EURASIAN WATERMILFOIL MANAGEMENT ON BIG CEDAR LAKE, ONTARIO: PROGRESS REPORT, 2018

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EXECUTIVE SUMMARY

This report is an update and evaluation of the eight-year Eurasian watermilfoil (*Myriophyllum spicatum*) control program on Big Cedar Lake, in the Kawartha Lakes region of Ontario. Since 2011, 345,800 native milfoil weevil (*Euhrychiopsislecontei*) eggs and adults have been stocked in Big Cedar Lake in an attempt to lower the abundance of, and ideally eradicate milfoil. In 2018, 25,000 weevil eggs were stocked over five treatment patches and five benthic mats (2.5m x 13.5m) were co-located at each site. These treatment patches, along with five control patches were selected and surveyed in late June (prior to weevil stocking), and again in late August (after stocking). The patches were assessed for weevil damage, milfoil stem density, as well as overall patch biodiversity. In addition, previous experiments from 2015 - 2017 were re-evaluated.

Following the initial years of stocking weevils there has been a considerable decrease in milfoil density throughout the lake. Despite this, since 2013, we have noticed a year-to-year pattern in milfoil density, which appears to alternate between a drop in milfoil density to a rise in density the following year. In saying this, 2018 appears to be a recovery year for milfoil density in Big Cedar Lake. Overall, milfoil density in 2018 was much lower than 2017 and the effect of last year's weevil and mat treatments appear to be positive. We believe that the lack of milfoil in 2018 may be partly due to the abundance of milfoil in 2017 which may have provided more habitat to accommodate weevils. Although weevils may offer lake managers a degree of control over invasive milfoil patches by reducing the density of thick dense milfoil monocultures, this study and previous studies suggest it is unlikely that milfoil will be reduced much further in Big Cedar Lake by milfoil weevils. We recommend that the management of milfoil in Big Cedar Lake should primarily focus on encouraging native plants to compete with milfoil, as this may be more successful at limiting milfoil abundance in targeted patches. We also recommend the continued monitoring of experimental patches throughout the lake to confirm conclusions regarding the effectiveness of the management program.

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INTRODUCTION

Management of Eurasian Watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*) is a challenging invasive aquatic plant that reproduces mainly through fragmentation, allowing it to spread quickly within and between lakes (Hamel, 2014). Milfoil begins its growth in the early spring and has the ability to survive at low light levels – enabling it to rapidly dominate the native aquatic plants of the littoral zone (Lund, 2010). Chemical treatments are difficult to control in aquatic ecosystems as herbicide applications have been found to have negative effects on non-target native species, potentially further degrading the ecosystem (Poovey et al., 2004; Harrahy et al., 2014). Attempts to control milfoil through mechanical harvesting can be labour intensive, and may exacerbate the problem by creating and spreading small plant fragments (Boylen et al., 1996). However, the proper containment and removal of fragments during mechanical harvesting may be a solution to this tired method. Furthermore, mechanical harvesting has the potential to remove problematic plant biomass and subsequently reduce plant growth in the following year (Nichols, 1975). Similarly, dredging is an effective control method as dredging to a depth below that of the photic zone limits growth of milfoil, although this can be a costly method (Nichols, 1975).

Figure 1. Native milfoil weevils (Euhrychiopsis lecontei) on Eurasian watermilfoil (Myriophyllum spicatum).

An alternative management strategy is the use of biological control methods, the most notable of which is the native milfoil weevil (*Euhrychiopsislecontei*), an aquatic beetle (Figure 1). The milfoil weevil only consumes plants in the *Myriophyllum* genus, but is also entirely dependent on these plants for habitat and reproduction (Newman, 2004). Weevils damage milfoil plants by removing stem tissue as larvae; this stem tissue removal can result in reduced buoyancy and increased mortality (Creed and Sheldon, 1995). Traditionally, northern watermilfoil (*Myriophyllumsibericum*) served as the host for milfoil weevils, thereby dictating their distribution, which is limited to northern USA and southern Canada (Newman, 2004). However, the emergence of Eurasian watermilfoil in many lake ecosystems has allowed weevils to expand their host range to include, and actually prefer, the exotic species (Painter and McCabe, 1988; Creed and Sheldon, 1993; Borrowman et al., 2015).

Additionally, benthic mats have been used as covers on the lake bottom to prevent rooted plants from obtaining the necessary sunlight for growth (KLSA, 2009). Materials such as landscaping fabric and plastic screening have been used as suppressive mats; however there are alternative options such as biodegrading jute and coconut husk that may be used. Benthic mats can be difficult to employ and move, especially in deeper water, and therefore using material that does not require removal is ideal. When left in the water, these mats will accumulate sediments, allow new plants to root on top of them which essentially buries the invasive milfoil, and then ultimately decompose.

History of Eurasian Watermilfoil Control in Big Cedar Lake

Since its introduction into Big Cedar Lake, Eurasian watermilfoil has flourished, establishing dense patches throughout the lake. In 2017, approximately 25 patches of this species were recorded, found at depths of 1.5-4.5m, during informal surveys of the lake. Frustrated and concerned over the spread of the exotic species, the Big Cedar Lake Stewardship Association sought a solution that did not rely on chemical input. In 2011, the consulting company, EnviroScience, implemented their Milfoil Solution program on Big Cedar Lake. This program involved augmenting native populations of milfoil weevils, in an effort to reduce the abundance of milfoil (EnviroScience, 2012). From 2011-2014, EnviroScience stocked the lake with 215,800 weevils and weevil eggs in over fifteen different locations (EnviroScience, 2014). Following this four-year project, Dr. Eric Sager and students of Trent University continued stocking weevils as part of a broader integrated management experiment.

The entire breakdown of the Big Cedar Lake weevil stocking program is shown in Table 1. In 2015, Big Cedar Lake was stocked with 25,000 weevil eggs in four locations identified by the lake stewards. Additionally, milfoil was experimentally hand-harvested at five locations in an effort to encourage the growth of native aquatic plants, and to provide a useful comparison of the long-term efficacy of the weevil program. Starting in 2016, we began managing milfoil using an integrated approach by stocking weevils along the edges of biodegradable benthic mats that were planted with native plant species.

Table 1. Breakdown of Milfoil Weevil egg stocking in Big Cedar Lake from 2011-2018

Year	**Lake Association Stocking**	**Private Stocking**	**Annual Total**
2011	30,000	23,000	53,000
2012	35,000	27,000	62,000
2013	45,000	22,000	67,000
2014	32,800	1,000	33,800
2015 *(Trent University)*	25,000	0	25,000
2016 (*Trent University)*	40,000	0	40,000
2017 (*Trent University)*	40,000	0	40,000
2018 (*Trent University)*	25,000	0	25,000
Total	**272,800**	**73,000**	**345,800**

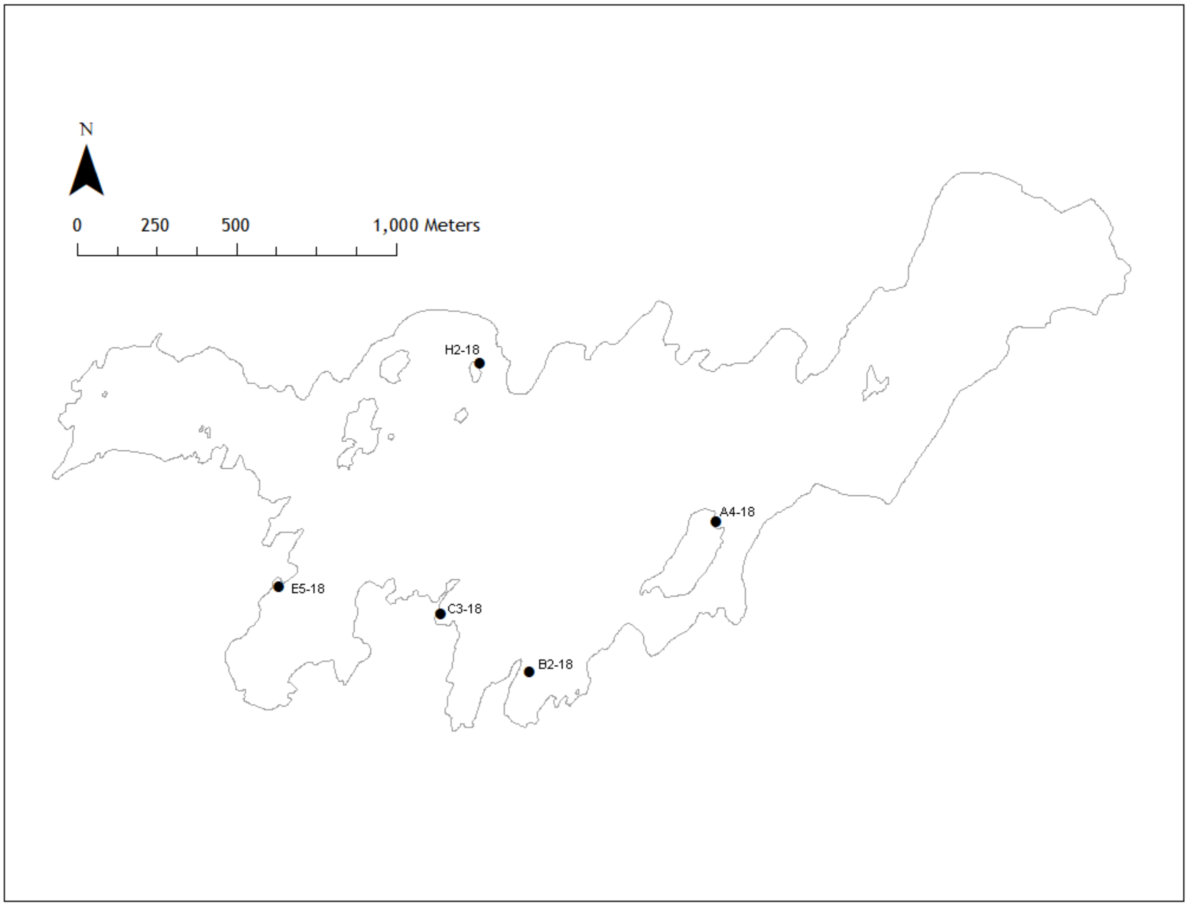

Figure 2.Locations of 2018 treatment sites at Big Cedar Lake

OBJECTIVES

In 2018, Trent University and Big Cedar Lake Stewardship Association have once again joined forces to implement a fully integrated Eurasian watermilfoil control project that incorporates both previous while at the same time explores the potential of new mitigation approaches. In doing so, we are able to bridge management objectives of both the association and the university to actively manage, preserve and improve the ecological health of Big Cedar Lake. By transitioning from solely weevil stocking to integrating multiple biological control techniques, we can ensure a necessary focus on the long-term health of the lake through a broader and more comprehensive approach, better known as the 'Healthy Lake Program'.

The key objectives of this report are as follows:

1) **Reassess the 2015 stocking. This experiment involved four sites that were stocked with weevils in July 2015. Since the start of this experiment, these sites have not been stocked with weevils. Milfoil was nearly or completely eradicated from these sites in 2016 but has since returned.**

2) **Reassess the 2016 stocking. This experiment involved five sites that were stocked with weevils. Additionally, in three of these sites, a vegetated benthic mat was installed as part of an integrated management approach.**

3) **Reassess the 2017 stocking. This experiment involved six sites that were stocked with weevils. Additionally, a vegetated benthic mat was installed at each of the six sites as part of an integrated management approach.**

4) **Provide preliminary data of the 2018 experiment. This experiment involved five sites that were stocked with weevils. Additionally, a vegetated benthic mat was installed at each of the five sites as part of an integrated management approach.**

5) **Discuss the progress of the program over the last four years, assess the overall status of milfoil within Big Cedar Lake, and recommend the future direction for the Healthy Lake Program.**

METHODS

Site Selection

In June 2017, informal lake surveys were used to determine appropriate treatment and control sites. Five treatment sites were selected based on their size, nuisance level, proximity to cottages, and their weevil stocking history (Figure 2). The chosen sites were also those considered most suitable for benthic mat applications, including the depth at which the patch was located and the amount of potential boat traffic. The existing plant communities within the patches were almost completely dominated by milfoil, and covering an area greater than 10m^2. Additionally, five control sites, also dominated by milfoil, were selected based on their physical similarities and proximity to the treatment patches. Despite most of the 2018 sites having never been selected in the past, we continued to utilize some control sites that had previously been used in 2015 – 2017.

Lab Culturing and Weevil Stocking

Figure 3. Trent University weevil culture lab: tanks filled with M. spicatum meristems and adult weevils

Over June and July 2018, adult *E. lecontei* weevils were collected from several locations across the Kawartha Lakes region. Weevils were grouped into sets of 150 and placed into aquariums filled with healthy milfoil meristems (Figure 4) harvested from Big Cedar Lake. After 5-6 days, the adult weevils were separated from the meristems, and total weevil egg counts were calculated. Egg-bearing meristems were bundled in sets of twenty, and tied together. Meristem bundles, including eggs, were transported in water-filled bags to Big Cedar Lake immediately after being removed from the tanks. From late July to early August, patches of milfoil were systematically stocked with weevil eggs by bunching multiple plants together and securing them with an egg-bearing meristem bundle – repeating this process throughout the patch. Theoretically, once the stocked weevil eggs hatch, the larvae move down the bunched milfoil plants, feeding on the stems and damaging the plants.

Benthic Mat Preparation and Employment

Five biodegradable benthic mats, measuring 2.5m x 13.5m, were prepared using coir material made from weaved coconut fiber and jute netting (Figure 4). Between early-July and mid-July, five benthic mats were installed at the treatment sites, where they were reinforced with heavy rocks to allow full saturation and prevent buoyant uplifting. Stocking of weevils always followed the installation of the mats.

Figure 4. Benthic mat preparation

Survey Methods

An initial survey of all milfoil patches was performed prior to weevil stocking in late June, while a follow-up survey was performed in late August, a month after weevil stocking. Milfoil stem density was collected in each site by conducting five repeated rake throws. The area harvested by each rake throw was estimated to be 0.171 m^2 by measuring the distance the rake travelled across the lake sediment. Species richness and percent cover were determined by sampling with a 40cm x 40cm quadrat – collecting 5 random samples from each site. Weevil damage was estimated by performing swimming transects, perpendicular through each site, where a total of 100 milfoil stems were sampled. Stems were examined under a dissecting microscope for the presence of weevil damage. Weevil damage includes evidence of larval eating and/or the presence of pupal chambers in the plant. Examples of weevil damage can be observed in figure 6.

Figure 5. Left: weevil larva burrowing into Eurasian watermilfoil stem. Right: evidence of larval feeding. Both images were from samples collected in Big Cedar Lake.

At the beginning of September, a full-lake survey was conducted to determine milfoil density on a lake-wide scale. After creating a coordinate grid layer across the lake we surveyed over 600 points, all of which were 40m apart. These locations were surveyed for milfoil density by conducting a single rake throw, as well as recording the top three species present and depth at each point.

Data Analysis

Data were analyzed using the *lme4* (Bates et al. 2015) and *car* packages (Fox & Weisberg 2011) in R (R Core Team 2012). Stem damage and milfoil density were assessed for normality and homogeneity of variance; milfoil density data from the 2017 dataset were log-transformed to improve normality. A linear mixed-effects analysis was used to evaluate the effect of weevil augmentation treatments on stem damage and milfoil density. Sampling year, treatment group, and time (either year or month)/treatment interaction were entered as fixed effects, while the variation between different survey patches was controlled by entering patch as a random effect. Time was treated as a categorical variable. Model residuals were inspected to ensure linearity and heteroscedasticity. P-values of the interaction effect were used to determine the significance of the weevil augmentation effect on weevil damage and milfoil stem density. Finally, a Kruskal-Wallis rank sum test was used to compare milfoil stem densities from 2011 to 2018 by combining both EnviroScience and Trent University datasets. This test was used because patch locations changed repeatedly throughout the seven-year program. The surveyed patches included in this analysis consistently included the largest patches of milfoil throughout the lake. Dunn's test, using Bonferroni-adjusted comparisons, was used to contrast year to year milfoil densities.

1) 2015 Experiment

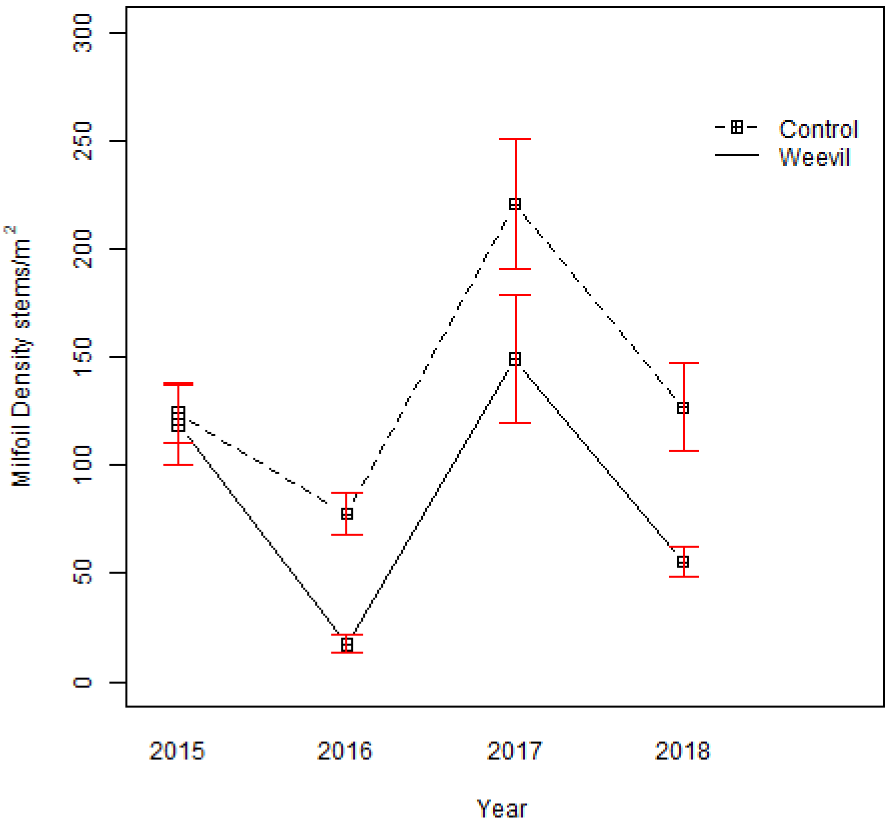

Figure 6.Milfoil density for the 2015 treatment season and observed for three years. This year had 4 control sites and 4 weevil sites.

After one year, the 2015 weevil augmentation experiment appeared quite successful (Figure 6). All stocked sites saw large reductions in milfoil density, especially when compared to the control sites, which were not stocked with weevils. The positive effect of weevil stocking 1 year after the treatment was significant. However, 2017 saw exceptional milfoil growth in both weevil-stocked and control sites, pushing densities above the initial 2015 levels. Although weevil stocked sites still reported lower densities relative to control sites in 2017, the effect of weevil stocking (2 years post-stocking) was no longer significant (p=0.1571). The fact that this effect was significant after 1 year of stocking suggested the need for continued stocking for weevils to suppress milfoil. In 2018, milfoil densities decreased at both treatment and control sites, the former falling between 2015 and 2016 levels.

2) 2016 Experiment

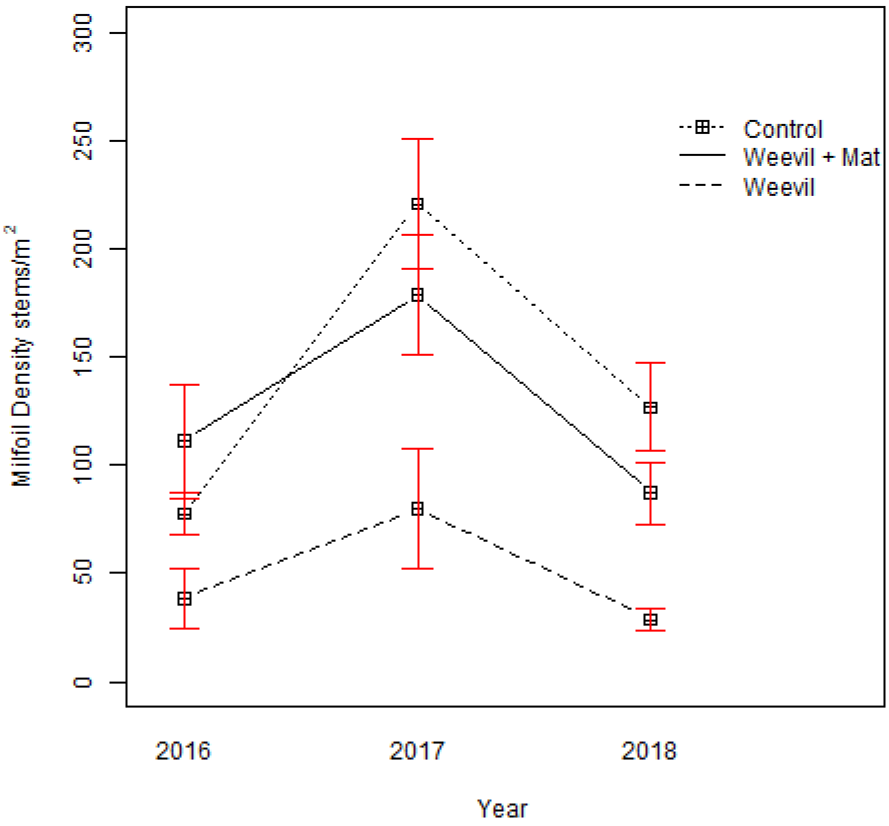

Figure 7.Milfoil density for the 2016 treatment season and observed for two years. This year had 4 control sites, 3 weevil + mat sites and 2 weevil sites.

The 2016 experiment appears to follow a similar pattern to that observed in the 2015 experiment (Figure 7). There was a large amount of milfoil growth throughout the lake during 2017, and this included our 2016 experiment sites. Statistically, the weevil and weevil + mat treatments didn't affect milfoil density (p=0.6122), however, milfoil density increased less in treated sites than in control sites. In addition, milfoil density does not appear to have been equal to begin with; judging by the figure, it appears that weevil treatment sites began 2016 with much lower milfoil densities than the other sites, which is likely the reason for its relatively low milfoil density in 2017 and again in 2018 compared to the other sites.

Of the three sites that received mats in 2016, two sites (F1-15 and G1-11) still have visible mats in 2017. Although both of these sites also have maintained a population of milfoil, including milfoil growing through mats, densities have reduced from 2017 levels. The third site's (A1-16) mat is not visible on the bottom of the lake and is covered with sediment, with native plant growth and very limited milfoil growth through the mat. It is possible that the type of substrate and geographic location of the mats may play important roles in whether the mats become covered with lake sediment. For instance, site F1-15 has a fairly rocky substrate, which may explain why the mat is still visible, and why the milfoil grew back through the mat. Whereas at site A1-16, the substrate is very loose and it is situated along a channel that receives heavy boat traffic, both which may have caused the mat to become buried and allow for other species to grow on top. Despite this, the lack of milfoil at site A1-16 is likely to be a result of the state of milfoil prior to treatment.

3) 2017 Experiment

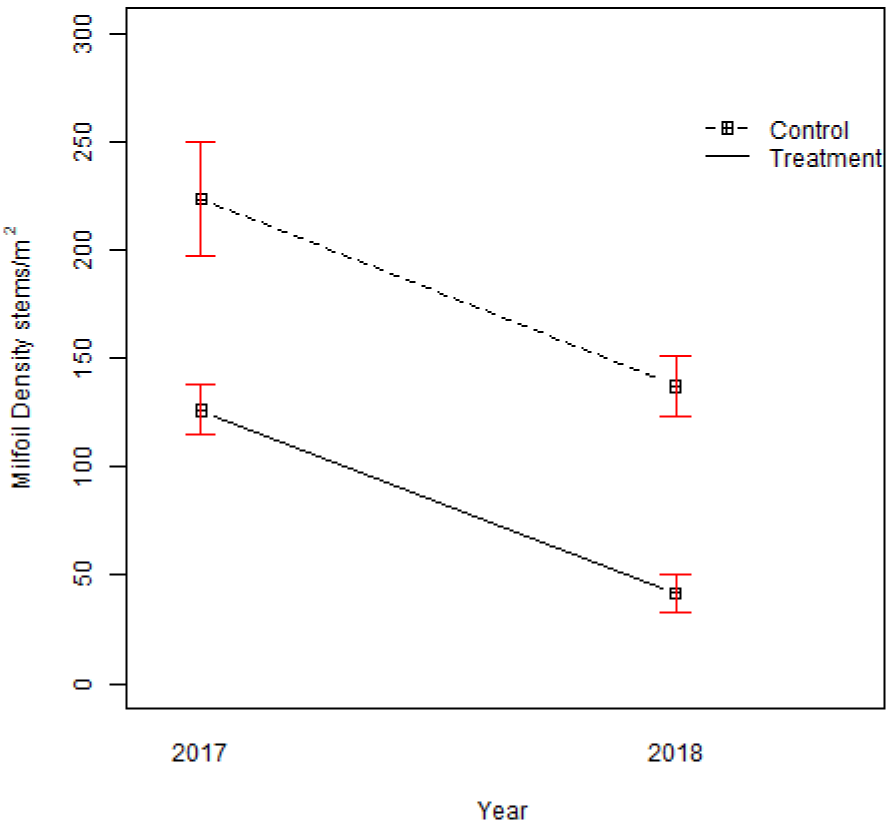

Figure 8. Milfoil density for the 2017 treatment season and observed for a years. This year had 6 treatment sites and 6 control sites.

The 2017 experiment appears to be successful as there was reduced milfoil growth throughout the lake during 2018, and this included our 2017 experimental sites (Figure 8). Similar to previous years, greater reductions in milfoil densities were observed in treatment sites when compared to control sites. During 2018, visits to the 2017 treatment sites proved that all mats are still visible.

4) 2018 Experiment

Weevil Damage

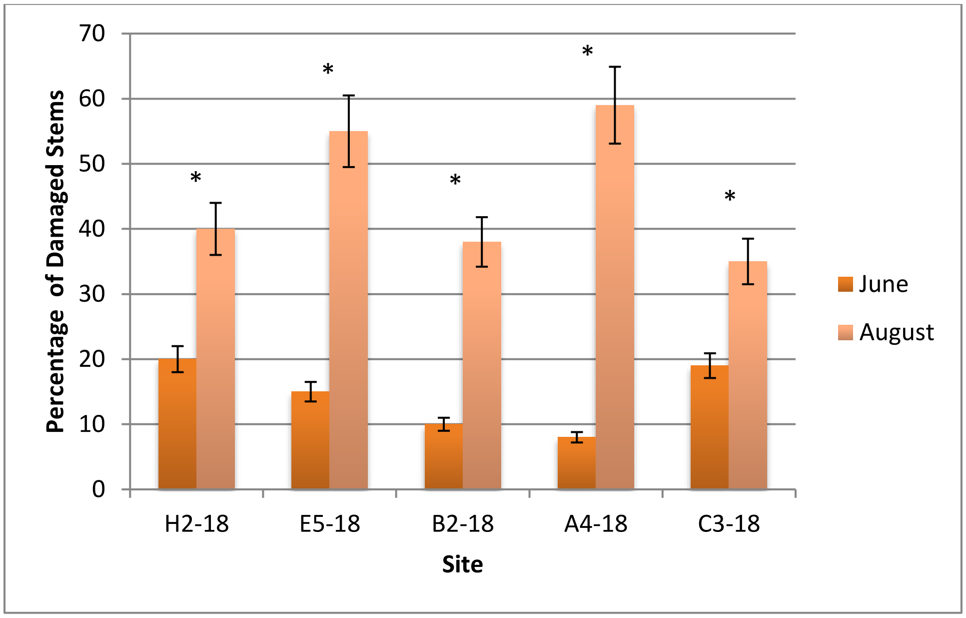

Figure 9.Average percentage of stems damaged by weevils, conducted through a transect survey of 100 milfoil stems at each ***treatment*** *site in June and August 2018. Error bars indicate 90% confidence intervals and asterisks indicate significant differences (p<0.05) between initial and final values.*

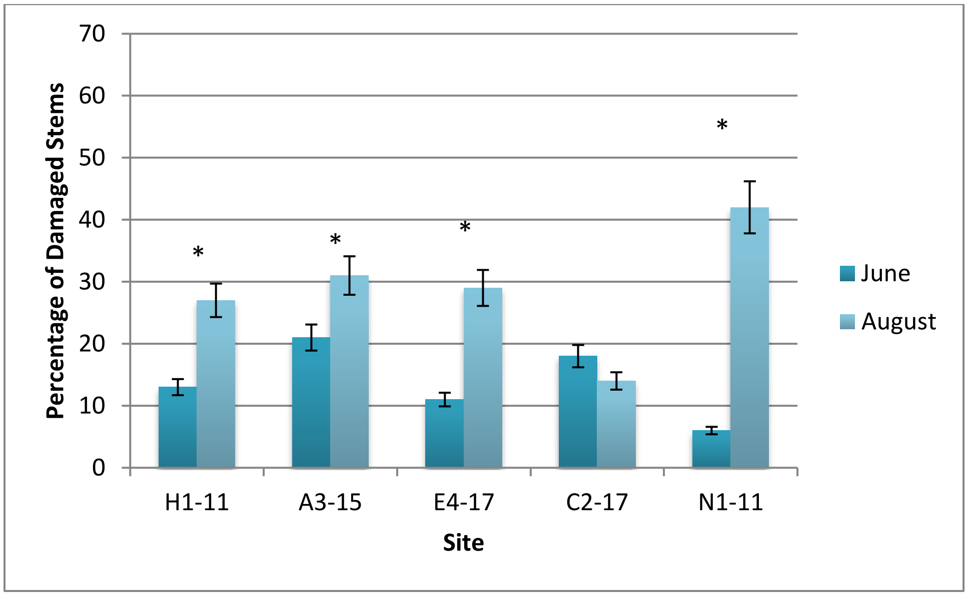

Figure 10. Average percentage of stems damaged by weevils, conducted through a transect survey of 100 milfoil stems at each ***control*** *site in June and August 2018. Error bars indicate 90% confidence intervals and asterisks indicate significant differences (p<0.05) between initial and final values.*

In 2018, all treatment sites had significantly higher weevil damage after being treated (Figure 9). This pattern was also observed in the control sites, where 4/5 sites had higher weevil damage at the end of the season (Figure 10). After stocking weevils in July, the greatest damage was seen in site A4-18 with an increase from approximately 8% to 58% (Figure 9). Most sites, regardless of treatment, showed increases in weevil damage throughout the summer, which indicates that there is still a healthy population of weevils in most milfoil patches in the lake (Figure 9 & Figure 10).

Stem Density

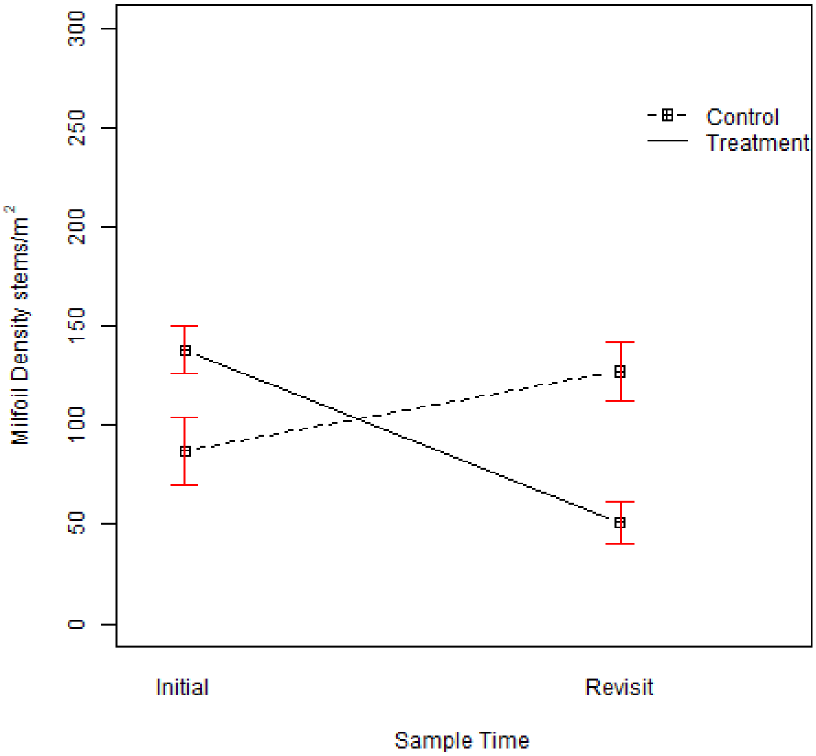

Figure 11. Milfoil density for the 2018 treatment sites observed initially in June and again in late August. This year had 5 control sites and 5 treatment sites.

In 2018, treatment sites had significantly lower milfoil densities after being treated, with all sites decreasing by the end of the season (Figure 11). In comparison, all five control sites increased in milfoil density.

DISCUSSION

Milfoil Densities in Experimental Sites

The most interesting results of this long-term study came out of the 2016 and 2017 experiments, which demonstrated a decline followed by a return of dense milfoil to patches treated with weevils in 2015. The 2018 results of these same sites show a decline in milfoil, with 2/4 weevil sites decreasing substantially. Results from 2016 and 2017 experiment sites demonstrate similar results and appear to follow the same pattern.

A lack of effective competition from native plant species may be giving milfoil plants a 'free ride' when recovering from weevil-induced collapses. In these patches, all control and treatment plots remained relatively low in species richness (approximately two species per plot) in both 2015 and 2016, potentially explaining the successful return of milfoil to these sites in 2017. We speculate that the poor response of native plant species to declines in milfoil is due to low native species' propagule pressure, particularly compared to the higher propagule pressure from the abundant milfoil. This disparity in propagule pressure is exacerbated by the speed of milfoil recovery in collapsed patches. Milfoil is ubiquitous in Big Cedar Lake, making it a matter of time before small fragments of the plant arrive and begin to recolonize favourable habitat. Small fragments, 6 cm in length, can rapidly colonize new habitat; pre-existing low plant densities facilitate this process making the plant excellent at colonizing previously disturbed habitats, including habitats created by the decline of other plants (Li et al. 2015, Smith &Barko 1990). Furthermore, the paucity of native plant species in milfoil-dominated patches makes it difficult for propagules of native plant species to arrive rapidly, and in large quantities.

Low propagule pressure can explain poor native species recovery in habitats post-removal of invasive species. A combination of a lack of native plant propagules and altered habitat conditions was used to explain the poor response of native species to lupin (*Lupinusarboreus*) removal in New Zealand sand dunes (Konlechner et al. 2015). Similarly, the limited passive recovery of native species in post-knotweed (*Polygonumcuspidatum*) riparian systems in Washington State was blamed on a lack of native propagules, and the presence of fast-growing exotic species (Claeson& Bisson 2013). Therefore, it is probable that in Big Cedar Lake, milfoil collapses are going to be followed by milfoil recolonization, unless there is effective competitionfrom native plants.

Continued Evidence of Weevil Saturation

Although the results from the 2018 experiment are only preliminary they already share similarities with previous experiments. As in previous years, both treatment and control patches in 2018 showed signs of extensive weevil damage throughout the year. This meant, in terms of weevil damage, weevil stocking didn't appear to have much of an effect, suggesting weevils are common throughout the lake. In previous reports we have discussed a predictive model developed by Miller et al. in 2011. This model demonstrated that the effect of weevil stocking diminishes as the initial adult population increases (Miller et al., 2011). When populations of adult weevils are initially high, there are only a limited number of opportunities for additional weevils to cause further damage to healthy patches (Miller et al., 2011). This in part represents a limit to the ability of weevils to reduce the abundance of milfoil. The model further predicts that milfoil's ability to auto-fragment and reproduce, and the weevil's dependence on milfoil as habitat, means that populations of milfoil and weevils will eventually reach an equilibrium, and stocking weevils indefinitely will eventually lead to diminishing returns (Miller et al., 2011). Based on this, we have previously suggested that even with further weevil stocking, milfoil damage in Big Cedar Lake will likely not reach above a range of 60-80%, and that there will be a limit to the ability of weevils to reduce milfoil density.

It is likely that we are close to this limit in Big Cedar Lake. Like in previous years, weevil damage in our 2018 experiment sites tended to decrease when initial weevil damage was high, and increase when the initial damage was low. Although there were changes throughout the year within individual patches of plants, the change tends to occur regardless of whether the sites were treated with weevils and mats or not. This means that there is an abundance of weevils throughout the lake.

Long-term Trends in Milfoil Density

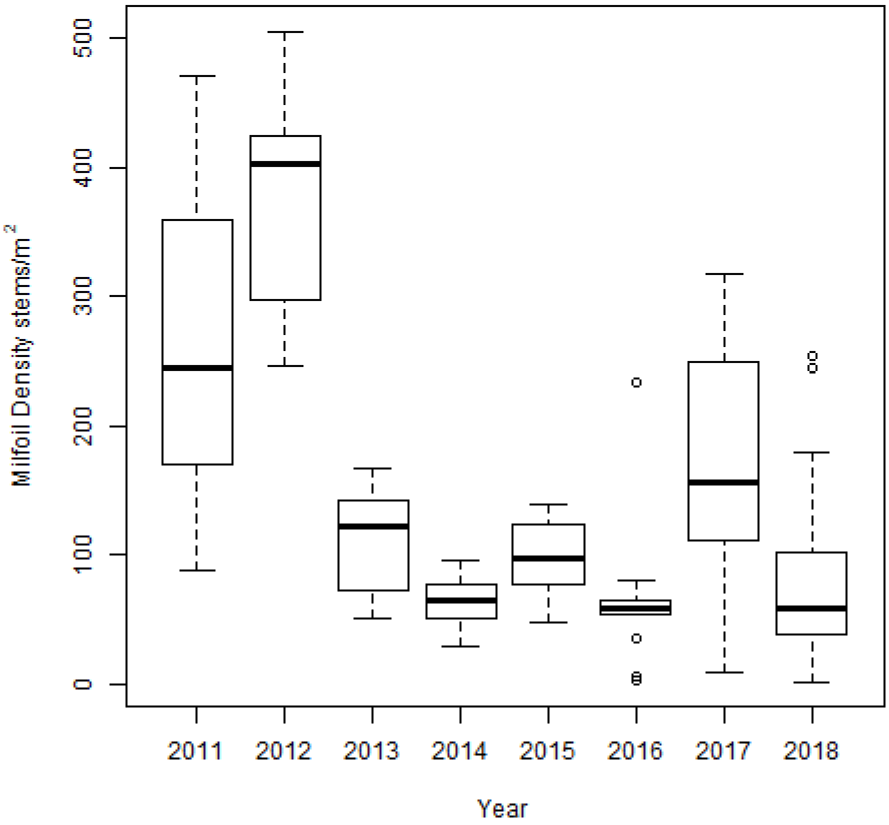

Figure 12. Historical changes in the average stem densities of milfoil patches in Big Cedar Lake from 2011-2018.

The pattern of year to year average milfoil density in patches throughout Big Cedar Lake (Figure 12) supports our suggestion that Big Cedar Lake may be experiencing diminishing returns on weevil stocking since 2013, as outlined by Miller et al (2011). Assuming the decline in milfoil densities from 2011 and 2013 was at least partially caused by the augmentation of weevil populations in the lake, additional weevil stocking in 2014-2017 appeared to have had little impact on milfoil density. However, 2017 appeared to have broken the trend from the previous 4 years. Milfoil density within the lake was the greatest since the first two years of weevil stocking on Big Cedar Lake. Interestingly, it was also the most variable since the first year of stocking. Milfoil densities ranged from close to 0, all the way to 300 stems/m2. Despite the large range in density, 2017 density was still significantly greater than both 2014 (p=0.0351) and 2016 (p=0.0021). Following this, milfoil densities decreased across the lake in 2018, following the year-to-year pattern and returning to the previously observed ‘threshold’ range.

Previously, EnviroScience suggested that the large density of milfoil in 2012 were because of a mild winter followed by an early spring and dry summer, providing optimal conditions for milfoil growth (EnviroScience, 2012). However, the weather conditions described in the 2012 EnviroScience report more closely describe the summer of 2016 rather than this most recent summer, which was wetter and cooler than the previous summer. A more likely reason for the high densities of milfoil in 2017 may be that the previous year had the lowest lake-wide levels of milfoil since the project began in 2011. It is plausible that the low milfoil levels of 2016 provided plenty of habitat (i.e. space) for milfoil to expand in 2017. As with the 2015 experiment, the lack of abundant native species and the ability of milfoil to rapidly recolonize lake beds put milfoil in a prime position to resume its dominance in the lake. In addition, it might be possible that low quantities of milfoil in 2016 may have slightly reduced the number of weevils in the lake, lessening the pressure on milfoil plants in 2017. In addition, the abundance of milfoil in 2017 may have increased possible habitat for weevils which in turn lowered milfoil densities for the 2018 season.

CONCLUSIONS

- Although weevils may offer lake managers a degree of control over invasive milfoil patches by reducing the density of thick dense milfoil monocultures, this study and previous studies suggest it is unlikely that milfoil will be completely eradicated from Big Cedar Lake by milfoil weevils.

- Average milfoil density for 2018 is relatively low, following the highest year of milfoil density (2017) since 2012. This pattern has been observed since 2013, where densities have alternated from higher to lower each year.

RECOMMENDATIONS

- Design the management plan to primarily focus on encouraging native plants to compete with milfoil, as this may be more successful at limiting milfoil abundance in targeted patches.

- Continue monitoring experimental patches (2015-present) throughout the lake. This will help to confirm conclusions regarding the effectiveness of the weevil program, milfoil abundance, as well as aid in site selection for preventative measures.

- Select material that can prevent milfoil from growing up through it, while allowing adequate spacing for native species transplanting.

- Install vegetated benthic mats when milfoil density in is low, to allow native plant species to colonize without competition from milfoil. This will allow us to avoid mechanically harvesting milfoil, a process that often creates hundreds of plant fragments.

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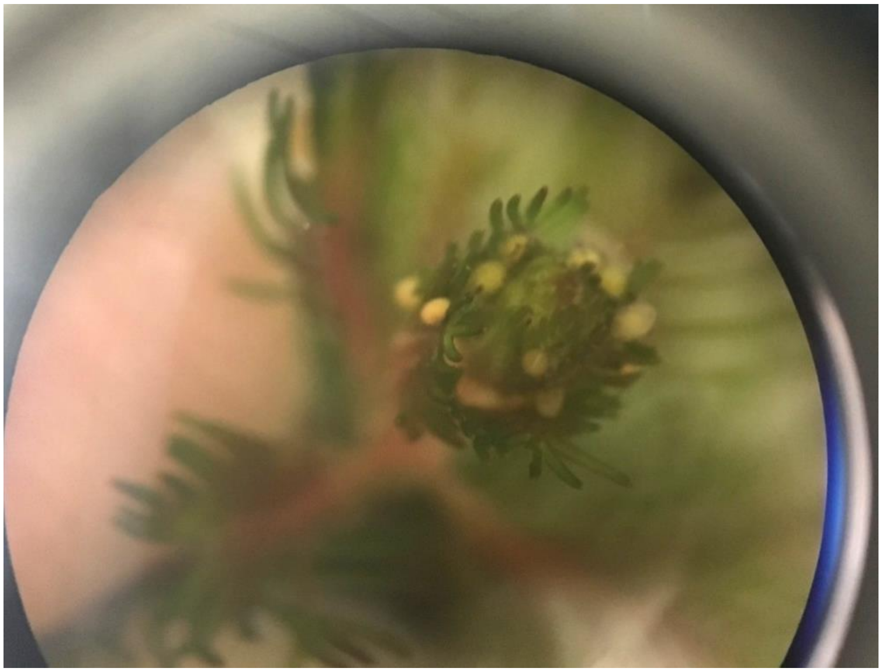
APPENDIX

Appendix 1: Images of benthic mat installation in Big Cedar Lake, 2018

Appendix 1.1 Benthic mat installation at site C3-18

Appendix 2: Images of laboratory techniques of weevil rearing at Trent University

Appendix 2.1 Image of weevil eggs deposited on an Eurasian watermilfoil apical meristem



Appendix 2.2 Image of an adult milfoil weevil on an Eurasian watermilfoil stem