Green Pond Research and Demonstration Project: Aquatic Invasive Species Management 2020 Final Report

December 26, 2020

Navigating This Report

This report is structured into 8 sections and 3 appendices. While the material is designed to be read in order, readers may go directly to sections of particular interest. To help readers, the following summary of sections is provided. See the Table of Contents for page numbers.

Section 1. Executive Summary: Provides a summary of the highpoints from the entire document of the Research and Demonstration project.

Section 2. The Challenge: Provides historic context of the problem of invasive species in Green Pond and descriptive information about invasive species and Green Pond.

Section 3. The 2020 Plan: Provides an overview and rationale for the 2020 plan with particulars about the HIGLIN/AERM*'s plan for hand removal in Green Pond and the agreement among the parties involved in the project.

Section 4. 2020 Execution: Regional and environmental conditions about invasive species are described and the major events and decisions which occurred during the 2020 field season are highlighted.

Section 5. Methods and Measures: Describes the methods used by the Dive Team and the measures used to quantify how much invasive plants were found and removed and how much native species were found.

Section 6. Results: Provides the tabulated and observed results of the projects activities including the results of the Dive Team operation, and the relative quantity and location of invasive and native species.

Section 7. Findings: Provides a summary of the useful insights garnered from the results about invasive plant species, particularly, EWM, and their management.

Section 8. Recommendations: Provides recommendations addressing the next stage of the Green Pond demonstrations project and the steps to bring the knowledge created by this project into the NJ Highlands region through education and demonstration with other lakes.

Appendix A. Water Temperature Profile Measurement: Provides details about the water temperature monitoring initiated in this project.

Appendix B. Submerged Aquatic Vegetation Assessment and Detection: Discusses the critically important processes and alternatives for finding targeted species in lakes.

Appendix C. Transect Survey Example Data: Provides examples of species population data gathered during the project.

* AERM (Aquatic Environmental Research and Management) is a subsidiary of HIGLIN which created the hand removal capability used by HIGLIN.

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.

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1. Executive Summary

Green Pond, a representative Highlands Region glacial-freshwater pond, was challenged by the invasive plant species Eurasian Watermilfoil (EWM). First discovered in the lake in 2013, EWM in 2019 proliferated from a 24 acres infestation in June to 174 acres in September, covering 53% of lake acres susceptible to EWM growth and closing the lake to boat traffic. The lake stewards, the Green Pond Corp. (GPC) and Lake End Corp. (LEC) Boards of Directors, sought an overall plan to gain and maintain control of EWM. As they developed the plan for 2020, they explored participation in their efforts with HIGLIN.

The 2020 plan envisioned an herbicide treatment of a large portion of the lake supplemented by herbicide provider recommended hand removal to address any residual growth that could occur in and outside the treatment area. A project was proposed by HIGLIN to test and demonstrate the efficacy of hand removal as an adjunct. The project was accepted and a Cooperation and Access Agreement was formalized among the GPC, LEC and HIGLIN. HIGLIN implemented the hand removal through a design that had three main elements: 1. A professional Dive Team; 2. Equipped with Invasive Species Removal (ISR) technology; and 3. Using a Search and Destroy method of operation. The method was designed to achieve economies for diver time in the water by detecting and removing invasive plants in one continuous process.

The HIGLIN 2020 Green Pond project commenced on June 1st and ended on September 18th. During the 15 week period, three weeks of training in hand removal, ISR technology, and Search and Destroy procedures occurred; and the equivalent of thirty full 10 hour days of hand removal were performed. As the field season unfolded, early and continuous application of the Search and Destroy methodology devised by HIGLIN removed EWM plants before they could fragment and proliferate. Additionally, the professional Dive Team supported by ISR was able during the entire season to effectively cover 636 acres, counting repetitive visits to some acres, an order of magnitude larger number, compared to the anticipated capacity to cover 50 acres. A much larger number of acres were covered because the Search and Destroy technique prevented the growth of and need to remove a large biomass. By detecting and removing EWM early and ISR preventing fragments, wider proliferation did not happen and saving time to cover more acres.

During the growing season, the Dive Team found EWM in the areas observed in September, 2019, but at no point did EWM rise to nuisance levels. Multiple rake toss surveys performed by two professional lake management groups, Princeton Hydro and Aquatic Technologies, found too little EWM to chemically treat. The planned herbicide treatment was cancelled in early August. The project's Search and Destroy operation, which had been successfully removing EWM plants before they could proliferate, continued by addressing all lake areas including those previously set aside in the plan for treatment. In total the Dive Team removed over 3052 pounds of plant material, estimated to include 85% EWM and 10% CLPW, invasive species, and 5% native species. The amount of EWM found in the September, 2020 diver/sonar survey of the entire lake was a small percentage of that found in the September, 2019 sonar survey.

The results and findings of the 2020 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 appears capable of covering enough acres in a growing season to responsively maintain control of EWM growth. Further testing of those findings given the single season sample is needed and recommended. Using data gathered from 2019 and 2020, the lake can be categorized into areas by relative probability and intensity of EWM growth which would guide the management of EWM, such as by scheduling the frequency of surveying each area during the season based upon its historic pattern of EWM growth.

2. The Project Challenge

2.1 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 widely dispersed infestations in 174 acres which required closing the lake to boat traffic in 2019. At that time, EWM detected by sonar was present in 53% of the 330 acres hospitable to EWM growth in Green Pond.

Areas Susceptible to EWM Growth
Figure 2.1

Red areas are depths less than 15 ft, most susceptible
Blue Areas are deeper than 15 ft. less susceptible

During those seven years, actions were taken by the lake stewards, who are the boards of the Green Pond Corporation and Lake End Corporation, and community volunteers to respond to EWM presence and establish some level of management and control. Four herbicide treatments of EWM in four different areas were performed under the guidance of Princeton Hydro (PH), the professional lake management group supporting the lake stewards. In 2014, a one acre area found in 2013 was treated with the herbicide, Reward. In 2017, multiple patches amounting to 7 acres were treated with Reward. In 2019, two separate areas of 3 acres and 17 acres were treated with the newly developed herbicide, ProcellaCOR.

The years when treatments were not done highlight the inconsistent evidence of EWM from year to year. In 2014, some was found but deemed stunted with no need to treat. None was detected in 2015 and 2016. In 2018, some patches were identified, but given the sparseness, PH recommended no treatment. Also, in parallel, sporadic detections of curly leaf pond weed occurred but none required remedial action.

As the problem grew, the lake stewards and community volunteers teamed to improve detection and removal activities. In 2014, an attempt to enlist volunteers to visually search for and identify EWM did not get off the ground. In 2018, another attempt led by a volunteer succeeded in recruiting interested parties. The group, Lake Watchers, was formed which greatly increased the surveillance and consequently the detection of EWM. In parallel, PH proposed and was directed to increase detection activities. In 2017 and 2018, rake toss and scuba diver inspections were added to and replaced transects studies in some instances. By 2018, 40 sampling locations were included by PH. Also in both years, volunteer scuba divers and professionals from PH hand removed patches of EWM found by PH and the Lake Watchers.

In 2019, a dramatic escalation of the detected EWM occurred. Coincidentally, a Lake Watcher volunteer proposed and implemented a sonar based detection methodology by identifying a unique sonar signature associated with EWM. Armed with this additional information, multiple volunteer dive crews were deployed to hand remove patches discovered in many parts of the lake. Despite those efforts and two herbicide treatments, the proliferation was found to be substantial. A sonar survey done in June had identified 24 acres of milfoil while one completed in September found 174 acres, an over 7 times increase in one season. Figure 2.1 below shows the results of both the June and September surveys. Shortly, thereafter, a meeting of the volunteer Milfoil Action Committee (MAC), established earlier in 2019 with the lake stewards, grappled with the explosive growth. MAC concluded that an overall plan to gain and maintain control of EWM was needed and should be ready to execute in the 2020 season.

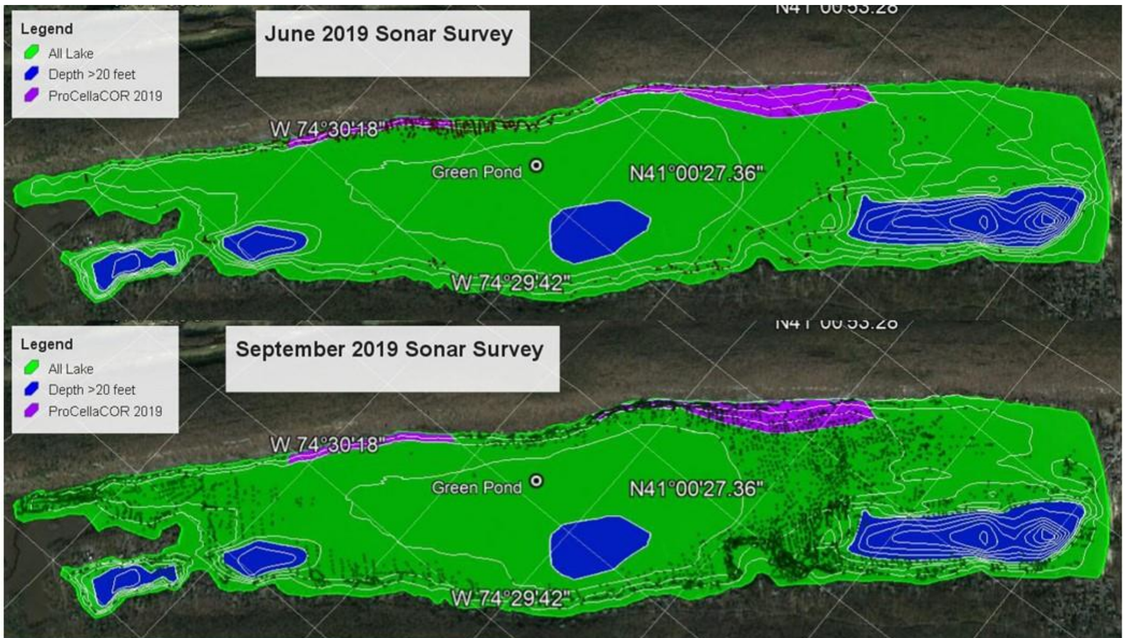


Figure 2.2 :Comparison of EWM plants present in June versus September, 2019

Black spots on maps indicate EWM plants

Later in 2019 as they developed their plan for 2020, the lake stewards engaged with HIGLIN, when it was formed as a newly created not-for-profit dedicated to help lakes in the NJ Highland Regions with challenges including invasive species. Sections 3 and 4 describe HIGLIN's role in the plan and execution.

2.2 The Challenger: Eurasian Milfoil (EWM)

Also known as "non-native", or "alien", invasive species 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 in an attempt to restore balance to ecosystems in trouble. Well know 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 aggressive competition found in its native country, Eurasian Watermilfoil (EWM) can grow very quickly once water temperatures are above 60 degrees and has multiple ways of reproduction (Smith and Barko 1990). The most notable is fragmentation, which consists of plant segments growing roots and breaking free to settle and grow in other areas. This allows EWM to multiply exponentially, especially once mature root systems are established in the benthos (Perkins and Sytsma 1987). These mature root systems yield taller and more densely growing plants each year, that outcompete native species for space, light, and nutrients (Madsen et al. 1995). This creates a significant problem for lake communities, where EMW eventually grows to the surface and creates large floating mats that impede watersports and decrease property values. At this stage the plant produces flowers on the surface that are fertilized and create seeds that can stay dormant for years, compounding the problem.

Multiple methods of removal have been used for EWM invasions in the past. The most widely used technique are large-scale herbicide treatments, as it is seen as the easiest way to manage the problem. More involved 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, this technique is 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. Problem with those afore mentioned techniques have been evident in multiple freshwater bodies of water in the Highland Lakes Region this and other years, such as Lake Hopatcong.

The technique considered 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 no other inlet and one small outlet which flows directly into a US DOD base’s wetland, stream, and lake ecosystem on its way to 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 and growing 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. 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.

3. The 2020 Plan

3.1 Introduction

This Research and Demonstration project envisioned a 2020 growing season in which EWM was brought under control below nuisance levels. Control was to be established through a complementary combination of herbicide treatment of a large portion of Green Pond planned by the lake stewards and hand removal which would search and destroy sparse areas and plants in and outside treated areas. The approach was supported by expert opinion provided by consultants, PH, and by SePRO, the manufacturer of ProcellaCOR, the EWM-specific herbicide selected by the lake stewards which stated:

"Because of the multi-year duration of control achieved from ProcellaCOR, lakes can maintain a milfoil-free waterbody in subsequent years through early season monitoring and by rapidly responding to any finds of re-growth in small areas with a hand removal effort, which should be successful in preventing any spread."

The planning for the 2020 growing season occurred during December 2019 and January, 2020. The importance of hand removal supported by ISR had come to the fore from research of lake communities in the northeast and mid-west of the USA who had success in controlling EWM. HIGLIN/AERM contracted with a manufacturer to produce two ISR boats to be used in its demonstration projects addressing invasive species. A professional dive team would be recruited, trained and deployed to operate the boats; the team was envisioned to be comprised of a foreman, dive scientist, and team divers. Job descriptions were developed, drafted and finalized with consultation from experienced ISR boat operators. Additionally, a new dive team ISR-boat operating technique of search and destroy was developed, tested and adopted as the removal approach. Commencing early in the season, the dive team would constantly survey specified areas with EWM growth potential and remove EWM plants found.

3.2 Hypothesis and Plan

The "Plan" developed for 2020 was based on two assumptions: 1) a significant portion of the Eurasian Water Milfoil (EWM) that was seen in 2019, would return in 2020 and continue to proliferate and 2) the likely capacity of a two (Invasive Species Removal) operation over the growing season would be a 50 acre coverage. This was based on conversations with multiple lakes stewards, ISR operators and searches of the available literature. Assumption 1 proved accurate by 2020 growth as shown Figure 3.1 shows the EMW present in the lake in September 2019 and all found during 2020.

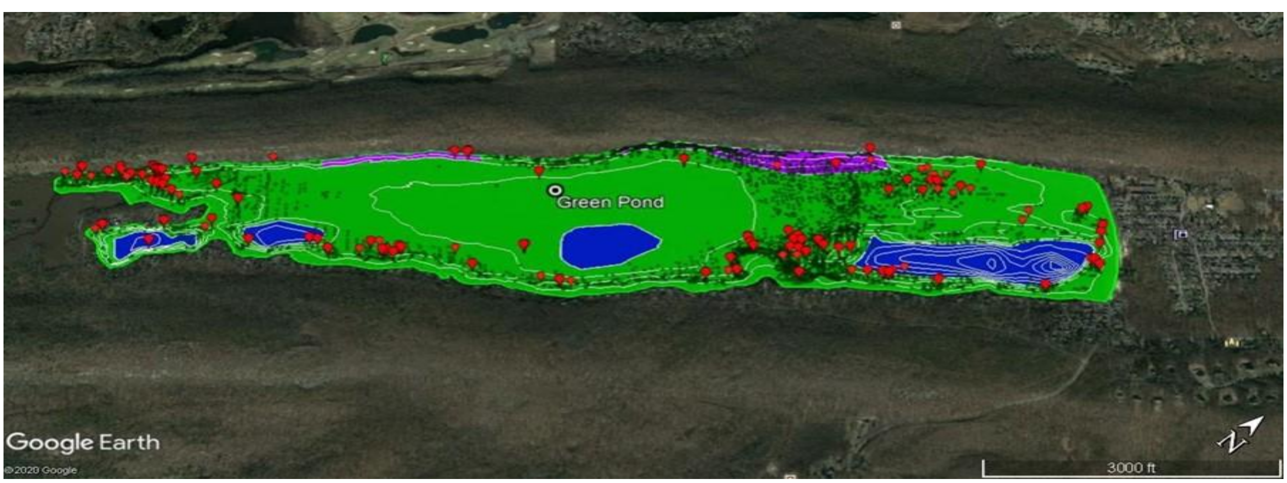


Figure 3.1 Mapping of EWM in Green Pond. 2019 EWM plants shown as small black dots and 2020 patches as red bullseyes. Deep glacier formed holes shown in blue. 2019 herbicide treated acres shown in purple.

There was a desire to test managing invasive aquatic vegetation (EWM was the major current component) by hand removal to work in conjunction with a major herbicide treatment, rather than future herbicide applications over time as areas became infested. A consistent removal program would continue to remove any newly found invasive species before they reached a reproduction stage and proliferated. Herbicide works most efficiently against more mature plant stands when a single application can be absorbed by the largest number of plants and eliminate them. However, it was unclear if the hand removal with ISR could manage the workload. Therefore a two part strategy was proposed and adopted that:

1. Assign a large area for ProCellaCOR treatment to rapidly reduce the level of EWM to a level that would not interfere with recreational activities and could be manageable by non-herbicide means.
2. Assigned a small area for ISR based hand-removal that would allow calibration of the productivity of both "search and destroy" operations and "area clearance" techniques. In the HIGLIN devised "Search and Destroy" technique, divers search for, identify, and remove invasive plants including sparsely distributed individual plants. In "Area Clearance", an established area of concentrated vegetation is removed, removing significantly more vegetation in a working day.

The approximate surveillance workload required in Green Pond can be seen from the bathymetry statistics shown in Figure 3.2. The question arose, what is the likely actual coverage potential? Green Pond has an acreage of 509 Acres, which does not include the outlet wetlands. Of that acreage, 168 Acres are between 10 and 15 feet deep. These depths have been the primary EWM habitat, although the bottom character and other factors make some parts less EWM habitable and some shallower areas have had significant EWM growth. Based on all factors, 330 acres were targeted to be inspected and cleared of any EWM.

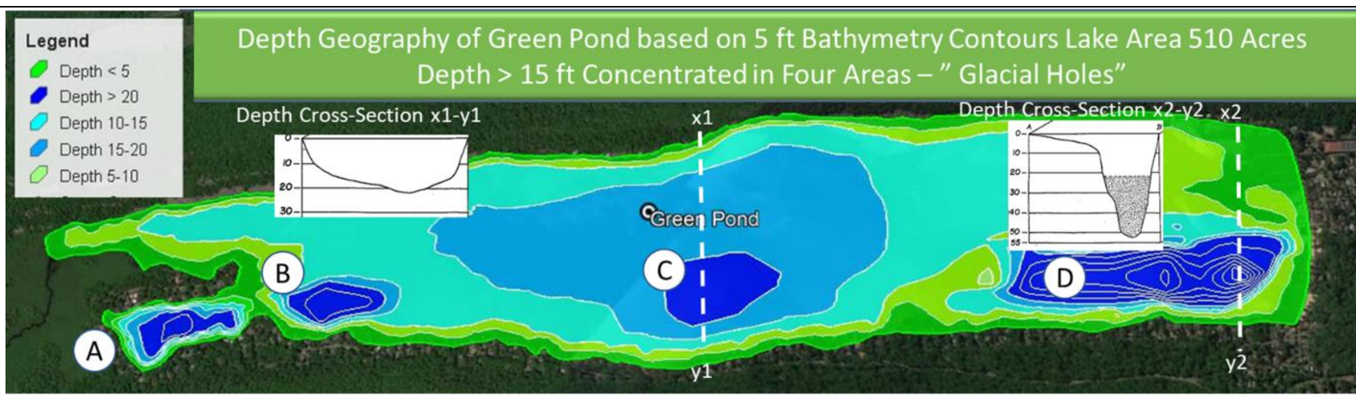
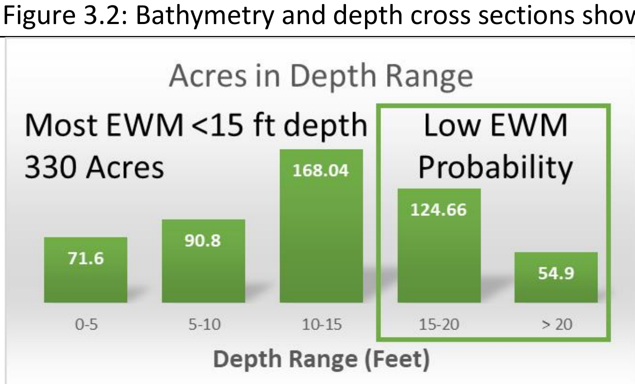


Figure 3.2: Bathymetry and depth cross sections show Green Pond's classical glacial "hole" character



In Green Pond EWM prefers depths< 15 feet.

Tabulating the total acreage in each depth interval shows 330 of the 510 acres are less than 15 foot depth

During the planning for the Research and Demonstration project in 2020, a baseline assumption was made that the removal coverage capacity of the ISR operation would be 50 Acres. This assumption was based on the experience of volunteer hand-removal in Green Pond over the 2019 season without ISR technology, conversations with organizations undertaking ISR removal, and literature reports. Most of the experiences were based on removing mature EWM at a significant density levels measured by stems per square meter. If a hand removal ISR supported approach were to be a part of management of invasive species, a level of confidence was needed that it could locate and remove invasive vegetation in all areas of the lake.

The successful removal of EWM from early in the 2020 season led to the decision to not do an herbicide treatment and instead, rely on hand removal only. Section 4.2 describes the events and decision in detail.

3.3 HIGLIN & AERM Invasive Species Removal (ISR)

HIGLIN's subsidiary, Aquatic Environmental Research and Management (AERM) identified three factors critical for performance to support HIGLIN's plan for hand removal. The three factors were new generation ISR boats, a professional dive team, and early and continual search and destroy. Those factors working together were 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 three paragraphs.

The ISR boats developed by AERM and the contracted equipment supplier, were similar but different in key ways compared to existing ISR boats. The removal capability was provided by the normal surface mounted system aboard the boat and had the power to collect plants and fragments that separate from the plants as they are handled. By adding sluice boxes, inspection of all materials being gathered by the divers would be performed to preserve wildlife (turtles, fish, etc.) or to separate refuse from the plant material before it was readied for disposal. Important safety features were added including 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 float (See Figure 3.3) would be attached to each ISR hose keeping the hose-end away from the lake bottom to prevent disturbing and/or removing of the lake bottom the sediment. In addition, to address the large infestations of EWM in New Jersey Highlands Region lakes, more removal capacity was required and 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, soon began demonstrating that a remarkably level of EWM and CLPW management could be achieved in this project.

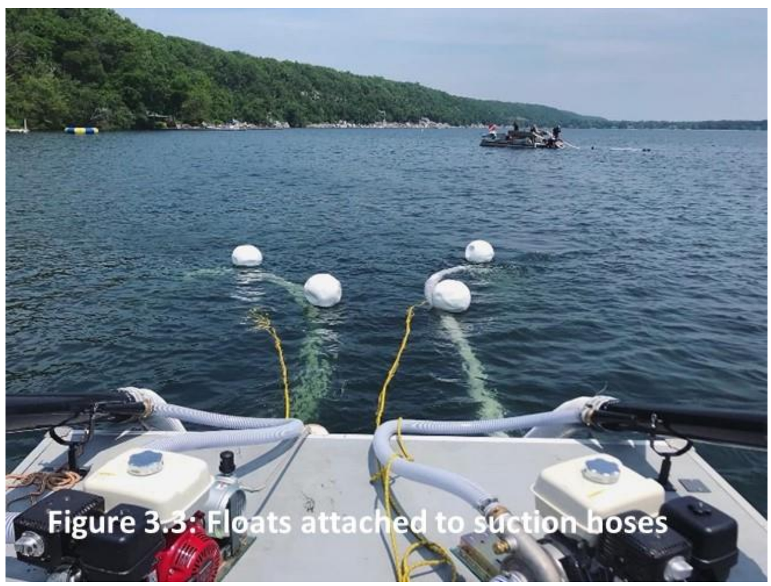


Figure 3.3: Floats attached to suction hoses

The building of the professional dive team commenced with the formulation of job roles and team structure. A foreman/boat captain was hired to assist recruiting and hiring additional members including one dive master/team scientist and seven diver/tenders. After receiving over fifty diver applicants and conducting online Zoom interviews, the finalists selected far exceeded AERM's initial expectations with their qualifications, certifications, experience, engagement, and enthusiasm It was clear from the outset that the assembled team working with the quality of the boats and equipment provided would have significantly greater capacity than that initially forecasted and assumed in the plan. Their actual performance proved to be the case as will be described in the 6.1 section below.

The standard approach ("Ares Clearance") to hand removal entailed addressing EWM when plants had grown to a sufficient height and density where hand removal would be effective and efficient. A perception of cost-effectiveness was achieved in this standard approach by having large patches and large plants to remove increasing pounds of plants gathered within a time interval. Performance typically being measured by the poundage removed rather than the more critical, impact on controlling EWM growth.

A new approach, "Search and Destroy", was devised and used which not wait for the appearance of mature plants but started seeking and removing early in the season when plants were small and sparse. 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.

3.4 Cooperation and Access Agreement

A Cooperation and Access Agreement was develop and approved by the three organizations engaged in this Research and Demonstration project, including GPC, LEC and HIGLIN. The agreement executed in May, 2020, provided the definition of the project and the terms and conditions for the three organization. The agreement established a Project Oversight Committee which subsequently became known as this research project's Steering Committee. The members of the committee were the presidents and vice presidents of the organizations' boards of GPC, LEC and HIGLIN. One main objective of the steering committee was facilitating the execution of the Research and Demonstration plan. The committee was active and engaged and helped immensely during execution by reviewing observations, data, and information which led to clarification and adjustments to the plan.

4. Execution of 2020 Plan

4.1 2020 Invasive Plant Conditions

As the 2020 growing season commenced in the Highlands Region, lakes which had experienced challenges with invasive plant species in previous years once again had substantial growth. Lake Hopatcong and Greenwood Lake, both of which years before had instituted mechanical harvesting programs for EWM, saw rapid and widespread infestations. Nearby Egbert's Lake and Lake Ames were thickly choked. As the season approached in Green Pond, concern arose whether the local mild winter and the colder than normal spring could cause changes in the timing of the growth of EWM which is highly sensitive to temperature. Consequently, the timing of the planned EWM control activities would also be impacted. The project team sought ways to monitor and react to changing conditions.

To implement the 2020 (EWM) control program, the project team sought to find the best time to initiate different controls. This meant finding ways to determine and predict the growth of EWM in Green Pond. The primary factors determining EWM growth are: the depth the plant is at, water clarity, seasonal water temperature and seasonal irradiance due to the number of sunny days (Gracie (1976) and Smith and Barko (1990)). Because of the widespread nature of the EWM problem, a number of mathematical models of EWM growth have been published over the years (Titus et al. (1975); Best and Boyd (1999); Best et al. (2001); Herb and Stefan (2006); Miller (2011)). These models show that the growth rate accelerates exponentially once the water temperature exceeds a "trigger temperature". In New Jersey, the trigger point is generally understood to be water temperature of 60 degrees F at the plant roots. In Green Pond most of the EWM has been found in the depth range of 10-15 feet, so predicting the starting point of EWM growth requires information on the water temperature at that depth.

Figure 4.1 HIGLIN Water Temperature Measurement Program

A measurement program was established by HIGLIN to collect water temperature profile data and showed that the 10-15 foot depth reached the trigger temperature by May 21. See Figure 4.1. The next 10 degree increase at the 15 foot level lagged the surface temperature increase by 6 days. The deeper water temperatures follow the ground water temperature of about 55 degrees F and stayed stable over most of the summer, which causes the observed lag between shallower and deeper temperatures. Temperatures in shallower areas were showing about 2 weeks more time at 70 degrees than those at depth, and EWM present at shallower depth posed an early threat from interference by boating. In response to prevent boat traffic from fragmenting and spreading plants, a program of hand removal in shallow areas was begun on June 21, 2020. A more detailed explanation of temperature monitoring and results is given in Appendix A.

4.2 Timeline of 2020 Events and Decisions

An operating plan is likely to require adjustments as soon as it starts to be implemented due to the developments in the initial stages of the operation and from sources exogenous to the project. Unexpected conditions arose from the outset and adjustment were made in response. A steering committee described in the project agreement was established to understand the actual conditions and challenges that would arise during the season. The steering committee made decisions to make changes to the plan. The following is a numbered summary providing the highlights of the project during the 2020 growing season. Figure 4.2 using the corresponding numbers depicts the time sequence of activities, events, and decisions.

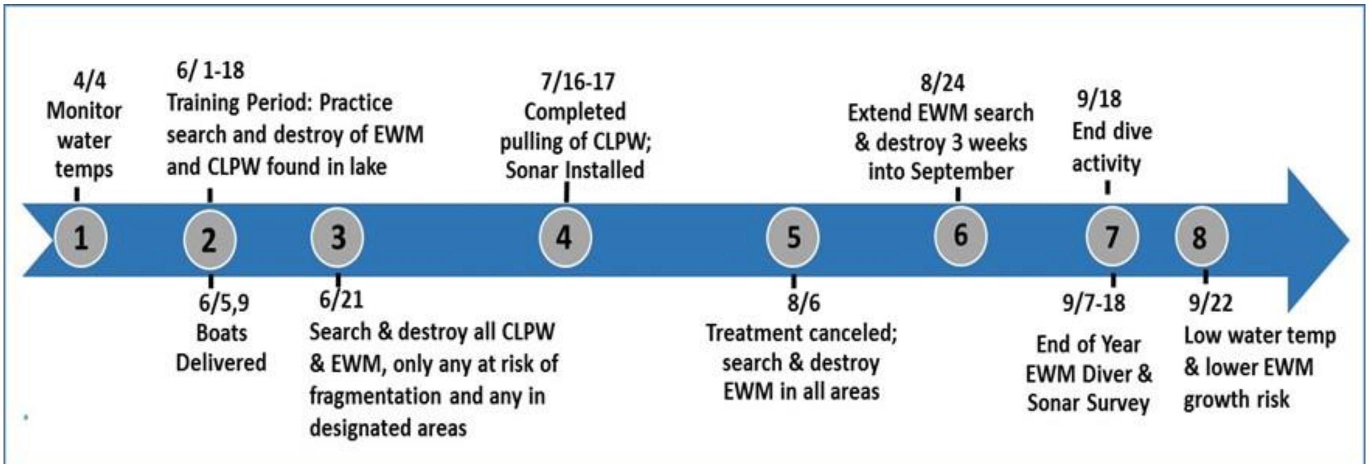


Figure 4.2 2020 Growing Season Timeline of Activities and Decisions

1. As the 2020 season approached, concern arose that the local mild winter and the colder than normal spring could cause a change in the timing of the growth of EWM which is highly sensitive to temperature. Consequently, a decision was made to monitor the temperature in the thermocline in multiple locations in the lake. The monitoring continued throughout the season.

2. Training of the dive team using the new ISR boats was planned to start on June first. Because the boat deliveries were delayed from May 29 to June 5 and 9, the training was adapted and extended an additional week. EWM was not plentiful because of the colder than normal water temperatures. Fortunately, small individual plants and clusters were found and used for search and destroy training. Early during training, CLPW was found in mature abundance in certain areas and was added to the invasive species targeted for removal. The dive team learned to remove plants in various growth stages and densities. During the training period, both Invasive species EWM and CLPW were found and removed every day. The number of individual Eurasian Watermilfoil plants increased dramatically, while other invasive species found early such as exotic water weed and Curly Leaf Pondweed started to decrease as ISR operations became more efficient.

3. After the training period, the plan called for the dive team to remove in predefined areas, bypassing areas that were planned to be treated with herbicide. During training, the team observed troubling conditions. EWM plants were growing to heights in shallow boat traffic areas which increased the chance of fragmentation and of carrying fragments into previously uninfected areas. Also, while the natural fragmentation of mature EWM was known, the dive team observed even small plants fragmenting. This information was shared with the steering committee who considered whether the dive team should address those newly discovered fragmentation issues. The steering committee sought advice of the herbicide manufacturer, SePRO and the service provider contracted to do the treatment, Aquatic

Technologies (Aqua Tech). Both agreed with the plan to have the dive team remove to prevent the fragmentation. In addition to removal in planned designated areas, the dive team would use its Search and Destroy approach to find and remove EWM plants that actively presented a risk of fragmentation.

4. By mid-July, the dive team had removed CLPW to the degree where it was not detected in the lake. During this period, small fragmenting EWM plants and a number of mature stands with potential to fragment from boat traffic were found and removed. Also, sonar equipment was installed on one boat. The foremen and team scientist were trained in its use. Sonar contacts detecting EWM plants would be used to help detect the plants during Search and Destroy and help with the end of year survey.

5. During July, multiple survey's done by the contracted herbicide applier, Aqua Tech and a rake toss by Princeton Hydro found minimal EWM; both sets of observations opened up the possibility of delaying or even cancelling the herbicide treatment. Early in August, Aqua Tech performed another survey finding too little remaining EWM to make a treatment effective, and consequently, recommended canceling the treatment. EWM had been removed and growth prevented. Following that recommendation, the steering committee canceled the planned 2020 treatment and simultaneously authorized expanding the Search and Destroy area for the dive team to include all acres in the lake.

6. While search and destroying throughout the lake, the dive team continually found small and medium EWM plants in numerous areas. While this level of presence did not result in any nuisance conditions, the concern arose that a late season bloom aided by warm water could nullify the extent to which EWM had been cleared from the lake. Such a bloom could also set up the lake for greater EWM growth in 2021. HIGLIN leadership recommended that the dive team planned schedule of 12 weeks be increased to 15 weeks, adding 3 weeks in September. The project had shifted from a test of the combination of herbicide treatment and hand removal to a test of hand removal alone controlling EWM. The steering committee approved the extension.

7. Starting in the second week of September, the dive team conducted an end of year diver and sonar survey of the entire lake. The results showed very minimal EWM. As a gauge of the effectiveness, at the end of 2020, around 80 EWM plants were found; while in 2019, the end of year survey showed over four thousand contact/plants found. Hand removal by the dive team ended in the second week of September.

8. During the fourth week of September, the water temperature measured at critical depths was found to be 65°, a temperature which reduced the possibility of a late season EWM bloom.

In summary, rising temperatures (over 60 degrees) led to increasing EWM growth, which was targeted and removed using the Search and Destroy approach. Traditional ISR efforts are often deployed on growth already at nuisance levels and are focused on dense acres of invasive plants. In Green Pond this year, the Dive Team removed invasive species before they became a nuisance, and so drastically decreased the plants' ability to grow.

5. Methods and Measurements

5.1 Methods

Central to the purpose of this project was demonstrating hand removal supported by ISR to determine its effectiveness. Using that approach and technology, Search and Destroy 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. In this project, removal was also 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 method used was to optimize what was achieved in controlling invasive species during the divers' "bottom time".

Search Methods

For search to be effective, sub-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, route tracking and defined survey areas.

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 20 foot distance. Consequently, bottom inspection has a relatively low detection threshold, meaning the species can be detected even with low presence, and a high accuracy 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.

Route tracking was accomplished with software and devices which recorded the location of each boat continually using GPS positioning. The ***Strava*** app on an Android phone and the Lowrance Sonar with its GPS capabilities were the technologies used. With the graphical tracking information they provided, verification of dive team's coverage of acres could happen in near real time.

Defined survey areas was the third sub-method employed in by the project. Based on the plant growth information gathered in 2019, areas of interest were identified and prioritized at the start of the 2020 season. Those were used to guide the selection of areas to Search and Destroy. As the season unfolded, the new plant growth information gathered helped refine the areas and update the priorities which in turn helped determine the weekly and daily work plan for the Search and Destroy operation.

At the end of the season, the lake was divided into nine areas using a number of factors. The goal of this delineation process was to ensure that each area 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 facilitating dive activity. The nine areas are:

1. Swimming Area- This includes the north end of the lake with both bathing beaches
2. Sand Bar- Shallow sandy area off the boating docks on the NW shore extending to Point Comfort area
3. Seven Sisters- Area along the West Shore centered off houses accessible only by boat
4. Outlet Cove- Silty area along the West Shore with the outlet stream
5. Shawgers Cove- Deep area along the SE shore, enclosed with shallow rocky ledge
6. Mid-Lake- Deep central area of the lake that extends from Point Comfort to the coves
7. East Shore--Shallow rocky area along the mid SE shore
8. Point Comfort – Rocky area off the shallow point on the east shore
9. Bass Hole- Deepest area of the lake located near the NE corner

Figure 5.1 provides a color coded mapping of the nine area, and categorizes each area according to its EWM growth pattern: Hot Spots, require the most frequent surveying, Moderates, and Rare. The red spots on the map indicate where EWN was found in the 2020 season.

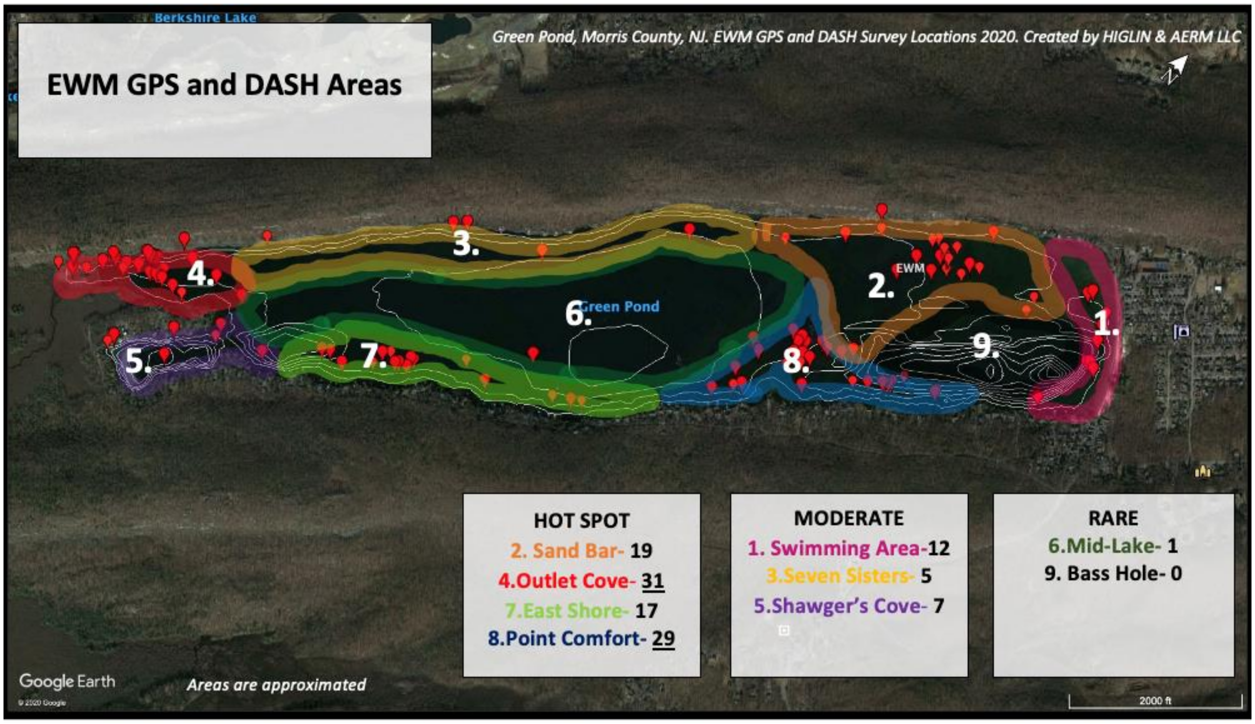


Figure 5.1 Invasive Species Areas

Destroy Methods

Invasive Species Removal The main method for removal, used in this project was hand removal assisted with ISR. Using five-inch diameter hoses attached to a Venturi system, two divers on each boat used a techniques 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 of the removal hose as shown in Figure 5.2. For larger plants a similar technique was used starting at the top of the

Figure 5.2: Harvesting small EWM plants

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 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'' onion bags. Full of plant material, these bags on average ended up weighing approximately 25 pounds.

Traditional hand removal without ISR was 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.

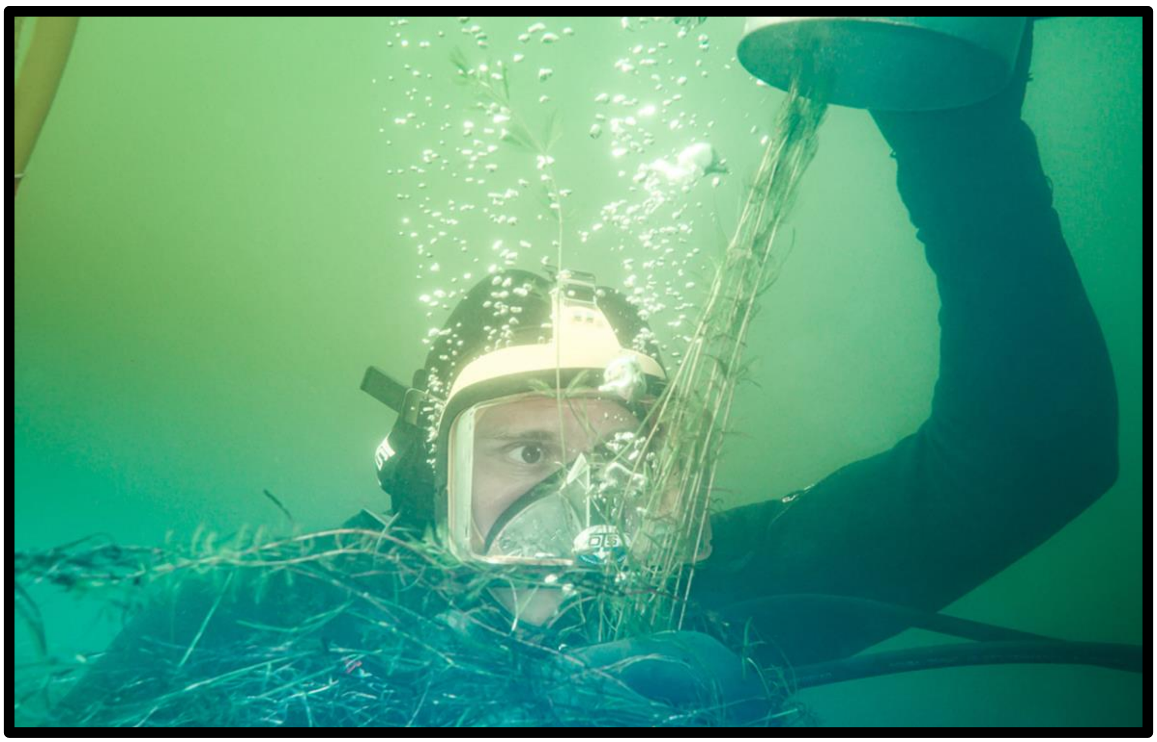


Figure 5.3 Team Diver removing tall EWM (*Myriophyllum spicatum*) from the Swimming Area in July, focusing on getting all plant material and minimizing fragmentation.

5.2 Measures

Search and Destroy Measures

Multiple measurements were continuously taken during the removal process. Most central to the Research and Demonstration's purpose was quantifying how much EWM and other invasive plants were found and removed during the 2020 growing season. This was accomplished using three different and complimentary measures: plant counts, weight of EWM removed, and GPS coordinate marking. Each method will be described below in detail.

Invasive species plant counts were used in the beginning and end of the field season to demonstrate the number of individual plants found. In the first week, less than EWM 100 plants were counted. Starting the second week, a much larger number of plants discovered made counting less accurate. Here the weight of plants was used to better represent the amount of invasive species found. Later in the season when little EWM was being found, plants were again counted in an attempt to better communicate the amount of invasive plants currently growing in Green Pond. At that time, close to 200 plants were found each day, totaling almost 1,000 plants each week. Trained divers have superior ability of to quantify and remove invasive species in comparison to rake tosses. That standardized technique used by aquatic consultants is not able to detect the true number of invasive plants even at those large numbers because EWM was kept below a nuisance level and the rake toss's high detection threshold.

GPS coordinate marking began the 3rd week of removal and was able to demonstrate when and where EWM was found to be growing. GPS markers were placed in areas where EMW had not been previously found, and marked multiple times in areas with dense growth or where it had been consistently found this year. GPS software on the Lowrance Sonar System and the GPS Tracks App were used to collect this data, which has been combined on Google Earth (Figure 5.4).

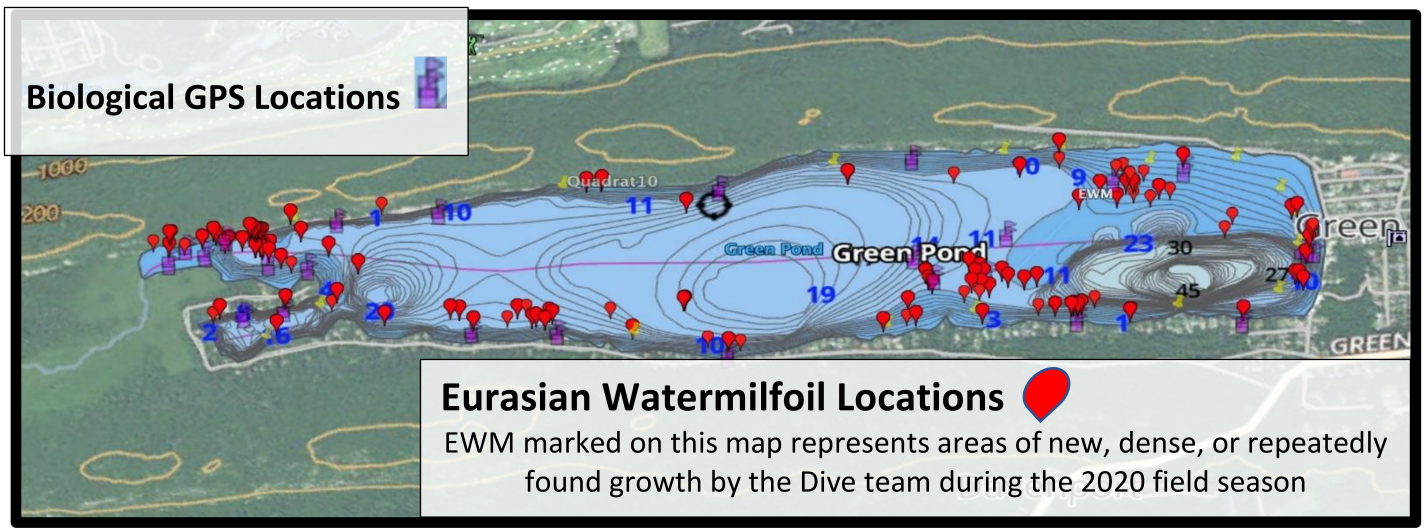


Figure 5.4 EWM and Biological Survey Locations 2020

Another method of measuring EWM utilized was the weight of aquatic plant material removed. This was done using plants' wet weight (WW), which describes the consistent measure used to establish how much each bag of plants weighs and entails a 10 minutes drying time which allows for excess surface water to evaporate and a more accurate measure. Unless specified otherwise, these bags were filled with 80-90% invasive species. This is due to the tendency of aquatic plants to grow together and on top of one another, and the diver's attempt to remove all root systems of targeted invasive species. On average bags consistently weighed about 25 pounds.

Combined, those three distinct ways of measuring invasive species growth present a comprehensive picture of its abundance and distribution in Green Pond this year.

Biological Measurements

Biological surveying techniques into all aquatic plant species were also conducted to better understand the aquatic ecosystem and represent the abundance of invasive species compared with native ones. Biological surveys are designed to show the diversity and abundance of species in a particular area.

Two techniques were used in this project. Fifty foot transects were conducted using underwater open reel tape measures, where each foot was surveyed for plant growth by two divers. This means each transect reported 100 points of data, with 25 transects recorded. Examples of plant counts from numerous samplings are shown in Appendix C. Quadrats (pictured in Figure 5.6) made of slim 5’ x 5’ PVC piping and a grid of 25 squares were also used to compare aquatic plant species by location and depth. Full results from all sampling are described in detail in Sections 6.2 and 6.3.

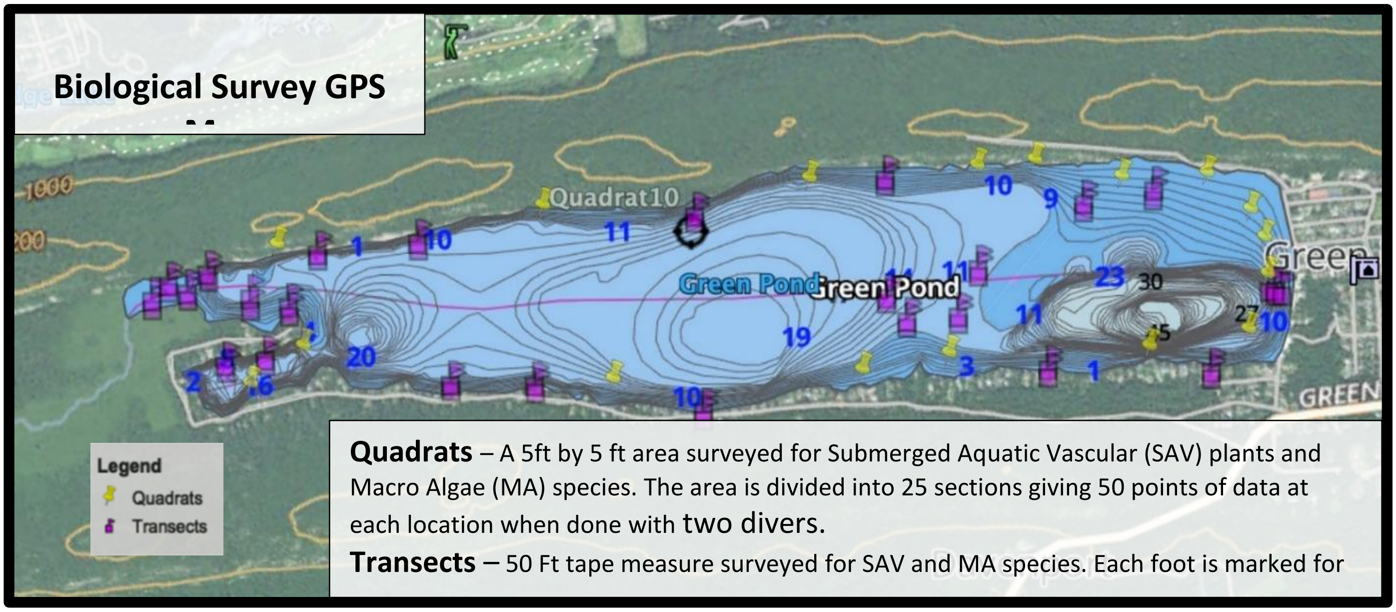


Figure 5.5
Biological Survey GPS Map

Biological survey locations were picked at random following standard survey techniques for the purpose of representing SAV plant growth in the lake for the 2020 field season. Depths numbered in black and blue.

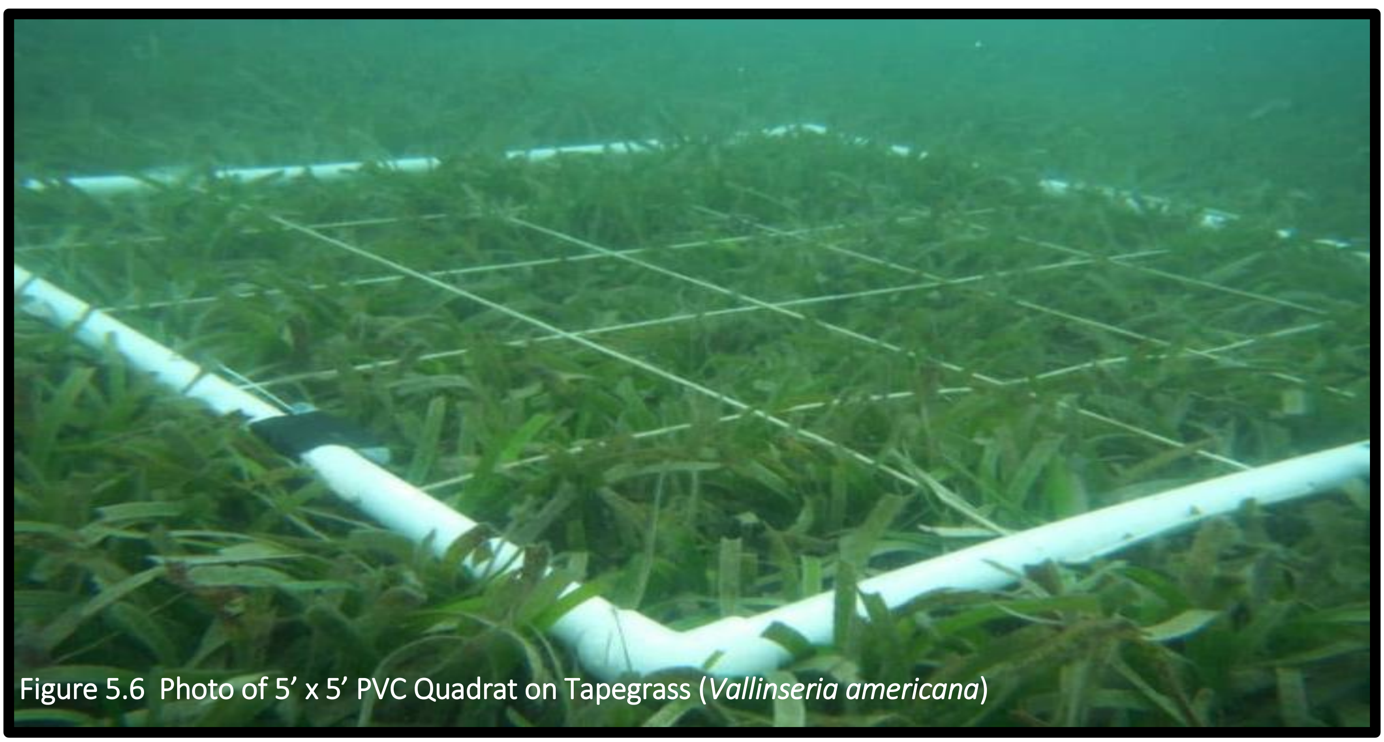


Figure 5.6 Photo of 5’ x 5’ PVC Quadrat on Tapegrass (*Vallinseria americana*)

6. Results

6.1 Search and Destroy Results

In the 2020 field season, a two ISR boat operation with two divers per boat continually in the water demonstrated the capacity to search out and clear 20 acres per day (10 acres per ISR boat per day). The keys factors in this were to start early and operate consistently to identify and remove invasive species as it emerged and before it could form the dense clusters that could only be cleared at a much slower rate.

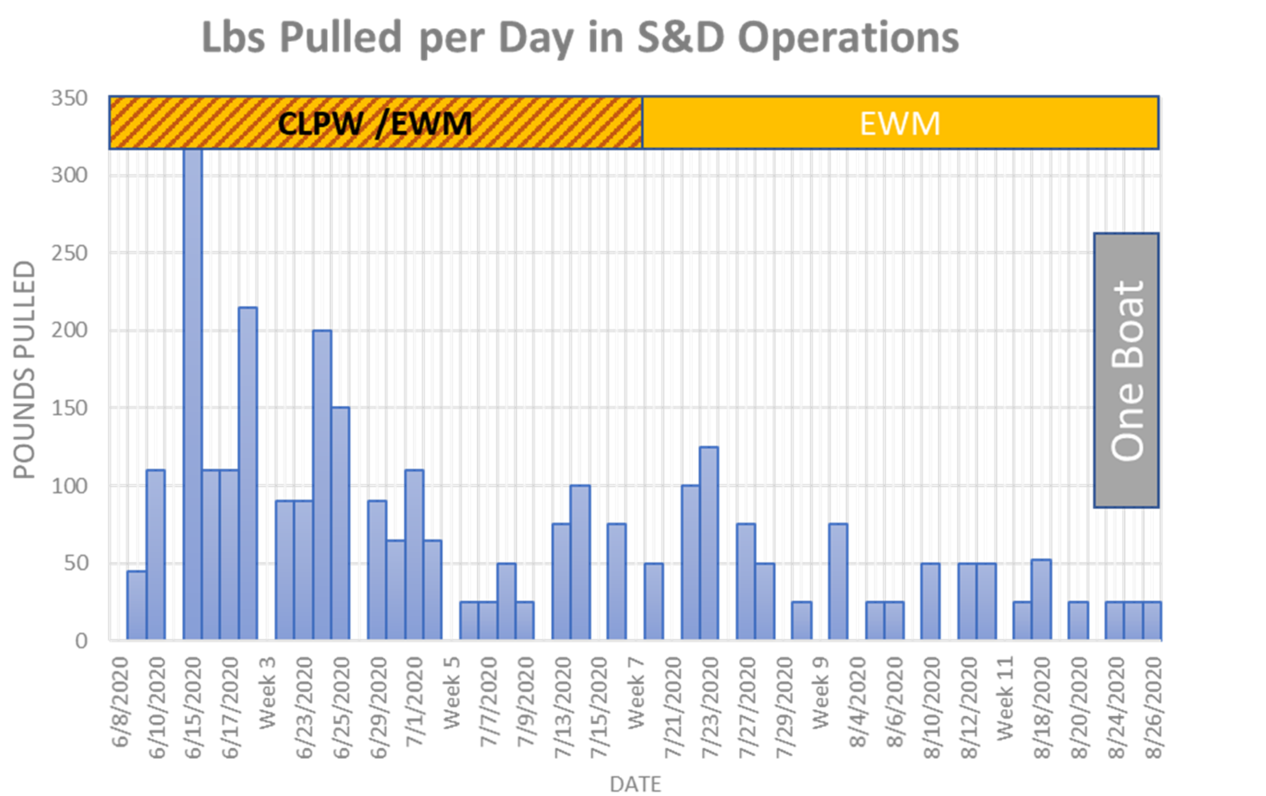


Figure 6.1 Data From Daily Log of Dive Team Search and Destroy

Figure 6.1 summarizes the data on the 2020 ISR growing season operation. It shows the pounds of vegetation collected each day on Search and Destroy Missions. Other days were occupied with area clearance missions where dense nuisance and EWM vegetation was removed in the beaches and other areas. In the beginning of the year, through June 25, the collected vegetation included EWM and curly leaf pond weed (CLPW), which is a cold water plant. As the lake warmed up, the CLPW began to recede and EWM was more present. From June 25 until July 15, collections included both vegetation types. By July 25 the collection was primarily EWM.

We can determine the area covered using the distance that the "Master Boat" traveled each day, which was recorded using a Strava app on an Android phone. The yards traveled per day can be extracted from that data and the amount of vegetation collected was measured at the end of the day. Operational time was divided between "Search and Destroy" missions and area clearance operations, particularly in the beach area. Although some "Search and Destroy" days were divided between removal and other vegetation survey tasks, they were counted as Search and Destroy, so productivity results are slightly conservative.

The collected data allowed assessment of operational capacity. Two divers operating with one boat were able to clear a 20 feet wide swath of the bottom. The 20 feet limit was set by visibility. So combining the yards covered by the "Master Boat" and assuming the second boat covered a similar area with the swath width we could calculate the acres covered in a day. Over the field season, the Dive Team operated in Search and Destroy mode for 30 days and covered 612 Acres using two boats. During the period from August 24-27 we were operating at reduced capacity due mechanical and staffing limitations. Figure 6.2 summarizes this data.

Type of Operation	Days	Lbs Removed		Acres Covered	
		YTD 6/9 to 8/27	8/24-27*	YTD 6/9 to 8/27	8/24-27*
Search and Destroy Invasive (CLPW, EWM)	30	2977	75	612	24
*One boat with four divers operating Mon- Tues due to mechanical issue Two boats operating Wed and Thursday with six divers (normal 8)					
Figure 6.2 Key Operational Data Summary					

During the period of September 7 to September 17 a year end survey was conducted and the Lowrance Sonar was able to record the tracks in a format that could be exported easily. Figure 6.3 shows the tracks traveled by the survey boat during the 2 weeks. The total distance traveled in the tracks gives confidence that required coverage is being achieved. The Princeton Hydro sample points are shown for comparison.

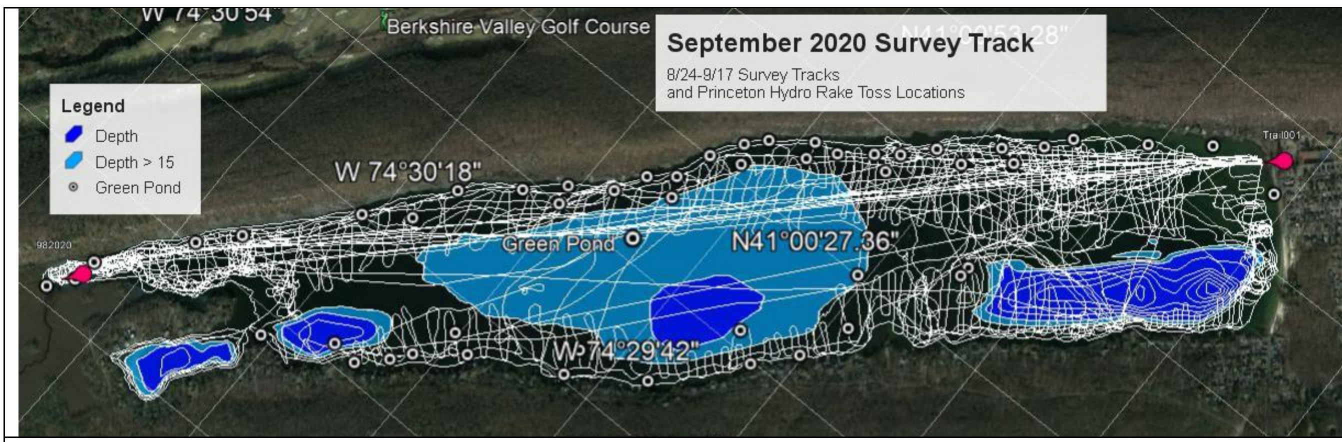


Figure 6.3 Single Boat Track for August 24-September 17 Illustrates ISR Lake Coverage

While the pounds of invasive species removed was significant, the more important gauge of the Dive Team's Search and Destroy efforts are the impacts on the presence of EWM in the lake and consequently, the level of control of EWM achieved. The impact can be understood with 2 comparisons. First, comparing 2019 to 2020 end of year's presence of EWM finds orders of magnitude less in 2020 as shown in Figure 6.4. At the end of 2019 growing season, a sonar survey found contacts which indicated over 4,000 EWM plants. However, at the end of 2020, a combined diver and sonar survey found less than 100 plants. The second comparison is between how much EWM was removed doing the whole season which was 2,600 pounds and the equivalent of 10 pounds found in the 2020 end of year survey, again orders of magnitude difference. Both comparisons show significant reductions in EWM presence and significant control of EWM.

In contrast to the cautious expectations assumed in the plan, the Dive Teams working two ISR Boats were able to demonstrate a "Search and Destroy" rate of approximately 20 acres per day. Clearance rates of denser vegetation such as removal of vegetation in the Beach and dock areas was approximately a quarter acre per day with one boat. The rates appear more than adequate to provide confident control over the course of a growing season.

Figure 6.4 Comparison of EWM plant found in September 2019 versus 2020

6.2 Invasive Species Results

EWM was the main focus of this Research and Demonstration project due to the extreme negative impact it can have on the lake environment and on the community member's ability to enjoy the lake. It was found in abundance in multiple locations, including The Swimming Area, Sand Bar, Outlet Cove, East Shore, and Point Comfort. See Figure 6.5. These dense areas of growth were found at varying times during the season and depended on the Dive Team's access to lake areas.

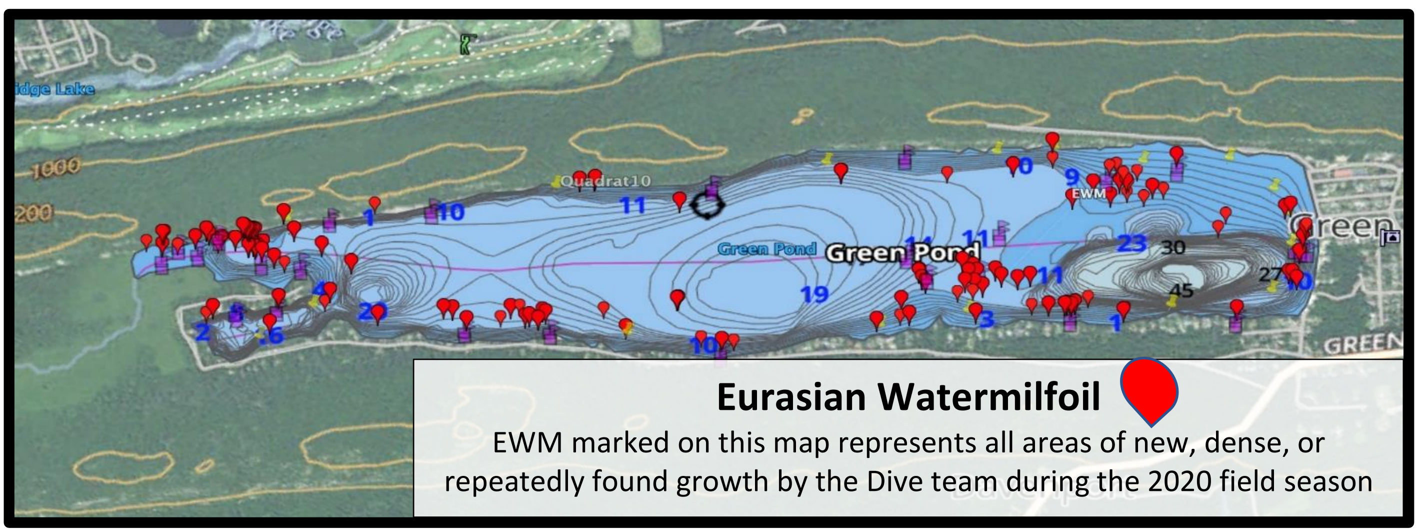


Figure 6.5 EWM Locations 2020

Small plants noticed throughout the year were found in almost all areas of the lake. Evidence such as exposed root systems or free-floating plants all pointed to EWM's ability to fragment far below the surface, which was also witnessed by divers during surveys. Because all EWM plants at risk of fragmenting and spreading throughout the water column, all such plants found were removed using ISR.

Particular hot spots using Green Pond Areas described earlier include the Swimming Area, Sand Bar, Outlet Cove, East Shore, and Point Comfort. Here EWM was found growing densely and or was frequently found throughout the field season, representing preferred growing conditions for this invasive species. Depths of less than 10 feet was found to be very important for most EWM growth, as seen on the Sand Bar and Outlet

Cove. Deeper areas with EWM growth include Shawgers Cove and the Swimming Area, where water quality was often found to be better than in other areas. Combined these preferences show the importance of light triggering EWM growth and its variability depending on water clarity.

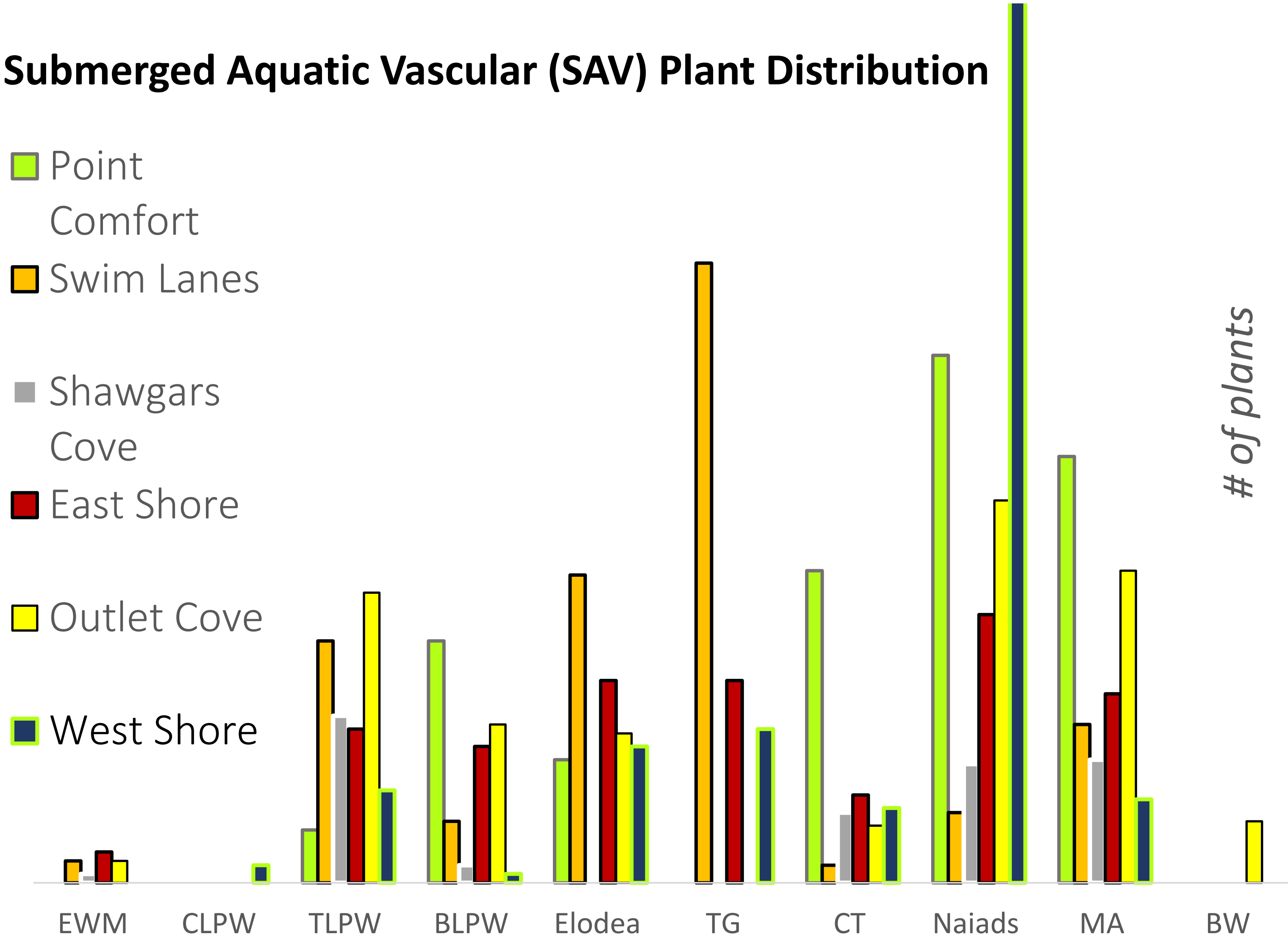
Areas not investigated with ISR early in the field season included the Swimming Area and Shawgers Cove, due to lack of boat access authorization and safety concerns. When these areas were authorized to be searched in July, large areas of dense EWM growth were found. At a depth of 15ft, plants were over 8 ft tall, fragmenting, and visible from the surface. Removing this and similar growth found in the Swimming Area and Shawgers Cover were essential to stopping EWM's ability to reproduce throughout the lake.

Bottom type preferences for EWM growth included rocky ledges or silty shallows seen along the East Shore and in the Outlet Cove, but EWM was also found growing in virtually all bottom conditions in Green Pond. In areas within depth range and free of dense native plant material, invertebrate activity, or other disrupting factors, EWM was occasionally found.

Biological surveys are designed to give a representative sample of the environment and conditions being surveyed. Although thousands of EWM plants were found and removed from the lake, they were not often found during transects and quadrats. When these measurement techniques show that even though these plants were kept below a nuisance and below 1% of the total SAV plant growth, the actual number of plants have the potential to grow exponentially and take over without management. See Figure 6.6.

Here EWM is shown as the next least abundance species after Curly Leaf Pond Weed and Bladderwort. It was however shown to be growing in multiple locations, along with many other native SAV plants. This finding reinforces the importance of continuously rechecking lake areas in an efficient way to prevent EWM stands being left unchecked to grow to the surface. This would increase the plants ability to reproduce through fragmentation and spread seeds throughout the lake.

Curly Leaf Pond Weed was not found in much of the biological surveying and followed its established life cycle to die off in July and August. Early ISR intervention in managing this invasive species stopped it from reaching the surface, fragmenting, and spreading to other areas of the lake. It was found most abundantly along the West Shore. The West Shore is made up of the ISR Area's the Sand Bar and Seven Sisters designations.



Green Pond, Morris County, NJ. SAV Plant Distribution. Created by GP for HIGLIN & AERM LLC

EWM- Eurasian Water Milfoil
TG- Tape Grass
CT- Coontail
CLPW- Curly Leaf Pond Weed
BLPW- Broad Leaf Pond Weed
TLPW- Thin Leaf Pond Weed
MA- Macro Algae (multiple sp.)
BW- Bladderwort

Figure 6.6
SAV Plant Distribution
2020

Data shown gives the number of different plant species found in each sampling location with Quadrat and Transects. Data was gathered between June- and Sept. of 2020

6.3 Native Species Results

There were many SAV plant species noted growing abundantly in Green Pond this summer, measured by observational reporting of divers and scientific surveying techniques discussed previously in section 4.3.2. Thousands of points of data were collected using complementary techniques to help accurately establish SAV plant abundance in the lake, which portrayed native plants making up approximately 99% of all growth as shown in Figure 6.7. The 1% of EWM must be understood in the context of the successful control of EWM achieved in 2020 which entailed removing 1.3 tons of EWM plants. In comparison, the end of year 2019 EWM growth would have constituted 25% to 30% of all growth. The

2020 measurements are consistent with PH and Aqua Tech findings in their rake toss surveys, which although are standard have shown to be at variance to what was found in the lake through diver observation. The combination of methods used to gather data on SAV plant growth during AER&M's 2020 field season lead to reliable findings on plant distribution and abundance.

The most abundant species found this year were Naiad sp, which are an important bottom growing SAV that mimics a grassland eco-system on land. This plant is not a nuisance unless pulled up by anchors or high energy storms and is actually incredibly important in combating growth of other unwanted species at it grows in a thick mat along the bottom. Thin Leaf and Broad Leaf Pond Weeds were the next most abundant species found in Green Pond, acting as an important structured environment for juvenile fish populations found in the lake. Prominent fish species found in Green Pond include yellow perch, large and small mouth bass, sunfish sp and crappie sp. Tape Grass was also abundant, especially in The Swimming Area and is important for holding the beaches in place with large root systems. Growing far below the surface most of the year, this is an incredibly desirable species with well documented ecosystem and anthropological benefits.

Macro Algae (MA) also represents a large amount growth found this year. Although abundant in all aquatic systems, overgrowth of particular harmful species to both people and their environment represent dangers and expenses worse even than invasive plant species. Some species were found to be growing abundantly and outcompeting large SAV species, but overall did not impede some plants' ability to grow well this year.

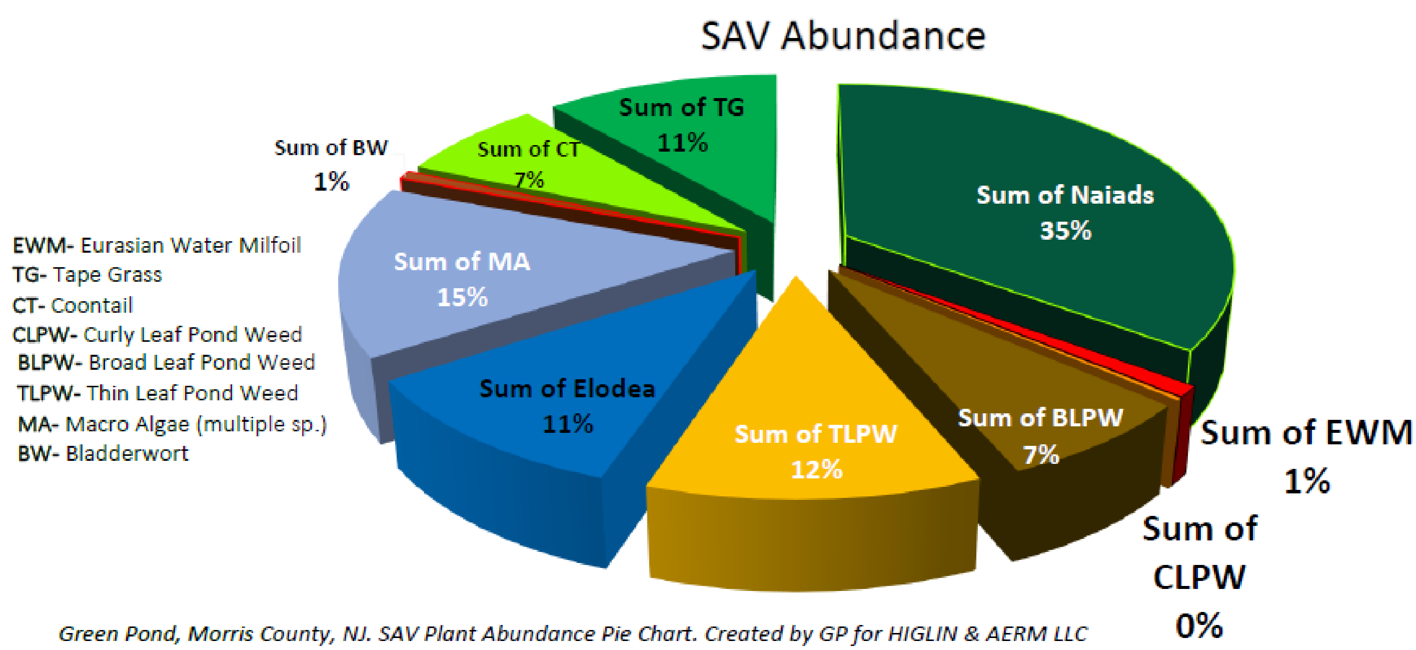


Figure 6.7 SAV Plant distribution in Green Pond based off transect and quadrat data from June – Sept 2020

Green Pond, Morris County, NJ. SAV Plant Distribution Cont. Created by GP for HIGLIN & AERM LLC

SAV Plant Distribution
2020
Figure 6.8

Data shown gives the number of different plant species found in each sampling location with Quadrat and Transects. Data was gathered between June- and Sept. of 2020

Different areas of the lake showed marked differences in SAV plant growth. Point Comfort surveys indicated an abundance of Naiad sp, MA, Coontail and Broad Leaf Pondweed. This area was of particular concern and was so was investigated using sonar and diver surveys (Figure 6.8). Here a large patch of tall plant growth was also investigated with drone footage, and then by the dive team to show large BLPW growing along the drop offs around the Bass Hole and Point Comfort (Figure 6.8).

The Swim Lanes most abundantly had Tape Grass, Water Weed sp (Elodea) and Thin Leaf Pondweed growing together with other native species. Tape grass again is an important SAV that has multiple benefits and is one of the least nuisance, so was often left upon clearing the swim lanes with ISR and hand removal.

Shawgers Cove had less overall growth compared to other places, most likely due to the steep drop and rocky bottom type. Most abundant in this area were Thin Leaf Pond Weed, MA and Naiad. Native Watermilfoil was also found in this location by divers trained in aquatic plant identification.

The East Shore had the highest amount of EWM growth found and Naiad as the most abundant species. This area also usually included a rocky ledge that inhibited plant growth in some places but created a more diverse benthic environment which may have allowed for this diverse group of species to grow.

The Outlet Cove represented another diverse area, and the only place where the carnivorous SAV plant species called Bladderwort was found. This species indicates a healthy zooplankton population, which is supported by PH findings in recent years. Thin Leaf Pond Weed, Broad Leaf Pond Weed, and Naiad sp were also abundant in this area.

Areas surveyed along the West Shore include the Sand Bar and the Seven Sisters. Naiad sp were by far the most abundant along this side of the lake, growing in large fields. Next Tape Grass and Elodea were often found growing along the Sand Bar.

Under normal conditions, when invasive vegetation is not present, there are shifts in the relative abundance of native species. There is a continuing competition between plant and algae. At any point in time, the population is determined by weather conditions (temperature, rain and ice levels) and other external factors changing the nutrient levels in the lake. Longer term patterns, such as those created by climate change also influence growth. In response, the populations shift. A significant event like the large EWM population in 2019 suppresses some plant species and when the invasives are removed, the native plants will compete for the vacant niche and it will take time to reestablish a balance. Some of this new growth may cause local nuisance population levels. In the future, there may be increasing need to address nuisance levels through remediation, possibly through hand removal. Any such intervention should only be planned and executed with full consideration of environmental impacts and with a goal to minimize any negative unintended reactions within the Green Pond ecosystem.

HIGHLANDS HIGLIN GLACIAL LAKES INITIATIVE

AQUATIC ENVIRONMENTAL RESEARCH & MANAGEMENT

7. Findings

The results of the Green Pond Research and Demonstration project have led to useful understandings about invasive plant species, particularly EWM, and their management in NJ Highlands lakes and potentially beyond in other lakes regions. Those insights arose from the research data and observations produced predominantly during 2020 and some supporting 2019 data. The following findings summarize those understandings.

- The high threat of EWM is recognized due to its ability to spawn fragments and seeds and to grow from fragments created by external forces. Less well known is the plant's fragmentation starts at an early stage of EWM development with even small plants creating fragments. Diver observation verified fragmentation of immature plants.
- Diver observation found significant EWM presence at deeper depths. While EWM growing preferences in Green Pond favor 10 feet or less, EWM does grows in 10 to 15 foot depths. The ability of EWM to growth in deeper water favors EWM because Green Pond's native plant species compete less at those depths.
- Because factors such as depth, nature of substrate, and competing native plants, lake areas conforming to EWM preferences will experience more EWM growth with higher probability and frequency. Areas of the lake can then be categorized by their relative probability of EWM growth which has been noted by observed patterns of growth over two years.
- Hand removal efforts are optimized when utilizing knowledge of the relative probability of EWM growth in lake areas to plan weekly and daily hand removal efforts. By performing Search and Destroy technique frequently in areas known to have greater and recurring growth, plants were removed before they could proliferate during the 2020 growing season.
- Accurate detection of the location of EWM growth is critical to its management. Because diver detection and sonar survey have low thresholds to detect EWM compared to other techniques, their use increases likelihood of early and accurate detection. The Dive Team continually found EWM in many areas of the lake, while PH and AT found little or no EWM using the rake toss technique.
- Early and continuous Search and Destroy detects and removes EWM before proliferation, and ISR prevents fragments which cause wider proliferation. Together, they prevent the growth of and therefore, the need to remove large biomass, saving time and permitting a much larger area to be searched and destroyed. During this season, 636 acres were addressed with Search and Destroy.
- EWM can be controlled below nuisance levels by a Dive Team staffed and equipped in the manner of this project and performing Search and Destroy early and continuously. This assertion is based on the amount of EWM, 2600 pounds, removed in 2020 and the small amount of EWM growth, less than 10 pounds, found at the end of the 2020 season and compared to the large biomass found at the end of the 2019 season.
- The sensitivity of EWM growth to temperature has been well documented in the literature. This project's results additionally demonstrate that temperature tracking helps decision-making regarding scheduling of hand removal activity. Early and late blooms can be anticipated and planned for. Costs associated with needless Dive Team work can be avoided.

8. Recommendations

Based upon the results and findings of the 2020 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 and potentially beyond through education and demonstration with other lakes in the region.

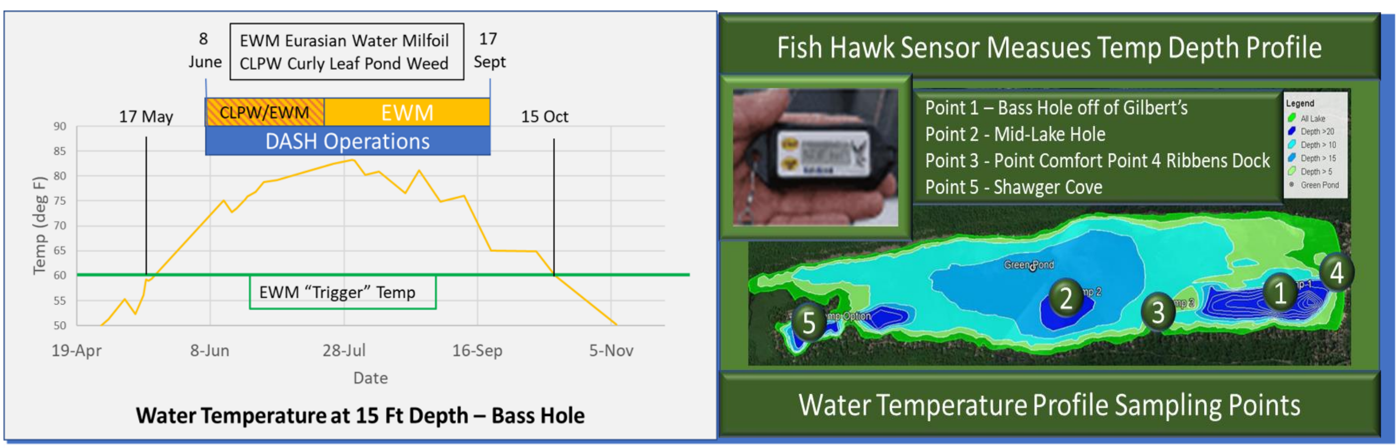
- The 2020 hand removal approach and operation should be used in the second stage of the project to its fullest extent for the 2021 growing season. The lake steward's plan for the second stage would flip their plan for the first stage. Hand removal would address all areas of the lake and be scheduled to start early in the season and continue until the risk of late season blooms is low. Herbicide treatment would be a planned secondary contingent control method to be used when the risk of losing control of EWM is present.
- Because of their superior detection results, the reliance on diver detection and sonar surveying should be maintained. Those detection processes would monitor the relative efficacy of the hand removal with the actual EWM growth. One important goal would be to ensure that the approach is controlling the growth of milfoil below nuisance levels or if not, to quickly alert the lake stewards of areas where a potential herbicide treatment could be required.
- 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. For example, the practice begun to be used in 2020 of organizing areas of the lake based upon pattern of EWM growth should be used to schedule the frequency of Search and Destroy in the areas during the growing season.
- Additional mitigation practices including the addition of mooring balls and fragmentation nets should be introduced into the lake. Those tools will further limit proliferation, particularly in curbing boats from creating EWM fragments.
- Further biological sampling should be taken to provide answers to important questions about why growth is happening in certain areas and not happening in others. An example is outflow locations which showed some correlation with higher level of EWM growth. That growth could be caused from higher nutrient availability in those areas.
- Research and Demonstration projects should be planned with other lakes in the Highlands region to ascertain whether the results of this first stage of the Green Pond project would be duplicated in other lakes and conditions. The conditions present in Green Pond of note included clarity of water, level of recreational use, the census of its native population, low levels of pollutants, and a mesotrophic ecosystem. The comparison with other conditions would determine the limits of the current study's findings and may lead to uncovering operational adjustment necessary to maintain efficacy and efficiently under different conditions. To that end, a Research and Demonstration project has been scheduled with Lake Hopatcong for 2021.
- The information and knowledge generated from this project should 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.

Appendices

Appendix A: Water Temperature Profile Measurement

A measurement program was established by HIGLIN to collect water temperature profile data and showed that the 10-15 foot depth reached the trigger temperature by May 21. The next 10 degree increase at the 15 foot level lagged the surface temperature increase by 6 days. The deeper water temperatures follow the ground water temperature of about 55 degrees F and stay stable over most of the summer, which causes the observed lag between shallower and deeper temperatures. Temperatures in shallower areas were showing about 2 weeks more time at 70 degrees than those at depth, and EWM present at shallower depth would pose an early threat to interference with boating and therefore spreading.

Temperature Measurement Program In 2020 HIGLIN volunteers undertook a program to measure the water temperature profile over the growing season. Five locations were selected, as shown in Figure PS-1. Two were in "holes", which allowed observation a long water column. In the case of the Bass Hole the measured water column extended to 55 foot of depth. Shawger Cove was also measured, although less frequently. Two shallower areas, near Point Cover and the Beach area were also measured.
The consumer market for sport fishing has several tools that are able to measure water temperature profiles, since that often indicates the best fishing depth. A "Fish Hawk" product was used for the observations and operates by lowering the unit into the water, typically attached to a weighted fishing line. It contains both pressure and temperature sensors, and it automatically records the temperature when the depth has increased by 5 feet. When the device is recovered the temperature can be read and recorded. The unit is shown in the figure. This observation action is recorded in the format shown in Figure PS-11.



PS-1 HIGLIN Water Temperature Profile Measurement Program

Lake Warm Up Temperature Profile The April to June Temperature data for the Bass Hole and Beach area shows how the temperature profile changed as the lake warmed up for the growth season. Below about 25 feet the temperature is relatively stable and tracks the ground water temperature, which is nearly constant. This deep water mass serves as a moderating effect on the water column temperature variation, warming the upper layers if the surface is cooler and cooling them if the surface is warmer. Furthermore less sunlight penetrates to the deeper depths and the water is warmed more by shallower depths that have absorbed more sunlight. In the shallower central lake "hole" the deep water warms somewhat faster.

Depth (ft)	2020 Date of Observation at "Bass Hole" (Point 1)																								
	4/25	4/28	5/1	5/7	5/11	5/12	5/14	5/14	5/15	5/16	5/16	5/17	5/18	5/21	5/24	5/25	5/26	5/27	6/2	6/3	6/4	6/6	6/7	6/9	6/12
Air Temp	48	46	58	52	61	57	69	69	87	68	80	69	71	72	71	77	82	82	70	76	85	88	77	85	84
	38	33	45	42	39	39	38	38	61	50	62	56	55	39	54	57	60	60	51	60	60	65	62	59	65
0	54.5	56	52.6	64.6	53.2	53.1	59.6	57.8	65.5	67.8	63.1	62.9	61.7	64.1	66.1	68.1	71.3	73.5	69.9	69	75.3	74.7	73.5	78.5	77.8
5		52.2	52.3	57.5	52.6	52.8	57.4	56.9	61.7	63.7	61.5	62.2	61.4	63.5	63.5	66	70.5	73.3	69	68.6	73.3	74.2	73.3	74.8	77.1
10	EWM	50.5	52.2	56	52.5	52.3	56.3	56.3	60.1	60.1	60	61.2	59.8	62.4	63.2	64.3	68.8	72.7	68.6	68.5	70.8	74	72.7	74	76.8
15		50	51.3	55.3	52.3	52.3	56.1	56.1	59.2	59	59.2	59.4	59.2	61.1	62.4	63.1	64.3	64.4	68.5	68.5	69.8	71.7	70.7	72	75.2
20		49	50.5	54.3	52.3	52.3	56	55.9	58.3	58.4	58.4	58.3	58.4	60	60.9	60.9	61.4	61.7	61.9	65	62.8	63.7	63.2	64.4	63.8
25		48.7	49.9	51.4	52.2	52.3	55.2	55.4	53.6	54	55.9	54	53.9	57.5	56.9	56	58.7	57.4	57.1	60.3	57.8	57.8	58.9	59.4	58.4
30		48.7	49.5	49.9	52.2	52.3	53.1	53.5	53.1	52.9	53.1	52.9	52.9	53.6	53.6	53.9	54.7	54.2	54.2	54.3	54.9	54.9	54	56	55.6
35	48.7	48.6	49	49.5	52.2	52.3		52.6	52.8	52.6		52.5	52.5	52.9	53.1	53.1	53.2	53.2	53.1	53.5	53.5	53.5	53.2	53.5	53.7
40		48.4	48.6	49.2					52.5			52.3		52.8	52.6	52.6	52.9	52.9	52.8		52.9			53.2	53.1
45									52.3			52.2			52.5										
50	48.4																								

Depth (ft)	2020 Temperature (deg F) on Date of Observation = at Ribbens Dock Point 4																						
	5/1	5/7	5/12				5/15			5/17	5/18	5/22		5/25			6/2	6/3	6/4	6/6	6/7	6/9	6/12
0	53.9	53.9	55.2				62.4			64.5	63.8	67.2		67.4			74.4	71	77.4	77.4	73.3	80.1	78.4
5	53.9	53.9	55.2				61.7			64.5	61.1	65		66.8			69.2	70	74	74	73.1	76.6	77.6

Figure PS-2 Fish Hawk Temperature Sensor was used to record Temperature at Depth at Sample Points. Littoral Shallower areas warm quicker while deeper water takes longer. 10-15 foot depths lagged surface temperature by 22 days

Water Column Temperature Profile over the Growing Season Figure PS-2 shows a sample of the measurement data at the "Bass Hole" (Point 1) and Beach area (point 4) taken over the growing season. It illustrates how the surface temperature of the water fluctuates rapidly, while deeper levels require more thermal energy to warm. At the deepest level the water temperature moves very little and tracks with the ground water temperature (as shown in Figure PS-3). The 10-15 foot depths move at a more uniform rate crossing the 60 degree point on 17 May and dropping back below that level by 15 October. One notable event occurred 20 August caused "turn over", when a storm mixed water from different depths so a net cooling occurred in swallower depths and warming occurred in deeper depths for a period of time.

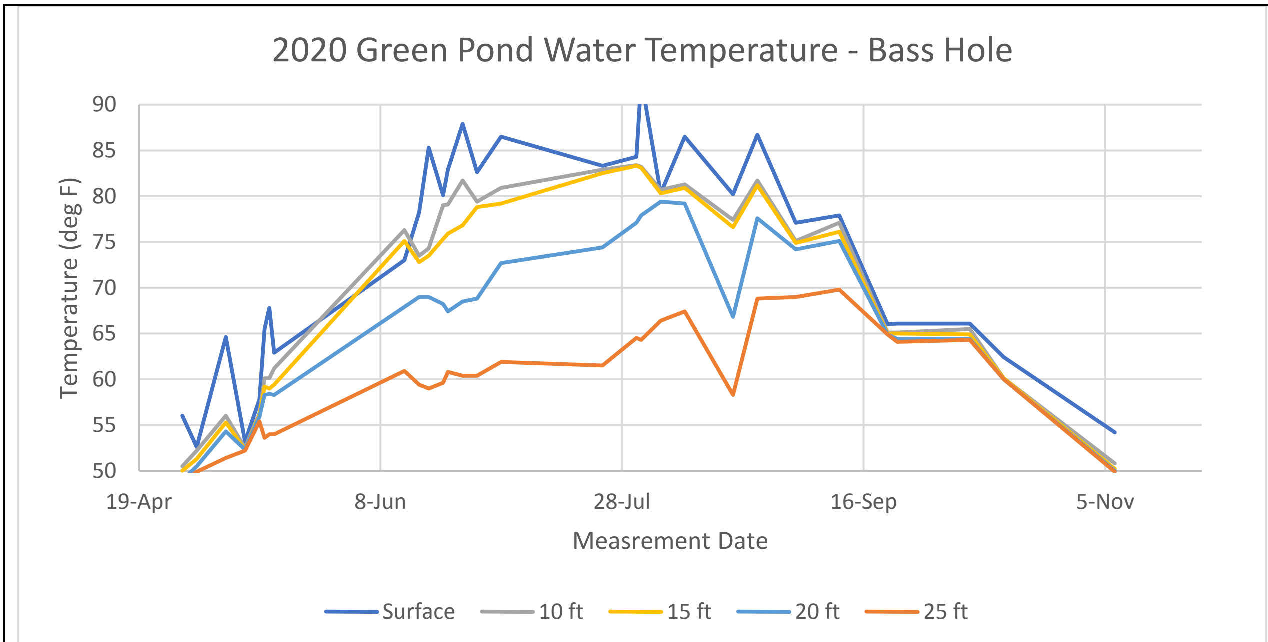
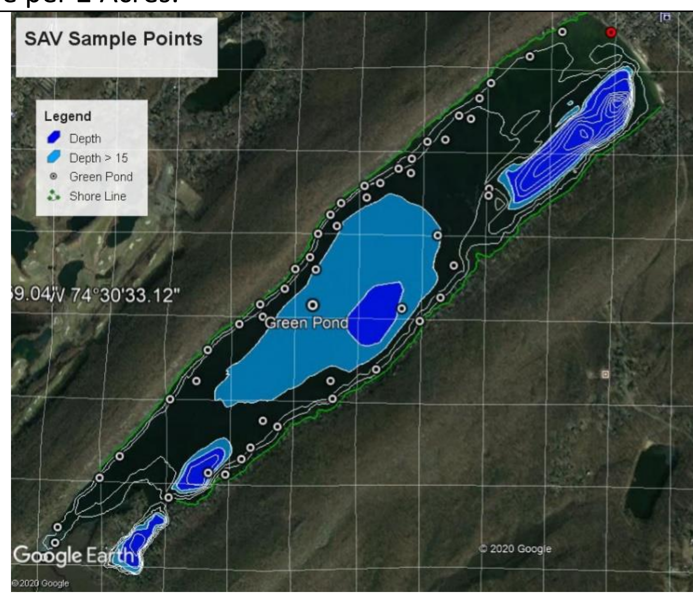


Figure PS-3 Water Temperature Profile Measurement over season. Thermal mixing caused by August storm narrowed temperature spread

Appendix B: Submerged Aquatic Vegetation Assessment and Detection

The goal of Submerged Aquatic Vegetation (SAV) Assessment is to determine the amount and relative abundance of vegetation species present in a body of water. Since the type of vegetation in a body of water varies due to depth, bottom morphology and composition, vegetation dynamics, the sampling points must be closer than the distance over which the vegetation varies. The number of samples taken is a compromise between thoroughness (and associated risk) and cost. As a reference point, the NY Department of Environmental Protection recommends a minimum density of one sample point for every hectare (2.2 Acres) of active area when doing initial assessments. In Green Pond the sampling is done 3 times during the growing season so the seasonal variation of species can be tracked.

Since 2015, Green Pond has used the standard Rake Toss technique for AV assessment, increasing the number of sample points as the EWM threat has increased. The locations of current set of observation points are shown in Figure BPS-1. The Shore lines of Green Pond are 2.1 miles for the West Shore and 2.0 miles for the East Shore (not including Shawgers Cove). The primary area for vegetation production is at about 10 foot of depth and, as can be seen in the figure, most of the sampling is around this depth line. A 200 foot wide strip along the West Shore would cover 50 Acres and 28 sample point are used (excluding the outlet cove) which is about 1.8 Acres per sample point average. There are 13 points used on 5,700 feet of the mile along East Shore, which has had less EWM growth. The narrow area near the North East hole is not sampled since the "hole" forms a natural barrier. For a 200 foot strip this is an area of 26 Acres, so the sampling density is approximately one sample per 2 Acres.



40 Rake Toss Sample Points are used for Aquatic Vegetation Assessment	Rake Toss Sample Point are mostly distributed around 10 foot depth line, most productive vegetation area

Figure BPS-1 Aquatic Observation Locations for Rake Toss Survey of Aquatic Vegetation (SAV) cover the littoral area with sample rate greater than once per 2 acres.

Because Green Pond has high clarity water, divers have good visibility over at least a 20 foot distance. Consequently, bottom inspection is another applicable technique for vegetation assessment and has a lower detection threshold since the uncertainties of the rake recovery process are not present. Detection sensitivity and confidence does depend on the sampled area. For an aggressive invasive like EWM,

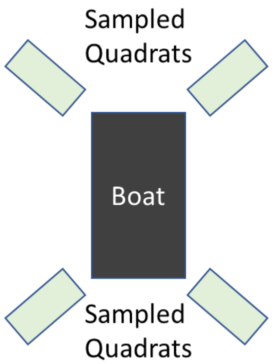
eradication requires sensitive detection. In 2020 Diver inspection classification of 13 quadrat locations was done and EWM was observed.
Any information on the vegetation growth can aid the efficiency of the process by using a rapid search process to direct (or "cue") more detailed classification studies to areas of high vegetation. The development of low cost sonar aides for sport fishing provides an attractive technique for such surveys since they can also sense underwater vegetation that form fish habitats. A second opportunity, particularly in the high clarity water of Green Pond, is surface visual observation by low flying drone aircraft. Both of these techniques were successfully employed in 2019 and 2020. Figure BPS-2 Summarizes the different techniques for both Aquatic Vegetation Classification and Location and their key features.

Figure BPS-2 Aquatic Vegetation Assessment Techniques

Technique	Summary	Methodology	Rate
	Vegetation Population Classification		
Rake Toss	Standard Assessment for Aquatic Vegetation at GPS defined locations. Capture and classify species	Sample recovery	15 pts – 6 hrs
	Rake capture efficiency and number of sample points determine detection threshold. Samples recovered for laboratory evaluation. Works in turbid water.		
Dive Inspection	Manually inspect and record species in a defined area on lake bottom	Area Inspection	10-20 Acres / day
	Detection threshold limited by diver visibility and time under water. Requires trained diver or sample collection.		
	Vegetation Location		
Dive	Examine bottom along track for species of interest. Can be combined with removal	inspection	10 Acres / day
Sonar (Hydro-Acoustic)	Identify and geo-locate target areas of interest using sonar equipped boat	Remote Sensing / signature discrimination	10 Acres / hour
Drone	Detection of emergent or subsurface vegetation up to visibility limit	Surface observation of lake from drone. High tech hyper-spectral imaging can extend depth of assessment	600 Acres + per hour

Rake Toss Observation and Limitations:
In 2018 Rake Toss sampling showed 30 % of the sites with EWM and by 2019 this had increased to 60 %. In 2020 while ISR operation was in process no EWM was observed. However that does not mean that it is not present. It means it was below a detection threshold of the method, which is determined by the number of sample points and the ability of the rake to reliably capture and retrieve small plants in the presence of significant quantities of other plant species.
Rake toss (also known as the point-intercept method) was originally described by Madsen in 1999 and has since become the standard technique for vegetation observation and classification. In fact it is legally required environmental data to support some types of permits. Green Pond has a accumulated long history of Rake Toss data taken by Princeton Hydro, that has been the standard means for evaluating Aquatic vegetation.
Rake Toss is a sampling technique that sets a number of points, determined by GPS co-ordinates, for repeated observations. At each point a rake collects samples of vegetation from the bottom and the

captured samples are then analyzed. Figure BPS-3 illustrates the process. At each of the locations a rake is tossed a calibrated distance in four directions to extract bottom vegetation and the recovered vegetation is then classified and counted to determine the relative concentration. The accuracy of the survey is determined by the number of sample points, the placement strategy (random, grid etc.). In Green Pond we have increased the number of survey points to 40 and samples are taken 3 times over the growing season. The current set of sample points was shown above.

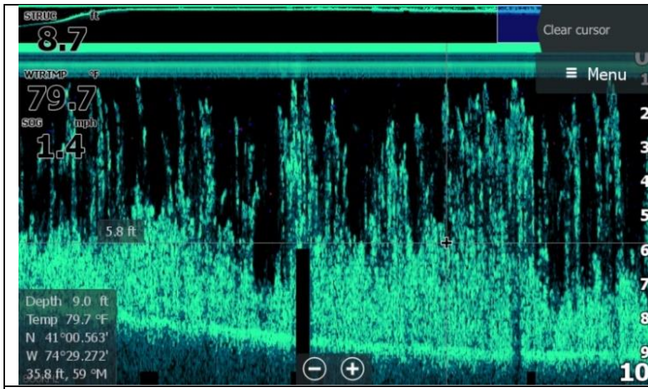
		 Medium
Aquatic Vegetation Recovered from Each Quadrat	Figure BPS-3: Rake and Captured Vegetation Vegetation Level Classified as None, Sparse, Medium and Dense	

The threshold plant density for detection by the rake toss method is difficult to assess. If there is a large amount of biomass in the sample, which would occur as the growing season advances, there is a much lower chance of the rake capturing the scarce plant. Valley observed this in 2006:

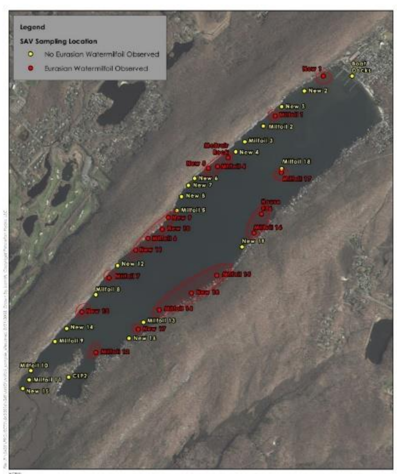
> "However, presence-absence data from point-intercept surveys is not sensitive to changes in biomass or bio-volume, and very large changes in plant abundance must occur before being detected by presence-absence sampling."

Diver Inspection: If the water body has sufficient clarity, the Rake Toss Capture Quadrat areas can be replaced by bottom areas delineated by bottom mounted frames and the number of each plant species found in the frame can be counted. This avoids the uncertainties of how different species are captured by the rake and how much of the total biomass in the quadrat is captured. In 2020 bottom vegetation inspection surveys were conducted by the Dive team both in areas defined by PVC quadrat markers and along linear transects defined by tape measures.

Sonar (Hydro-Acoustic) Observation: The availability of low cost consumer sonar for sport fishing, integrating both GPS geolocation and sophisticated signal processing, allows the identification of aquatic vegetation. Anglers use this to find and locate fish habitats of interest. Affordable underwater cameras are also available that can be lowered to provide a visual view of the subsurface environment. More sophisticated signal processing algorithms can be applied to recorded sonar data to provide other analysis of returns to provide full lake views of vegetation density.

	
EWM and Coon-Tail Sonar Returns	Deployable Underwater Camera can be used to examine vegetation
Figure BPS-4 Sonar Vegetation and Camera	

In 2013 Feller showed that sonar observation can isolate EWM with high probability using its comparatively rapid growth that raised it above surrounding species as it raced for the surface. In 2019, a volunteer championship Bass fisherman worked together with the GPC manager to identify a signature that could help sonar separate EWM from other plants such as Coon-Tail. Figure BPS-4 shows that sonar returns taken observed of a mixture of Coon-Tail and EWM. In addition to the height of growth that can increase the probability of the vegetation being EWM certain characteristics were also found.

	 June 28,2019 Sonar Survey – 700 Contacts
2018: 40 Sample Points - Taken 3X over season	Figure BPS-5 2018: 30 % EWM RT Positive Vs. 2019: 25 Ac Sonar ID in June 28

This methodology was applied in 2019 and the June 28, 2019 Hydro Acoustic (Sonar) survey results compared well with the previous year EWM Rake Toss Survey EWM locations.

In 2015, Valley observed:

> "Two methods, point- intercept and hydro acoustic mapping, are gaining increased attention in the United States because of their objectivity and repeatability, ease of implementation, and scalability."

The use of sonar observation has proven helpful in isolating EWM through multiple lake surveys during 2019 and 2020. Generally, in those surveys, the sonar isolation results was corroborated by visual inspection from the surface and/or from divers in the water. In late June 2020, a sonar survey of hot spots was undertaken to help target the hand removal demonstration activity. The sonar isolation was verified by divers inspecting the locations where EWM presence was identified except in one area where no EWM was found. Instead, Coontail was found in abundance. This was the first evidence of false positives readings of EWM.

The Coontail was logged by the divers marking locations as shown in Figure BPS-6. Coontail has the a very similar sonar return to EWM's sonar return. In all other instance of the June 2020 sonar survey, EWM was found in the locations indicated by the survey.

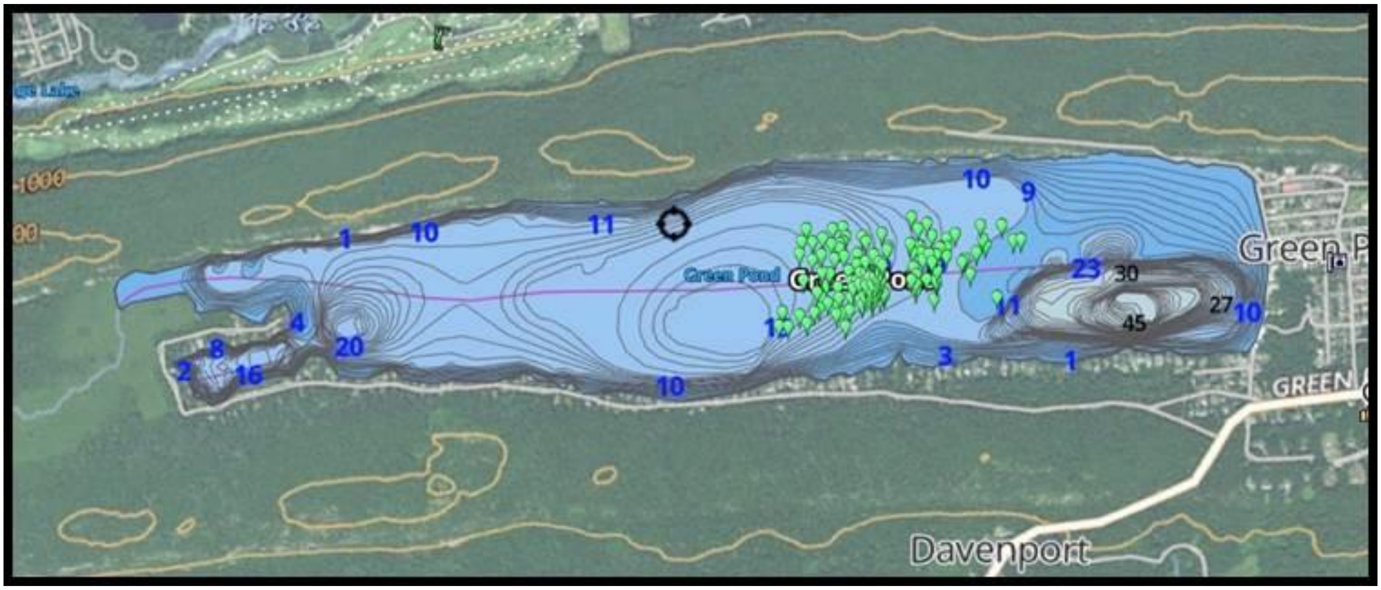


Figure BPS-6. GPS Coordinates for the native plant Coontail (*Ceratophyllum demersum*) identified as EWM. These were captured using the GPX track software in July 2020.

Drone Observation: A drone can provide a low altitude observation of the entire area of Green Pond in a short amount of time, which allows visual observation of emergent plant or subsurface vegetation to a depth allowed by the water clarity (measured as the Secchi depth in water quality studies). The depth of Aquatic Vegetation observation and some classification can be extended by the use of high technology remote sensing incorporating hyper-spectral imaging, but this requires the ability to carry larger more expensive instruments. With the high clarity of Green Pond water vegetation can be spotted at depths exceeding 10 feet. With visual observation the Drone observation serves as a cue for direct observation to classify the plants. Figure PS-6 shows an example of a large mid-lake vegetation growth spotted and later classified by the Dive Team as Broad Leaf Pond Weed.

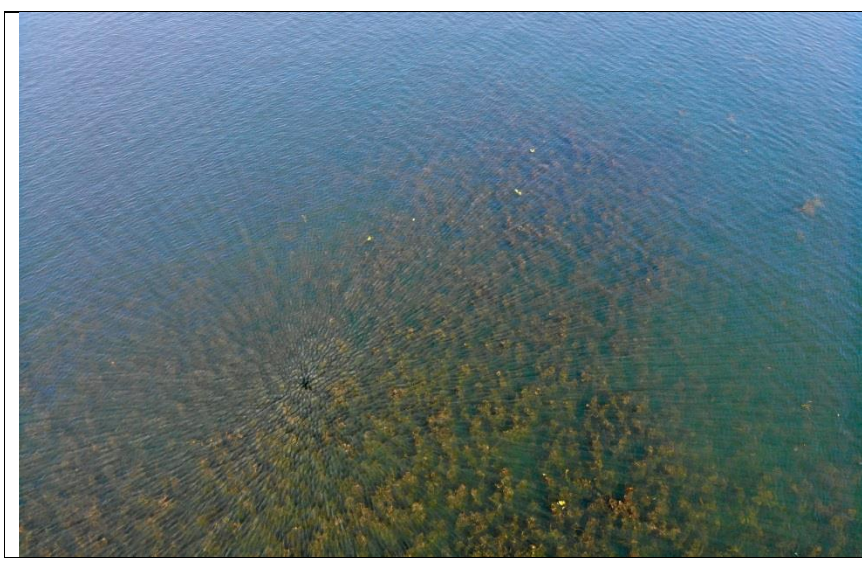


Figure BPS-7
Drone view of mid-lake vegetation Dive Team inspection identified this as **Broad Leaf Pond Weed.**

Appendix C: Transect Survey Example Data

Figure GP-1 shows species surveyed in Green Pond during the 2020 field season. Each number represents the tallies marked along each foot of the transect, counting the number of plants found. This shows whether there are stands of one species of plants, or if an area is diverse with many different species growing together without outcompeting one another. The total score shows how much of the area was covered with vegetation, as blank areas were not tallied. Tentative conclusions drawn from these findings are found in section 6.

EWM- Eurasian Water Milfoil
TG- Tape Grass
CT- Coontail
CLPW- Curly Leaf Pond Weed
BLPW- Broad Leaf Pond Weed
TLPW- Thin Leaf Pond Weed (multiple sp.)
MA- Macro Algae (multiple sp.)
BW- Bladderwort

Date	Location	Transect	Quadrat	Depth	EWM	Naiads	TG	CT	CLPW	BLPW	TLPW	Elodea	MA	BW	Total
15-Jul	Swim Area	Trans - 1		10	2	2	39	1	0	2	26	13	14	0	99
15-Jul	Swim Area	Trans - 2		8	1	6	26	2	0	5	8	22	10	0	80
16-Jul	Point Comfort	Trans - 3		15	0	0	0	38	0	0	0	0	60	0	98
16-Jul	Point Comfort	Trans - 4		8	0	16	0	25	0	33	1	12	10	0	97
16-Jul	Point Comfort	Trans - 5		10	0	40	0	5	0	22	0	10	15	0	92
16-Jul	Point Comfort	Trans - 6		8	0	54	0	2	0	0	11	6	11	0	84
20-Jul	Shawgers Cove	Trans - 7		4-16	0	5	0	8	0	0	23	0	12	0	48
20-Jul	Shawgers Cove	Trans - 8		4-18	2	22	0	8	0	4	15	0	16	0	67
20-Jul	East Shore	Trans - 9		4-8	2	12	0	2	0	0	4	23	12	0	55
20-Jul	East Shore	Trans - 10		4-8	2	15	0	15	0	0	7	11	4	0	54
21-Jul	Swim Lanes	Trans - 1		10	1	5	50	1	0	3	6	7	5	0	78
21-Jul	Swim Lanes	Trans - 2		8	1	3	26	0	0	4	15	28	7	0	84
21-Jul	Outlet Cove	Trans - 11		6	0	8	0	4	0	0	33	8	5	0	58
21-Jul	Outlet Cove	Trans -12		6	0	10	0	1	0	0	11	12	10	0	44

Transect Survey Example Data
Figure GP-1

Transects are marked with GPS coordinates and labeled based of ISR Survey Areas

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