Summary of Peer-Reviewed Research on LFA/Bioaugmentation

Compiled by: Jennifer L. Jermalowicz-Jones, PhD Candidate
Restorative Lake Sciences, Spring Lake, Michigan

Many management strategies are used for dealing with excessive plant growth in lakes. One of the more controversial strategies is the use of aeration. Based on past and current literature, discuss the various types of aeration, how aeration directly or indirectly affects aquatic plants, and give recommendations as to when and if this strategy would be and not be favored over others.

Multiple methods of aquatic plant control have been used to control excessive submersed aquatic vegetation (SAV) growth and include: aquatic herbicides, mechanical harvesting, biological control, dredging, and more recently, laminar flow aeration. A reduction of Eurasian Watermilfoil (EWM) or other exotics is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984).

Scientifically peer-reviewed literature on the effects of aeration on submersed aquatic vegetation is extremely limited. This is largely due to the fact that previously studied forms of aeration (hypolimnetic aeration and fountain aeration) showed little effect on SAV growth. Laminar flow aeration (LFA) has been shown to reduce organic muck on lake bottoms if used with added aerobic bacteria and reductions in nuisance SAV growth have been noted (Cooley et *al*., 1980; Jermalowicz-Jones, *in progress*; Turcotte et *al*., 1988). To fully understand the operations of a laminar flow system, I will first discuss the other two forms of aeration.

Fountain aeration is used to aerate small bodies of water that are in close proximity to the fountain. It is generally not considered for large-scale aeration projects. It functions by drawing water from the surrounding area (usually shallow) and exposing the fountain of water to the air before it is replaced with more dissolved oxygen (DO). This form of aeration is effective at increasing the DO in the proximal waters but has not been shown to reduce SAV and algae growth. Since fountain aeration is turbulent, it displaces filamentous algae and some nearby SAV without addressing their growth (Jermalowicz-Jones, personal observation).

Hypolimnetic aeration utilizes aeration devices that draw water up from the depths and then aerate the water at the surface before the water then diffuses into the lower layers. This technology has shown great promise in reservoirs and other large, deep lakes, as it moves a considerable amount of water and results in significantly increased DO (Verma and Dixit, 2006). Most of these aerators consist of solitary units that are placed over the deep basins to thermally destratify them. A study by Slagowski et *al*. (2009) using this technology showed no significant impacts of aeration on the growth of EWM in Lake Cochituate (eastern Massachusetts).

Laminar flow aeration systems are retrofitted to a particular site and account for variables such as water depth and volume, basin morphometry, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute DO throughout the lake water column and sediments for efficient microbial utilization. A laminar flow aeration (LFA) system utilizes diffusers that are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to deliver DO to the sediments and water via convectional currents. In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment.

A detailed study by Jermalowicz-Jones (2010-present) of Indian Lake (Cass County, Michigan) also indicated a significant reduction of organic sediments in bio augmented/aerated regions, as well as a decline in the relative proportion of blue-green algae and the presence of the rooted, submersed, exotic aquatic plant EWM. Similarly, Turcotte et *al*., (1988) discovered a significant decline in EWM after aeration and bio augmentation was implemented. Cooley et *al*., (1980) discovered that aeration decreased the nuisance exotic *Hydrilla verticillata* by 20% in a 21-day period. They concluded that a decline in iron from the aeration may have caused the *Hydrilla* to be killed off at a higher rate. Thus, this effect appears to be an indirect effect of aeration.

Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. Below is a review of possible mechanisms that discuss how aeration (and bio augmentation) may affect SAV growth.

Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A reduction in sediment organic matter has reduced EWM growth in Wing Lake (Oakland County, MI) and Maple Lake (Van Buren County, MI; Jermalowicz-Jones, unpublished data) as these sites have exhibited reductions in EWM abundance as well as sediment organic matter in the same locations. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine water bodies that received aeration and bio-augmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed.

Possible mechanisms of SAV reductions:

Conversion of ammonia nitrogen to less usable forms for SAV growth:

In the presence of oxygen, sedimentary ammonia (NH_3+) is rapidly converted to nitrate (NO_3-), nitrite (NO_2-), nitrous oxide (NO), and finally nitrogen N_2 gas by denitrifying bacteria in the water and sediment. Nitrogen in the sediments is derived primarily from decaying plant matter. The conversion of ammonia (NH_3+) to organic nitrogen is necessary for the formation of lake bottom sediment and adds bulk density. The release of

NH_3+ under anoxic conditions follows the accumulation of NH_3+ in sediments where nitrification cannot occur, and NH_3+ assimilation by anaerobic microbes declines. The imminent accumulation of NH_3+ then results in toxicity to aquatic organisms (Camargo et *al*., 2005; Beutel, 2006). Conversion of NH_3+ to less usable forms of nitrogen for SAV may allow for nutrition deficiencies in some plants. Thus, if aeration is used, it must accompany supplementation of aerobic bacteria that can reach critical population counts in the sediments to effectively break down the organic matter under oxic conditions. Such conditions have been shown to promote aerobic bacteria growth. A study conducted by Ramco in 1993, utilized a Biological Activity Reaction Test (BART) to determine the degree of activity by various bacteria. The result of their study indicated that the numbers of aggressive aerobic bacteria increased with an increase in aeration relative to the non-aerated control region. The BART test indicated higher activity of sulfate-reducing bacteria, slime-forming bacteria, iron-related bacteria, fluorescing pseudomonads, and total aerobes in the barge and tube-aerated sites than in the control (non-aerated) site. Such data suggests a strong synergy between bio-augmentation and aeration, which may be utilized to decompose organic matter in the sediments.

Loss of rooting medium:

Sediments with large particle size may inhibit rooted aquatic plant growth through mechanical impedance, whereas sediments with smaller particle sizes tend to favor rooted SAV growth unless those sediments are highly flocculent and rooting is not possible. This was observed in Paradise Lake (Emmet County, MI) and Austin Lake (Kalamazoo County, MI) where entire milfoil plants uprooted and drifted onto the shore since rooting was no longer possible with the sediment becoming more unconsolidated due to loss of compacted organic matter (Jermalowicz-Jones, in progress).

Other benefits of LFA:

There has been considerably more research on the effects of aeration on water column nutrients since anoxia is related to sediment phosphorus release.
Wang et *al*. (2008) showed that although organic matter in sediments may restrict the release of soluble reactive phosphorus (SRP) to overlying waters, the fraction of dissolved organic phosphorus (DOP) is readily released by organic matter under anoxic conditions. Thus, reduction of the organic matter layer may reduce the total nutrient pool available for release in eutrophic lake systems. The concentrations of phosphorus in both sediments and the water column fluctuate seasonally in lakes with reported increases occurring during the summer (Clay and Wilhm, 1979). Furthermore, Jeppesen et *al*., (1999) discovered that the upper 20-25 cm of lake sediments in Lake Sobygaard (Denmark) released phosphorus and that if the external phosphorus loads were halted, the lake would not reach equilibrium until at least 10-20 years. This emphasizes both the need for watershed protection and also for the use of aeration to reduce bottom nutrient release. They emphasized that LFA systems which operate in hyper-eutrophic waters may need many years of operation for a trophic shift to occur.

When LFA is recommended over other SAV management methods:

LFA systems along with bio-augmentation have shown significant improvements to lakes and include SAV control. The results of this technology appear to differ greatly among sites and require extensive research. If the overall goal of a lake management program is to just control SAV, then aeration may not yield the most immediate results. Often, the use of a mechanical harvester or aquatic herbicides is much more expedient in the reduction of SAV biomass. Mechanical harvesters are usually not recommended for species like EWM since they fragment and can spread further. Aquatic herbicides also do not remove excessive plant biomass and this contributes to sediment bulk density which reduces water depth and increases muck accumulation. Dredging is often cost-prohibitive and temporary, although it may be used to temporarily deepen an area and remove dense SAV. Annadotter et *al*. (1999) mentioned that dredging activities previously implemented in Lake Finjasjön, a shallow eutrophic lake in Sweden, were terminated when sediments left after removal failed to halt the release of phosphorus into the water column. Since many lakes contain several meters of sediments, it is unlikely that dredging could affordably remove all sediments and some degree of continual phosphorus release from sediments will occur in eutrophic systems where the sediment layer is anoxic. Thus, if the overall goal of a lake management program is to solely reduce EWM or other nuisance SAV, then aeration may not be satisfactory. In these cases, more immediate and direct outcomes from the use of aquatic herbicides or mechanical removal of nuisance native SAV may be desired. If the desired outcome is more holistic and includes increased DO, water clarity, reduced cyanobacteria blooms and organic muck, and possibly nuisance SAV, then LFA would be the preferred tool.

References Cited

Annadotter, H., G. Cronberg, R. Aagren, B. Lundstedt, P. Nilsson, and S. Ströbeck. 1999. Multiple techniques for lake restoration. *Hydrobiologia* 395/396:77-85.

Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundel sediments in lakes using hypolimnetic oxygenation. *Ecological Engineering* 28(3): 271-279.

Camargo, J.A., A. Alonso, and A. Salmanca. 2005. Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. *Chemosphere* 58: 1255-1267.

Clay, E.M., and J. Wilhm. 1979. Particle size, percent organic carbon, phosphorus, mineralogy, and deposition of sediments in Ham's and Arbuckle lakes. *Hydrobiologia* 65(1):33-38.

Cooley, T.N., P.M. Dooris, and D.F. Martin. 1980. Aeration as a tool to improve water quality and reduce the growth of Hydrilla. *Water Research* 14:485-489.

Fenchel, T., and T.H. Blackburn. 1979. Bacteria and Mineral Cycling. Academic.

Jeppesen, E., M. Sondergaard, L.M. Svendsen, and T.L. Lauridsen. 1999. Lake and catchment management in Denmark. *Hydrobiologia* 395/396: 419-432.

Laing, R.L. 1978. Pond/Lake Management organic waste removal through multiple inversion. In house report. Clean-Flo Lab, Inc.

Ogwada, R.A., K.R. Reddy, and D.A. Graetz. 1984. Effects of aeration and temperature on nutrient regeneration from selected aquatic macrophytes. *Journal of Environmental Quality* 13(2):239-243.

Slagowski, N., M. Mann-Stadt, and J.L. Durant. 2009. Use of upflow water circulators for managing Eurasian Watermilfoil in Lake Cochituate, Eastern Massachusetts. Prepared for the Massachusetts Department of conservation and Recreation, Boston, MA.

Turcotte, A.C., C.V. Déry, and K.F. Ehrlich. 1988. Manipulation of microbial ecosystems to control the aquatic plant Eurasian Watermilfoil. Preprint paper. Département de Biologie, Université de Sherbrooke, Sherbrooke, Québec, CANADA J1K 2R1.

Verma, N. and S. Dixit. 2006. Effectiveness of aeration units in improving water quality of Lower Lake, Bhopal, India. *Asian Journal of Experimental Science* 20(1): 87-95.

Wang, S., X. Jin, H. Zhao, X. Zhou, and F. Wu. 2008. Effects of organic matter on phosphorus release kinetics in different trophic lake sediments and application of transition state theory. *Journal of Environmental Management* 88:845-852.