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

January 6, 2021

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.

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.

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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 Highlands Region glacial-freshwater lake, is challenged by the invasive plant species Eurasian Watermilfoil (EWM) and to a lesser degree Curley Leaf Pond Weed (CLWP). First discovered in 2013, EWM infested 174 acres in 2019, covered 53% of lake acres susceptible to EWM growth, which resulted in closing the lake to boat traffic. Green Pond is managed by two organizations, the Green Pond Corp. (GPC) and Lake End Corp. (LEC) Boards of Directors, who serve as the stewards of the lake. In 2020, the lake stewards engaged with HIGLIN in a Demonstration Project to experiment and discover an overall plan that would gain and maintain control of EWM. In the first year of the project, 2020, HIGLIN's approach successfully maintained control of EWM below nuisance levels and prevented plants from cresting about the surface stopping the development of seeds. In 2021, despite encountering more EWM growth than in 2020 arising from different weather conditions, the team was able to successfully keep EWM below nuisance levels for the duration of the 2021 season and again prevented any plants from reaching the surface.

HIGLIN's approach uses hand removal supported by Invasive Species Removal (ISR) technology. Four main elements comprise the approach: 1. A professional Dive Team; 2. Two dive boats equipped with ISR technology; 3. A Search and Destroy method of operations; and 4. Managing the removal effort by breaking the lake into 9 management zones.

The Dive Team started operations on June 7th and found substantially more EWM than was present in 2020. At the start of 2020, EWM was widely present but the plants were small, under one foot and CLPW was plentiful. In 2021, CLWP was sparse and EWM was abundant and tall with plants ranging from one foot to eight feet. This initial pattern held throughout the season. By the end of 2021, comparatively little CLPW was removed, 70 lbs compared to 1,285 in 2020, but four and a quarter times the EWM was removed, 7,436 lbs. compared to 1,742 lbs. There were significant weather differences between 2020 and 2021. In 2021 the weather was warmer leading to warmer water which both kills off CLPW (a cold water plant) and boosts EWM growth. Furthermore there were several storm events whose high winds created turbulence, causing fragmentation and distributing fragments across the lake.

Better alignment of seasonal EWM operations with the current weather will support better management of EWM. When the start of removal operations is aligned with the start of the EWM growing season, the first stage of EWM growth fueled by starch in the plants roots can be harvested. As our experience in 2020 and other research has shown, the removal of these young plants will impede EWM from dominating other species and prevent them from achieving mature proliferation capabilities. In 2021 we found a new hot spot, the Beach Zone, likely due to the dominant South to North winds in the lake driving fragments into shallower waters where they establish themselves. Fragments from 2020 and 2021 were the likely cause of the 2021 hot spot. In 2021, netting was installed to capture fragments driven by prevailing winds and protect bathing areas from EWM infestation.

The results and findings of the 2021 field season highlight future approaches to controlling EWM in Green Pond and similar lakes and ponds. A professional dive team supported by ISR using Search and Destroy and management zones appears capable of covering enough acres in a growing season to responsively maintain control of EWM growth, even when faced with abundant growth arising from weather favorable to EWM.

2. The Project Challenge

2.1 Controlling Invasive Plant Species in Green Pond

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

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

In late 2019, the lake stewards engaged HIGLIN to develop a plan of action. During 2020 and 2021, HIGLIN executed the first two years of the Green Pond Demonstration Project. The project seeks to demonstrate the efficacy of controlling EWM through hand removal supported by Invasive Species Removal (ISR) technology. The two year results of the project are: EWM was controlled successfully. EWM never presented a nuisance, and never breached the surface preventing the spawning of any seeds. Of note, the inconsistent pattern of EWM presence continued during the last three year interval with 2020 showing less than would be suggested by the end of year 2019 presence and 2021 showing much more than 2020. A main challenge of this report is to separate the positive impacts of the project's Dive Team removal efforts from other factors, such as weather, which cause variation in year to year EWM growth.

2.2 The Challenger: Eurasian Milfoil (EWM)

Invasive species, also known as "non-native", or "alien", have been found in the United States since colonization. Since the start of globalization, this phenomenon has impacted most places in the world. Species evolved for a certain set of conditions can wreak havoc on an ecosystem that has developed without them, and so there have been many invasive species removal projects 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 highly competitive growth environment found in its native areas, EWM developed the ability to grow very quickly once water temperatures are above a "trigger temperature" (typically 60 degrees at Green Pond latitudes). The first seasonal stage of milfoil growth is fueled by starch stored in the plants' root system. That boost gives EWM a "head start" in its competition with other species. Once it is the first to reach the surface the plant forms a canopy, denying other slower growing plants the light, and allowing it to exclusively dominate an area. Once established, EWM has multiple ways of reproduction (Smith and Barko 1990): seeds, root shoots, tip rooting and fragmentation.

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

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

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

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

2.3 The Challenged: Green Pond

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

Aquatic plant growth in Green Pond has been variable over the last 10 years. Multiple different native species compete for dominance in the lake, but most are low-growing and remain along the benthos for their entire life cycle. The high water clarity of Green Pond enables this cover vegetation over much of the lake. Ground cover reduces the success rate of EWM fragments establishing themselves and delays the development of those that are successful. (Eichler, et al, 1995) One of the most abundant aquatic plant species found in Green Pond is Naiad (*Naiad sp.)* and grows in meadow-like fields along the bottom of the lake. Similar to any grassland, this species creates a diverse ecosystem for fish, invertebrates, and other plants to grow together. Other important native species in Green Pond include Coontail (*Ceratophyllum demersum*) noted as the most abundant plant in 2020, pondweeds (*Potamogeton spp*.), waterweeds (*Elodia spp*.), and Tape Grass (*Vallinseria americana*). Each play essential roles such as decreasing shoreline erosion, acting as a food source, or absorbing excess nutrients. Combined, these plants help to keep the ecosystem healthy. Green Pond has undertaken yearly Surveys of Aquatic Vegetation using standard Rake Toss measures since 2010. Currently there are 40 sample points along the lake littoral.

3. The 2021 Plan

3.1 Introduction

The 2021 Research and Demonstration project envisioned a growing season in which EWM was, once again as in 2020, brought under control below nuisance levels. Control would be established solely through utilization of the HIGLIN Invasive Species Removal (ISR) capability, the Dive Team. Additionally, if at any point in the season, the Dive Team was losing control in an area, a contingent treatment of the herbicide, ProcellaCOR, would be used in that area.

The planning for the 2021 growing season occurred during December 2020 and January, 2021. The importance and viability of the HIGLIN Invasive Species Removal (ISR) approach had come to the fore because of the results realized in the first year of the project. EWM had been controlled below nuisance levels and no plants had grown above the surface of the lake. The operations would mirror 2020 in so far as the three main elements of the ISR boats, the professional Dive Team and the Search and Destroy approach would be repeated. A new element of predefined lake management zones would be used in the management of EWM, seeking to improve effectiveness and efficiency.

3.2 Hypothesis and Plan

The “Plan” developed for 2021 was based on two assumptions: 1) the amount of Eurasian Water Milfoil (EWM) that will be present in 2021 is uncertain given the variable growing patterns over the last eight years and 2) the HIGLIN Dive Team will maintain control of EWM. Both assumption proved to be accurate with an unexpected 4¼ fold increase in the amount of EWM removed. Nonetheless, the Dive Team maintained control of EWM throughout the season never allowing plants to breach the surface.

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

1. The HIGLIN/AERM Dive Team will provide the capability and capacity to control EWM below nuisance levels.
2. The use of ProcellaCOR will be held as a contingent alternative that could be deployed to address areas where the Dive Team was unable to maintain control.

The Dive Team would continue its Search and Destroy practice operating in all acres with special attention to those likely to have EWM The surveillance workload required in Green Pond can be seen from the bathymetry statistics shown in Figure 3.2. Green Pond has an acreage of 509 Acres. Of that acreage, 168 Acres are between 10 and 15 feet deep. Based on all factors, 330 acres were targeted to be physically inspected and cleared of EWM. To ensure complete coverage was occurring, the lake would-be broken into nine zones for scheduling and reporting, Given 2020 observation, a Dive Team boat on average covers 10 acres a day in Search and Destroy mode. With 96 boats days planned for 2021, the Dive Team would be potentially capable of visiting 960 acres during the season. The frequency of revisiting acres will be determined by historic pattern of EWM growth and also changing condition experienced in 2021. A detailed discussion of the operation is contained in Section 5.

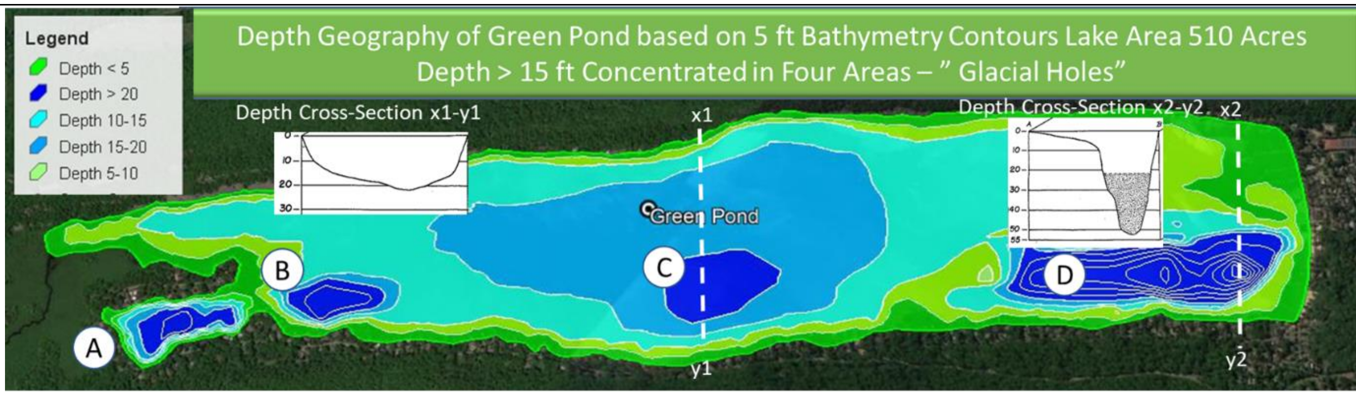
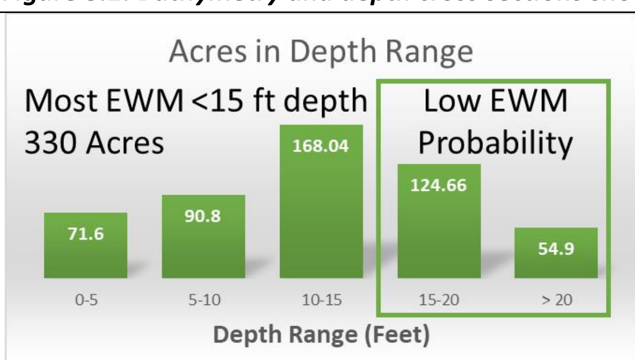


Figure 3.2: Bathymetry and depth cross sections show Green Pond's classical glacial "hole" character



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

3.3 HIGLIN & AERM Invasive Species Removal (ISR)

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

The ISR boats developed by AERM and the contracted equipment supplier, although similar to existing ISR boats, contain several important innovations.. The removal capability is provided by suction pumps mounted on the boat which have the power to collect plants and fragments. Sluice boxes, support inspection of all materials gathered by the divers and help to preserve wildlife (turtles, fish, etc.) and to separate refuse from the plant material before it was readied for disposal. Important safety features include an emergency oxygen kit, hard-wired underwater communication to stay in constant contact with divers, a dedicated hookah pump to ensure adequate air flow for divers, and air hoses equipped with filters that removed moisture and particulates to help ensure clean air for breathing. In order to minimize environmental impact, surface floats (See Figure 3.3) are attached to each ISR hose keeping the hose-end away from the lake bottom to prevent disturbing and/or removing the sediment. In addition, to address the large infestations of EWM in New Jersey Highlands Region lakes, more removal capacity is achieved by doubling the normal removal power on the boat which allowed for double the normal level of divers to be in the water simultaneously. The resultant operation, consisting of two boats, four divers using four removal hoses during all work times, has demonstrated a remarkably level of EWM and CLPW removal capacity.

Figure 3.3: Floats attached to suction hoses

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

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

Our 2020 project report recommended that the practice tested in 2020 of organizing the lake into zones based upon area qualities and pattern of EWM growth should be used to schedule the frequency of Search and Destroy in the zones during the growing season. In 2021, the zone structure was implemented and used for scheduling, management, and reporting of the removal efforts. The zone structure used is described in Section 5.

3.4 Cooperation and Access Agreement

A Cooperation and Access Agreement was developed and approved by the three organizations engaged in this Research and Demonstration project, including GPC, LEC and HIGLIN. The agreement executed in May, 2021 provided the definition of the project and the terms and conditions for the three organization. The agreement continued the use of research project's Steering Committee established in 2020. The members of the committee were members of the organizations' boards of GPC, LEC and HIGLIN. The steering committee facilitated communications and the execution of the Research and Demonstration plan. The committee was actively engaged and helped immensely during execution by reviewing observations, data, and information which led to clarification and adjustments to the plan.

4. Execution of 2020 Plan

4.1 2021 Invasive Plant Conditions

The Dive Team started operations on June 7th ,the same time as 2020, but they immediately found different conditions than were present in 2020.. In 2020, EWM was widely present but the plants were small under one foot and CLPW was plentiful. In 2021, CLWP was sparse and EWM was abundant and tall with plants ranging from one foot to eight feet. This initial pattern held throughout the season. By the end of 2021, comparatively little CLPW was removed 70 lbs compared to 1,285 in 2020, but four and a quarter times the EWM was removed, 7,436 lbs. compared to 1.742. Weather was a main contributor with higher air temperatures leading to warmer water and storms with high winds leading to turbulence causing fragmentation and proliferation across the lake

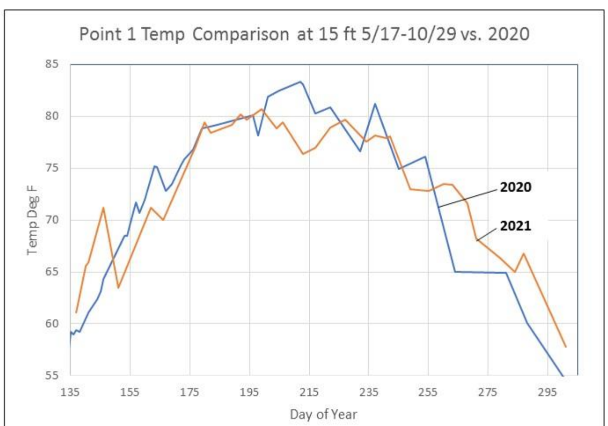


Figure 4.1 Water temperature comparisons 2021 and 2020

In reviewing the factors which could account for the differences including nutrient loading, the depth of the plants, water clarity, seasonal water temperature, and seasonal irradiance due to the number of sunny days (Gracie (1976) and Smith and Barko (1990)), one factor, water temperature, came to the fore. The 2021 growths of EWM and CLPW were the consequence of the marked difference between the cold 2020 Spring and the warmer spiking temperatures in 2021 as shown in Figure 4.1. The smaller amount of CLPW reflected the warmer water temperature which caused the plants to die off. The opposite is true of EWM which favors warmer water which was also helped by the absence of a competing CLPW early on. A number of models of EWM growth, (Titus et al. (1975); Best and Boyd (1999); Best et al. (2001); Herb and Stefan (2006); Miller (2011)), show that the growth rate accelerates exponentially once the water temperature exceeds a “trigger temperature”. The trigger point in New Jersey, generally understood to be temperature 60 degrees F at the plant roots, was exceeded earlier in 2021, May 18, than 2020 Consequently, plants had been growing and proliferating longer before the Dive Operations started compared to 2020, giving EWM a head start to dominate other species. Warmer temperatures in the early part of the year further accelerated EWM growth. Further, the temperatures remained higher in 2021 elongating the EWM growing season and Dive Team operations.

The impacts of storms including two hurricanes, Elsa and IDA, and other high winds events caused water cooling, fragmented EWM and dispersed fragments in areas not experienced in 2020. The Beach Zone is a prime example of those forces due to its northern most location in direct line with prevailing winds. In 2020, the Beach had a moderate amount of EWM. In 2021, the zone became the hottest hot spot, accounting for the highest percentage, 29%, of EWM removed. A similar northward concentration can be expected in 2022, although the beach netting may help contain this.

The changing conditions required adjustments to the plan for 2021 which the next section will discuss.

4.2 Timeline of 2021 Events and Decisions

An operating plan is likely to require adjustments when implemented due to new developments. A steering committee described in the project agreement was established to understand the actual conditions and to make decisions if changing the plan was required. The following is a numbered summary providing the highlights of the project during the 2021 growing season. Figure 4.2 uses the corresponding numbers and depicts the time sequence of activities, events, and decisions.

1. As the 2021 season approached, concern arose that the warmer than normal spring could cause a change in the timing of the growth of EWM which is highly sensitive to temperature. Temperature monitoring of the thermocline at multiple locations in the lake done in 2020 was re-initiated once again on May 18 which was delayed by a late boat delivery. Water temperature at 15 feet depth registered 60^{o}, commonly seen as a trigger point for EWM growth, on May 18 confirming an early start to the growing season for EWM. The monitoring continued throughout the season.

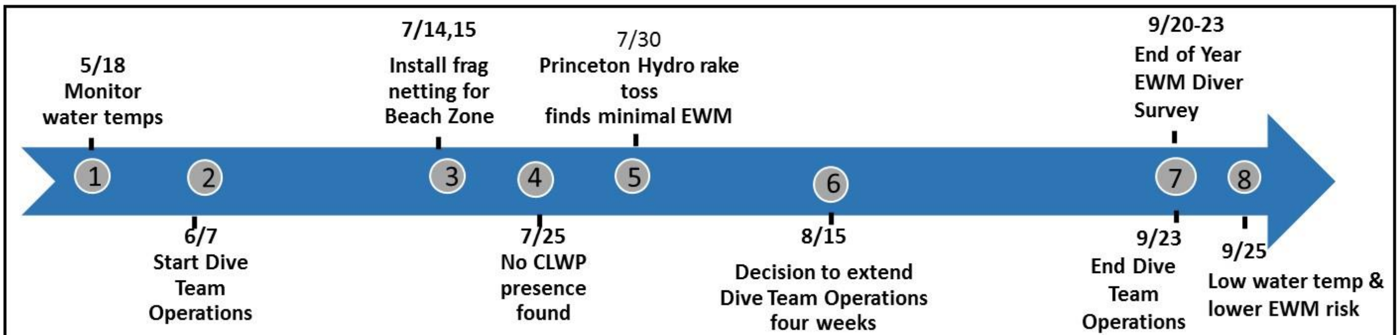


Figure 4.2 2021 Growing Season Timeline of Activities and Decisions

2. Dive team operations commenced on June 7. Following the plan, the team immediately addressed removing EWM throughout the lake using the Search and Destroy method. Plants up to 6’ to 8’ and auto fragmenting were discovered in line with an early start of the growing season.

3. The Beach Area Zone became a hot spot this season with the most EWM removed of all zones. After due deliberation and approval by the steering committee, fragmentation nets were installed along its southern perimeter at the end of week 6. The aim was to capture wind driven fragments in the nets preventing them from rooting, growing, and proliferating. In subsequent week, nuisance plants and EWM fragments were found and removed from the nets.

4. By July 22, the dive team had removed CLPW and water temperature had risen to the degree that CLPW was not detected in the lake.

5. During July and August, multiple survey's done by Princeton Hydro using rake toss found minimal EWM. Princeton Hydro observed that the dive team was successfully controlling EWM. Further as a consequence of that control, the contingent use of herbicide would not be needed.

6. With the amount of EWM removed and the temperature both continuing to be high, concerns arose that more time was needed to address EWM growth. Also, 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 2022. HIGLIN leadership recommended that the dive team planned schedule of 12 weeks be increased to 16 weeks, adding 4 weeks in September. The steering committee approved the extension.

7. Starting in the fourth week of September, the dive team conducted an end of year diver survey of the lake. The results showed continuing presence of EWM but with declining amounts and sizes. Dive Team invasive species removal operations ended on September 23.

8. Later in the fourth week of September, the water temperature measured at critical 15' depths was found to be 65°, a temperature which reduced the possibility of a late season EWM bloom.

In summary, high early season temperatures (over 60 degrees) led to increases EWM growth, which was targeted and removed by the dive Team. This year in Green Pond, the Dive Team removed invasive species before they became a nuisance, and before they could grow high enough to breach the surface and seed.

5. Methods and Measurements

5.1 Introduction

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

5.2 Removal Methods

5.2.1 Search Methods

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

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 accurately detected earlier in the growth cycle and at a lower density compared to other techniques. Rake toss has a high threshold, meaning a species presence must be high before detection occurs. This is due the limited number of sampling locations and the design of the rake. For example, when EWM plants are small, the surrounding more mature native plants will tend to fill the rake's tines leaving small plants uncollected. Another, alternative method is sonar survey which has a lower threshold of detection than rake toss and can be more time efficient than diver detection. Detection sensitivity and accuracy of identification are important with an aggressive invasive like EWM whose eradication requires sensitive detection. For further understanding of the range of assessment and detection methods, an analysis of alternates is provided in Appendix B in last year's report, Green Pond Research and Demonstration Project: Aquatic Invasive Species Management 2020 Final Report December 26, 2020 which can be found on the HIGLIN website, HIGLIN.org

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, GPS Traks on iPhone 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 lake management zones was the third sub-method employed. Based on the plant growth information gathered in 2019 and 2020, areas of interest were identified and prioritized at the start of the 2021 season. Those were used to guide the selection of areas to Search and Destroy. The lake was divided into nine zones using a number of factors. The goal of this delineation was to ensure that each zone would be prioritized and searched with a frequency warranted by its growth patterns. The factors included depth, previously recorded growth patterns, bottom features, and natural surrounding terrain. For example, depth is one of the most important factors to consider as it relates to the growth preferences of EWM. Depth determines temperature as well as the amount of light penetrating the water column. An area made up of acres with similar depth would then be expected to have similar growth patterns, leading to better decision making about survey frequency and facilitating dive activity. Three categories of survey frequency were defined. Red Zones require frequent surveillance and extra clearance time. Yellow Zones require between 2 or 4 Search and Destroy passes a season. Green Zones require high speed passes because of their sparse slow growth in a large area. At the start of the 2021 season, two zones, Outlet Cove and Point Comfort were the only Red Zones. At seasons end, the Beach had also become a Red Zone.

Figure 5.1 provides a color coded mapping of the nine zones corresponding to zones in list below. The nine

1. Beach- 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

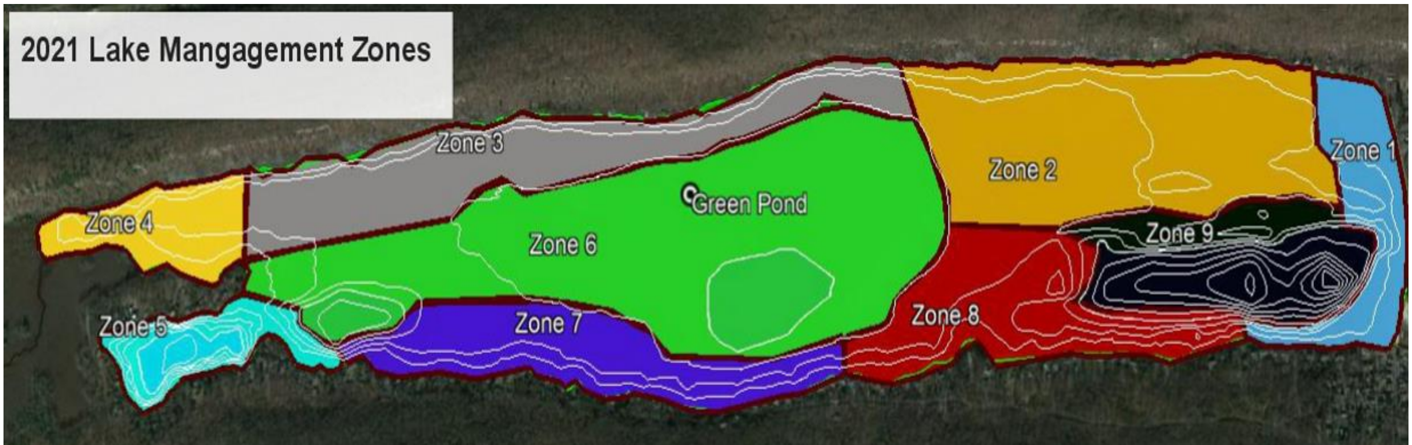


Figure 5.1 Lake Management Zones

5.2.2 Destroy and Clearance Methods

The main method for both Destroy and Clearance removal is hand removal assisted with ISR. Using five-inch diameter hoses attached to a Venturi system, two divers on each boat used a 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 plant and following it down to a point, where the diver reaches into the sediment and pulls out larger EWM roots. Some plants could also be removed by hand, and then brought back to the removal hose floating above the benthos with buoys. These techniques along with careful removal of invasive species lead to a very small number of native plants, animals and foreign objects entering the Venturi system and minimal sediment. Anything that was brought onboard unintentionally ran back into the lake through sluice boxes or could be removed from the onion bags. Upon removing, aquatic plant material is transported by the removal hose to sluice boxes onboard and flows into 15’’ x 25’’ biodegradable onion bags. Full of plant material, these bags on average ended up weighing approximately 25 pounds.

Figure 5.2: Harvesting small CLPW plants

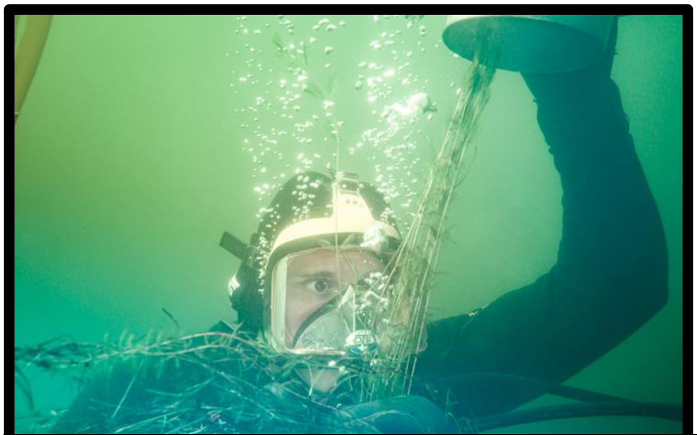


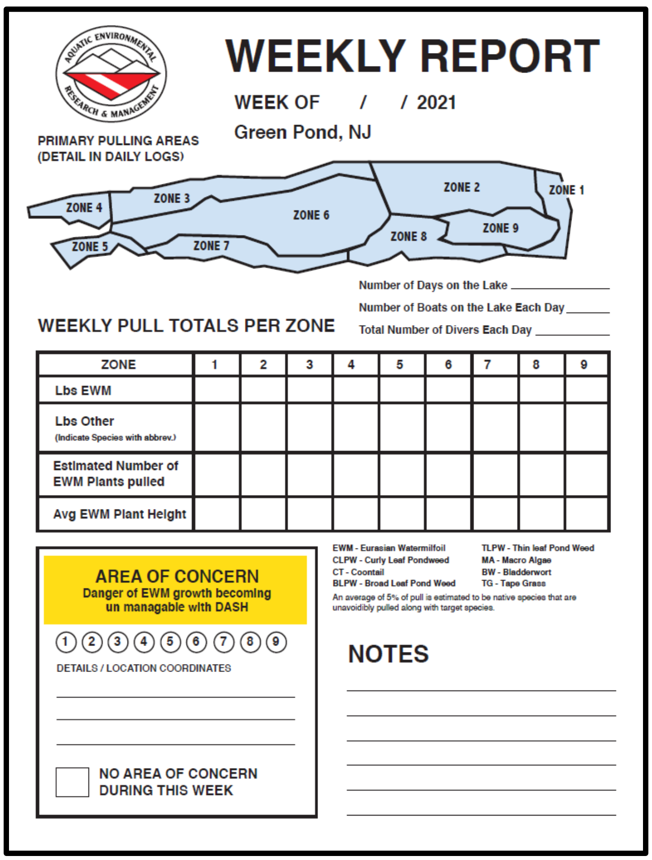
Figure 5.3 Team Diver removing tall EWM, focusing on getting all plant material and minimizing fragmentation.

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

5.3 Measures

5.2.1 Removal Measures

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



WEEKLY REPORT

WEEK OF / / 2021

Green Pond, NJ

PRIMARY PULLING AREAS (DETAIL IN DAILY LOGS)

Number of Days on the Lake ______

Number of Boats on the Lake Each Day ______

Total Number of Divers Each Day ______

WEEKLY PULL TOTALS PER ZONE

ZONE	1	2	3	4	5	6	7	8	9
Lbs EWM									
Lbs Other (Indicate Species with abbrev.)									
Estimated Number of EWM Plants pulled									
Avg EWM Plant Height									

EWM - Eurasian Watermilfoil
CLPW - Curly Leaf Pondweed
CT - Coontail
BLPW - Broad Leaf Pond Weed
TLPW - Thin leaf Pond Weed
MA - Macro Algae
BW - Bladderwort
TG - Tape Grass

An average of 5% of pull is estimated to be native species that are unavoidibly pulled along with target species.

AREA OF CONCERN
Danger of EWM growth becoming un managable with DASH

① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

DETAILS / LOCATION COORDINATES

☐ NO AREA OF CONCERN DURING THIS WEEK

NOTES

Figure 5.4: Weekly Measurements Reports

These measures are reported by zone: pounds of EWN and other specified species removed, number of EWM plants removed, and average height of EWM removed. These measures provide a numeric picture of the scope and breath of the EWM growing in the lake. The removal of CLPW is also tracked.

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

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

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

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

5.2.2 Temperature Measures

A volunteer temperature measurement program was maintained by HIGLIN using a Fish Hawk Sensor.

Figure 5.5: GP Temperature Measurement Program

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

6. Results

6.1 2021 Invasive Species Removal Results and Comparison to 2020

In the 2021 field season, a two ISR boat operation demonstrated the capacity to control EWM in the face of a 425% year to year increase (up to the 7,436 pounds) of EWM removed. The keys results of that control were EWM was never a nuisance despite its increased level and no plants were allowed to breach the lake's surface preventing the production of seeds   The keys control factors used were to operate consistently to identify and remove invasive species' plants as they emerged and to flexibly and methodically cover zones in the lake based on historic growing patterns and adjusting to in year conditions.

Figure 6.1 summarizes weekly EWM and CLPW removal by the Dive Team in both 2020 and 2021. It shows the daily average pounds of vegetation collected in each week of the seasons. The differences between the two years are evident from the start in both invasive species. The factor of spiking higher initial 2021 temperature substantially increased growth of the warm water loving EWM while suppressing that of the patterns of each year. In 2020, the impact of normal increasing temperatures is evident in the complementary peaking and decline of CLWP and EWM, as CLPW declines EWN increases cold water CLPW. The scope of the impact of early high temperatures is seen in the different growth However, in 2021 from the start, there was almost no CLPW and EWM had already reached a peak and continued to peak further.

The Dive Team was capable of managing the peaks created by the impact of weather. The impact of 2021 weather conditions, such as, storm events with high winds and heavy rains including two hurricanes, Elsa and Ida , are likely evident in the some of the growth peaks in EWM growth pulling data. The late 2021 season behavior of EWM is indicative. In 2020, the ultimate peak happened in week 7 which started a slow decline for the rest of the season. In 2021, the ultimate peak occurred in week 10 which started a decline abruptly reversed in week 13. Hurricane IDA's strong winds and pounding rains fragmented and spread late season fragile EWM plants. The mid-August decision to extend the Dive Team operation 4 weeks into September was fortuitous. The Dive Team capped and reversed the peak preventing growth that would be carried over to the next year.

Figure 6.1 Tracking EWM Removal by Week in 2020 & 2021

		2021	2020
Growing Season	Start	5/18	5/18
	Stop	10/29	10/15
	Duration (Days)	164	150
Operating Season	Start	6/7	6/8
	Stop	9/23	9/17
	Duration (Days)	109	102
	Work Days	63	59
EWM S&D Harvest (Lbs)		7.436	1,742
CLPW	S&D Harvest (Lbs.)	70	1,285
	Season (Days)	28	45
Cleared Vegetation (lbs)		730	2,575

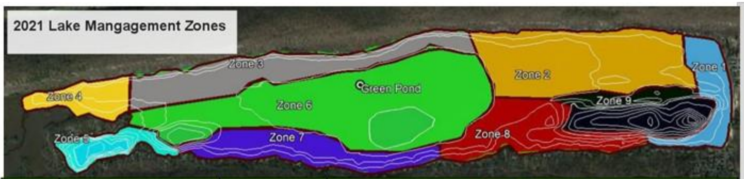
Figure 6.2 Key Data Comparison 2021 vs. 2020

The 2021 Dive Team operations were helped by what was learned from 2020 operations. This present analysis was helped in comparing 2020 and 2021 to provide context and to help highlight cause and effect differences. Figure 6.2 summarizes key data highlighting the similarities and dissimilarities between 2020 and 2021. Of note, both operations seasons started in the same week but faced very different conditions. The growing season for EWM was longer in 2021 as well as the operating season. The 2021 growing season for CLPW was shorter because of the same different conditions between years.

6.2 By Management Zone Results

As described in Section 5.2.1, the lake was broken into 9 defined lake management zones. Management by those zones was implemented in 2021 through scheduling removal efforts by zone, gathering measurement data by zone, and reporting results by zone. The idea of zones was developed during the 2020 season with high level rudimentary data gathered which makes some comparisons between 2020 and 2021 possible. Below is a summary by zone of EWM removed in 2021. See Appendix A for more details of zone results.

The right side of the chart highlights the relative portion of total EWM removed by each zone. Two zones, 1 and 8 account for 51% of all EWM removed and four zones, 1, 8, 2 and 7 account for 83%. The left side of the chart lists the zones and corresponding data including total acres in the zone, pounds removed, pounds per zone acre, and number of plants per zone square yard. Zones are categorized and color coded in red, yellow or green by the amount and intensity of the EWM removed. In 2020 using a similar process, two hot spots, or high intensity zones, were identified: zones 4 and 8. In 2021, three hotspots, 1, 4 and 8, occurred.



Zone #	Name	Zone Acres	2021 Year End Lbs. Pulled	2021 Year End Lbs. / Acre	2021 Year End Plants / Sq Yd
1	Beaches	26.7	2118	79.3	0.244
2	Sand Bar	92.3	1487	16.1	0.058
3	Seven Sisters	62.4	280	4.5	0.013
4	Outlet Cove	21	910	43.3	0.151
5	Shawger	18.7	180	9.6	0.028
6	Mid Lake	149	220	1.5	0.004
7	East Shore	43.5	575	13.2	0.043
8	Point Comfort	48.5	1666	34.4	0.120
9	Bass Hole	43			

- 7,436 lbs total EWM Pulled in 2021
- Pounds / Acre is indicator of Zone EWM Activity

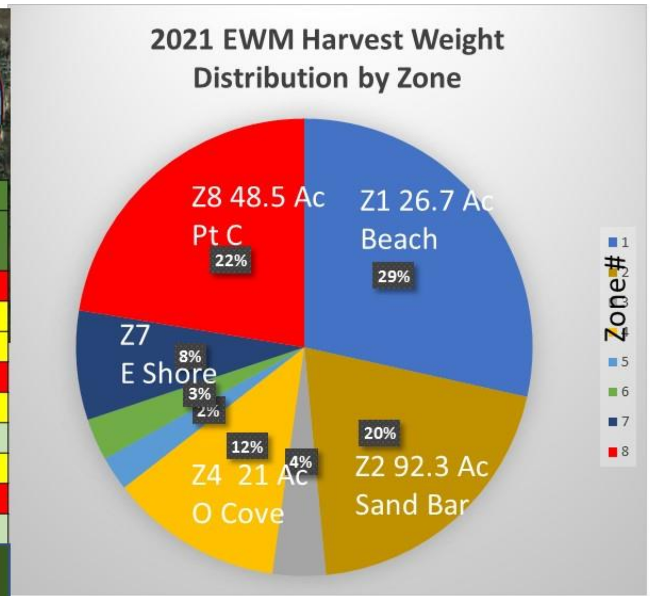


Figure 6.3 2021 Removal Statistics by Zone Describing the Distribution of Removed EWM

5

The emergence in 2021 of the zone 1 hotspot is noteworthy because that zone alone accounted for more than a quarter of all EWM removed. The zone's growth peaks involved removal of so much EWM that elongated time was devoted to clear the zone, approximating Clearance mode as opposed to Search and Destroy. That time devoted to one zone threatened to interrupt the Search and Destroy of other zones which, if left unattended, could be at risk of losing control of EWM. Consequently, sequestration of a portion of zone 1 was done through netting installed to capture fragments preventing them from rooting and growing in the zone. Figure 6.4 maps the weekly EWM removed from zone 1 and shows the impacts of a weather event, Hurricane Elsa, which hit on July 8 and 9, and the sequestration netting installed at the end of week 6. After a one week lag, the pattern of growth spurred by Elsa was capped and showed a substantial decline in growth as anticipated. This experiment showed the effectiveness of complementary selective use of sequestration netting.

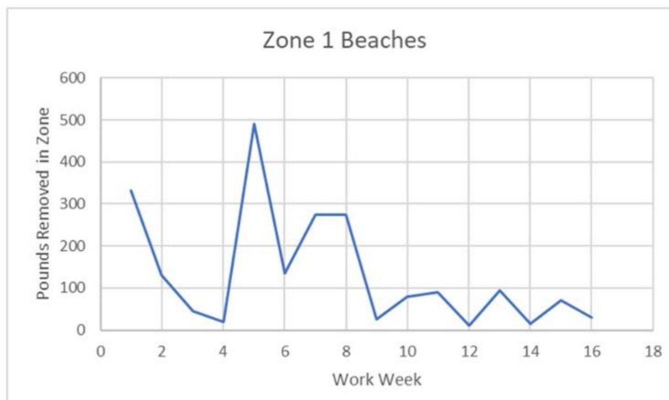


Figure 6.4 Zone 1 2021 Pattern of Growth: LBS removed per Week

The proliferation impact of fragments which have the potential to migrate, root, and grow was reinforced in an experiment run by the Dive Team Scientist. The experiment sought to monitor regrowth in areas that were cleared by the Dive Team. Any delayed regrowth was apparently caused by fragments which migrated into the area subsequent to it being cleared. A full description of the experiment will be in the 2021 Dive Team Scientist's report which will be posted on HIGLIN.org.

In order to complete the data picture in comparing 2020 to 2021, the level of EWM activity by zone and locations can be calculated and mapped which is summarized in Figure 6.5 below. The left side of the figure compares the percent of each zone's acres where EWM was present. In total, 27 acres or 6% of total acres were active in 2020 while 93 acres or 20% were active in 2021. The right side of the charts displays the locations of EWM presence aggregated into area acres. The top map shows 2021, the bottom 2020.

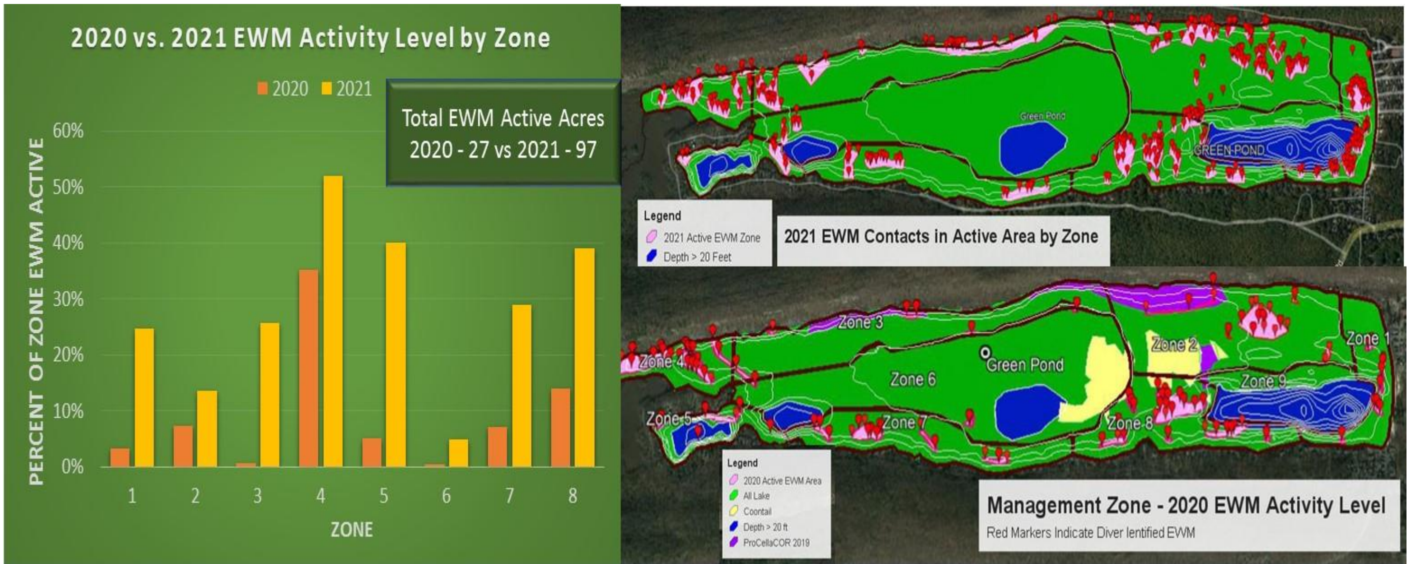


Figure 6.5: Comparing 2020 vs. 2021 EWM Activity Level by Zone and Location of Active Acres

While the 2021 season showed a substantial increase in EWM growth, it is nonetheless important to keep in perspective the overall invasive species health of Green Pond. Comparing intensity of GP EWM infestations to other lakes can be done by applying scales developed to categorize varying intensities of EWM growth (Kelting & Laxson, 2012). Using those standard scales, Green Pond zones were rated. Figure 6.6 provides the results of applying those scales to the Green Pond zones. It is noteworthy that no zone was higher that "Light" with each of the three hot spots in that category. All other zones were in the lowest category "Scattered". This analysis should not be understood to reduce the threat EWM has for Green Pond which is great if not effectively controlled. The analysis reinforces the effectiveness of the ISR removal capability being demonstrated by this project to keep EWM from becoming a nuisance.

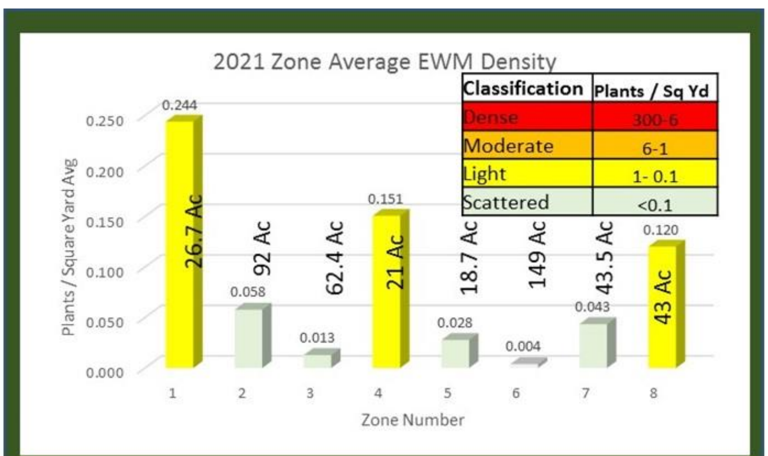


Figure 6.6 2021EWM Intensity Ratings of Zones

7. Findings

The results of the 2021 Green Pond Research and Demonstration project have led to additional useful understandings about EWM and its management in NJ Highlands lakes. The insights arose from the research data and observations produced during 2021 and supporting 2020 data. The findings reported in the 2020 report were generally supported by observations from this year. Any refinements will be noted in the descriptions below. The following points summarize the new additional understandings.

- The EWM growth and proliferation continue to show significant variation year to year. Examining factors that could influence that variance, nutrient loading, outside-in migration, resident aquatic flora and fauna, and human behavior appeared to have remained relatively constant. However, weather, which was different between 2020 and 2021, was most likely is a factor. Numerous differences in the EWM growth between 2020 and 2021 are relatable to differences in weather observed and measured. Increased attention to weather and its impacts will support better prediction and response in managing EWM.
- The start of the Green Pond EWM growing season is determined by lake bottom water temperature with 60° F, as a generally accepted trigger point. Air temperature which impacts lake water temperature vary year to year, and consequently, the start of the EWM growing season also varies.
- The timing of the season’s start of diver ISR removal is critical to address the first seasonal stage of growth when EWM is using starch stored in its roots from the previous season to accelerate vertical growth. When that growth is not addressed in time, EWM dominates other species and achieves second stage maturity quickly beginning the cycle of fragmentation and root stolen development.
- The increased weekly EWM quantities and plant sizes stayed consistently higher from 2020 to 2021. One factor contributing to the increase was an early warmer spring which meant removal efforts started later on the EWM growth curve in 2021. More plants reached the fragmentation stage and a significant amount of fragments was observed. The windy weather and storm events widely dispersed those fragments.
- The EWM increase in the Beach Zone provides an example of the previous points. Its location downwind from the prevailing winds make it a EWM receiving area. The significant decrease of its EWM growth after the installation of netting to capture fragments suggests that sequestration through netting should be accepted as an effective tool to use in managing and studying EWM.
- Subsequent EWM growth behavior was studied in an experiment by the Dive Team Scientist in order to understand areas cleared using Search and Destroy. Further structured research could help provide understanding of effectiveness of the removal approach used in this project.
- Accurate and timely detection of EWM and its location is critical throughout the season to optimize the effectiveness and efficiency of removal efforts.
- The second year of the project shows that EWM can be controlled below nuisance levels by a Dive Team staffed and equipped as in this project. This assertion is based on the amount, 7,432 pounds, and proliferation of EWM removed in 2021.

8. Recommendations

Based upon the results and findings of the 2021 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.

- While the volunteer efforts to methodically measure water column temperatures has been effective, further enhanced water temperature tracking should be implemented. Enhancements should include starting measurement earlier well before the season, adjunct capability to observe for the presence of milfoil when temperatures meet the thresholds for growth, and technology that detects and reports temperature automatically without human presence. The influence of weather and wind are also important factors that can be evaluated with good local data which is not currently available and should be sought.

- The capability to detect the presence of EWM and it location should be increased. Because of their superior detection results, the reliance on diver detection and sonar surveying should be maintained, however, greater efficiency and effective may be achieved by adding capability beyond the Dive Team and its two boats. Additional volunteer systematic scouting with equipment should be explored and potentially implemented.
- The use of automated GPS trackers to provide continuous boat position information can provide better information on where the most troublesome areas are in the lake, without imposing additional burden on the Dive Team. This data will allow better operational planning.
- 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, intentionally integrate a structured systematic clearance method in high activity EWM source areas rather than only an intercept Search and Destroy approach.
- Utilize sequestration netting for a number of purposes: first, to control EWM proliferation, for example in the Beach and Outlet Cove Zones; second, to perform experiments to determine the source of regrowth in areas cleared by either the Search and Destroy or Clearance methods, and third, by strategically locating netting, determine the flow of fragments out from or into areas. Extend experiments conducted in 2021 EWM regrowth rates
- The HIGLIN EWM removal approach and operation should continue to be used to its fullest extent for the 2022 growing season. Hand removal would address all areas of the lake and be scheduled to start early in the season and continue until the risk of late season blooms is low. Herbicide treatment would be a planned secondary contingent control method to be used when the risk of losing control of EWM is present.
- Research and Demonstration projects should be planned with other lakes in the Highlands region to ascertain whether the results of the Green Pond project would be duplicated in other lakes and conditions. During 2021, progress was made with the lake stewards of Lake Hopatcong, the LH Commission ad LH Foundation to explore and experiment with the EWM control approaches used by HIGLIN. Those efforts should be brought to fruition.
- The information and knowledge generated from this project should be shared with other lakes in the Highlands Region through educational materials and presentations. One vehicle for sharing is NJCOLA, an existing lake association body. NJCOLA meets regularly to educate and inform its membership about relevant scientific and practical knowledge to enhance their lake management effort. HIGLIN should continue to develop a relationship with NJCOLA,

HIGHLANDS HIGLIN GLACIAL LAKES INITIATIVE

AQUATIC ENVIRONMENTAL RESEARCH & MANAGEMENT

Appendices

Appendix A: Green Pond 2021 EWM Removal Summary by Zone

Report Date	2021 Op Week	EWM Harvest From Zone (Pounds)								Week Summary			
		1-Beaches	2-Sand Bar	3- Seven Sisters	4-Outlet Cove	5-Shwgr Cove	6-Mid Lake	7-East Shore	8-Point Comfort	Wk Tot	Wk Days	Divers	Daily Avg
6/7/2021	1	333	177	0	0	0	0	0	35	**545**	4	6	136
6/14/2021	2	130	0	5	115	0	0	35	10	**295**	3	6	98
6/21/2021	3	45	75	0	95	25	0	0	55	**295**	4	6	74
6/28/2021	4	20	120	100	40	55	70	10	30	**445**	4	7	111
7/5/2021	5	490	50	5	15	15	0	25	45	**645**	4	7	161
7/12/2021	6	135	65	10	40	25	35	50	60	**420**	4	8	105
7/19/2021	7	275	65	0	35	0	0	0	185	**560**	4	7	140
7/26/2021	8	275	55	5	75	5	0	0	35	**450**	4	7	113
8/2/2021	9	25	275	25	105	0	0	85	25	**540**	4	8	135
8/9/2021	10	80	85	55	95	0	0	40	375	**730**	4	7	183
8/16/2021	11	90	75	20	65	5	20	30	290	**595**	4	7	149
8/23/2021	12	10	60	0	115	0	35	195	16	**431**	4	7	108
8/30/2021	13	95	35	0	0	25	25	15	80	**275**	4	6	69
9/6/2021	14	15	135	5	40	0	35	25	70	**325**	3	6	108
9/13/2021	15	70	150	0	0	0	0	0	330	**550**	4	5	138
9/20/2021	16	30	65	50	75	25	0	65	25	**335**	4	5	84
Zone Summary	**Total Lbs**	**2,118**	**1,487**	**280**	**910**	**180**	**220**	**575**	**1,666**	**7,436**	**62**	**105**	**120**
	Area (Ac)	**26.7**	**92.3**	**62.4**	**21**	**18.7**	**149**	**43.5**	**48.5**	**Lbs**	**Days**	**Dive Wks**	**Lbs. Avg**
	Lbs/Ac	**79.3**	**16.1**	**4.5**	**43.3**	**9.6**	**1.5**	**13.2**	**34.4**	**Year to Date Total**			

Harvest Weight Scale
500
450
400
350
300
250
200
150
100
50
0

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