

White Paper:

SolarBee Experience in Inhibiting Submersed Macrophyte Growth

(last updated February 4, 2010)

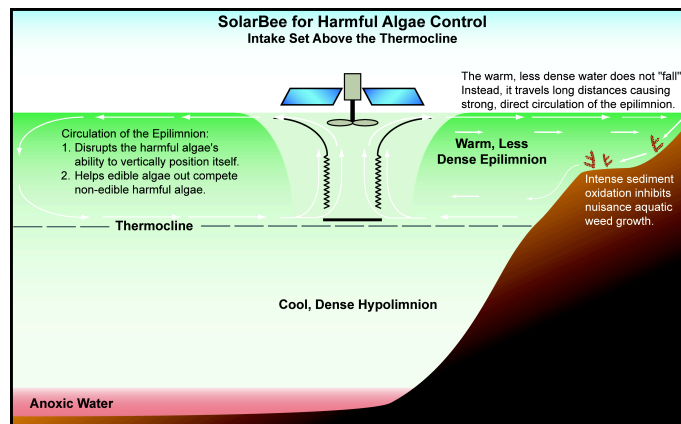
1. Background

In January 2007, the SolarBee Division of Pump Systems, Inc. (PSI) became SolarBee, Inc. PSI had been in the water movement business since 1978, and developed the solar-powered water circulation technology in 1998 for the primary purpose of enhancing dissolved oxygen (DO) distribution in wastewater ponds using renewable energy. In September 2001, PSI named this technology the "SolarBee".

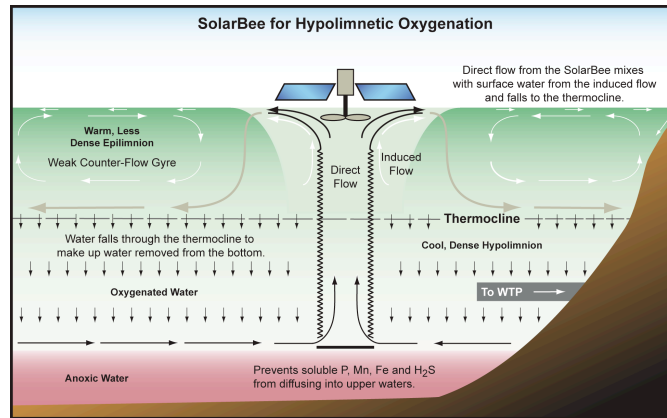
The earliest machines pumped 2,500 gallons per minute (GPM) and were applied mostly in wastewater ponds, though a few were deployed in lakes up to 63 acres of surface area. In mid-2002, the flow rate was increased to 10,000 GPM enabling broader applications in a variety of lakes. The SolarBee's near-laminar horizontal flow (both to and away from the machine) creates long-distance circulation (LDC) that impacts up to 35 acres or more per machine; the circulation effect is additive, and we are now in over 300 ponds, lakes and reservoirs from < 1 acre to nearly 12,000 acres in size. The ability to completely mix 100s of acre-feet with one machine has been proven by dye tests conducted by the EPA in Ohio, Chlorine Tracer Tests performed in an 11 acre 90 MG potable water tank in San Francisco, CA, Nitrification Study by Glendale, CA, and the Wastewater Mixing Study by Bennett, CO (see <http://www.solarbee.com>).

In freshwater applications, each SolarBee is deployed in one of two ways depending on the goals of the owner:

(a) with the intake hose shallow, i.e., above the thermocline, to provide LDC for just the upper waters (epilimnion) to control blue-green algae (cyanobacteria) blooms. Typical results of mixing the epilimnion include noticeable improvements in water clarity, in part because of increased autoflocculation and because algal nutrients are now being taken up by more edible algae rather than toxic, inedible blue-greens. Zooplankton populations and fish communities thrive with the additional food source, thus reducing algal densities in the water column.



(b) with the intake hose deep, i.e., below the thermocline, to provide hypolimnetic (bottom water) oxygenation and mixing in order to limit the upward progression of anoxic conditions from the lake bottom, and to minimize the accumulation of inorganic chemicals (e.g., soluble phosphorus, manganese, iron, hydrogen sulfide, and methyl mercury) in bottom waters. By January 2010, SolarBees had been deployed successfully in over 300 lakes worldwide for one or both of the above-mentioned purposes.



2. Chronology of Observed LDC Impacts on Submersed Macrophyte Growth

In 2000, the lake manager from Mirror Lake (North Dakota), one of the first lakes to use the original 2,500 GPM units for epilimnetic circulation, reported that submersed aquatic weed growth appeared to be less than in years past. This was not something we had envisioned as a potential impact of circulation. We heard similar unsolicited comments from other lake owners in 2001 and 2002, but nothing dramatic. In the summer of 2002 we installed one SolarBee in each of two lobes of a 7-acre raw water supply reservoir in Lloyd, NY. The town's objective was to reduce the buildup of organic substances on the bottom of the lake, which they deemed responsible for imparting a taste and odor to the water that rendered it totally unusable for the city's drinking water supply. An extremely dense crop of Eurasian watermilfoil (EWM) hindered the installation, almost preventing the use of a flat-bottom boat to deploy the units. A year after installing the units (late 2003), the lake manager reported that water clarity and quality were greatly improved; the reservoir was now back on line as a source of water, and, to their surprise, the EWM had all but disappeared (although still widely prevalent in the other four lakes in their system). One employee stated that "the weeds were so thick, you couldn't get an oar through them - now there are only sporadic traces." When additional lake owners reported submersed macrophyte reductions in 2003 and 2004, we began to investigate the possible ecological mechanisms for this phenomenon.

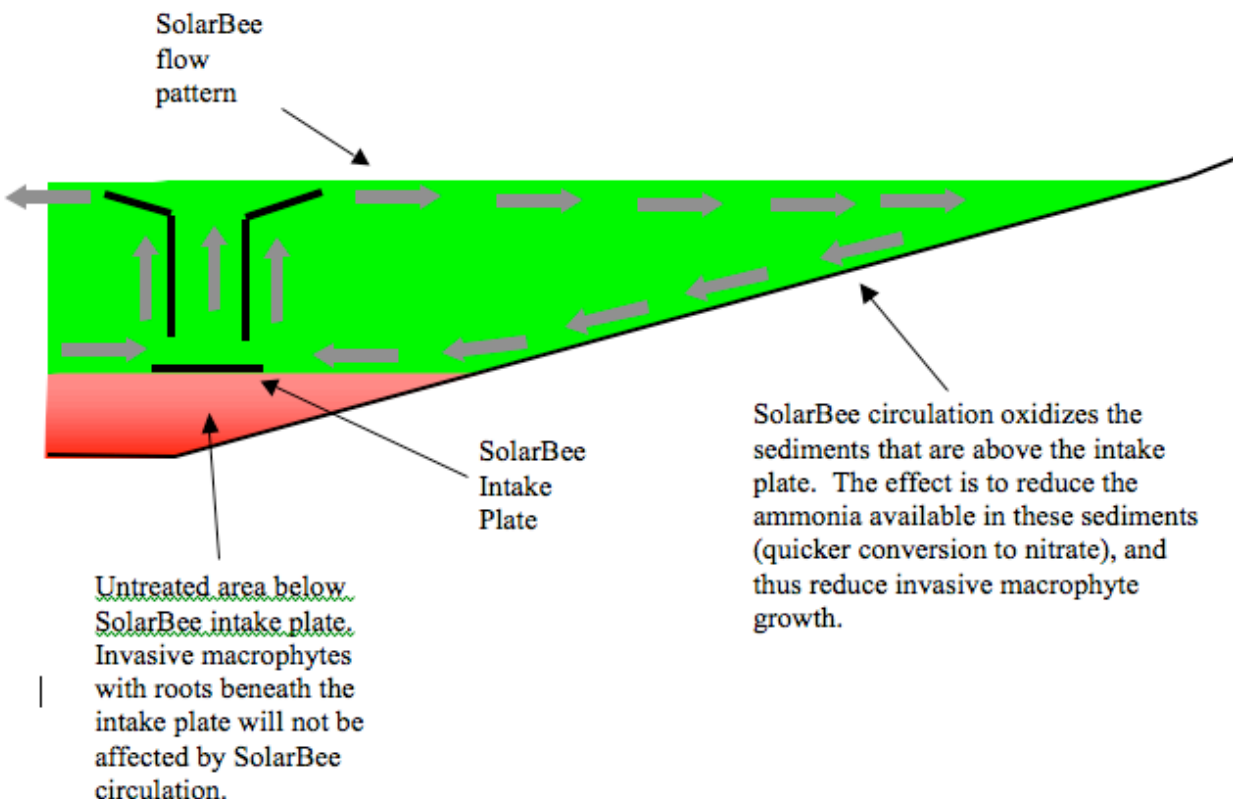
By the end of 2004 there were SolarBees in about 75 lakes nationwide, with about ten of them reporting some degree of submersed macrophyte growth inhibition. Also noteworthy was that in all the lakes there was a varying degree of water clarity improvement due to the suppression of cyanobacteria blooms. In some cases, maximum Secchi depths went from a few feet to over 17 feet. The standard paradigm in lake management has been: 1) poison the algal community with a copper-based algaecide, 2) the water clears up as the dead algae settle to the bottom, 3) the submersed macrophytes rapidly take over, 4) herbicides are then applied to the macrophytes, and 5) macrophytes die off and cyanobacteria blooms return.

This never-ending cycle can be quite costly – both to the lake owner and to the lake's ecology. But in the hundreds of SolarBee-treated lakes where water clarity has improved, invasive weeds have

rarely made a significant presence. And if there were invasive weeds already, noticeable reductions were observed by lake owners. Consistent with this apparent inhibition was the lake in Lloyd, NY, as well as other lakes that had reported EWM reductions in previous years, that continue to experience sustained EWM reductions each subsequent year. These independent observations suggest that the paradigm assumption that submersed macrophyte growth is primarily limited by light availability may not be valid - since there was/is plenty of water clarity, yet invasive weed growth has not become a significant problem in any treated lake where the SolarBees are properly deployed consistent with the working hypothesis described below.

3. Working Hypothesis of the Possible Mechanism for Impacting Macrophytes

The SolarBee pulls water from all directions at the depth of the intake hose. So if the intake hose is set at 8 feet, water will be pulled to the machine from the shoreline down to 8 feet in the water column. These near-shore surface waters that are pulled along the lake sediments down to 8 feet, and then horizontally back to the machine, are naturally enriched with DO from algal photosynthesis and oxygen transfer across the air-water interface. Evidence of this slow, but constant movement of oxygen-rich water over littoral zone sediments has been demonstrated in dye studies, sludge reduction in wastewater ponds, increases in fish spawning sites, and sediment compaction along lake shorelines. It is important to appreciate that water movement across the lake bottom is too slow to resuspend sediments. It is also important to understand that sediments beneath the SolarBee intake hose *will not* be impacted. So, if the SolarBee is in 10 feet of water with the intake hose set at 8 feet, the sediments from 8 to 10 feet will not receive enhanced oxidation. Submersed macrophytes will still grow beneath and around the SolarBee in the 8-10 ft zone, but empirical observations indicate that plant growth diminishes in height as they extend into the water column above the SolarBee intake hose. The drawing below illustrates these relationships.



We believe that this slow, but continual oxidation of near-shore lake sediments is the likely key to submersed macrophyte control through long-distance circulation. Based on consultations with leading aquatic macrophyte scientists with the Army Corps of Engineers and a review of relevant literature, our working hypothesis is the following:

The continual oxidation of littoral sediments and overlying waters negatively impacts the health and growth of invasive submersed aquatic plants by limiting ammonia-N availability.

To properly examine this comprehensive working hypothesis, we must break it down into sub-issues.

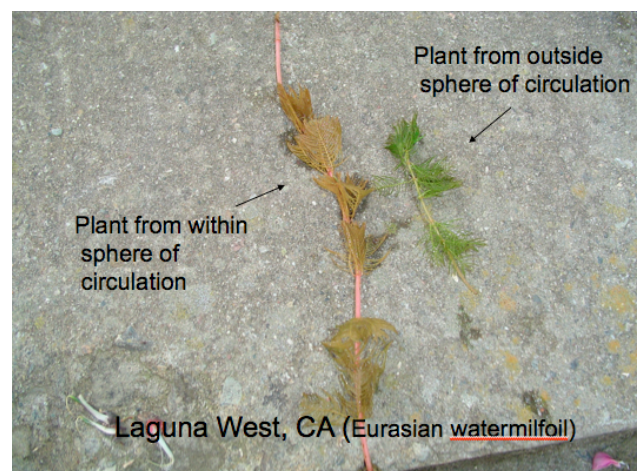
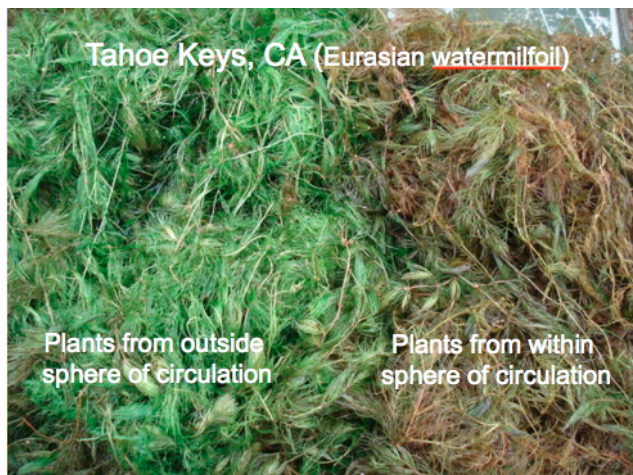
- 1) *Are sediments the major source of nutrients for submersed macrophytes?*
Yes: well established in the scientific literature (e.g., Barko and Smart 1981),
- 2) *Can ammonium-N availability limit the growth of submersed macrophytes?*
Yes: well established in the scientific literature (e.g., Nichols and Keeney 1976; Anderson and Klaff 1986; "Thus, unlike P, the availability of N may under some circumstances limit the growth of [EWM]" Smith and Barko 1990),
- 3) *Can enhanced oxygen availability promote the oxidation of ammonium-N to nitrate-N?*
Yes: well established in the scientific literature (e.g., any basic microbiology or limnology text book describes bacteria-mediated nitrification),
- 4) *Can SolarBee-induced LDC oxidize littoral sediments?*
Yes: empirical evidence supporting that the near-laminar return flow of oxygen-rich water back to the machine oxidizes littoral sediments include: EPA dye study, sludge digestion in wastewater ponds, sediment compaction along lake shores, and dramatic increases in fish spawning in littoral areas; and
- 5) *Is there any empirical evidence that SolarBee-induced circulation negatively impacts submersed invasive macrophytes?*
Yes: Yellowing and subsequent death of plants, consistent with severe nitrogen deficiency; effective, sustainable aquatic weed reduction (as a secondary benefit) in over 30 lakes utilizing SolarBees; negative impact on lightly-rooted invasives, but not effective on plant species with deeper roots or rhizomes, e.g., water shield (*Braenia schreberi*) and white lily (*Nymphaea* sp.) or emergent plants such as cattail (*Typha* sp.); in the 300+ lakes and reservoirs where SolarBees have significantly improved water clarity since 2000, invasive aquatic macrophytes have rarely made a significant presence and have been apparently inhibited; and, a Canadian company sells an up-flow, wind-powered circulator that has been reported to effectively control EWM in 20-30 lakes and ponds since 1999 (but with a much smaller affected area per machine).

The sub-issues above, together with the brief bibliography below, clearly illustrate that the ammonia-N limitation working hypothesis does not create any new theory or new science requiring peer-review for acceptance. Every single relevant issue has been either long established in the peer-reviewed scientific literature, is inherently logical, and/or is well established in the empirical

evidence - the only new issue we raise is the scope or sphere of influence. But the concept of controlling certain invasive aquatic macrophyte species by limiting sediment ammonia-N availability through sediment modification and/or oxidation already has very strong support in the published scientific literature. This is also consistent with the long-held paradigm described above, except that the real reason why submersed macrophytes experience rapid growth after the blue-green algae are killed is because decomposing algae provide a significant input of ammonia-N to the sediments, thus fertilizing the aquatic weeds. So, one ancillary benefit of blue-green algae bloom control through SolarBee's epilimnetic circulation is to reduce N inputs to the sediments for aquatic plant uptake (which is part of the slow approach for macrophyte control).

There are over 30 ponds, lakes and reservoirs since 2000 reporting significant reductions of one or more invasive submersed aquatic macrophyte species due to SolarBee circulation. Plant species that have been specifically observed to be negatively impacted include Eurasian watermilfoil (*Myriophyllum spicatum*), curly leaf pond weed (*Potamogeton crispus*), sago pondweed (*Potamogeton pectinatus*), coontail (*Ceratophyllum demersum*), and American elodea (*Elodea canadensis*). These are all relatively lightly-rooted plants susceptible to being impacted by sediment oxidation and modification. On the other hand, testing has shown little impact on more deeply-rooted species such as water lilies (*Nymphaea* sp.) and water shield (*Braenia schreberi*). This is viewed as a positive aspect as many native species tend to be more deeply rooted, and thus not inhibited by oxidizing superficial sediments. Unfortunately, the aquatic weed hydrilla (*Hydrilla verticillata*) also has roots and runners several inches below the sediment surface, and testing in Florida has not yet demonstrated a similar inhibitory impact as with lightly-rooted submersed plants.

We presented our working hypothesis, together with empirical data and photographic evidence of unhealthy plants collected from several lakes to help explain the ecological relationships consistent with observations made in over 170 lakes (at the time), in a technical presentation at the national Aquatic Plant Management Society's (APMS) annual meeting in July 2006. Below are two slides from that presentation.



Appreciating that presenting at the national APMS annual meeting is a form of peer-review, we specifically asked the audience if anyone could find in the scientific literature or from their own professional experience any shred of evidence that would otherwise contradict any aspect of our

working hypothesis, or provide any alternative explanation for the consistent observations made by independent lake owners. The silent response from the room full of aquatic plant management scientists, students, and herbicide applicators affirmed our conclusions; this was not surprising considering the strong empirical and scientific literature support for ammonia-N limitation of growth.

The following are among the peer-reviewed, scientific articles relevant to the inhibition of some submersed aquatic macrophyte species through sediment modification and ammonia-N limitation:

Anderson, M.R. and J. Kalff, (1986). Nutrient limitation of *Myriophyllum spicatum* growth *in situ*. *Freshwater Biol.* 16: 735-743.

Barko, J.W. and R. M. Smart, (1981). Sediment-based nutrition of submersed macrophytes. *Aquatic Botany*, 10: 339-352.

Barko, J.W. and R. M. Smart, (1986). Sediment-related mechanisms of growth limitation in submersed macrophytes, *Ecology*, 67(5): 1328-1340.

Barko, J.W. et al., (1991). Sediment interactions with submersed macrophyte growth and community dynamics. *Aquatic Botany*, 41: 41-65.

Barko, J.W. et al., (1986). Environmental factors and their consideration in the management of submersed aquatic vegetation: a review. *J. Aquatic Plant Manage.* 24: 1-10.

Barko, J.W. et al., (1988). Interrelationships between the growth of *Hydrilla verticillata* (L.f.) Royle and sediment nutrient availability. *Aquatic Botany*, 32: 205-216.

James, W.F. et al., (2004). Impacts of sediment dewatering and rehydration on sediment nitrogen concentration and macrophyte growth. *Can. J. of Fish. and Aquatic Sc.*, 61(4): 538-546.

Lillie, R.A. and J.W. Barko, (1990). Influence of sediment and groundwater on the distribution and biomass of *Myriophyllum spicatum* L. in Devils Lake, Wisconsin. *J. of Freshwater Ecology*, 5(4): 417-426.

Nichols, S.A. and D.R. Keeney, (1976). Nitrogen nutrition of *Myriophyllum spicatum* uptake and translocation of ¹⁵N by shoots and roots. *Freshwater Biol.* 6:145-154.

Smith, C.S. and J.W. Barko, (1990). Ecology of Eurasian watermilfoil, *J. Aquatic Plant Manage.*, 28: 55-64.

4. Research efforts

Our management experience with invasive weed inhibition through SolarBee-induced circulation is as follows: When sediment oxidation is initiated in the fall and continues into spring, we typically see a significant decline in invasive aquatic weeds the following summer, although there can still be plants emerging from depressions in the sediments where organic matter accumulates. Most remaining plants become visibly unhealthy, taking on a yellowish color consistent with nitrogen deficiency (see photos above). On the other hand, when SolarBees are

installed in late spring or early summer, submersed plant growth is not immediately inhibited. However, as the summer progresses plants frequently become unhealthy, dislodge from the sediment substrate, and float to the lake surface. These dislodged plants can be so thick on the surface that the SolarBee becomes plugged requiring frequent manual cleaning. Although temporarily unsightly, this is a result of sediment oxidation that when continued into the fall and following spring, 2nd year plant growth typically shows visible reductions and only minor clogging at worst. As long as enhanced circulation continues throughout the year, aquatic weed suppression also continues unabated into subsequent years.

When researching this topic, it is important to distinguish the machine from the mechanism. The hypothesized mechanism is induced ammonia-N limitation through sediment oxidation. If ammonia-N does not become limiting, then plants will continue to grow. For example, if there are significant ammonia-rich groundwater inputs, oxidizing superficial sediments will not be effective. It is also possible that substantial leaf litter accumulation on the lake sediments can contain high ammonia concentrations in the interstitial water, also making submersed macrophyte control via sediment oxidation difficult. The SolarBee is deployed to achieve LDC and sediment oxidation, but variable results reflect sediment chemistry, organic loading, and bathymetric features (e.g., under water berms) that can impede the near-laminar return flow back to the machine. And, as noted above, sediments at depths below the level of the SolarBee intake hose(s) do not directly benefit from LDC, so significant weed reductions should not be expected.

There have been numerous documented demonstrations and tests conducted during the past several years where units were provided at cost. The results, although variable, are completely consistent with the working hypothesis. For example, Tahoe Keys Marina, CA has a relatively flat bottom, as does Monona Bay, WI. In both those tests, authorities mandated (because of misguided concerns of sediment resuspension) that the intake hoses be two to three feet above the bottom. The results were that bottom sediments were not oxidized and EWM bottom growth was not prevented, though EWM in shallower waters was impacted as indicated by the photo above. Significant EWM reductions were observed at the adjacent Beaver Cove, a shallower part of Tahoe Keys Marina. The 2-year demonstration at Monona Bay was further compromised by the fact that units were installed at the end of May and removed in October of each year, though homeowners around Monona Bay still reported visible aquatic weed reductions in near-shore areas.

At Lake Cochituate, MA, 2 units were installed in fall of 2006, but one unit moved during the winter and the other did not run for 4 months. Nevertheless, the Master's student on the project collected data in the summer of 2007 to "evaluate the SolarBee", instead of examining relevant ecological relationships associated with LDC and appreciating the fact that requisite test conditions had not been established. Unfortunately, the student did not discuss results with us before presenting data at professional meetings and concluding that the SolarBees "didn't work". Rather than elucidating underlying ecological relationships associated with sediment oxidation via LDC, the project evolved into an overly simplistic analysis based on incorrect assumptions. It may be relevant that the state agency funding the project actively promoted herbicide use and publicly expressed negative comments about the SolarBee before the study began.

Results at Conesus Lake, NY showed measureable EWM reductions in treated areas (i.e., in littoral waters above the depth of the SolarBee intake hose) in both years (2006-07) of the study. This is a case where only half the recommended units were used in the pilot study because of budgetary

constraints. And although EWM reductions were noted, the consultant for the study concluded that because observed differences did not meet a 95% confidence level, EWM reductions could not be attributed to SolarBee-induced circulation. Not only is a 95% threshold for an ecological pilot study unreasonable, the consultant ignored our advice and erroneously assumed for analytical purposes that EWM growing at depths beneath the SolarBee intake hose should be also impacted. Unfortunately, and similar to Lake Cochituate, the study did not address ecological relationships that would help explain observed variability.

The best documented study to date was conducted in Timnouth Pond, VT. This is where one SolarBee was installed in 2006 to treat one half of a 78-acre lake. Detailed transect mapping of both invasive and native plants conducted prior to and the year following the installation showed EWM reductions only in the treated half of the lake, while native species (including rare and protected species) did well. Water clarity and overall lake health was also noticeably better in the treated half. So, in 2008 the lake owners acquired a second unit to complete treatment of the whole lake. There have not been any cyanobacteria blooms and water clarity has noticeably improved since both units were installed. With improved water clarity and shallow depths throughout the lake, there has been a reemergence of native aquatic plants. Annual transect mapping has documented that native plants accounted for 47% of the coverage in 2005, as compared to 94% in 2009. In 2009, EWM had only 3.4% coverage, and many remaining plants looked scrawny and unhealthy, consistent with ammonia-N limitation. At the same time, native species richness (a measure of biodiversity) has increased over the past four years. In most lakes, species richness decreases dramatically with an EWM infestation – the opposite has occurred in Timnouth Pond. So although EWM has a presence in Timnouth Pond, it is neither dominating nor outcompeting native plants. In fact, a noted rare and endangered species (*Elatine minima*) has also done relatively well.

5. Summary

After 10 years of very consistent empirical evidence, we have considerable confidence that SolarBee-induced circulation can reduce and inhibit the growth of certain invasive aquatic weeds in freshwater lakes over time. Although we are still fine-tuning SolarBee deployment parameters, best results have occurred when the units were installed in the fall and the intake hoses were placed below the depth of the macrophyte beds. Evidence of ammonia-N limitation is very strong, and we continue to encourage collaborative research through universities and other institutions to identify and document the physiological mechanisms involved, and to indicate how to best deploy SolarBees for optimal and predictable control. Additionally, we are collecting data on other aquatic macrophyte species that may also be impacted. We do not anticipate the same impact for all submersed aquatic species as we have seen for EWM, and there are some plants whose physiology is unaffected by SolarBee-induced circulation. For example, we know that LDC does not affect deeply-rooted plants such as water lilies. Nevertheless, solar-powered LDC represents the most environmentally friendly approach to achieve sustainable management of the growth of many notoriously invasive aquatic weeds.

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