (*Anabaena, Aphanizoma* and *Microcystis*). Duarte et al. (1992) characterized mesotrophic lakes as having highly variable species composition, but generally diatoms (e.g., *Melosira*) were dominant.

Succession in Eutrophic Systems. Lampert et al. (1986) described typical seasonal succession in a eutrophic lake as having a spring bloom composed of diatoms and small flagellates following ice melt which shifts to a late summer community dominated by cyanophytes. A clear-water period may occur between these two communities during which biomass as measured by chlorophyll *a* and transparency as measured by Secchi depth are high. Hutchinson (1967) considered diatoms *Asterionella, Fragilaria, Synedra, Melosira,* and *Stephanodiscus* to be indicative of eutrophic conditions. Margalef (cf. Rosas et al. 1993) classified *Asterionella, Fragilaria, Anabaena, Microcystis*, and *Oscillatoria* as eutrophic species. Rott (1984) described seasonal succession in eutrophic systems as being similar to that in mesotrophic systems. Summer blooms are usually composed of chlorophyta (green algae), particularly small, coccoid forms or *Cosmarium*. Late summer blooms are typically composed of cyanophytes. Trifonova (1989) added that maximum biomass occurred in July-August and was attributed to cyanophytes, dinoflagellates, and chlorophytes. Smaller blooms in spring and late Autumn were dominated by diatoms (*Melosira* and *Synedra*). Duarte et al. (1992) also considered cyanophytes to be indicative of eutrophic systems.

CHAPTER III

MATERIAL AND METHODS

Study Site

Tenkiller Ferry Lake, located in Cherokee and Sequoyah counties, Oklahoma, was chosen as the study site because it has recently exhibited symptoms of cultural eutrophication, specifically high algal productivity (Nolen et al. 1989); a Clean Lakes Phase I study is currently in progress; basin morphometry favors longitudinal gradients; its mainstem, the Illinois River, is the subject of considerable controversy concerning water quality problems warranting remedial measures; and in addition to recreational value, Tenkiller is a water source for several communities and the effects of planktonic community management could have a negative impact on municipal water supplies.

Tenkiller Ferry Lake was completed in 1952 by the U.S. Army Corps of Engineers (USACE). The dam is located on the Illinois River, 20.6 km above its confluence with the Arkansas River. The reservoir is 40 km long; has a surface area of 5223 ha; 209 km of shoreline; and a volume of 80,650 ha-m at normal pool (Nolen 1989). Tenkiller's drainage area covers approximately 4170 km^2 in Arkansas and Oklahoma. The reservoir has a mean depth of 16 m with a maximum of 42 m near the dam. In addition to water supply, the reservoir provides flood control, hydropower and recreation. Because recent studies (Nolen et al. 1989) have indicated increased eutrophication, Tenkiller provides an excellent setting for phytoplankton assemblage surveys to be coupled with nutrient limitation assays.

The U.S. Environmental Protection Agency (EPA) currently is funding a Clean Lakes Phase I study being conducted by the Oklahoma State University Water Quality Research Lab. Water quality data from that study will be correlated with phytoplankton community assemblages and nutrient limitation assay results.

Sampling stations were chosen to coincide with those of the EPA study. Sampling stations were based on lake morphometry and previously established water quality trends. These stations include one in the headwaters and six in the mainstem of the reservoir. The headwater station was located at the access point at Horseshoe Bend, a location suspected to be most heavily impacted by allochthonous inputs (Figure 8, Table I). Station 2 was located in the mouth of the Caney Creek arm and Station 3 in the mouth of the Dry Creek arm. Station 4 was located at the point where the reservoir shows significant increases in width and depth, below the Highway 82 bridge between Elk Creek and Cherokee landings. Station 5 was located off the island near Petit Bay. Station 6 was located downstream from the island near Chicken Creek. The final mainstem station (Station 7) was located in the deepest part of the impoundment, off the south face of the small island northeast of the dam.

Chemical Analyses

Profiles of dissolved oxygen, temperature, and conductivity for the six mainstem stations and surface readings of these parameters at Station 1 were recorded from 14 Feb 92 to 21 Oct 93 (Table II). In addition to those parameters, turbidity and pH were recorded for water samples collected with a 2 ℓ Van Dorn sampler 0.5 m below the surface and 0.5 m above the sediment at each of the seven stations. Portions of these samples were then transferred to acid washed high-density polyethylene (HDPE) bottles, stored on ice, returned to the lab, and analyzed within 48 hours. These analyses included orthophosphate and total phosphorus using Lind's (1985) persulfate

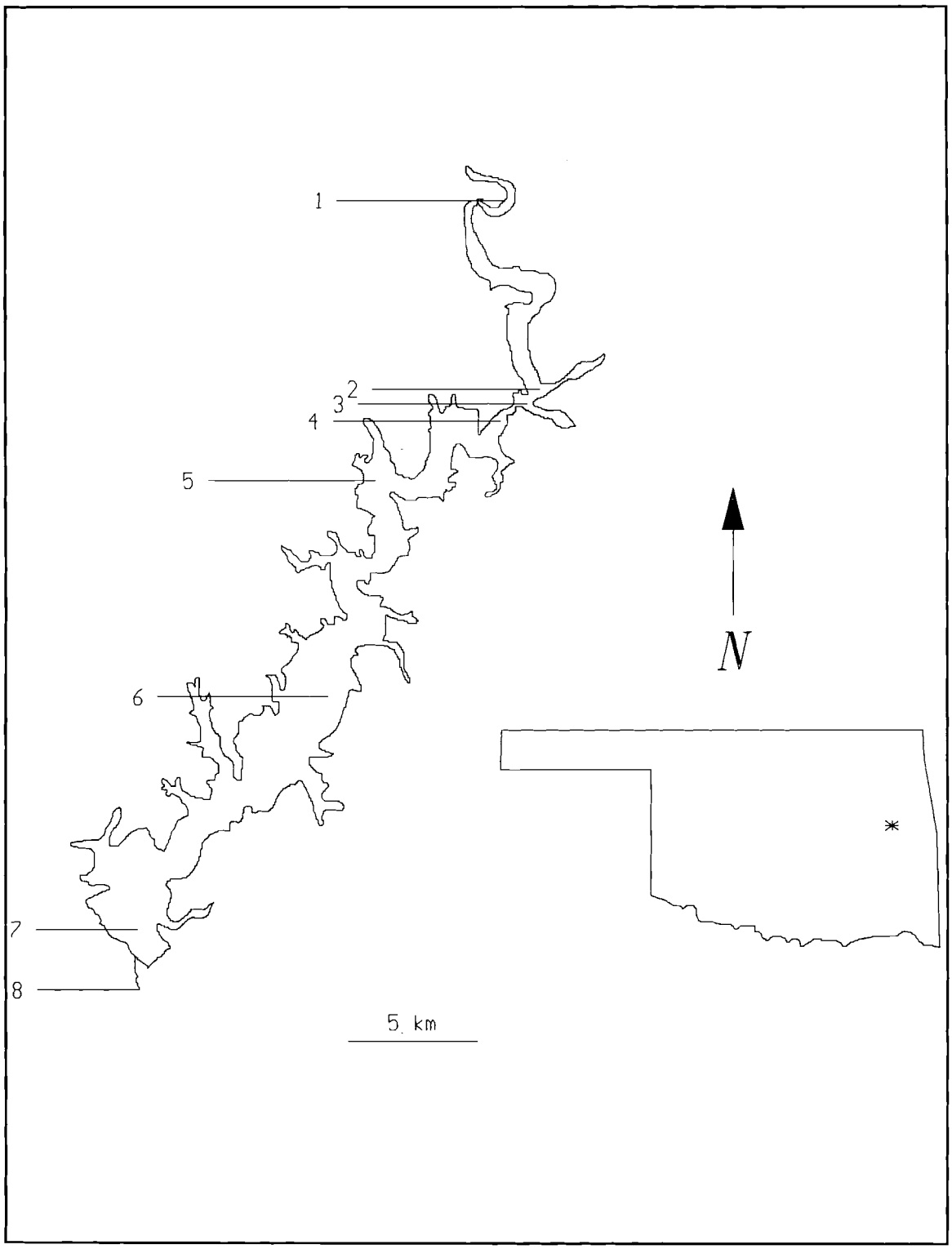

Figure 8. Tenkiller Ferry Lake Sampling Stations.

Table I. Geographic Position of Sampling Stations.

Station	Latitude	Longitude
1	35°49.24 N	94°54.18 W
2	35°46.01 N	94°53.16 W
3	35°45.79 N	94°53.52 W
4	35°45.39 N	94°54.36 W
5	35°44.25 N	94°57.18 W
6	35°40.54 N	94°58.59 W
7	35°36.21 N	95°02.88 W
8	35°35.48 N	95°03.55 W

digestion/molybdate colorimetric procedure. Samples were also analyzed for Cl, NO_2-N, NO_3-N and SO_4^{3-} using a Dionex System 12 Ion Chromatograph (IC). Total nitrogen was analyzed using Bachman and Canfield's method (1991). Nitrogen to phosphorus (N:P) ratios were calculated using both orthophosphate and total phosphorus. Since N:P ratios are normally determined for unfiltered, unautoclaved samples using orthophosphate, yet samples for algal assays were autoclaved for sterilization and solubilization of nutrients, N:P ratios using total phosphorus were appropriate. Total alkalinity, phenolphthalein alkalinity and total hardness as mg $CaCO_3$ were analyzed using Lind's (1985) method. Concurrent samples were collected 0.5 m below the surface in 1 ℓ opaque non-acid washed HDPE bottles, stored and transported as previously described, and returned to the lab for chlorophyll *a* analysis as described by Lind (1985).

Trophic status was estimated using Carlson's trophic state index (TSI) (Carlson 1977). A TSI was calculated for stations one through seven using chlorophyll *a*

Table II. Sample Collection Dates.

Sampling date	Algae sample	AA:BT water	Sampling date	Algae sample	AA:BT water
14 FEB 92	+	-	26 MAY 93	+	-
25 APR 92	+	-	25 JUN 93	+	-
04 JUN 92	+	-	25 JUL 93	+	-
04 JUL 92	+	-	04 AUG 93	+	+
01 AUG 92	+	-	18 AUG 93	+	-
19 AUG 92	+	-	02 SEP 93	+	+
12 SEP 92	+	-	15 SEP 93	+	-
24 OCT 92	+	-	01 OCT 93	+	+
08 MAR 93	+	-	21 OCT 93	+	-
18 APR 93	+	-			

AA:BT: Algal Assay : Bottle Test

values collected during summer stratification. Use of biological data, such as chlorophyll *a*, was recommended by Carlson to provide data which was most free from interferences such as turbidity or high humic acid content. Carlson also suggested using data collected during summer stratification to reduce the variability in chlorophyll *a* caused by spring and fall mixing. Differences between the TSI's at different stations were detected based upon quartile distributions.

In the interests of quality assurance/quality control (QA/QC) procedures, triplicates of at least one sample were analyzed for each of the laboratory parameters. In addition, EPA lab certification standards and HACH standards of known concentrations were tested as unknowns. Field blanks of double deionized water in

appropriate HDPE bottles (acid washed or non-acid washed for chlorophyll *a*) were transported to the field, stored on ice,and returned for analysis. Laboratory blanks of double deionized water were also analyzed as unknowns.

Nutrient Limitation Assays

Samples from the above stations at 0.5 m below the surface were collected in the manner previously described, stored in non-acid washed 1 ℓ HDPE bottles on ice, and transported to the lab for use in the Printz Algal Assay: Bottle Test (Miller et al. 1978) on 4 August, 3 September, and 1 October 1993. These dates were chosen because late summer is a period of stabilization in planktonic communities and physico-chemical conditions. Coupled with a date in October when conditions first began to destabilize, these dates should provide the best estimate of nutrient limitation as it relates to indigenous phytoplankton communities.

Axenic cultures of *Selenastrum capricornutum* obtained from Dr. Richard Starr at the University of Texas at Austin were grown to log-growth phase and used to inoculate samples. Samples were spiked with additions of nitrogen, phosphorus, disodium ethylenedinitrilo tetraacetate (EDTA), and nitrogen + phosphorus (Table III). EDTA is a chelator which insures that trace minerals in water are available for algae. Twenty-five ml samples were cultured for 14 days under constant temperature and light intensity in 125 mℓ erlenmeyer flasks with foam stoppers. Correction for variable light and temperature within the constant temperature room and regulation of CO_2 availability and pH were maintained by shaking and rotating samples at least four times daily. Samples from one randomly chosen station were cultured in triplicate and results compared to estimate standard deviations. In addition field blanks as described above were cultured as blank controls.

On days 7, 9, 11, 13, and 14, sample turbidity was measured at 678 and 750 nm

Table III. Definition of Nutrient Additions.

Sample ID
Control
Control + 0.05 mg P/l as K_2HPO_4
Control + 1.00 mg N/l as $NaNO_3$
Control + 1.00 mg EDTA/l
Control + 0.05 mg P/l as K_2HPO_4 + 1.00 mg N/l as $NaNO_3$

using a Secomam S.1000G UV-visible spectrophotometer and used to estimate growth curves. Ocular counts of a least four samples were conducted on day 14 according to Lind's (1985) counting method using a Palmer-Maloney cell. A linear regression was performed using the software package QUATTRO-PRO® to correlate ocular counts with turbidity and estimate cells/mℓ. According to Miller et al. (1978), growth rate should not be used as a growth parameter as it is indirectly related to external nutrient concentrations. Therefore, maximum standing crop (MSC) expressed as cells/mℓ is the growth parameter reported. The nutrient whose addition resulted in the greatest increase in MSC was termed the limiting nutrient.

Phytoplankton Community Structure

Phytoplankton grab samples were collected from mainstem stations concurrent with water samples from 0.5 m below the surface. They were preserved with Lugol's solution as described by Lind (1985) and returned to the lab to be stored at 4° C in the dark until they could be identified and enumerated. Samples were concentrated by centrifugation then analyzed in triplicate by the field method using a Palmer Maloney

cell (Lind 1985). Dominant genera were identified and counted.

Species composition was compared with algal assay results to determine whether nutrient limitation drives species composition. Annual trends in species composition were established for riverine, transition and lacustrine zones based on samples from Stations 2, 5, and 7.

Statistical Analysis

Statistical methods were conducted according to procedures outlined in Steele and Torrie (1980) using QUATTRO-PRO® and SYSTAT® software. Longitudinal zonation as depicted by physico-chemical parameters was tested for using the Mann-Whitney Test as described by Zar (1974). Nutrient limitation was verified by treatment culture growths which were significantly different ($\alpha = 0.05$) from growth of control cultures. Longitudinal zonation of phytoplankton communities as measured by community indices such as total cell count, species diversity, ratio of pennate to centric diatoms and percent blue-green algae was also tested for using the Mann-Whitney test. Phytoplankton community indices were related to physico-chemical parameters via canonical correspondence analysis of transformed data using SYSTAT® software. The data were transformed to account for differences in the magnitude of values. Nutrient limitation was also related to phytoplankton community indices in such a manner.

CHAPTER IV

RESULTS AND DISCUSSION

Limnological Data

Lake Tenkiller displayed decreasing values of epilimnetic orthophosphate, total phosphorus and turbidity from station 1 to station 7 (Table IV). This trend was also exhibited by nitrogen species; however, mean total nitrogen values were slightly higher at station 7 than station 6 and mean nitrate nitrogen values were greater at stations 6 and 7 than station 5. These values were to be expected given the morphometric characteristics of the reservoir. Increases in depth and width of the reservoir between stations 2 and 4 resulted in decreases in water velocity which in turn allowed suspended particles to settle out. The dilution factor of nutrients further increased with proximity to the dam due to increases in lake basin width and depth. This trend was in accordance with Thornton et al.'s (1990) explanation of the longitudinal zonation of reservoirs.

Mean chlorophyll *a* concentrations peaked around stations 3 and 4, then decreased toward station 7. This trend was also in agreement with Thornton et al. (1990) who suggested phytoplankton are light limited in the more turbid headwaters of a reservoir. However, as particles settle out yet nutrient concentrations remain relatively high, primary productivity peaks. Finally, as dilution continues to decrease nutrient concentrations, decreases in chlorophyll *a* follow.

Table IV. Epilimnetic Nutrient Concentration Statistics of Lake Tenkiller.

PARAMETER	STATION	MEAN	MEDIAN	S	n
o-PHOSPHATE	1	0.11	0.09	0.05	16
(mg/ℓ)	2	0.05	0.04	0.03	18
	3	0.04	0.03	0.03	18
	4	0.04	0.03	0.03	18
	5	0.03	0.02	0.03	18
	6	0.02	0.01	0.02	18
	7	0.02	0.01	0.02	18
TOTAL	1	0.14	0.12	0.07	16
PHOSPHORUS	2	0.08	0.08	0.03	18
(mg/ℓ)	3	0.08	0.08	0.04	18
	4	0.08	0.07	0.04	18
	5	0.05	0.05	0.03	18
	6	0.04	0.02	0.04	18
	7	0.03	0.02	0.04	18
NITRATE	1	1.27	1.18	0.56	16
(mg/ℓ)	2	0.53	0.46	0.44	17
	3	0.49	0.36	0.45	18
	4	0.46	0.34	0.42	18
	5	0.38	0.21	0.38	18
	6	0.44	0.30	0.40	18
	7	0.47	0.30	0.36	18
TOTAL	1	2.25	2.18	1.00	16
NITROGEN	2	1.45	1.16	0.75	17
(mg/ℓ)	3	1.40	1.23	0.77	17
	4	1.34	1.17	0.66	17
	5	1.06	0.79	0.60	17
	6	0.97	0.74	0.59	17
	7	1.01	0.74	0.64	17

S = Standard Deviation; n = sample size

Table IV. Continued.

PARAMETER	STATION	MEAN	MEDIAN	S	n
TN:TP	1	17.95	14.86	8.60	16
	2	18.66	15.74	8.70	17
	3	19.58	16.95	10.95	17
	4	18.75	15.64	9.53	17
	5	21.23	15.06	15.71	17
	6	31.34	27.47	21.69	17
	7	44.04	26.40	39.72	17
CHLOROPHYLL-a	1	8.16	2.55	16.97	16
($\mu g/\ell$)	2	25.82	28.60	15.41	22
	3	27.51	28.01	13.64	18
	4	26.23	28.66	11.35	18
	5	17.63	15.62	9.87	22
	6	13.42	11.62	8.22	22
	7	12.60	8.95	10.38	18
PHAEOPHYTIN	1	1.27	1.06	1.41	15
($\mu g/\ell$)	2	1.15	0.60	1.39	21
	3	1.67	1.30	1.66	17
	4	2.16	1.43	2.35	17
	5	1.15	0.52	1.68	21
	6	0.76	0.13	1.41	21
	7	1.04	0.07	1.70	17
TURBIDITY	1	13.67	8.70	10.36	11
(NTU)	2	11.11	6.30	11.04	15
	3	14.26	8.30	14.63	15
	4	8.03	5.80	5.31	14
	5	6.22	4.50	6.39	15
	6	4.18	2.25	5.30	15
	7	3.81	2.10	5.54	15

S = Standard Deviation; n = sample size

Longitudinal Zonation

Riverine Zone

Orthophosphate, total phosphorus, nitrate, total nitrogen, and chlorophyll *a* concentrations at station 1 were significantly higher ($\alpha = 0.01$) than other in-lake stations (Table I). Nephelometric turbidity measurements indicated no significant difference in turbidity at stations 1, 2, 3 or 4. Secchi depths were not measured at station 1 as data was collected from the shore, rather than in the pelagic zone. The ratio of total nitrogen to total phosphorus (TN:TP) was not significantly different among stations 1, 2, 3, 4, or 5.

Turbidity was similar from station 1 through 4, and, along with Secchi depth measurements, placed stations 1 through 4 in the riverine zone. However, as Secchi depths were not measured at station 1, Secchi depth was not weighed as heavily in determining longitudinal zonation as other variables. In addition, because statistical analysis of nitrate and TN:TP did not divide lake stations into at least three groups of stations which were significantly different from one another, those parameters were not given equal weight in determination of lake zonation. Thus, because phosphorus, nitrogen, and chlorophyll *a* concentration were significantly higher at station 1 than other stations, I concluded that the riverine zone included station 1 but generally terminated before reaching stations 2, 3 or 4.

Transition Zone

Orthophosphate, total phosphorus and total nitrogen concentrations between stations 2, 3 and 4 were not significantly different. Nitrate concentrations were not significantly different between stations 2 through 7, indicating that nitrate concentrations were not a useful tool in delimiting Tenkiller longitudinal zonation.

Table V. Statistical significance of Epilimnetic Nutrient Concentrations Using the Mann-Whitney Test.

NUTRIENT		ST1	ST 2	ST 3	ST 4	ST 5	ST 6
Orthophosphate (mg/ℓ)	2	**	--	--	--	--	--
	3	**	NS	--	--	--	--
	4	**	NS	NS	--	--	--
	5	**	**	**	*	--	--
	6	**	**	**	**	NS	--
	7	**	*	**	**	*	NS
Total Phosphorus (mg/ℓ)	2	**	--	--	--	--	--
	3	**	NS	--	--	--	--
	4	**	NS	NS	--	--	--
	5	**	**	**	*	--	--
	6	**	**	**	**	*	--
	7	**	**	**	**	**	NS
Nitrate (mg/ℓ)	2	**	--	--	--	--	--
	3	**	NS	--	--	--	--
	4	**	NS	NS	--	--	--
	5	**	NS	NS	NS	--	--
	6	**	NS	NS	NS	NS	--
	7	**	NS	NS	NS	NS	NS
Total Nitrogen (mg/ℓ)	2	**	--	--	--	--	--
	3	**	NS	--	--	--	--
	4	**	NS	NS	--	--	--
	5	**	*	NS	NS	--	--
	6	**	NS	*	*	NS	--
	7	**	**	*	**	NS	NS

* = significant (α = 0.05); ** = highly significant (α = 0.01)

NS = not significant

Table V. Continued.

PARAMETER		STATION					
		1	2	3	4	5	6
TN:TP	2	NS	--	--	--	--	--
	3	NS	NS	--	--	--	--
	4	NS	NS	NS	--	--	--
	5	NS	NS	NS	NS	--	--
	6	**	**	**	**	**	--
	7	**	**	**	**	**	NS
CHLOROPHYLL-a ($\mu g/\ell$)	2	**	--	--	--	--	--
	3	**	NS	--	--	--	--
	4	**	NS	NS	--	--	--
	5	**	NS	*	**	--	--
	6	**	*	**	**	*	--
	7	**	**	**	**	**	NS
TURBIDITY (NTU)	2	NS	--	--	--	--	--
	3	NS	NS	--	--	--	--
	4	NS	*	NS	--	--	--
	5	**	**	*	*	--	--
	6	**	**	**	**	*	--
	7	**	**	**	**	**	NS
SECCHI DEPTH (Meters)	2	--	--	--	--	--	--
	3	--	NS	--	--	--	--
	4	--	NS	NS	--	--	--
	5	--	**	**	**	--	--
	6	--	**	**	**	**	--
	7	--	**	**	**	**	NS

* = significant (α = 0.05); ** = highly significant (α = 0.01)

NS = not significant

Orthophosphorus and total phosphorus concentrations as well as turbidity at stations 2,

3, and 4 were significantly higher ($\alpha = 0.05$) than stations 5, 6, and 7. Total nitrogen concentrations at station 2 were not significantly different from those at stations 3, 4 or 6. No significant difference existed between chlorophyll *a* concentrations at station 2, 3, or 4 though concentrations at only stations 3 and 4 were significantly higher than station 5. No significant difference between nephelometric turbidity or Secchi depth was determined for stations 2, 3, and 4. Secchi depth at station 2 was not significantly different from those at stations 3 or 4 but was significantly ($\alpha = 0.01$) less than those at stations 5, 6, and 7.

Assuming the riverine zone included only station 1, use of phosphorus, nitrogen and, chlorophyll *a* concentration and Secchi depth gradients to determine longitudinal zonation of Lake Tenkiller would include stations 2, 3, and 4 in the transition zone. Nephelometric turbidity gradients placed station 5 in the transition zone. As the majority of the parameters grouped stations 2, 3, and 4 as not being significantly different from each other, the transition zone was likely to include these stations for most of the year. Given the migratory nature of longitudinal zonation (Thornton et al.1990), station 5 could sometimes be included in the transition zone.

Lacustrine Zone

Though orthophosphate concentrations did not differ significantly among stations 5, 6, and 7, total phosphorus was significantly higher ($\alpha = 0.05$) at station 5 than stations 6 and 7. No significant difference existed between total phosphorus concentrations at stations 6 and 7. Though station 5 did not differ significantly in total nitrogen concentrations from stations 3, 4, 6 or 7, station 4 concentrations were significantly ($\alpha = 0.05$) greater than stations 6 and 7. Chlorophyll *a* concentrations and turbidity at station 5 were significantly ($\alpha = 0.01$) greater than those at 6 and 7. No significant difference existed between concentrations or turbidity at station 6 and

7. Secchi depth at station 5 was significantly less than at stations 6 and 7 but no significant difference existed between secchi depth at 6 and 7.

Use of phosphorus, total nitrogen, and chlorophyll *a* concentration gradients as well as turbidity and Secchi depth to determine longitudinal zonation of Lake Tenkiller generally placed stations 5, 6, and 7 in the lacustrine zone. Though station 5 differed significantly from stations 6 and 7 in to total phosphorus, nitrogen species, chlorophyll *a*, Secchi depth, and turbidity, significant differences exist with regard to several parameters between station 5 and stations 2, 3, and 4, leading to the conclusion that station 5 was near the gradient between the transition and lacustrine zone. I assumed that though station 5 sometimes exhibited characteristics of the transition zone, it was more often associated with the lacustrine zone. Finally, the longitudinal zonation of reservoirs is seasonally dynamic; *i. e.*, no abrupt boundaries exist between zones but rather zone delineation is temporarily and spatially variable. Although a station may not always fall into the same reservoir zone, for the purposes of this study, stations are assumed to fall within the same zone year-round.

Trophic Status of Reservoir Zones

The trophic structure of an aquatic system is defined by the qualitative and quantitative aspects of energy transfer (Lindeman 1942). Calculation of a trophic state index (TSI) produces a simple measure of these energy transfers. TSI values, illlustrated in Box and Whisker format (Figure 9) from Lake Tenkiller support the distribution of lake zonation as established by comparison of physico-chemical parameters from within the lake. Box and Whisker plots illustrate an entire data range: error bars represent minimum and maximum values; top and bottom of the box represent upper and lower quartiles, respectively; median values are illustrated by the midline in the box; the notch represents the approximate statistical domain; and box

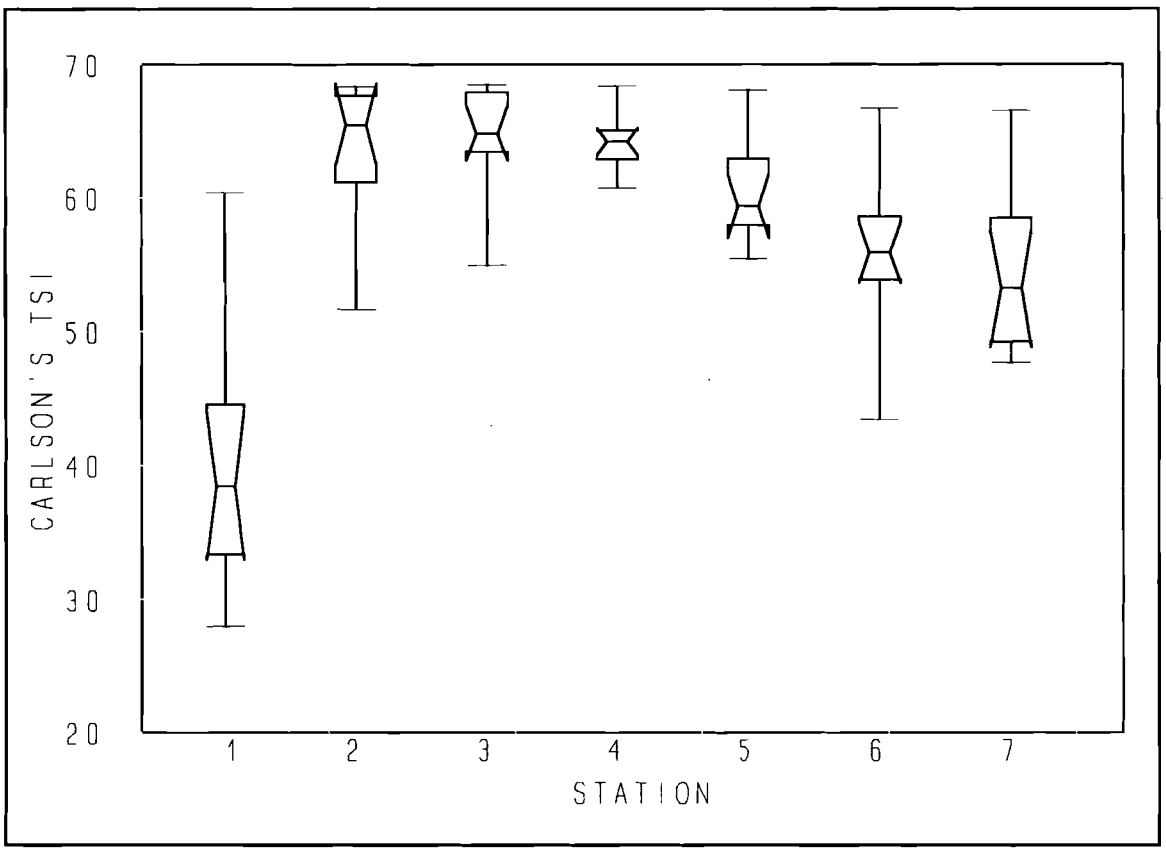

Figure 9. Carlson's Trophic State Index (TSI-chlorophyll *a*) for Lake Stations.

width is representative of sample size. TSI's for Tenkiller could have been used to classify station 1 as mesotrophic, stations 2 - 4 as hypereutrophic, and stations 5 - 7 as eutrophic (Carlson 1979). The classification of station 1 as mesotrophic was most likely due to higher turbidity which inhibited phytoplankton productivity. Trophic status based upon total phosphorus (Carlson 1979) would classify stations 1- 4 as hypereutrophic and stations 5, 6, and 7 as eutrophic (Figure 10).

Nutrient Limitation Assays

In nutrient limitation assays, potential nutrient limitation is defined by significant differences in biomass between control and treatments (Table VI). Statistically significant ($\alpha = 0.05$) differences between phosphorus and phosphorus plus nitrogen

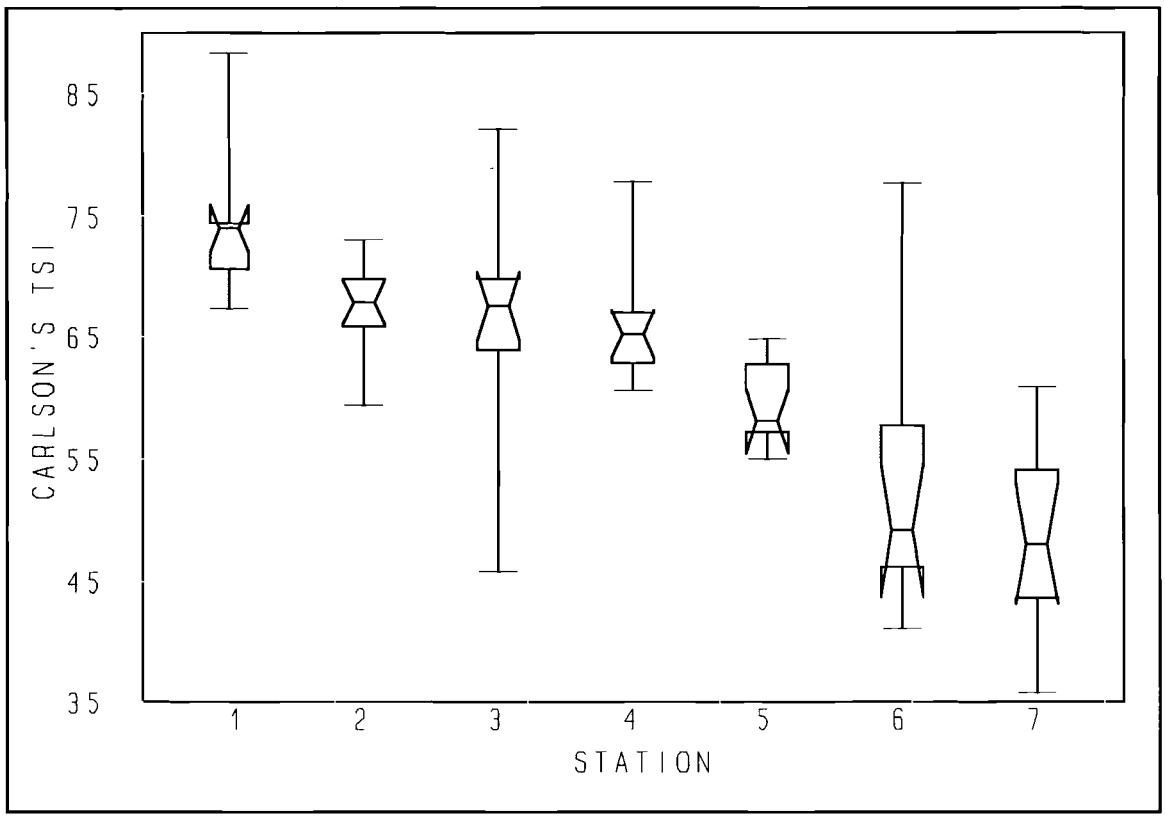

Figure 10. Carlson's Trophic State Index - Total Phosphorus.

spiked treatments and controls for 4 Aug 1993 indicated phosphorus limitation at all in-lake stations (Figure 11). Results from 2 Sep 1993 displayed more variable limitation (Figure 11). Station 2 exhibited nitrogen limitation; stations 1, 3, 4, and 5 displayed dual limitation, both phosphorus and nitrogen were needed; and results from stations 6 and 7 indicated phosphorus limitation. On 1 Oct 1993, stations 2, 3, 5, 6, and 7 displayed phosphorus limitation (Figure 11). Stations 1 and 4 exhibited dual limitation of nitrogen and phosphorus.

Longitudinal Zonation of Nutrient Limitation

Nutrient limitation was variable between the longitudinal zones of the reservoir as determined from physico-chemical parameters. Results from the riverine zone,

Table VI. Interpretation of Nutrient Limitation Assay Results (Adapted from Page et al. 1985).

NUTRIENT SPIKE					RESULT
P	N	P + N	EDTA	C	
*	NS	*	NS	0	Phosphorus Limited
NS	*	*	NS	0	Nitrogen Limited
NS	NS	*	NS	0	Dual Limitation
NS	NS	NS	*	0	Trace Element Limitation
*	*	*	*	0	Dual Limitation

P = phosphorus enriched, N = nitrogen enriched, EDTA = EDTA enriched, C = control, * = Significant (α = 0.05) difference in growth over controls, NS = no significant growth over that of controls.

though limited, indicated that both nitrogen and phosphorus were limiting (Figures 12, 13). Results in the transition zone were much more variable, as expected given the definitive characteristics of the zone, where nitrogen, phosphorus, and dual limitation were indicated (Figure 11). Nutrient limitation in the lacustrine zone was exclusively phosphorus limitation with the exception of station 5 on 2 Sept. 93.

Although results from the riverine zone did indicate potential nutrient limitation, it was likely that those results were due to weaknesses in the method, rather than actual nutrient limitation. Given the high turbidities at station 1, it was likely that phytoplankton at station 1 were light limited, rather than nutrient limited.

Results of nitrogen limitation in the transition zone on 2 Sep 93 were probably due to low nitrate concentrations on that day (0.04 mg/ℓ at station 2, 0.09 mg/ℓ at station 3, and 0.04 mg/ℓ at station 4). The variability of assay results from

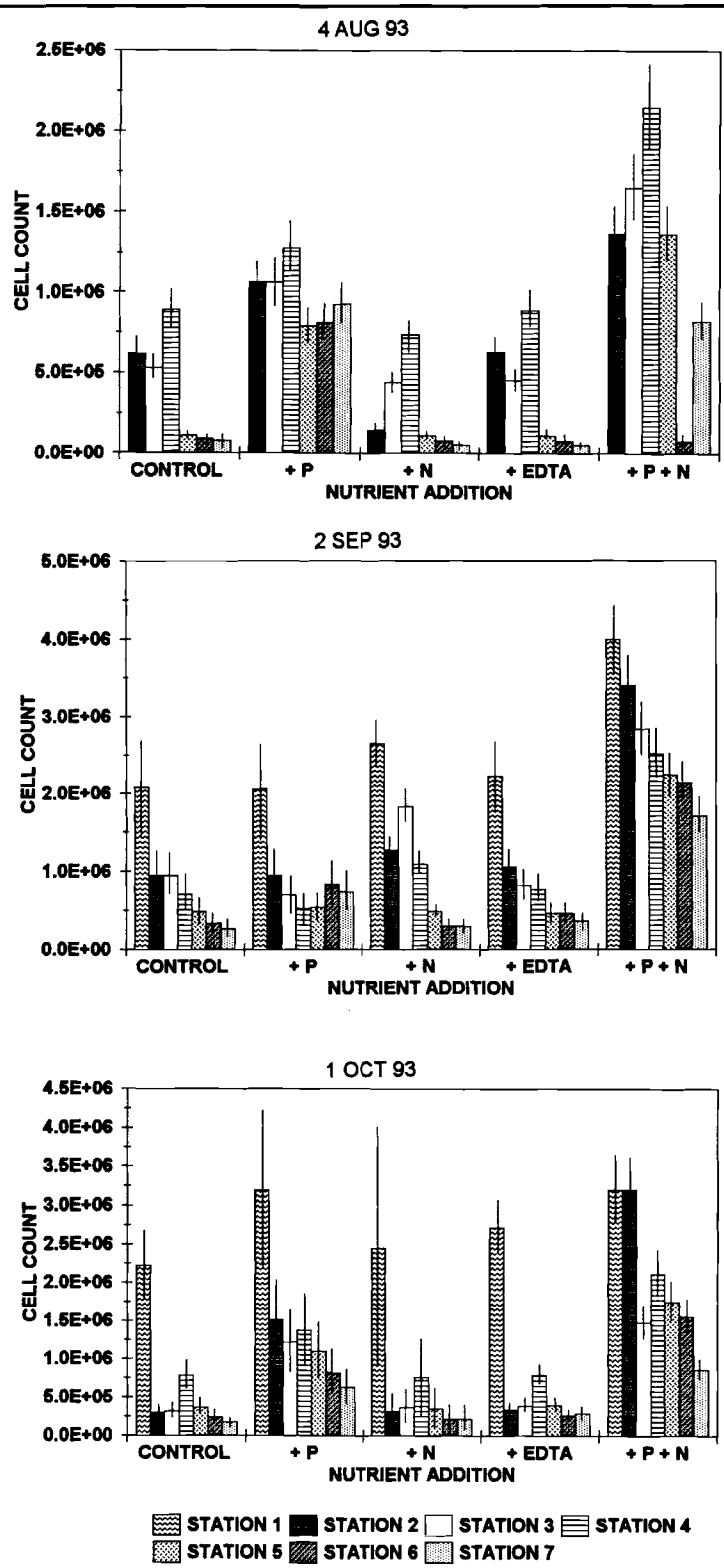

Figure 11. Algal Assay : Bottle Test Results for Tenkiller Ferry Lake.

transition zone stations alludes to the heterogeneity of that zone.

Gakstatter and Katko (1986) found sites on the Illinois River to be primarily phosphorus limited (excluding sites with influence from point source discharges). In addition, some sites were limited by some unknown factor, presumably a trace element which was not identified. This phosphorus limitation in the river and reservoir was due more to high nitrogen concentrations than to low phosphorus concentrations. That high nitrogen to phosphorus ratio was actually beneficial for the reservoir. Had the ratio been skewed in the other direction, nitrogen limitation may have resulted, which in turn could have resulted in phytoplankton communities dominated by blue-green algae for a longer portion of the year, given the ability of many blue-green algae to fix atmospheric nitrogen and thus out-compete other algae when nitrogen is the limiting nutrient (Shapiro 1973).

Phytoplankton Distribution

Phytoplankton Community Structure

Phytoplankton assemblages were temporally and spatially variable (Table VII, Figure 12, Appendix A). Most genera were collected throughout the pelagic zone of the lake. Notable anomalies in the phytoplankton communities included dinoflagellate blooms of *Peridinium* spp. recorded in the Caney Creek Cove on 14 Feb 1992 and in the Sixshooter Creek Cove on 8 Mar 1993. Conspicuous dinoflagellate blooms occurred at stations 2, 3, and 4 on 25 Jun 1993 (Figure 12).

Dinoflagellate blooms are most common under calm, stratified conditions (Harris 1986). Binary fission is their most common form of reproduction and optimal cell division occurs predominantly nocturnally in the calm epilimnion in hard waters with high calcium content. (Harris 1986). These blooms are typical in the summer populations of productive systems (Reynolds 1984). This preference for calm water

Table VII. Phytoplankton Genera Collected from Lake Stations.

Phyllum	Genera	Station
Chlorophyta	*Actinastrum spp.*	2, 3, 4, 5, 6, 7
	Ankistrodesmus spp.	2, 3, 4, 5, 6, 7
	Chlamydomonas spp.	2, 3, 4, 5, 6, 7
	Chlorella spp.	2, 3, 4, 5, 6, 7
	Closterium spp.	2, 3, 5, 6, 7
	Coelastrum spp.	2, 3, 4, 5, 6, 7
	Cosmarium spp.	2, 4, 5, 6, 7
	Crucigenia spp.	2, 3, 4, 5, 6, 7
	Gleocystis spp.	2, 3, 4, 5, 6, 7
	Gonium spp.	2, 3, 4, 5, 6, 7
	Kirchnerella spp.	7
	Mougeotia spp.	4, 5
	Oedogonium spp.	2, 3, 4, 5, 6, 7
	Oocystis spp.	2, 3, 4, 5, 6, 7
	Pandorina spp.	2, 3, 4, 5, 6, 7
	Pediastrum spp.	2, 3, 4, 5, 6, 7
	Platydorina spp.	2, 3, 4, 5, 6, 7
	Rhizoclonium spp.	4, 7
	Richterella spp.	5, 6
	Scenedesmus spp.	2, 3, 4, 5, 6, 7
	Staurastrum spp.	2, 3, 4, 5, 6, 7
	Stephanoon spp.	3
	Tetraedron spp.	3, 4, 5, 6, 7
	Ulothrix spp.	2, 3, 4, 5, 6, 7
Chrysophyta	*Asterionella spp.*	2, 3, 4
	Cyclotella spp.	2, 3, 4, 5, 6, 7
	Cymbella spp.	2, 3, 5, 7
	Dinobryon spp.	3, 4
	Gomphonema spp.	2, 3, 5
	Mallomonas spp.	2, 3, 4, 5, 6, 7
	Melosira spp.	2, 3, 4, 5, 6, 7
	Navicula spp.	2, 3, 4, 5, 6, 7
	Synedra spp.	2, 3, 4, 5, 6, 7
Cryptophyta	*Cryptomonas spp.*	2, 3, 4, 5, 6, 7
Cyanophyta	*Anabaena spp.*	2, 3, 4, 5, 6, 7
	Aphanocapsa spp.	2, 3, 4, 5, 6, 7
	Chroococcus spp.	3, 4
	Lyngbya/Oscillatoria spp.	2, 3, 4, 5, 6, 7
	Merismopedia spp.	2, 3, 4, 5, 6, 7
	Microcystis spp.	2, 3, 4, 5, 6, 7
	Microspora spp.	2
	Sphaerocystis spp.	2, 3, 4, 5, 6, 7
	Spirulina spp.	2, 3, 4, 5, 6, 7
Euglenophyta	*Euglena spp.*	2, 3, 4, 5, 6, 7
Pyrrhophyta	*Ceratium spp.*	2, 3, 4, 5, 6, 7
	Gymnodinium spp.	2, 4, 5
	Peridinium spp.	2, 3, 4, 6, 7

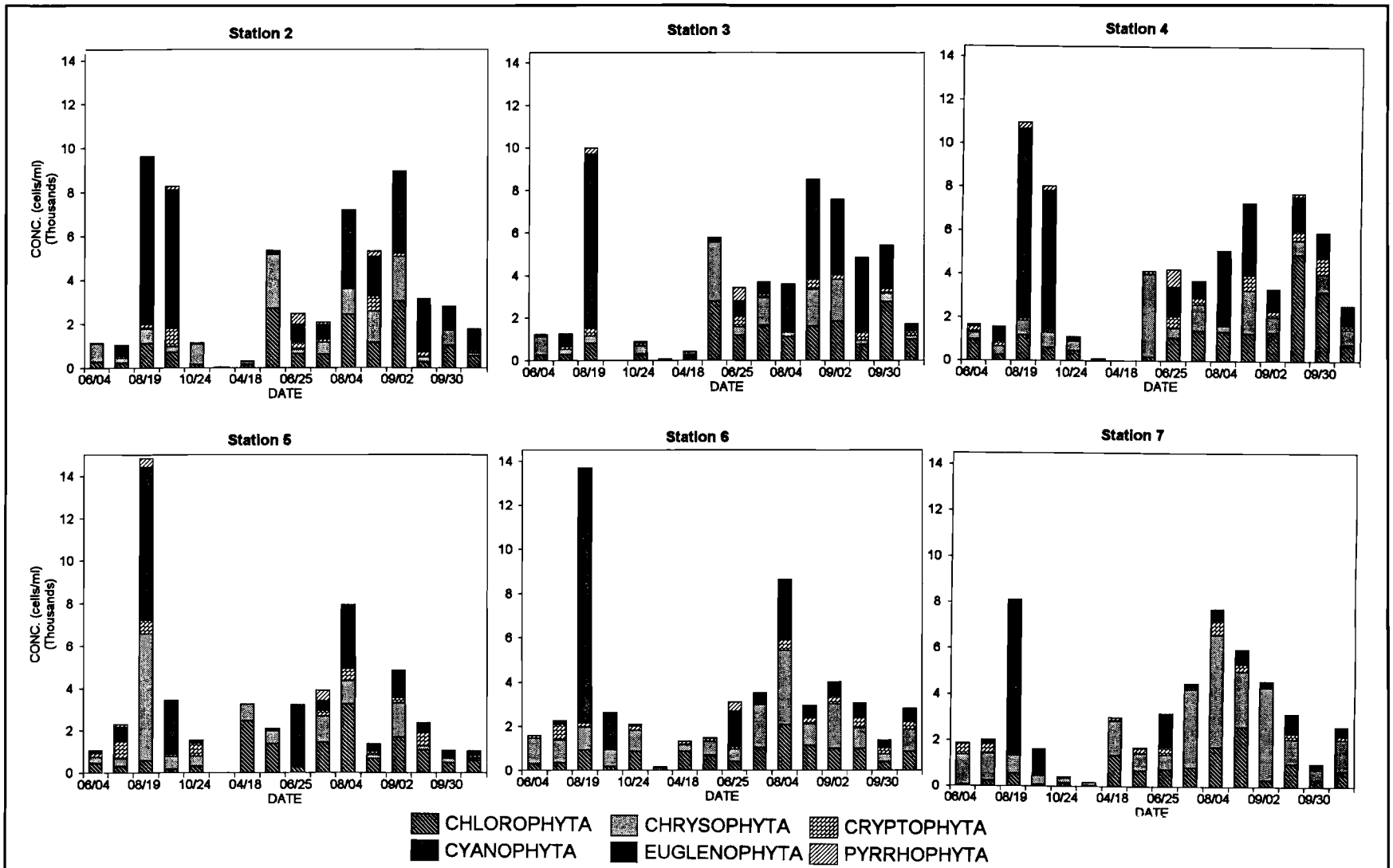

Figure 12. Spatial and Temporal Variation in Tenkiller Phytoplankton Communities.

explains the locations of the blooms; coves are more protected from the wind. This also explains why dinoflagellate cells were more concentrated in the transition zone on 26 Jun 1993 as the upper end of the reservoir is narrower and thus often less wind-whipped than at lower stations as well as having the higher nutrient concentrations which are favored by dinoflagellate blooms.

All but 16 of the 47 genera found were ranked as organic pollution tolerant (Palmer 1969). Seven of the genera were ranked as clean water algae (Clesceri et al. 1989). The annual maximum biomass occurred in August of both years (Figure 12). All but one of the 47 genera were found during the summer, 30 were found in the spring, and 37 were found during the fall. Twenty-six of the genera were reported previously in a national eutrophication survey (Hern et al. 1978) and 16 were reported in an ecological investigation report by the Oklahoma Department of Wildlife Conservation (Summers 1961). Mean cell densities ranged from 32.6 cells/ml at station 2 on 8 Mar 93 to 14839 cells/ml at station 5 on 19 Aug 92. Although some average cell densities were surprisingly high, results were similar to average cell densities reported by Gakstatter and Katko (1986) in their Aug 85 assessment of the Illinois River and Tenkiller Ferry Lake. The greatest average cell densities occurred when blue-green algae were dominant. However, given the small cell size of most blue-green taxa, an increase in cell counts per mℓ may not necessarily correlate with an increase in biomass.

Seasonal Trends in Community Structure

Phytoplankton community structure at all stations followed expected seasonal trends with spring blooms dominated by diatoms, and an early summer community composed primarily of green algae (Figure 12). Late summer and early fall communities were dominated by blue-green algae. The onset of cooler temperatures

and the breakdown of stratification were followed by decreases in blue-green abundance and subsequent increases in green algae and diatom populations.

Longitudinal Zonation of Phytoplankton Communities

Although the phytoplankton community structure at the upper end of the lake was typically different from that near the dam, no significant differences ($\alpha = 0.05$) were observed between average total cell count, species diversity (Shannon-Weaver 1949), ratio of centric to pennate diatoms, or percent blue-green algae between any of the six stations where phytoplankton were collected. It was suspected that the seasonal oscillations in the communities may have overshadowed the differences between stations and thus data were corrected for seasonal variation (Phillips et al. 1989) and reanalyzed. No statistically significant differences ($\alpha = 0.05$) were found between total cell count, species diversity, ratio of centric to pennate diatoms or percent blue-green algae between the six in-lake stations.

However, because statistical and ecological significance are not always coincidental, qualitative differences between phytoplankton communities in the transition and lacustrine zone were noted. Observable differences occurred in the predominant phyla among the different reservoir zones (determined as per physico-chemical parameters). In the transitional zone, blue-green algae were most often the dominant taxa (Figure 12). *Lyngbya/Oscillatoria, Spirulina, Microcystis* and *Merismopedia* accounted for 43.6, 43.7, and 48.1 % of summer collections and 34.5, 30.5, and 15.1 % of fall collections at stations 2, 3, and 4 respectively. Diatoms dominated most often in the lacustrine zone of the reservoir. *Cyclotella, Navicula, Synedra, Melosira* and *Cymbella* accounted for 26.3, 29.5, and 47.1 % of summer communities, 21.9, 31.5, and 48.7 % of spring communities, and 15.9, 34.3, and 43.2 percent of fall communities at stations 5, 6 and 7, respectively.

Phytoplanktonic Community Structure as Related to Physico-chemical Parameters

Use of canonical correspondence analysis (CCA) to relate water quality parameters to phytoplankton community indices such as species diversity, chlorophyll *a* concentrations, total cell counts, ratio of centric to pennate diatoms, and percent blue-green algae abundance indicated that turbidity and Secchi depth correlated best with the fore-mentioned indices for stations 2 - 6 (Table VIII).

Table VIII. Canonical Loadings for Water Quality Parameters.

PARAMETER	UNIVAR. F VALUE	CANONICAL CORRELATION			
		0.733	0.568	0.442	0.150
Total Nitrogen	3.065*	0.317	0.597	0.613	0.409
Total Phosphorus	0.008**	-0.397	0.654	0.501	-0.405
Secchi Depth	0.001**	0.579	-0.434	-0.612	-0.320
Turbidity	0.002**	-0.524	0.797	-0.063	0.295

*: $\alpha = 0.05$; **: $\alpha = 0.01$; Multivariate F (largest root criterion) = 3.857**

To test for effects of longitudinal zonation of physico-chemical parameters on phytoplankton community structure, CCA was performed on data from within the transitional zone and the lacustrine zone (Table IX). In the transition zone, the univariate F value for Secchi depth was not statistically significant so that parameter could not be correlated to algal community indices. Phytoplankton communities correlated best to trends in turbidity; however, nutrient trends (total phosphorus in particular) were also correlated with phytoplankton community indices.

This correlation suggested that turbidity influences phytoplankton productivity in the transition zone, rather than phytoplankton productivity influencing turbidity. That

Table IX. Canonical Loadings for Zoned Water Quality Parameters.

PARAMETER	UNIVAR. F VALUE	ZONE	CANONICAL CORRELATION			
			0.850	0.767	0.674	0.340
Total Nitrogen	0.041*	TRANS	0.523	0.186	0.747	-0.366
Total Phosphorus	0.017*	TRANS	-0.560	-0.339	0.747	0.120
Secchi Depth	0.087	TRANS	0.254	0.416	0.746	0.453
Turbidity	0.008**	TRANS	-0.701	0.394	0.558	-0.205
			CANONICAL CORRELATION			
			0.773	0.632	0.563	0.182
Total Nitrogen	0.002**	LACUS	0.062	0.959	-0.190	0.200
Total Phosphorus	0.023*	LACUS	-0.471	0.537	0.251	-0.654
Secchi Depth	0.001**	LACUS	0.867	-0.493	0.054	0.047
Turbidity	0.000**	LACUS	-0.552	0.428	0.686	0.203

*: $\alpha = 0.05$; **: $\alpha = 0.01$: Transitional Multivariate F (largest root criterion) = 3.070**, Lacustrine Multivariate F = 4.316**

directionality of influence was supported by Thornton's definition of the transition zone where productivity is impacted by decreases in turbidity without excessive decreases in nutrient availability (Thornton et al. 1990).

Lacustrine phytoplankton communities were best correlated to trends in Secchi disk readings (Table IX). Again this correlation was expected given the mechanics of longitudinal zonation, suggesting that phytoplankton productivity influences Secchi depth, rather than secchi depth directing phytoplankton productivity. Total nitrogen concentrations trends also were well correlated to phytoplankton community indices.

Phytoplankton Community Structure as Related to Nutrient Limitation

There was no statistical significance in either multivariate (largest root criterion F

= 0.827, P = 0.911) F values or univariate F values for CCA comparing nutrient limitation assay results to phytoplankton community indices (Table X). Therefore, CCA did not show any significant correlation between nutrient limitation and any of the phytoplankton community indices.

However, monthly nutrient limitation results still can be compared to corresponding in-lake phytoplankton community structure. Limiting factors define phytoplankton community structure by allowing certain taxa to become most common

Table X. Canonical Loadings for Nutrient Limitation Assay Results..

PARAMETER	UNIVARIATE F VALUE	CANONICAL CORRELATION
		0.327
Total Cells	0.061	0.189
Chlorophyll *a*	0.560	-0.563
Species Diversity	0.008	0.067
Centric : Pennate	0.487	0.526
% Blue-green	0.051	0.173

based upon differential light, temperature, current, and nutrient requirements. The ability of blue-green algae to fix atmospheric nitrogen allows them to out-compete other taxa under conditions of nitrogen limitation, given adequate phosphorus concentrations. Given high nutrient concentrations, if phosphorus is the limiting nutrient, green algae are expected to dominate. If both nitrogen and phosphorus are limiting, co-dominance of green and blue-green algae can be expected (Miller et al. 1978). Correlation between nutrient limitation assay results and in-lake phytoplankton communities suggests nutrient limitation of phytoplankton productivity rather than

limitation by some other factor.

Correlation between nutrient limitation results (Figure 11) and phytoplankton community structure (Figure 12) were better in the lacustrine zone than in the transition zone. Given nutrient limitation results, dominant taxa were as expected for stations 5 and 7 on 4 Aug 93, 6 and 7 on 2 Sep 93 and 5, 6, and 7 on 1 Oct 93. Dominant taxa were as expected for stations 2 and 4 on 2 Sep 93 and station 3 on 1 Oct 93. These results suggested that nutrients were the predominant factor controlling phytoplankton productivity at the lacustrine stations, but that other factors such as light and turbulence may have been equally important in limiting phytoplankton productivity in the transition zone. These results supported Thornton's definition of the reservoir zones (Thornton et al. 1985).

Degradation of Tenkiller Ferry Lake

Changes in environmental conditions which are perceived by the public are not always supported by documentation. The USEPA Clean Lakes Study on Beaver Lake, Arkansas, indicated that there had not been significant changes in the water quality of Beaver Lake between the 1974 USEPA National Eutrophication Survey (NES) and the 1991 USEPA Clean Lakes (CL) Phase I Study (FTN 1992), contrary to public opinion. In fact, the NES report for Tenkiller indicates eutrophic conditions existed in 1974 (USEPA 1977). However, a comparison between median values from the NES report ($n = 4$), a 1985-86 US Army Corps of Engineers (USACE) study ($n = 9 - 16$) (USACE 1988) and the 1992-93 CL Phase I Study ($n = 11 - 22$) indicated that significant changes have occurred in the water quality of Tenkiller Ferry Lake (Table XI).

Though no significant difference existed among the quartile distributions for Secchi disk, Turbidity, Total Nitrogen or Nitrate-Nitrogen of the 3 different studies,

Table XI. Median values for Limnological Parameters From Studies on Tenkiller Ferry Lake.

1974 USEPA NES Station						**4**		**3**		**2**		**1**	
Relative Distance[b]						0.27		0.65		0.79		0.98	
Secchi Disk (meters)						0.76		1.67		2.03		2.03	
Nitrate-N (mg/ℓ)						0.35		0.41		0.39		0.43	
Total Nitrogen (mg/ℓ)						1.05		0.91		0.79		1.11	
Total Phosphorus (mg/ℓ)						0.05		0.04		0.03		0.04	
Chlorophyll *a* (μg/ℓ)						9.50		6.85		5.30		4.50	
'85-86 USACE	**14**	**13**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Relative Distance[b]	0.01	0.24	0.32	0.37	0.46	0.52	0.57	0.68	0.74	0.77	0.80	0.92	0.99
Secchi Disk (meters)	0.70	0.60	0.80	1.00	1.10	1.30	1.25	1.35	1.65	1.80	1.80	2.10	2.10
Nitrate-N (mg/ℓ)	0.36	1.00	0.48	0.14	0.53	0.30	0.19	0.33	0.60	0.37	0.28	0.68	0.52
Total Phosphorus	0.21*	0.17*	0.15*	0.12*	0.14*	0.14*	0.10*	0.10*	0.06	0.09*	0.10*	0.10*	0.10*
Chlorophyll *a* (μg/ℓ)	5.30**	30.20*	25.10*	19.55	17.00	14.00*	11.25	10.50	12.00*	11.80*	11.85*	9.70*	10.90*
Turbidity (NTU)	8.0	8.0	6.0	5.5	4.0	4.0	3.0	3.0	2.5	3.0	2.0	2.0	2.0
'92-93 USEPA CL Station		**1**		**2**		**3**		**4**		**5**		**6**	**7**
Relative Distance[b]		0.01		0.26		0.27		0.33		0.52		0.72	0.97
Secchi Disk (meters)		---		0.85		0.86		0.90		1.40		2.05	2.30
Nitrate-N (mg/ℓ)		1.18[c]**		0.46		0.36		0.34		0.21		0.30	0.30
Total Nitrogen (mg/ℓ)		2.18[c]		1.16		1.23		1.17		0.79		0.74	0.74
Total Phosphorus (mg/ℓ)		0.12[c]*		0.08*[c]**		0.08*		0.07*		0.05		0.02	0.02
Chlorophyll *a* (μg/ℓ)		2.55		28.60		28.01*		28.66*		15.62*		11.62*	8.95*
Turbidity (NTU)		8.7		6.3		8.3		5.8		4.5		2.3	2.1

[b]: Relative distance from dam calculated as % of total thalweg length with dam = 1.00; [c]: signif. > than any value from NES study, however no comparable station between NES and CL study; *: signif. > than NES study; **: signif. different from USACE study

significant differences existed among the chlorophyll *a* and total phosphorus distributions in certain areas of the lake. Total phosphorus and chlorophyll *a* concentrations were significantly higher in 1985-86 than in 1974. Though these concentrations decreased somewhat between 1985-86 and 1992-93 at some CL stations (likely due to implementation of tertiary treatment at Talequah, OK waste water treatment plant and best management practices in the basin), total phosphorus concentrations remained significantly greater at CL stations 2 - 4 in 1992-93 than in 1974. These increases were manifested in significantly higher chlorophyll *a* concentrations from CL stations 3 - 7 between 1974 and 1992-93. Thus Tenkiller exhibited signs of degradation in the 1992-93 CL study.

Conclusions and Discussion

Tenkiller Ferry Lake is a reservoir with high ambient nutrient concentrations primarily resulting from non-point source pollution. The reservoir was divided longitudinally into three zones as defined by physico-chemical parameters such as nutrient concentrations and turbidity. Use of biotic parameters to define longitudinal zonation met with limited success. Though chlorophyll *a* concentrations could be used to delimit reservoir zones, various community indices such as species diversity and percent blue-green algae could not be used to define zones. Other detectable differences in biotic parameters between zones included dominant phyla and occurrence of certain genera.

Trophic classification based upon nutrient concentrations and chlorophyll *a* concentrations categorized Tenkiller as a eutrophic system. However, the degree of eutrophy was variable among zones, with the lacustrine zone being less eutrophic than the transition and riverine zones. Eutrophy of the transition and riverine zone was variable depending upon which parameters were used. The riverine zone was less

eutrophic than the transition zone based upon biotic parameters and the transition zone was less eutrophic than the riverine zone based upon abiotic parameters. Phytoplankton seasonal succession patterns were also most like those of eutrophic systems. Blue-green algae were relatively abundant in the phytoplankton community during summer and fall.

Potential nutrient limitation also was different among reservoir zones. Nutrient limitation was more variable in the transition zone, where primarily both nitrogen and phosphorus were limiting. However, phosphorus was the primary limiting nutrient in the lacustrine zone. Primary limiting factors also differed between the two zones. Nutrients were the primary limiting factor in the lacustrine zone, but differences between algal assay results and phytoplankton community structure indicates that factors such as light and turbulence may be equally if not more important than nutrients in limiting productivity in the transition zone.

Given the high ambient nutrient concentrations under the influence of primarily non-point source pollution, the limiting nutrients and the current phytoplankton community patterns, it has become essential that action be taken to slow the degradation of the reservoir. This could be done most effectively by controlling phosphorus discharge into the watershed through the use of best management practices. Though nitrogen concentrations were also high, nitrogen is less easily manipulated and thus nitrogen control is a less feasible option. Should control of nitrogen sources into the basin such as animal wastes and fertilizer runoff be targeted, it is essential that phosphorus control also be exercised lest the phosphorus to nitrogen ratio become reduced to a level which would stimulate dominance of blue-green algae.

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APPENDIX A - PHYTOPLANKTON COUNTS

APPENDIX A

PHYTOPLANKTON COUNTS

	Grid Count	Total Count	#/ml
STATION 2			
4 JUN 92			
centrales		3108	684.58
pennales		664	146.26
Scenedesmus		107	23.57
Spirulina		104	22.91
Crucigenia		18	3.96
Gonium		290	63.88
Pediastrum		825	181.72
Actinastrum		8	1.76
Cryptomonas		6	1.32
TOTAL		5130	1129.96
2 JUL 92			
Scenedesmus		603	217.08
Oedogonium		11	3.96
centrales		27	9.72
Anabaena		6	2.16
Chlorella		34	12.24
Microcystis		1330	478.80
pennales		587	211.32
Peridinium		18	6.48
Pediastrum		11	3.96
Ceratium		9	3.24
Closterium		2	0.72
Cryptomonas		284	102.24

Continued	Grid Count	Total Count	#/ml
Actinastrum		6	2.16
TOTAL		2928	1054.07
19 AUG 92			
Gleocystis	17	6054.68	605.47
Peridinium	26	260	26.00
Cryptomonas	6	2136.94	213.69
Lyngbya/Oscillatoria	122	43451.20	4345.12
pennales	10	3561.57	356.16
Microcystis	21	7479.31	747.93
Spirulina	44	15670.93	1567.09
centrales	8	2849.26	284.93
Aphanocapsa	22	7835.46	783.55
Scenedesmus	14	4986.20	498.62
Crucigenia	6	60	6.00
Mallomonas	4	40	4.00
Merismopedia	5	1780.79	178.08
Actinastrum	6	60	6.00
Ceratium	5	50	5.00
Pediastrum	2	20	2.00
TOTAL	318		9629.63
12 SEP 92			
Gleocystis	7	3739.65	277.01
Peridinium	3	1602.71	118.72
Cryptomonas	20	10684.72	791.46
Lyngbya/Oscillatoria	94	50218.19	3719.87
pennales	2	1068.47	79.15
Microcystis	15	8013.54	593.60
Spirulina	33	17629.79	1305.91
centrales	4	2136.94	158.29
Platydorina	1	534.24	39.57
Scenedesmus	4	2136.94	158.29
Crucigenia	4	2136.94	158.29
Mallomonas	1	534.24	39.57

Continued	Grid Count	Total Count	#/ml
Merismopedia	17	9082.01	672.74
Actinastrum	1	534.24	39.57
Ceratium	1	534.24	39.57
Pandorina	1	534.24	39.57
Anabaena	1	534.24	39.57
TOTAL	209		8270.77
24 OCT 92			
Melosira	34		93.62
centrales	214		589.28
pennales	97		267.10
Platydorina	4		11.01
Pandorina	3		8.26
Chlorella	26		71.59
Closterium	3		8.26
Gleocystis	14		38.55
Scenedesmus	3		8.26
Lyngbya/Oscillatoria	6		16.52
Microcystis	4		11.01
TOTAL	408		1123.48
8 MAR 93			
pennales	5	50	5.26
Melosira	2	20	2.10
Scenedesmus	3	30	3.16
Cryptomonas	4	40	4.21
centrales	17	170	17.89
TOTAL	31		32.63
18 APR 93			
centrales	8	80	22.86
pennales	32	320	91.43
Gomphonema	7	70	20.00
Gleocystis	1	10	2.86
Chlorella	50	500	142.86
Cryptomonas	3	30	8.57

Continued	Grid Count	Total Count	#/ml
TOTAL	101		288.57
26 MAY 93			
Asterionella	6	1227.61	129.22
centrales	1080		2160.00
Chlorella	109	22301.52	2347.53
pennales	4	818.40	86.15
Oedogonium	5	1023.01	107.68
Cryptomonas	6	1227.61	129.22
Pediastrum	1	204.60	21.54
Anabaena	2	409.20	43.07
Actinastrum	3	613.80	64.61
Scenedesmus	4	818.40	86.15
Gleocystis	2	409.20	43.07
Crucigenia	1	204.60	21.54
Sphaerocystis	1	204.60	21.54
Melosira	4	818.40	86.15
TOTAL	122		5347.47
25 JUN 93			
Pediastrum	1	234.54	18.61
Peridinium	26	6098.11	483.98
Anabaena	23	5394.48	428.13
Pandorina	10	2345.43	186.15
Aphanocapsa	9	2110.88	167.53
Oocystis	8	1876.34	148.92
Cryptomonas	18	4221.77	335.06
Gonium	2	469.09	37.23
Gleocystis	6	1407.26	111.69
Lyngbya/Oscillatoria	12	2814.51	223.37
Mallomonas	4	938.17	74.46
Scenedesmus	3	703.63	55.84
Sphaerocystis	2	469.09	37.23
Coelastrum	3	703.63	55.84
pennales	6	1407.26	111.69

Continued	Grid	Total Count	#/ml
TOTAL	133		2475.73
23 JUL 93			
Ulothrix	4	836.20	64.32
Peridinium	6	1254.29	96.48
Oocystis	6	1254.29	96.48
Gleocystis	14	2926.68	225.13
Cryptomonas	10	2090.49	160.81
Staurastrum	3	627.15	48.24
Aphanocapsa	28	5853.37	450.26
Pandorina	2	418.10	32.16
Mallomonas	2	418.10	32.16
pennales	31	6480.52	498.50
Scenedesmus	10	2090.49	160.81
Microcystis	10	2090.49	160.81
Spirulina	2	418.10	32.16
Ceratium	1	209.05	16.08
TOTAL	129		2074.41
4 AUG 93			
Gonium	12	2195.83	731.94
Scenedesmus	17	3110.77	1036.92
pennales	19	3476.74	1158.91
Microcystis	28	5123.61	1707.87
Aphanocapsa	21	3842.71	1280.90
Chlorella	3	548.96	182.99
Oocystis	1	182.99	61.00
Gleocystis	6	1097.92	365.97
Spirulina	2	365.97	121.99
Platydorina	1	182.99	61.00
Anabaena	8	1463.89	487.96
TOTAL			7197.46
19 AUG 93			
Gleocystis	5	2003.39	139.61
pennales	48	19232.50	1340.24

Continued	Grid Count	Total Count	#/ml
Spirulina	36	14424.38	1005.18
Cryptomonas	25	10016.93	698.04
Aphanocapsa	20	8013.54	558.43
Merismopedia	4	1602.71	111.69
Peridinium	6	2404.06	167.53
Mallomonas	3	1202.03	83.77
Lyngbya/Oscillatoria	1	400.68	27.92
Chlamydomonas	18	7212.19	502.59
Ceratium	3	1202.03	83.77
Platydorina	4	1602.71	111.69
Pediastrum	2	801.35	55.84
Crucigenia	5	2003.39	139.61
Anabaena	3	1202.03	83.77
Scenedesmus	4	1602.71	111.69
Pandorina	3	1202.03	83.77
TOTAL			5305.13
2 SEPT 93			
Scenedesmus	5	5306.60	363.47
pennales	22	23349.04	1599.25
centrales	6	6367.92	436.16
Merismopedia	25	26533.00	1817.33
Pediastrum	1	1061.32	72.69
Ankistrodesmus	6	6367.92	436.16
Spirulina	8	8490.56	581.55
Chlamydomonas	9	9551.88	654.24
Anabaena	8	8490.56	581.55
Gonium	7	7429.24	508.85
Microcystis	9	9551.88	654.24
Gleocystis	9	9551.88	654.24
Cryptomonas	2	2122.64	145.39
Coelastrum	2	2122.64	145.39
Cosmarium	2	2122.64	145.39
Staurastrum	1	1061.32	72.69

Continued	Gierid	Total Count	#/ml
Euglena	1	1061.32	72.69
TOTAL	122		8868.56
16 SEPT 93			
Aphanocapsa	27	5524.23	753.30
Microcystis	31	6342.63	864.90
Lyngbya/Oscillatoria	8	1636.81	223.20
pennales	5	1023.01	139.50
Spirulina	3	613.80	83.70
Gleocystis	7	1432.21	195.30
centrales	3	613.80	83.70
Merismopedia	17	3478.22	474.30
Cryptomonas	8	1636.81	223.20
Pediastrum	1	204.60	27.90
Anabaena	1	204.60	27.90
Microspora	1	204.60	27.90
Actinastrum	1	204.60	27.90
TOTAL	113		3152.72
30 SEPT 93			
Scenedesmus	7.00	2417.80	185.98
pennales	24.33	8404.73	646.52
centrales	1.00	345.40	26.57
Merismopedia	14.67	5065.87	389.68
Pediastrum	1.67	575.67	44.28
Actinastrum	1.33	460.53	35.43
Gleocystis	4.67	1611.87	123.99
Ankistrodesmus	6.33	2187.53	168.27
Spirulina	14.33	4950.73	380.83
Microcystis	9.00	3108.60	239.12
Gonium	10.00	3454.00	265.69
Chlamydomonas	8.67	2993.47	230.27
Peridinium	2.67	921.07	70.85
TOTAL	105.67		2807.48
21 OCT 93			

Continued	Grid Count	Total Count	#/ml
Gleocystis	24	5367.21	365.12
Spirulina	4	894.53	60.85
Aphanocapsa	40	8945.35	608.53
Microspora	12	2683.60	182.56
Cryptomonas	8	1789.07	121.71
pennales	4	894.53	60.85
centrales	4	894.53	60.85
Merismopedia	20	4472.67	304.26
TOTAL	116		1764.73
STATION 3			
4 JUN 92			
centrales		3328	698.8807
pennales		808	169.6802
Gleocystis		621	130.4101
Pediastrum		8	1.680002
Anabaena		5	1.050001
Gonium		537	112.7701
Actinastrum		8	1.68
Melosira		7	1.47
Chlorella		8	1.68
Cryptomonas		499	104.79
Scenedesmus		19	3.99
Euglena		4	0.84
Dinobryon		4	0.84
Spirulina		4	0.84
TOTAL		5860	1230.601
2 JUL 92			
Scenedesmus		763	274.68
Microcystis		1626	585.36
pennales		650	233.99
Cryptomonas		291	104.76
Melosira		1	0.36
Ceratium		14	5.04

Continued	Grid Count	Total Count	#/ml
Peridinium		25	8.99
Chlorella		17	6.12
Pediastrum		9	3.24
centrales		38	13.68
Actinastrum		7	2.52
Oedogonium		12	4.32
TOTAL		3453	1243.07
19 AUG 92			
Mallomonas	1	331.59	55.27
Lyngbya/Oscillatoria	97	32164.70	5360.78
Spirulina	26	8621.47	1436.91
Microcystis	19	6300.30	1050.05
Cryptomonas	7	2321.16	386.86
Aphanocapsa	4	1326.38	221.06
Gleocystis	7	2321.16	386.86
Actinastrum	2	663.19	110.53
Scenedesmus	4	1326.38	221.06
pennales	5	1657.97	276.33
Ceratium	1	331.59	55.27
Platydorina	1	331.59	55.27
Pediastrum	1	331.59	55.27
Merismopedia	2	663.19	110.53
TOTAL	181		10003.11
12 SEP 92			
CONTAMINATED			
24 OCT 92			
Gleocystis	30		60
Melosira	30		60
Chlorella	48		96
Oocystis	18		36
Peridinium	32		64
Cryptomonas	78		156
Gonium	35		70

Continued	Grid Count	Total Count	#/ml
pennales	75		150
centrales	68		136
Scenedesmus	7		14
Microcystis	2		4
Pediastrum	3		6
Pandorina	10		20
Platydorina	5		10
Ceratium	1		2
Actinastrum	3		6
Lyngbya/Oscillatoria	3		6
Crucigenia	3		6
TOTAL	451		902
8 MAR 93			
Scenedesmus	2	20	2.74
centrales	14	140	19.18
pennales	26	260	35.62
Coelastrum	4	40	5.48
Cryptomonas	4	40	5.48
Oedogonium	2	20	2.74
Melosira	2	20	2.74
TOTAL	54		73.97
18 APR 93			
Spirulina	2	20	4.55
Cryptomonas	3	30	6.82
centrales	18	180	40.91
Chlorella	107	1070	243.18
pennales	44	440	100.00
Gomphonema	2	20	4.55
Closterium	4	40	9.09
Melosira	4	40	9.09
Scenedesmus	7	70	15.90
Oedogonium	2	20	4.55
TOTAL	193		438.64

Continued	Grid Count	Total Count	#/ml
26 MAY 93			
centrales	1160		2562.79
Chlorella	124	27100.34	3151.20
Anabaena	7	1529.86	177.89
pennales	3	655.65	76.24
Cryptomonas	1	218.55	25.41
Oedogonium	9	1966.96	228.72
Asterionella	3	655.65	76.24
Scenedesmus	2	437.10	50.83
Actinastrum	3	655.65	76.24
Coelastrum	1	218.55	25.41
Melosira	18		39.77
Gleocystis	1	218.55	25.41
TOTAL	1332		6516.15
25 JUN 93			
Peridinium	21	5939.45	539.95
Pandorina	20	5656.62	514.24
Anabaena	15	4242.46	385.68
Gleocystis	8	2262.65	205.69
Cryptomonas	19	5373.79	488.53
Aphanocapsa	6	1696.99	154.27
Oocystis	5	1414.15	128.56
Ceratium	4	1131.32	102.85
Sphaerocystis	3	848.49	77.14
Pediastrum	1	282.83	25.71
Coelastrum	3	848.49	77.14
Chlamydomonas	5	1414.15	128.56
Lyngbya/Oscillatoria	7	1979.82	179.98
Scenedesmus	1	282.83	25.71
Mallomonas	7	1979.82	179.98
centrales	8	2262.65	205.69
Gonium	1	282.83	25.71
TOTAL	134		3445.39

Continued	Grid Count	Total Count	#/ml
23 JUL 93			
Actinastrum	1	343.44	28.15
Scenedesmus	10	3434.38	281.50
pennales	45	15454.69	1266.78
Microcystis	6	2060.63	168.90
Oocystis	24	8242.50	675.61
Aphanocapsa	6	2060.63	168.90
Gleocystis	16	5495.00	450.41
Mallomonas	2	686.88	56.30
Pandorina	2	686.88	56.30
Cryptomonas	6	2060.63	168.90
Platydorina	2	686.88	56.30
Merismopedia	4	1373.75	112.60
Staurastrum	1	343.44	28.15
Ulothrix	1	343.44	28.15
Peridinium	2	686.88	56.30
Lyngbya/Oscillatoria	1	343.44	28.15
Euglena	1	343.44	28.15
Gonium	2	686.88	56.30
TOTAL	132		3715.88
4 AUG 93			
Microcystis			1497.3
Chroococcus			294.7
Chlorella			796.4
Lyngbya/Oscillatoria			495.4
Tetraedron			8
Navicula			111.4
Scenedesmus			191.1
Cyclotella			23.9
Cymbella			8
Melosira			15.9
Pediastrum			127.4
TOTAL			3609.3

Continued	Grid Count	Total Count	#/ml
19 AUG 93			
Stephanoon	2	1748.41	134.49
pennales	26	22729.32	1748.41
Crucigenia	3	2622.61	201.74
Aphanocapsa	15	13113.07	1008.70
Gleocystis	10	8742.05	672.47
Spirulina	43	37590.80	2891.60
Scenedesmus	3	2622.61	201.74
Merismopedia	12	10490.45	806.96
Chlamydomonas	6	5245.23	403.48
Cryptomonas	7	6119.43	470.73
TOTAL			8540.31
2 SEPT 93			
Pediastrum	3	1923.25	184.93
Crucigenia	5	3205.42	308.21
Merismopedia	17	10898.42	1047.92
Gleocystis	17	10898.42	1047.92
Spirulina	14	8975.17	863.00
pennales	26	16668.17	1602.71
Aphanocapsa	17	10898.42	1047.92
Cryptomonas	4	2564.33	246.57
Scenedesmus	5	3205.42	308.21
centrales	6	3846.50	369.86
Lyngbya/Oscillatoria	9	5769.75	554.78
TOTAL	123		7582.04
16 SEPT 93			
Gleocystis	5	2185.51	203.30
Microcystis	4	1748.41	162.64
Merismopedia	20	8742.05	813.21
Cryptomonas	10	4371.02	406.61
Aphanocapsa	26	11364.66	1057.18
Crucigenia	7	3059.72	284.62
Lyngbya/Oscillatoria	23	10053.35	935.20

Continued	Grid Count	Total Count	#/ml
Anabaena	6	2622.61	243.96
pennales	5	2185.51	203.30
Scenedesmus	7	3059.72	284.62
Spirulina	7	3059.72	284.62
TOTAL	120		4879.28
30 SEPT 93			
Crucigenia	21	8780.05	888.67
Merismopedia	7	2926.68	296.22
Scenedesmus	7	2926.68	296.22
Microcystis	8	3344.78	338.54
Cryptomonas	5	2090.49	211.59
Lyngbya/Oscillatoria	16	6689.57	677.08
Gleocystis	16	6689.57	677.08
Chlamydomonas	21	8780.05	888.67
Ankistrodesmus	1	418.10	42.32
Aphanocapsa	14	5853.37	592.45
pennales	9	3762.88	380.86
Spirulina	3	1254.29	126.95
Anabaena	3	1254.29	126.95
TOTAL	131		5543.61
21 OCT 93			
Ulothrix	16	2903.02	227.69
pennales	11	1995.83	156.54
Gleocystis	39	7076.11	554.99
Cryptomonas	16	2903.02	227.69
Pandorina	8	1451.51	113.84
Spirulina	11	1995.83	156.54
Scenedesmus	9	1632.95	128.07
Merismopedia	13	2358.70	185.00
TOTAL	123		1750.35
STATION 4			
4 JUN 92			
Spirulina		183	38.43

Continued	Grid Count	Total Count	#/ml
Scenedesmus		1427	299.67
Pediastrum		20	4.20
Chlorella		2221	466.41
Actinastrum		30	6.30
Cryptomonas		1486	312.06
centrales		1368	287.28
pennales		212	44.52
Gonium		533	111.93
Dinobryon		2	0.42
Platydorina		338	70.98
Oedogonium		3	0.63
Mougeotia		13	2.73
Euglena		1	0.21
Coelastrum		4	0.84
TOTAL		7841	1646.61
2 JUL 92			
Scenedesmus		632	240.16
Microcystis		1377	523.26
pennales		818	310.84
Cryptomonas		529	201.02
Ceratium		18	6.84
Pediastrum		10	3.80
Anabaena		8	3.04
Melosira		12	4.56
centrales		257	97.66
Oedogonium		16	6.08
Spirulina		372	141.36
Actinastrum		5	1.90
Peridinium		15	5.70
Lyngbya/Oscillatoria		60	22.80
TOTAL		4129	1569.02
19 AUG 92			
Peridinium	6	2747.50	209.73

Continued	Grid Count	Total Count	#/ml
Mallomonas	1	457.92	34.96
Lyngbya/Oscillatoria	107	48997.08	3740.24
Spirulina	88	40296.67	3076.08
Microcystis	20	9158.33	699.11
Cryptomonas	4	1831.67	139.82
Aphanocapsa	23	10532.08	803.98
Gleocystis	16	7326.67	559.29
Actinastrum	2	915.83	69.91
Scenedesmus	6	2747.50	209.73
pennales	18	8242.50	629.20
Coelastrum	3	1373.75	104.87
Cosmarium	2	915.83	69.91
Pediastrum	1	457.92	34.96
Merismopedia	11	5037.08	384.51
Crucigenia	3	1373.75	104.87
Ceratium	2	915.83	69.91
Staurastrum	1	457.92	34.96
TOTAL	314		10976.02
12 SEP 92			
Peridinium	3	848.49	121.21
Mallomonas	3	848.49	121.21
Lyngbya/Oscillatoria	52	14707.21	2101.03
Spirulina	56	15838.53	2262.65
Microcystis	20	5656.62	808.09
Cryptomonas	4	1131.32	161.62
Aphanocapsa	14	3959.63	565.66
Gleocystis	6	1696.99	242.43
Actinastrum	1	282.83	40.40
Scenedesmus	3	848.49	121.21
pennales	11	3111.14	444.45
Gonium	1	282.83	40.40
Cosmarium	1	282.83	40.40
Anabaena	1	282.83	40.40

Continued	Grid Count	Total Count	#/ml
Merismopedia	13	3676.80	525.26
Crucigenia	3	848.49	121.21
Ceratium	2	565.66	80.81
Euglena	2	565.66	80.81
centrales	3	848.49	121.21
TOTAL	199		8040.478
24 OCT 92			
Peridinium	13	260.00	52.00
Mallomonas	14	280.00	56.00
Spirulina	7	140.00	28.00
Microcystis	10	200.00	40.00
Cryptomonas	12	240.00	48.00
Pandorina	42	840.00	168.00
Gleocystis	28	560.00	112.00
Melosira	19	380.00	76.00
Scenedesmus	11	220.00	44.00
pennales	40	800.00	160.00
Actinastrum	13	260.00	52.00
Chlamydomonas	18	360.00	72.00
Staurastrum	2	40.00	8.00
Merismopedia	8	160.00	32.00
Crucigenia	2	40.00	8.00
Pediastrum	3	60.00	12.00
centrales	34	680.00	136.00
TOTAL	276		1104
8 MAR 93			
Peridinium	1	10.00	3.23
Cryptomonas	4	40.00	8.00
Platydorina	1	10.00	2.00
Oocystis	1	10.00	2.00
Gonium	1	10.00	2.00
Scenedesmus	3	30.00	6.00
pennales	8	80.00	16.00

Continued	Grid Count	Total Count	#/ml
centrales	22	220.00	44.00
TOTAL	41		83.23
18 APR 93			
CONTAMINATED			
26 MAY 93			
centrales	1838		3492.2
Melosira	32		60.8
Cryptomonas	81		153.9
Pediastrum	2		3.8
Actinastrum	22		41.8
pennales	128		243.2
Gleocystis	38		72.2
Sphaerocystis	3		5.7
Chlorella	36		68.7
Scenedesmus	2		3.8
Microcystis	2		3.8
TOTAL	2184		4149.6
25 JUN 93			
Pediastrum	2		30.16
Peridinium	52		784.13
Anabaena	48		723.81
Pandorina	21		316.67
Aphanocapsa	18		271.43
Oocystis	16		241.27
Cryptomonas	36		542.86
Gonium	4		60.32
Gleocystis	12		180.95
Lyngbya/Oscillatoria	24		361.90
Mallomonas	8		120.63
Scenedesmus	6		90.48
Sphaerocystis	4		60.32
Coelastrum	6		90.48
pennales	12		180.95

Continued	Grid Count	Total	#/ml
centrales	10		150.79
TOTAL	279		4207.14
23 JUL 93			
Coelastrum	4	1326.38	111.46
pennales	38	12600.60	1058.87
Aphanocapsa	18	5968.71	501.57
Mallomonas	6	1989.57	167.19
Tetraedron	1	331.59	27.86
Gleocystis	12	3979.14	334.38
Spirulina	5	1657.97	139.33
Oocystis	19	6300.30	529.44
Cryptomonas	11	3647.54	306.52
Scenedesmus	5	1657.97	139.33
Peridinium	3	994.78	83.59
Microcystis	2	663.19	55.73
Pandorina	3	994.78	83.59
Gonium	2	663.19	55.73
Actinastrum	1	331.59	27.86
Crucigenia	2	663.19	55.73
Staurastrum	1	331.59	27.86
TOTAL	133		3706.06
4 AUG 93			
Synedra			39.8
Microcystis			2269.8
Chlroococcus			294.7
Chlorella			1115
Lyngbya/Oscillatoria			886.4
Melosira			143.4
Scenedesmus			111.5
Cyclotella			39.8
Navicula			39.8
Asterionella			15.9
Pediastrum			127.4

Continued	Grid Conunt	Total Count	#/ml
TOTAL			5083.5
19 AUG 93			
pennales	31	21293.13	1980.76
Spirulina	32	21980.00	2044.65
Merismopedia	12	8242.50	766.74
Cryptomonas	11	7555.63	702.85
Ankistrodesmus	3	2060.63	191.69
Microcystis	3	2060.63	191.69
Scenedesmus	5	3434.38	319.48
Aphanocapsa	5	3434.38	319.48
Gleocystis	5	3434.38	319.48
Chlamydomonas	6	4121.25	383.37
Pediastrum	1	686.88	63.90
TOTAL			7284.07
2 SEPT 93			
Scenedesmus	12	2747.50	345.49
pennales	24	5495.00	690.99
Spirulina	22	5037.08	633.41
Gleocystis	13	2976.46	374.29
Microcystis	11	2518.54	316.70
Pediastrum	3	686.88	86.37
Cryptomonas	9	2060.63	259.12
Crucigenia	7	1602.71	201.54
Chlamydomonas	5	1144.79	143.96
centrales	1	228.96	28.79
Pandorina	5	1144.79	143.96
Merismopedia	2	457.92	57.58
Actinastrum	1	228.96	28.79
TOTAL	115		3310.984
16 SEPT 93			
Anabaena	3	1602.71	178.08
Crucigenia	3	1602.71	178.08
pennales	11	5876.60	652.96

Continued	Grid Count	Total Count	#/ml
Pandorina	7	3739.65	415.52
Gonium	2	1068.47	118.72
Rhizoclonium	12	6410.83	712.31
Pediastrum	2	1068.47	118.72
Gleocystis	13	6945.07	771.67
Microcystis	10	5342.36	593.60
Peridinium	2	1068.47	118.72
Chlamydomonas	33	17629.79	1958.87
Merismopedia	4	2136.94	237.44
Scenedesmus	5	2671.18	296.80
Spirulina	8	4273.89	474.88
Aphanocapsa	2	1068.47	118.72
Cryptomonas	7	3739.65	415.52
Actinastrum	6	3205.42	356.16
TOTAL	130		7716.744
30 SEP 93			
Actinastrum	2	1479.42	97.01
Pediastrum	3	2219.13	145.52
Merismopedia	3	2219.13	145.52
Crucigenia	7	5177.98	339.54
Gleocystis	9	6657.40	436.55
Spirulina	8	5917.69	388.05
pennales	17	12575.10	824.60
Chlamydomonas	16	11835.38	776.09
Cryptomonas	15	11095.67	727.59
Anabaena	6	4438.27	291.03
Scenedesmus	8	5917.69	388.05
Pandorina	7	5177.98	339.54
Gonium	12	8876.54	582.07
Aphanocapsa	7	5177.98	339.54
Staurastrum	1	739.71	48.51
Ulothrix	1	739.71	48.51
TOTAL	122		5917.69

Continued	Grid Count	Total Count	#/ml
21 OCT 93			
Staurastrum	5	1265.30	89.42
Gleocystis	12	3036.71	214.61
Chlamydomonas	4	1012.24	71.54
pennales	36	9110.13	643.83
Ankistrodesmus	8	2024.47	143.07
Scenedesmus	7	1771.41	125.19
Spirulina	32	8097.89	572.29
Aphanocapsa	9	2277.53	160.96
Cryptomonas	11	2783.65	196.72
Lyngbya/Oscillatoria	2	506.12	35.77
centrales	3	759.18	53.65
Actinastrum	1	253.06	17.88
Merismopedia	3	759.18	53.65
Ulothrix	1	253.06	17.88
Peridinium	4	1012.24	71.54
Crucigenia	4	1012.24	71.54
Pediastrum	1	253.06	17.88
TOTAL	143		2557.418
STATION 5			
4 JUN 92			
centrales		762	167.64
pennales		528	116.16
Spirulina		259	56.98
Scenedesmus		756	166.32
Pediastrum		22	4.84
Actinastrum		4	0.88
Cryptomonas		1008	221.76
Gonium		659	144.98
Platydorina		223	49.06
Oedogonium		1	0.22
Chlorella		434	95.48
Peridinium		71	15.62

Continued	Grid Count	Total Count	#/ml
Coelastrum		57	12.54
Melosira		1	0.22
Ceratium		10	2.20
Euglena		22	4.84
TOTAL		4817	1059.74
2 JUL 92			
Microcystis		1560	592.8
pennales		511	194.18
Cryptomonas		2098	797.24
Ceratium		297	112.86
Peridinium		11	4.18
Scenedesmus		799	303.62
centrales		428	162.64
Pediastrum		11	4.18
Actinastrum		4	1.52
Oedogonium		11	4.18
Spirulina		238	90.44
Anabaena		8	3.04
Melosira		4	1.52
Chlorella		26	9.88
Lyngbya/Oscillatoria		21	7.98
TOTAL		6027	2290.26
19 AUG 92			
pennales	258		4902
Ceratium	4		76
Peridinium	17		323
Gonium	2		38
Cryptomonas	32		608
Lyngbya/Oscillatoria	22		418
Spirulina	344		6536
Chlorella	8		152
Gleocystis	3		57
Actinastrum	2		38

Continueded	Grid Count	Total Count	#/ml
Staurastrum	2		38
Scenedesmus	5		95
Microcystis	2		38
centrales	54		1026
Oocystis	6		114
Merismopedia	2		38
Pediastrum	1		19
Anabaena	5		95
Euglena	7		133
Pandorina	2		38
Melosira	3		57
TOTAL	781		14839
12 SEP 92			
Peridinium	2	40.00	26.67
Pandorina	1	20.00	13.33
Lyngbya/Oscillatoria	29	580.00	386.67
Spirulina	105	2100.00	1400.00
Microcystis	7	140.00	93.33
Cryptomonas	6	120.00	80.00
Aphanocapsa	22	440.00	293.33
Gleocystis	4	80.00	53.33
Scenedesmus	7	140.00	93.33
pennales	28	560.00	373.33
Staurastrum	1	20.00	13.33
Pediastrum	1	20.00	13.33
Merismopedia	27	540.00	360.00
Ceratium	1	20.00	13.33
centrales	17	340.00	226.67
TOTAL	258		3440
24 OCT 92			
Melosira	50		197.92
Peridinium	8		31.67
Cryptomonas	154		609.58

Continued	Grid Count	Total Count	#/ml
Pandorina	8		31.67
Actinastrum	4		15.83
centrales	44		174.17
Scenedesmus	18		71.25
Oocystis	4		15.83
Chlorella	16		63.33
Gleocystis	16		63.33
Crucigenia	4		15.83
Spirulina	14		55.42
Pediastrum	6		23.75
pennales	28		110.83
Staurastrum	6		23.75
Microcystis	14		55.42
TOTAL	394		1559.58
8 MAR 93			
NO VISIBLE CELLS			
18 APR 93			
pennales	9	1730.93	288.49
centrales	12	2307.90	384.65
Chlorella	44	8462.30	1410.38
Melosira	3	576.98	96.16
Scenedesmus	27	5192.78	865.46
Closterium	2	384.65	64.11
Oedogonium	2	384.65	64.11
Gleocystis	2	384.65	64.11
TOTAL	101		3237.47
26 MAY 93			
centrales	251		476.90
Chlorella	83	11912.67	1267.31
Melosira	5	717.63	76.34
Mallomonas	2	287.05	30.54
Scenedesmus	6	861.16	91.61
Cryptomonas	5	717.63	76.34

Continued	Grid Count	Total Count	#/ml
Asterionella	1	143.53	15.27
Sphaerocystis	1	143.53	15.27
pennales	1	143.53	15.27
Lyngbya/Oscillatoria	1	143.53	15.27
TOTAL	356		2080.12
25 JUN 93			
Anabaena			876.10
Lyngbya/Oscillatoria			1871.70
Ceratium			10.00
Navicula			11.90
Cyclotella			6.00
Chlorella			23.90
Microcystis			21.90
Mougeotia			2.00
Sphaerocystis			234.90
Peridinium			2.00
Synedra			15.90
Eucapsis			79.60
Chroococcus			19.90
Synechococcus			10.00
Chlorococcus			17.90
Gomphonema			2.00
Melosira			4.00
TOTAL			3209.70
23 JUL 93			
Ceratium	2	400.68	64.63
Gleocystis	19	3806.43	613.94
pennales	35	7011.85	1130.94
Mallomonas	3	601.02	96.94
Anabaena	2	400.68	64.63
Sphaerocystis	3	601.02	96.94
Pandorina	6	1202.03	193.88
Staurastrum	1	200.34	32.31

Continued	Grid Count	Total Count	#/ml
Cryptomonas	8	1602.71	258.50
Aphanocapsa	5	1001.69	161.56
Peridinium	14	2804.74	452.38
Tetraedron	5	1001.69	161.56
Scenedesmus	7	1402.37	226.19
Lyngbya/Oscillatoria	7	1402.37	226.19
Pediastrum	1	200.34	32.31
Ulothrix	3	601.02	96.94
TOTAL	12		3909.83
4 AUG 93			
Oocystis	7	1615.05	556.91
Scenedesmus	9	2076.50	716.03
Chlorella	2	461.44	159.12
Gleocystis	1	230.72	79.56
Pediastrum	2	461.44	159.12
Ankistrodesmus	19	4383.71	1511.63
Staurastrum	1	230.72	79.56
pennales	11	2537.94	875.15
centrales	3	692.17	238.68
Cryptomonas	7	1615.05	556.91
Microcystis	19	4383.71	1511.63
Merismopedia	2	461.44	159.12
Spirulina	7	1615.05	556.91
Aphanocapsa	9	2076.50	716.03
Euglena	1	230.72	79.56
TOTAL	100		7955.92
19 AUG 93			
pennales	12	3036.71	117.25
Ulothrix	32	8097.89	312.66
Chlamydomonas	12	3036.71	117.25
Gleocystis	13	3289.77	127.02
Microcystis	27	6832.60	263.81
Cryptomonas	18	4555.07	175.87

Continued	Grid Count	Total Count	#/ml
Pediastrum	6	1518.36	58.62
centrales	4	1012.24	39.08
Scenedesmus	8	2024.47	78.17
Lyngbya/Oscillatoria	11	2783.65	107.48
Euglena	1	253.06	9.77
Merismopedia	7	1771.41	68.39
TOTAL	151		1475.37
2 SEPT 93			
Pediastrum	3	3183.96	108.30
pennales	45	47759.40	1624.47
Gonium	8	8490.56	288.79
Merismopedia	8	8490.56	288.79
Scenedesmus	10	10613.20	360.99
Gleocystis	10	10613.20	360.99
Spirulina	17	18042.44	613.69
Anabaena	3	3183.96	108.30
Cosmarium	1	1061.32	36.10
Peridinium	6	60.00	2.04
Microcystis	7	7429.24	252.70
Actinastrum	1	1061.32	36.10
Cryptomonas	6	6367.92	216.60
Pandorina	3	3183.96	108.30
Chlamydomonas	11	11674.52	397.09
Euglena	1	1061.32	36.10
Mallomonas	3	30.00	1.02
TOTAL	143		4840.37
16 SEPT 93			
Gleocystis	15	3898.48	271.67
Gonium	2	519.80	36.22
Microcystis	7	1819.29	126.78
Staurastrum	1	259.90	18.11
Spirulina	5	1299.49	90.56
Cryptomonas	34	8836.55	615.79

Continued	Grid Count	Total Count	#/ml
Chlamydomonas	12	3118.78	217.34
Chodatella	2	519.80	36.22
Scenedesmus	12	3118.78	217.34
pennales	9	2339.09	163.00
Actinastrum	8	2079.19	144.89
Merismopedia	11	2858.89	199.23
centrales	1	259.90	18.11
Tetraedron	5	1299.49	90.56
Anabaena	3	779.70	54.33
Ankistrodesmus	3	779.70	54.33
Ulothrix	1	259.90	18.11
TOTAL	131		2372.59
30 SEPT 93			
Gonium	9	3183.96	98.27
Scenedesmus	2	707.55	21.84
Chlamydomonas	11	3891.51	120.11
Gleocystis	5	1768.87	54.59
Pediastrum	2	707.55	21.84
Actinastrum	1	353.77	10.92
Coelastrum	1	353.77	10.92
Ulothrix	6	2122.64	65.51
Ankistrodesmus	2	707.55	21.84
Platydorina	5	1768.87	54.59
pennales	17	6014.15	185.62
centrales	2	707.55	21.84
Cryptomonas	9	3183.96	98.27
Microcystis	19	6721.69	207.46
Merismopedia	2	707.55	21.84
Spirulina	2	707.55	21.84
Anabaena	4	1415.09	43.68
TOTAL	99		1080.97
21 OCT 93			
Ulothrix	37	5310.47	323.81

Continued	Grid Count	Total Count	#/ml
pennales	8	1148.21	70.01
Cryptomonas	17	2439.94	148.78
Microcystis	23	3301.10	201.29
centrales	3	430.58	26.25
Gleocystis	16	2296.42	140.03
Chlamydomonas	5	717.63	43.76
Spirulina	2	287.05	17.50
Scenedesmus	6	861.16	52.51
Gonium	3	430.58	26.25
TOTAL	120		1050.19
STATION 6			
4 JUN 92			
Scenedesmus		865	155.69
Pediastrum		13	2.34
Cryptomonas		577	103.85
centrales		232	41.76
pennales		6204	1116.63
Gonium		370	66.59
Platydorina		146	26.28
Oedogonium		10	1.80
Chlorella		239	43.02
Coelastrum		116	20.88
Peridinium		57	10.26
Ceratium		5	0.90
Melosira		3	0.54
Richterella		6	1.08
Closterium		4	0.72
TOTAL		8847	1592.33
2 JUL 92			
Cryptomonas		1864	708.32
pennales		2558	972.04
Microcystis		200	76.00
Scenedesmus		788	299.44

Continued	Grid Count	Total Count	#/ml
Ceratium		19	7.22
centrales		135	51.30
Pediastrum		5	1.90
Peridinium		14	5.32
Chlorella		120	45.60
Oedogonium		15	5.70
Spirulina		126	47.88
Lyngbya/Oscillatoria		82	31.16
Anabaena		13	4.94
Richterella		2	0.76
Melosira		17	6.46
TOTAL		5958	2264.04
19 AUG 92			
Lyngbya/Oscillatoria	63	11650.46	5825.23
Spirulina	43	7951.90	3975.95
Cryptomonas	2	369.86	184.93
Aphanocapsa	11	2034.21	1017.10
Gleocystis	4	739.71	369.86
Scenedesmus	5	924.64	462.32
pennales	9	1664.35	832.18
Melosira	2	369.86	184.93
Merismopedia	8	1479.42	739.71
Crucigenia	1	200.34	100.17
TOTAL	148		13692.37
12 SEP 92			
Lyngbya/Oscillatoria	81	1620.00	265.57
Spirulina	299	5980.00	980.33
Cryptomonas	9	180.00	29.51
Aphanocapsa	18	360.00	59.02
Gleocystis	24	480.00	78.69
Scenedesmus	21	420.00	68.85
pennales	162	3240.00	531.15
Pandorina	1	20.00	3.28

Continued	Grid Count	Total Count	#/ml
Merismopedia	88	1760.00	288.52
Crucigenia	3	60.00	9.84
centrales	58	1160.00	190.16
Pediastrum	2	40.00	6.56
Microcystis	25	500.00	81.97
Chlamydomonas	6	120.00	19.67
Peridinium	2	40.00	6.56
Mallomonas	3	60.00	9.84
Staurastrum	2	40.00	6.56
Actinastrum	1	20.00	3.28
TOTAL	805		2639.34
24 OCT 92			
Melosira	130		425.86
Peridinium	4		13.10
Cryptomonas	64		209.65
Gonium	4		13.10
centrales	70		229.31
Oocystis	118		386.55
Chlorella	104		340.69
Ceratium	2		6.55
Gleocystis	12		39.31
Spirulina	16		52.41
pennales	90		294.83
Scenedesmus	20		65.52
Staurastrum	1		3.28
Pandorina	2		6.55
Microcystis	3		9.83
Coelastrum	2		6.55
Pediastrum	1		3.28
TOTAL	643		2106.38
8 MAR 93			
Peridinium	18		34.2
centrales	58		110.2

Continued	Grid Count	Total Count	#/ml
pennales	7		13.3
Melosira	2		3.8
Gleocystis	1		1.9
TOTAL	86		163.4
18 APR 93			
Melosira	3	506.12	38.93
centrales	14	2361.89	181.68
Chlorella	48	8097.89	622.92
pennales	6	1012.24	77.86
Peridinium	11	1855.77	142.75
Scenedesmus	5	843.53	64.89
Gleocystis	6	1012.24	77.86
Cryptomonas	1	168.71	12.98
Oedogonium	6	1012.24	77.86
Closterium	2	337.41	25.95
TOTAL	102		1323.69
26 MAY 93			
Mallomonas	4	369.86	38.93
centrales	226		429.40
Chlorella	52	4808.13	506.12
Coelastrum	8	739.71	77.86
Pandorina	2	184.93	19.47
Gleocystis	7	647.25	68.13
Cryptomonas	16	1479.42	155.73
Oedogonium	4	369.86	38.93
Scenedesmus	3	277.39	29.19
pennales	11	1017.10	107.06
Lyngbya/Oscillatoria	3	277.39	29.19
TOTAL	336		1500.04
25 JUN 93			
Ceratium	3	848.49	62.85
Anabaena	27	7636.43	565.66
Lyngbya/Oscillatoria	42	11878.90	879.92

Continued	Grid Count	Total Count	#/ml
pennales	17	4808.13	356.16
Peridinium	17	4808.13	356.16
Mallomonas	7	1979.82	146.65
Coelastrum	3	848.49	62.85
Gleocystis	7	1979.82	146.65
Cryptomonas	6	1696.99	125.70
Aphanocapsa	7	1979.82	146.65
Sphaerocystis	7	1979.82	146.65
Melosira	2		3.80
centrales	29		55.10
Euglena	1		1.90
Pediastrum	3	848.49	62.85
TOTAL	178		3119.56
23 JUL 93			
Pandorina	4	1039.59	105.01
Gleocystis	14	3638.58	367.53
pennales	68	17673.11	1785.16
Coelastrum	5	1299.49	131.26
Lyngbya/Oscillatoria	5	1299.49	131.26
Oocystis	6	1559.39	157.51
Mallomonas	2	519.80	52.50
Aphanocapsa	6	1559.39	157.51
Crucigenia	2	519.80	52.50
Melosira	4	1039.59	105.01
Peridinium	1	259.90	26.25
Anabaena	4	1039.59	105.01
Tetraedron	1	259.90	26.25
Spirulina	2	519.80	52.50
Pediastrum	2	519.80	52.50
Actinastrum	1	259.90	26.25
Cryptomonas	2	519.80	52.50
Staurastrum	1	259.90	26.25
Scenedesmus	4	1039.59	105.01

Continued	Grid Count	Total Count	#/ml
TOTAL	134		3517.82
4 AUG 93			
pennales	45.33	12028.29	3341.19
Merismopedia	6.67	1768.87	491.35
Oocystis	10.67	2830.19	786.16
Aphanocapsa	7.33	1945.75	540.49
Cryptomonas	6.67	1768.87	491.35
Microcystis	6.67	1768.87	491.35
Ankistrodesmus	8.33	2211.08	614.19
Spirulina	9.00	2387.97	663.33
Anabaena	7.33	1945.75	540.49
Scenedesmus	6.00	1591.98	442.22
Actinastrum	0.67	176.89	49.14
Staurastrum	1.67	442.22	122.84
Gleocystis	1.00	265.33	73.70
TOTAL	117.33		8647.79
19 AUG 93			
Gleocystis	6	1989.57	150.72
pennales	36	11937.41	904.35
Mallomonas	1	331.59	25.12
Chlamydomonas	7	2321.16	175.85
Cryptomonas	12	3979.14	301.45
Microcystis	7	2321.16	175.85
centrales	1	331.59	25.12
Ankistrodesmus	23	7626.68	577.78
Ulothrix	2	663.19	50.24
Scenedesmus	5	1657.97	125.60
Spirulina	12	3979.14	301.45
Merismopedia	2	663.19	50.24
Staurastrum	3	994.78	75.36
TOTAL			2939.14
2 SEPT 93			
pennales	62	22081.76	2007.43

Continued	Grid Count	Total Count	#/ml
Chlamydomonas	6	2136.94	194.27
Cryptomonas	11	3917.73	356.16
Scenedesmus	2	712.31	64.76
Gleocystis	7	2493.10	226.65
Microcystis	4	1424.63	129.51
Spirulina	6	2136.94	194.27
Lyngbya/Oscillatoria	3	1068.47	97.13
Gonium	3	1068.47	97.13
Aphanocapsa	5	1780.79	161.89
Ankistrodesmus	12	4273.89	388.54
Actinastrum	1	356.16	32.38
Merismopedia	2	712.31	64.76
TOTAL	124		4014.87
16 SEPT 93			
pennales	36	12363.75	852.67
Gleocystis	6	2060.63	142.11
Lyngbya/Oscillatoria	5	1717.19	118.43
Cryptomonas	21	7212.19	497.39
Microcystis	3	1030.31	71.06
Spirulina	15	5151.56	355.28
Ankistrodesmus	22	7555.63	521.08
Aphanocapsa	1	343.44	23.69
centrales	3	1030.31	71.06
Merismopedia	3	1030.31	71.06
Actinastrum	2	686.88	47.37
Scenedesmus	4	1373.75	94.74
Staurastrum	1	343.44	23.69
Chlamydomonas	7	2404.06	165.80
TOTAL	129		3055.41
30 SEPT 93			
pennales	22	8338.94	297.82
Ulothrix	10	3790.43	135.37
Microcystis	15	5685.64	203.06

Continued	Grid Count	Total Count	#/ml
Chlamydomonas	2	758.09	27.07
Pediastrum	4	1516.17	54.15
Gonium	9	3411.39	121.84
centrales	4	1516.17	54.15
Spirulina	2	758.09	27.07
Cryptomonas	21	7959.90	284.28
Scenedesmus	3	1137.13	40.61
Aphanocapsa	8	3032.34	108.30
Cosmarium	1	379.04	13.54
TOTAL	101		1367.26
22 OCT 93			
pennales	32	8316.76	803.55
Chlamydomonas	10	2598.99	251.11
Cryptomonas	16	4158.38	401.78
Gleocystis	17	4418.28	426.89
Tetraedron	1	259.90	25.11
Ulothrix	5	1299.49	125.55
Scenedesmus	1	259.90	25.11
Aphanocapsa	8	2079.19	200.89
centrales	7	1819.29	175.78
Mallomonas	1	259.90	25.11
Microcystis	5	1299.49	125.55
Lyngbya/Oscillatoria	3	779.70	75.33
Spirulina	6	1559.39	150.67
TOTAL	112		2812.43
STATION 7			
4 JUN 92			
Ceratium		127	24.13
Cryptomonas		2521	478.99
Peridinium		53	10.07
Coelastrum		99	18.81
Scenedesmus		165	31.35
centrales		101	19.19

Continued	Grid Count	Total Count	#/ml
pennales		6696	1272.24
Staurastrum		15	2.85
Pediastrum		6	1.14
Closterium		4	0.76
Melosira		32	6.08
TOTAL		9819	1865.61
2 JUL 92			
Cryptomonas		1181	448.78
pennales		2954	1122.52
centrales		146	55.48
Scenedesmus		576	218.88
Melosira		20	7.6
Oedogonium		23	8.74
Spirulina		160	60.8
Ceratium		13	4.94
Microcystis		225	85.5
Peridinium		15	5.7
Anabaena		16	6.08
TOTAL		5329	2025.02
19 AUG 92			
Peridinium	3	335.45	26.41
Mallomonas	2	223.63	17.61
Lyngbya/Oscillatoria	287	32091.44	2526.88
Spirulina	428	47857.62	3768.32
centrales	9	1006.35	79.24
Cryptomonas	3	335.45	26.41
Aphanocapsa	37	4137.22	325.77
Gleocystis	32	3578.14	281.74
Scenedesmus	18	2012.70	158.48
pennales	77	8609.90	677.94
Coelastrum	3	335.45	26.41
Pediastrum	1	111.82	8.80
Merismopedia	12	1341.80	105.65

Continued	Grid Count	Total Count	#/ml
Crucigenia	2	223.63	17.61
Staurastrum	6	670.90	52.83
TOTAL	920		8100.12
12 SEP 92			
Peridinium	2	40.00	4.21
Mallomonas	1	20.00	2.11
Lyngbya/Oscillatoria	115	2300.00	242.11
Spirulina	317	6340.00	667.37
centrales	8	160.00	16.84
Cryptomonas	6	120.00	12.63
Aphanocapsa	14	280.00	29.47
Gleocystis	10	200.00	21.05
Scenedesmus	14	280.00	29.47
pennales	168	3360.00	353.68
Coelastrum	3	60.00	6.32
Pediastrum	1	20.00	2.11
Merismopedia	76	1520.00	160.00
Crucigenia	2	40.00	4.21
Staurastrum	3	60.00	6.32
Chlamydomonas	6	120.00	12.63
Ceratium	1	20.00	2.11
Microcystis	20	400.00	42.11
Oedogonium	1	20.00	2.11
TOTAL	768		1616.84
24 OCT 92			
Mallomonas	2	40.00	0.42
Lyngbya/Oscillatoria	2	40.00	4.21
Spirulina	4	80.00	8.42
centrales	8	160.00	16.84
Cryptomonas	14	280.00	29.47
Gleocystis	13	260.00	27.37
Scenedesmus	7	140.00	14.74
pennales	52	1040.00	109.47

Continued	Grid Count	Total Count	#/ml
Coelastrum	2	40.00	4.21
Pediastrum	5	100.00	10.53
Melosira	44		83.60
Crucigenia	2	40.00	4.21
Actinastrum	3	60.00	6.32
Chlamydomonas	7	140.00	14.74
Oedogonium	27	540.00	56.84
TOTAL	192		391.39
8 MAR 93			
Cryptomonas	2	20	3.08
Oedogonium	25	250	38.46
centrales	50		95.00
pennales	13	130	20.00
Peridinium	2	20	3.08
Gleocystis	2	20	3.08
Melosira	3		5.70
Microcystis	1	10	1.54
Platydorina	1	10	1.54
TOTAL	99		171.47
18 APR 93			
Oedogonium	27	4636.41	482.96
centrales	650		1235.00
Chlorella	46	7899.06	822.82
pennales	6	1030.31	107.32
Cryptomonas	9	1545.47	160.99
Scenedesmus	2	343.44	35.77
Melosira	8	1373.75	143.10
TOTAL	748		2987.96
26 MAY 93			
centrales	7	747.93	82.19
Chlorella	40	4273.89	469.66
Coelastrum	5	534.24	58.71
pennales	26	2778.03	305.28

Continued	Grid Count	Total Count	#/ml
Cryptomonas	21	2243.79	246.57
Sphaerocystis	3	320.54	35.22
Gleocystis	2	213.69	23.48
Chlamydomonas	6	641.08	70.45
centrales	190		361.00
Platydorina	1	106.85	11.74
Cosmarium	1	106.85	11.74
TOTAL	302		1676.04
25 JUN 93			
Pediastrum	5	1265.30	105.44
Sphaerocystis	4	1012.24	84.35
Mallomonas	2	506.12	42.18
Scenedesmus	2	506.12	42.18
Cryptomonas	16	4048.95	337.41
pennales	11	2783.65	231.97
Anabaena	26	6579.54	548.29
Cosmarium	1	253.06	21.09
Gleocystis	14	3542.83	295.24
Lyngbya/Oscillatoria	41	10375.43	864.62
Peridinium	2	506.12	42.18
Oocystis	10	2530.59	210.88
Ceratium	1	253.06	21.09
TOTAL	135		2846.92
23 JUL 93			
pennales	91	31252.81	3156.85
Melosira	4	1373.75	138.76
Staurastrum	2	686.88	69.38
Cryptomonas	4	1373.75	138.76
Gleocystis	12	4121.25	416.29
Kirchnerella	2	686.88	69.38
Tetraedron	3	1030.31	104.07
Mallomonas	1	343.44	34.69
Scenedesmus	3	1030.31	104.07

Continued	Grid Count	Total Count	#/ml
Pandorina	1	343.44	34.69
Oocystis	1	343.44	34.69
Spirulina	1	343.44	34.69
Merismopedia	1	343.44	34.69
centrales	2	686.88	69.38
Aphanocapsa	1	343.44	34.69
TOTAL	129		4475.09
4 AUG 93			
Actinastrum	2	369.86	123.29
Spirulina	7	1294.50	431.50
Ankistrodesmus	6	1109.57	369.86
Gleocystis	12	2219.13	739.71
Cryptomonas	10	1849.28	616.43
Staurastrum	1	184.93	61.64
Chlamydomonas	3	554.78	184.93
Anabaena	1	184.93	61.64
Scenedesmus	4	739.71	246.57
TOTAL	125		7705.33
19 AUG 93			
Cryptomonas	7	3365.69	323.62
Chlamydomonas	11	5288.94	508.55
Ankistrodesmus	21	10097.06	970.87
Spirulina	3	1442.44	138.70
pennales	51	24521.44	2357.83
Scenedesmus	4	1923.25	184.93
Gleocystis	10	4808.13	462.32
Lyngbya/Oscillatoria	1	480.81	46.23
Aphanocapsa	6	2884.88	277.39
Merismopedia	3	1442.44	138.70
Staurastrum	6	2884.88	277.39
Tetraedron	3	1442.44	138.70
Ulothrix	1	480.81	46.23
Euglena	1	480.81	46.23

Continued	Grid Count	Total Count	#/ml
Mallomonas	1	480.81	46.23
TOTAL	129		5963.92
2 SEPT 93			
pennales	146	96845.45	3889.38
Gonium	3	1989.98	79.92
Scenedesmus	4	2653.30	106.56
Spirulina	8	5306.60	213.12
centrales	4	2653.30	106.56
Gleocystis	4	2653.30	106.56
Microcystis	2	1326.65	53.28
Peridinium	5	50	2.01
Staurastrum	9	90	3.61
Cosmarium	2	20	0.80
Chlamydomonas	3	30	1.20
Anabaena	3	30	1.20
Pediastrum	4	40	1.61
TOTAL	197		4565.81
16 SEPT 93			
centrales	8.00	5128.67	197.26
Merismopedia	8.33	5342.36	205.48
Eutetramonas	1.00	641.08	24.66
Staurastrum	1.33	854.78	32.88
pennales	35.00	22437.92	863.00
Kirchnerella	6.67	4273.89	164.38
Scenedesmus	4.67	2991.72	115.07
Spirulina	11.67	7479.31	287.67
Ankistrodesmus	14.67	9402.56	361.64
Cryptomonas	9.67	6197.14	238.35
Aphanocapsa	4.33	2778.03	106.85
Gleocystis	9.67	6197.14	238.35
Lyngbya/Oscillatoria	10.33	6624.53	254.79
Tetraedron	0.31	195.89	7.53
Ulothrix	0.33	213.69	8.22

Continued	Grid Count	Total Count	#/ml
Chlamydomonas	0.67	427.39	16.44
Pediastrum	0.33	213.69	8.22
Cosmarium	1.00	641.08	24.66
TOTAL	127.97		3155.42
30 SEPT 93			
pennales	47	12470.51	395.89
centrales	7	1857.31	58.96
Cryptomonas	10	2653.30	84.23
Merismopedia	6	1591.98	50.54
Gleocystis	3	795.99	25.27
Microcystis	4	1061.32	33.69
Spirulina	5	1326.65	42.12
Scenedesmus	9	2387.97	75.81
Pediastrum	2	530.66	16.85
Staurastrum	3	795.99	25.27
Aphanocapsa	5	1326.65	42.12
Gonium	18	4775.94	151.62
TOTAL	119		1002.36
22 OCT 93			
Pandorina	6.33	1646.02	82.30
Melosira	16.33	4245.01	212.25
Pediastrum	4.33	1126.23	56.31
Ulothrix	5.67	1472.76	73.64
Scenedesmus	10.67	2772.25	138.61
Cryptomonas	16.33	4245.01	212.25
Chlamydomonas	16.33	4245.01	212.25
Rhizoclonium	4.33	1126.23	56.31
pennales	71.67	18626.07	931.30
centrales	16.67	4331.64	216.58
Aphanocapsa	10.00	2598.99	129.95
Microcystis	4.33	1126.23	56.31
Lyngbya/Oscillatoria	12.00	3118.78	155.94
Staurastrum	3.00	779.70	38.98

Continued	Grid Count	Total Count	#/ml
Sphaerocystis	0.67	173.27	8.66
Crucigenia	0.33	86.63	4.33
TOTAL	199		2585.99

VITA

Shanon Haraughty

Candidate for the Degree of

Master of Science

Thesis: THE RELATIONSHIP BETWEEN NUTRIENT LIMITATION AND PHYTOPLANKTON COMMUNITY STRUCTURE IN TENKILLER FERRY LAKE

Major Field: Zoology

Biographical:

Personal Data: Born in Panorama City, California, 27 September 1968, daughter of John and Norma Haraughty.

Education: Graduated Shawnee Mission East High School, Shawnee Mission, Kansas, May 1986; received Bachelor of Science degree in biology/Pre-Veterinary Medicine from Kansas State University, Manhattan, Kansas, May 1990; completed requirements for the Master of Science degree at Oklahoma State University in May 1995.

Professional Experience: Research Assistant, Water Quality Research Lab, Oklahoma State University, April 1992 to present.