BIOCONTROL OF EURASIAN WATERMILFOIL USING MILFOIL WEEVIL: STATE OF UNDERSTANDING REPORT

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ERSC-4840H

Trent University

Winter 2022

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1.0 BACKGROUND

Myriophyllum spicatum, known as Eurasian watermilfoil (EWM), has been an aquatic plant species of extensive disruption in many freshwater systems in Canada and the United States (EDDMapS, 2022). Due to its highly competitive nature, EWM tends to displace native plant species and will colonize to form dense beds in freshwater bodies (Boylen et al, 1999). As it begins to grow quickly in the springtime, these dense beds have the capacity to shade out native plant species which negatively affects species richness within lakes and so reduces the systems resiliency (Boylen et al, 1999). These beds have posed concerns for people using the lake as they have potential to disrupt the normal structure and function of the lake ecosystem and hinder watercraft usage (Simkovic, 2020; Boylen et al, 1999). Additionally, the presence of this introduced species may impact property value of lakeside cottages (Olden and Taymayo, 2014). In order to gain control over the spread of *M. spicatum* several different methods have been tested, each with their advantages and disadvantages (Simkovic, 2020). Biological control through the use of the milfoil weevil, *Euhrychiopsis lecontei*, has been suggested as a cheaper and ecologically conscious alternative to chemical or mechanical methodologies (Newman et al, 1996; Sheldon and Creed, 1995).

E. lecontei is a native species of weevil that has been associated with the decline of EWM (Creed and Sheldon, 1995; Sheldon and Creed 1995; Newman et al, 1996). Before the introduction of EWM, this specialized insect would traditionally feed and reproduce on stands of *M. sibiricum*, a native variety of milfoil found in hard water lakes of Canada and the United States (Solarz and Newman, 2001; Newmaster et al, 1997). Since the introduction of EWM, it has been found the milfoil weevil will preferentially select *M. spicatum* over *M. sibiricum* for a host plant (Solarz and Newman, 2001; Borrowman et al, 2014). Because of this preference, the milfoil weevil targets EWM, subsequently promoting the colonization of native macrophytes. Other insects that have been studied as a control for EWM stands include the larval stages of *Acentria ephemerella* (a moth) and *Cricotopus myriophylli* (a midge), however, the biological behavior of *E. lecontei* is considered to have the greatest potential for sustained control over EWM spread (Newman, *personal communication;* Newman and Biesboer, 2000). As stem-miners, milfoil weevils lay their eggs on the tip of the plant's stem where they hatch, and the larvae bore down through the stem before they pupate (Newman, 2004). Adult weevils emerge, feed on the foliage of the plant, and restart the cycle, which can occur three to five times over the summer, dependent upon water temperatures in optimal conditions (Newman, 2004). The larval tunneling not only reduces the plant's buoyancy and therefore access to sunlight, but it also disrupts the flow of essential gasses, carbohydrates and photosynthates, and reduces the viability of stems (Newman et al, 1996; Creed and Sheldon, 1995). An important factor in controlling EWM is the reduction of carbohydrate stores in the roots of overwintering plants because it reduces their ability to re-establish the following spring (Creed and Sheldon, 1995). It has been suggested that the boring done by the weevil larvae also invites negative secondary effects through the establishment of diseases and pathogens in damaged plants (Newman, *personal communication*; Sheldon and Creed, 1995). At the end of the season, the adult female weevils move to shore by drifting or limited flight where they overwinter in vegetation five to ten meters from the shoreline under approximately one centimeter of duff (Newman, *personal communication;* Thorstenson, *personal communication*). It is also believed that some stages of the weevil life cycle (i.e. pre-pupae or pupae) also allow them to overwinter under the ice (Sager, *personal communication*). When spring temperatures break the weevils' winter dormancy, they fly a short distance to the nearest milfoil bed and commence their summer cycle (Newman, 2004).

By hindering the physiological processes of existing plants and reducing the ability for new establishment, it has been demonstrated that *E. lecontei* can suppress the production of EWM biomass in a freshwater system (Creed and Sheldon, 1995; Newman et al, 1996; Thorstenson, 2021a). Although this method of control has shown some promise, the logistics of establishing a successful weevil rearing program can be difficult to navigate, and results have been varied (Thorstenson, *personal communication*; Borrowman, *personal communication*). This report will summarize the current standard methodology and limiting factors as determined through interviews with experts, peer-reviewed literature and a series of lake management plans and reports. Furthermore, this report will identify relevant regulatory restrictions and considerations, a financial breakdown and focus points for future research.

Interviews were conducted with three individuals who have contributed extensively to the understanding of milfoil-weevil interactions within the context of biocontrol. Dr. Ray Newman of the University of Minnesota specializes in invasive aquatic biology and is well established in the literature regarding weevil behaviourism as it affects milfoil species. Amy Thorstenson was a recommended contact by Newman because she currently with Golden Sands Resource Conservation and Development Council of Wisconsin as their Regional Aquatic Invasive Species Coordinator. Over the years she has developed a refined framework for rearing weevils as a biocontrol agent on EWM and works at establishing this methodology with lake groups. Lastly, Kyle Borrowman was contacted because of his experience studying and stocking weevils in central Ontario. Kyle completed his graduate studies at Trent University before working with EnviroScience, Inc. as an aquatic biologist and project manager. Dr. Eric Sager also provided key insights to his experience with weevil stocking in central Ontario. Sager is a leader in aquatic plant ecology in Ontario and has worked with numerous lake groups for the management of their lakes.

2.0 CURRENT METHOD

There have been several methodologies used in previous weevil farming attempts, however they are not all effective at producing a large number of weevils for stocking (Thorstenson, 2006). Generally, weevil production is done in either larger outdoor tubs (100 gal) or smaller indoor tanks (10 gal) (Thorstenson, 2006; Cooper, 2018). Efforts documented in Springville Pong, Thomas Lake and Lake Joanis demonstrated that using large outdoor tubs (100 gal) rather than smaller indoor tanks (10 gal) produced a better average return rate and was more cost-effective (Thorstenson, 2006). Winter rearing programs were not recommended by Newman, Thorstenson or Borrowman because of the lack of fresh milfoil to provide the weevils and the amount of pollution produced (*personal communication*).

The following is a summary of the methods created by Thorstenson for Golden Sands RC&D (2017). Cattle troughs (100 gal) should be placed in a level, sunny area. Though it is suggested that lake groups start with four to six tubs, the production may need to scale up for the required number of weevils as each tub will produce around 670 weevils (depending on seasonal conditions). These tanks should have some sort of removable screening to create a barrier between the weevils and potential contamination. Dechlorinated well water or filtered lake water should be used to fill the tubs and healthy stems of milfoil, or “food bundles” should be placed into tubs to provide food and egg laying sites. Food bundles are created by bundling healthy milfoil collected from the recipient lake after it’s been trimmed of roots and decaying pieces. It is important that these stems still have the tips of the meristem intact otherwise the weevils will not deposit their eggs on them. The stems should also be cleaned of other invertebrates and algae to minimize competition for the weevils. Food bundles generally consist of 15 healthy stems and will need to be replaced every 21 days. From the starter stock, add 70 adult weevils to each tank. After 54 weevils can be released into the lake by transporting and attaching EWM bundles to stems of the desired beds. This process can also be performed in the lake itself by floating the troughs with foam and installing input and output locations for lake water with a fine filter to keep fish and algae out, but the care instructions remain the same.

2.1 MONITORING

Monitoring of macrophyte community and weevil population should be performed annually to determine the population dynamics over time. The expected trend is that weevil population density will increase as years pass and milfoil occurrences minimize (Lillie, 2000; Cooper, 2018). If a sustained, heightened population is not observed over multiple years, there is likely a limiting factor that is prohibiting the lake from supporting an increase in weevil population, and alternative methods of control should be considered (Newman, *personal communication*; Golden Sands RC&D, 2017).

The following suggested methods for macrophyte and weevil surveys are based on the Golden Sands RC&D Manual (2017). The method suggests a point-intercept survey, where predetermined coordinates are generated from map data. At each point, the sampler would drop a sampling rake and pull up the macrophytes present. Species present and a fullness index are recorded. Two separate EWM stems should be collected at the same location, bagged, and stored in a cooler to be assessed later for their weevil count. Additional observations can be recorded including depth, dominant shoreline type, temperature and water clarity as these are helpful for understanding spatial distribution. The weevil densities should be interpreted, by EWM bed to get an understanding of how stocked weevils are moving throughout the lake.

2.2 STARTER STOCK

A challenge with weevil stocking is sourcing the starter stock to begin with. Historically there have been companies from whom a starter stock could be purchased, but those companies are now unavailable (Golden Sands RC&G, 2017). Additionally, for stocking programs in Canada, weevils must be of Canadian origin to meet federal regulations (Borrowman, *personal* communication). In order to implement a weevil augmentation program, starter stock must be collected and cultivated, and there are a variety of ways to do this. Weevils should be collected early in the season from high density lakes that have no zebra mussels or other invasive species of concern (Thorstenson, *personal communication*; Borrowman, *personal communication*; Sager, *personal communication*). Borrowman (*personal communication*) suggested floating over EWM beds to collect adult weevils which are then cultivated and used to stock the recipient lakes. Thorstenson, on the other hand, would harvest EWM stems from areas known to have a high weevil density which would include adults, larvae and eggs (*personal communication*). These weevils are then cultivated for the duration of the first generation before the adults are collected and stocked into tubs with milfoil from the recipient lake. The Department of Natural Resources (DNR) of Wisconsin does not allow milfoil stems from two lakes to be held together before stocking to prevent different hybrids from entering new lakes (Thorstenson, *personal communication*).

2.3 PREDATOR EXCLUSION

As predation has been studied to be a limiting factor in some southern lakes (Ward and Newman, 2006), recent advances in weevil biocontrol involve the use of predator exclusion cages to augment the natural population of weevils of a given lake (Thorstenson, 2021). These cages are made of sturdy rubber netting attached to five of six sides of the cage with an opening on the bottom. The netting was small enough to prevent minnows from entering, but large enough that the weevils can move freely through it. With these cages in place, the weevils are provided a refuge where they can increase the population density without predation pressures. To date, the studies of Lake Joanis (Thorstenson, 2021) have documented a strong positive response in weevil population density without recent stocking. This is a relatively new methodology and is only relevant in lakes where predation is thought to be a limiting factor, but one that is thought to show promise.

2.4 EMPHASIS ON RESTORATION

Interviews with Newman and Thorstenson, echoing their published work, has a strong emphasis on restoration as the best method for control of invasive species (*personal communication*). Weevils are biologically equipped to minimize the spread of EWM as is their role in freshwater ecology (Creed and Sheldon, 1995), but bolstering ecosystem health by fostering native plant communities, reducing water turbidity and excess inputs will also provide a defense against this invasive species (Thorstenson, *personal communication*; Newman, *personal communication*; Golden Sands RC&D, 2017; Cooper, 2018; Sager, 2019). An example of this can be seen in the efforts at Big Cedar where weevil stocking was being exercised but ultimately required support for the native plant community to become established once EWM declines occurred (Cooper, 2018; Sager, 2019). In order to augment the community of native macrophytes, benthic mats were applied onto milfoil patches that had been previously stocked with weevils, and subsequently vegetated with transplanted native species (Sager, 2019). Though these efforts help to augment the resilience of the ecosystem, they are difficult to scale up to a level of maximum efficiency (Sager, 2019; Sager, *personal communication*). Nonetheless, a holistic approach is required in order to improve lake health to a point that it is receptive to the decline of EWM.

3.0 LIMITING FACTORS

3.1 SOURCE LAKE DENSITY

Weevils can be found in most Ontario lakes that contain milfoil species, whether that species is of the native or introduced variety (Borrowman, *personal communication*; Borrowman et al, 2014). However, they may not currently have the population density that is required to inflict any kind of control on the competitively expanding EWM. Hence the reasoning for a stocking program to augment these numbers to provide the desired service. In order to implement a cost-effective stocking program, there needs to be a source lake with weevils at a high enough density that practitioners are able to efficiently collect weevils early in the season to begin rearing a starter stock for the treatment lake (Borrowman, *personal communication*; Thorstenson, *personal communication*; Newman, *personal communication*). Additionally, great care must be taken to ensure that no further introduction of problematic species occurs. A source lake should not contain zebra mussels, for example, to limit the likelihood of introduction if the recipient lake does not already contain them (Borrowman, *personal communication*; Sager, *personal communication*).

Finding a source lake requires a survey of nearby lakes to understand where the highest densities of weevils exist in order to simplify the collection process in the springtime (Newman, *personal communication*; Thorstenson, *personal communication*). Even with a knowledge of local population densities, they are constantly subject to external factors and may unexpectedly drop any given year (Newman, *personal communication*). This is especially true in the springtime when temperature determines when dormancy is broken and thus when populations in the water are high enough to be collected efficiently (Newman, *personal communication*). If the starter stock is not collected until later in the season, it will affect the number of weevils that can be reared and stocked into the lake and limit the number of generations produced in the season (Newman, *personal communication*). This ultimately will affect the amount of damage and control that can be done unto EWM.

3.2 HABITAT

An initial survey should be conducted to gather a comprehensive understanding of the lake ecology and characteristics, as there is an abundance of factors that could influence the ability to support a large weevil population (Newman, *personal communication*; Creed, 2000). Surveys of shoreline type, water temperatures, initial weevil population density and nutrient loading should be taken to ensure weevil stocking is an effective control method (Thorstenson, 2021a; Sager, *personal communication*). Additionally, surveys of native plant communities and water clarity should be completed yearly to understand how the macrophyte community will shift in the absence of EWM (Newman, *personal communication*).

3.2.1 Shoreline

Though there is some uncertainty of the overwinter behaviourisms of the milfoil weevil, there have been suggestions that shoreline characteristics could play a hand in spring return rates. During interviews with Thorstenson and Newman, both individuals emphasized the importance of having a natural shoreline. Overwintering milfoil weevils have been found up to ten meters from the shoreline, so it is recommended that lake residents refrain from mowing, raking, or managing their lawns and gardens from September to May if they are within this zone (Thorstenson, *personal communication*; Newman, *personal communication*; Golden Sands RC&D). The type of natural shoreline does not seem to have an influence on weevil success, so long as there is a minimum of one centimeter of duff, or leaf litter, that they can bury themselves in (Thorstenson, *personal communication*). Weevils tend to prefer overwintering habitats that are high and dry, so wetlands that block their access to higher ground can become problematic for overwinter survival (Thorstenson, *personal communication*). Thorstenson and Newman have both suggested anecdotally that large cattail beds may negatively influence the population's overwintering ability, however, this has not been consistent with other studies (Sager, *personal communication*).

Compounding the importance in supporting an optimal weevil population, having natural shorelines will provide habitat for a variety of other components of a healthy ecosystem (Gundersen et al, 2010). It will also assist in buffering an excess of nutrients and sediment from entering the lake, which in turn will limit the amount of algal growth and improve water clarity so a healthy population of native macrophytes can thrive as EWM declines (Gundersen, 2010).

3.2.2 Lake

The challenge during the summer months is to keep the optimal amount of weevils on the stems of EWM so they can enact as much damage as possible. Factors such as bed characteristics, predation and boat traffic can dissuade expansion or remove weevils from their host plant and ultimately reduce the efficiency of the stocking program.

Weevils move through the EWM primarily by climbing from stem to stem (Thorstenson, *personal communication*). Because of this, stands that are thicker and denser will provide an ease of access to new egg laying sites as the weevil population grows through the summer (Thorstenson, *personal communication*). Beds milfoil of where density is sparse or those which occur at greater depths to have lower densities of weevils (Thorstenson, *personal communication*; Newman, *personal communication*). In more southern ranges of the milfoil weevil, fish predation has been suggested as a strong limiting factor relating to bed size and location, though it has not been observed in lakes in Ontario (Sager, *personal* communication). Newman and Thorstenson both indicated in their interviews that a strong presence of stunted bluegill, sunfish and panfish populations may influence the success of weevil stocking programs. The Golden Sands methodology suggests completing a fish survey similar to the methods used by Ward and Newman (2016).

Wave action caused by boat traffic can also have a negative effect on stocking initiatives. Similar to harvesting, disturbances caused by boats can dislodge adults and break off the tops of stems where the eggs, larvae, and pupae are found (Thorstenson, *personal communication*). Additionally, if the weevils are not present on the stems that are broken off, there is a strong likelihood that the viability of the fragments are still intact and so will further perpetuate the establishment of EWM. The shape of the stand may play into its ability to shelter weevils from dislodgement. Stands that exist in the traditional round shape are more likely to buffer the effects than stands that appear in thinner strips (Newman, *personal* communication). Consideration must be taken when selecting the location to receive weevils as it must be in a location with minimal disturbances and would benefit from signage to remind lake users to be mindful (Borrowman, *personal communication*; Golden Sands RC&D, 2017).

3.2.3 Wind

Prevailing winds may also have an influence on the desired effects of weevil stocking. It is possible that strong winds at specific times in the weevils' life cycle may redistribute a portion of the population by blowing them to the leeward shores and away from stocking sites (Newman, *personal communication*; Lillie, 2000). This could have an effect on the amount of damage inflicted during the season, but it could also hinder the overwinter survival if the leeward shoreline is more developed and so less suitable for the weevils (Lillie, 2000). Thorstenson disagreed, saying that weevils will tend to redistribute themselves over the years and wind has very little to do with it – which highlights the importance of having a higher percentage of shoreline that is naturalized (*personal communication*).

3.3 LOGISTICS

3.3.1 Intensive Labor Component

A successful weevil rearing program requires a strong, long-term commitment from a team of people who are ready do physically demanding work. Thorstenson recommends a group of at least four to six people so that the physicality of the job does not become overwhelming for the participants (*personal communication*). The process of collecting, bundling, and monitoring requires a great deal of heavy lifting and bending which might not be suitable for everyone. There is a significant time commitment required for the collection of starter stock. The collection itself is a time consuming process, but there also be a significant amount of surveying and research done beforehand to select appropriate lakes to collect from. Both the collection of weevils and the preliminary surveying are learned skills that will take time to hone.

3.3.2 Volunteer Commitment

The use of weevils for biocontrol has been criticized for being too costly when the variation of results is so unpredictable (Madsen et al, 2000). Average prices per weevil are usually over a dollar, costing lake groups thousands of dollars per year (Borrowman, *personal communication*; Thorstenson, 2006; Madsen et al, 2000). A strong volunteer base is key to keeping costs at a manageable level (Thostenson, *personal communication*). With the methodology Thorstenson proposes through Golden Sands and volunteer participation, the cost is brought down to 30 cents per weevil (USD). There has been a substantial community interest in past projects and the opportunity for volunteer participation has been well received (Thorstenson, *personal communication*; Newman, *personal communication*). However, the volunteers must be able and willing to handle the demanding workload. Generally, the demographics that become involved are students and retirees (Thorstenson, *personal communication*), so the workload must be modified and divided to suit individual needs. The most successful programs tend to be those with a solid core group of volunteers, especially as interest tends to drop off after the initial year (Thorstenson, *personal communication*).

3.3.3 Managing Expectations

As mentioned, this program—along with most biocontrol applications—is intended for long term control of species of concern (Golden Sands RC&D, 2017). Previous applications of this program have failed because the lake partners have become disappointed in the lack of viable results after a year or two (Thorstenson, *personal communication*; Borrowman, *personal communication*). Populations of weevils have been known to fluctuate, as does the occurrence of EWM (Cooper, 2018). A strong monitoring program can help quantify shifts in population dynamics over the duration of the program and shed light on the effectiveness of weevil stocking in specific lakes (Golden Sands RC&D, 2017). Newman et al (1996) suggest including the assessment of carbohydrate stores in above and below ground EWM tissues along with nutrient content of stand sediment to properly evaluate the extent of weevil-influenced biomass declines. Weevils will damage the vascular tissue that would normally allow for the transportation of carbohydrates to the root system (Newman et al, 1996). In doing so, they stunt the plant's ability for early establishment the following spring and allow time and space for native plant species to establish instead (Creed and Sheldon, 1995). Several years of maintained weevil populations and native plant establishments are required to create a balance that will control the spread of EWM (Newman et al, 1996; Thorstenson, *personal communication*; Borrowman, *personal communication*; Golden Sands RC&D, 2017).

4.0 REGULATORY CONSIDERATIONS

Biological control using weevils must conform to the established regulations as provided by both provincial and federal agencies. The movement of biomass can create avenues of transmission for other harmful or undesired entities. This section will provide some clarity in these areas so future projects may operate within legal and ethical guidelines.

4.1 *PROVINCIAL &FEDERAL REGULATIONS*

Currently, the provincial and federal regulations regarding the movement of weevils only pertrain to the movement of weevils across provincial or federal borders. Sourcing stock weevils from areas outside Ontario requires approval from the Ministry of Northern Development, Mines, Natural Resource and Forestry under Section 54 of the Fish and Wildlife Conservation Act (Brinsmead, *personal communication*). Additionally, if the weevils are being sourced outside of Canada, approval from the Canadian Food Inspection Agency would also need to be acquired because the importation over federal borders (Brinsmead, *personal communication*).

4.2 *LOCAL SPECIES OF CONCERN*

The unintentional spread of invasive species becomes a forefront concern when transporting biological mass from one lake system to another. Care must be taken to not introduce species of concern into the recipient lake, especially if they are not already present. The careful selection of stock lakes must be limited to lakes that do not contain these species. In Haliburton County, many invasive species have been identified. The species that have been recorded with the greatest occurrences that are not already present in Drag and Spruce lakes are purple loosestrife, common reed, zebra mussels, Chinese mystery snail, and banded mystery snail (EDDMaps, 2022). For the purposes of weevil stocking, the three of major concern are zebra mussels, Chinese mystery snail, and banded mystery snails as they have the greatest ability to hitchhike into the reciepent lake through collected samples. The following will briefly describe each species and where they have been documented within Haliburton County. These lakes should be avoided when sourcing stock weevils to reduce the likelihood of transfer into Drag and Spruce lakes.

4.2.1. *Zebra Mussels*

Zebra mussels (*Dreissena polymorpha*) are small shellfish thought to have been introduced in Ontario from the ballasts of ships arriving from the Black and Caspian Sea in (Benson et al., 2022; DFO, 2021). The rapid dispersal of zebra mussels is attributed to its ability to mobilize in all stages of its life; larval drifting and attaching to boats or boat trailers moving within and between lakes (Benson et al., 2022). Zebra mussels are about the size of a fingernail and have characteristic alternative dark and light stripes, though there is some colour variation in number and colour of these stripes (Benson et al., 2022). They generally attach themselves to hard surfaces (including the shells of other mussels) but have been known to attach themselves to macrophytes as well (Benson et al., 2022). As filter-feeders, zebra mussels get their food from the water column in the form of algae, phytoplankton and other small particles, so they tend to clear the water column, improving water quality (Benson et al, 2022).

Large numbers of zebra mussels can lead to biofouling of water intake and effluent pipes, fishing gear and navigational markers (Benson et al, 2022). Ecologically, they reduce the biomass of phytoplankton available in a waterbody, which changes the foundation of food webs and subsequently alters the trophic regime currently in place (Benson et al, 2022). The reproductive stages of zebra mussels generally commence in the spring, but in temperature polluted areas fertilization may occur year-round, therefore anthropogenic influences on water temperature can increase the annual fertilization rate (Benson et al, 2022). There are several methods that have been essayed in the treatment of zebra mussels including chemical, physical and biocontrol, however preventative measures are the most effective in preventing the spread of this species (Great Lakes Commission, 2018).

Zebra mussels have been documented in Canning, Davis, and Kawagama Lakes and Minden Bay of Haliburton County. It is important that weevil stock is not collected from these lakes as zebra mussels in all life stages are easily transported between lakes. Proper care should be taken when moving boats and equipment between lakes that have documented zebra mussel presence.

4.2.2. *Chinese Mystery Snail*

The Chinese Mystery Snail, or *Cipangopaludina chinensis*, is a species of snail first observed in the Great Lakes area between 1931 and 1942 (Kipp et al, 2022). The native range of this species is from Southeast Asia to Eastern Russia and was thought to have been brought North America to be sold in food markets (Kipp et al, 2022). The shell of this snail can reach over 6 cm in length, sports seven large whorls, and can range in colour from olive green to reddish-brown (Kipp et al, 2022). They are found in slow moving water with silt, sand or mud bottoms and feed non-selectively on organic and inorganic matter by scraping the sediment (Kipp et al, 2022).

Chinese mystery snails have a very high fertility rate and produce a high number of young in each catch (Kipp et al, 2022). Larger females produce a larger number of young rather than larger individuals, so the population increases quickly once established (Kipp et al, 2022). As their numbers increase, they displace native snail species and with their large, thick shells they are not easily incorporated into the food web which impacts energy transfer between trophic levels (Kipp et al, 2022). Additionally, they are thought to potentially impact the system by acting as carriers for parasites and disease (Kipp et al, 2022). As they are a popular species for personal aquariums, one means of introduction is thought to be through the disposal of aquarium contents into lakes (McAlpine et al, 2016). This species is also able to survive long period of drought or other unfavourable conditions and so can travel between lakes on boats, trailers and other equipment if they are not cleaned properly (McAlpine et al, 2016).

Currently, there have been sightings of Chinese mystery snails at Little Bob, Gull, and Beech Lakes of Haliburton County. This is the most reported species of concern in Haliburton country so great care should be taken when moving between lakes and these lakes should be avoided as weevil stock source lakes (EDDMaps, 2022).

4.2.3. *Banded Mystery Snail*

The banded mystery snail, *Viviparus georgianus*, is a smaller snail ranging in size from 1-4.5 cm in shell length and is native to southeastern and midwestern states (Morningstar et al, 2022). Its name comes from the distinct brown bands presented on its otherwise yellowish green shell (Morningstar et al, 2022). Its introduction further north occurred when it was purposefully released into the Hudson River in the 1850s where it continued to expand its range into Canada (Morningstar et al, 2022). Other sources of introduction include being released from aquariums and hitchhiking on watercraft vehicles either in water or over land, as they are capable of surviving lengths of time outside water (Kipp et al, 2022). Banded mystery snails will establish themselves in areas with sediment ranging from sand to detritus, where in the spring to fall they coexist at high densities with macrophytes in shallower areas (Kipp et al, 2022). Like the Chinese mystery snail, larger females produce larger catches and females of the banded mystery snail may carry multiple catches at a time which can quickly increase the population size (Kipp et al, 2022).

Concern surrounding banded mystery snails comes mainly from the large seasonal die offs that will pollute the shoreline and nearshore waters, creating unfavourable conditions for recreational usage (Kipp et al, 2022). Ecologically, they are thought to be a potential source of parasites for fish and birds that have adopted them as source of prey, and they may influence trophic dynamics by consuming fish eggs and displacing native snail species (Kipp et al, 2022). There are few management options for banded mystery snails as they are physiologically better equipped to survive chemical treatment, so application may hinder the native snail population and exasperate the population growth (Kipp et al, 2022). There is some potential for biocontrol as some fish and bird species have been observed to consume banded mystery snails, but no methods have been tested (Kipp et al, 2022).

Sightings of banded mystery snails have been observed in Haliburton County at Moore, Gull, Twelve Mile, Horseshoe, and Boshkung Lakes. As is the case with other species of concern, traffic from these lakes should be limited and they should be avoided for use as source lakes for weevil stock.

5.0 FINANCIAL BREAKDOWN

The financial commitment required to use weevils as a means of control on EWM for Drag and Spruce Lakes is dependant on the density of weevils currently present in the lake, and the density of weevils that need to be stocked on an annual basis (return rates). As mentioned previously, volunteer commitment is key to keeping costs low as they reduce the general cost from the standard “buck-a-weevil” to an average of 0.30 cents USD, or 0.38 cents CAD (Golden Sands, 2017). This number comes mainly from the infrastructure required for moving and rearing weevils, and for the initial and continued monitoring needed to evaluate the progress of the program. If stock weevils are being bought from an external source, the price per weevil will increase although there are currently no vendors for this service.

Materials required to create the rearing infrastructure include cattle troughs, lumber, wire mesh, plastic pools, and a variety of hardware (Golden Sands, 2017). The quantity of material required depends on the goal density for stocked weevils. Thorstenson (2022), recommends beginning with four 100-gallon troughs the initial year to gauge the work involved with this project, and adding more in subsequent years if labour allows for it. For this initial set up, the general cost for material will be around $1600. Some materials may be donated to keep costs down. This figure assumes that personal watercrafts will be used for the collection and distribution of weevils and does not include gas for motorized boats. Another consideration that may influence the price is the source of water. Filtered water is recommended to fill and continuously top up the troughs, so depending on the location of the rearing project, water may need to be brought onto the site and hosing required to operate.

Monitoring is the most expensive component in the financial demand for weevil control – unless weevil stock is purchased from an external source. Initial monitoring should be done for baseline data of macrophyte composition, EWM density and weevil density. Subsequent monitoring should be performed annually for three years to evaluate the return rates and overall effect of the program. The monitoring could be preformed by two students working 30 hrs/wk over the summer months. At a rate of 16$/hr, the cost of monitoring is around $46 000 for all four years. There are government programs available that may subsidize a portion of this cost.

6.0 FUTURE RESEARCH

Future research regarding the feasibility of a weevil farming operation on Drag and Spruce Lakes should involve the assessment of lake specific qualities to ensure a strong likelihood that heightened weevil densities will be sustained. An understanding of the species interaction, population dynamics and physical characteristics that are currently influencing these lakes will give insight into how EWM management might be received and give a baseline with which to evaluate future efforts.

6.1 *PLANT COMMUNITY COMPOSITION*

A lake-wide survey of plant community composition is important in understanding what the community structure resembled prior to any colonization by EWM, and how EWM is influencing the current structure. With this insight, the degree to which EWM has affected the native biota can be assessed and appropriate management in appropriate quantities can be undertaken. Having a strong understanding of the native plant community structure will help inform integrated restoration by indicating which species to support while EWM densities diminish.

6.2 *NATIVE WEEVIL DENSITIES*

Management of EWM using weevils first requires information on the densities of both the current weevil population and the EWM beds. The general density for weevil control is between 0.5-2 weevils per EWM stem depending on the lake conditions (Newman, *personal communication*). For an efficient farming operation, a survey should first be conducted to have an understanding of the baseline weevil densities (Golden Sands, 2017). Stocking rates can then be calculated and inform time and resource inputs.

6.3 *LAKE CHARACTERISTICS*

Specific measurements of quality for the lake-wide environment give an indication of the ecological structure that will be naturally present, and the biotic community that can be supported. There are several parameters that can be used to discern the quality of a waterbody. The following items should be included with plant community composition and weevil densities in a survey before commencing a restoration project for the control of EWM as they all play a part in weevil and macrophyte population dynamics.

6.3.1 *Water Characteristics*

The structure of a plant community is dependent on how much light is able to penetrate through the water column, making it available for photosynthesis (Dar et al, 2014). The light requirements vary between species, but EWM canopies have been observed to hinder light penetration for some submersed species (Dar et al, 2014; Boylen 1999). Including water clarity measurements in a baseline survey will determine if the light requirements of the native plant community will be satisfied in the place of EWM beds.

Similarly, seasonal temperature shifts also play a role in determining the composition and distribution of aquatic plant communities (Dar et al, 2014). Additionally, because weevil reproduction is temperature dependent, it is important to know the general water temperature trends to be expected on Drag and Spruce lakes (Borrowman, *personal communication*). There needs to be a sufficient number of reproductive cycles throughout the year in order for the weevils to have an optimal effect on EWM spread (Sager, *personal communication*)., so understanding when those cycles can be expected to commence in a year will help provide an accurate prediction of resources required for management success.

Nutrient availability is also a predictor of macrophyte community assemblages (Dar et al, 2014). Nitrogen and phosphorus are linked to high vegetative growth in freshwater lakes, so testing water samples for these nutrients may determine where point source nutrient inputs could be supporting a heightened macrophyte community (Dar et al, 2014).

6.3.2. *Sediment Characteristics*

The type of substrate and its chemical composition will influence the composition of the community of macrophytes that are found there (Dar et al, 2014). Factors including organic matter content, alkalinity, oxygen availability, nitrogen and phosphorus content and sediment composition (i.e. clay, sand silt) all play a role in the establishment of macrophytes with different plant groups having varied tolerances for each factor (Dar et al., 2014). Assessment of sediment type and chemical characteristics will help predict the how the macrophytic community will shift post-management. To aid in the control of EWM, supporting or transplanting native macrophytes that can thrive in the conditions currently supporting EWM beds will help reduce recolonization by of the non-native species.

6.3.3. *Shoreline Characteristics*

As mentioned by Thostenson and Newman (*personal communications*), a naturalized shoreline is an important factor in supporting the overwintering population of weevils. If this type of management is to succeed, the proper physical characteristics should be available for maximum success. These characteristics include a natural shoreline five to ten meters from the water, and a layer of duff for the weevils to bury themselves in (Thostenson, *personal communication*).

7.0 FINAL REMARKS

Biocontrol using the *E. lecontei* has been successful for the control of *M. spicatum* in many lakes, including some in Ontario. However, there are major lake-specific considerations that must be observed and evaluated to ensure that this method is the most efficient for the lake in question. Preliminary surveys will determine the lake characteristics that may influence the success of returning populations, and a multi-year commitment will ensure that the appropriate amount of time and resources are available for the ongoing project. The objective is to augment native biological components to foster ecosystem resiliency and diminish the negative effects of a competitive introduced species. The overall health of the ecosystem should be considered, so additional or integrated restoration approaches may be required for the optimal outcome (Sager, 2019; Newman, *personal communication*).

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