Environmental Factors Affecting Aquatic Plant Growth Potential in Marinuka Lake, Wisconsin

by William F. James

PURPOSE: Submersed aquatic macrophytes play in important role in stabilizing sediment from resuspension, sequestering nutrients, and reducing algal growth in shallow lakes. Loss of vegetation is usually accompanied by changes in stable state to one characterized by higher turbidity, low light penetration, and frequent noxious algal blooms. Aquatic vegetation once played an important role in stabilizing the sediment and providing important fish and water fowl habitat in Marinuka Lake, Wisconsin. However, macrophyte biomass levels have declined significantly in the last decade with accompanying shifts toward blue-green algal dominance. Although reasons for this vegetation decline are not precisely known, it may be related to changes in light regime due to excessive algal growth induced by watershed phosphorus loading. Other possible factors include changes in sediment fertility, carp damage, or a physical stress such as drought or excessive pool fluctuations. The objectives of this research were to evaluate environmental factors that may inhibit submersed aquatic macrophyte growth in this lake and to use these findings to develop management scenarios for improving growth and successful propagation.

BACKGROUND: The presence or absence of aquatic macrophytes in shallow aquatic systems is the outcome of alternative stable states that are driven by complex interactions and feedback loops between the biotic community and abiotic environment (Scheffer et al. 1993). When present, macrophyte communities provide feedback by dampening wave activity, reducing sediment resuspension, and stabilizing the sedimentary environment (James and Barko 1994; Koch 1996). Increased macrophyte productivity favors accretion of nutrients for sustained growth and reproduction, maintenance of a diverse and abundant invertebrate community, a fishery dominated by piscivores, and development of a clear water state. Catastrophic events and accelerated eutrophication can stress macrophyte populations and light condition, driving these systems toward another stable state characterized by frequent resuspension, high turbidity and decreased light penetration, enhanced nutrient recycling, and dominance by algal blooms due to the loss of macrophytes' stabilizing influences. From a management standpoint, it is desirable to promote macrophyte growth in shallow systems to improve water quality and community structure. However, re-establishment of macrophytes in shallow lakes that have lost these communities is often difficult because light conditions are no longer favorable for their persistence and growth (Kimber et al. 1995a, 1995b; Korschgen et al. 1997; Scheffer 1998; Doyle and Smart 2001). Rehabilitating shallow, turbid lakes to promote macrophyte growth and reversal to a clear water state requires a knowledge of factors contributing to poor light levels and a means of predicting the success of macrophyte re-establishment under different management scenarios to improve the underwater light climate (Blom et al. 1994a, 1994b; Van Duin 1992; Van Duin et al. 1992). Loss of submersed macrophyte coverage may also lead to changes in sediment fertility and texture due to increased sediment resuspension in shallow littoral regions and focusing to deeper regions (James and Barko 1993). As a consequence, reduced sediment nitrogen availability and eroded substrates characterized by coarse-grained sediments in littoral environments would make vegetation re-establishment much more difficult. The objectives of this research were to examine the growth potential of an experimental submersed macrophyte, sago pondweed, as a function of sediment fertility and light regime, and to identify management options for successful re-establishment of macrophyte communities in Marinuka Lake, Wisconsin.

METHODS:

Study Site. Marinuka Lake is a small (surface area = 40 ha) impoundment of the agriculturally managed Beaver Creek watershed located near Galesville, WI (Figure 1). The lake has a maximum depth of only 3 m and a mean depth of 1 m. Depth contours less than 1 m represent nearly 40 percent of the lake surface area. Submersed macrophytes, dominated by *Ceratophyllum demersum*, *Elodea canadensis*, *Potamogeton gramineus*, and *Stukenia pectinata*, once occupied approximately 85 percent of the lake in the late 1980's and early 1990's. The community has steadily declined over the last decade.

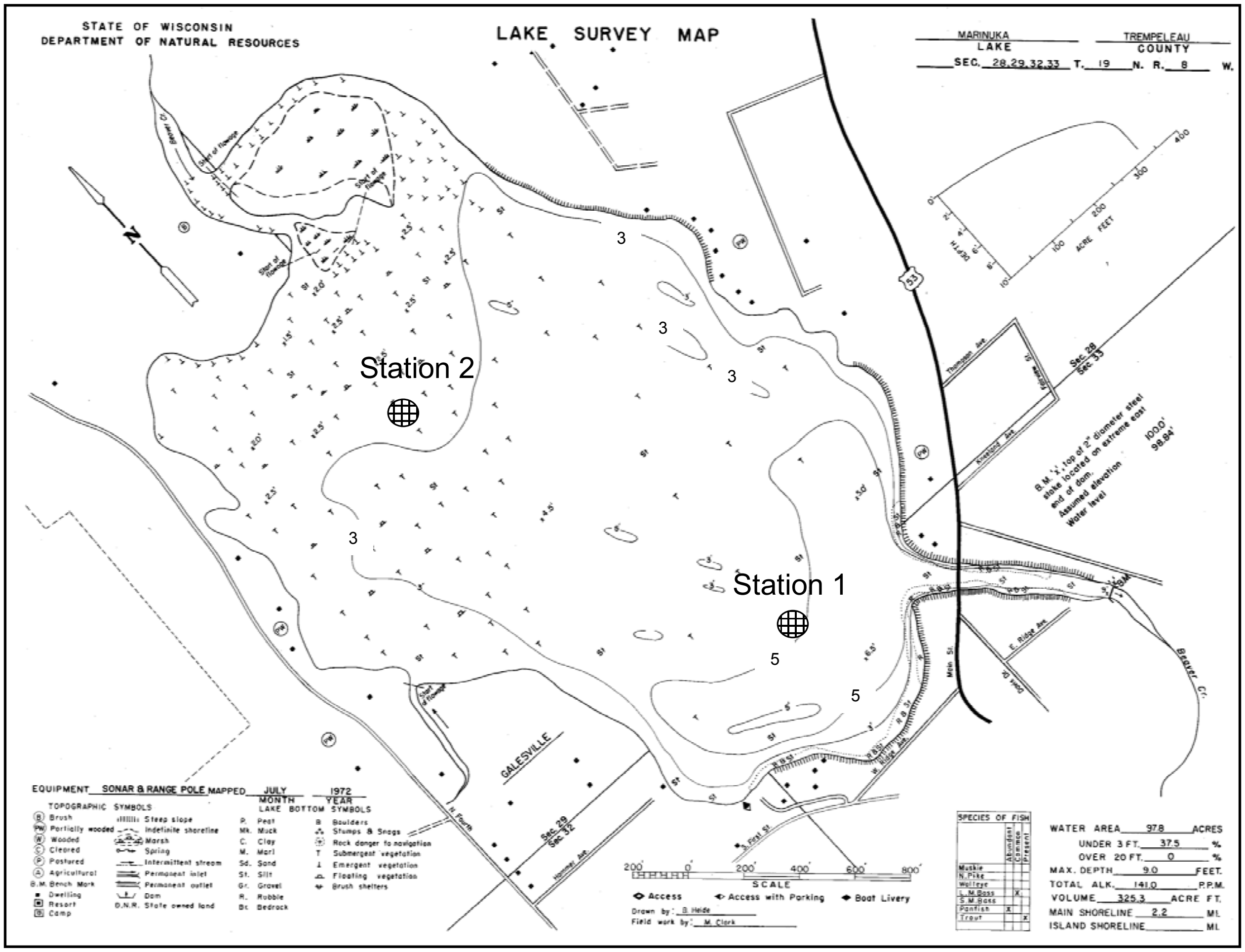

Figure 1. Map of Marinuka Lake showing station locations.

Experimental evaluation of plant growth potential on Marinuka Lake sediments. Aquatic sediments were collected from Marinuka Lake and Eau Galle Reservoir (Spring Valley, WI) for use in comparative controlled growth experiments. The sediment from each lake was gently homogenized and placed in planting containers (4 in. long by 4 in. wide by 5 in. deep) to a depth of 4 in. Propagules (i.e., vegetative tubers) of sago pondweed, purchased commercially (Kester W.F.G. Nurseries, Omro, WI), were germinated prior to initiation of the experiment and transplanted into experimental containers. Ten replicates for each sediment type (one plant per container) were incubated in a large outdoor facility consisting of plant growth tanks (4 ft in diameter by 4 ft in height) filled with locally obtained groundwater (Figure 2). A 30-percent shade cloth was deployed above the plant growth tank to simulate natural underwater light conditions. A circulation pump was placed in the tank to provide gentle mixing and promote atmospheric carbon dioxide flux into the tank throughout the experiment. Plants were cultivated on each sediment type for approximately 12 weeks between May and mid-August, 2004.

Figure 2. Experimental plant growth tank in which the sago pondweed containers were cultivated.

Sediments from each lake used in the plant growth study were analyzed for moisture content and sediment density using methods described in Håkanson (1977). Exchangeable ammonium-nitrogen concentrations in the sediments were determined colorimetrically on a Lachat QuikChem water chemistry analyzer after extraction with 1 M sodium chloride solution according to Bremner (1965). Analyses were conducted on sediment prior to planting and incubation. At the end of the experiment, sago pondweed shoots and roots were harvested from each container to determine biomass and tissue nitrogen content. Biomass was measured to the nearest 0.1 g after drying at 65 °C. Tissue nitrogen content was determined according to Allen et al. (1974). Statistical comparisons between plant biomass, tissue nitrogen content, and sediment exchangeable ammonium-nitrogen content for the different sediments were assessed using comparison of means (t-test; Statistical Analysis System (SAS) 1994) to determine the impacts of sediment fertility on plant growth.

Field-scale growth studies. Using the same germination procedures and experimental containers, 10 replicates for each sediment type were placed at the 1-m depth in an enclosure (i.e., a fine meshed cage placed around the experimental area) in the lake near station 2 (Figures 1 and 3) to protect them from disturbance by carp. Ten additional replicates containing Marinuka Lake sediment were deployed outside of the enclosure at the same depth for examination of possible carp disturbance. Plants were allowed to grow between May and Early August, 2005 (10 weeks).

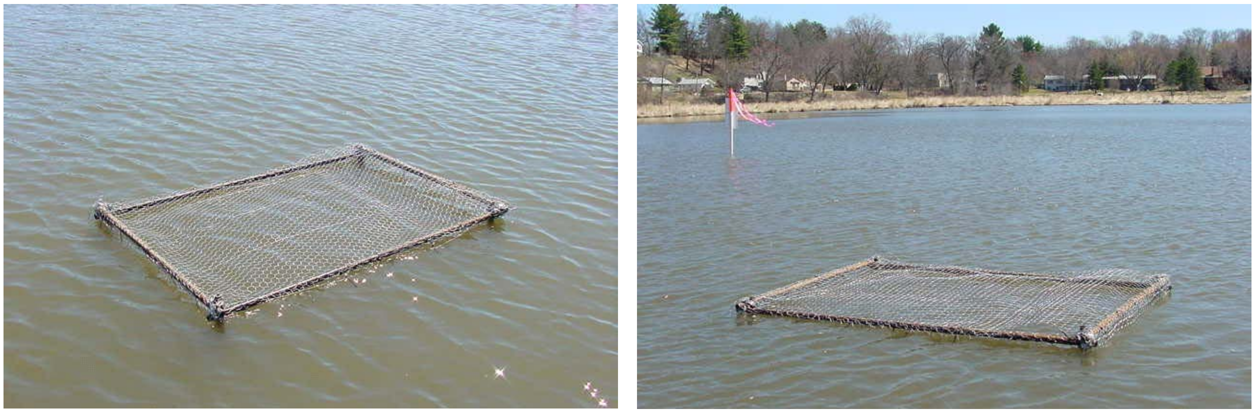

Figure 3. Field enclosures.

Water quality. Sampling stations were established in the southern portion (station 1; approximately 2.5 m deep) and northern bay (Station 2; approximately 1 m deep) of the lake for examination of seasonal water quality patterns (Figure 1). Between May and September 2005, integrated (i.e., composited over the entire water column using a PVC sampler with a one-way check valve) water samples were collected at these stations at three-week intervals for analysis of total nitrogen, total phosphorus, chlorophyll, total suspended solids, and turbidity. Total nitrogen and phosphorus were analyzed on a Lachat QuikChem water chemistry analyzer after digestion with potassium persulfate (Ameel et al. 1993). Chlorophyll was determined fluorometrically after extraction with 50:50 DSMO and acetone (Welschmeyer 1994). A known volume of water sample was filtered through a glass fiber filter (Gelman A/E 2.0 µm nominal pore size) and dried to a constant weight at 105 ^{o}C for determination of total suspended solids. Turbidity was measured on a Hach Turbidometer. In situ variables (temperature, dissolved oxygen, pH, conductivity; Hydrolab Quanta water quality meter) were measured at 0.5-m intervals. Secchi disk transparency was measured using a 10-cm-diam alternating black and white disk to the nearest centimeter. Profiles for light attenuation characteristics (i.e., the amount of photosynthetically active radiation penetrating the water column) were collected at 0.2–m intervals or less with a Licor radiometer model LI1000. The light attenuation coefficient (k_d) was calculated as:

$$k_d = \frac{\ln\left(I_o / I_z\right)}{z} \tag{1}$$

where I_o is the surface radiation ($\mu E \cdot s^2$) and I_z is the radiation at depth z. A plot of $ln(I_o/I_z)$ versus z is shown in Figure 4 for a period of relatively high Secchi transparency (May) and more turbid conditions (July). Thus, a higher k_d value indicates less light penetration into the water column.

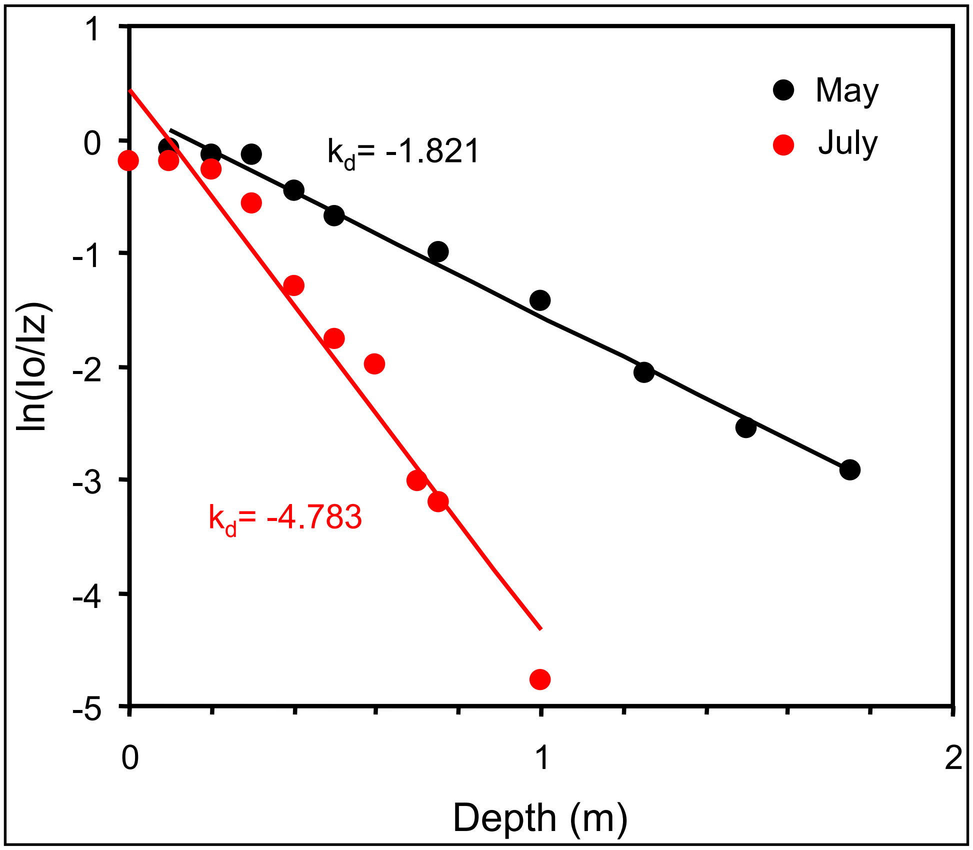

Figure 4. k_d plots for Marinuka Lake in May and July, 2005. The water column was more turbid in July than in May resulting in a higher k_d in July (i.e., less light penetration).

Turbidity studies and weather information. YSI 6000 data sondes and turbidity probes were deployed 0.3 m above the sediment surface at station 2 for examination of daily and seasonal variations in turbidity. Wind speed and direction information was obtained from the nearby LaCrosse Airport, LaCrosse, WI.

RESULTS AND DISCUSSION:

Growth potential on various sediments. There were no differences in mean root and shoot biomass, tuber production, or tissue nitrogen content for plants cultivated on Eau Galle versus Marinuka Lake sediments (Table 1). The sediments from each lake exhibited similar moisture content and exchangeable ammonium-nitrogen concentrations. Levels of exchangeable ammonium-N were on the high end of the range suitable for sago pondweed growth (0.009 to 0.065 $mg \cdot g^{-1}$; Kantrud 1990) suggesting that sediment N was not limiting plant growth. Tissue N concentrations were approximately 1 percent of shoot biomass, which is within the range of concentrations reported for sago pondweed (Kantrud 1990). These results suggested that Lake Marinuka sediment fertility was probably not limiting plant growth and the sediments themselves would be expected to support a healthy aquatic community.

Table 1. Comparison of mean sediment ammonium-N (NH_4-N) and plant biomass variables for sago pondweed grown under experimental conditions (Experiment 1) using sediments collected from Marinuka Lake and Eau Galle Reservoir. One standard error of the mean is shown in parentheses. No significant differences (t-test; n=5 to 10; SAS 1994) were found between means.

Variable	Marinuka	Eau Galle
Sediment Exchangeable NH_4-N ($mg \cdot g^{-1}$)	0.065 (0.003)	0.067 (0.004)
Sago Tissue N (%)	0.93 (0.09)	1.01 (0.09)
Sago Shoot Mass (g)	5.4 (0.5)	6.8 (0.7)
Sago Root Mass (g)	5.5 (0.4)	5.6 (0.3)
Sago Tuber Number	20.5 (4.2)	22.7 (6.3)

Growth potential in field-scale experiments. Sago pondweed growth in planted containers placed in Marinuka Lake was much less compared to growth in tanks under controlled conditions (Table 2). Plant shoot (i.e., stems and leaves) and root growth in the laboratory were two times greater than the growth observed in the lake (measured as biomass). Similarly, root biomass was lower by a factor of 15 for plants grown in the lake versus the experimental growth tank. Interestingly, tissue nitrogen content was very high for plants cultivated in the lake; however, this variable was probably artificially high due to the occurrence of nitrogen-rich attached algae on the plants which were difficult to remove. There were no differences in growth as measured by biomass for plants grown in the enclosure versus those cultivated in the open water, indicating that carp damage was not regulating plant growth in Marinuka Lake.

Table 2. Comparison of mean plant biomass variables for sago pondweed grown on Marinuka Lake and Eau Galle Reservoir sediment in protective enclosures and in the open water. One standard error of the mean is shown in parentheses. No significant differences (ANOVA; n = 3 to 10; SAS 1994) were found between means.

Variable	Marinuka Enclosed	Eau Galle Enclosed	Marinuka Open
Sago Tissue N (%)	3.77 (0.17)	3.16 (0.02)	2.85 (0.06)
Sago Shoot Mass (g)	2.3 (0.8)	2.0 (0.6)	1.5 (0.2)
Sago Root Mass (g)	0.2 (0.1)	0.4 (0.1)	0.3 (0.1)

Water quality patterns. Turbidity exhibited several peaks between May and September that were primarily associated with periods of precipitation rather than periods of high wind (Figure 5). For instance, turbidity did not fluctuate during a period in late May when maximum wind speed exceeded 50 MPH. Significant relationships between wind speed and turbidity were not observed (Figure 6). The lack of wind-generated sediment resuspension may be attributed to the small fetch (i.e., length of the lake in the direction of prevailing winds) of the lake. However, turbidity peaks were observed in conjunction with precipitation events that usually exceeded 1 in. per day (Figure 5; exceptions occurred in early June and Late August). In situ turbidity also increased above baseline conditions between late June and August in conjunction with the occurrence of algal blooms (see below).

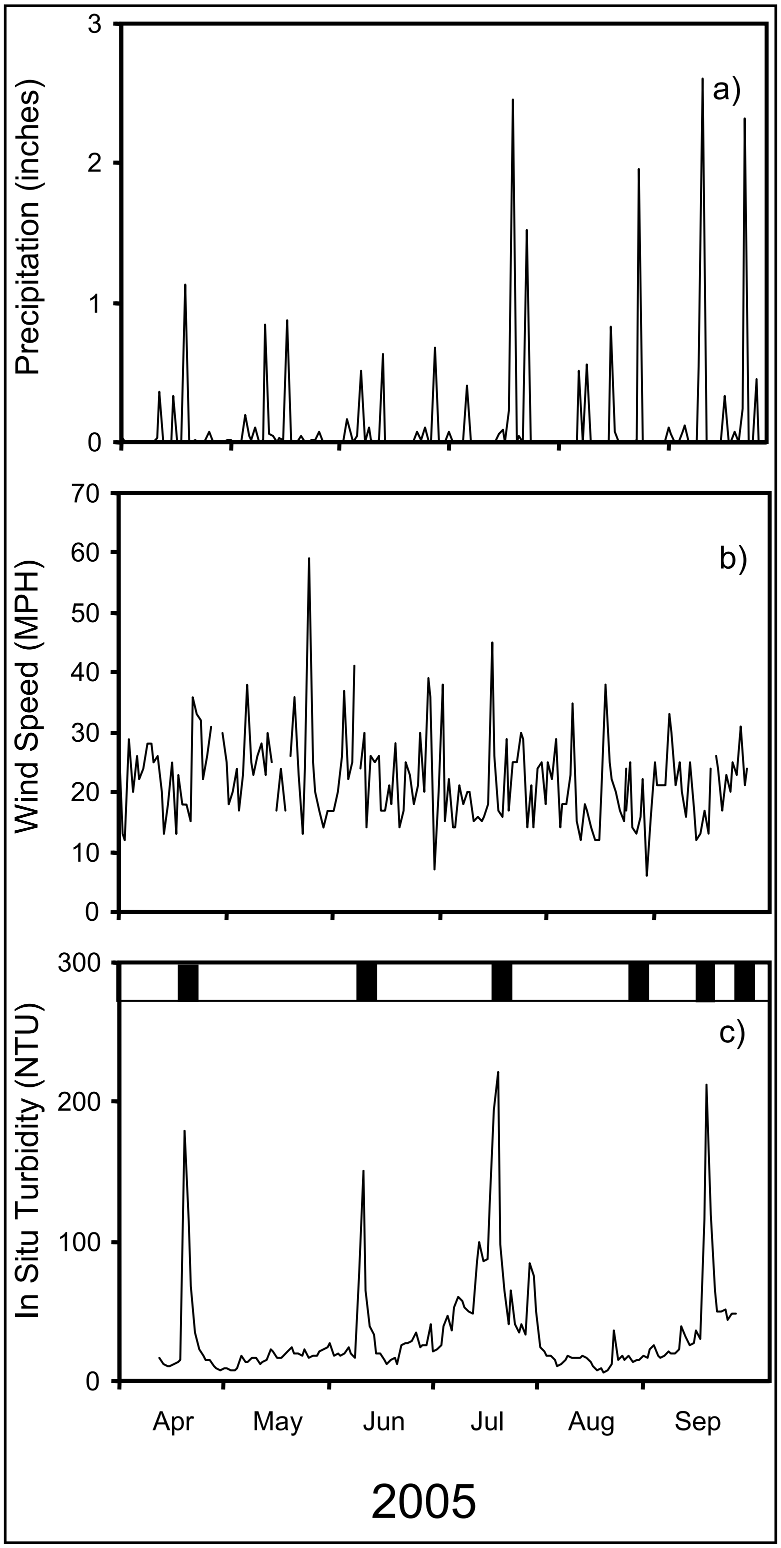

Figure 5. Seasonal variations in (a) daily precipitation, (b) daily maximum wind speed (MPH = miles per hour), and (c) mean daily in situ turbidity at station 2 in Marinuka Lake, 2005. Black bars in panel c represent periods of elevated precipitation.

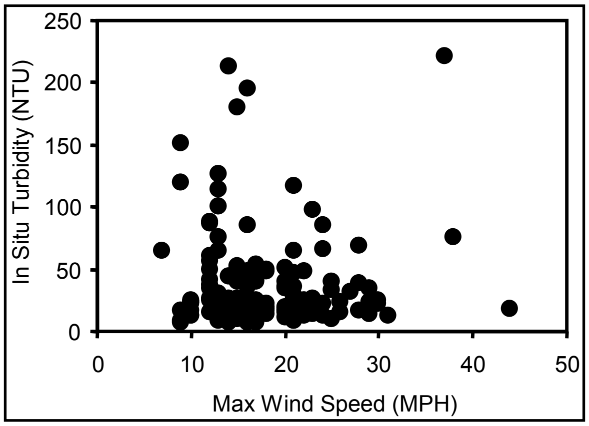

Figure 6. Daily maximum wind speed versus mean daily turbidity.

Chlorophyll exhibited peaks in concentration that exceeded 100 mg·m^{-3} in mid-May, late June, and late August (Figure 7). During periods of elevated chlorophyll, Secchi disk transparency declined to 0.5 m and k_d increased to > 2 m^{-1}. Declines in Secchi disk transparency and increases in k_d were directly related to the chlorophyll concentration in the water, indicating that algal blooms contributed to high k_d (Figure 8). An exception occurred on 28 July, where high turbidity and the highest k_d recorded in 2005 were the result of storm inflows. Summer mean concentrations of total phosphorus, chlorophyll, and Secchi disk transparency for Marinuka Lake were very high and indicative of eutrophic conditions (Table 3).

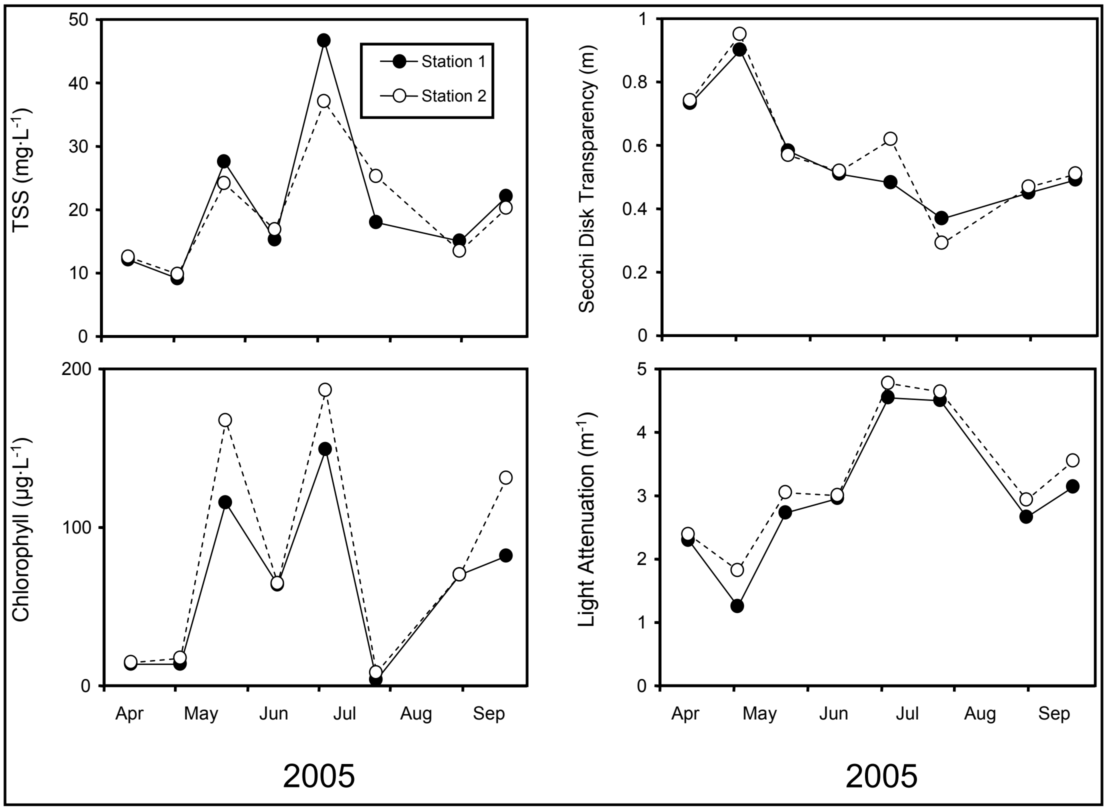

Figure 7. Seasonal variations in total suspended solids (TSS), chlorophyll, Secchi disk transparency, and the light attenuation coefficient (k_d) at stations 1 and 2.

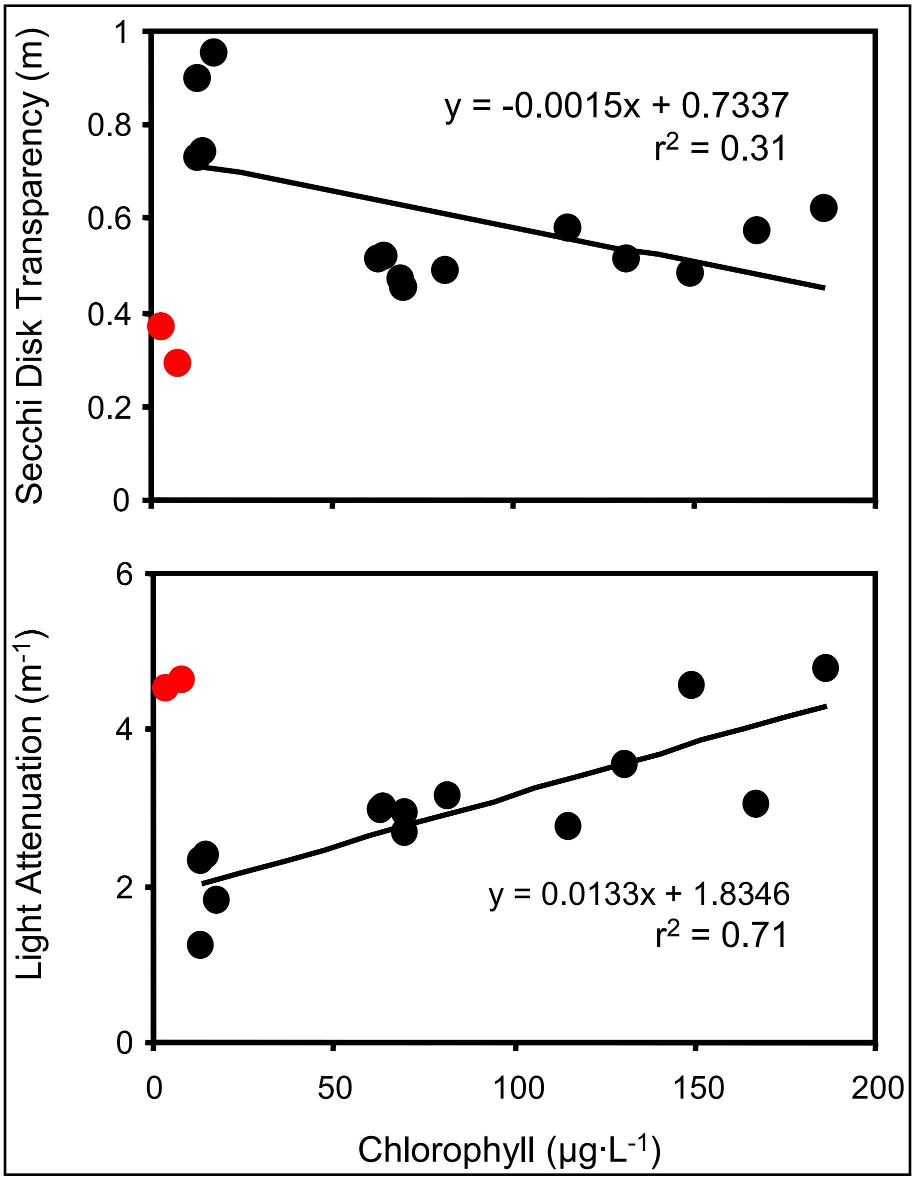

Figure 8. Chlorophyll versus Secchi disk transparency (upper panel) and light attenuation (lower panel). Red solid dots represent a period of elevated precipitation in late July and are not included in the regression analysis (SAS 1994).

Table 3. Mean summer Secchi disk transparency (*SD*), chlorophyll (*chl$_a$*) concentration, total phosphorus (*TP*) concentration, and trophic state index values for stations 1 and 2 of Marinuka Lake.

Station	**SD (m)**	**Chl$_a$ (µg L^{-1})**	**TP (mg L^{-1})**	**Wisconsin Trophic State Index**			**Carlson Trophic State Index**		
				TSI$_{SD}$	**TSI$_{CHLa}$**	**TSI$_{TP}$**	**TSI$_{SD}$**	**TSI$_{CHLa}$**	**TSI$_{TP}$**
1	0.56	63.78	0.124	68.1	66.2	65.5	68.4	71.3	73.7
2	0.58	82.40	0.145	67.6	68.2	67.9	67.9	73.8	75.9

Synthesis and management recommendations. Precipitation events and high total suspended solids loading from the watershed resulted in declines in water clarity that could limit light availability for aquatic plant growth and reproduction. These declines were very short-lived and water clarity returned to nominal conditions rapidly. However, results also suggested that frequent algal blooms in the summer contributed to longer-term (i.e., weeks) periods of poor water clarity (although not as poor as during storm inflows) that were probably more important in limiting aquatic plant growth in the lake. Light is an important factor in aquatic plant growth and k_d on the order of 3 to 4 m^{-1} during the summer suggested that algal blooms were effectively shading the aquatic plants in the lake, resulting in stressed growth and potentially low tuber production for next year's crop. In contrast, sediment nutritional quality and/or carp damage did not appear to be factors negatively affecting plant growth and persistence in the lake.

Clear information is lacking regarding the minimum critical light levels needed for sago pondweed growth and tuber production. Best and Boyd (2003a) suggested that a nominal k_d of 1.07 m^{-1} or less is required for successful sago pondweed growth and population increase. They indicated that sustained population persistence is stressed as k_d approaches $> 2\ m^{-1}$. Sago can overcome light limitation to some degree by forming a canopy; however, k_d patterns in Marinuka Lake were well above 2 m^{-1}, suggesting that sago pondweed reproduction and tuber formation was likely severely stressed or completely shut down. High k_d due to elevated phosphorus concentrations and algal blooms may be causing declines in the sago pondweed plant population by impacting the plants' ability to form enough tubers for next year's population cohort. A plant growth model such as POTAM (Best and Boyd 2003b) would be useful in predicting population growth, persistence, and plant distribution response to improvements in water clarity and could be used as a tool for setting target goals for managing the aquatic plant community in the lake.

Results from this study suggested that successful re-establishment of a healthy aquatic plant community in Marinuka Lake depends on reducing algal bloom frequency and magnitude to a level that does not cause light-limited aquatic plant growth. Under improved light conditions, the native sago pondweed population could increase over a number of years due to increased tuber production. Since phosphorus is most likely the nutrient that stimulates algal growth in the lake, management plans would have to evaluate the phosphorus budget of the lake (i.e., loading of phosphorus to the lake from the watershed and from the sediments stored in the lake) and target important sources for reduction. Relationships between k_d and chlorophyll, established in this study, could be used in conjunction with a loading-reduction eutrophication response model such as BATHTUB (Walker 1996) to predict the amount of phosphorus reduction required to decrease both algal bloom magnitude and frequency and k_d to ranges that are favorable to sago pondweed growth and persistence (Figure 9). External sources of phosphorus from the watershed would need to be managed via implementation of land use practices that reduce the runoff of phosphorus and/or trap it in buffer zones before reaching the lake. Internal sources of phosphorus could be managed via chemical precipitation (i.e., alum) techniques.

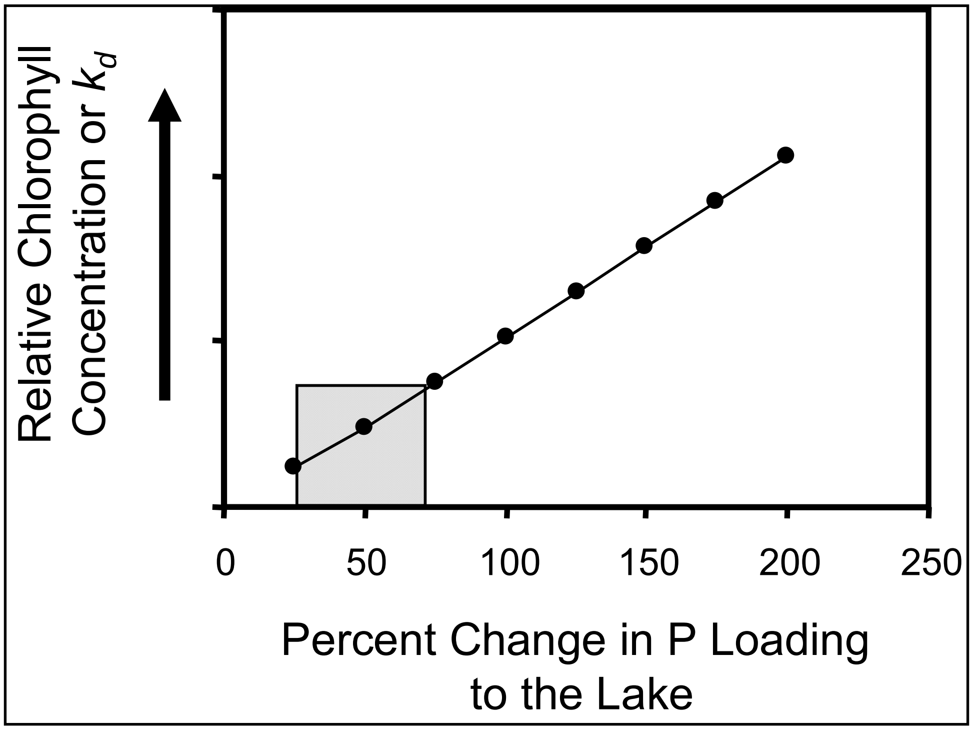

Figure 9. An example of use of the loading-reduction eutrophication response model BATHTUB to predict the response of mean summer chlorophyll concentration to reductions (or increases) in phosphorus loading to the lake. For instance, a 50-percent reduction in loading resulted in a 64-percent reduction in mean summer chlorophyll in this example. This information can be used in conjunction with the plant growth model POTAM to estimate the required percentage of phosphorus load reduction to improve light conditions in the lake for successful sago pondweed growth and persistence (shown by the gray box).

Another strategy to consider is establishment of small founder populations of sago pondweed in various regions of the lake that could successfully compete for light and nutrients once established. Small shoreline areas could be temporarily isolated from the main portion of the lake for recolonization. Partitions to isolate these areas would consist of fence posts and plastic barrier material or bales of straw; the objective is to temporarily inhibit water exchange for a season or two. The enclosed area would probably need to be treated with alum to limit algal growth and decrease k_d. Viable tubers of sago pondweed (and other native species) could be purchased commercially and planted in the enclosed areas. Future persistence of the population after the barriers are removed would still be susceptible to algal-induced light limitation. However, re-establishment of dense, healthy stands of sago pondweed might be sufficient to regulate algal biomass via localized scavenging of nutrients (by attached algae and algae inhabiting the sediment) and by providing refugia for zooplankton grazers that keep local algal populations in check.

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POINTS OF CONTACT: This technical note was written by William F. James of the Eau Galle Aquatic Ecology Laboratory, Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC). For additional information, contact the manager of the Aquatic Plant Control Research Program, Robert C. Gunkel (601-634-3722, *Robert.C.Gunkel@erdc.usace.army.mil*).

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