Science Report 2021
Green Pond Research and Demonstration Project: Aquatic Invasive Species Management

Gerald Principe, Team Scientist of Aquatic Environmental Research & Management,
a subsidiary of Highlands Glacial Lakes Initiative, Inc.
NJ, USA

This report has been compiled from observational and scientific data collection from the 2020 and 2021 AER&M field seasons. Data collected has yet to be analyzed for statistical significance due to the sample being too small. This study has not been peer reviewed but does cite many published and recognized sources on the issues at hand. The invasive species management project in Green Pond and subsequent reports aim to demonstrate the ability for ecologically responsible remediation of invasive species through repeatable methods and sustainable practices. The views expressed in this paper are those of the author and do not necessarily represent those of any organizations associated with the project.

Abstract

It is sometimes the case that the cure is worse than the disease when dealing with invasive species management. This research and demonstration project conducted in Green Pond by the Aquatic Environmental Research & Management Dive team has shown successful control of aquatic invasive species, specifically Eurasian Watermilfoil (*Myriophyllum spicatum*) using ecologically responsible techniques. Suction assisted hand harvesting technology was utilized by a team of divers to search and destroy invasive and targeted nuisance species for two growing seasons, in which Eurasian Watermilfoil (EWM) growth remained below nuisance levels. Efforts to curb EWM proliferation seem to be aided by healthy native aquatic plant species, indicated by transect and quadrat data collected in 2020 and 2021. Initial experimentation shows successful removal of EWM by the dive team, with a lasting reduction in growth by over 75% four weeks after removal. Regrowth seen four weeks after initial clearance was identified as fragmentation, highlighting the ability of this invader to re-colonize after being extirpated from an area. More data collection and analysis are needed to better understand EWM's preferred growing conditions, but initial analysis indicates depth, hydrology, and native cover as the most influential factors. Most importantly, Eurasian Watermilfoil presents an annual threat regardless of management technique and any remediation should be as sustainable as possible.

Introduction

Eurasian Water Milfoil is an ecological, multibillion dollar problem across North America's bodies of freshwater (Pimentel et al., 2005). Discovered here in the early 1900's it has been impossible to irradicate once introduced and has caused problems with recreation and real estate around lake communities ever since (Zhang and Boyle, 2010). These problems arise from EWM's ability to grow faster in the spring than other native species, outcompete those species for light, and produce fragments that continue to grow while floating to a new place to proliferate. These characteristics create tall dense forests and mats of vegetation that impede water sports and decrease property values, which in turn generates economic impacts from the necessary remediation (Lovell and Stone 2005) Although there are many, a few remediation techniques have been markedly more successful and utilized than others. One of the most diverse is physical harvesting, consisting of multiple techniques including-

1. Mechanical Harvesting
2. Hand Harvesting
3. Suction Harvesting

Mechanical harvesting is possibly the most widely utilized physical removal method and is accomplished using large tractor-like mowing equipment. These machines come in many shapes and sizes, can cover a large area, and can collect or cut tons of plant material each day. This method is therefor especially successful at removing dense stands of emergent wetland species such as reeds and cattails (Carson et al, 2018). According to biologists at the US Army Engineer Research and Development Center, free-floating plants like water hyacinth (*Pontederia crassipes*) are also often targeted with this method and quickly removed, but with lower efficiency due to increased weight and potential for plants to float away. For submerged species this technique is even less cost effective and has greater potential to impact the environment due to the non-selective nature of removal, resuspension of sediment, and potential for bycatch (Sperry et al, USACE). Additionally, submerged aquatic species like EWM can regrow shortly after this kind of removal (Johnson and Bagwell 1979).

Hand harvesting is accomplished with a team of divers and can remove submerged aquatic plants more effectively than mechanical harvesting. Invasive species can be removed completely including root systems, leaving healthy native species behind to offer habitat for fish and invertebrates while providing competition for AIS regrowth (Petruzzella et al. 2018). However, hand removal is not possible with most emergent and free-floating species, and extremely limited when it comes to management area. Only small or sparsely growing populations of submerged species can be effectively controlled with hand harvesting alone (Madsen, 2000).

Suction harvesting uses what is essentially an underwater vacuum for divers to remove aquatic invasive species selectively. Although like dredging equipment, sediment is not removed from the system but re-suspended in the water column, along with any bycatch. Sedimentation curtains are placed around a removal area to allow sediment to fall back in place and limit fragmentation. These operations typically start when AIS growth has reached its peak and equipment can be placed in areas of dense growth to be removed. Although faster than hand harvesting alone, this process has historically been slow at less than 100^2 meters / person / day (Eichler et al. 1993). Disturbed sediment contained by curtains can also decrease effectiveness due to a divers' decreased ability to see underwater.

For this demonstration project, a new combination of hand and suction harvesting has created an ideal removal method that overcomes the challenges discussed above. Suction assisted hand harvesting allows divers to remove invasive species quickly and effectively. This is done with suction hoses suspended from the bottom, early action in the growing season, and ability to quickly move divers to new areas of invasive growth. Sediment is not resuspended, bycatch is negligible, and visibility remains about the same. More detailed information on this novel removal method is described later in this report, and in the 2020 and 2021 Green Pond Research Demonstration Project Report.

There are many other remediation methods used to manage invasive species. Some of the most utilized today include herbicide treatments, lake drawdowns, dredging, benthic barriers and fragmentation curtains. In any management plan, it is essential to employ multiple techniques to ensure continued success with changing conditions. Some of these remediation techniques have a larger effect on the environment, which also must be considered.

The ecological disaster invasive species create come from both their ability to outcompete native species, and our remediation methods. Invasive species are known to pose a significant threat to biodiversity (Wilcove et al 1998; Daiser and Burnett, 2006) which in turn can negatively impact important fish and animal populations. Keystone species like the American Beaver (*Castor canadensis*) that hold our ecosystems together are especially susceptible (Krogh *et al.,* 2001). In addition, eutrophication is accelerated by increased land use in most lake communities which creates an even better environment for invasive species and harmful algae / bacteria blooms. These disturbances to the environment compound each other and can have noticeable impacts on ecosystem services (Grantham et al., 2020). Therefore, we must be particularly careful to not further disrupt the ecosystem with our chosen remediation method.

Due to disturbances in the environment and to monitor them, data collection on aquatic plant species is essential. Along with environmental data like depth, bottom type, temperature, and invertebrate activity, this information can be used to identify areas where EWM is most problematic. With enough data and analysis this can also explain which characteristics are most important to EWM growth, and in turn what most impedes its growth. Monitoring these data points long term along with water quality information can also show trends in overall ecosystem health. There are numerous ways to collect this data, with differing levels of detection ability. The most prevalent collection techniques include-

1. Rake Toss
2. Transects
3. Quadrats

The rake toss method consists of dragging a rake with varying size teeth across the bottom, which is then brought on deck to identify plants found along its path. This can be done quickly and repeated often to cover large areas or get more accurate data which can be used for analysis, but this speed and ease come at a disadvantage. This method has a high detection threshold for invasive species and can destroy plants in the sample, making it hard to identify them without laboratory analysis. They also do not gather data on other important environmental factors without the addition of equipment like sonar or cameras.

Transects and quadrats are often done in conjunction with one another, as each can be used in different ways. Transects are line surveys conducted along a tape measure placed above the bottom, parallel or perpendicular to shore. This can cover a relatively large area and give a good representative sample of the species or conditions in the area. Quadrats consist of a square grid, usually placed alongside a transect at varying distances and can offer evidence on total plant cover of the lake bottom, as well as which species are most abundant. This type of sampling does take longer to conduct with additional equipment and a team of 4 or more divers.

By combining ecologically responsible removal methods with data collection, a successful and overall constructive operation can be created. While managing the invasive species problem, the team can monitor ecosystem health and adjust based on data collection to be as effective and efficient as possible. The objectives of this study are to share successful and environmentally conscious remediation techniques and data on invasive species growth. Armed with this knowledge along with a tested new removal method, lake communities can reconsider remediation techniques currently in use that could further degrade the health of our freshwater systems.

Materials and Methods

For this research and demonstration project located in Green Pond NJ, suction assisted hand harvesting and transect /quadrat placement have been used as the main methods for invasive species management for the last two years. These methods have a low detection threshold for invasive species with divers in the water, ability to find small plants, and be particular about which species to remove. Divers can also remove root structures and contain fragments unlike other physical harvesting. Following approval from Green Pond Corporation and Lake End Corporation in 2020, AER&M's professional dive team began managing the AIS identified in the pond, EWM and Curly-Leaf Pondweed (*Potamogeton crispus*, CLPW). More detailed information on 2020 field season can be found in the Green Pond Research and Demonstration Project Report.

This effort has been aided by the communities' long term water quality consultants Princeton Hydro (LLC). Previous techniques used since the detection of EWM in 2013 with rake toss and observational data included multiple herbicide treatments along with volunteer hand pulling efforts, but in 2019 the largest amount of EWM growth recorded closed the pond to recreation and inspired action with the new approach described in this study.

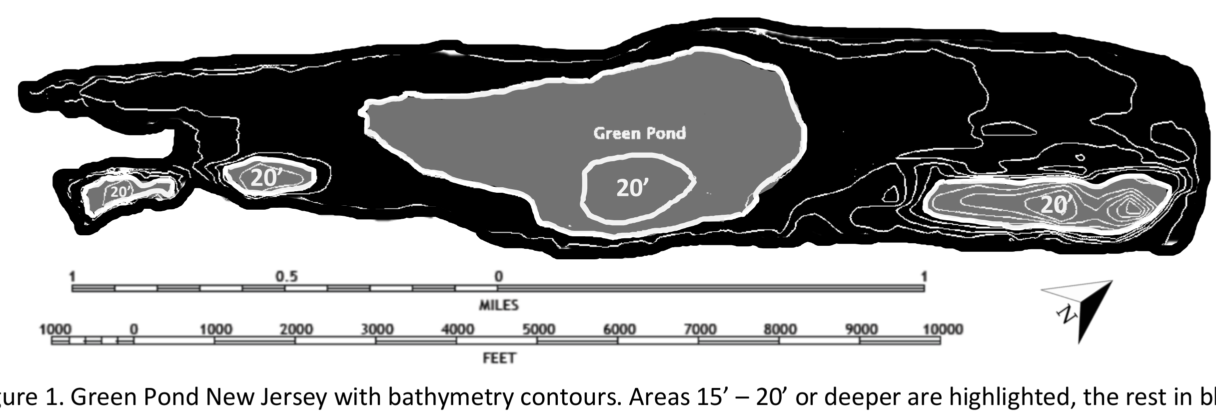

Figure 1. Green Pond New Jersey with bathymetry contours. Areas 15' – 20' or deeper are highlighted, the rest in black represents areas susceptible to EWM growth.

Study Site

Green Pond, located at 41.00617N, 74.49398W is a glacial made, spring fed pond larger than most at approximately 500 acres. Land use around the pond is mostly residential, with two bathing beaches located at the north end of the lake. Prevailing winds typically from the southwest push fragments from the coves toward the beaches but are variable due to the area's geography. The pond drains through an important marsh and river ecosystem at the southwest end and is considered mesotrophic. This medium level of productivity leads to a clear pond with open water Secchi disk readings from 7 – 15' (Princeton Hydro, 2020) and a balanced aquatic ecosystem. This exceptional water quality also allows EWM to access light at depth and colonize about 330 acres of the lake bottom, anywhere from 3-18' where the deepest plant was found by the AER&M dive team in 2021.

To effectively manage these areas of potential EWM growth, the lake was broken down into nine management zones (Figure 2). These zones were determined following depth contours, specifically the 15'- 20' mark where EWM is not as great a threat. Other factors include bottom type and geography, making the two coves on the left (zones 4 and 5) and Swim Area on the right (zone 1) defined management areas. In 2021 a fragmentation curtain was placed along the swimming area to impede the flow of fragments in and out of this widely utilized management zone. Frequency of removal in each zone was determined by the likelihood of EWM growth based on growing preferences from previous data gathered by the dive team in 2020.

Removal

All aspects of this research and demonstration project were accomplished through repeatable methodology, most of which have been used previously by the scientific community. Central to the AER&M mission is invasive species removal, which was accomplished through suction assisted hand harvesting with increased ability and precision compared to previously used physical removal techniques. This included two dive boats, one with the Lawrence Chart plotter to assess the bottom type below, each with two 50' long 5" diameter suction hoses attached to the Venturi pumping systems and sluice boxes. Two divers equipped with OTS Guardian masks and wired comes, Hookamax G2005c compressor / air supply line, and a strength member operated the suction hoses. A large focus was placed on removing the entire invasive plant, including root structures in the sediment to avoid regrowth. More information on these specialized dive boats can be found in the Green Pond Demonstration Project Reports.

The weight of invasive species removed was compiled by management zones, defined by depth and physical characteristics associated with EWM growth as described earlier. These zones were cleared using two techniques-

1. Search and Destroy of sparse invasive growth
2. Clearance of dense invasive or nuisance growth

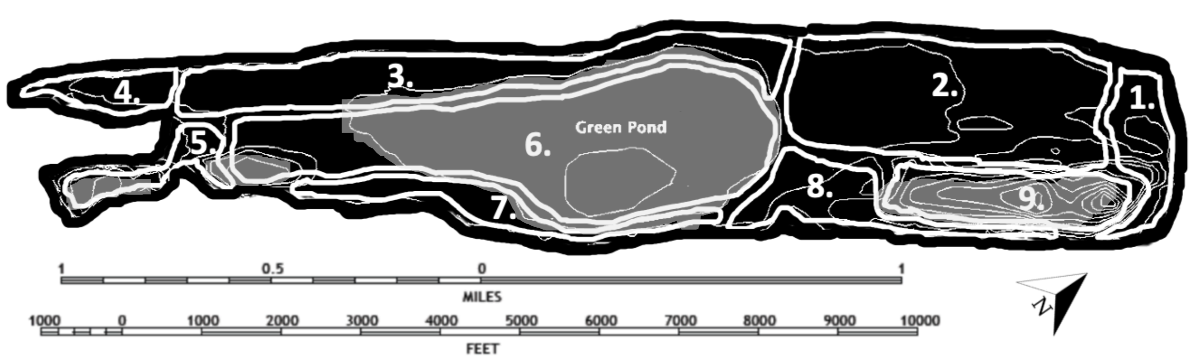

Figure 2. Green Pond divided into nine management zones that run counterclockwise, created by depth contours, geography and EWM growing preferences. Zone areas are approximated, and areas >15' are highlighted. Zone 1: Swim Area, Zone 2: Sand Bar, Zone 3: Seven Sisters, Zone 4: Outlet Cove, Zone 5: Shawgar's Cove, Zone 6: Mid- Lake, Zone 7: Southeast Shore, Zone 8: Point Comfort, Zone 9: Bass Hole.

During the Search and Destroy approach divers were moved along the bottom with suction hoses suspended by adjustable buoys. Individual plants were removed by hand as the boat continued to move, or divers would communicate to the boat captain to pause while they position to remove larger plants or patches of invasive growth. Sediment was left undisturbed as divers focused on remaining above the lake bottom, suspended by the suction hose and buoy system. Clearance of more dense patches of EWM or nuisance native growth in the swimming area took longer to accomplish as the boat must stop and circle an area needed to be cleared. Anchoring was done as little as possible to reduce the risk of fragmentation and interference with the divers. During clearance mode, two divers can remove over 1000lbs of material in approximately 6 hours of diving. This created the maximum operating capacity used by the scientist to report excessive invasive growth too great for the dive team to handle alone. ProcellaCOR herbicide was kept as an emergency measure to target any excessive invasive growth, due to its ability to target EWM.

All invasive species found were removed by the diver and then place into the hose, which then transported plant material on deck via the sluice boxes to 25lb onion bags. The coarse mesh-like material allows for incidental by-catch like muscles and crayfish to fall back into the lake or be easily removed. AIS removal was measured through a wet weight gathered after 10 minutes of drying time to allow for as consistent field measurements as possible, and then attributed to a management zone. Because zone size varies significantly, a more accurate comparison between them would be-

$$\frac{lbs\ removed}{zone\ acres}$$

This calculation helps to alleviate biased weight measurements from larger zones where increased EWM weight might exist as a function of area as opposed to growing preference.

Research

To better understand invasive species ability to grow in Green Pond, data was gathered using three complimentary techniques-

1. GPS coordinates of EWM using the GPS Tracks Software and Lawrence Chart plotter
2. Cursory biological sampling using transects and quadrats
3. Weight measurements described in Removal

Invasive species data was again compiled using the management zones this time with GPS coordinates plotted by the boat captain from communication with the divers. A point was placed every new EWM plant or patch within 1ft^2 that had not already been marked. To account for zone size, the number of EWM contacts per zone acre was calculated with the following equation-

$$\frac{EWM\ Contacts}{zone\ acres}$$

Biological sampling included transects and quadrats across four of the management zones, where five of each sampling technique was done per zone (Figure 3). Sampling was conducted by the dive scientist and divers with plant ID training to ensure accurate identification. Transects were 50’ placed perpendicular to shore, with a 5’ by 5’ quadrat placed randomly alongside.

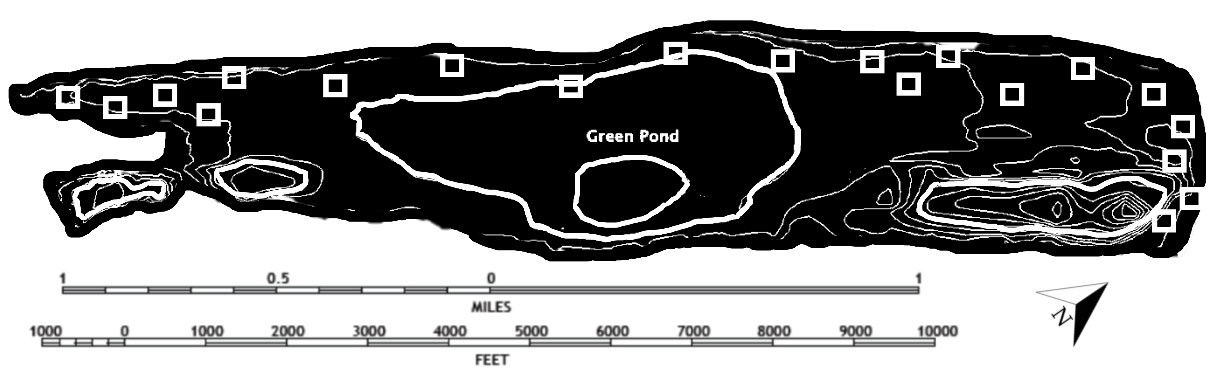

Figure 3. Green Pond bathymetry is shown with survey locations conducted in August – September of 2021. Survey methods include transect and quadrat placement at each location and were completed evenly across management zones. Survey location is approximated and numbered counterclockwise, starting at the Swim Area (zone 1).

Data collection focused on aquatic plant abundance of the 10 most relevant groups or species found in Green Pond, including-

Eurasian Water Milfoil (*Myriophyllum spicatum*)
Curly Leaf Pondweed (*Potamogeton crispus*)
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.*)

Additional information gathered with each survey included depth, bottom type, presence of fish / invertebrates, and proximity to an inflow area.

Overall plant coverage of the bottom was estimated using data collected by the transects and quadrats. A complete score of 100 for transects or 50 for quadrats would show 100% coverage. These values were combined, and the average for each management zone was calculated-

$$\%\,Coverage = \left(\frac{\Sigma\, plants\ per\ zone}{Total\ possible\ score}\right) \text{x}\,100$$

The Shannon Diversity Index (*H*), Equitability Index (E_H), and Simpson Index for Diversity (*D*) were also calculated using species data gathered at the survey sites in Figure 3. They were analyzed using the following equations-

$$H = -\Sigma(p_i \cdot \ln(p_i))$$

Where:
Σ = sum
ln = Natural Log
p_i = the proportion of the entire community made up of species "i"
The higher the *H* value, the greater diversity.

$$E_H = \frac{H}{\ln(S)}$$

Where:
H = Shannon Diversity Index
S = Total number of unique species
Value between 0-1; where 1 indicates complete evenness.

$$D = \frac{\Sigma n(n-1)}{N(N-1)}$$

Where:
n = the total number of organisms of a particular species
N = the total number of organisms of all species
Value between 0-1; the higher the *D* value, the more diverse a community.

These values compared year to year can show potential changes to species diversity overall, or in specific management zones. The comparison between these values and EWM abundance is another interesting analysis that could show invasive species impact on native species diversity.

The weight of EWM removed can be compared to other utilized research techniques to draw the most comprehensive conclusion possible. The irregular schedule of removal focused on efficiency creates skews to the weight data, but the research techniques combined can still reveal potential invasive species growing preferences and constraints.

Regrowth Experiment

To measure how quickly EMW could grow back after removal by the dive team, on July 12th a quadrat was placed and monitored in an area historically prone to invasive growth along the south-west shore in zone 3 at 41.00233N, 74.50377W. First this area was cleared of invasive species, which included an EWM patch large and dense enough to fill the quadrat along with several individual plants in the area. Native species were left growing in the quadrat to mimic the natural environment, which included naiads, pond weeds, and algae spp.

Every 14-16 days, the quadrat was checked for and cleared of any invasive species growth. Special care was taken to note characteristics of this growth including morphology and height (when present) to better understand the biological processes occurring. This monitoring event took place four times in 2021, starting in July and ending in September. Invasive plants found growing in the quadrat could be identified as two types of growth-

1. Fragmentation
2. Regrowth from removed plants

Fragments were identified by exposed roots from multiple nodes, either floating or with a root system that extended through native plant growth into the sediment. They could also often be identified by an attached browning stalk. These characteristics have also been found amongst newly growing bright green shoots, which were often connected to this dying stalk and exposed root system.

Regrowth from removed plants can usually be identified by small bright green shoots, but lack the morphology described above. Sometimes root fragments left behind are exposed but reach up from the sediment as opposed to down into it, distinctly different from fragment morphology. After some time, a fragment becomes a new establish plant and loses these characteristics,
creating fragments of its own. To gather more data on this, invasive species fragments would have to be left to grow and monitor.

Results

Removal

In total almost 7,500lbs of invasive species were removed by the AER&M Dive team in 2021. Although operations never came close to maximum capacity for removal each day, there was a significant increase in EWM removed compared to the 1,700lbs in 2020. More densely growing EWM was encountered throughout the 2021 growing season, with more than double the number of active growing areas.

Curly Leaf Pondweed weight removed decreased by comparison, representing only 70lbs or 1% of invasive species removed in 2021 compared with an estimated 15% in 2020.

The R^2 value of 33% for the 2020 removal trendline shows a weak relationship between the amount of AIS removed and the passing of time, as well as a steep decline in the average weight removed (m = -27, Figure 4.) This could represent a decreased population of invasive species as dive operations continued through the growing season, which had few high energy storm events. Data from 2021 showed almost no relationship between these two variables, with a R^2 value of only 0.3%. However, there was still a slight decline overall in EWM removed during 2021 seen in the negative m value of -1.6. An increased number of high energy storms in 2021, two hurricanes in particular correlate with peaks in removal weight seen in weeks 5 and 10.

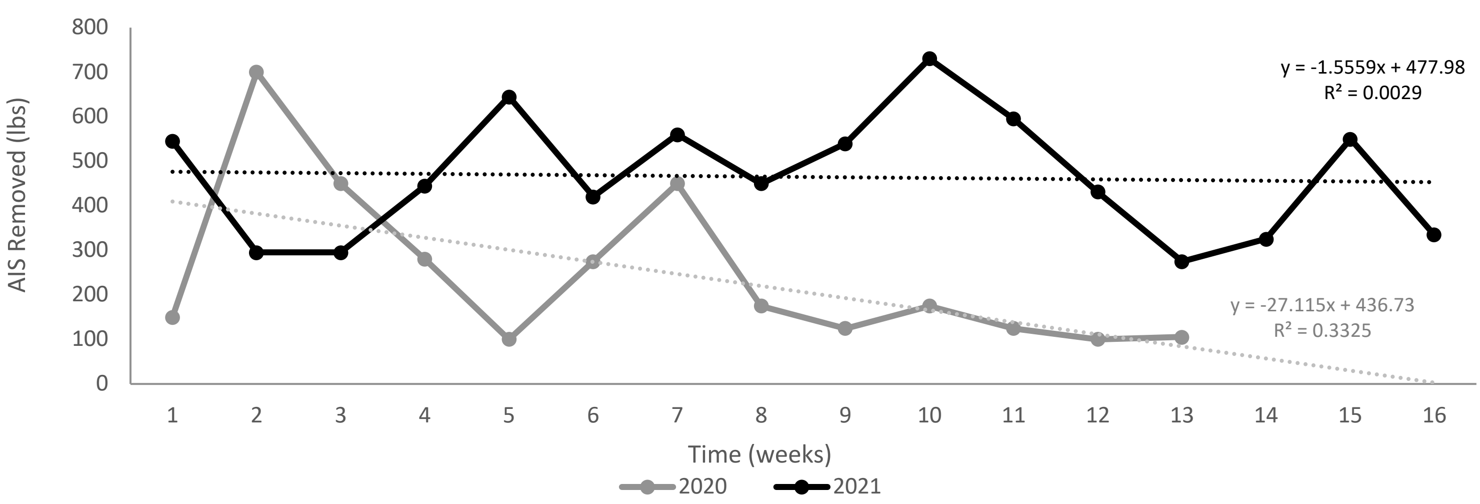

Figure 4. The weight of Aquatic Invasive Species removed by the AER&M Dive team is compared to the time in weeks for the 2020 and 2021 field seasons. The linear trendline equations are shown with the goodness of fit measurement R^2 values.

Attributing the weight of EWM removed to management zones in 2021 allowed comparison of these zones as invasive species "hot spots". Zone area (and therefore yield) varies, so the lbs removed per zone was calculated to give a more accurate measure of EWM growth in each zone. This calculation highlighted four zones with greater than 15lbs / acre of growth (Table 1.) These are listed from highest to lowest yield / acre.

1. Swim Area (zone 1)
2. Outlet Cove (zone 4)
3. Point Comfort (zone 8)
4. Sand Bar (zone 2)

Dive operations focused on removal especially around the swim area and marina in zone 1. This was done in response to requests from GPC and a desire to keep these areas especially clear of AIS, which could contain their spread due to boat activity and give continued respite to community members. Harvesting in areas with dense growth (more than 10 plants per ft^2) found at the beaches required dive operations to change from search and destroy to clearance mode, which made removal take much longer. This happened in the other hotspots mentioned albeit less often, as well as along the southeast shore. The fragmentation curtain deployed around the Swim Area was routinely cleared of EWM and on average 30 fragments were found and removed each week.

TABLE 1. GREEN POND ZONE MANEGMENT INFORMATION IS DISPLAYED WITH TOTAL WEIGHT OF EWM REMOVED, AND WEIGHT / ACRE IN EACH ZONE. REMOVAL WAS CONDUCTED LAKE WIDE BETWEEN JUNE 7TH AND SEPTEMBER 23RD, 2021. HIGHLIGHTED ROWS REPRESENT ZONES WITH >15 LBS / ACRE.

Zone Number	Zone Name	Acres / Zone	Lbs / Acre	Lbs Pulled
1	**Swim Area**	**26.7**	**79.3**	**2118**
2	**Sand Bar**	**92.3**	**16.1**	**1487**
3	Seven Sisters	62.4	4.5	280
4	**Outlet Cove**	**21**	**43.3**	**910**
5	Shawgar's Cove	18.7	9.6	180
6	Mid Lake	149	1.5	220
7	Southeast Shore	43.5	13.2	575
8	**Point Comfort**	**48.5**	**34.4**	**1666**
9	Bass Hole	43	-	-

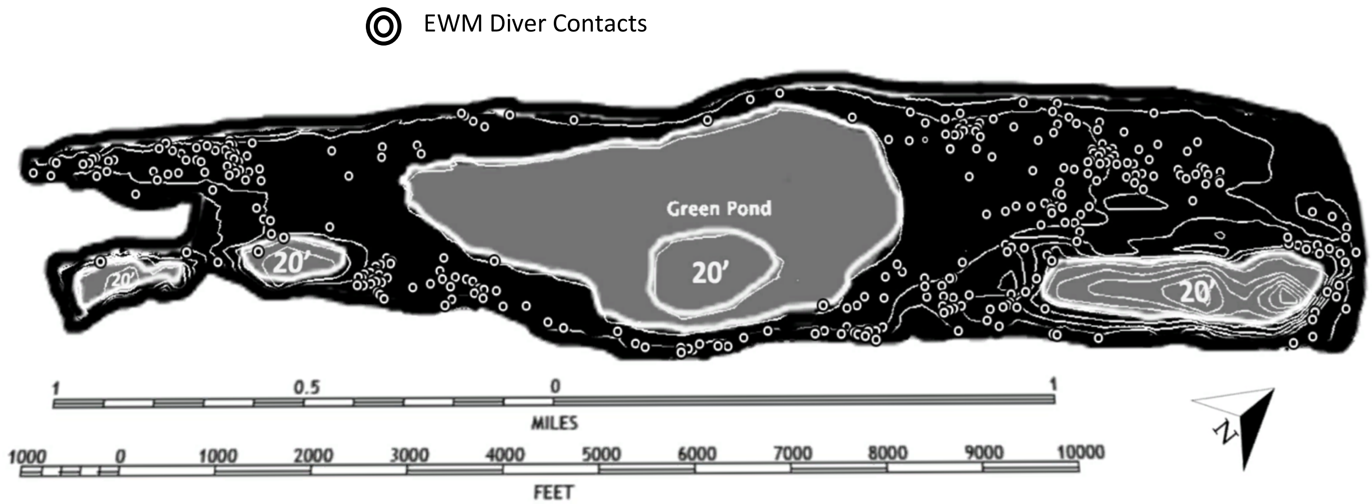

Figure 5. EWM contacts made by the AER&M dive team from June – September 2021 along with Green Pond bathymetry. Each contact represents one or more growing EWM plants within 1 ft^2 and does not include regrowth in areas already marked.

Research

GPS Coordinates taken during the 2021 field season by the research vessel totaled 312 diver contacts with EWM. Each point represents new growth of one or more plants found by the divers in 1 ft^2, and multiple points together show patches of growth in almost all lake management zones with the exceptions of zone 6 and 9. Areas with the highest amount of EWM contacts / zone acres represent hotspots based on diver contacts as opposed to weight removed. This offers a second set of data on invasive species location and abundance, which can create a more accurate picture of EWM growth. Hotspots with more than 1 contact per acre are listed from highest to lowest-

1. Outlet Cove (zone 4)
2. Point Comfort (zone 8)
3. Southeast shore (zone 7)
4. Swim Area (zone 1)

Biological data collection using transects and quadrats did not meet the sample size needed for statistical analysis. This was done to prioritize effective invasive species removal of the large weight and abundant fragments found by the dive team in 2021. Samples completed evenly across the first four management zones still have the potential to reveal possible growing preferences and be compared with the other invasive species location data to create the best management plan possible

There was a noticeable increase of EWM found in management zones with a smaller number of native species (Figure 6). The percent coverage created from the zones' combined coverage score also demonstrates this phenomenon, with the smallest amount of EWM growing in the zone with the most native coverage-

1. Swim Area 52%	19 EWM
2. Sand Bar 30%	29 EWM
3. Seven Sisters 75%	17 EWM
4. Outlet Cove 39%	37 EWM*

* Created from 2021 transect and quadrat data

The Shannon Diversity Index (*H*) for Green Pond in 2021 based on the biological survey data was 1.8, and evenness (E_H) was 0.86. The Simpson Index (*D*) had a value of 0.8. All values indicate good overall species diversity and evenness between species. More complete data collection from each management zone could be compared with EWM hotspots to show trends in biodiversity and evenness in relation to invasive species.

Figure 6. The combined number of native species (grey) and EWM (black) found in each management zone. Species were identified and counted using transects and quadrats completed during August – Sept of the 2021 field season.

Regrowth Experiment

Two weeks after the regrowth quadrat was placed and cleared of AIS, it showed no EWM regrowth. Individual EWM plants were removed from the surrounding area, some identified as fragments through exposed root systems and a browning stalk. EWM was of course cleared after each visit (when present), with a particular focus on removing the entire root system.

Two weeks later in the middle of August, 5 out of 25 squares (20%) had 2” - 2’ EWM plants present. These plants were also identified as fragments, with roots growing through native species and in some cases new shoots appearing underneath native growth.

Two weeks later at the beginning of September a single 2’ EWM fragment was found lying on top of the quadrat with roots several inches long in multiple places on the plant not yet rooted. Again, the surrounding area was cleared of invasive species.

The final monitoring of the EWM quadrat mid-September showed 6 out of 25 squares (24%) with 2” - 3’ EWM, again mostly identifiable as fragments.

The results from this research and demonstration project aim to help highlight the ability of EWM to fragment and regrow, as well as our ability to manage it responsibly. Hopefully it will offer guidance to other management groups with questions on the ability of physical harvesting and be an outline for effective and environmentally mindful management.

Discussion

Effective invasive species management should reduce alien populations to a point where they are not a nuisance to humans, and do not disrupt the native ecosystem. Due to EWM’s ability to reproduce in multiple ways and create seeds that lay dormant for years, it is virtually impossible to completely remove once introduce to a water way and management of the population is the only real option (Zhang and Boyle, 2010). Long-term management demands those in charge to be conscious of any unintended consequences to the environment from remediation, as this may end up being more impactful than the original management problem.

Physical harvesting alone, specifically suction assisted hand harvesting has shown to be successful at managing invasive species growth in Green Pond in both 2020 and 2021. Virtually invisible to most residence, at no point did EWM growth impede watersports or use of the pond as it did in 2019. This means that the dive team's removal hindered seed growth and dispersal, as few plants were seen at the surface. Success can also be seen in declining EWM populations found and removed by the dive team during each field season, represented by negative *m* values in figure 4. The steep decline shown in 2020 may show a greater handle on AIS growth, also indicated by a relatively large R^2 value. In 2021 a larger amount of EWM growth was found starting in week 1, which meant an increased ability for fragmentation and proliferation throughout the pond. This is further indicated by the much larger quantity of EWM removed overall in 2021 compared with 2020, as operations were otherwise relatively consistent with the same number of divers and similar length field seasons.

Ideally, EWM growth found and removed during the field season should start and end small. This would represent starting operations before fragmentation can create exponential growth that impedes effective removal and ending operations when growth has virtually stopped. This can be accomplished through early monitoring by community members using temperature and observational data that can identify the best time to initiate dive operations. If operating effectively, growth could show a peak mid-season but should become harder to find as the invasive population is pushed to zero. This effort can be aided by other environmentally conscious management techniques if necessary, including fragmentation curtains and benthic barriers. Emergency use of a targeting herbicide like ProcellaCOR can also be considered if invasive growth becomes unmanageable, possibly in particular management zones.

Organization of EWM abundance by management zones identified three distinct hotspots, listed here based on comparison between weight removal and diver contacts-

1. Outlet Cove
2. Point Comfort
3. Swim Area

These three areas are markedly different, each with distinct physical characteristics. For example, the Swim Area beaches are sandy, Point Comfort rocky, and the Outlet Cove silty. EWM was found in these areas anywhere between 3' and 18', which demonstrations it's wide depth range. Limited biological surveys showed very different compositions of native growth at each location, with a dense muscle bed in zone 2 that impeded virtually all SAV growth including EWM. Consistent in each hotspot is a decrease in native species growth, and hydrology that pushes fragments towards these zones due to prevailing winds and drainage. This indicates the ability of EWM to grow regardless of substrate or physical conditions. Instead, it may be influenced by the abundance of native species growth, health of an ecosystem (muscle bed formation), and the flow of fragments in a water system. Slight changes to management zones are warranted as new information or patches of growth are discovered to better encompass EWM hotspots.

The regrowth experiment showed no EWM two weeks after removal but did show about 25% regrowth four weeks after the initial clearance of dense EWM. This regrowth was identified as fragmentation by exposed root systems from multiple nodes, accompanied by a browning stalk. Along with this morphology, new green shoots were seen coming from the sediment, connected by root systems to the fragments. The lack of regrowth in week two and morphology identified in week four shows the ability for fragments to land and grow new shoots in two weeks or less. This highlights the need for early and continued removal of EWM to be effective.

This research and demonstration project has shown the ability for EWM to fragment and quickly proliferate each growing season, regardless of the previous year's management success (Figure 4). It has also shown that EWM growth can be controlled with physical removal alone, specifically with the novel method described in this study. Although management has thus far been a success, it is important to note the increase in weight of EWM removed in 2021 compared with 2020. This could be influenced by many factors including increased high energy storms or an early growing season, but it indicates the abundance of invasive species has grown. Relatively small growth found at the end of 2020 and the large amount found at the start of 2021 again represents the ability of EWM to proliferate and spread quickly if not effectively managed each season.

Effective management of EWM must start early in the growing season and focus on hotspots to visit repeatedly for removal. Hotspots should be identified using multiple measurement techniques to avoid bias and a comprehensive management approach should be utilized to ensure the decline of invasive species each year. Fragmentation curtains and benthic barrier placement can both impede and be used to measure EWM growth, and so should be used more often to aid removal projects. In Green Pond specifically, benthic barriers could be placed at the beaches early in the season to decrease invasive and nuisance native growth in an EWM hotspot and area most used by residence.

Another important factor in invasive species growth and overall lake water quality is nutrient loading and water runoff. Anthropogenic additions to the ecosystem often include nutrients, fertilizers, insecticides, and herbicides which have a synergistic negative impact on the aquatic environment (Relyea, 2005). Sustainable runoff and water management techniques are essential to keep this pollution in check, as it is often undetected until systemic problems are noticed by the community. Ecologically responsible management techniques include protecting or planting trees and native flora at runoff locations such as Mountain Laurel *(Kalmia latifolia)* or native grass species (*Panicum virgatum*). These plant roots create a buffer zone in problem areas along shore, capturing nutrients and chemical pollution (Lee *et al., 2003*). Similarly, runoff can be diverged or collected with a raised garden bed.

Key characteristics described in this study that allowed for successful and sustainable aquatic invasive species management include-

1. Targeted physical removal of invasive species
2. Management of the area using zones
3. Prescence throughout growing season
4. Biological / Environmental data collection
5. Utilization of complimentary management techniques

The most important consideration is the significance of the problem invasive species, and their management creates for our lakes, ponds, and rivers. Humans have and always will settle these areas, relying on them for drinking water, our food supply, and recreation. If we continue to disrupt the natural environment with our remediation, these important systems will continue to degrade, causing a loss of biodiversity and essential ecosystem services. Education around these issues must happen to create a sustainable mindset in management for the continued use of our freshwater environments.

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