Effects of Nitrogen and Phosphorus Fertilization on Primary Productivity: A Case History of Grayson Lake, Kentucky

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Abstract: Although fertilization has been a common practice to increase fish production in low nutrient lakes and ponds, applicability of the practice in larger reservoirs is questionable. Under the assumption that increased algal production moves up the food web to fish, we fertilized Grayson Lake, Kentucky, surface water with high N to P ratio fertilizer during springs 1994 and 1995. April through July 1994 we added 1 kg P/ha and 22 kg N/ha over a 9-week period to approximately 162 ha of lake surface area. During 1995 we increased loading to 7 kg P/ha with 22 kg N/ha. Weekly photic zone water samples were taken directly after fertilization (within 1 day). Water quality and primary production were assessed in fertilized and unfertilized lake regions. Alkalinity, inorganic nitrogen, soluble reactive phosphorus, and chlorophyll *a* concentrations were not significantly higher in the fertilized areas ($N = 40$ in 1994, $N = 50$ in 1995, $P > 0.1$ Mann-Whitney test). Secchi depth was also unaffected by fertilization. The large volume and rapid hydrologic renewal probably contributed to the lack of increased primary production after fertilization. Although total P always averaged greater than 57 µg/liter, chlorophyll *a* never averaged higher than 4.7 µg/liter. Secchi depths averaged less than 1.7 m, suggesting non-algal turbidity was high. We conclude that fertilization is an ineffective technique to increase fish production in large reservoirs (e.g., kilometers long) because factors other than nutrient concentrations, such as temperature, light, available habitat, and top-down predation, may determine primary productivity and fish survival.

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In Eastern Kentucky, fertilization is a common management practice to increase primary productivity and fish productivity in small lakes and ponds, as well as reser-

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voirs. A number of reservoir watersheds in this region are extensively forested and have sparse human population density. Reservoir water inflow is low in nutrients because of the fairly pristine watershed and lack of pollution. The Kentucky Department of Fish and Wildlife historically has fertilized reservoirs in an attempt to increase the quality and quantity of gamefish and to control dense growth of submersed aquatic vegetation that can inhibit boating and swimming.

In southern Appalachian reservoirs, there is a correlation between phosphorus and fish yield (Ney and Yurk 1989). Generally, eutrophic lakes have higher densities of bass than oligotrophic reservoirs (Buynak 1986, Ney 1996). Correlations between fish yield and chlorophyll *a* have been noted before, but making management decisions based upon simple correlations of a single variable can result in incorrect actions (Havens 1999). For example, because pre-fertilization fish populations were not assessed, it is unclear whether fertilization was the cause of increased fish production. Further, other ecological factors may affect a fishery's success (e.g., size of lake, available habitat, temperature, and water level fluctuations). If too much fertilizer is added, excess phosphorus can result in reduced dissolved oxygen and create fish kills.

The role of phosphorus in controlling freshwater lake productivity is well described in numerous studies (Hecky and Kilham 1988), and the relative ratio of phosphorus to nitrogen can determine the algal community structure (Tilman 1977, Smith 1979, Smith 1983, Culver 1991). To avoid possible negative ramifications of fertilization, such as cyanobacteria blooms, we adjusted normal fertilization recommendation. Based upon Boyd's (1990) recommendations most fertilization programs in Kentucky suggest at least 1 gallon per surface acre of commercial tobacco fertilizer (9-18-9) be applied every 2 weeks in April and May and throughout the growing season until August whenever Secchi depth exceeds 0.61 m. Higher N:P ratio fertilizer can increase edible phytoplankton necessary to provide larval fish with optimal zooplankton (Helal and Culver 1991). We also adjusted the timing of fertilization to create a zooplankton bloom that would coincide with hatching fry becoming planktivorous (March through May).

The objectives of this research were to determine if fertilization could increase the nutrient concentrations in the photic zone of a medium-sized Kentucky reservoir and, if so, if this would result in increased primary production to increase larval bass survival.

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Methods

Site Description

Grayson Lake is a U.S. Army Corps of Engineers impoundment built in 1968 for flood control within the Little Sandy River drainage in northeastern Kentucky. The dam collects and controls runoff from a 508-km^2 watershed, about 70% of which is secondary growth mixed mesophytic forest (dominated by oak and hickory). Tobacco and corn are grown on bottomland along the tributaries; coal seams in the watershed have been strip mined. Although not as influential on Grayson Lake water quality, oil and natural gas are extracted in the watershed.

Like most impoundments in steeply sloping landscapes, the lake is serpentine with a narrow channel and little littoral development (D_L = 13.6). At summer pool (196.59 m above mean sea level) the reservoir has a surface area of 611 ha, 13,199,725 m^3 net volume, 6 m mean depth, and 32 km pool length. Water renewal averages 73 days.

The dramatic water level changes between summer and winter pools (sometimes over 3 m), along with the steep banks, inhibit littoral vegetation establishment. In order to achieve suitable game fish populations for angling, fish have been stocked annually since 1969 with primary emphasis on largemouth bass *(Micropterus salmoides)* and their prey—gizzard shad *(Dorosoma cepedianum)* and threadfin shad *(D. petenense).*

Fertilization and Water Analysis

We fertilized 162 ha in the middle of Grayson Lake weekly between mid-April and the first week of June 1994 and 1995. In 1994, we misted 9,842 liters (at 0.5–1.0 gallons/acre/week) of 23-3-0 liquid fertilizer over the surface of the lake for 8 consecutive weeks. During 1995, we increased phosphorus loading by applying 1,893 liters of 0-20-20 (at 0.4 gallon/acre/week) along with 9,842 liters of 23-0-0. The approximate mass of each nutrient added, based upon analysis of the fertilizer, is shown in Table 1.

Within 24 hours of fertilization, we took duplicate Secchi depth readings and photic zone water samples from 3 areas of the lake that were fertilized and 3 areas that were not impacted by fertilization. Photic zone samples were obtained by mixing 500 ml water samples, taken at 0.5-m intervals throughout the photic zone, in an acid-washed bucket. Samples were filtered on the boat, and the filter was placed in a foil-covered centrifuge tube. Filters, filtrate, and unfiltered water were kept on ice in the field; soluble nutrients were analyzed within 12 hours of sampling.

Chlorophyll *a* was extracted from filtered algae (GF/A 0.45 µm glass fiber filters) with 90% alkaline acetone and analyzed flourometrically (U.S. Environ. Protection Agency 1979, method 445.0). Alkalinity was measured by 0.02 N H_2SO_4 titration to a 5.0 pH endpoint (Larson and Henley 1955). Nitrate (NO_3) was determined with a variation of the sulfanilamide method following cadmium reduction (Henrickson and Selmer-Olsen 1970). Ammonia (NH_3) was determined with a Nesslerization technique (Jenkins 1968); soluble reactive phosphorous (SRP) was measured with the ascorbic acid method (Murphy and Riley 1962) on filtered water. Total phosphorous (TP) was determined following a persulfate and H_2SO_4 digestion (U.S. Environ. Protection Agency 1979, method 365.3).

To determine if fertilizer increased nutrient concentrations or algal biomass, we compared average fertilized and unfertilized water quality parameters each year to determine if fertilization increased nutrients or chlorophyll or decreased Secchi

Table 1. Water quality in Grayson Lake during large-scale fertilization.

Year	Site type	P kg/ha	N kg/ha	Secchi m	Chl. a µg/liter	TP µg/liter	SRP µg/liter	TIN µg/liter	Alkalinity mgCaCO3/liter
1994	Fertilized	1	22	1.26	3.37	56	29	697	19.7
1994	Control	0	0	1.48	3.11	95	26	598	18.9
1995	Fertilized	7	22	1.30	4.47	61	26	243	21.3
1995	Control	0	0	1.67	3.21	57	21	224	20.7

depth. Because of the large inter-annual variability in water quality, it was irrational to compare between years. Each year was treated separately. Because not all the data fit normality requirements, we compared averages using the Mann-Whitney test (comparing medians) as well as the *t*-test (comparing means). Mann-Whitney results were commensurate with *t*-test. We used Statview 4.0 for Macintosh for all data analyses. Due to the variability of field data, we chose a 0.1 significance level for all tests.

Results

During both years TP concentrations were typical of those found in eutrophic lakes (Table 1). Although 1995 TP was higher than 1994 (when less P was added), the control site also had higher TP concentrations, indicating the increase was not due to fertilization. Combined nitrate and ammonium concentrations (total inorganic N = TIN) were higher during 1995 in both control and fertilized sites than in 1994 whereas alkalinity was low both years. Overall, there was no relationship between SRP or TP and chlorophyll *a* (Fig. 1), nor was there any strong relationship between nitrogen and chlorophyll.

Secchi transparency was low in Grayson Lake, which can be indicative of high algal biomass. However, chlorophyll *a* was not associated with a low transparency; therefore, algal biomass is not the main cause of lake turbidity in Grayson Lake.

Neither *t*-tests nor Mann-Whitney tests found significant difference between fertilized and unfertilized areas either year ($N = 50$ in 1994, $N = 40$ in 1995, $P > 0.10$ both years). Neither fertilization regime (high N:P in 1994 and increased P in 1995) created any change in nutrient concentrations, transparency, or algal biomass.

Discussion

We did not find a significant increase in nutrient concentrations, transparency, or algal biomass in the fertilized areas of Grayson Lake. Lack of response could be attributed to top-down trophic dynamics (Carpenter et al. 1985). Grayson Lake is in the trophic range where top-down dynamics have been observed in other lakes (Elser and Goldman 1991). If the excess algal production was quickly eaten by zooplankton which were in turn eaten by larval fish or other planktivors (such as shad), we would have expected to see some other effects of consumer control of the ecosystem. Top-

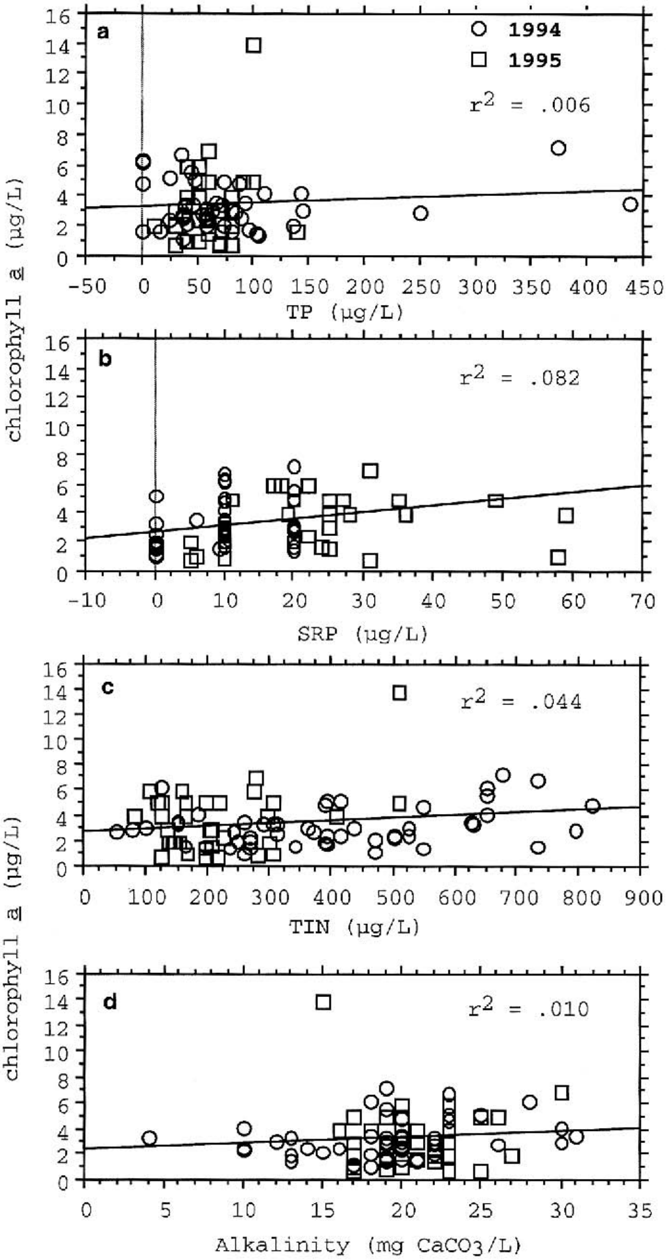

Figure 1. Relationship between algal biomass (chlorophyll *a*) and a) total phosphorus (TP), b) soluble reactive phosphorus (SRP), c) total inorganic nitrogen (TIN), and d) alkalinity during large-scale reservoir fertilization in Grayson Lake, Kentucky.

down trophic dynamics could explain the lack of increased algal biomass; however, it is unlikely. For the top-down theory to be correct, the amount of algae lost to upper trophic levels would have to be the exact magnitude required to keep chlorophyll *a* concentrations the same as the control sites every week. It seems unlikely that the predator response was the exact magnitude required to produce no discernible change in transparency, chlorophyll, or nutrients.

Lake transparency is determined by non-algal suspensoids. Some of the lowest Secchi depths occur after storms. The highest correlation with turbidity in eastern Kentucky reservoirs is total suspended solids (Davis and Reeder 2001). Total suspended solids are not commensurate with algal biomass. The most probable cause of the excess turbidity is sediment from watershed runoff or lake turbulence.

Zooplankton populations were not significantly different when fertilized and unfertilized zones were compared. Both areas were dominated by smaller zooplankters (Spier 1995, Remley 1997, Davis and Reeder 2001). The lack of larger size classes of plankton suggest that foraging pressure has allowed smaller zooplankters to dominate. Since no large predatory zooplankton were found, it is likely that our plankton community structure resulted from size selective predation by planktivorous fish including larvae. A possible increase in shad populations with fertilization supports this hypothesis (Buynak et al. 2001).

Even though the fertilizer was misted on the lake surface, because is more dense than water, it may still have quickly sunk out of the photic zone, especially if it reacted with suspended sediment or algae (Rigler 1956, Schindler 1977, Boyd 1997). Given the loading rate and average depth, phosphorus levels may have been too low to increase production. This could be due to loss from the system or dilution in the water column. However, there is little relationship between chlorophyll *a* and total P or soluble reactive P, so we do not think phosphorus is a primary limiter of production in Grayson Lake.

Nutrient concentrations were high in both fertilized and unfertilized areas of Grayson Lake during both study years. However, lakes with similar P and N concentrations generally have greater algal biomass (Carlson 1977, Kratzer and Brezonik 1981). Because phosphorus was apparently not used to enhance production of chlorophyll *a*, we would have expected greater transparency in Grayson Lake. These results suggest Grayson Lake productivity may be limited by available nitrogen or light (Kratzer and Brezonik 1981, Carlson 1991).

Before the reservoir was fertilized we established that algae had adequate bioavailable phosphorus. Crawford (1995) measured TP concentrations of 75.8 µg/liter and SRP of 32.9 µg/liter during the 1993 growing season. Accordingly, our P application rates were lower than most recommendations because we wanted to reduce the possibility of creating blooms of inedible algae and epilimnetic anoxia.

Because algae need at least 10 times more N than P, nitrogen can become a limiting factor. If N becomes limiting to green algae and diatoms, nitrogen-fixing cyanobacteria gain a competitive advantage and may dominate the phytoplankton (Tilman 1977, Smith 1979). Due to nitrogen fixation, Boyd (1997) suggested that N:P ratios be 1.3–1.7:1. Culver (1991), based upon the resource ratio hypothesis

(Tilman 1977, Smith 1979), found that a N:P of at least 20:1 was necessary to create plankton communities optimal for fry production in hatchery ponds. To reduce production of inedible cyanobacteria, we kept our nitrogen loading higher than most recommendations. In 1994, our TN:TP was about 16:1, but this was variable; and about 10:1 in 1995. Some nutrient ratio models (Kratzer and Brezonik 1981, Carlson 1991) suggest occasional N limitations. There was not a strong relationship between N and chlorophyll *a*, nor were Grayson Lake plankton populations dominated by cyanobacteria. Therefore, nitrogen is probably not a primary limiter of production in Grayson Lake.

Another possible limiting factor is carbon. Grayson Lake's lowest alkalinity was 6 mg $CaCO_3$/liter, and averaged just below 20 mg $CaCO_3$/ liter. Boyd (1997) suggested that lakes with alkalinity less than 20 mg $CaCO_3$/liter will not have sufficient carbon for production, and highly productive ponds may require up to 100 mg $CaCO_3$/ liter. However, early studies of lake productivity (Schindler 1977), supported by years of subsequent research (reviewed by Hecky and Kilham 1988), suggested that carbon would rarely be limiting in freshwater lakes. Because most algae can utilize free CO_2 or bicarbonate (at some physiological expense) it should be rare for lake algal communities to be carbon limited (Wetzel 2001). We did not find any correlation between alkalinity and chlorophyll *a* suggesting that carbon is also not a primary limitation to algal production.

According to some models developed by Carlson (1977, 1991) and Kratzer and Brezonik (1981) our nutrient concentrations were sometimes indicative of a nitrogen or non-nutrient limitation. The relative nutrient ratios and low Secchi depths (in relationship to the low chlorophyll) are not uncommon in reservoirs in our region (Davis and Reeder 2001). Since none of the common limiting factors to lake production seem to be controlling Grayson Lake, it leads us to suggest that temperature and light may be the primary limiters of phytoplankton production. This may also play some role in the survival of larval bass.

Conclusions

It is unlikely that the presence or absence of nutrients are the most important factors influencing fish growth and survival in Grayson Lake. Fertilization does not seem to be a fruitful mechanism for increasing bass survival (Buynak et al. 2001). Even in lakes where fertilization does increase primary production, it may not always result in the desired effect. Fertilization of Kentucky reservoirs in the past has resulted in fish kills. Mountain reservoirs have a small surface area in relationship to their volume, and are therefore prone to summer hypolimnetic anoxia even if they are oligotrophic. Because of past fertilization, some lakes are now listed by the Kentucky Division of Water as "unsuitable for use" because of "management actions" taken by the Kentucky Department of Fish and Wildlife (Ky. Environ. Protection Cabinet, Div. Water 1996).

The highest fish diversity is in lakes that are mesotrophic (Dodson et al. 2000).

Although high diversity is not a goal of single species management; high diversity does suggest a healthy ecosystem, which is often a desirable goal. Fertilization to eutrophy may decrease species richness and will reduce dissolved oxygen in the water column. In mountain reservoirs, with a low surface area to volume, oxygen concentrations are often anoxic in the bottom of the photic zone, regardless of trophic status. Therefore, any scheme with the potential to reduce oxygen in the cooler waters must be approached with caution.

We also found fertilization was cost prohibitive. We were unable to increase nutrients or fish production with $30,000 in fertilizer over a 2-year period. It is possible that fertilization must occur more often, or over a period of many years to reach the desired effect. If a number of large reservoirs were fertilized with more fertilizer for longer time it is unlikely the benefits would outweigh the costs. We have not seen a potential benefit, and the possible outcomes (fish kills have occurred due to overfertilization in the past) may not be what we desire.

Reservoirs are complex ecosystems with a number of biotic and abiotic interactions. Focusing on increasing one variable without examining the entire system can cause result in making expensive and ineffective management decisions (Havens 1999). For example, in reservoirs built in steeply sloping landscapes, the lack of littoral flora likely provides inadequate cover for nesting and food (especially aquatic insects). Further, the dramatic water level fluctuations retard reproductive success. Fish production is significantly higher in lakes with sufficient macrophytes (Keast 1984, Carpenter and Lodge 1986, Wilcox and Meeker 1992). A management plan that created wetland habitat would be more beneficial than fertilization in reservoirs like Grayson Lake.

Literature Cited

Boyd, C.E. 1990. Water quality in ponds for aquaculture. Ala. Agric. Exp. Sta., Auburn. 482pp.

______. 1997. Practical aspects of chemistry in pond aquaculture. Prog. Fish-Cult. 59:85–93.

Buynak, G.L. 1986. Habitat preferences of black bass in Kentucky. Fish. Bull. Ky. Dep. Fish and Wildl. No. 81.

______, B. Mitchell, L. Kornman, A. Surmont, B.C. Reeder, and S. Malvestuto. 2001. Responses to artificial fertilization at Grayson Lake, Kentucky. North Am. J. Fish. Manage. 21:393–403.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. and Oceanogr. 22:361–369.

______. 1991. Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs. Pages 59–71 *in* Proceedings of a national conference on enhancing the states' lake management program. Monitoring and lake impact assessment. Chicago, Ill.

Carpenter, S. R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634–639.

______, and D.M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. Aquat. Bot. 26:341–370.

Crawford, R. W. 1995. The feasibility of trophic manipulation in Grayson Lake, Kentucky. M.S. Thesis, Morehead State Univ., Morehead, Ky. 111pp.

Culver, D.A., 1991. Effects of the N:P ratio in fertilizer for fish hatchery. Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen 24:1503–1507.

Davis, S.E. and B.C. Reeder, 2001. Spatial analysis of water quality in Eastern Kentucky reservoirs. Aquat. Ecosyst. Health Manage. 4:463–477.

Dodson, S.I., S.E. Arnott, and C.L. Cottingham. 2000. The relationship in lake communities between primary productivity and species richness. Ecology 81:2662–2679.

Elser, J.J. and C.R. Goldman. 1991. Zooplankton effects on phytoplankton in lakes of contrasting trophic status. Limnol. and Oceangr. 36:64–90.

Havens, K.E. 1999. Correlation is not causation: a case study of fisheries, trophic state and acidity in Florida lakes. Environ. Pollution 106:1–4.

Hecky, R.E. and P. Kilham. 1988. Nutrient limitations of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment. Limnol. and Oceanogr. 33:796–882.

Helal, H.A. and D.A. Culver. 1991. N:P ratio and plankton production in fish ponds. Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie 24:1508–1511.

Henrikson, A. and A.R. Selmer-Olsen. 1970. Automatic methods for determining nitrate and nitrite in water and soil extracts. Analyst 95:514.

Jenkins, D. 1968. The differentiation, analysis, and preservation of nitrogen and phosphorus forms in natural waters. Pages 265–280 *in* R.A. Baker, ed. Trace inorganics in water. Am. Chem. Soc. Washington D.C.

Keast, A. 1984. The introduced macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. Can. J. Zool. 625:1289–1303.

Kentucky Environmental Protection Cabinet, Division of Water. 1996. Report to Congress on water quality. Frankfort, Ky. 235pp.

Kratzer, C.R. and P.L. Brezonik. 1981. A Carlson-type trophic state index for nitrogen in Florida Lakes. Water Res. Bull. 17:713–715.

Larson, T.E. and L.M. Henley. 1955. Determination of low alkalinity or acidity in water. Anal. Chem. 27:851–852.

Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta 27:31–36.

Ney, J.J. 1996. Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fisheries. Pages 285–295 in L.E. Miranda and D.R. DeVries, eds. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc., Bethesda, Md.

______. and J.J. Yurk. 1989. Phosphorus-fish community biomass relationships in southern Appalachian reservoirs: can lakes be too clean for fish? Lake and Reservoir Manage. 5:83–90.

Remley, A.W. 1997. Effects of fertilization on the water quality of Grayson Lake, Kentucky. M.S. Thesis, Morehead State Univ., Morehead, Ky. 118pp.

Rigler, F.H. 1956. A tracer study of the phosphorus cycle in lake water. Ecology 37:550–562.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes; natural mechanisms compensate for deficiencies of nitrogen and carbon in eutrophied lakes. Science 195:260–262.

Smith, V.H. 1979. Nutrient dependence of primary productivity in lakes. Limnol. Oceanogr. 24:1051–1064.

______. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science 221:669–670.

Spier, T.W. 1995. The effect of nitrogen and phosphorus fertilization on Grayson Lake, Ky. M.S. Thesis, Morehead State Univ., Morehead, Ky. 135pp.

Tilman, D. 1977. Resource competition between planktonic algae: an experimental and theoretical approach. Ecology 58:338–348.

U.S. Envrionmental Protection Agency (EPA). 1979. Methods for the analysis of water and waste. U.S. EPA, Washington, D.C. EPA-600/4-79-020. 460pp.

Wetzel, R.G. 2001. Limnology Lake and river ecosystems. Third ed. Acad. Press. 106pp.

Wilcox, D.A. and J.E. Meeker. 1992. Implications for faunal habitat related to altered macrophyte structure in regulated lakes in northern Minnesota. Wetlands 12:192–203.