Green Pond Demonstration Project: Aquatic Invasive Species Management

2022 Report

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Acknowledgements

This project would not have been possible without the volunteer work of many people, too many to name. Particularly noteworthy, are the volunteers from the Green Pond community who made significant contributions of time and effort, many of whom had previously helped their lake as members of the Lake Watchers and the Milfoil Action Committee. Green Pond is truly "A Volunteer Community."

We express enormous thanks to the Green Pond Corporation and Lake End Corporation Boards of Directors for working together with HIGLIN so willingly and enthusiastically, supporting this Research and Demonstration project. Special thanks to the Board members who served on the Steering Committee for their guidance and support. The Board's support HIGLIN helped create results which will benefit the lakes in the Highlands Region.

The leaders and staff of the New Jersey Highlands Coalition were critical in making this project happen through their fiscal sponsorship and administrative service. Their encouragement and support boosted our confidence to move forward.

We must recognize the work and dedication of the professionals of the Dive Team including the foremen, the team scientist, the divers, and the assistants who performed with competency and enthusiasm.

This project and the establishment of a dive program would not have been possible without the generous donations from the community and the corporations.

Learn more about HIGLIN, AERM, and the dive program at www.HIGLIN.org. Contact us at HIGLININFO@gmail.com and see photos of this season's dive team in action on Instagram at HIGLIN2020.

This report was produced by members of HIGLIN and AERM with contributions from Peter Steensma, Eric Gustavsen, Emilio De Lia and Gerald Principe. HIGLIN would like to acknowledge and thank Paul and Trudy Heerema for lake temperature data collection and Manny Loizides for lake depth history data.

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1. Executive Summary

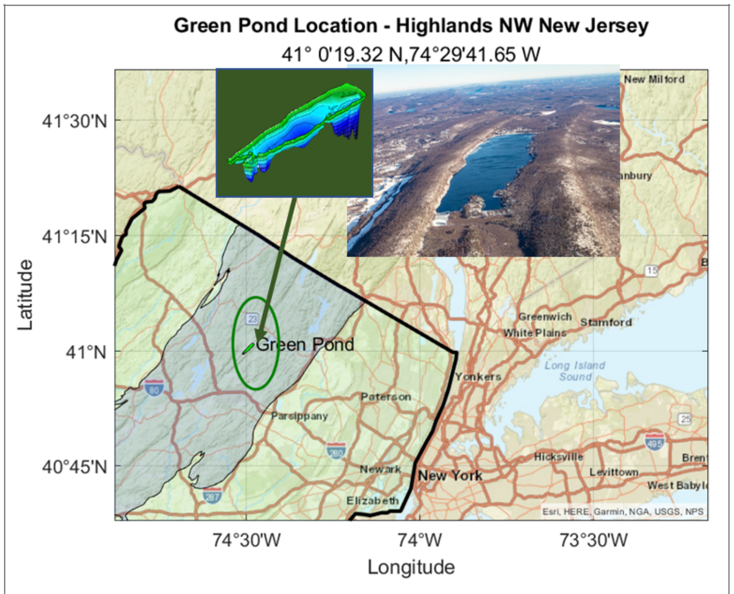


Figure 1 Green Pond is a glacial lake in the Highlands Region of New Jersey. The region provides drinking water to 6.3 million people

The Highlands region of New Jersey provides clean drinking water to over 6.3 million people. In 2019 the Highlands Glacial Lakes Initiative was formed to develop and demonstrate improved invasive species management techniques using diver-based removal. Green Pond, shown in the figure 1, Is a 507 Acre glacial lake in the Highlands Region, and the lake managers agreed to be a host for the project.

The project has operated since 2020. During the project different weather conditions have changed the yearly EWM level present, however the dive team was able to successfully keep EWM below nuisance levels for the duration of the 2020, 2021 and 2022 seasons and again prevented any plants from reaching the surface stopping the development of seeds.

HIGLIN and its subsidiary, Aquatic Environmental Research and Management (AERM) have identified four factors critical for performance to support HIGLIN's plan for hand removal. The four factors include new generation ISR boats, a professional dive team, early and continual search and destroy and management by predefined zones. Those factors working together are designed to improve the effectiveness and efficiency of hand removal to control invasive species in lakes. These are complimented by managing the removal by dividing the lake into nine management zones and an integrated program of operational and lake environmental data collection.

In 2022, the Dive Team started operations on May 30 and found more EWM than was present in 2021. In 2022, CLPW was higher than 2021 (155 lbs. vs 70 lbs.) but lower than 2020 (1285 lbs.) and was found only over the first 33 days of the season, the shortest period to date. This correlated with the observation of warmer water temperatures. EWM was abundant and tall with plants ranging from one foot to eight feet. This initial pattern held throughout the season. By the end of 2022, four and a quarter times the EWM was removed, 31,121 lbs. compared to 7,436 lbs. removed in 2021. There were significant early season weather differences between 2022 and 2021. In 2022 the weather was warmer leading to warmer water which both kills off CLPW (a cold-water plant) and boosts EWM growth. Furthermore, there was a drought in 2022 that, by July 24, brought the water level below the level of the outlet berm, reducing lake outflow. The level continued to drop to a level one foot less than in previous operating years and remained at that level for the rest of the growing season. A shallower lake level may have enabled EWM to grow in areas that did not have sufficient light at the bottom to permit robust growth.

In 2022 we again found the Beach Zone a hot spot, likely due to the dominant South to North winds in the lake driving fragments into shallower waters where they establish themselves. Fragments from 2021 were the likely cause of the 2022 hot spot. During the 2022 season the netting installed around the swim area in 2021, continued to captured fragments driven by prevailing winds, protected bathing areas from EWM infestation. The largest concentration of EWM was found in the North West sector of the lake immediately upwind from the beach.

Alignment of timing and intensity of seasonal EWM operations with the current weather and wind patterns is important in managing EWM. When the start of removal operations is aligned with the start of the EWM growing season, the first stage of EWM growth can be harvested. This growth spurt is fueled by starch stored in the plant's roots, and EWM uses this to establish EWM dominance over native species. As our experience in 2020 and other research has shown, the removal of these young plants will impede EWM from dominating other species and also prevent them from early season fragmentation and mature proliferation capabilities.

The results and findings of the 2022 field season highlight future approaches to controlling EWM in Green Pond and similar lakes and ponds. A professional dive team supported by ISR using Search and Destroy and management zones appears capable of covering enough acres in a growing season to responsively maintain control of EWM growth, even when faced with abundant growth arising from weather favorable to EWM.

During the 2022 season HIGLIN shared information with neighboring Beaver Lake and Lake Hopatcong, in addition to the State of New Jersey Water Supply authority. Presentations have been invited by the Northeast Aquatic Plant Management Society. This is described further in section 7.

2. The Project Challenge

2.1 Controlling Invasive Plant Species in Green Pond

In a seven-year span, the invasive plant species challenge in Green Pond grew from a single one-acre area of Eurasian Watermilfoil (EWM) in 2013 to 2019, when the infestation had dispersed over 174 acres, requiring the lake to be closed to boat traffic. At that time, EWM detected by sonar was present in 53% of the 330 acres hospitable to EWM growth in Green Pond.

During those seven years, actions taken by the lake stewards, who are the boards of the Green Pond and Lake End Corporations, highlight the inconsistent evidence of EWM from year to year. During that period, Princeton Hydro (PH), the professional lake management group supporting the lake stewards, guided the determination of EWM presence primarily based on an increasing grid of rake-toss sample points, and recommended remedial actions if required. In 2014, the one-acre area first found in 2013 was treated with the herbicide, Reward. None was detected in 2015. In 2016, EWM was found and treated in two areas. In 2017, multiple patches amounting to 7 acres were treated with Reward. In 2018, some patches were identified, but given the sparseness, PH recommended no treatment. In 2019, two separate areas of 3 and 17 acres were treated with the newly developed herbicide, ProcellaCOR. 2019 represented a dramatic escalation of the detected EWM. A sonar survey done by a volunteer in June identified 24 acres of milfoil while one completed in September found 174 acres, an over 7 times increase in one season.

In late 2019, the lake stewards engaged HIGLIN to develop a plan of action. From 2021 to 2022, HIGLIN executed the first two years of the Green Pond Demonstration Project. The project seeks to demonstrate the efficacy of controlling EWM through hand removal supported by Invasive Species Removal (ISR) technology. The three-year results of the project are: EWM was controlled successfully. EWM never presented a nuisance, and never breached the surface preventing the spawning of any seeds. Of note, the inconsistent pattern of EWM presence continued during the last three-year interval with 2020 showing dramatically less than would be suggested by the end of year 2019 presence and 2021 and 2022 showing progressively higher levels.

2.2 The Challenger: Eurasian Milfoil (EWM)

Invasive species, also known as “non-native”, or “alien”, have been found in the United States since colonization. Since the start of globalization, this phenomenon has impacted most places in the world. Species evolved for a certain set of conditions can wreak havoc on an ecosystem that has developed without them, and so there have been many invasive species removal projects to restore balance to ecosystems in trouble. Well known species that remain a threat are the Lionfish in the Caribbean, the Cane Toad in Australia, and the Zebra Mussel in the United States.

The focus of this Research and Demonstration project is the invasive aquatic species Eurasian Watermilfoil (Myriophyllum spicatum). This aquatic plant is native to diverse freshwater systems in Europe, Asian, and northern Africa. Due to the highly competitive growth environment found in its native areas, EWM developed the ability to grow very quickly once water temperatures are above a “trigger temperature” (typically 60 degrees at Green Pond latitudes). The first seasonal stage of milfoil growth is fueled by starch stored in the plants' root system. That boost gives EWM a "head start" in its competition with other species. Once it is the first to reach the surface the plant forms a canopy, denying other slower growing plants the light, and allowing it to exclusively dominate an area. Once established, EWM has multiple ways of reproduction (Smith and Barko 1990): seeds, root shoots, tip rooting and fragmentation.

The most notable is fragmentation, which can occur two ways. 1) Auto-fragmentation consists of plant segments growing roots and breaking free to settle and grow in other areas. 2) Mechanical fragmentation (also called allo-fragmentation) occurs when the plant is disturbed by factors such as wind and boat turbulence and boat props chopping up the plant. 3) The plant also sheds shoots from its lower portions as they are shaded by the plant's canopy residing closer to the surface. These shoots can drift to the bottom and form root structures. Auto-fragments can survive 45 days or more before rooting and can be carried over long distances by currents. Fragmentation, particularly auto-fragmentation, is at its height near the end of the season when the plant is most fragile and readily fragments.

Once mature root systems are established in the benthos (Perkins and Sytsma 1987) it can rapidly colonize an area and expand its exclusive domain. These mature root systems or stolon's, yield taller and more densely growing plants each year, that outcompete native species for space, light, and nutrients (Madsen et al. 1995). When dense EMW patches grow to the surface, their canopies eventually create large floating mats that impede watersports and decrease property values. In this final stage, the plant produces flowers on the surface which fertilized and create seeds that can stay dormant for up to seven years, compounding the problem. Given the effectiveness of EWM to complete with other species, it is no wonder that once established, lake communities have a difficult time controlling this invasive species. The recent application of genetic analysis to EWM infestations has shown they can hybridize with native milfoil species and the hybrid species exhibits many invasive traits. Eradicating EWM early can help avoid this.

Multiple methods of removal have been used for EWM invasions in the past. The most widely used technique are large-scale herbicide treatments. Other methods include mechanical removal, and biological controls such as introduction of Grass Carp or the Milfoil Weevil. Without the ability to predict with any accuracy how a complex and delicately balanced ecosystem will be affected by the introduction of a new species, biological controls are widely discouraged. Herbicide treatments and mechanical removal although effective and safe for humans, may also have unintended consequences on an ecosystem. The reduction of native and invasive fragmenting plants increases the amount of nutrients in a water column, and along with the decaying plant material directly from herbicide treatments creates conditions for dangerous algae and bacteria blooms (Mikulyuk et al. 2020). Mechanical Removal creates fragments that can cause additional growth of the targeted invasive species.

The technique studied in this Research and Demonstration project is hand removal and is considered an ecologically responsible management technique. When implemented with Invasive Species Removal (ISR), hand removal can decrease potential negative impacts of a removal and lead to better understanding of the ecosystem involved. Along with mitigation practices like the addition of mooring balls and fragmentation nets to stop boats from furthering fragmentation, this has shown to be an effective method for aquatic invasive species removal and is discussed in detail in section 3.4, "Invasive Species Removal (ISR)".

2.3 The Challenged: Green Pond

The freshwater system that is the focus of this Research and Demonstration project is unique. Green Pond, a representative glacial-made freshwater pond in Highlands Region, is fed by natural springs with only one small outlet which flows directly into a US DOD base's wetland, stream, and lake ecosystem, before joining the Rockaway River and eventually the Passaic River. The outlet is a true marsh, meaning woody plants similar to trees dominate the growth and create important structure in the ecosystem. This outlet acts as a kind of filter for the lake and helps to sequester carbon, nutrients, and harmful chemicals. The ecosystem remains at medium productivity, which is also known as mesotrophic. Medium productivity slows the process of eutrophication, and the progression of increasing nutrients in the water column which could lead to overgrowth of algae, which has a negative cascading effective on the fish and other animals that live off the lake. Multiple endangered species like Bald Eagle (*Haliaeetus leucocephalus*), and Timber rattlesnake (*Crotalus h. horridus*) all depend on the health of this ecosystem to survive, and it is essential that it be maintained.

Aquatic plant growth in Green Pond has been variable over the last 10 years. Multiple different native species compete for dominance in the lake, but most are low-growing and remain along the benthos for their entire life cycle. The very clear water of Green Pond (Sechi Depth 8.2-10.8 ft) enables this cover vegetation over much of the lake. Ground cover reduces the success rate of EWM fragments establishing themselves and delays the development of those that are successful. (Eichler, et al, 1995) One of the most abundant aquatic plant species found in Green Pond is Naiad (*Naiad sp.)* and grows in meadow-like fields along the bottom of the lake. Similar to any grassland, this species creates a diverse ecosystem for fish, invertebrates, and other plants to grow together. Other important native species in Green Pond include Coontail (*Ceratophyllum demersum*) noted as the most abundant plant in 2020, pondweeds (*Potamogeton spp*.), waterweeds (*Elodia spp*.), and Tape Grass (*Vallinseria americana*). Each play essential roles such as decreasing shoreline erosion, acting as a food source, or absorbing excess nutrients. Combined, these plants help to keep the ecosystem healthy. Green Pond has undertaken yearly Surveys of Aquatic Vegetation using standard Rake Toss measures since (need to get date). Currently there are 40 sample points along the lake littoral.

3. The 2022 Plan

3.1 Introduction

The 2022 Research and Demonstration project envisioned a growing season in which EWM was, once again as in 2021, brought under control below nuisance levels. Control would be established solely through utilization of the HIGLIN Invasive Species Removal (ISR) capability, the Dive Team. Additionally, if at any point in the season, the Dive Team was losing control in an area, a contingent treatment of the herbicide, ProcellaCOR, would be used in that area.

The planning for the 2021 growing season occurred during December 2021 and January, 2022. The importance and viability of the HIGLIN Invasive Species Removal (ISR) approach had come to the fore because of the results realized in the first year of the project. EWM had been controlled below nuisance levels and no plants had grown above the surface of the lake. The operations would mirror 2021 in so far as the three main elements of the ISR boats, the professional Dive Team and the Search and Destroy approach would be repeated. Lake management zones would continue to be used in the management of EWM.

3.2 Hypothesis and Plan

The plan developed for 2022 was based on two assumptions: 1) the amount of Eurasian Water Milfoil (EWM) that will be present in 2022 is uncertain given the variable growing patterns over the last eight years and 2) the HIGLIN Dive Team will maintain control of EWM. Both assumptions proved to be accurate with an unexpected 4-fold increase in the amount of EWM removed. Nonetheless, the Dive Team maintained control of EWM throughout the season never allowing plants to breach the surface.

There was a desire and need to verify the capability of the Dive Team demonstrated in 2020 to manage invasive vegetation, with EWM the major component, through hand removal supported by ISR technology. Flipping the 2020 plan, herbicide treatment would become the contingent alternative if the Dive team failed to maintain control. Therefore, a two-part strategy was proposed and adopted that:

> The HIGLIN/AERM Dive Team will provide the capability and capacity to control EWM below nuisance levels.

> The use of ProcellaCOR will be held as a contingent alternative that could be deployed to address areas where the Dive Team was unable to maintain control.

The Dive Team would continue its Search and Destroy practice operating in all acres with special attention to those likely to have EWM.

3.2.1 Workload analysis

The surveillance workload is determined by the number of acres that can grow the invasive species, For EWM in Green Pond high growth risk is water depth less than 10 feet and medium risk for water levels between 10-15 feet. Green Pond from the 2013 bathymetry statistics shown in Figure 3.2 indicate that a total area of 507 Acres. Of that acreage, 159 Acres are below 10 feet in depth and support robust EWM growth and an additional 169 Acres, between 10 and 15 feet deep, can support EWM. Based on all factors, 330 acres were targeted to be physically inspected and cleared of EWM as required.

At a search rate of 10 acres per day boat day (2020 metric) a single pass would take 36 boat days. For 2022 an operating season of 108 boat days was planned which allowed for three visits. The frequency of revisiting acres is further allocated by zone based on historic pattern of EWM growth and changing conditions. A detailed discussion of the operation is contained in Section 5.

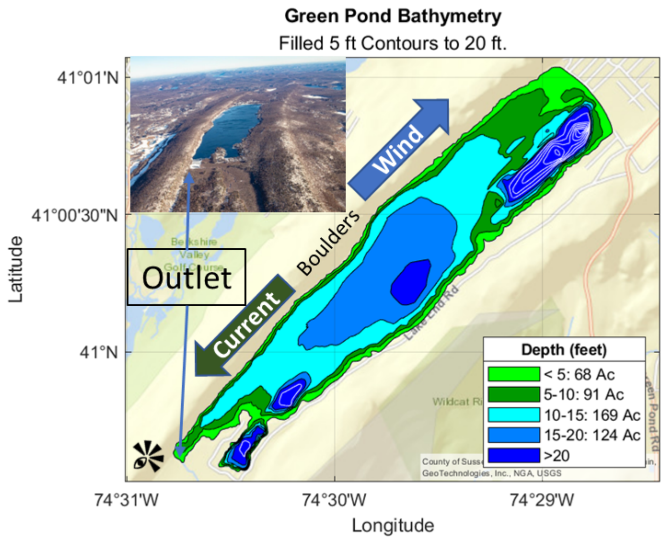


Figure 3-2 a: 159 Acres are primary EWM Areas. Additional 169 Acres can support EWM

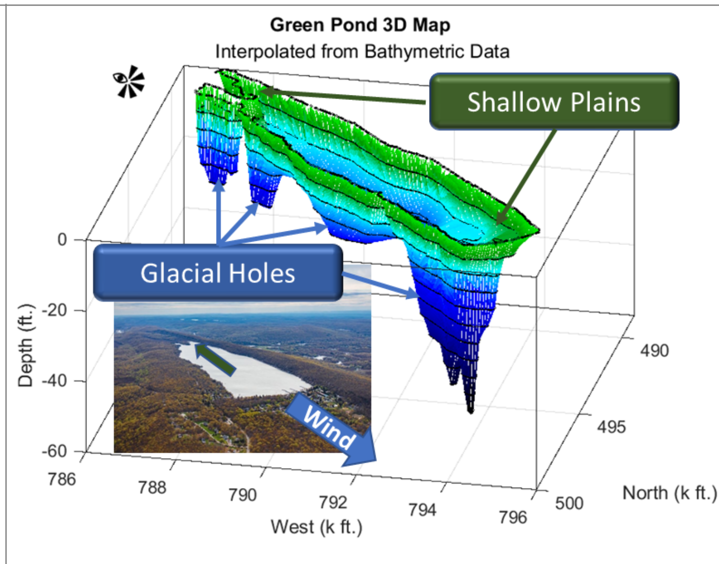


Figure 3-2 b: EWM fragments will concentrate at North and South Lake ends due to wind and current

3.2.2 Zone Based Planning

In 2021 management zones were defined to support more specific planning and tracking. Zones 5 and 6 were modified slightly in 2022 to better encompass similar growing areas. These were used in 2022 planning and operations management. The lake is divided into nine zones using a number of factors. The goal of this delineation was to ensure that each zone would be prioritized and searched with a frequency warranted by its growth patterns. The factors included depth, previously recorded growth patterns, bottom features, and natural surrounding terrain. For example, depth is one of the most important factors to consider as it relates to the growth preferences of EWM. Depth determines temperature as well as the amount of light penetrating the water column. An area made up of acres with similar depth would then be expected to have similar growth patterns, leading to better decision making about survey frequency and timing thus making better use of dive time. Figure 3.3 provides a color-coded mapping of the nine zones and feature descriptions.

Zone	Features	Zone	Features
1.Beaches	*North end of the lake: marina and two bathing areas*	5. East Cove	*Deep area along the SE shore, enclosed with shallow rocky ledge*
2. Sand Bar	*Shallow sandy area s on the NW shore*	6. Mid-Lake	*Deep central area of the lake that extends from Point Comfort to the coves*
3. Seven Sisters	*West Shore area centered off houses accessible only by boat*	7. East Shore	*Shallow rocky area along the mid SE shore*
4. Outlet Cove	*Silty area along the West Shore with the outlet stream*	8. Pt Comfort	*Rocky area off the shallow point on the east shore*
Zones are defined based on common characteristics and natural boundaries		9. Bass Hole	*Deepest area of the lake located near the NE corner*

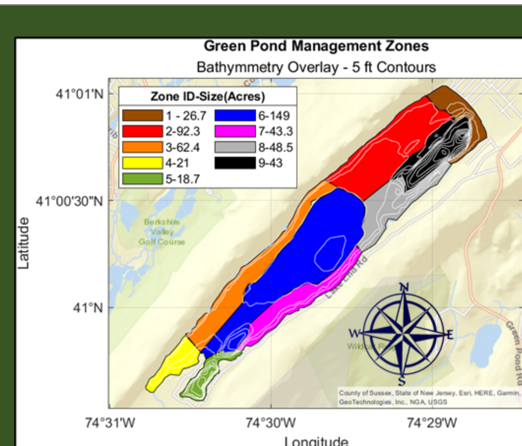


Figure 3.3 a): Management Zone features show differing growth conditions	**b) Zone Locations on lake**

The EWM risk of each of the zones can be assessed based on the water depth in that zone. The water depth in a zone is a key indicator of its ability to support EWM growth and a tool for allocating boat work time. Figure 3.4 shows how many acres in each zone are: 1) at levels less than 10 feet deep (shown in pink) where a strong EWM presence can occur; 2) levels between 10-15 feet (shown in yellow), where EWM is can occur but is less robust; and 3) levels above 15 feet deep (shown in green) where EWM is unlikely. Pink Zones require frequent surveillance and extra clearance time. Yellow Zones require between 2 or 4 Search and Destroy passes a season. Green Zones require high speed passes because of their sparse slow growth in a large area.

Zone	Area in Acres				% Area < 10 ft	
	Total	*<10*	*10-15*	*>15*	*All*	*% Zone*
1	26.7	23.7	1.6	1.4	15%	89%
2	92.4	49.2	42.6	0.6	31%	53%
3	62.5	14.2	46.6	1.7	9%	23%
4	21	14.1	5.8	1.1	9%	67%
5	18.7	7.3	0.6	10.8	5%	39%
6	149.2	4.7	16.9	127.6	3%	3%
7	43.5	17.2	22.7	3.6	11%	40%
8	48.3	21.9	19.7	6.7	14%	45%
9	43	4.3	8.1	30.6	3%	10%
Total	505.3	156.6	164.6	184.1	31%	All Lake
EWM Risk		High	Medium	Low		

Figure 3.4 a: Depth Profile of each zone is an indication of EWM growth risk

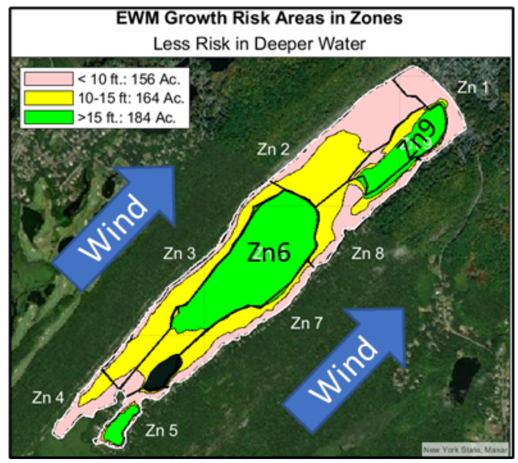


Figure 3.4 b: EWM risk map by zone helps allocate work time

3.3 HIGLIN & AERM Invasive Species Removal (ISR)

HIGLIN and its subsidiary, Aquatic Environmental Research and Management (AERM) have identified four factors critical for performance to support HIGLIN's plan for hand removal. The four factors include new generation ISR boats, a professional dive team, early and continual search and destroy and management by predefined zones. Those factors working together are designed to improve the effectiveness and efficiency of hand removal to control invasive species in lakes. Each factor will be briefly described in the following paragraphs.

The ISR boats developed by AERM and the contracted equipment supplier, although similar to existing ISR boats, contain several important innovations. The removal capability is provided by suction pumps mounted on the boat which have the power to collect plants and fragments. Plants are hand pulled by divers and fed into hoses which are suspended by buoys so that the hoses never have contact with the lake bottom. Sluice boxes, support inspection of all materials gathered by the divers and help to preserve wildlife (turtles, fish, etc.) and to separate refuse from the plant material before it was readied for disposal. Important safety features include an emergency oxygen kit, hard-wired underwater communication to stay in constant contact with divers, a dedicated hookah pump to ensure adequate air flow for divers, and air hoses equipped with filters that removed moisture and particulates to help ensure clean air for breathing. In order to minimize environmental impact, a surface floats (See Figure 3.3) are attached to each ISR hose keeping the hose-end away from the lake bottom to prevent disturbing and/or removing the sediment. In addition, to address the large infestations of EWM in New Jersey Highlands Region lakes, more removal capacity is achieved by doubling the normal removal power on the boat which allowed for double the normal level of divers to be in the water simultaneously. The resultant operation, consisting of two boats, four divers using four removal hoses during all work times, has demonstrated a remarkably level of EWM and CLPW removal capacity.


Figure 3.3: Floats attached to suction hoses

The professional dive team is built through the specification of job roles and team structure. A foreman/ boat captain assists volunteer management in recruiting and hiring the other members including one dive master/team scientist and seven diver/tenders. Experience has shown that there are many applicants who are screened by conducting online Zoom interviews. The finalists selected have exceeded AERM's initial expectations with their qualifications, certifications, experience, engagement, and enthusiasm. For two seasons in operation, the professional team working with the quality of the boats and equipment have provided significantly greater capacity than that initially forecasted.

The standard approach to hand removal had been Area Clearance. This approach is undertaken when EWM has grown to a sufficient height and density would make removal efforts more effective and efficient. More pounds of plants can be gathered within a work period. This implicitly assumes that the correct performance metric is the poundage removed rather than the more critical, impact on controlling EWM growth. An alternate approach, "Search and Destroy", was devised and used extensively in this project. The approach does not wait for the growth of large dense plants but starts seeking and removing early in the season when plants were small. Divers have a unique ability to see plants at an early stage in their life cycle. While those plant conditions are somewhat more difficult to handle, the benefit is plants are removed before they could proliferate through fragmentation and other means. EWM growth and proliferation can thus be stopped rather than allowed to happen. The key elements of the approach are: 1. Search and destroy must start early and be continual and thorough and 2. Plants must be removed in their entirety. A well-equipped ISR supported professional dive team provided the means to deliver those key elements.

Our 2020 project report recommended that the practice tested in 2020 of organizing the lake into zones based upon area qualities and pattern of EWM growth should be used to schedule the frequency of Search and Destroy in the zones during the growing season. In 2021 and 2022, the zone structure was implemented and used for scheduling, management, and reporting of the removal efforts. Additionally, it has allowed detailed 2021 and 2022 comparisons. The zone structure used is described in Section 3.

3.4 Cooperation and Access Agreement

A Cooperation and Access Agreement was developed and approved by the three organizations engaged in this Research and Demonstration project, including GPC, LEC and HIGLIN. The agreement executed in May, 2022 provided the definition of the project and the terms and conditions for the three organization. The agreement continued the use of research project's Steering Committee established in 2020. The members of the committee were members of the organizations' boards of GPC, LEC and HIGLIN. The steering committee facilitated communications and the execution of the Research and Demonstration plan. The committee was actively engaged and helped immensely during execution by reviewing observations, data, and information which led to clarification and adjustments to the plan.

4. Execution of 2022 Plan

4.1 2022 Invasive Plant Conditions

The Dive Team started operations on May 30, but immediately found higher levels than were present 2021. CLPW was found during the first 33 days of the season, a shorter time than in 2021, but at twice the level. The higher level and shorter duration correlated with the warmer water column temperatures observed. Similarly, a higher level of EWM was also observed, with the beach area the first zone of focus. This higher level continued though out the season, as seen in higher weekly harvest than in 2021. Fragments removed from the nets first installed in 2021, showed a high level of EWM activity as well. By the end of 2022, 4.2 times more the EWM was removed, 31,121 lbs. compared to 7,436 lbs. Weather was a significant contributor with higher air temperatures leading to warmer water and a drought lowering the water level, increasing the area available for EWM growth. In 2021 there had been several mid-season storms, including hurricanes Elsa and Ida (9/1-2/2021), that fragmented EWM and dispersed the fragments. These spread EWM seedling plants, particularly in the North end of the lake. With favorable early season growth conditions, it is likely that these seedlings then presented themselves in 2022 as new plants.

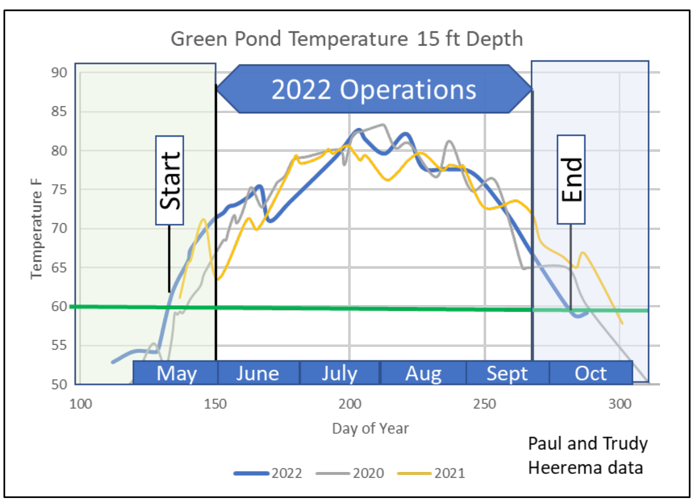


Figure3.2: In 2022 Warm Water Temperatures started earlier and dropped earlier than previous years

Water Temperature Impacts: A number of models of EWM growth, (Titus et al. (1975); Best and Boyd (1999); Best et al. (2001); Herb and Stefan (2006); Miller (2011)), show that the growth rate accelerates exponentially once the water temperature exceeds a "trigger temperature". Although root system activity begins at about 50 F, stem activity in New Jersey, is generally understood to be temperature 60 degrees F at the plant roots. As shown in figure 3.2, in 2022 this was exceeded earlier in 2022, May 12 giving EWM a head-start to dominate other species. Continued warmer temperatures in the early part of the year further accelerated EWM growth.

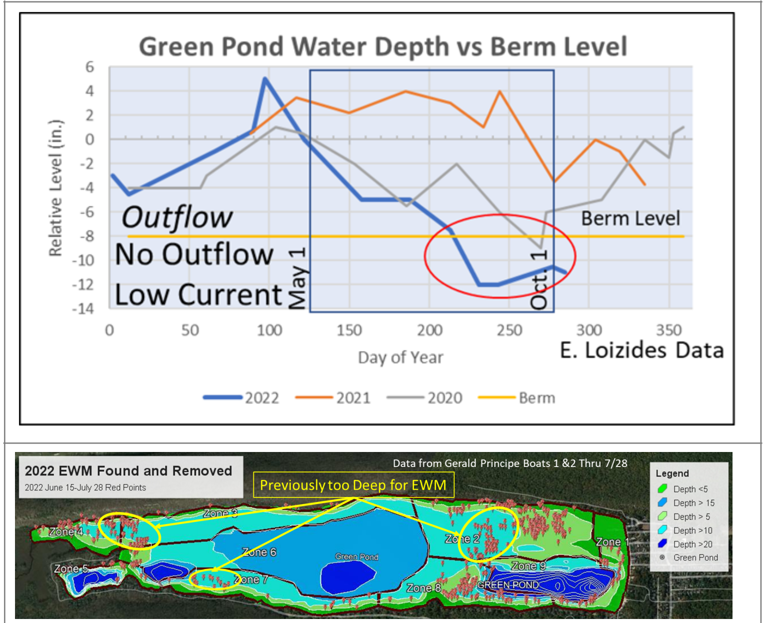
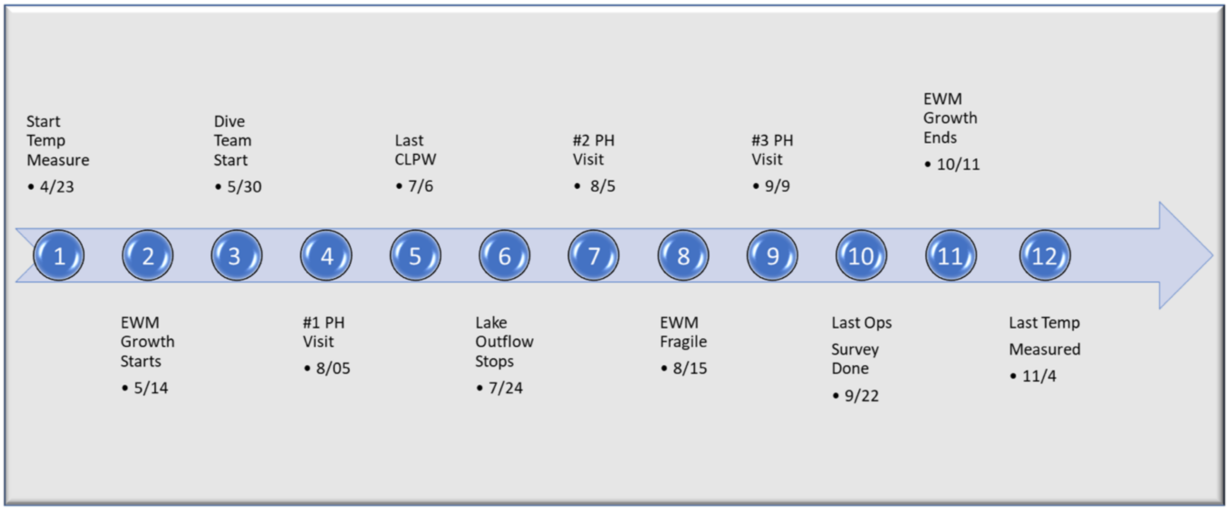


Figure 3.3: Low Lake levels in 2022 added EWM acreage

Water Level Impacts: Throughout 2022 there were lower water levels than in the last few years, as shown in figure 3.3 . After mid-season the outlet flow ceased and this continued for the balance of the season. The lower water level increased the acreage EWM can grow in and it was found in areas not previously observed. The increase has been estimated as 15 acres and because it is deeper water, the impact was felt later in the year. Longer term monitoring has shown similar drops, but 2022 was exceptionally long.

4.2 Timeline of 2022 Events and Decisions

An operating plan is likely to require adjustments when implemented due to new developments. A steering committee described in the project agreement was established to understand the actual conditions and to make decisions if changing the plan was required. The following is a numbered summary providing the highlights of the project during the 2022 growing season.



1. A temperature monitoring program was able to start on April 23 and continued throughout the season. This was earlier than last May 18 in 2021, which was delayed by a late boat delivery. This program measures the water column temperature at multiple locations in the lake.
2. Water temperature at 15 feet depth registered 60^{o}, commonly seen as a trigger point for EWM growth, on May 14 confirming an early start to the growing season for EWM.
3. Dive team operations commenced with one boat on May 30, earlier than in 2021 which started on June 7. This enabled us to respond to the earlier start of EWM growth.
4. A Princeton Hydro Lake Survey visit on June 5, found significant EWM in the Beach Area. To assure the area was cleaned before boating activity could spread it, this area was made a priority for the Dive Team. When they had done this, they moved to focus on Zone 4 and survey the rest of the lake. Princeton Hydro also confirmed that other New Jersey lakes were finding a higher EWM level earlier.
5. The last Curly Leaf Pondweed was found on July 6, more than two weeks earlier than the last 2021 encounter on July 25. This correlated with other observations of warmer water in 2022.
6. On July 24 a drought caused the lake water level to decrease below the level of the outlet berm, this reduced any outflow current. This was a decrease of 12 inches compared to previous years and this allowed more acreage to host EWM, particularly in Zones 2 and 4. Drought conditions and low outflow continued for the balance of the season.
7. Princeton Hydro Lake survey on August 5 by rake toss.
8. On August 15 many of the EWM plants that were encountered were very fragile and had fragments with developed root structures that broke off easily. This is part of the EWM reproduction cycle. The Dive

Team was able to remove plants before they reached a seed production stage. Many fragments were also found in the nets installed in 2021 to protect the Beach area. Plant sizes found seemed to be smaller than earlier in the season.

9. Princeton Hydro Lake Survey on September 9 by rake toss.
10. The season concluded on September 23 with a survey of the lake and removal of any plants found.
11. By October 11 the water temperature at the 15 foot level had fallen to 60 degrees, and the EWM was in a senescence stage, This was earlier than in 2021 date of October 20, and may have caused a higher mortality for fragments starting as new plants in 2023.
12. The last temperature measurement on November 4 confirmed the low temperature levels.

In summary, high early season temperatures (over 60 degrees) and low lake water levels led to increases EWM growth which was targeted and removed by the Dive Team before becoming a nuisance and before they could grow high enough to breach the surface and seed. No contingent treatment of the lake was recommended.

5. Methods and Measurements

5.1 Introduction

Central to the purpose of this project was demonstrating hand removal supported by ISR to determine its effectiveness in controlling invasive species. Using that approach and technology, Search and Destroy Technique was the predominant method used for locating and removing invasive plants. By combining searching and destroying into a single process, economies of effort were achieved; when plants were found, they could be removed immediately. To a lesser degree Area Clearance was another technique used when addressing occurrences of large areas of dense growth. The difference between Search and Destroy to Area Clearance is the speed at which the Dive Team moves along the lake bottom. This difference is made clear by comparing relative area productivity. In Search and Destroy mode, one boat on average can cover 10 acres a day; while in Clearance mode, one boat on average cover 1 acre per day. Removal was at times guided by the steering committee's deliberations described in section 4.2 above. Because costs associated with putting the divers into the water are high, a main goal of the methods used are to optimize what was achieved in controlling invasive species during the divers' "bottom time".

5.2 Removal Methods

Removal operations consist of both finding (search) and removing the invasive plants. If the search process is independent of the removal process, a geolocation system to transfer target to the removal team is needed.

5.2.1 Search Methods

For search to be effective, methods are needed to ensure that all acres of the lake with the potential for invasive species growth are thoroughly addressed throughout the growing season. Those sub-methods include diver detection, geo-tracking of EWM reports and boat operations, and defined survey zones.

Experiments were also conducted in 2022 on the use of underwater drones for geo-location of invasives and potential targeting of the dive efforts.

Diver detection is simply the recognition of plants by the divers as they move along the lake bottom. Because Green Pond has high clarity water, divers have good visibility to a 20-foot distance. Consequently, bottom inspection has a relatively low detection threshold, meaning the species can be accurately detected earlier in the growth cycle and at a lower density compared to other techniques. Rake toss has a high threshold, meaning a species presence must be high before detection occurs. This is due the limited number of sampling locations and the design of the rake. For example, when EWM plants are small, the surrounding more mature native plants will tend to fill the rake's tines leaving small plants uncollected. Another, alternative method is sonar survey which has a lower threshold of detection than rake toss and can be more time efficient than diver detection. Detection sensitivity and accuracy of identification are important with an aggressive invasive like EWM whose eradication requires sensitive detection. For further understanding of the range of assessment and detection methods, an analysis of alternates is provided in Appendix B in Green Pond Research and Demonstration Project: Aquatic Invasive Species Management 2020 Final Report December 26, 2020 which can be found on the HIGLIN website, www.HIGLIN.org

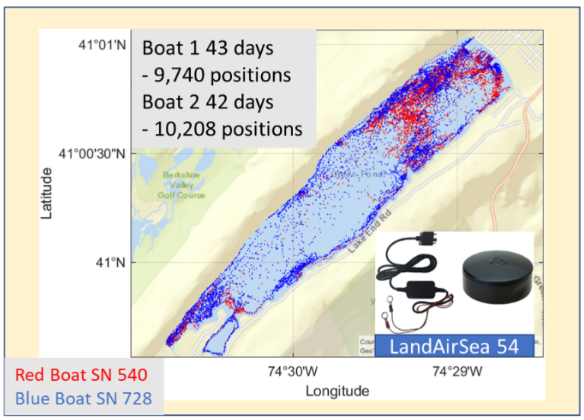


Figure 5.1: 2022 Boat Tracking Experiment

Geo-location: Boat tracking and geo-location was accomplished with software and devices which recorded the location of each boat continually using GPS positioning. GPS Traks on iPhone and the Lowrance Sonar with its GPS capabilities were the technologies used. However transferring the locations was a problem and the tracking process was a distraction to the boat drivers. In 2022 a high resolution, automatic and continuous boat position monitoring system was introduced to reduce operator workload. As shown in Figure 5.1, the units broadcast the boats GPS position over a cellular network and provides a display on a vendor web site from which the data can be download. This data was used to track the relative workload in different zones and the density of boat positions in a zone. With the tracking information they provided, quantification of the dive team's coverage of acres could happen in near real time.

The Zone location structure, previously described, serves as a geo-reference for locating where in the lake a harvest was taken from. Bags are tagged with the zone they were collected in and the statistics are recorded daily. It is also used for siting reports of potential invasive locations.

5.2.2 Destroy and Clearance Methods

The main method for both Destroy and Clearance removal is hand removal assisted with ISR. Using five-inch diameter hoses attached to a Venturi system, two divers on each boat used a technique to effectively remove invasive species found during an ISR survey. With small individual plants, the diver separates any root system from the sediment and introduces the plant into the opening

Figure 5.2 Harvesting small CPW plants

of the removal hose as shown in Figure 5.2. For larger plants a similar technique was used starting at the top of the plant and following it down to a point, where the diver reaches into the sediment and pulls out larger EWM roots. Some plants could also be removed by hand, and then brought back to the removal hose floating above the benthos with buoys. These techniques along with careful removal of invasive species lead to a very small number of native plants, animals and foreign objects entering the Venturi system and minimal sediment. Anything that was brought onboard unintentionally ran back into the lake through sluice boxes or could be removed from the onion bags. Upon removing, aquatic plant material is transported by the removal hose to sluice boxes onboard and flows into 15'' x 25'' biodegradable onion bags. Full of plant material, these bags on average ended up weighing approximately 25 pounds.

Figure 5.3 Team Diver removing tall EWM, focusing on getting all plant material and minimizing fragmentation.

Traditional hand removal without ISR was sometimes utilized in limited areas where accessibility was difficult and fragmentation of invasive species was not a concern, Pondweeds, waterweeds, and tape grass were the most abundantly found plants. Two divers using surface-to-air breathing systems hand removed all plants growing off the bottom, attempting to get the roots and slow the regrowth of native plants in the bathing area. Tape Grass was left to grow as much as possible; its large root systems help to decrease shoreline erosion and hold the beach sand in place.

5.3 Measurements

5.3.1 Removal Measures

Multiple measurements were continuously taken during the removal process. Central to achieving the research and demonstration's goals was quantifying how much EWM and other invasive plants were found and removed during the 2021 growing season. In order to ensure consistent and complete reporting of key measures, daily and weekly reporting standards were established and embodied in Daily and Weekly Reports, see Figure 5.4 for the Weekly. The Weekly Reports were compiled by the Dive Team Scientist and published and distributed widely to the project Team and the lake stewards. The report contained many key measures.

These measures are reported by zone: pounds of EWM, CLPW and other specified species removed, number of EWM plants removed, and average height of EWM removed. These measures provide a numeric picture of the scope and breadth of the EWM growing in the lake.

Figure 5.4: Weekly Measurements Reports

Additionally, operational data are provided including days worked in the week, the number of boats and divers engaged. Also, as an early warning, any areas in danger of becoming uncontrollable would be identified.

Because the weight of removed aquatic plant material is a critical measure to help determine the extent of plant growth and team productivity, a standard accepted way of measuring is used. The plants' wet weight (WW) describes a consistent measure used to establish how much each bag of plants weighs. A 10-minute drying time occurs before weighing which allows for excess surface water to evaporate and a more accurate measure. On average, bags consistently weighed about 25 pounds.

In addition to the Weekly Report measures, GPS coordinate markings of removed plants were also gathered in order to locate when and where EWM was found. GPS software on the Lowrance Sonar System and the GPS Tracks App were used to collect this data. In 2022 automated boat tracking was introduced.

Combined, all of the above distinct measures provide a comprehensive picture of abundance and distribution of plant species in Green Pond this year.

5.3.2 Temperature Measures

A volunteer temperature measurement program was maintained by HIGLIN using a Fish Hawk Sensor. Water column temperatures at 5-foot intervals were taken weekly at five locations. EWM growth is sensitive to water temperature with 60° being a trigger for EWM growth and decline. A more detailed explanation of temperature monitoring is given in **in last year's report, Green Pond Research and Demonstration Project: Aquatic Invasive Species Management 2020 Final Report December 26, 2020 Appendix A** which can be found on the HIGLIN website, www.HIGLIN.org

Figure 5.8: GP Temperature Measurement Program

5.3.3 Water Depth Measurement

In 2022 Green Pond experienced a period of drought, as discussed earlier. A resident has maintained a multi-year program of monitoring water levels at his residence. These levels have been referenced to the established level of the berm at the lake output.

6. Results

6.1 2022 Invasive Species Removal Results and Comparison to Previous Years

In the 2022 field season, a two ISR boat operation demonstrated the capacity to control EWM in the face of a 425% year to year increase (up to the 31,521 pounds) of EWM removed. The key results of that control were EWM was never a nuisance despite its increased level and no plants were allowed to breach the lake's surface preventing the production of seeds the key control factors used were to operate consistently to identify and remove invasive species' plants as they emerged and to flexibly and methodically cover zones in the lake based on historic growing patterns adjusted to current conditions.

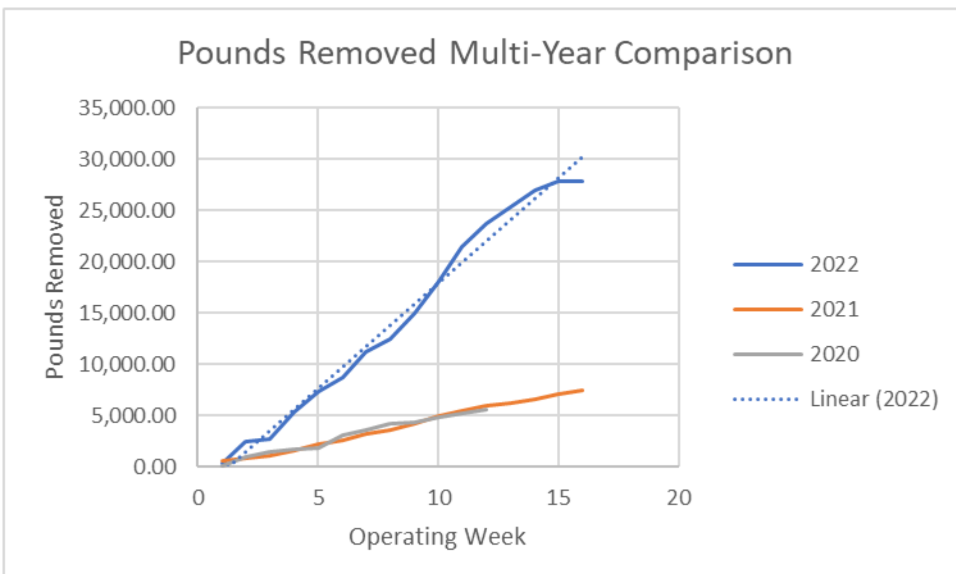


Figure 6-1 Removal comparison 2020 - 2022

Figure 6.1 shows the comparison of the cumulative pounds of EWM and CLPW removed by the Dive Team in the 2020, 2021 and 2022 seasons. The differences between years reflect changing growth conditions, largely driven by weather conditions causing water temperature changes. When early season temperatures were cold, such as 2020, a larger population of CLPW, which grows best in cold water, was found and the emergence of EWM, which grows better in warmer water, was later. Initial 2021 and 2022 temperatures were higher than 2022, substantially increasing growth of EWM while suppressing CLPW. Additionally, 2021 weather conditions, such as, storm events with high winds and heavy rains including two hurricanes, Elsa (7/09/2021) and Ida (9/1-2/2021), which impacted the water column temperatures and accelerated plant fragmentation are likely evident in the growth pattern. The Dive Team was capable of managing the peaks created by the impact of weather.

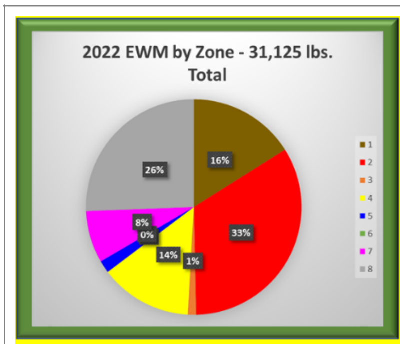
		2022	2021	2020
Growing Season	Start Date > 60 F	5/12	5/18	5/18
	Stop Date < 60 F	10/11	10/29	10/15
	Duration (Days)	152	164	150
Operating Season	Start Date	5/30	6/1	6/8
	Stop Date	9/29	9/23	9/17
	Duration (Days)	122	114	102
EWM Removed (Lbs)		31,121	7.436	1,742
CLPW	Removed (Lbs.)	155	70	1,285
	Season (Days)	33	42	63
Cleared Vegetation (Lbs)		Not Recorded	730	2,575

Figure 6-2 Key Performance Metrics from 2020 to 2022

The 2022 Dive Team operations were helped by what was learned from previous year operations. Figure 6.2 summarizes key data highlighting the similarities and dissimilarities between years. 2022 started a week earlier than previous years. The growing season for EWM was longer in 2022, it started earlier but also ended earlier, while the operating season was longer. The 2022 growing season for CLPW was shorter because of the warmer season start, although more was harvested than in 2021.

6.2 Results by Management Zone Results

As described in Section 5.2.1, the lake is divided into 9 defined lake management zones. Zones were used to schedule removal efforts, gather measurement data, and report results. The idea of zones was developed during the 2020 season, and fully implemented in the 2021 season, so good year on year comparisons can be made in 2022.



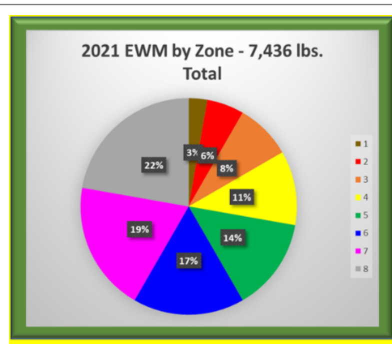
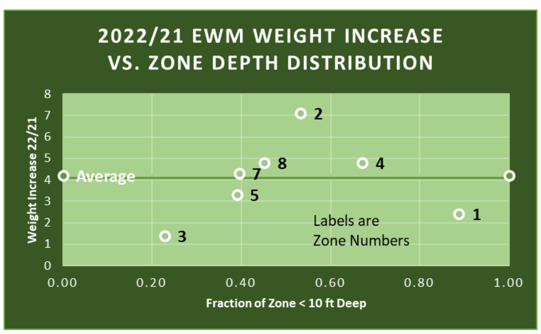


Figure 6.3: Zones 2,8,1 and 4 were largest contributors to 2022 EWM harvest. 2022 Harvest reported no zone 6 (mid-lake) harvest and small Zone 3 (West shore) contribution. Isolated Zone 5 (Outlet Cove) showed less increase than the average.

The pie charts in Figure 6.3, show the relative contributions of each zone to the total EWM removed for both 2022 and 2021. In 2022 there were significant increases from Zones 1 and 2 and significant relative decreases in the contributions from Zone 3, 5 and 6. Although a 2021 harvest was recorded from Zone 6, the 149-acre area in the center of the lake, no report was made in 2022. Similarly, the contribution from Zone 3, located along the West shore, decreased. Zones 3 and 6 cover 212.4 acres of which only 18.9 acres are at a depth less than 10 feet (using the reference bathymetry). Zone 5 is a deep closed cove in the South East corner of the lake, and its entrance area. Because it is closed and the prevailing winds go northward, away from the area, once cleared there is little opportunity for introduction of EWM other than by boat borne fragments. In 2022, Zone 5 EWM increased 3.3 times, lower than the average increase of 4.2 times The depth profile is a glacial hole and most growth is at the periphery or entrance area. To understand the increase in Zones 1, 2 and 4, further analysis is presented.

Figure A-2 in Appendix A shows a quantitative comparison of the harvest and includes data on the zone size and depth distribution. In 2022, Zones 2,8,1 and 4 (in order) contributed 89% of the EWM harvest from 189 Acres (37 % of the lake area). Zones 2, 4 ,8 and 7 (in order) showed the most significant increase from 2021 to 2022.

There are several factors that could cause this change: 1) thicker EWM growth in the area (more plants per unit area increases density), 2) plants are covering more of the zone area, which can be accelerated by lower lake levels 3) plants removed at different times of the season, when they are larger because they are either more mature and or growing in deeper water. The biomass of a plant can increases several times over the growing season.



Zone	Depth % < 10 ft.	15 ft.	Change 2022/2021 Per Ac	Ac<10
1	89%	95%	2.4	2.4
2	53%	99%	7.1	6.2
3	23%	97%	1.4	4.7
4	67%	95%	4.8	2.3
5	39%	42%	3.3	5.1
6	3%	14%	0.0	0.0
7	40%	92%	4.3	6.6
8	45%	86%	4.8	5.9

Figure 6.4 Zones Depth Profile Influences Harvest Weight Increase from 2022 to 2021. Zone 2 topography allowed 30 % increase in area less than 10 ft deep with 1 ft water drop

In 2022 the protracted drop in water level from August to October changed the growth area available to EWM. Figure 6.4 shows the correlation between the 22/21 increase in a zone's harvest and the fraction of the zone that is less than 10 feet in depth. There is a strong correlation for zones 2,4,1. Zone 1 is already almost all below 10 ft depth and showed a 2.2-fold increase, while zone 2, with a topography that increased the area by 30 % with a 1 ft level drop, showed the largest increase. Zone 4 topography did not provide for as much EWM area increase with dropping lake depth.

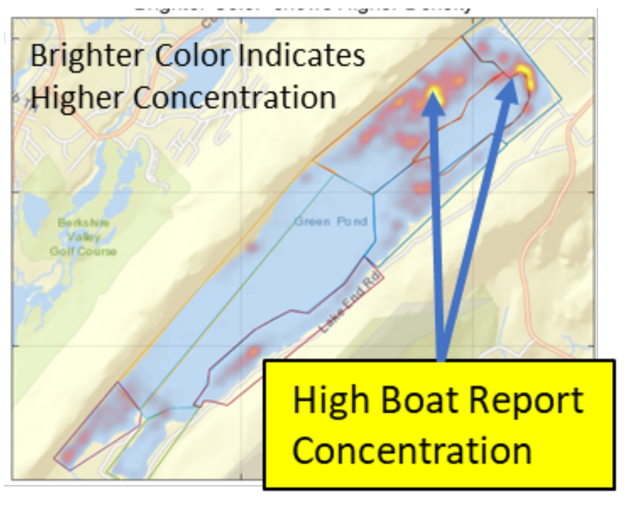


Figure 6.5: Location of highest density of EWM Removal Activity in 2022. Zones 1 & 2 took 54 % of work time for 37 % of area less than 15 ft. deep (from 6/12-8/31)

In 2022, real time boat position data was available to measure the time spent in each zone and area covered by the boats. The boat locations data from 6/12-8/31, plotted as a density of positions in figure 6.5, shows zones 1 and 2 had the most concentrated activity corresponding to more concentrated patches of EWM. Work in zones 1 and 2 consumed about 54 % of the boat work time. Zone 1 operation around the marina docks is a time-consuming process. The late season EWM growth in Zone 2 demanded extended dive time to clear.

Figure A-2 also shows the inferred EWM density for 2022 and 2021. The estimate of EWM density is made by computing both the pounds per acre and pounds per acre less than 10 ft depth (based on reference bathymetry), where most EWM is found. In 2022 the densest were zones 8,4,1 and 2 while in 2021 they were Zone 4,1,8 (in order). Zone 8 EWM density increase 5 times between 2021 and 2022, more than any other zone. Why? To evaluate this further a comparison of zone removal results was made between 2021 and 2022.

Zone work schedule Figure 6.6 looks at when the densest areas (zones 1,2,4 and 8) produced the most harvest. The curves show how much of the total year harvest from a zone was taken by each work week.

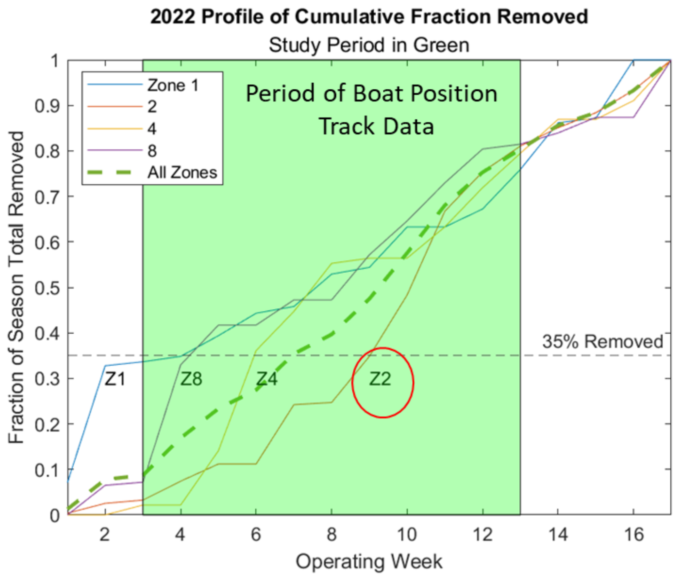


Figure 6.6 a) 2022 Pattern of Zone Removal showed 35% of year total collected in first pass. Zone 2 removal profile was extended due to lake depth change increasing EWM production area late in year.

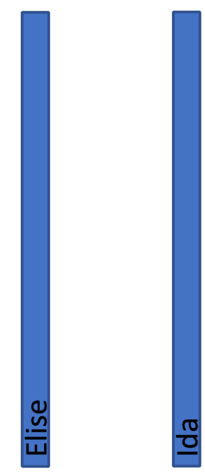


Figure 6.6 b) 2021 Pattern of Zone Removal showed 50% of year total collected in first pass. Hurricane Elise fragmentation would be higher in Zone 2&8, while all zones would be equally impacted by Ida timing.

Ideally the curve would be a step shape from 0 to 100 % with all plants cleared in the first visit. But first clearance is not perfect and plants mature at different rates across the zone. So, the characteristic is a first step followed by a line as subsequent visits clear the balance of growth. One of the advantages of zone-based analysis is seen here since the overall harvest (dashed line) appears as a single rising curve and does not give the next level of insight on the lake and operational dynamics. In 2021, the first visit typically recovered 50 % of the year's total harvest from a zone, while in 2022 the first visit typically recovered 30%. Zone 2, which had a heavy "second harvest" due to lake level drop, had a protracted clearance. This could create additional opportunity for fragment spreading and early follow up in 2023 should be done.

Hurricanes Elise and Ida were two events in 2021 that may have impacted the 2022 EWM distribution by causing water turbulence that accelerated fragmentation creation and movement in the lake. By the time Elise occurred, many of the zones had been cleared already, but only 50% of Zone 2 and about 30% of Zone 8 had been cleared. These zones would have been disproportionally affected, potentially causing increase in the in-zone density in 2022 and an increase in Zone 1 density due to fragments being blown in. When Ida occurred most of the zones had been largely cleared but any remaining EWM was at a very fragile state. This potentially could also have contributed to the increase in Zone 1 found in 2022. The 2022 area of most intense Zone 1 clearance work (figure 6.5) occurred in the area that Zone 8 fragments would have landed.

Productivity in 2022 – a new metric: In 2022 we were able to use the automated boat reporting data to determine how much time the boats spent in each zone. By processing this data with the weekly EWM harvest data a harvest productivity (pounds removed per hour of boat work time) can be found for each zone. The peak levels of approximately 70-85 lbs./boat hour are below previous estimates of a 1000 lb. per work day (125 lbs./hr.) capacity. The lower levels of 35 lbs. per hour in Zones 1 and 5 are likely related to the close to shore operation in these zones with the presence of docks requiring more maneuvering.

Year on Year Zone Comparison

1. The EWM harvest increased again but was managed. Other than water temperature effects, the 2022 EWM level was impacted by an unusual drought and potentially by EWM fragmentation effects from the tropical storms experienced in July and September of 2021.
2. Zone 1 was the second largest consumer of dive team time in the period from 6/12-8/31/2022. Before 6/12 it also occupied much of the time. Zone 1 depth is almost all below 10 feet and was the first zone cleared in 2021 and 2022. This zone showed only a 2.4-fold increase in EWM harvest, which was likely held down by the netting installed in 2021 to keep the beach areas clean. Zone 1 is a "terminal zone" where the wind pattern accumulates stray fragments. The dive team found and cleared fragments trapped by the net several times during the year. The marina area also continues to provide a vector to import and export EWM to and from other portions of the lake.
3. Zone 4 is also a "terminal area" where lake current will accumulate stray fragments. It increased more than zone 1 increased. The bottom topography of Zone 4 allowed for the second largest EWM percentage area growth due to dropping water levels.
4. Zone 2 showed the largest increase, likely due to the "second harvest" from the nominally 30% expansion in EWM growth area caused by the August water level drop due to drought. The zone topography has a low slope, so a small lake level change will add significant EWM growth area. Zone 2 consumed the largest amount of dive time in 2022.
5. Zone 8 increase was similar to zone 4. The timing of the 2021 storm was optimum to impact both zone 8 and Zone 1.

During 2022 experiments were conducted on regrowth of EWM and are described in the appendix B.

7. Sharing

7.1 Adjacent Lakes and State of New Jersey Policy Planning

Beaver Lake (in Hardyston) has suffered from floating Lyngbya, Spirogyra, and pondweeds accumulating along shorelines and around docks, interfering with enjoyment of the lake. HIGLIN hosted a visit from Beaver Lake representatives to share information on their boats, operation and weed removal technology. Based on this, Beaver Lake designed a system to help remove their nuisance vegetation and remove potentially problematic biomass. The system was placed on a barge and comprised of an intake mechanism floating just under the water's surface. The operator on the barge maneuvers it to suck up the weeds onto a separation table. A second operator slides the weeds off the table and into strainer buckets. The equipment was installed and piloted in July 2022 and continued to be improved upon during the season with advice from HIGLIN's dive team.

Lake Hopatcong, New Jersey – HIGILN has multiple conversations with the mayors of the Township of Hopatcong, Jefferson township, board members of the Lake Hopatcong commission and the Lake Hopatcong Foundation. There appears to be great interest in a demonstration project however the timing was not ideal given the number of other projects in progress on Lake Hopatcong. HIGLIN will be revisit this in spring of 2023.

State of New Jersey Water Supply Authority - In August, HIGLIN hosted a visit from Ken Klistein (Director of Watershed Protection Programs for the NJ Water Supply Authority) and Heather Desko (Senior Watershed Protection Specialist at NJ Water Supply Authority). They reached out to HIGLIN to find out more about the hand pulling project developed and carried out on Green Pond. They are both scientists committed to maintaining water quality throughout the entire watershed. Heather is involved in drafting clean water policy for the State of NJ, which, after vetting, would be sent to the Legislature for transformation into law and is proposed to cite HIGLIN's demonstration project in her policy proposal.

7.2 Conference Presentations

HIGLIN was invited to speak at the Northeast Aquatic Plant Management Society's Autumn Webinar Series on December 12. Gerry Lauro presented "Grassroots to 501c(3)" high lighting how HIGLIN evolved and how the community engagement and support for the hand pulling efforts mobilized this effort.

HIGLIN and AERM were also invited to speak at the Northeast Aquatic Plant Management Society's Seminar from January 10-12 in Hyannis, Mass. Eric Gustavsen and Gerald Principe presented 'Managing Eurasian Watermilfoil Using Hand Harvesting 2020-2022, describing the evolution of HIGLIN and the innovative suction assisted hand harvesting technology used for the Green Pond Demonstration Project.

8. Findings

The results of the 2022 Green Pond Research and Demonstration project have led to additional useful understandings about EWM and its management in NJ Highlands lakes. In 2022 we were able to use the detailed 2021 zone data and previous 2020 data to gain further insights into EWM trends and improved techniques. In 2022 we were able to introduce Lake Depth data and automated high resolution boat tracking to gain additional insights. The findings reported in previous reports were generally supported by observations from this year. Any refinements will be noted in the descriptions below. The following points summarize the new additional understandings.

- The EWM growth and proliferation continue to show significant variation year to year. Examining factors that could influence that variance, nutrient loading, outside-in migration, resident aquatic flora and fauna, and human behavior appeared to have remained relatively constant. However, weather, which varied each year from 2020 to 2022, was a significant factor. In 2022 water level, which fell significantly due to drought and increased the attractive EWM growth area was a significant factor, particularly in zones 2 and 4 where it added the most acreage. The windy weather and storm events in 2021 may have accelerated fragment generation and dispersal leading to increased 2022 activity.
- The 2022 weather fluctuation is likely not a complete explanation of the increase. Zone 1 was the first area collected both years and had little opportunity for area expansion, since most of the zone is below 10 ft. The results still reflect a 240 % increase in the number of plants, likely due to boat activity and fragments from 2021 storms appearing as new plants or from both causes. The earliest feasible clearance in high-risk zones such as 2 and 8 will reduce spreading potential.
- Timing of zone collection, with particular attention to zones with the highest risk of spreading fragments to other areas due to wind driven and flow driven currents appears to manage EWM in following years.
- The start of the Green Pond EWM growing season is determined by lake bottom water temperature with 60° F, as a generally accepted trigger point. Air temperature which impacts lake water temperature vary year to year, and consequently, the start of the EWM growing season also varies. In 2022 the season started earlier than in 2021 which was earlier than 2020.

- The timing of the season's start of diver ISR removal is critical to address the first seasonal stage of growth when EWM is using starch stored in its roots from the previous season to accelerate vertical growth. When that growth is not addressed in time, EWM dominates other species and achieves second stage maturity quickly beginning the cycle of fragmentation and root stolen development.
- Lake water level is an important element in the complete picture of the EWM growth environment.
- Automated boat tracking data can provide a useful picture of the situation in near real time. The iPad with GPS tracking increased to boat position knowledge with respect to zone boundaries. The addition of a wireless iPad interface could further improve this.
- Subsequent EWM growth behavior was studied in an experiment by the Dive Team Scientist in order to understand areas cleared using Search and Destroy. Ongoing structured research will continue to help provide understanding of effectiveness of the removal approach used in this project.
- The third year of the project shows that EWM can be controlled below nuisance levels by a Dive Team staffed and equipped as in this project. This assertion is based on the amount, 31,125 pounds, removed in 2022.

9. Recommendations

Based upon the results and findings of the 2022 Green Pond Research and Demonstration project, a number of recommendations can be made addressing the next stage of the Green Pond project and the next steps in spreading knowledge created by this project into the NJ Highlands region.

- The program of activity in 2023 should be adjusted to focus on the highest impact zones as early as possible, increasing early season activity even at the expense of late season activity.
- The environmental collection of water column temperature and local weather should include the systematic collection and archiving of lake water level data. Opportunities to automate these collections should continue to be evaluated.
- The capability to detect the presence of EWM and its location should be increased. Because of their superior detection results, the reliance on diver detection and sonar surveying should be maintained, however, greater efficiency and effective may be achieved by adding capability beyond the Dive Team and its two boats. Additional volunteer systematic scouting with equipment should be explored and potentially implemented, building on the results of 2022 experiments.
- Continue the use of automated GPS trackers to provide continuous boat position information can provide better information on where the most troublesome areas are in the lake, without imposing additional burden on the Dive Team.
- Additional testing of hand removal management processes and tools should be planned with the aim to further optimize the effectiveness and efficiency of the operations.
- Utilize sequestration netting for a number of purposes: first, to control EWM proliferation, for example in the Beach and Outlet Cove Zones; second, to perform experiments to determine the source of regrowth in areas cleared by either the Search and Destroy or Clearance methods, and third, by strategically locating netting, determine the flow of fragments out from or into areas. Extend experiments conducted in 2021 and 2022 on EWM regrowth rates
- The HIGLIN EWM removal approach and operation should continue to be used to its fullest extent for the 2023 growing season. Hand removal would address all areas of the lake and be scheduled to start early in the season and continue until the risk of late season blooms is low. Herbicide treatment is the planned secondary contingent control method to be used if hand pulling is found to be ineffective in keeping EWM controlled below nuisance levels.

- Research and Demonstration projects should be planned with other lakes in the Highlands region to ascertain whether the results of the Green Pond project would be duplicated in other lakes and conditions. During 2021, progress was made with the lake stewards of Lake Hopatcong, the LH Commission ad LH Foundation to explore and experiment with the EWM control approaches used by HIGLIN. Those efforts should be brought to fruition.
- The information and knowledge generated from this project should continue to be shared with other lakes in the Highlands Region through educational materials and presentations. One vehicle for sharing is NJCOLA, an existing lake association body. NJCOLA meets regularly to educate and inform its membership about relevant scientific and practical knowledge to enhance their lake management effort. HIGLIN should continue to develop a relationship with NJCOLA, and consider presenting at the National Association of Lake Managers.

Appendices

Appendix A: Green Pond 2022 EWM Removal Summary by Zone

This appendix contains the data on removal weight by zone for 2022. Figure A-1 shows the weekly detail and figure A-2 shows the total for both 2022 and 2021 by zone.

2022 EWM Harvest From Zone (Pounds)															
Zones	Zone No. and Name		1-Beaches	2-Sand Bar	3- Seven Sisters	4-Outlet Cove	5-East Cove	6-Mid Lake	7-East Shore	8-Point Comfort	Week Summary Data				
	Zone Area (Acres)		26.7	92.3	62.4	21	18.7	149	43.5	48.5					
	Zone Ac < 10 ft deep		23.7	49.2	14.2	14.1	7.3	4.7	17.2	21.9					Harvest Weight
Day #	Report Date	Op Week									Wk Tot	Boat Days	Divers Days	Daily Avg	
149	5/30/2022	1	360	40							400	3	11	133	
156	6/6/2022	2	1300	230						525	2055	7	30	294	500
163	6/13/2022	3	45	75		95	25			55	295	8	27	37	450
170	6/20/2022	4	60	440						2080	2580	7	28	369	400
177	6/27/2022	5	230	400		520			175	705	2030	7	23	290	350
184	7/4/2022	6	250		90	960					1300	6	24	217	300
191	7/11/2022	7	75	1380		375	25		200	445	2500	8	30	313	250
198	7/18/2022	8	360	50	50	460	250		175		1345	6	20	224	200
205	7/25/2022	9	75	1075		50			460	800	2460	7	26	351	150
212	8/1/2022	10	450	1425	125				580	600	3180	7	32	454	100
219	8/8/2022	11		1950		300	25		350	675	3300	8	28	413	50
226	8/15/2022	12	200	915	50	375			150	600	2290	8	33	286	0
233	8/22/2022	13	440	600	50	330	76			85	1581	6	20	264	
240	8/29/2022	14	520	425	25	325			175	200	1670	8	29	209	
247	9/5/2022	15	50	350					200	275	875	4	17	219	
254	9/12/2022	16	650	525		180	190				1545	8	36	193	
261	9/19/2022	17		705		390				1020	2115	8	39	264	
	Zone Summary	Total Lbs	5,065	10,585	390	4,360	591	-	2,465	8,065	31521	116	453	272	
		Lbs/Ac	189.7	114.7	6.3	207.6	31.6	0.0	56.7	166.3	Lbs	Days	Dive Wks	Lbs. Avg	
		Lbs/Ac<10	213.7	215.1	27.5	309.2	81.0	0.0	143.3	368.3	Year to Date Total				

Figure A-1 Weekly Summary Data for 2022 Green Pond EWM Removal by Zone

	Zone	1	2	3	4	5	6	7	8	Total
Acres	Total	26.7	92.3	62.4	21	18.7	149	43.5	48.5	462.1
	<10 ft	23.7	49.2	14.2	14.1	7.3	4.7	17.2	21.9	152.3
2022	Total Lbs	5,065	10,585	390	4,360	591	0	2,465	8,065	31,521.0
	Lbs/Ac	189.7	114.7	6.3	207.6	31.6	0.0	56.7	166.3	68.2
	Lbs/Ac<10	213.7	215.1	27.5	309.2	81.0	0.0	143.3	368.3	207.0
2021	Total Lbs	2,118	1,487	280	910	180	220	575	1,666	7,436.0
	Lbs/Ac	79.3	16.1	4.5	43.3	9.6	1.5	13.2	34.4	16.1
	Lbs/Ac<10	89.4	34.5	5.8	131.9	15.8	1.5	21.9	62.6	48.8
Total Lbs. 22 /21		2.4	7.1	1.4	4.8	3.3	0.0	4.3	4.8	4.2
Note: Color coding in each row is from largest (red) to smallest (green)										

Zone	Depth % <		Change 2022/2021	
	10 ft.	15 ft.	Per Ac	Ac<10
1	89%	95%	2.4	2.4
2	53%	99%	7.1	6.2
3	23%	97%	1.4	4.7
4	67%	95%	4.8	2.3
5	39%	42%	3.3	5.1
6	3%	14%	0.0	0.0
7	40%	92%	4.3	6.6
8	45%	86%	4.8	5.9

Figure A-2 Yearly Summary Data for 2022 and 2021 for Green Pond EWM Removal by Zone

EWM Removal Statistics by Zone for 2022 and 2021 show Zones 2,8,1 and 4 contributed 89% of 2022 harvest from 37 % of the total lake area. In 2021 the same zones contributed 83% of the total harvest.

Appendix B: Regrowth experiments

In 2021 and 2022, quadrats were placed at 10ft and monitored to study how EWM redeveloped an area after being cleared by the dive team. The 2021 season included one study site with EWM, and 2022 had two pairs of quadrats (4 total) at two study locations, one with and one without EWM. One quadrat at each site was cleared of all growth, while in the other native plants were left to grow. In 2022 an additional quadrat was placed on a muscle bed, and supplementary data was collected on aquatic plant growth, bottom type, water clarity, and invertebrate activity.

2021

Zone 3 EWM Quadrat (41.00233N, 74.50377W) found 0-25% regrowth at each biweekly visit where EWM was cleared, and native plants were left to grow. EWM regrowth was classified as fragmentation based on divers finding plants with characteristics typical of fragments.

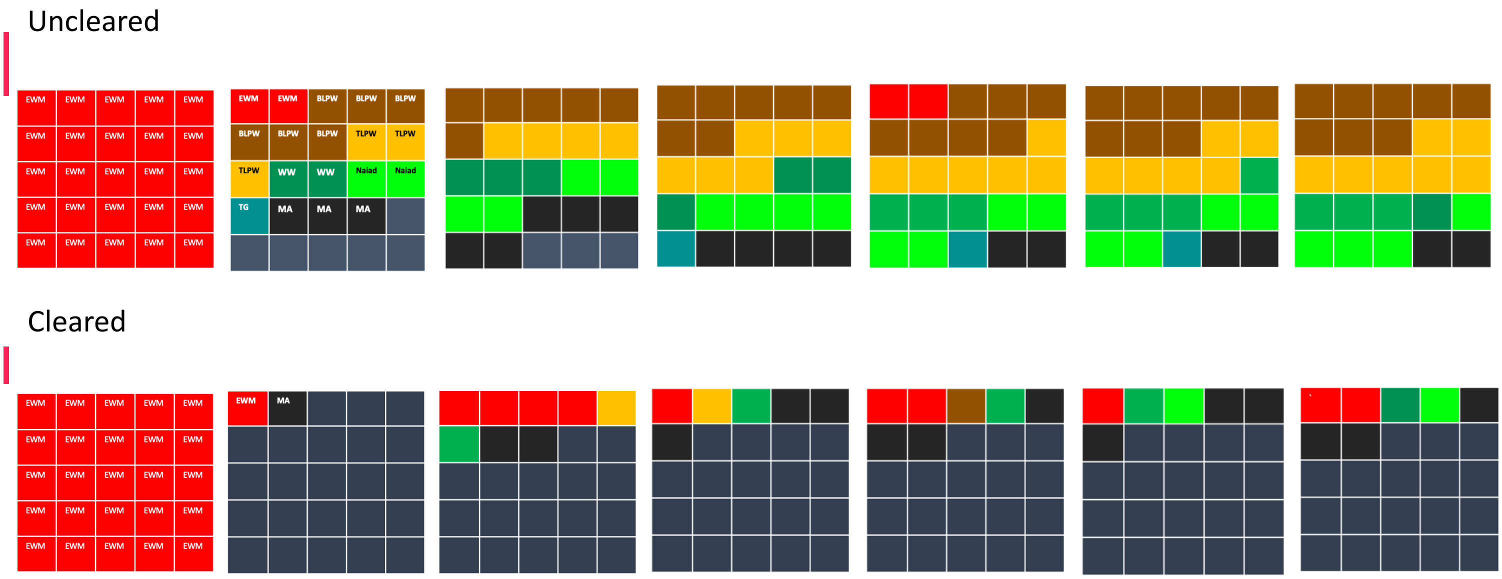
2022

Zone 3 Control Quadrats (41.00872N, 74.49524W) were placed in an area without EWM growth to compare conditions with the EWM Quadrats. No EWM was found here during 2022, even in the cleared quadrat, and water clarity remained below average (<4ft).

Zone 2 EWM Quadrats (41.01324N, 74.48597W) found 0-20% regrowth cumulatively every two weeks but were checked and cleared weekly. An average of 11 mussels per quadrat were found, and water clarity remained excellent (>10ft). EWM regrowth was also classified as fragmentation. Below is a representation of the two quadrats at each visit.

Zone 2 Mussel Quadrat (41.01482N, 74.48604W) found no aquatic plant growth, and 52 native pearly mussel.

2022 EWM Regrowth Quadrats



Eurasian Water Milfoil (*Myriophyllum spicatum*),

Broad Leaf Pondweed (*Potamogeton natans*),

Thin Leaf Pondweeds (*P. nodosus, P. epihydrus, P. foliosus, P. friesii*),

Naiads (*Najas minor, N. flexilis*),

Waterweed (*Elodea canadensis*),

Tape Grass (*Vallisneria americana*),

Coontail (*Ceratophyllum demersum*),

Bladderwort (*Utricularia spp.*),

Other macrophytes (Chara *spp., Nitella spp.*)

Navy squares in the quadrat grid represent bottom without aquatic growth

The regrowth quadrats demonstrated EWM's ability to quickly recolonize an area with fragments after being cleared. This shows the importance of persistent management of EWM and other invasive species that create fragments.

The increased instances of EWM regrowth shown in the quadrat cleared of native plants could demonstrate the ability of natives to compete with EWM and decrease the success of fragmentation. This ability was also demonstrated by the transect and quadrat data gathered in 2020 and 2021, which is discussed in the AER&M Dive Team Science Report.

The lack of EWM growth seen in the control quadrat at the same depth as the EWM quadrats reveals an important influence in the ability of this invasive species to grow. Since depth and native species abundance were similar, and EWM is found in both fine and sandy sediment, the remaining differences between sites include water clarity and invertebrate activity. These factors are outlined in the table below.

2022 Quadrat Data Collection	Control Quadrat	EWM Quadrat	Mussel Bed
Muscle Density (m/q)	1	12	52
Secchi Disk (ft)	4	>10	>10
EWM Growth (p/q)	0	10	0

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