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# BELLA VISTA LAKES PROJECT: FERTILITY MANAGEMENT

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**Bella Vista Lakes Project: Fertility Management**

J. Thad Scott[1]

[1]Department of Crop, Soil, and Environmental Science, University of Arkansas, Fayetteville, AR

## Introduction

Excessive concentrations of nitrogen (N) and (P) are commonly recognized as pollutants in eutrophic waterways. As a result, societal awareness of the positive effects of these nutrients in oligotrophic ecosystems and their central role in regulating biological productivity are limited (Anders and Ashley 2007). Managing N and P load reductions into freshwater lakes has led to measured decreases in trophic status (i.e. eutrophy to oligotrophy) of some lakes (Anderson et al. 2005, Conveney et al. 2005, Romo et al. 2005). This managed reversal of eutrophication has been termed 'cultural oligotrophication' or the human-induced reduction of excess nutrients in aquatic systems (Stockner et al. 2000). A classic example of this shift from eutrophy to oligotrophy is Lake Washington near Seattle, where wastewater diversion greatly decreased algal biomass and productivity, and changed algal community composition (Edmondson 1994).

A goal when managing lakes solely for drinking water and/or aesthetics is to manage the systems toward relatively biologically unproductive systems. However, the designated use of many lakes includes recreational fishing and harvestable fish populations, and oligotrophic systems often lack the nutrients required to support a robust biological community. Studies of eutrophic, lentic systems shifting to oligotrophy have shown both immediate (Yurk and Ney 1989) and delayed (Jeppesen et al. 2005, Sondergaard et al. 2005) responses in production and nutrient concentration due to reduced external nutrient loading.

How can we maintain a vibrant fish community and simultaneously ensure high quality waters for human consumption and contact recreation? The key is balancing the fertility needs of a water body with what is supplied via management. Although lake fertilization has been used as a tool in fisheries management, uniformed activities can lead to the overuse and misuse of fertilizers. Therefore, detailed studies are needed that demonstrate quantify the efficiency of whole lake fertilization and the conditions in which fertilization are needed. The objective of this study was to derive a generalized fertilization model for Bella Vista Lakes. The intent is to develop a tool that uses simple and readily available information to develop a fertilizer recommendation for any lake given the conditions of the lake, season, and weather patterns. This document describes the data collected during 2014-2015 in order to construct the fertilizer calculation tool for each lake, and demonstrates the use of the tool for lake fertility management.

The overall goal for lake fertility management as stated in the Bella Vista Nutrient Management Plan, which has been approved by the Arkansas Natural Resource Commission, is to maintain an average Secchi Transparency of approximately 1.5 – 2.0 m in all Bella Vista Lakes. The fertilization tool is specifically constructed to achieve this goal by using simple information on current secchi transparency and the desired secchi transparency of the lake. In most instances, the desired secchi transparency is between 1.5 – 2.0 m. According to the approved Bella Vista Nutrient Management Plan, lakes should not be fertilized to achieve any secchi transparency less than 1.5 meters.

**Materials and Methods**

All seven Bella Vista Lakes (Ann, Avalon, Brittany, Lomond, Norwood, Rayburn, and Windsor) were sampled during the growing season (March 1 – October 31) in 2014 and 2015. In-situ measurements were conducted, and water samples were collected, twice monthly on approximately the $1^{st}$ and $15^{th}$ day of each month. In-situ measurements included secchi transparency, water temperature, specific conductivity, dissolved oxygen, and pH. These measurements were obtained by the Bella Vista Lake Management Staff primarily using a Eureka multiparameter datasonde. Some in-situ measurements were made with a YSI 600 XLM multiparameter datasonde due to technical malfunctions with the Eureka unit owned by the Bella Vista POA.

Water samples were also generally collected and processed by the Bella Vista Lake Management Staff, with some assistance from University of Arkansas Limnology Laboratory Staff. Briefly, water samples were collected at a single location in each lake near the dam. Prior to sampling, the photic depth of the water was estimated by lowering a LiCor Quantum sensor through the water column until the measured irradiance was 1% of the surface irradiance. That depth was marked as the photic depth, which was divided into 3-5 equal proportions and a sample was collected from each proportion and composited into a single sample. This provided us an average water column sample from the photic zone of each lake.

Samples were placed on ice and returned to the Bella Vista Lake Management Laboratory for processing. Briefly, approximately 300-600 ml of water was filtered through three 25 mm GFF filters (100-200 ml water per filter). The filters were retained for particulate carbon/nitrogen, particulate phosphorus, and chlorophyll-a analyses. The filtrate was retained for total dissolved nitrogen, total dissolved phosphorus, and nitrate analyses. Additionally, a sample collected from deep water (~15 m) on each date was filtered similarly and the filtrate was retained for soluble reactive phosphorus and ammonium analyses.

Data were compiled into a single database for all lakes. The nutrient concentrations, phyto-plankton biomass (measured as chlorophyll-a), and secchi transparencies were analyzed for temporal variation and compared to common values for oligotrophic, mesotrophic, and eutrophic lakes (Wetzel 2001). Average annual total phosphorus, chlorophyll-a, and secchi transparency values for each lake were combined with literature data, as well as other data from Ozark Lakes, to derive a regional model for lake fertility. This model was then combined with bathymetric information from the Bella Vista Lakes to derive a fertilizer model for each lake.

**Results and Discussion**

When compared to the average conditions of Lake Trophic indices shown by Wetzel (2001), all seven Bella Vista Lakes are generally meso-trophic (Table 1). Lakes Brittany and Lomond show some signs of oligotrophy, particularly as it relates to their chlorophyll-a concentrations and secchi transparencies. Alternatively, Lakes Norwood and Rayburn show some signs of eu-trophy, particularly as it relates their chlorophyll-a concentrations and secchi transparencies.

The management goal for all of these lakes is 1.5 – 2.0 meters secchi transparency, which would approximately result in a Meso-Eutrophic rating for each lake. Thus, the average growing season secchi transparency should be approximately 2.0 meters, but never be less than 1.5 meters. Indeed, when raw data from each lake is shown for both years of monitoring, it is clear that the secchi transparency frequently exceeded 2.0 meters in all lakes (Figure 1). These results indicate that all seven lakes routinely qualified for fertilization during the 2014-2015 growing season. Lakes Brittany and Lomond typically

Table 1. Average total nutrient concentrations, chlorophyll-a concentrations, and secchi transparency for each Bella Vista Lake for the 2014 and 2015 growing seasons. Labels in parentheses shows the trophic state associate with each average value according to the categories shown in Wetzel (2001). The column on Average Trophic State represents an estimate trophic state based on the combination of all variables.

| Lake | Total Phosphorus (mg/L) | Total Nitrogen (mg/L) | Chlorophyll-a (µg/L) | Secchi Transparency (m) | Average Trophic State |
|---|---|---|---|---|---|
| Ann | 0.037 *(mesotrophic)* | 0.66 *(oligotrophic)* | 9.3 *(mesotrophic)* | 2.4 *(eutrophic)* | Mesotrophic |
| Avalon | 0.031 *(mesotrophic)* | 0.67 *(oligotrophic)* | 9.0 *(mesotrophic)* | 3.0 *(eutrophic)* | Mesotrophic |
| Brittany | 0.042 *(mesotrophic)* | 0.63 *(oligotrophic)* | 6.6 *(mesotrophic)* | 3.7 *(mesotrophic)* | Oligo-Mesotrophic |
| Lomond | 0.050 *(mesotrophic)* | 0.64 *(oligotrophic)* | 6.9 *(mesotrophic)* | 3.5 *(mesotrophic)* | Oligo-Mesotrophic |
| Norwood | 0.052 *(mesotrophic)* | 0.63 *(oligotrophic)* | 11.2 *(eutrophic)* | 2.4 *(eutrophic)* | Meso-Eutrophic |
| Rayburn | 0.044 *(mesotrophic)* | 0.62 *(oligotrophic)* | 14.6 *(eutrophic)* | 2.3 *(eutrophic)* | Meso-Eutrophic |
| Windsor | 0.048 *(mesotrophic)* | 0.86 *(mesotrophic)* | 7.0 *(mesotrophic)* | 2.6 *(eutrophic)* | Mesotrophic |

exhibited the greatest secchi transparency, while Lakes Norwood and Rayburn exhibited the least. Overall, 68% of secchi transparency measurements during the 2014-2015 growing season exceeded the 2.0 secchi transparency target. Thus, on average, these lakes qualified for lake fertilization on two of every three visits.

Secchi transparency in Ozark Lakes, like many lakes in North America (Carlson 1977) is strongly controlled by the magnitude of phytoplankton biomass suspended in the water column. This is typically measured as the cholorophyll-a concentration of the water column. Chlorophyll-a concentrations in Bella Vista Lakes ranged from 0.5 – 36 µg/L during the 2014-2015 growing seasons (Figure 2). An average chlorophyll-a concentration of 4.6 µg/L is considered a mesotrophic lake and an average chlorophyll-a concentration of 14.3 µg/L is considered a eutrophic lake.

The primary limiting nutrient for most lakes in North America is typically assumed to be phosphorus (Schindler et al. 2008). The total phosphorus concentrations in Bella Vista Lakes ranged from 0.009 – 0.1 mg/L during the 2014-2015 growing season (Figure 3), indicating that these lakes were typically mesotrophic relative to phosphorus availability. Other studies have indicated that nitrogen can limit phytoplankton growth in lakes (Scott et al. 2008) and can be particularly limiting in Ozark Lakes (Scott and Grantz 2013). Nitrate concentrations in Bella Vista Lakes regularly fell below the detection level in the 2014-2015 growing seasons (Figure 4). This indicates a strong likelihood that these lakes were co-limited by nitrogen availability.

Numerous studies have shown that the secchi transparency of many lakes is strongly controlled by the chlorophyll-a concentration in the water column (Carlson 1977). Indeed, the Bella Vista Lakes appear to conform to this model (Figure 5, top panel), which is not surprising given the relatively small amount of inorganic turbidity in these water bodies. Interestingly, the Bella Vista Lakes also strongly conform to the total phosphorus-chlorophyll-a models which demonstrate the primary importance of phosphorus as a limiting nutrient in lakes (Figure 5 bottom panel). The fact that a substantial amount of the

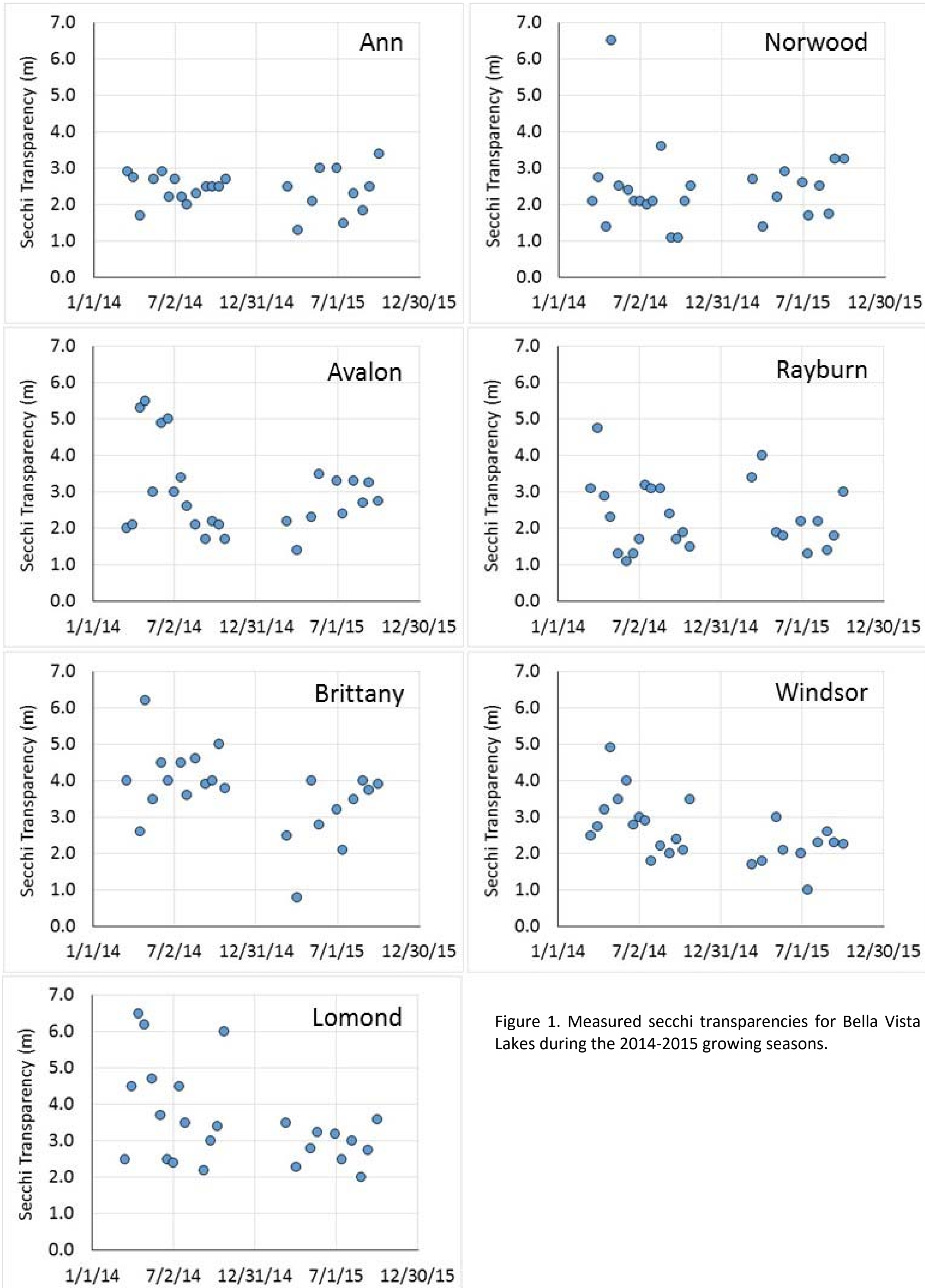
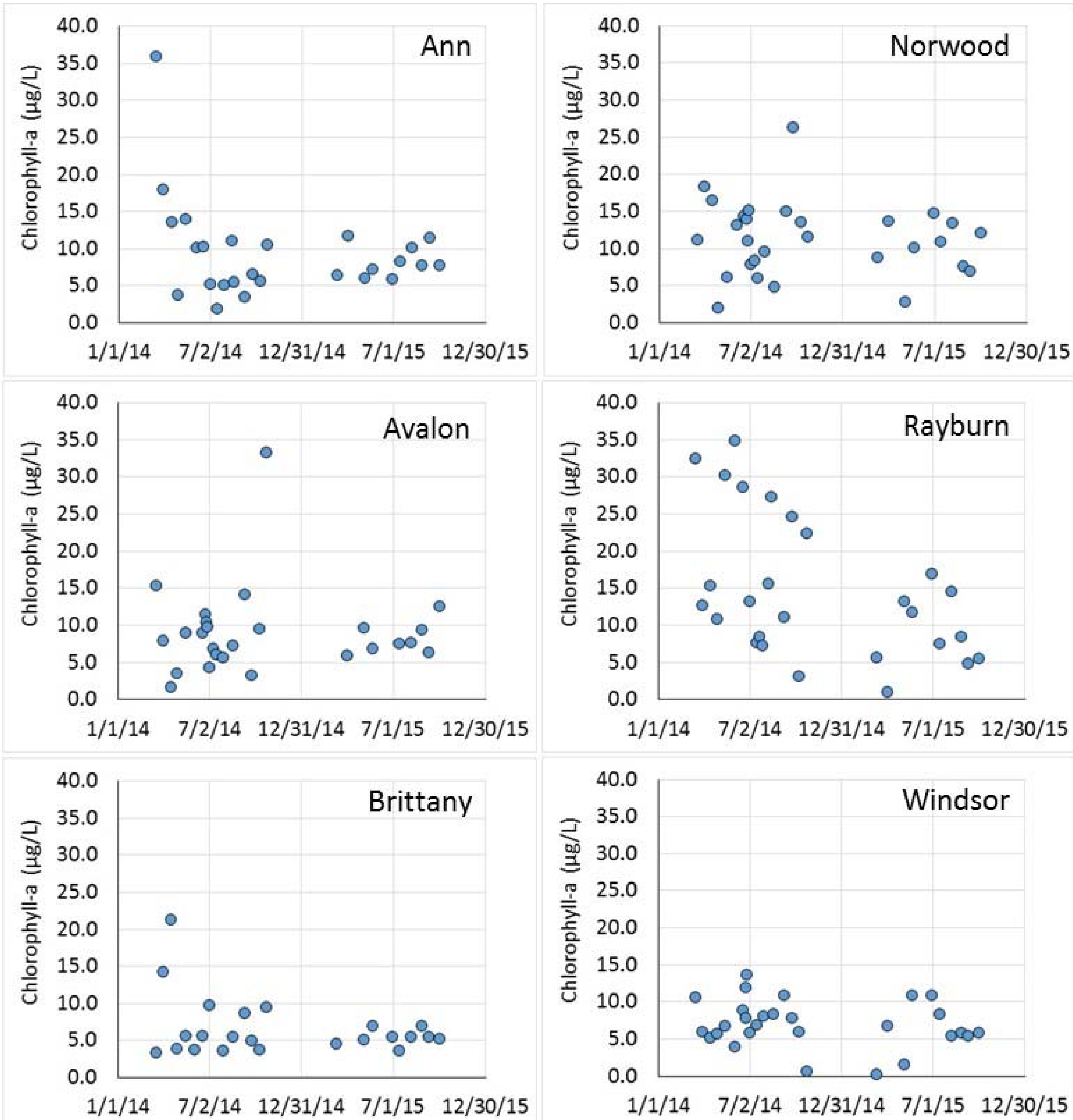



Figure 1. Measured secchi transparencies for Bella Vista Lakes during the 2014-2015 growing seasons.



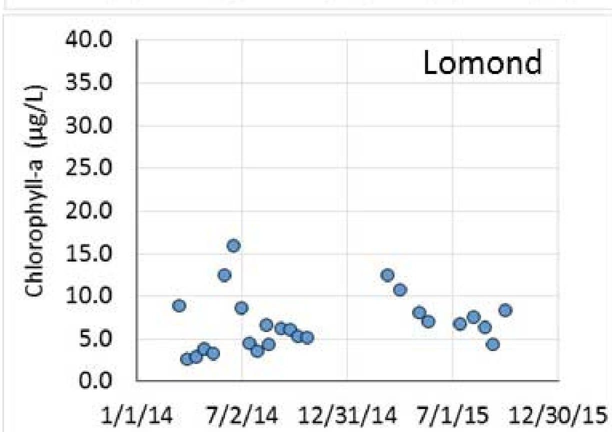




Figure 2. Measured chlorophyll-a concentrations for Bella Vista Lakes during the 2014-2015 growing seasons.

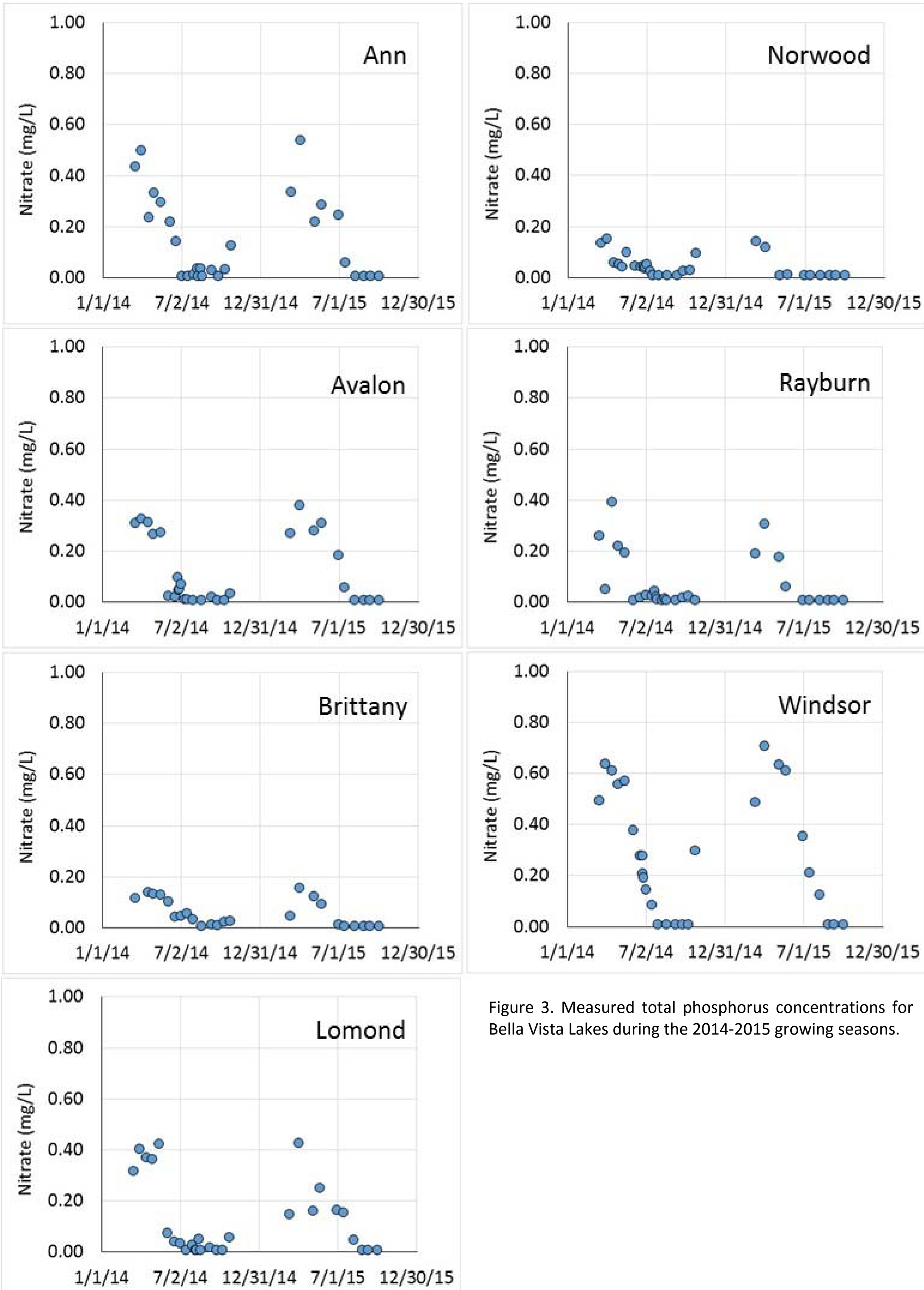



Figure 3. Measured total phosphorus concentrations for Bella Vista Lakes during the 2014-2015 growing seasons.

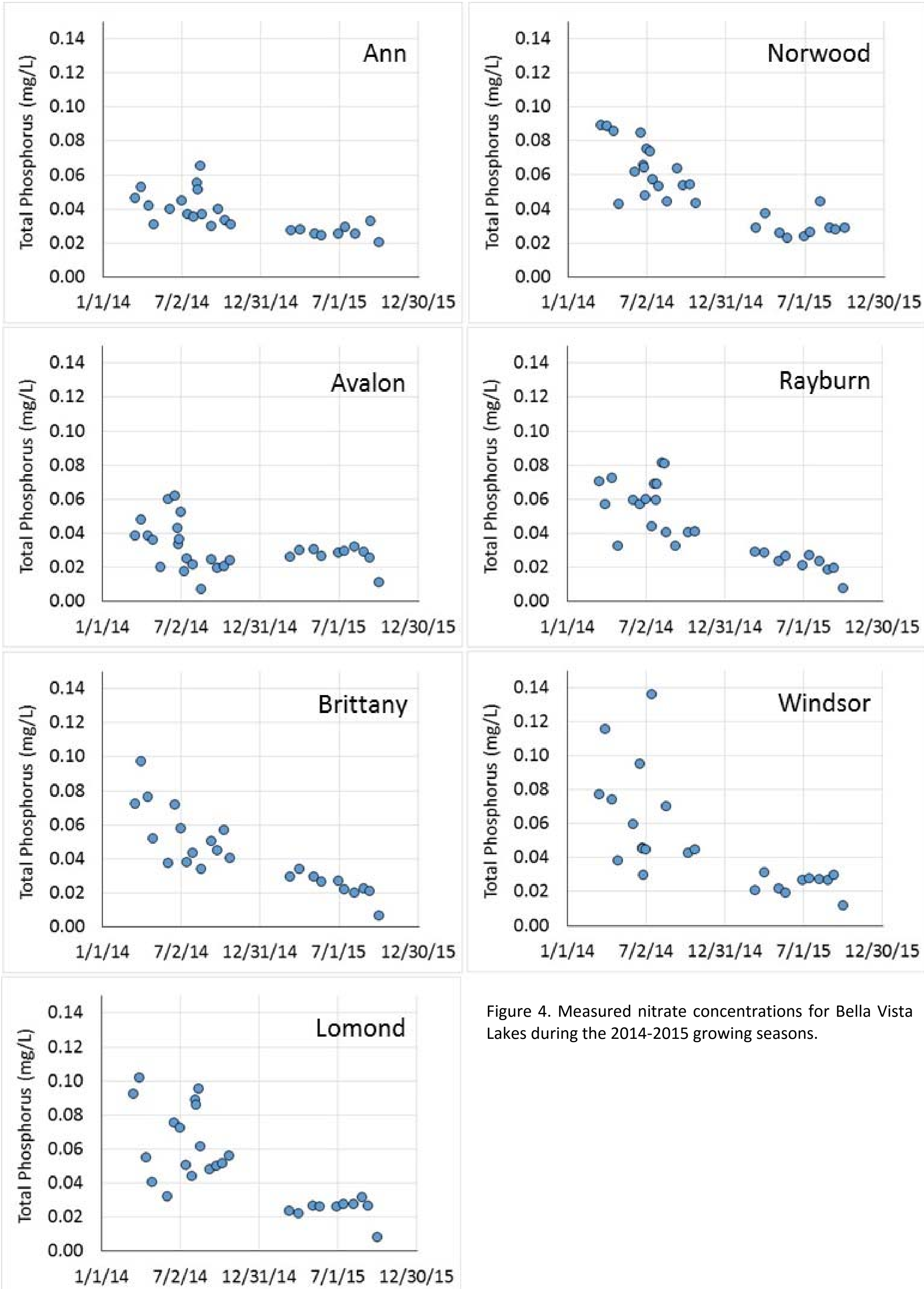



Figure 4. Measured nitrate concentrations for Bella Vista Lakes during the 2014-2015 growing seasons.

data occurs above the average line in the top panel, and below the average line in the bottom panel, signifies the importance of nitrogen as a co-limiting nutrient in the Bella Vista Lakes. Couple this with the information that total nitrogen concentrations in these lakes indicate that they should be oligotrophic further corroborates the importance of nitrogen (along with phosphorus) in any fertility management program for these lakes.

Although the Bella Vista Lakes appear to generally conform to the total phosphorus-chlorophyll-a-secchi transparency model for most North-American lakes, the range of data for the Bella Vista Lakes was insufficient to derive an independent statistical model for these lakes alone. An alternative approach would be to use the general model for all North American Lakes. However, when the data from this study were combined with data from nearby Beaver Lake, regionally-specific relationships between chlorophyll-a and secchi transparency, and total phosphorus and chlorophyll-a were obvious. Thus, these data were combined into a single dataset for the construction of a simple model of lake fertility for Ozark Lakes (Figure 6). The model indicates that the measured secchi transparency for any Bella Vista Lake can be used to estimate the chlorophyll-a concentration in that lake according to the uppermost equation in Figure 6. Iteratively, the chlorophyll-a concentration estimated from the secchi transparency can be used to compute an estimated total phosphorus concentration needed to support that level of phytoplankton biomass. Thus, having a measured and target secchi transparency allows a manager to compute two total phosphorus concentrations, the current and the target phosphorus concentration needed to achieve the target secchi transparency. The difference between the current total phosphorus concentration and the target total phosphorus concentration is the final phosphorus fertilizer concentration that needs to be added to the lake to achieve the target secchi. In months where nitrogen limitation is likely (June – October; Figure 4), phosphorus fertilization should be

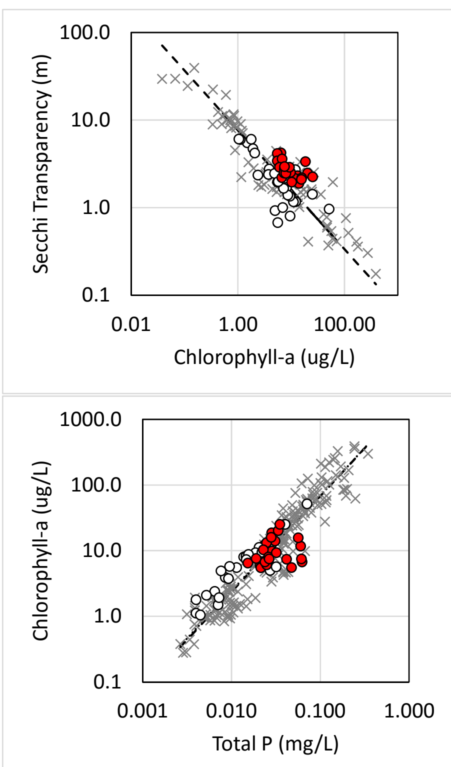



Figure 5. Top panel: Relationship between annual growing season average chlorophyll-a concentrations and secchi transparency in lakes across North America (gray X), Beaver Lake in Northwest Arkansas (white circles), and Bella Vista Lakes (red circles). Bottom panel: Relationship between average growing season total phosphorus and chlorophyll-a for the same sites as the top panel.

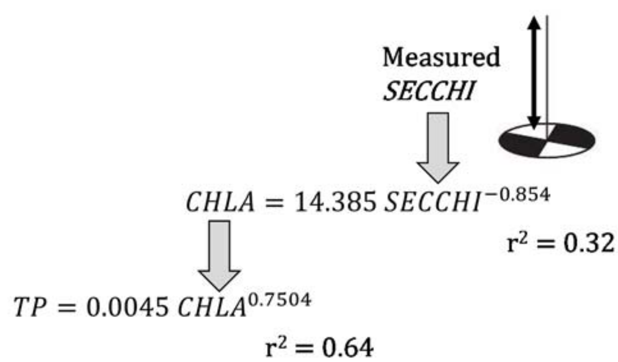



Figure 6. Lake fertility model derived using data from the seven Bella Vista Lakes during the 2014-2015 growing season and twelve sites on Beaver Lake during the 2015 growing season.

supplemented with nitrogen fertilization on a 10:1 (N:P) basis.

In order to determine the amount of fertilizer to be used in order to achieve the target total phosphorus (and total nitrogen) concentrations, information on the bathymetry of the lake and the depth to which light is penetrating the water column is needed. This information is embedded within the fertilizer calculation tool. The light penetration depth is a function of the current secchi transparency and is calculated from that direct relationship (Figure 7). The bathymetry data is embedded within the fertilizer calculator and is only dynamic in the sense of computing a variable photic zone volume based on variation in the photic zone depth. Fertilizer comes in many different forms. The fertilizer calculation tool was constructed based on two fertilizers that were selected as preferable by the Bella Vista Lake Management Staff, High Phosphorus Fertilizer (10:52:4, N:P:K) and Urea Fertilizer (48:0:0, N:P:K). The fertilizer calculation tool will need to be adjusted if the fertilizer used in the lakes changes to a different form.

Once a lake has been identified as in need of fertilizer (i.e. between the months of March and October when water temperature exceeds 60°F and secchi transparency is greater than 2 m), the current and target secchi, along with the month (3-10) can be plugged into the appropriate calculator in the accompanying Excel file (see Figure 8). It is important to remember that each calculator (worksheet in Excel file) is specific to an individual lake because the depth-volume relationship is embedded within the calculator for each lake. Thus, the calculator for Lake Brittany should not be used to determine the fertilization rate for Lake Lomond, and vice-versa.

In the example fertilizer calculator shown in Figure 8, we see that in July, Lake Avalon has a current secchi transparency of 3.5 meters. The desired secchi transparency for Lake Avalon is 2 meters. The boxes highlighted in yellow are the only boxes that can be edited in the calculator.

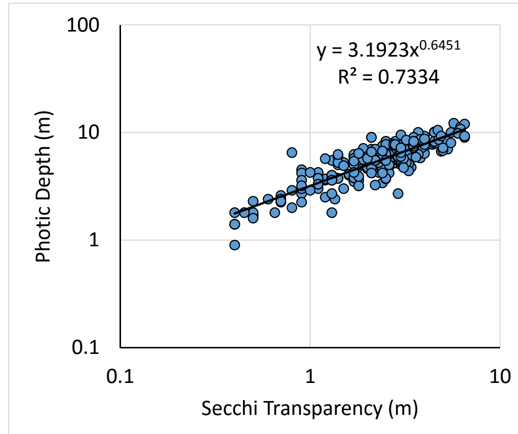



Figure 7. Relationship between measured secchi transparency and measured photic depth for all Bella Vista Lakes in the 2014-2015 growing season.

The component calculations on the right-hand side of the calculator provide information about the calculations. These cells cannot be edited but are provided for user information, if interested. The boxes highlighted in green on the calculator show the specific number of fertilizer bags (either High Phosphorus or Urea) that should be used to achieve the desired secchi transparency. These cell cannot be edited in the calculator.

When the current and target secchi values, along with the month number are plugged into the calculator, the number of bags of High Phosphorus Fertilizer and Urea Fertilizer needed to achieve the target secchi transparency will be shown in the box so labelled. These fertilizers should be added to the lake only after they have been dissolved on board the boat, as depicted in Figure 9. Ship-board dissolution is necessary because the fertilizers, in most instances, may not dissolve as fast as they sink through the water column. During the growing season when the water is warm, all seven Bella Vista Lakes exhibit strong thermal stratification. Thus, solid fertilizers may sink to the bottom and be cut off from the photic zone and therefore have no impact on phytoplankton growth. Although ship-board dissolution adds labor to the fertilization effort, it is entirely necessary for effective fertilization.

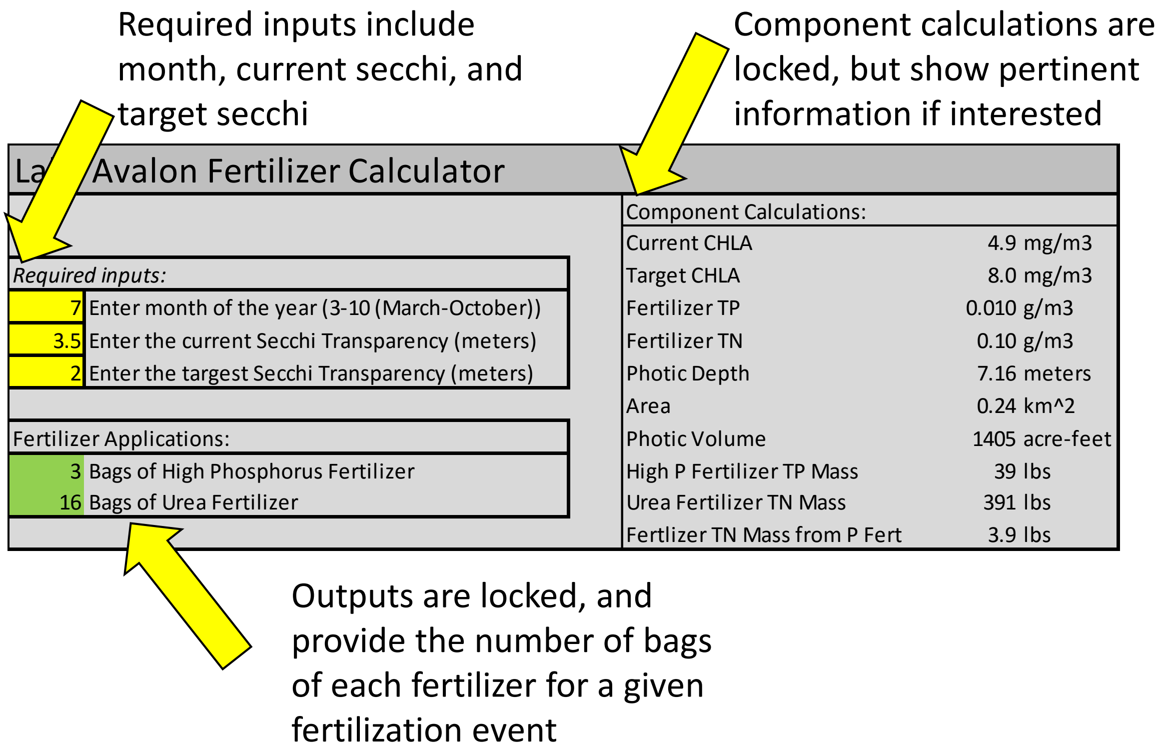



Figure 8. Relationship between measured secchi transparency and measured photic depth for all Bella Vista Lakes in the 2014-2015 growing season.

Figure 9. Method for distributing chemical fertilizer in lakes. The number of bags of each fertilizer is determined from the fertilizer calculator and the fertilizer is dissolved shipboard and pumped slowly into lake as the boat travels around the entire lake.

**Literature Cited**

Anders, P. J., and K. I. Ashley. 2007. The clear-water paradox of aquatic ecosystem restoration. Fisheries. 32: 125-128.

Anderson, J. A., E. Jeppesen, and M. Sondergaard. 2005. Ecological effects of reduced nutrient loading (oligotrophication) on lakes: an introduction. Freshwater Biology. 50: 1589-1593.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22: 361-369.

Coveney, M. F., E. F. Lowe, L. E. Battoe, E. R. Marzolf, and R. Conrow. 2005. Response of a eutrophic, shallow subtropical lake to reduced nutrient loading. Freshwater Biology. 50: 1718-1730.

Edmondson, W. T. 1994. Sixty years of Lake Washington: a curriculum vitae. Lake and Reservoir Management. 10: 75-84.

Jeppesen, E., J. P. Jensen, M. Sondergaard, and T. L. Lauridsen. 2005. Response of fish and plankton to nutrient loading reduction in eight shallow Danish lakes with special emphasis on seasonal dynamics. Freshwater Biology. 50: 1616-1627.

Romo, S., M. J. Villena, M. Sahuquillo, J. M. Soria, M. Gimenez, T. Alfonso, E. Vicente, and M. R. Miracle. 2005. Response of a shallow Mediterranean lake to nutrient diversion: does it follow similar patterns as in northern shallow lakes? Freshwater Biology. 50: 1706-1717.

Schindler, D.W., R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M.J. Paterson, K.G. Beaty, M. Lyng, S.E.M. Kasian. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences 105: 11254-11258.

Scott, J.T., and E.M. Grantz. 2013. N2 fixation exceeds internal nitrogen loading as a phyto-plankton nutrient source in perpetually nitrogen-limited reservoirs. Freshwater Science 32: 849-861.

Scott, J.T., R.D. Doyle, S.J. Prochnow, and J.D. White. 2008a. Are watershed and lacustrine controls on planktonic N2 fixation hier-archically structured? Ecological Appli-cations 18: 805-819.

Sondergaard, M., J. P. Jensen, and E. Jeppesen. 2005. Seasonal responses of nutrients to reduced phosphorus loading in 12 Danish lakes. Freshwater Biology. 50: 1605-1615.

Stockner, J. G., and E. A. MacIsaac. 1996. British Columbia lake enrichment program; two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management. 12: 547-561.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, 3rd ed. Academic Press.

Yurk J.J., and Ney J.J. 1989. Phosphorus-fish community biomass relationships in southern Appalachian Reservoirs: Can lakes be too clean for fish? Lake and Reservoir Management. 5: 83-90.