The Paradise Lake Case Study for Milfoil Control: A Lesson in Community-Driven Management Philosophy

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Figure 1

Introduction and Overview

Paradise Lake *(Figure 1)* is located in Emmet and Cheboygan Counties. The lake surface area is approximately 1,878 acres and it has a maximum and average depth of 15.1 feet and 3.9 feet, respectively. The shoreline length is about 14.3 miles and the watershed is approximately 16,685 acres, which is nearly nine times larger than the lake. Primary land uses in the watershed include wetlands (nearly 50%), followed by forested lands (nearly 21.4%). Paradise Lake contains one inlet (Mud Creek) and one outlet (Carp River). The Carp River outlet drains Paradise Lake into the Straits of Mackinaw.

In recent years, the lake has become colonized with Zebra Mussels (*Dreissena polymorpha*), which has resulted in increased light transparency of the lake water and has caused accelerated growth rates of all aquatic vegetation, including the exotic submersed aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). Invasive milfoil had become a significant threat to the native aquatic vegetation communities within Paradise Lake, severely impeded navigation and recreational activities within the lake, and created a swimming hazard in areas of dense canopy growth *(Figure 2)* over the past decade. A scientific study by Halstead et al. in 2003 demonstrated the decrease in lakefront property values as a result of lake milfoil invasions. Previous surveys of Paradise Lake by aquatic scientists during July of 2009, consisted of 609 sampling locations located throughout the lake and determined that approximately 497 acres of milfoil colonized the entire lake.

The community of Carp Lake, which partially resides around Paradise Lake, desired to implement a non-chemical approach to potentially reduce the milfoil problem. So, during the summer of 2012, scientists recommended an integrated management approach with weevil implantation in areas not previously stocked with the weevil *Euhrychiopsis lecontei*, along with the use of laminar flow aeration and bio augmentation in the West Basin. The latter management method was recommended for the West Basin because most of the basin was colonized by a large canopy of invasive milfoil and the 400-acre area would have required an unknown and potentially unaffordable quantity of weevils to effectively reduce the dense milfoil growth.

The laminar flow aeration approach was also recommended because it would likely not interfere with the weevil life cycle and may have provided a favorable habitat for the weevil until milfoil food limitation was a limiting factor for weevil sustainability.

Milfoil Reduction from Weevil Activity

The aquatic weevil, *Euhrychiopsis lecontei* naturally exists in many lakes; however, the lack of adequate populations in these lakes requires that the populations be augmented or enhanced for successful control of milfoil. The Paradise Lake Association and Paradise Lake Improvement Board have been stocking the lake with weevils consistently since 1998. The weevils have had adequate time to establish a robust population that continues to decrease milfoil stem density in many areas of the lake. Peer-reviewed scientific research by Newman and Biesboer (2000) demonstrated that the requirements for weevil stocking density to obtain adequate control of milfoil may be as high as 150-300 weevils per square meter. It is important to note that this number refers to a "stocking density", which implies the number of weevils that should be added in a stocking area for ultimate population growth. To accomplish the observed mortality of milfoil

Figure 2

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stems in Paradise Lake, a similar stocking density to that recommended by researchers has been implemented in Paradise Lake with measured success.

The weevils feed almost entirely on Eurasian Watermilfoil and will leave native aquatic species unharmed. The weevils burrow into the stems of the milfoil and remove the vascular tissue, thereby reducing the plant's ability to store carbohydrates (Newman et *al.* 1996). Eventually, the milfoil stems lose buoyancy and the plant decomposes on the lake bottom. The weevil life cycle consists of larval, pupae, and adult life stages, which all are involved in the destruction of the milfoil plants. In the initial stages of biological control, larvae are applied to the apical (top) portions of stems and destroy the vascular tissue (Creed and Sheldon 1993, Newman et *al.* 1996), which significantly hinders stem elongation. During the pupation stage, stem vascular tissue is further destroyed during the construction of the pupal chamber. During the adult phase, mature weevils feed on the milfoil leaves and stems.

Recent research has shown that the weevils require a substantial amount of aquatic plant biomass for successful control of Eurasian Watermilfoil. In addition, the weevils require adequate over-wintering habitat since they over-winter within shoreline vegetation. Lakes with sparse milfoil distribution and abundant metal and concrete seawalls are not ideal candidates

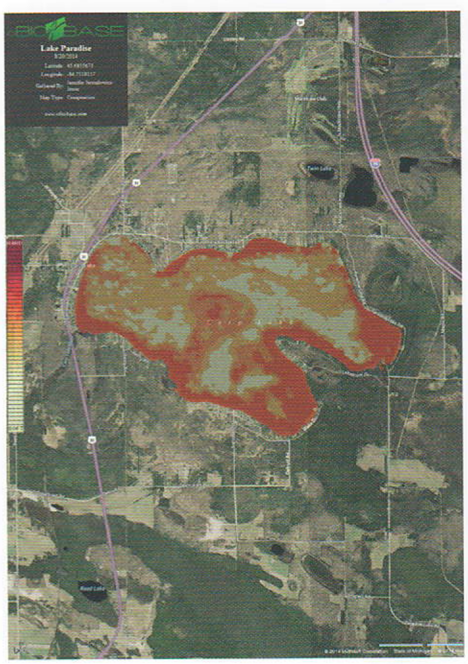

Figure 3

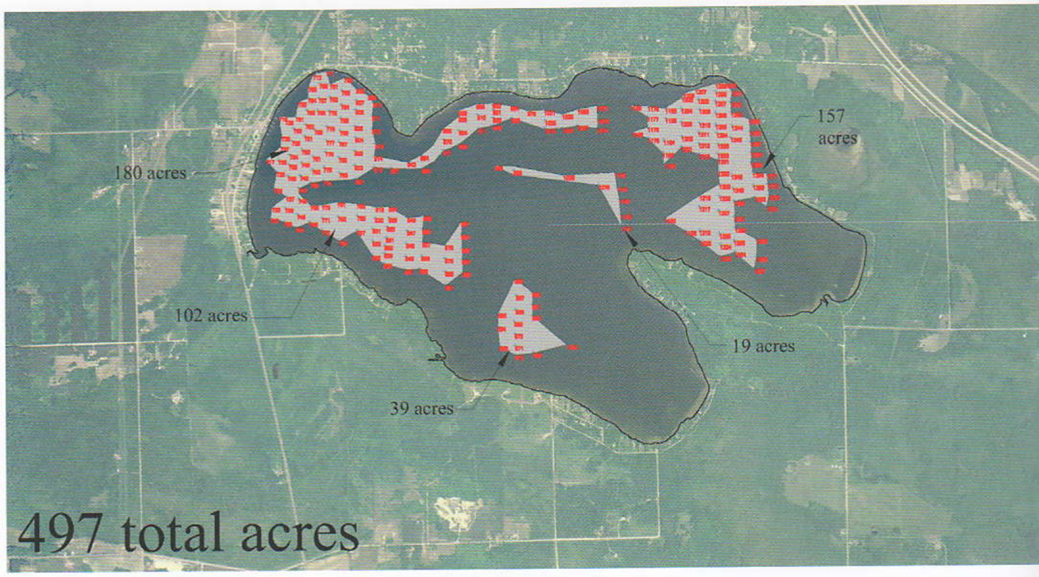

Figure 4

for the milfoil weevil. There is a favorable amount of overwintering vegetation of high biotic integrity around the Paradise Lake shoreline to support sustained weevil populations. The presence of this riparian vegetation along with good water quality and dense beds of milfoil may explain the efficacy of the weevil on the Paradise Lake milfoil population reduction in the eastern, northern, and southern regions of the lake.

Milfoil Reduction from Laminar Flow Aeration and Bio Augmentation

A primary objective of the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive muck is reduced to yield a greater water depth or more desirable substrate. Additionally, scientists have discovered that the use of this aeration technology along with microbial supplementation (bio augmentation) can effectively reduce ammonia nitrogen which is an essential nutrient for some rooted, submersed aquatic plants such as milfoil (Jermalowicz-Jones et al., 2015). This occurs as the aerated sediments are oxidized and nitrogen is converted from the reduced (ammonia) and bioavailable form to the oxidized (nitrate) form that is less utilized by rooted aquatic vegetation. This finding is supported by rigorous peer-reviewed research and more is being actively pursued. Beutel (2006) found that lake oxygenation eliminates release of ammonia from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that ammonia oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls.

A lake sediment sampling study in 2011 revealed that sediments in the West Basin of Paradise Lake are rich in organic matter (muck) and the sediment depths are more than four meters thick in many areas (*Figure 3*). The soft organic muck layer throughout the lake closely overlaps with the presence of large milfoil beds. A comparison of the original milfoil biomass cover in (*Figure 4*) to the bottom hardness map created by scientists in 2014 demonstrates that the majority of the milfoil is located in areas with soft, organic sediments. These sediments are measurably high in nutrients such as phosphorus and nitrogen. Although much of the lake sediment is of glacial origin, the immediate watershed around Paradise Lake also contributes an estimated 5,598 kg year^{-1} and 308 kg year^{-1} of nitrogen and phosphorus, respectively. Potential loads from shoreline septic systems alone for nitrogen and phosphorus were estimated to be 2,657 kg year^{-1} and 232 kg year^{-1}, respectively.

A laminar flow aeration system was retrofitted to the 400-acre West Basin of Paradise Lake during the summer of 2012. The aeration system is derived from several components which consist of in-water components such as 57 micro-porous ceramic diffusers, 77,000 feet of self-sinking airline, and bacteria and enzyme treatments for sediment nutrient and muck reduction. On-land components consist of three locally-sourced sheds, one 10.0 horsepower compressor, and two 11.5 horsepower compressors along with cooling fans and ventilation.

During the summer of 2014, scientists studied the reduction of milfoil in the West Basin of Paradise Lake and noted that the milfoil canopy had not re-surfaced, was significantly reduced and had disintegrated in many areas of the basin (*Figure 5*). In 2011, there were approximately 220 acres of milfoil in the West Basin. Estimates from 2014 indicate that the milfoil cover in the West Basin has been reduced by 73% to 59 acres. Another study by Turcotte et al. (1988) analyzed the impacts of bio augmentation on the growth of milfoil and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading.

Conclusions

Aquatic plant management method(s) must satisfy the needs of lake residents through the enhancement of recreational activities such as boating (navigation), swimming, and fishing, and in the protection of riparian property values. Management options had to complement the socio-economic climate that influenced riparians and individual components of the Paradise Lake ecosystem. The Carp Lake community emphasized their philosophical needs for a solution to the milfoil problem that was holistic and did not utilize herbicides. This approach may not be possible for many lake communities since lake sediment types and responses to nutrient reduction with aeration can differ significantly among aquatic ecosystems. Additionally, the efficacy of biological control (weevils) may be hampered or compromised by the lack of proper overwintering emergent aquatic vegetation, necessary stocking densities or lack of data to determine adequate stocking densities, or other ecological factors. This case study represents the use of two natural strategies for milfoil reduction that one community implemented with a successful outcome. The co-determination of management objectives between lake managers and communities must also incorporate social and environmental philosophies and may require strong patience in observation of outcomes as long as the implemented strategies are compatible with both the lake ecology and the community dynamics.

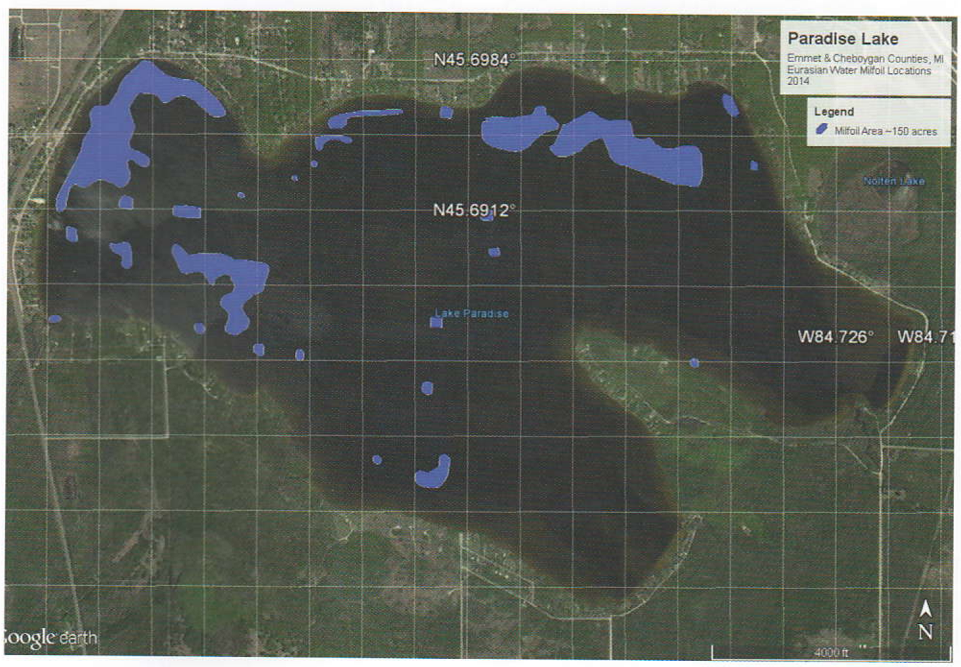

Figure 5

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