ERDC/TN APCRP-EA-22
May 2010

Management of Half Moon Lake, Wisconsin, for Improved Native Submersed Macrophyte Growth

by William F. James

PURPOSE: Direct biomass control programs (i.e., herbicide, biocontrol, mechanical) that target non-native macrophyte species may not always produce the desired goal of restoring native macrophyte community dominance in shallow aquatic systems. Native reestablishment is often complicated by eutrophic conditions, enhanced nutrient recycling, and frequent nuisance algal blooms that result in poor light penetration and limited colonizable macrophyte habitat. Half Moon Lake is a eutrophic, urban oxbow lake exhibiting high densities of the non-native *Potamogeton crispus* in early summer followed by high chlorophyll, total phosphorus, and light attenuation. These patterns are, unfortunately, typical for many lakes located in agricultural regions of the upper midwestern United States. Although Half Moon Lake is shallow and supports a native submersed macrophyte community, poor underwater light conditions limit their growth and propagation. The purpose of this research was to examine algal, nutrient, light attenuation characteristics, and underwater light habitat for submersed macrophyte growth and to project changes in these variables and improvement in light penetration as a result of managing the lake to control internal phosphorus loads.

BACKGROUND: Submersed macrophytes play an important structuring role in biological community dynamics and water quality conditions of aquatic ecosystems (Jeppesen et al. 1998). Submersed macrophyte communities promote increased light penetration and water clarity by dampening wave shear stress and stabilizing flocculent sediment from resuspension (Barko and James 1998). They also provide refugia for young fish and habitat for a diversity of invertebrates. These interactions and feedbacks foster a fishery dominated by piscivores, increased grazing pressure on pelagic phytoplankton, and high transparency; features that are desirable both from an ecosystem perspective and for aesthetic and recreational reasons.

Eutrophication can negatively impact submersed macrophyte growth and community diversity by stimulating excessive algal productivity and decreasing light penetration. In addition, invasion by rapidly growing non-native species such as *Potamogeton crispus* can exacerbate declines in native submersed macrophyte populations in north-temperate climates by forming a dense canopy in early summer that attenuates light. For eutrophic systems that have become light-limited by algal-induced attenuation, direct biomass control of *P. crispus* (i.e., via herbicides or mechanical harvesting) may not be sufficient to restore native macrophyte communities, particularly meadow-forming species, in areas they previously inhabited. Under these conditions, additional management may be needed that focuses on reducing algal biomass in order to improve the underwater light climate for reestablishment of native submersed macrophytes. The objectives of this research were to examine current light conditions in a shallow, eutrophic system and forecast the effects of phosphorus management and algal biomass reduction on potential light habitat improvement for native macrophyte communities.

STUDY SITE: Half Moon Lake is a relatively small (0.5 km^2 and 8.9 x 10^5 m^3), shallow (mean depth = 1.6 m, maximum depth = 4 m) urban lake located in Eau Claire, Wisconsin (Figure 1). An oxbow of the Chippewa River, the bathymetry resembles that of a river channel. The eastern portion of the lake is isolated by a causeway that restricts water exchange with the rest of the lake. Forty percent of the surface area is less than 2 m deep. External inputs to the lake occur primarily via a storm sewer system that drains residential, commercial, and industrial land uses from a 2.3-km^2 watershed. The phosphorus budget has been dominated by internal loading from sediment (42 percent), decomposition of *P. crispus* and recycling to the water column (20 percent), and sediment resuspension by motor boat activity (17 percent). In contrast, external phosphorus loading accounts for only 21 percent of the phosphorus budget (James et al. 2002). The lake is classified as eutrophic (Carlson TSI_{CHLA} = 74); mean summer trophic state indicators are 0.110 $mg \cdot L^{-1}$ total phosphorus, 82 $mg \cdot m^{-3}$ viable chlorophyll, and 1.1 m Secchi transparency.

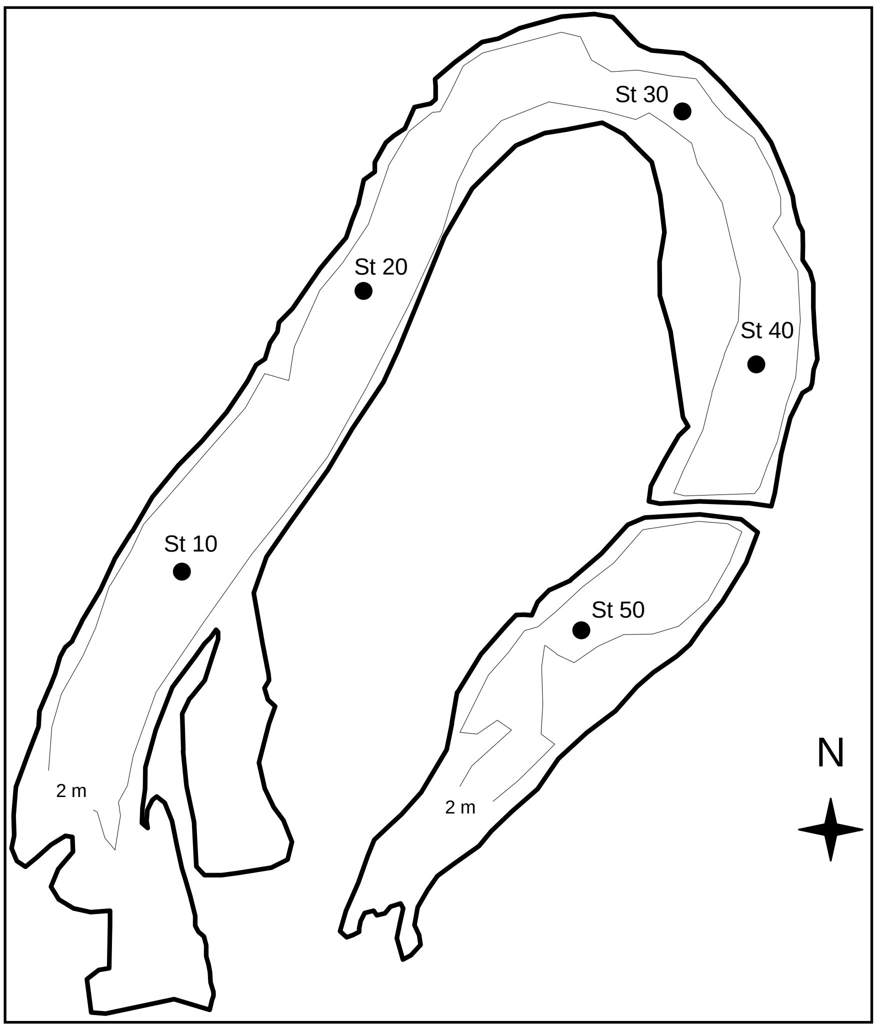

Figure 1. Map of Half Moon Lake showing water quality sampling stations.

The macrophyte community is dominated by *P. crispus*. Turions germinate in late March and the population can occupy > 75 percent of the lake surface area by early June, attaining peak biomass levels greater than 100 g dry mass·m $^{-2}$. Native submersed and emergent macrophyte species are dominated primarily by *Ceratophyllum* and *Elodea* sp.

METHODS: Five stations were established in the lake for water quality monitoring purposes (Figure 1). Monitoring was conducted biweekly at each station between May and September 2008. Water temperature, dissolved oxygen, conductivity, and pH were measured in situ at 0.5-m intervals using a sonde unit (Hydrolab Quanta, Hach Inc., Loveland, CO) that precalibrated against known standards and Winkler titrations. Underwater photosynthetically active radiation was measured at 10- to 25-cm intervals using a cosine quantum radiometer (Model LI1000, Li-Cor, Inc., Lincoln, NE). The light attenuation coefficient was calculated as

$$k_d = \frac{\ln(I_o) - \ln(I_z)}{z}$$

where I_o is the surface radiation ($\mu E \cdot s^2$) and I_z is the radiation at depth z (m). Water samples were collected biweekly at 1-m intervals from the surface to within 0.1 m above the sediment surface for total phosphorus, soluble reactive phosphorus, and viable chlorophyll. Samples collected from anoxic water were filtered in the field through a 0.45-µ syringe filter without exposure to air. Total phosphorus samples were predigested with potassium persulfate according to Ameel et al. (1993) before analysis using automated analytical procedures. Soluble reactive phosphorus was analyzed colorimetrically using the ascorbic acid method (American Public Health Association 2005). Samples for viable chlorophyll were filtered onto glass fiber filters (Gelman A/E; 2.0 µ nominal poresize) and extracted in 50:50 dimethyl sulfoxide:acetone before fluorometric determination (Welschmeyer 1994). In mid-June, *P. crispus* biomass was quantified at 143 stations in the lake using the point-intercept method (Madsen 1993). A rake pull method was used to collect samples. The rake was lowered to the sediment and raised to the lake surface at a constant, slow rate while twisting the handle to snag *P. crispus* stems within a ~ 0.13-m ^{2} area. The samples were dried to a constant mass at 65 ^{o}C in a forced-air drying oven. Biomass (g ·m $^{-2}$) at each station was estimated as dry mass divided by the circular area covered by a 180-deg twist of the rake.

RESULTS AND DISCUSSION: *P. crispus* was present at 80 percent of the sampling sites in June 2008. Lake-wide biomass was moderate at 50 g dry mass·m $^{-2}$ (± 8 Standard Error), which may have been attributable to a late ice-out (April 23) and cool spring water temperatures relative to other years. During the *P. crispus* growing period between April and mid-June, light attenuation was low while Secchi transparency exceeded 1.5 m (Figure 2). Viable chlorophyll and total phosphorus were also low during this period.

Senescence in June coincided with stratification and the development of anoxic conditions in the bottom waters (Figure 3). Concentrations of total phosphorus increased substantially in late June and exceeded 0.05 mg·L $^{-1}$ at most stations throughout the summer (Figure 2). Viable chlorophyll concentrations increased in conjunction with elevated total phosphorus, exceeding 25 mg·m $^{-3}$ at stations 10 through 40. Peaks in chlorophyll concentration greater than 100 mg·m $^{-3}$ were observed in August. Concentrations of total phosphorus and chlorophyll were lower throughout the summer at station 50 compared to the other stations. This portion of the lake is isolated by the causeway, shallower, and exhibited higher submersed macrophyte densities (primarily natives) in the summer that could have suppressed algal growth.

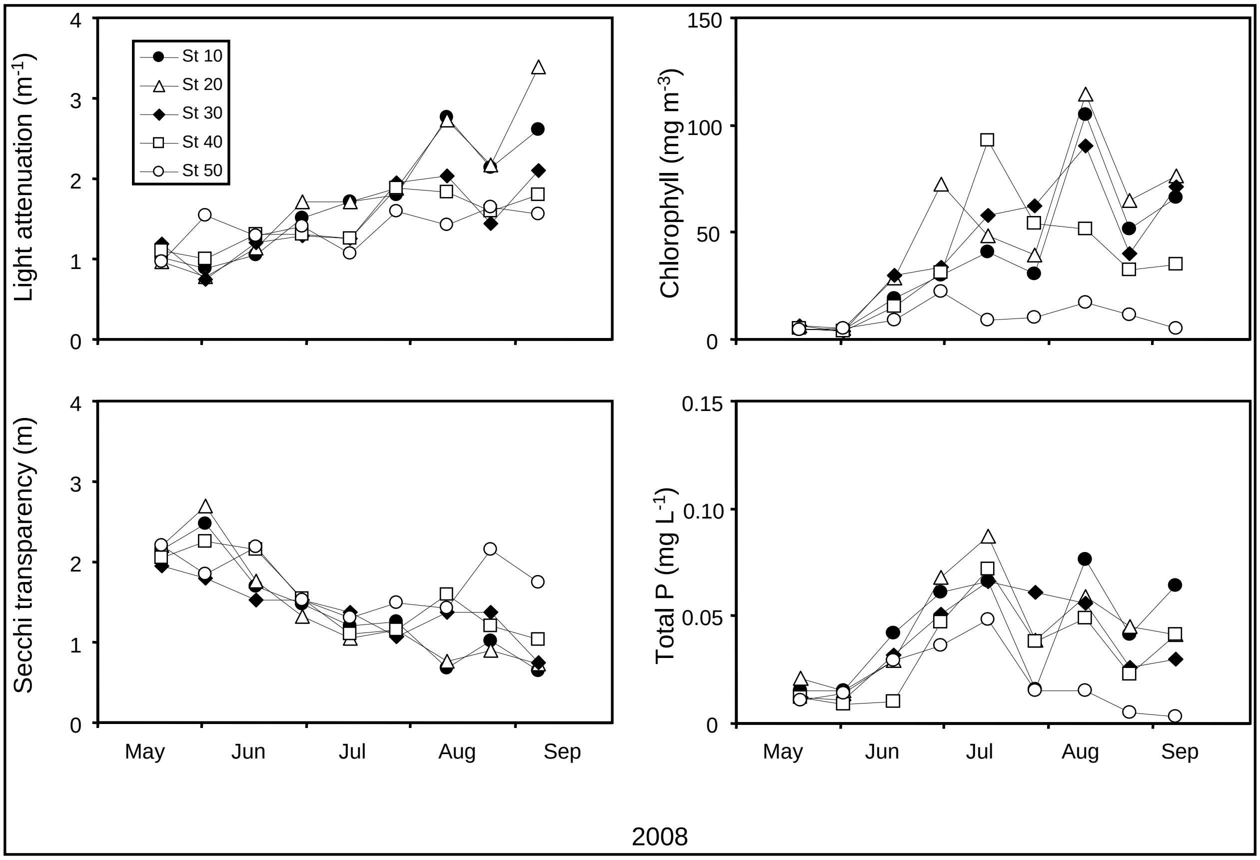

Figure 2. Seasonal variations in light attenuation, Secchi transparency, chlorophyll, and total phosphorus (P) at various stations in Half Moon Lake.

Viable chlorophyll concentrations were positively related to total phosphorus (Figure 4), suggesting that most phosphorus was in a particulate form as algal biomass. *Ceratium hirundinella* dominates the algal assemblage in Half Moon Lake (Brakke 1995) and migrates vertically to the lake bottom on a diel basis. This capability provides *C. hirundinella* with a competitive advantage for accessing internal phosphorus loads originating from anoxic sediment for growth. Rates of phosphorus release from sediments in the lake are high (range = 2.3 to 11.7 $mg \cdot m^{-2} \cdot d^{-1}$) and, thus, represent an important nutritional source to this species.

During the July-September period of high chlorophyll, Secchi transparency declined while the light attenuation coefficient increased (Figure 2). Overall, the light attenuation coefficient was negatively related to Secchi transparency (Figure 5). Since the lake was sheltered from wind-induced sediment resuspension and external loading was low during the summer, it was assumed that non-algal suspended sediment concentrations were minor in the water column and that light attenuation was affected primarily by algal biomass. Indeed, strong relationships were observed between viable chlorophyll concentration and Secchi transparency or the light attenuation coefficient (Figure 6), supporting this assumption.

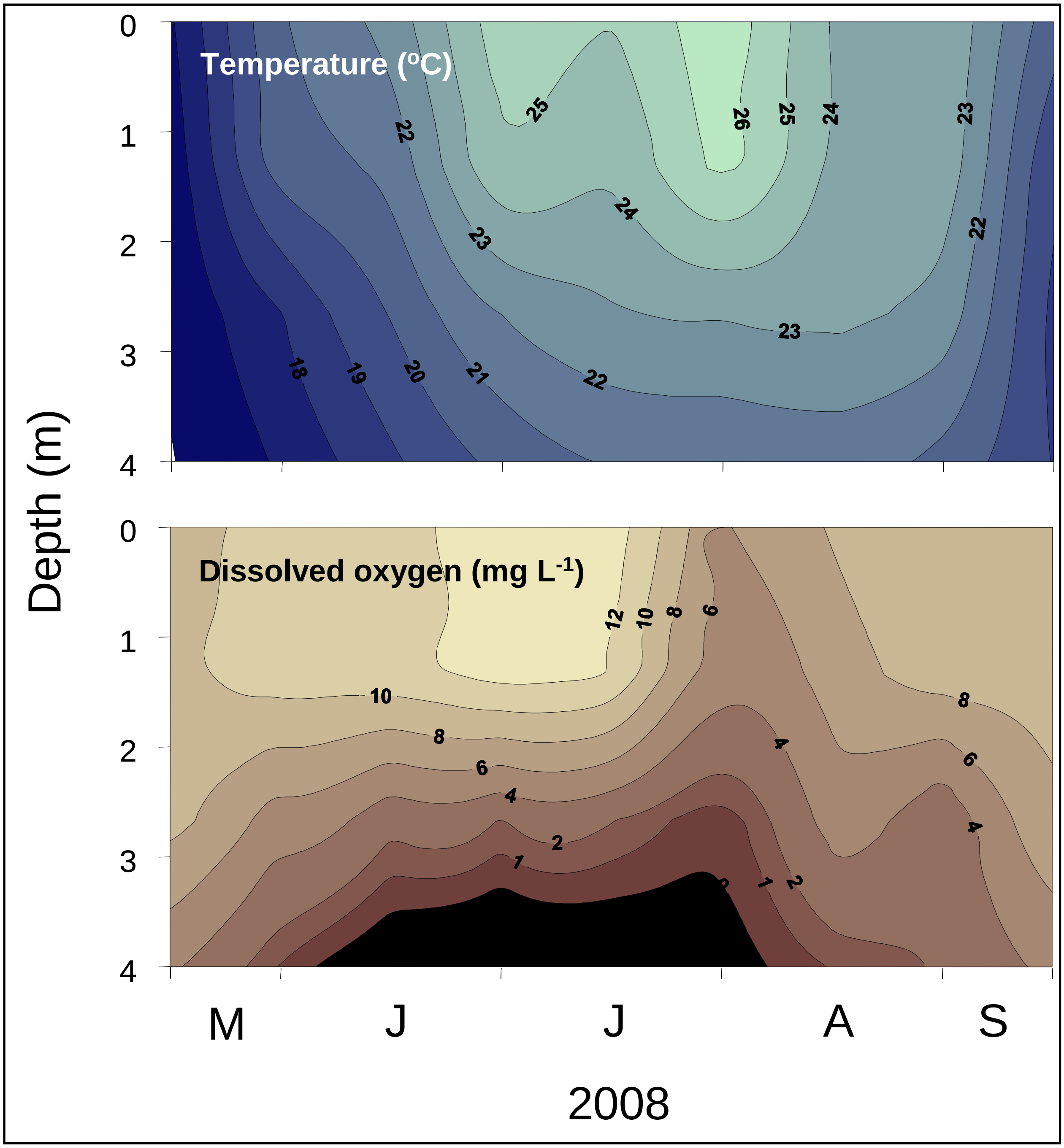

Figure 3. Seasonal and depth-related variations in water temperature and dissolved oxygen contours. Black region in lower panel represents anoxia.

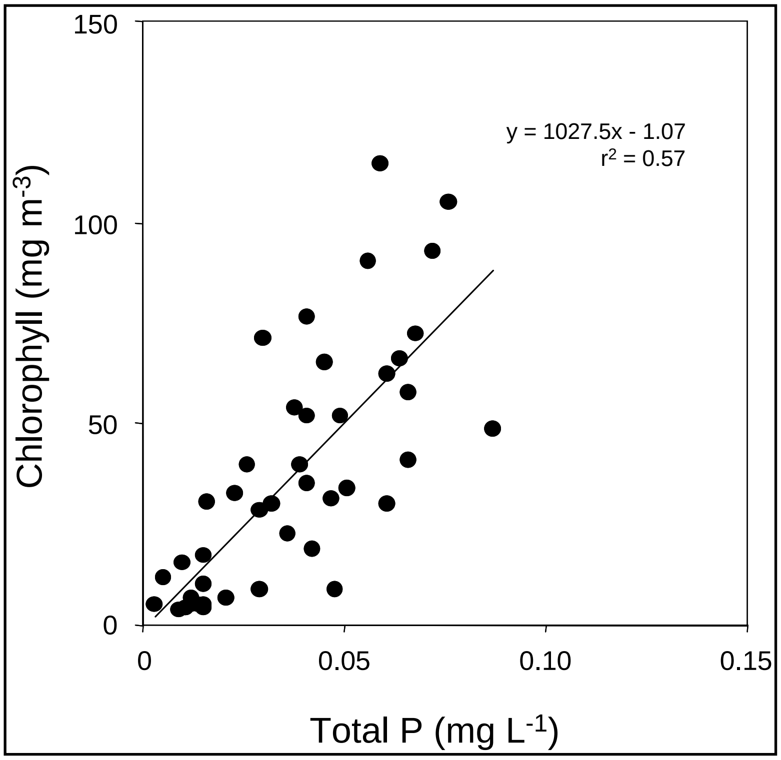

Figure 4. Chlorophyll versus total phosphorus (P) regression relationships.

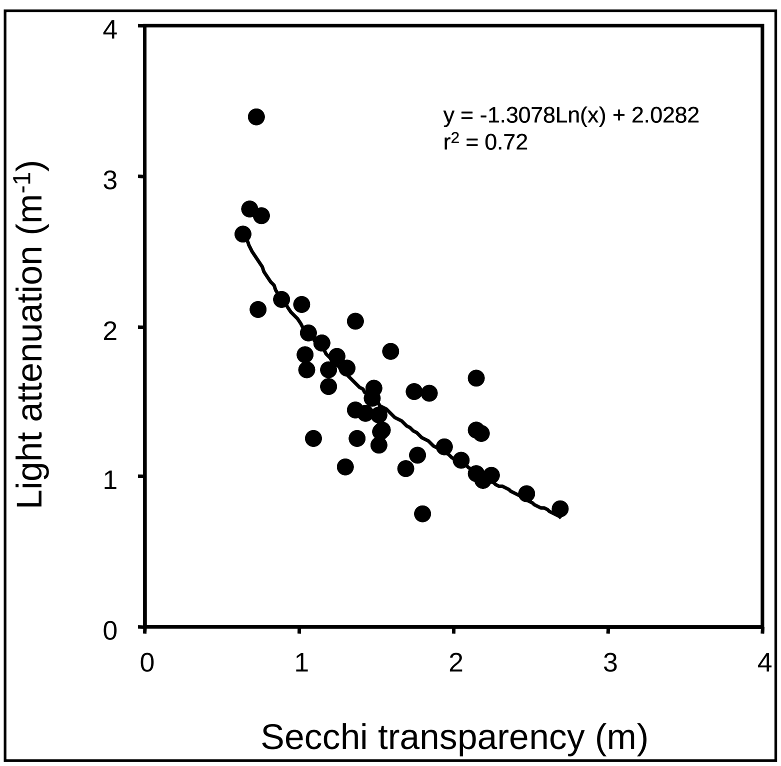

Figure 5. Light attenuation versus Secchi transparency regression relationships.

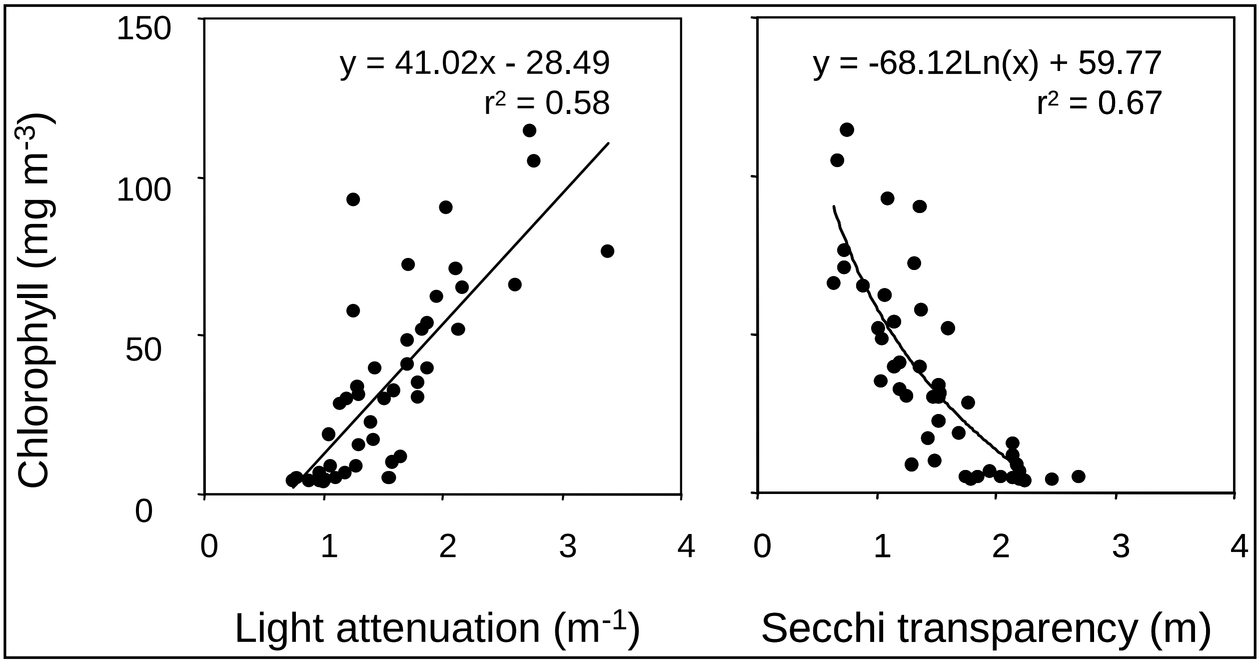

Figure 6. Regression relationships between chlorophyll and light attenuation or Secchi transparency.

Regression models developed by Middelboe and Markager (1997) were used to estimate present depth limits in Half Moon Lake for caulescent (i.e., *Elodea canadensis*) and rosette-forming (i.e., *Vallisnaria americana*) aquatic macrophytes. These models suggested a maximum depth with minimum light conditions for growth of only 1.9 m and 0.8 m for caulescent and rosette-forming submersed macrophytes, respectively. These maximum depths represented 38 and 16 percent of the lake surface area, and most of that coverage was located in the southwestern and southeastern region with little suitable light habitat in the main channel area of the lake.

In an earlier study, James et al. (2002) constructed a phosphorus budget for the lake and found that internal recycling processes (primarily phosphorus release from sediments deposited in the lake) were driving high algal productivity. James et al. used the water quality model *Bathtub* (Walker 1996) to explore the impact of managing various phosphorus sources on viable chlorophyll reduction and increased Secchi transparency (Table 1). James et al. reported that reducing phosphorus inputs to the lake would lead to a predicted substantial decline in total phosphorus and viable chlorophyll, resulting in a decrease in the light attenuation coefficient and an increase in Secchi transparency (Table 1). Improvements in the light climate as a result of phosphorus management would result in a greater than 300-percent increase in the maximum depth and area of the lake that could potentially be colonized by meadow-forming submersed macrophytes. For caulescent forms, favorable light habitat after management represented 100 percent of the lake bottom. These model projections suggested that nuisance algal blooms in shallow eutrophic systems can have a negative impact on native submersed macrophyte growth by impairing light penetration and reducing the maximum colonizable depth. Thus, management strategies for native macrophyte communities in Half Moon Lake need to consider phosphorus control to reduce algal-induced light attenuation, in addition to selective biomass control of *P. crispus*.

Table 1. Management scenarios at Half Moon Lake, Wisconsin.

Scenario	Total P (mg L^{-1})	Chlorophyll (mg m^{-3})	Secchi Transparency (m)	Light Attenuation (m^{-1})	Z_{max} (m)[1]		Light Intensity (% Surface)		Light Habitat (% Total Area)	
					Caulescent	Rosette	Caulescent	Rosette	Caulescent	Rosette
1999 conditions[2]	0.109	82	1.1	1.9	1.9	0.8	0.2	2.6	38	16
Post internal P loading reduction conditions[3]	0.038	17.7	3.8	0.3	4.8	2.5	8.0	26.3	100	56

[1] z_{max} = maximum inhabitable depth for submersed macrophyte growth.
[2] James et al. 2002.
[3] *P* loading reduction management includes (1) eliminating motorboat activity and sediment *P* resuspension, (2) reducing *P. crispus* biomass and decomposition, and (3) reducing *P* flux from sediments.

Management to reduce internal phosphorus loading and improve light condition for native macrophyte growth is threefold for Half Moon Lake. Motorboat activity has been restricted on the lake to reduce phosphorus resuspension. Canopy-shading and phosphorus contributions via *P. crispus* decomposition will be controlled by annual early spring herbicide treatments (years 2009-2012) to selectively target this species with minimal impact to native macrophytes (Skogerboe et al. 2008). The goal of management is to reduce the viable turion bank in the sediments by selectively controlling *P. crispus* before the onset of turion production over a 3- to 4-year period. *P. crispus* life cycle is unusual in that it propagates primarily via vegetative structures called turions that settle to the sediment after macrophyte senescence and overwinter until spring. Since dense plant populations form on the order of 1000 turions $\cdot m^{-2}$, a large turion bank can accumulate in sediments that is viable for many years to ensure propagation. Finally, phosphorus release from sediments will be managed using buffered alum-aluminate to drive algal productivity toward phosphorus-limited growth (year 2011). The goal is to decrease internal phosphorus loading from sediment by 90 percent in order to reduce algal biomass and increase light penetration. Subsequent technical notes will describe methodology for estimating alum dosage to control internal phosphorus loading from the sediment.

POINTS OF CONTACT: This technical note was prepared by William F. James, Research Aquatic Biologist, Eau Galle Aquatic Ecology Laboratory, Environmental Laboratory, U.S. Army Engineer Research and Development Center. For additional information, contact the manager of the Aquatic Plant Control Research Program, Dr. Linda Nelson (601-634-2956, *linda.s.nelson@usace.army.mil*).

James, W. F. 2010. *Management of Half Moon Lake, Wisconsin, for improved native submersed macrophyte growth. APCRP Technical Notes Collection.* ERDC/TN APCRP-EA-22. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *www.wes.army.mil/el/aqua*.

REFERENCES

Ameel, J. J., R. P. Axler, and C. J. Owen. 1993. Persulfate digestion for determination of total nitrogen and phosphorus in low nutrient water. *American Environmental Laboratory (October 1993)*:8-10.

American Public Health Association. 2005. *Standard methods for the examination of water and wastewater*. 21st ed., Washington, DC.

Barko, J. W., and W. F. James. 1998. Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation, and resuspension. In *Ecological Studies 131. The structuring role of submerged macrophytes in lakes*, ed. E. M. Jeppesen et al., 423. New York: Springer-Verlag.

Brakke, D. 1995. *An evaluation of thermal structure, trophic status and the potential impact of boating on nutrient concentrations in Half Moon Lake, Wisconsin*. Eau Claire, WI: Department of Biology, University of Wisconsin.

James, W. F., J. W. Barko, H. L. Eakin, and P. W. Sorge. 2002. Phosphorus budget and management strategies for an Urban Wisconsin Lake. *Lake Reserv. Manage.*18:149-163.

Jeppesen, E., M. Søndergaard, M. Søndergaard, and K. Christoffersen. 1998. *Ecological Studies 131. The structuring role of submerged macrophytes in lakes*, 423. New York: Springer-Verlag.

Madsen, J. D. 1993. Biomass techniques for monitoring and assessing control of aquatic vegetation. *Lake Reserv. Manage.* 7:141-154.

Middelboe, A. L., and S. Markager. 1997. Depth limits and minimum light requirements of freshwater macrophytes. *Freshwat. Biol.* 37:553-568.

Skogerboe, J. G., A. Poovey, K. D. Getsinger, W. Crowell, and E. McBeth. 2008. *Early-season, low dose applications of endothall to selectively control curlyleaf pondweed in Minnesota lakes.* APCRP Technical Notes Collection. ERDC/TN APCRP-CC-08. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/aqua/*.

Walker, W. W. 1996. *Simplified procedures for eutrophication assessment and prediction: User manual*. Instruction Report W-96-2. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Welschmeyer, N. A. 1994. Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. *Limnol. Oceanogr.* 39:1985-1992.