Methods for the Control of Eurasian Watermilfoil in Drag and Spruce Lakes

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Abstract

This study aims to determine the best practices for Eurasian watermilfoil control, the methods that have the best chance of success, and the most cost-effective solutions, while also focusing on how coconut fibre mats differ from burlap mats as a bottom barrier control technique. A thorough examination of over 30 peer-reviewed articles discussing Eurasian watermilfoil outbreaks in different areas and their control methods to eradicate such outbreaks were used. Nine methods of control were discovered through these articles, each vastly different in terms of time, effort, cost, equipment, and required knowledge for use. The methods of control described herein include rototilling, hand harvesting, bottom barriers, the milfoil weevil, lake drawdown, grass carp, suction harvesting, herbicides, and an integrated approach using two or more of the methods. Hand harvesting was one of the most cost-effective control methods for small areas, while bottom barriers were among the most cost-effective options for larger areas. The use of *Euhrychiopsis lecontei*, the milfoil weevil, was an option proven effective for use in the same region as Drag and Spruce Lakes and less costly than some other methods. This study has found that an integrated approach using hand harvesting and bottom barriers seems to be the most cost- and time-effective technique because it allows for optimal results in specific areas as needed without long-term harmful effects to native species. This integrated approach would also allow the Drag and Spruce Lakes Property Owners Association to continue providing their services and programming without significant lake access disruptions.

Keywords

Eurasian watermilfoil, invasive, fragmentation, biodegradable, anoxic, eradication.

Introduction

Morphology

Eurasian watermilfoil, known scientifically as *Myriophyllum spicatum*, is an aquatic perennial plant invasive to North American waters (Smith & Barko, 1990). This plant flowers twice per year in the early to mid-summer months, sprouting small pink flowers with spikes from a red-brown or white-pink coloured stem. These stems hold three to five feather-like leaves, growing in a whorl pattern from points along the stem in intervals of approximately one inch (Department of Natural Resources, n.d.). This species is often found in more shallow waters of less than three metres deep but in an attempt to overtake everything in its path; it can be found rooting in areas over three times as deep (OFAH/OMNRF Invading Species Awareness Program, 2021a). *Myriophyllum spicatum*, not to be confused with the native *Myriophyllum sibiricum*, was introduced to Canadian waters through British Columbia in the 1970s (OFAH/OMNRF Invading Species Awareness Program, 2021a; Newroth, 1993). However, Eurasian watermilfoil can hybridize with the native northern watermilfoil mentioned above, leading to the influx of a more aggressive species capable of causing more damage (OFAH/OMNRF Invading Species Awareness Program, 2021a).

Concerns and Significance

Eurasian watermilfoil has proven itself to be incredibly harmful to native species and aquatic ecosystems and is challenging to eradicate. One of the biggest concerns behind the emergence and persistence of Eurasian watermilfoil is how easily it can spread, fragmenting and rooting in new locations if disturbed. Other concerns include issues with the environment thick surface mats of Eurasian watermilfoil create: fish and wildlife are disturbed, oxygen and nutrient levels decrease significantly, light penetration is limited, water flow is compromised, invertebrate populations are harmed, and sockeye are unable to spawn in functional areas (Dunbar, 2009). Similarly, the Eurasian watermilfoil (EWM) surface mats inhibit reasonable enjoyment of the water and any water-based activities and cause loss of value to properties situated on affected lakes (Olden and Tamayo, 2014). Early intervention is key to preventing outbreaks of larger EWM, which are more time-consuming and costly to control. These concerns make studying EWM imperative for determining the best practices for managing its spread and significant for many environmental organizations, stakeholders, and cottagers.

Project Purpose

The information in this report is provided to guide future best practice management decisions for the control of Eurasian watermilfoil in Drag and Spruce Lakes. Goals of this project include: to provide a description of best practices for the control of EWM with attention to effectiveness, sustainability, and risk of spread of each control measure; to provide a comparative analysis of burlap bottom barriers and coconut fibre bottom barriers for the control of EWM; and to identify further surveys, literature reviews, and fieldwork that would improve the DSLPOA understanding of managing EWM with the support of the community of property owners and visitors to Drag and Spruce Lakes. The research questions developed to help reach these goals include: which methods are available for the management of EWM, which methods have seen the most success in high-density and low-density patches of EWM, and which methods are the most cost-effective?

Methods

A systematic approach was used to review all aspects of the literature regarding control strategies of Eurasian watermilfoil. I searched all databases for peer-reviewed research papers on Eurasian watermilfoil morphology, different methods of invasive species management, and associated costs through Google Scholar and Trent Online Library databases. These resources provided several relevant peer-reviewed articles regarding Eurasian watermilfoil and other aquatic invasive species. Following this more general research, individual journals were searched for similar keywords and topics. These journals included *Invasive Plant Science and Management*, *Journal of Aquatic Plant Management*, *Lake and Reservoir Management*, and *Hydrobiologia*, among others. The next step was to find similar articles using the articles' references through the first two steps. All articles that were chosen to be suitable for the topic of Eurasian watermilfoil control were then studied more thoroughly. Through these methods, over 30 peer-reviewed articles were found for this research review.

Drag and Spruce Lakes Property Characteristics

The Drag and Spruce Lakes Property Owners Association (DSLPOA) has been working hard to contain the influx of invasive watermilfoil in recent years. Situated in Haliburton County, the DSLPOA acts as a steward for the area; promotes the responsible use of the lakes; supports cottage owners in the area; and seeks to persevere the health of the lakes through activities such as reporting on lake health, monitoring changes to the water, and carrying out Eurasian watermilfoil control methods (DSPLOA, n.d.).

Currently, there are four outbreaks in the area recorded by the DSLPOA (DSPLOA, 2021). The primary outbreak is notably the largest at 20,000 square feet in the Harris Beach area.

The following site is near Podmore Beach and is the second-largest outbreak at 9,000 square feet. The next outbreak is situated on the northwestern side of East Bay and measures about 1,500 square feet. This site requires immediate attention due to its proximity to the shoreline (DSPLOA, 2021). The final outbreak is near Bonham Bay's northwest side, although the size of this outbreak is not yet determined (DSPLOA, 2021).

The Eurasian watermilfoil invasion on Harris Beach has previously been treated using bottom barriers with containment curtains and hand harvesting (DSPLOA, n.d.). With water quality being the number one personal enjoyment value noted by cottagers surveyed by the DSLPOA in 2011, it is of no surprise that Eurasian watermilfoil control is a top priority (DSPLOA, 2011).

Eurasian Watermilfoil Management Options

Issues with Eurasian watermilfoil in North American lakes have led to many different possibly viable control methods to be studied. While some of these control options have proven to be less successful and others have become staple methods to try, all possible techniques will be discussed in the following sections of this report. Rototilling, hand harvesting, benthic (bottom) barriers, introduction of *Euhrychiopsis lecontei*, lake drawdown, stocking of *Ctenopharyngodon idella*, suction harvesting, aquatic herbicides, and an integrated approach using two or more methods simultaneously have been frequently discussed in the literature as options for Eurasian watermilfoil control and possible eradication. These methods can be classified as physical/mechanical, chemical, or biological. The DSLPOA prefers physical control methods in the given environment; however, chemical and biological methods will be addressed in-depth as well.

Rototilling

Rototilling is a physical management method carried out using specially constructed rotavators equipped for invasive plant control (Gibbons and Gibbons, 1988). The rotavator machinery is used to churn up the thick sediment on the lake's bottom and extract the root systems of the target species. For Eurasian watermilfoil control, the goal is to pull up the plant's deep roots, thereby killing the plant and allowing for the containment, collection, and proper dry disposal of as many possible stems in a given area. This method relies on the entirety of the plant to be uprooted and disposed of to prevent fragmentation and re-rooting in the lakebed or nearby areas (Gibbons and Gibbons, 1988; Newroth, 1993). Rototilling has been noted as a viable option for invasive species control by many organizations in the available literature, with the Okanagan Basin Water Board discussing its use in-depth (Dunbar, 2009).

Rototilling can be a good option for Eurasian watermilfoil control as it has many positive aspects. This method is an ideal option for areas with high public use since it does not leave any tools behind (as is the case with bottom barriers) and does not limit public access outside of treatment intervals (Newroth, 1993). Rototilling can be done much later in the year than some other treatment options, with proven success up until the late fall. Late season treatment may lower the chance of fragmentation, which can cause new outbreaks and expansion of Eurasian watermilfoil and allow for treatment during the off-peak season for cottagers in the area. This method has been shown to reduce invasive species such as Eurasian watermilfoil significantly, with one study showing a decline in EWM stem density by 63-90% after treatment (Gibbons and Gibbons, 1988). In addition, this method can be used for large-scale operations, and it has the benefit of being non-chemical. Rototilling can also be a quick option because only one treatment is usually required per season. Although multiple passes over an area may be necessary, there is no upkeep or monitoring needed between these quick annual treatments (Dunbar, 2009). Similarly, this method is multi-functional in that it can be scaled down into a localized treatment as EWM populations decline (Dunbar, 2009; Gibbons and Gibbons, 1988). Finally, rototilling can be both time and cost-effective as treatments can be scaled back until no longer necessary as the time required between treatments increases in response to lowered EWM densities (Gibbons and Gibbons, 1988).

With that said, this treatment option has a few notable drawbacks that can impact its viability. Some studies for invasive species control have presented evidence that rototilling is less effective over more extended periods; one such study found that EWM populations could re-establish in as little as one year post-treatment in Kalamalka Lake, British Columbia (Newroth, 1993). Studies done in the last five years have also questioned mechanical control techniques and their impact on the health and safety of aquatic species residing on the bottom of the waterbody. Rototilling, in particular, leads to damages caused by the high-velocity tiller, which create short-term changes on the lake bottom, add stress on the ecosystems found therein, and potentially expose the water to the contaminants held within the sediment (Gibbons and Gibbons, 1988). Finally, initial treatments of the rototilling option can be time-consuming and expensive; for example, the Okanagan Basin Water Board determined they spent approximately $2,500 per hectare on average by 2013 when attempting EWM control through this method (Okanagan Basin Water Board, 2013).

Hand Harvesting

Hand Harvesting is a commonly used technique for the control of Eurasian watermilfoil and other invasive species. To manage aquatic species using this method, divers are employed to estimate the percent cover of a particular species in their given area before removing every root of the species and placing them into mesh diving bags for containment. After the mesh bags are packed, they will be collected from the top of the water by the above-water crew, looking out for fragments (Kelting and Laxson, 2010). The above-water crew can be assisted through the use of containment curtains to prevent fragments from spreading. The cost of hand-harvesting has increased significantly, rising from $23 per kilogram of EWM removed in 2004 to $485 per kilogram in 2008 (Kelting and Laxson, 2010). Some of the costs could potentially be mitigated by prioritizing areas for surveying and paying close attention to the density of watermilfoil each year, not to be over-prepared as others have been (Kelting and Laxson, 2010). Even with the increasing price per kilogram of plant matter removed, this method is cost-effective, and future expenditures can be scaled down as EWM declines.

In addition to the benefit of being more budget-friendly than some other methods, hand-harvesting comes with a host of advantages. Hand harvesting has proven to be a very effective management method for many types of aquatic invasive species, even being dubbed the best management practice by some (Dunbar, 2009). This method has proven to be effective in different studies, with one citing over an 80% reduction in Eurasian watermilfoil while having minimal impact on the surrounding native and non-target species and little impact on the area's aquatic fauna (Boylen, Eichler, and Sutherland, 1996). Other studies have found that hand-harvesting used alone or in a combined treatment with bottom barriers has reduced EWM density to less than 5% for more than 90% of the Upper Saranac Lake (Kelting and Laxson, 2010). It has decreased the total number of plants from 21,200 to 3,953 in one year in Lake George and has led to 11 out of 21 management sites being EWM free for two years in Kootenay Lake (Boylen, Eichler, and Sutherland, 1996; Newroth, 1993). Finally, hand-harvesting efforts can be scaled back over time as EWM stem density decreases, with a recommended maintenance program every two to three years following initial control; such adaptations will save on effort hours required and annual expenditure (Boylen, Eichler, and Sutherland, 1996).

There are a few disadvantages to hand-harvesting, including the possibility of fragmentation that can cause the spread of EWM to other areas (Cooper, DeBues, and Sager, 2017). In addition to this, hand harvesting is a prolonged process that requires attention to detail, and if done in deeper water, requires divers to assist the process, which will increase costs and effort days (Codd-Downey, et al., 2020).

Benthic Bottom Barriers

Benthic barriers, or bottom barriers, have been frequently researched and have emerged as one of the best aquatic invasive species control methods. A few different types of bottom barriers are used that fall into biodegradable or synthetic categories, each coming with its own application methods, advantages, and disadvantages (Caffrey, et al., 2010; Codd-Downey, et al., 2020). The primary way this physical control method works is by preventing light, nutrients, and plant growth from passing through the bottom barrier (Dunbar, 2009). The best practice for laying bottom barriers depends on the size of the area being treated. In areas, less than $200m^2$, the most common method of laying biodegradable mats requires laying pre-cut sheets of matting over the area with the help of divers (Caffrey, et al., 2010). The material is secured to the bottom using weights placed along the edges of the barrier. Less effort is required to place biodegradable types of mats as they will become saturated with water quickly, causing them to sink into place easier than plastic barriers (Caffrey, et al., 2010).

Some other advantages of bottom barriers include using it as a stand-alone method with satisfactory results, while some other methods are better suited to an integrated approach

(Laitala, et al., 2012). Bottom barriers are also well researched with proven efficacy through a variety of studies showing its success. One such study concluded that bottom barriers could reduce EWM biomass by up to 100% in eight weeks, while another cited the control of EWM in as little as four months (Caffrey, et al., 2010; Laitala, et al., 2012). Other advantages of biodegradable types of matting include the ability to contain EWM fragments underneath the barriers; its degradation in two to three years with no intervention or excess cost; no residue left behind in the water; its durability and permeability that prevent anoxic conditions; and allowing for movement of macroinvertebrates and water, with some types of barriers even allowing native species to grow on top of them, increasing the competitiveness of native species (Caffrey, et al., 2010; Codd-Downey, et al., 2020; Newroth, 1993). In addition to these advantages, some research has shown that the primary recolonization of native species can occur within 30 days of the mats being removed or degrading, leaving no long-term damages (Boylen, Eichler, and Sutherland, 1996). Vegetated benthic mats have been highly suggested as a method for increasing native species competition in combination with *Euhrychiopsis lecontei*, as described below (Cooper, DeBues, and Sager, 2017).

Although bottom barriers have a long list of advantages touted in various articles, there are also crucial disadvantages. Due to the all-encompassing nature of bottom barriers, they can harm native plants as they are not selective and will affect any species they are laid over (Boylen, Eichler, and Sutherland, 1996; Codd-Downey, et al., 2020; Laitala, et al., 2012). They are also not a good option for areas of high public use as they should not be tampered with once placed (Newroth, 1993). Some evidence suggests laying bottom barriers should include sediment removal if being laid in sediment deeper than four centimetres, which could ultimately be more time-consuming and costly than other methods (Laitala, et al., 2012). Some studies have suggested that bottom barriers were not able to achieve the level of control expected, with some areas showing re-established EWM populations in up to 71% of treated areas within one year of barrier removal (Boylen, Eichler, and Sutherland, 1996; Madsen, Wersal, and Woolf, 2015; Newroth, 1993). Following the application of bottom barriers, some other disadvantages can appear. These issues may include billowing of the mat, which occurs due to the gases released by the underlying plants as they decompose when trapped under a non-permeable mat (Dunbar, 2009; Hill, 2007). Similarly, benthic barriers are susceptible to issues of damage or dislocation, which could make them ineffective and require a significant amount of maintenance to prevent or resolve (Dunbar, 2009; Newroth, 1993).

Euhrychiopsis Lecontei (Milfoil Weevil)

The milfoil weevil is a commonly used biological control agent that is highly specific to Eurasian watermilfoil. It is native to North America and can damage EWM by eating the leaf tissue (Reeves, et al., 2008). There are a few different techniques for increasing weevil populations discussed in the literature: conservation biocontrol to enhance existing populations; inoculative biocontrol to release weevils with the hope of expansion; or a combination of these two strategies (Alwin, 2009). Weevils offer a chemical-free, possibly self-maintaining biological control for EWM with numerous benefits and a few disadvantages.

One key benefit of using weevils as a control method is that they do not need much management after being stocked into the desired area since they will eat and lay eggs on EWM without extra intervention. In addition to this, weevils are highly selective: they do not significantly impact non-target species around them (Sheldon and Creed, 2003). Weevils are advantageous due to their ability to bolster their own numbers; they can sustain themselves and will therefore require fewer retreatments or interventions following the initial release (Sheldon and Creed, 2003). Due to this self-propagation, weevils likely will not require interventions such as removal like non-biodegradable bottom barriers, follow-up treatments multiple times per season like rototilling, or precise attention to detail during treatments like hand harvesting or drawdown. In addition to these benefits, weevils are also not overly sensitive to their surroundings. While they prefer to be placed in areas with rich sediment, they will adapt in less ideal conditions (Sheldon, 1997). Finally, weevils have been used in the Kawartha Lakes for previous studies and shown some success, indicating that they would be suitable for the area (Cooper, et al., 2017).

Weevils do also come with some disadvantages. Unlike rototilling or hand harvesting techniques, using weevils for control will not yield immediate results like the general public usually expects to see (Reeves, Kershner, and Hilovsky, 2008). Similarly, because they are a biological control agent, it is hard to predict how weevils will react after being introduced. While weevils can adapt to some conditions, they are sensitive to temperature. They cannot survive in conditions above 34^{o}C, which may be a disadvantage given the ever-increasing air and water temperatures worldwide (Sheldon, 1997). Weevils also do not naturally occur in large enough populations to control EWM effectively without stocking, so it is possible restocking may be required on different occasions in the desired area (Alwin, 2009). Even once they are stocked to adequate numbers, predation risk can make them unsuitable for an area (Harvel, Knight, and Miazga, 2017; Miller and Crunkilton, 2019). Another disadvantage seen with any biological control agent is the risk of introducing pathogens or parasites to the site (Sheldon and Creed, 2003). Finally, because the weevil larvae have the most notable effect on EWM, they must be given the proper conditions for survival to produce the desired outcome of significantly lowering biomass of EWM in a given area (Sheldon and Creed, 2003).

Drawdown

Drawdown is a less used management method that saw moderate success of EWM control throughout the 1980s and 1990s when more research was conducted (Lonergan, Marsicano, and Wagener, 2014). Drawdown of a lake occurs in the winter with a reduction in lake water level, usually by around two metres (Lonergan, Marsicano, and Wagener, 2014; Siver, et al., 1986). Drawdowns can be done either shallow by reducing the water level by up to 2.5 metres or deep by reducing the water level up to three metres, depending on the depth of EWM growth (Lonergan, Marsicano, and Wagener, 2014).

The drawdown control method has some advantages, including it being a relatively simple and cost-effective process with near-immediate results of killing EWM within 24-48 hours of being frozen to -5^{o}C (Lonergan, Marsicano, and Wagener, 2014). Because the freezing rate does not have to be controlled as EWM does not have a tolerance capacity to freezing, this process is amongst the easiest (Lonergan, Marsicano, and Wagener, 2014). Drawdown also reduces the risk of fragmentation as the plants are not moved prior to freezing. Finally, evidence suggests that drawdowns do not cause damage to the native species in the lake (Lonergan, Marsicano, and Wagener, 2014).

On the other hand, it is possible that drawdowns may cause erosion to the shoreline, can lead to a loss of animals that are overwintering in the lake, and could potentially lead to a loss of non-target species that are affected by the lowered lake level (Lonergan, Marsicano, and Wagener, 2014). Surveying must be done to record the depth of EWM rootbeds to ensure a deep enough drawdown; otherwise, deeper-rooted populations will persist (Siver, et al., 1986).

*Ctenopharyngodon Idella (*Grass Carp)

Ctenopharyngodon idella as a biological control agent is another invasive species control method that is not used as often as some of the critical approaches previously listed. Like the weevil, grass carp introduction is a biological technique for managing EWM in certain areas. It can be stocked to an area just as the weevil is, with one study citing an average of 50 grass carp per hectare added for control in four Florida lakes (Van Dyke, Leslie, and Nall, 1984). Studies carried out using grass carp as a control method have produced positive results, with one noting a decline in percent frequency of EWM from 45.6% to 21.1% in eight years (Leslie, et al., 1987; Van Dyke, Leslie, and Nall, 1984). However, it is essential to note that grass carp are an invasive species that carry a long list of harmful effects for the areas they make their way into. Although they will be discussed herein for the sake of comprehensiveness, grass carp are not a reasonable control option as they are illegal to release in Ontario (FOCA, n.d.). The harmful effects of this species will be discussed following the possible advantages of this option in terms of EWM control.

There are two main advantages to using this method. Grass carp are very selective, just like the weevil, so they do not usually eat any species that are not favourable to them (Leslie, et al., 1987). They are also easy to contain in one area as barriers can be put up to prevent their expansion to other areas of the lake (Leslie, et al., 1987). However, the fish may find a preference for another non-target species in the lake that could lead to it being destroyed (Leslie, et al., 1987). Having to place barriers or recapture the carp may be required, which would increase costs and could lead to an ineffective outcome for this method. Although this method has been researched by many, it has been found that grass carp do not particularly enjoy Eurasian watermilfoil unless other species are less desired or less available. This could endanger other non-target species if more desirable to grass carp and therefore take much longer to see decreases in EWM (Leslie, et al., 1987; Van Dyke, Leslie, and Nall, 1984). Additionally, grass carp are dangerous to release in Ontario due to their natural ability to outcompete native species for basic needs (OFAH/OMNRF Invading Species Awareness Program, 2021b).

Suction Harvesting

Suction harvesting or diver-assisted suction harvesting (DASH) uses vacuum systems from a boat to extract all plant material in the treatment area from the bottom of the lake. The extracted plant material is then pumped into a containment area, referred to as a wet well, on a second boat (Eichler, et al., 1993). Suction harvesting is often used closely with hand harvesting. There are several advantages and disadvantages to this method, with the disadvantages being significant enough that some organizations will avoid its use.

Some key advantages of suction harvesting include steering the vacuum around groups of native plants to prevent total clearing of the treatment area, which is seen with bottom barriers (Codd-Downey, 2020). Similarly, the harvesting effort required for eradicating EWM can be dramatically decreased after the initial treatment period. One study showed that just 20% of the initial harvesting effort was required for maintenance treatments in Lake George (Boylen & Sutherland, 1996). This method has also proven its efficacy in some studies with the ability to reduce EWM from the most abundant species to the fifth most abundant species in Lake Geroge, by percent (%) cover, in as little as 28 days (Boylen & Sutherland, 1996). In addition to its efficacy, suction harvesting has also been noted as being 50 times faster than hand-harvesting, bringing up approximately 2m^2 of plant material in just five minutes of treatment (Codd-Downey, 2020). Finally, this method could reduce the possibility of fragmentation that hand-harvesting exacerbates as all plant material is immediately sucked into the hose for disposal. However, more research is needed on the longer-term impacts of this method for risks and impacts to the ecosystem.

The disadvantages of using suction harvesting for EWM management range from issues with efficacy to cost concerns. Some studies have shown that suction harvesting cannot eradicate EWM entirely and significantly impacts native species in the treatment area every time it is used (Boylen & Sutherland, 1996). Suction harvesting can also be less effective depending on the conditions it is used in: if sediment is too dense, complete root extraction may not occur; but if sediment is too soft, this method could eradicate non-target species found dwelling on the bottom of the lake (Codd-Downey, 2020). Suction harvesting is also one of the most expensive methods for invasive species control as it comes with a significant cost for installing the suction system on the boats used, ongoing costs for running and maintaining the equipment, and associated expenses for the diving crew (Codd-Downey, 2020; Dunbar, 2009). Finally, this method can be disruptive to aquatic organisms and surrounding property owners alike as it generates vibrations and noise pollution during the treatment periods, which can last for days at a time (Tucker, 2017).

Herbicides

There are a number of herbicides cited in the literature as appropriate chemical control methods for EWM. The main chemical treatments used for invasive species control in North America include herbicides such as diquat, endothall, triclopyr, fluridone, and 2,4-D (US Army Corps of Engineers, 2011). However, only diquat is approved for aquatic use in Canada (Simkovic, 2020). There are a number of advantages and disadvantages to each herbicide but given the inability to use anything but diquat in Canadian aquatic environments, only the specifics of diquat will be more thoroughly discussed.

Some of the advantages of using diquat to manage EWM are that it has been proven to be an effective control method of invasive species; it works quickly after application with results as soon as 30 minutes after exposure; and it has a lower cost than other methods like suction harvesting (Raine, 1998; Simkovic, 2020). The price of diquat is approximately $8 per acre when applied according to the manufacturer's instructions; however exact prices vary significantly among the limited sources available (Raine, 1998). More generally, herbicides can have advantages such as allowing herbicide-tolerant native plants to grow with less competition as the target species dies; allowing the target species to provide structural habitats and excess oxygen as they die; and not inciting any public use restrictions such as fishing, swimming, or potable water use for extended periods of time (US Army Corps of Engineers, 2011).

The disadvantages of using chemical management techniques often outweigh the advantages. Diquat, in particular, has negative aspects because it is damaging to all plant species, including native plants, even at its lowest acceptable dose of 74 micrograms per litre (µg/L) (Simkovic, 2020). Simkovic, 2020, also described other effects of diquat, including negative pressure on micro and macroinvertebrates in the area, increased risk of eutrophication, increased public concern over the safety of the water, a limited application timeframe (as diquat can only be used after July 1st and can only be used once per year), and public use and consumption restrictions for five days after application. As with herbicides in general, other disadvantages to using diquat include the herbicide only being suited to small treatment areas, the need for multiple treatments over a long period of time, and some becoming inactive very quickly if they are applied in unsuitable conditions (Codd-Downey, 2020).

Integrated Approaches

Integrated approaches were discussed in many articles as a way to adjust the method they used for better results. Integrated or combined approaches offer a unique double defence against EWM, making it much more targeted and applicable to a specific area. Integrated approaches are preferred for many different scientific studies as they can address more than one concern and produce better results. For EWM control, an integrated strategy that merges methods for declining EWM while increasing native species has a higher potential for producing the desired long-lasting outcome (Madsen, Wersal, and Woolf, 2015). A combined method of targeted control and promotion of native species has been noted as the most sustainable and cost-effective method for effectively managing EWM long-term (Madsen, Wersal, and Woolf, 2015). Many studies have used more than one management technique in the same area at a given time in order to increase the overall effectiveness of their treatment program (Adamec and Husák, 2002; Alwin, 2009; Boylen, Eichler, and Sutherland, 1996; Cooper, DeBues, and Sager, 2017; Newroth, 1993). While studies using integrated approaches saw vast improvements in the stem density of EWM in their specific lakes, two critical issues arose when using an integrated management technique. The main issue with a combined approach of a few techniques is not able to monitor the efficacy of each approach on its own to determine if they are best for the given environment (Codd-Downey, et al., 2020). In combination, it is more difficult to recognize which of the methods is either less effective or unsuitable for the current conditions. Similarly, employing workers with varying levels of attention to detail and utilizing equipment with varying levels of accuracy can limit the overall estimation of suitability for the different approaches being used (Codd-Downey, et al., 2020).

Management Options Summary Chart

Table 1: Summary chart listing the method name, advantages, disadvantages, and costs associated with each EWM control method. All prices in this chart have been roughly calculated from above amounts to account for inflation rates.

Method	Advantages	Disadvantages	Cost
Rototilling	Does not limit public access to areas between treatments. Has a lower chance of fragmentation due to being carried out in the fall. Has proven to be effective (63-90% reduced stem density immediately). Suitable for large-scale projects. Only one treatment per season is necessary. Can be used as an effective localized treatment. Cost and effort can be reduced over time.	Possibly ineffective over longer periods. EWM can re-establish itself within one year after treatment. Can harm aquatic species. Puts stress on ecosystems in the lake. Could possibly expose the water to the contaminants held within the sediment. Time-consuming. Expensive.	Roughly $0.30 per m^2 (For the Okanagan Basin Water Board, by 2013).
Hand Harvesting	Could be cheaper than other methods, depending on the size of the treatment area. Cost can be further reduced as EWM declines. Proven effective with over an 80% EWM reduction in one study. Has minimal impact on native and non-target species.	Fragmentation is a key concern. Takes a lot of time and effort. Requires a high degree of attention to detail. Divers are needed in deeper waters.	Approximately $600-$700 per kilogram of EWM dry weight.

	Has little impact on aquatic fauna. Recommended maintenance is only required every 2-3 years.		
Bottom Barriers	Can be used alone or in combination with other methods. Proven it can be successful in EWM control by up to 100% in 8 weeks. Biodegradable options. Fragments are contained under mats. Biodegradable types can degrade in 2-3 years without intervention. No residue or chemical changes are left in the water with the use of biodegradable options. Durable and permeable. Some types allow native species to grow on top. No long-term damages. Increase native species competition, which can naturally help control EWM.	Harm native species. Not good for areas with high public use. Cannot be tampered with once laid down. May require sediment removal in some situations. Possible that they do not control EWM for long periods, with evidence of a 71% regrowth in 1 year. Issues such as billowing can occur naturally, ruining placement. Susceptible to damage or dislocation, making mats ineffective.	Approximately $13 per m^2 2 metre by 8-metre coconut fibre mats were $325 each in 2018 for the Chandos Lake project. Containment curtains would be an extra cost, at approximately $5,000 per year for the Farlain Lake project (2019-2021).

Milfoil Weevil	Mostly self-sustaining. Highly selective, preserving native species. Require fewer treatments over time than some other methods. Do not require high levels of attention to detail as they will find EWM on their own. Adaptable to different sediment conditions. Have been successfully used in Kawartha Lakes.	Do not yield immediate results. Hard to predict how they will respond. Sensitive to temperature conditions over 34ºC. Not naturally occurring in large enough numbers for EWM control without intervention. At the risk of predation. Could bring pathogens/parasites to the area. Larvae need optimal conditions to thrive.	Approximately $1.26 per weevil with a minimum of 10,000 to 50,000 weevils required per project.
Drawdown	Simple. Cost-effective. Occurs quickly, killing EWM within 48 hours. Does not require controlled freezing. Reduces risk of fragmentation. Do not cause long-term damage to native species.	Could cause erosion. Can kill species overwintering. Could lead to a loss of non-target species. Surveying must be done regularly to ensure a deep enough drawdown to kill EWM roots.	Low to no cost to the DSLPOA as Parks Canada manages the annual drawdown of the lake as part of the Trent-Severn Waterway servicing projects.

Grass Carp	Can be stocked to the required numbers based on the introduction site size. Have shown some success with EWM control, such as a 24.4% decline in EWM in 8 years. Selective; will not eat many native species. Easy to contain.	Although they have proven effective, some studies have shown that grass carp do not initially like EWM. Having to contain or capture the carp would increase costs and effort. Could be ineffective, hard to know how the carp will react to the new environment. Could put non-target species at risk of eradication. Could take much longer to see damages to EWM if the carp prefer a different species in the lake first. Illegal to release Grass Carp in Ontario.	Between $6 to $20 per fish.
Suction Harvesting (DASH)	Can steer the vacuum around native plants, preventing some impact. Harvesting efforts can be decreased over time. Proven efficacy. Up to 50 times faster than hand harvesting. Could possibly reduce fragmentation risks.	Some studies have shown that this method does not completely eradicate EWM. Has a significant impact on native species. Can be less effective depending on the conditions it is used in; sediment plays a big role. One of the most expensive methods. Disruptive to aquatic organisms and property owners due to the noise pollution it creates.	Approximately $45,000 for DASH equipment, SCUBA, and trained divers on contract for four days for the Farlain Lake project (2019-2021).

Herbicide (Diquat)	Proven to be effective. Works quickly after application. Lower cost than some other methods. Can allow native species to grow if they are herbicide-tolerant. Target species provide structural habitats and oxygen as they die. Public use restrictions are only in place for up to a week following treatment. Lower fragmentation risk.	Damaging to all plant species. Puts negative pressure on all macroinvertebrates in the treatment area. Increases the risk of eutrophication. Could increase public concern regarding the safety of the water. Has a limited timeframe for application, once per year and not before July 1st. Has restrictions against public use and consumption for five days after treatment. Many herbicides are only suitable for small areas. There is a need for multiple treatments over time. Some herbicides can quickly become inactive in unfavourable conditions.	Limited price information is available. Approximately \$0.004 per m^2 \$1,100 for one day if used as a spot treatment for the Farlain Lake project (2019-2021).

Integrated Approaches	Are more targeted and effective than using one method. Highly adjustable to the area, budget constraints, and preferences of the organization. Can address more than one concern at a time. Produce better, quicker results. Merges methods of decreasing EWM while increasing native species, giving the native species a better chance of survival and the possibility of a positive, long-lasting outcome.	Combining approaches takes away the ability to evaluate each method on its own. Could cause setbacks if one method is not suitable for the environment. Using volunteers of different levels of training and attention to detail causes inconsistency. More costly up front as multiple methods are being used.	Cost depends on the options being used together.

Comparative Analysis of Burlap Bottom Barriers and Coconut Fibre Bottom Barriers

Burlap bottom barriers, also known as jute barriers, are applied generally using the same techniques as coconut fibre or coir bottom barriers. In treatment areas of more than $200m^2$, the best way to lay burlap or coir bottom barriers is by using a mat dispenser mounted onto a boat. The dispenser lays the mat directly onto the water surface, where it can quickly become submerged. Divers lay the mat down to the desired area, ensuring there is no billowing or folding in the material before placing weights along the edges of the mat to keep it in place (Caffrey, et al., 2010). Studies have shown that coconut fibre mats are best weighed down with heavy rocks to prevent billowing and allow the mats to become fully saturated with water without moving (Cooper, DeBues, and Sager, 2017). Studies on the use of burlap bottom barriers have demonstrated that special weights or burlap sandbags placed at selected intervals around the edge of each mat are the ideal methods (Caffrey, et al., 2010). Benthic barriers can be supplemented by adding native plants on top of the barrier, potentially increasing native species' competition as growth through the barrier occurs. The mats can then be left in place until they degrade, which is one of the key benefits to these types of barriers—the lack of required upkeep.

More studies on the use of burlap barriers than coconut fibre barriers make the estimated cost of using coir mats hard to find. One study mentioned using coconut fibre mats to treat Eurasian watermilfoil in Chandos Lake; they found 2x8m bottom barriers to cost approximately $325 each, excluding installation costs (DSLPOA EWM Working Committee, n.d.). In addition to this, I have reached out to *Cocomfort*, the only legitimate, organic, Canadian-based coir geotextile and mat seller I could find. I have requested a quote, but I have not heard back from them at this time. A number of studies have used burlap bottom barriers for invasive species control; however, only one study talked specifically about recent prices for this type of material. Dense burlap (610 g) can cost approximately \$4.78 per m^2 (Wood, 2017). When it comes to choosing a mat material based on cost, looser woven burlap options (200 g) may be cheaper and better for allowing gas exchange. However, because the coconut fibre showed much lower regrowth and biomass than both loose and dense woven burlap, it may be worth the extra cost (Hofstra and Clayton, 2012; Wood, 2017).

Benthic barriers have shown varying levels of success when used for the treatment of Eurasian watermilfoil. However, the type of mat material used does not seem to significantly affect the time it takes to see effective results. Coconut fibre mats have produced successful results in five months, preventing 40-95% of plant growth through the barrier for nine different tested species (Hofstra and Clayton, 2012). One study suggested burlap bottom barriers could reduce EWM biomass by up to 100% in just eight weeks, and another study noted complete success in as little as four months (Caffrey, et al., 2010; Laitala, et al., 2012). Even with the quick results that benthic barriers can produce, it is possible that Eurasian watermilfoil can regrow once the mats have degraded; therefore, several annual treatments are often required to see more permanent results.

Both burlap and coconut fibre benthic barriers are natural and biodegradable, putting them in the preferred material category of barriers available. Consequently, they have very similar advantages and disadvantages associated with their ability to be environmentally safe. These can be found in the control methods summary table, with some specific pros and cons listed in the table below. Due to their similar compositions, the main differentiating factors are their cost and sizing options.

Comparative Analysis Summary Chart

Table 2: Summary comparison of the method, cost, outcome, advantages, and disadvantages of coconut fibre benthic barriers and burlap benthic barriers.

	Coconut Fiber Mat	Burlap Mat
Method For Treatment	Larger areas are often covered with the help of a boat-mounted mat dispenser and divers in the water to guide mat placement as it sinks. Smaller areas can be treated by divers manually laying the mats without the help of a dispenser. Weights are then placed along the edges of the mats to keep them in place so they will not billow, move, or become damaged. Mats can be cut to an appropriate size for handling. After placement, the mat will not need to be removed as it will degrade.	Larger areas are often covered with the help of a boat-mounted mat dispenser and divers in the water to guide mat placement as it sinks. Smaller areas can be treated by divers manually laying the mats without the help of a dispenser. Weights are then placed along the edges of the mats to keep them in place so they will not billow, move, or become damaged. Mats can be cut to size for either of these methods. Mats are left in place until they degrade.
Time of Placement	Mid to late July.	Late June or July.
Cost	~\$20.31/m^2	~\$4.78 per m^2.

Outcome of Treatment	Has shown success in limiting plant regrowth through the barrier. Can be effective in less than four months.	Has varied success based on the thickness of the woven yarn used. Can be effective in less than four months with evidence of success in just eight weeks.
Advantages	pH neutral. Best for limiting species growth through the barrier when compared to burlap. Can come from a Canadian company that carries only organic products.	Do not create anoxic conditions. Durable. Can be certified organic to prevent any chemicals from entering the water.
Disadvantages	Non-selective; can kill all species underneath it. May be more expensive than burlap. Weights used to hold it down can sink into the sediment. Can billow or become displaced. Inhibit public use of the treated areas.	Non-selective; can kill all species underneath it. Weights used to hold it down can sink into the sediment. Not as effective as coconut fibre for reducing plant growth. Can billow or become displaced. Inhibit public use of the treated areas.

Conclusion

This study has found a number of viable control methods for EWM outbreaks. Using this data, it can be determined that an integrated approach using hand harvesting and bottom barriers seems to be the most cost-effective and time-effective technique because it allows for optimal results in specific areas as needed, without long-term harmful effects to native species. In addition, such an integrated approach would allow the Drag and Spruce Lakes Property Owners Association to continue providing their services and programming without any major disruptions to lake access in affected areas. For bottom barriers, thick untreated burlap matting may be the best choice given its low cost compared to coconut fibre matting and its versatility when it comes to placement and sizing options. Similarly, while coconut fibre matting has shown success in just four months, burlap matting has proven successful in as little as eight weeks. While other methods mentioned may also prove successful, many require more research to better understand their efficacy. Finally, method cost, availability, legislative restraints, the effort required, and time constraints can make other methods less suitable for the Drag and Spruce Lakes area.

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Appendix A

Figure A1. Locations of currently recorded EWM outbreaks in the Drag and Spruce Lakes. Retrieved from: https://www.google.com/maps/d/u/0/viewer?ll=45.08017517158591%2C-78.40736806663408&z=13&mid=1hQwcWgRmU5LQnPlgKIQSz3h9LEGpCnBk.

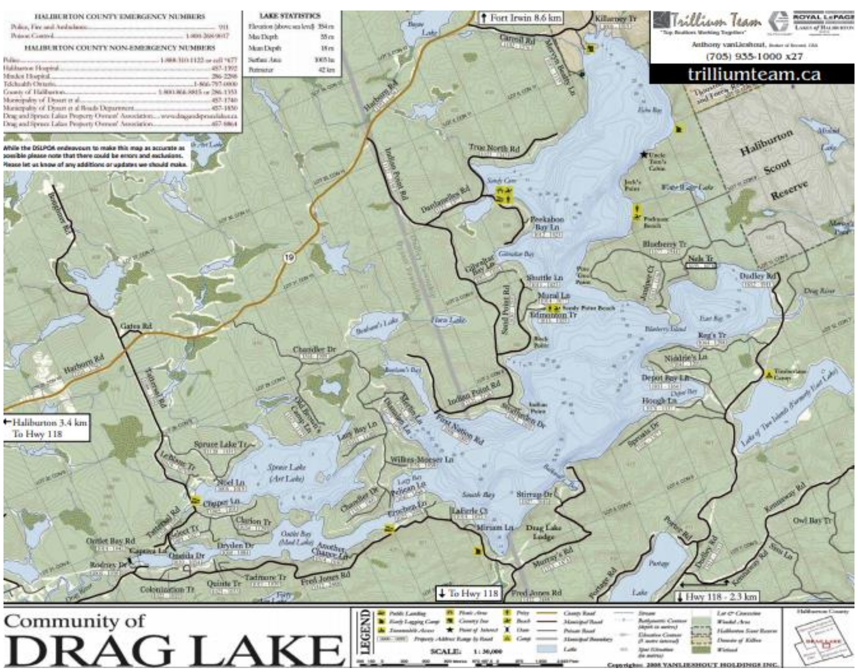

Figure A2. Map of the Drag and Spruce Lakes area in Haliburton County. Retrieved from: https://cewf.typepad.com/DragSpruceMaps.pdf.

Figure A3. Eurasian watermilfoil. Retrieved from: https://www.lakegeorgeassociation.org/educate/science/lake-george-invasive-species/eurasian-milfoil/.

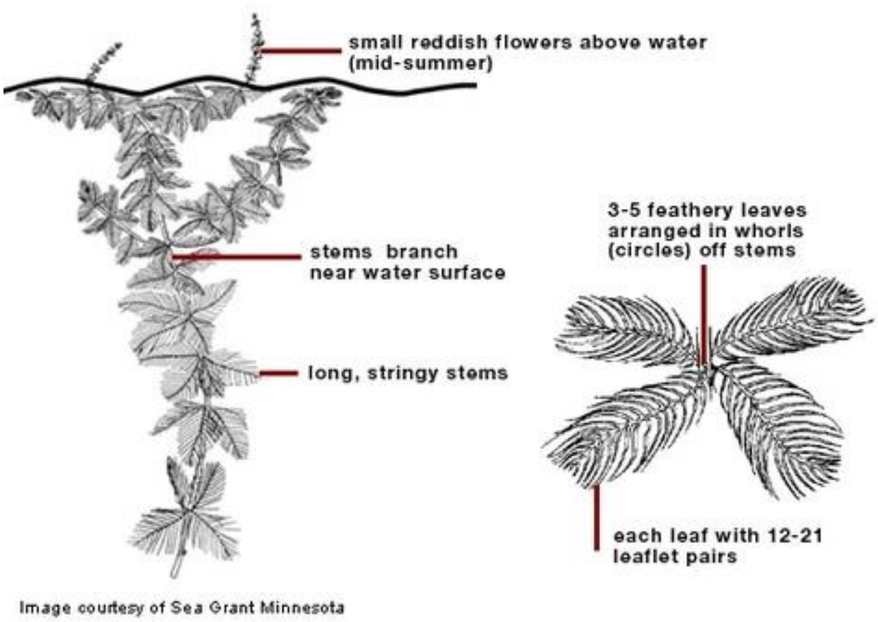

Figure A4. Descriptive photograph indicating key points of Eurasian milfoil morphology. Retrieved from: https://www.watershedcouncil.org/eurasian-watermilfoil.html.

Figure A5. Comparison of Eurasian watermilfoil and Northern watermilfoil physical characteristics. Retrieved from: https://twitter.com/invspecies/status/1276142420120539142?lang=de.