Chautauqua Lake Monitoring Program
Submersed Aquatic Vegetation Survey – Final Report

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Introduction

Chautauqua Lake, located in Western New York's Chautauqua County, is a popular destination for boating, fishing, and other forms of outdoor recreation. The shoreline is heavily developed and spans the towns of Busti, Chautauqua, Ellery, Ellicott, and North Harmony. The waterbody supports 42 miles of shoreline, spans over 13,000 surface acres, and is divided into two unique basins. Despite being similar in size, the southern basin tends to be shallower, warmer, and more nutrient rich when compared to the northern basin (Smith 2020; EcoLogic 2018).

The topography surrounding Chautauqua Lake has resulted in an extensive littoral zone that has the ability to support a highly productive ecosystem. Historic records and recent surveys have determined that the submersed aquatic vegetation (SAV) community of Chautauqua Lake is exceptionally diverse with over 50 total recorded aquatic plant species present since first surveyed in 1937 (Johnson 2018). Of these, five non-native SAV species, Eurasian Watermilfoil (*Myriophyllum spicatum*), Brittle Naiad (*Najas minor*), Starry Stonewort (*Nitellopsis obtusa*), Water Chestnut (*Trapa natans*) and Curly-leaf Pondweed (*Potamogeton crispus*) have been periodically documented within the waterbody over time.

The growth of these non-native species can impair the recreational, ecological, and economical uses of Chautauqua Lake. To date, mechanical harvesting has been the most widely used method for aquatic plant management in the waterbody. Throughout the 2020 growing season alone, more than 13 million pounds of aquatic vegetation was removed from Chautauqua Lake (CLA 2020). More recently, select regions of the lake have also been treated with herbicides to target nuisance plant growth. Continual monitoring for abundance and distribution of both the native and non-native SAV species within Chautauqua Lake is a critical step in evaluating the overall sustainability of the aquatic ecosystem, and for determining an appropriate long-term management strategy.

This study was developed such that our results can be comparable to the research that has been done at Chautauqua Lake in previous years. SAV species presence and abundance data were collected following a point intercept-based methodology that had been previously applied within this system. Concurrently, hydroacoustic (sonar) data were recorded to determine SAV biovolume and acreage estimates.

Methods

The lakewide aquatic vegetation monitoring survey of Chautauqua Lake occurred August 31st - September 9th, 2020.

Macrophyte Survey

Point-intercept methods followed the guidelines proposed by Madsen (1999) and Racine-Johnson (2019) to provide direct survey effort and historical data comparisons between macrophyte survey years. Pre-established survey points, previously utilized by Solitude Lake Management, were uploaded to an on-board GPS enabled chartplotter with ~5 ft horizontal accuracy. Of the 1000 potential point locations for the 2020 fall survey, 980 points were sampled (2019: 865 points; 2018: 1301 points). Among each sample point location, *two* rake tosses were conducted where a visual estimate of whole-rake density was recorded (Table 1). Each retrieved rake also received a species-specific relative abundance estimate (Figure 1). When applicable, floating and emergent shoreline species were also documented at each point location using a binary system. Abundance ratings of non-SAV were not recorded.

Sonar-Based Biovolume Survey

Each survey vessel was configured with a Lowrance HDS-7 Gen3 consumer-grade fish-finding echosounder and chartplotter to record passive sonar tracks during the point-intercept survey (Figure 1). The echosounding transducer emits a 200kHz acoustic signal through the water column which is returned back to the receiver. Sonar data was saved by the echosounder to 32GB memory cards for further processing. Boat speed did not exceed 7mph between point-intercept locations to ensure accurate interpolation of SAV presence and abundance. Sonar logs were recorded for ~2 hrs each. In total, 63 sonar logs took place to map the littoral zone.

Raw .Sl2 sonar data files were uploaded to BioBase C-Map cloud-based processing service to extract bathymetry estimates and SAV biovolume (quantity of the water-column occupied by SAV; *0-100%*) from boating transects. All processed sonar logs were then exported as tabular data for further GIS post-processing, mapping, and statistical analysis.

In Situ Water Quality & Turbidity Survey

Among 30 discrete point-intercept sampling locations, water quality parameters and water clarity measurements were recorded. Sampling locations were defined prior to the start of the lake wide survey to ensure uniform spatial representation across the lake with 1.13 mile average spacing between points.

A YSI handheld data logger was deployed at the select water quality points to measure profiles of Dissolved Oxygen (DO), Temperature, pH, and Conductivity. At each sampling point, recordings occurred 1.5 ft from the benthic layer and every subsequent 3 ft until the sensing probe was 3 ft from the top of the water column. Conducting measurements in this fashion can help illuminate water quality parameters which could influence SAV presence and abundance based on bathymetric profile.

To determine relative turbidity, a Secchi disk with industry standard recording measurements was utilized. A secchi measurement was taken when the disk was no longer visible to the surveyor when lowered in the water column. These readings can be useful in locating the boundaries of suspended solids, specifically planktonic algal blooms, between the north and south basins.

Post-Processing and Data Analytics

To create rake-toss density estimates for mapping and for relative species abundance estimates, both rake-toss throws were averaged to represent each survey point. For example, at any given point, two rake estimates of *moderate* density would be provided a weighted average score of *moderate*, whereas one rake toss of *no plants* and one rake toss of *moderate* density would be given a score of *sparse*. The weighted density values were then deployed in point and heat density mapping.

Point-intercept data was further tabulated in Microsoft Excel to provide appraisals of SAV species presence, frequency, and abundance. Species abundances were classified as *trace*, *sparse*, *moderate*, or *dense* as a function of their estimated percent cover on the rake and the respective rake fullness estimate. For example, a *sparse* rake with 50% occupancy of Eurasian watermilfoil and 50% Coontail resulted in a *trace* estimate of both Eurasian watermilfoil and Coontail at the surveyed point. Further, a *dense* rake with 100% cover of Eurasian watermilfoil resulted in a *dense* species rating for Eurasian watermilfoil. Resulting values were then used to identify native and non-native dominance and distribution throughout the lake.

Since sonar data does not provide species specific information, but rather a generalization of SAV water column occupancy and spatial breadth, point-intercept data was attributed to biovolume estimates. To provide acre estimates of SAV, specifically Eurasian watermilfoil, rake-toss point data was combined with the exported echosounding outputs from BioBase into QGIS 3.14. Survey point interpolation occurred using an inverse distance weighted (IDW) geostatistical function. An IDW is utilized to predict the non-surveyed areas between survey points. Input variables for IDW considered the mean buffered distance between rake-toss locations to account for nearest neighbor influence. That is, alike SAV species were given a higher probability of occupying an area than plants which were less prevalent in proximity. The resulting interpolation raster was then clipped to the sonar biovolume areas where a non-occupancy threshold of <10% biovolume was set. This value is standard for interpolated biovolume datasets to reduce the possibility of false-positive SAV detection when evaluating submersed plant bed breadth using sonar.

Results

This survey was able to evaluate SAV growth throughout much of Chautauqua Lake's littoral zone (Figure 2). In total, 980 sites were sampled for SAV presence and abundance. Lakewide, no plants were found at 116 of the 980 sampling sites. The most frequent rake density across the lake was a moderate rating (36%), followed by sparse rake estimates (28%) (Figure 3). SAV biovolume was highly variable along the shoreline of the lake but was generally more dense in the north basin when compared to the south basin (Figure 4). The mean biovolume throughout the lakewide survey area was 39.7%.

Eurasian Watermilfoil (EWM) was the most dominant SAV sampled throughout the lake system with a frequency of 58% of rakes tossed (Figures 5 - 6; Table 2). Despite EWM density, the survey also recorded eight species of floating and emergent macrophytes, and 24 other submersed plant and algal species (Table 2). Twelve of the 24 SAV discovered occurred with less than 5% frequency. Among all species identified, four submersed species (*M. spicatum; P. crispus; N. major; N. obtusa*) were non-native and two of the shoreline species (*P. australis; P. cuspidatum*) were non-native. Based upon point-intercept and sonar surveys, there is a lakewide estimate of 2,214 acres of EWM.

Curly-leaf Pondweed (CLP) was identified at 50 sites, but due to plant phenology and management tactics, most plants were small in stature at the timing of the fall survey (Appendix I). Often, only single plants were identified at rake retrieval, or as newly sprouted propagating bodies, known as turions (Figure 7). CLP turions were found in both basins, but the greatest concentration was found within the south basin (Figure 8).

White Waterlily (6%) and Japanese Knotweed (3%) were the two most frequently occurring shoreline species. Though prevalent among many northeastern lake systems, non-native Common Reed was only found among six sites on the north basin (Table 2).

The point-intercept survey did locate Starry Stonewort among 13 sampling locations, specifically sites in the south basin. Further, Brittle Naiad was found for the first time in several years near the outlet in the town of Ellicott.

As in years past, exotic zebra mussels were discovered throughout the north and south basins (Figure 9). Likewise, the most frequent and dense zebra mussel populations were found within areas dominated with EWM.

At the time of the lakewide survey, there were several algal blooms starting from Bemus Bay and worsening further into the south basin. This was especially apparent by the visible planktonic blooms (visually green water-color) which were occurring on the east and west shorelines of the south basin (Figure 10). Furthermore, lakewide turbidity (poor water clarity) increased significantly in the south basin (Table 4), with the presence of suspended algae.

North & Central Basin Results

Town of Chautauqua

There were 381 sampling locations encompassing the town of Chautauqua's littoral zone (Figure 11). Compared to the 2019 survey, EWM was found at 8% less sampling sites. However, EWM acreage is the second-highest estimate of the waterbody, with an appraised 777 acres of EWM (Figure 12). In total, 93% of sites within the Town of Chautauqua contained vegetation with the most frequent rake density being *moderate* (44%), followed by *sparse* (28%).

Of the surveyed points, Coontail was the most dominant species with 74% occurrence, followed by EWM (64%) and Water Stargrass (57%) (Table 5). The town of Chautauqua had the highest species richness, containing 23 of the 24 submersed species found in the lake. Four of the native SAV were found among at least 50% of the sampling locations. Furthermore, the greatest diversity of native pondweeds was found in this portion of the waterbody. Likewise, the greatest biovolume estimate from hydroacoustic measurements for an individual town occurred within the town of Chautauqua, having an average of 52.1% biovolume (vertical water column occupancy with SAV).

Village of Mayville

Of the 113 points occurring in Mayville, all were occupied with SAV (Figure 13). Rake density estimates were greatest in this portion of the lake with 72% of locations having a *moderate* or *dense* rating (Table 6). These density ratings are consistent with previous reports of rake density estimates which have occurred in past survey years.

The most dominant species recovered was EWM, with 84% occurrence among surveyed points and an acreage estimate of 291.2 acres. Water Stargrass and Common Waterweed tied for the second most occurring SAV in the Village of Mayville at 78.0% each. Coontail was the third most frequently located species at 77.0% occurrence (Table 6). Species richness was also high in this region of the waterbody, with 20 of the 24 SAV species present. Starry Stonewort was found at only one location near Chautauqua Mariana. The Village of Mayville had the highest water column occupancy of any incorporated region on the lake at 66.9% biovolume.

Town of Ellery

In total, 279 sampling locations were surveyed representing most of the littoral zone of along the town of Ellery and Bemus Bay (Figure 14). Overall, the town of Ellery accounts for ~45% of the EWM acreage within the waterbody at an estimated 994 acres (Figure 15). The average biovolume estimate was slightly less than the lake average at 34.3% vertical water column occupancy.

Among the point-intercept areas, 15% contained no plants, while 60% of locations were either *trace* or *sparse* (Table 7). Among sites sampled, 20 SAV species were located, including CLP (n=13 sites) and Starry Stonewort (n=3 sites). EWM (54%) was the most dominant species, with native Water Stargrass as the second most abundant (40%) (Table 7). Both invasive shoreline species (Japanese Knotweed: 10 points; Common Reed: 2 points) were found along the shoreline as well.

Compared to the 2019 survey, there was a 7-fold increase in Western Waterweed (2020: 57 points; 2019: 8 points; 2018: 0 points). Furthermore, there was an increase in the abundance of Water Stargrass and Wild Celery compared to the 2019 survey reporting (Solitude Lake Management 2019).

Village of Bemus Point

There were 33 sampling locations within the littoral portion of Bemus Point, with 67% of points having a *moderate* or *dense* rating (Figure 16; Table 8). The most frequently occurring SAV was Coontail (74.0%), followed by Ivy-Leaved Duckweed (50%). This portion of the waterbody had the highest frequency of Ivy-Leaved Duckweed. Common Waterweed and EWM also had notable point-intercept occurrence at 47% and 41%, respectively (Table 8). While not the dominate species, EWM continues a strong presence in the Village of Bemus Point, being well distributed along the shoreline areas and having an acreage estimate of 73.8 acres. Water column occupancy was higher than the lake average at 46.2% biovolume.

Curly-leaf Pondweed was discovered among 18% of sampling sites and found exclusively among the deepest sampling locations. While only observed as *trace* and *sparse* rake estimates, this population of CLP was the highest of all other Villages.

South Basin Results

Town of Busti

There were 123 sites sampled for SAV in the town of Busti (Figure 17). The hydroacoustic survey provided similar occupancy results with an estimated average of 29.7% biovolume. From survey efforts, there is an estimated 522 acres of EWM within the town of Busti (Figure 18). Overall, this portion of the waterbody contained the least dense rake ratings, with most assessments noting 60% sampling locations containing *trace* or *sparse* estimates (Table 9).

In total, 14 SAV were recorded with EWM being almost twice as abundant as Coontail at 59% occurrence (Table 9). Though not prevalent both CLP (n=3 sites) and Starry Stonewort (n=1 site) were identified along the shoreline. There was no Common Reed found along the shoreline of the town of Busti.

Village of Lakewood

The 61 sites visited within the Village of Lakewood revealed 23% of sampling locations contained no vegetation, with the majority of rake estimates being either *trace* or *sparse* (70% collectively) (Figure 19; Table 10). Compared with the other surveyed villages, EWM had the greatest dominance in this portion of the lake, with 62% of sampled sites identified. Based upon interpolation procedures, there is an estimated 419.5 acres of EWM. Coontail, Water Stargrass, and Slender Naiad were identified ~25% of the survey points (Table 10). Water column occupancy for this location of the waterbody was 10% less the lakewide average, at 26.7% biovolume.

The two other invasive SAV were discovered, Starry Stonewort and Brittle Naiad, were located adjacent Lakewood Community Park. Neither of these two species are recently documented in Village of Lakewood.

<u>Town of Ellicott</u>

With 35 sampled locations, the town of Ellicott had the fewest points surveyed with 23% of sites containing no vegetation (Figure 20). The lowest average biovolume estimate from hydroacoustic monitoring throughout the lake system also ensued in Ellicott (19.5% biovolume). Overall, there are an estimated 349 acres of EWM (Figure 21).

Rake density within the Town of Ellicott was most commonly *trace* or *sparse*, with 44% frequency each (Table 11). Only 11 SAV were located in this portion of the lake (Table 10). Unlike most of the towns, Coontail occurred at a decreased frequency as the 7th most abundant species. EWM was found at over half of the survey points (51%) with Western Waterweed as the second most frequently discovered species (40%). This portion of the waterbody also had the greatest occurrence of Brittle Naiad (20%).There were few shoreline species located near the survey points, however both White and Yellow waterlily were present.

The greatest number of CLP turions was located in the middle portion of the outlet and found with a 28% sampling occurrence. However, it is difficult to compare if CLP was well established in this area (or if turions were deposited by water flow) since this portion of the outlet had not been surveyed in two years.

<u>Village of Celoron</u>

With 16 sampling locations adjacent to the Village Celoron, this portion of the lake had the lowest rake density and water column occupancy estimate at 14.8% biovolume (Figure 22). This appears to be an analogous finding to the 2018 survey reporting that this area of the lake has the lowest SAV density (Solitude Lake Management 2018). EWM was discovered at 56% occupancy, with Western Waterweed found at 44% occupancy (Table 12). There is an estimated 16.0 acres of EWM established in the Village of Celoron. The non-native SAV, Brittle Naiad, was the third most common species with a frequency of 31% of survey points.

At the timing of this survey, there was *no* water chestnut (*Trapa natans*) discovered in the outlet area of Celoron.

Town of North Harmony

The 162 point-intercept locations spanned the entire shoreline of North Harmony (Figure 23). Based on the echosounding and point-intercept survey conducted, there are an estimated 403 acres of EWM within the town of North Harmony (Figure 24). The town of North Harmony had the second highest biovolume average of the lake system at 40.1% water column occupancy.

In North Harmony, there were 89% of sites identified as containing SAV, and 39% of sites had *moderate* rake density estimates. The second most frequent density rating was *dense*, at 28% occurrence. In all, there were 17 submersed species with Coontail as the most frequently discovered SAV (63% occurrence), followed by EWM (54% occurrence) (Table 13). The next three most common SAV (Common Waterweed, Water Stargrass, and Wild Celery) were of similar distribution status as in 2019. Starry stonewort was present at five of the surveyed sites. Further, the town of North Harmony had the greatest distribution of Japanese Knotweed, with 17 separate locations identified (Table 13). Compared to 2019, there is an increase in EWM distribution, although EWM appears as second abundant to Coontail (Solitude Lake Management 2019).

Herbicide Treatment Zone Results

During the 2020 growing season, there were three regions within the lake which had herbicides applied to manage standing EWM populations (Figure 25). A collective 56.4 acres were treated among select locations of Bemus Point (7.0 acres), Lakewood (20.2 acres), and Busti (29.2 acres). Within those treated areas, the point-intercept survey identified 27.8% of the point locations void of vegetation, 34.6% of points as either *trace* or *sparse*, and 38.4% were *moderate* or *dense* rake estimates. Overall, the most frequently identified SAV within these treated regions were Coontail and Wild Celery, with an occurrence of 61.5% and 30.8%, respectively. Among the treatment zones, only three points contained EWM at an occurrence of 11.5%. This represents a 46.5% reduction in EWM presence compared to the lakewide average.

Village of Bemus Point Treatment

There were only three survey points found within the Bemus Point treatment zone, with one point containing *trace* EWM. Based upon interpolation estimates, the EWM acreage within the treatment zone is 3.2 acres. There were eight SAV species within the treatment zone including EWM, Water Stargrass, Coontail, Wild Celery, Common Waterweed, Ivy-leaved Duckweed, Southern Naiad, and Clasping-leaf Pondweed. The estimated water column occupancy based on sonar records is 35.5% biovolume (-4.2% lakewide average).

Village of Lakewood Treatment

Within the Lakewood treatment area, seven survey points were sampled, with *no* EWM found among any of the sampling points. Only three survey points contained vegetation, with no *dense* rake estimates. There were three SAV identified which included Coontail, Wild Celery, and Southern Naiad. The estimated water column occupancy based on sonar records is 9.8% biovolume (-29.9% lakewide average).

Town of Busti Treatment

In total, sixteen point locations were surveyed within the Busti Treatment zone, with two points containing *sparse* EWM estimates. Based upon interpolation estimates, the EWM acreage within the treatment zone is 4.8 acres. There were five SAV species within the treatment zone including EWM, Coontail, Wild Celery, Western Waterweed, and Slender Naiad. The estimated water column occupancy based on sonar records is 33.6% biovolume (-6.1% lakewide average).

Discussion

Eurasian Watermilfoil and Curly-leaf Pondweed are the two most prevalent non-native submersed species in Chautauqua Lake. Previous survey reports suggest SAV was most frequently along the 10-ft contour line (Solitude Lake Management 2018). Overall, we encountered similar results and determined EWM was most commonly identified around the 5-ft depth range (Figure 25). Plant biomass depth can be influenced from year to year by factors such as water level and turbidity. Although EWM was most abundant, it frequently co-occurred with other native SAV instead of being confined in densely populated monocultures. Two native species, Coontail and Water Stargrass, had similar or greater relative when compared to EWM, and often comprised much of the biomass in the ‘dense’ rake tosses (Figure 26). Nevertheless, EWM growth is a contributing factor in the reduction of the recreational value of Chautauqua Lake (Figure 27).

Overall, species richness (number of SAV species at a given point) was greatest from Snug Harbor Marina north to Chautauqua Marina in the north basin (Figure 28). While non-native species can reduce ecologic and recreational function by dominating the habitat, future management direction should consider maximizing EWM control while minimizing native species impacts in the highly diverse portions of the lake.

The greatest density of EWM was in the north basin near the town of Chautauqua. Although lower rake densities were recovered in the south basin, managers should consider that EWM is still prevalent in that area (Figures 5 and 6). Results from the fall 2020 survey closely match those density estimation maps from 2018 and 2019. Since there were portions of Bemus Bay and Ellery shoreline not surveyed in the past two years, it is difficult to quantify how plant abundance has shifted among those management areas. However, there does seem to be a decrease in the presence of EWM in the south basin when compared to previous survey years, particularly 2018.

In general, treated regions of the lake had lower rake abundance and presence of EWM compared with untreated, adjacent areas (Figure 25). Overall, treated regions were void or contained low abundance estimates of EWM but still had an average species richness of five native SAV. The most common and dominate species present among all treated areas was Coontail.

Curly-leaf Pondweed was found throughout the waterbody during the fall 2020 survey, however estimates of presence and abundance from late summer and fall surveys likely underrepresent abundance that would be present earlier in the year (April – June; Appendix 1). Based upon previous surveys conducted at Chautauqua Lake, the greatest seasonal CLP abundance would likely be found during peak growth, which occurs late spring. Unlike other SAV found throughout the lake, the unique growth pattern of CLP allows for early season competition with other SAV. However, by late-July the plant has mostly senesced, or no longer in vegetative form. Therefore, when conducting a fall survey, CLP plants will most often be present among areas of high turion density and often found as recently sprouted turions. The greatest turion density was found near the mouth of the outlet in the towns of Ellicott, Ellery, and Busti (Figure 8). A high density of CLP turions is in this portion of the lake could be attributed to water flow and plant fragment deposition. The life cycle of the plant may also predispose plant fragments to form turions as the shoots senesce. High levels of turion formation from mechanically separated shoots was previously observed in late June on Findley Lake, NY by Rob Richardson. This could potentially lead to very high turion deposition rates downstream of June/July mechanical harvesting activities, but this hypothesis should be investigated to confirm or refute on Chautauaua Lake.

Conclusions

- Overall water quality and clarity is significantly greater in the north basin than the south basin.
- At the timing of the survey, a planktonic algae bloom extended from Bemus Bay to the bridge, and south towards the outlet on both shorelines which could heavily influence the community of submersed species found.
- Eurasian Watermilfoil is the most widespread submersed plant species, with 58% occurrence across the lake.
- Starry Stonewort was identified at 13 sampling locations distributed across the waterbody.
- *Lyngbya* spp. was found among 22 sites; the highest density and occurrence was in Bemus Bay. While considered native to the region, dense *Lyngbya* spp. growth can impact the recreational use of a waterbody due to its thick mat-forming tendencies.

- While Curly-leaf Pondweed was present during the survey, most of the vegetative portions of the plant had senesced. Therefore, a spring or early summer survey would be more appropriate to identify the distribution of CLP.
- Curly-leaf Pondweed turions were prevalent in the south basin, with the highest propagule density in the outlet area of Ellicott. Future survey and management efforts should focus on high-density turion regions of the lake next season.
- Curly-leaf fragments should be monitored to see if turion formation is greater around time of senescence and if this has any linkage to mechanical harvesting activities.
- The lakewide average hydroacoustic biovolume estimate was 39.7%, with the greatest biovolume recorded in the north basin.

In summary, our point intercept and echosounding findings were consistent with 2018 and 2019 surveys and found that non-native Eurasian Watermilfoil is the most dominant SAV within the waterbody. It was most commonly found at 5 ft depth and was widespread throughout the lake. The distribution and abundance of EWM should be considered with future management decisions. Yearly monitoring should be continued to ensure that any changes in SAV distribution and abundance are tracked over time.

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APPENDIX

I. Species Overview: Curly-leaf Pondweed *(Potamogeton crispus* L.*)*

Distribution/History

Potamogeton crispus (Curly-leaf Pondweed, CLP) is a cosmopolitan species with a broad native range that includes regions in Europe, Asia, Africa, and Australia (Bolduan 1994). The first documented population of *P. crispus* in the US occurred in Delaware in 1859 (Nichols and Shaw 1986). It rapidly spread throughout the northeastern United States and parts of Canada and became recognized as a nuisance, aggressive invader (Bolduan 1994). Today, it has been recorded in all of the continental US states (Thayer 2020). In New York, *P. crispus* has been found in 47 of 62 counties (Weldy et al. 2020). *P. Crispus* has been consistently documented during aquatic vegetation surveys at Chautauqua Lake since 1937 (Johnson 2019).

Identification

P. crispus belongs to the Potamogetonaceae (Pondweed) family. It grows completely submersed in the water column and can be found in freshwater lakes, rivers, and streams. Leaves of *P. crispus* are linear, range in color from light to dark green to red, are arranged alternately along a thin, light colored stem, and have distinctly wavy/crinkled margins. Depending on environmental conditions, *P. crispus* stems can grow up to 1 to 3 m long. In early summer, *P. crispus* often develops small flowers arranged in small emergent spikes that can be visible from the water's surface. While these flowers can produce viable seeds, *P. crispus*' primary forms of reproduction are through its vegetative, rhizomatous growth and through the production of turions (winter buds) that develop within leaf axils. *P. crispus* turions can resemble small pinecones as they are rigid, greenish-brown in color, and resilient. P. crispus is morphologically similar to other pondweed species such as *P. richardsonii* and *P. praelongus*.

Life Cycle

The life cycle of *P. crispus* is unique among aquatic plants. Much of its vegetative growth occurs in early to late spring and with most biomass senescing by early fall. Growth phases depend on water temperature and light availability. Peak biomass production usually occurs in mid- to late-spring when water temperatures are between 10 – 15°C and light availability is fairly low. Turions are formed (5 – 13 per shoot) and inflorescences emerge during this time as well. In the summer months, *P. crispus* biomass dies back and the mature turions are released into the water column where they stay dormant until water temperatures begin to cool. Turions often break their dormancy in the fall when small, narrow leaves sprout. The turions remain in this form throughout the winter when water temperatures remain below 10°C.

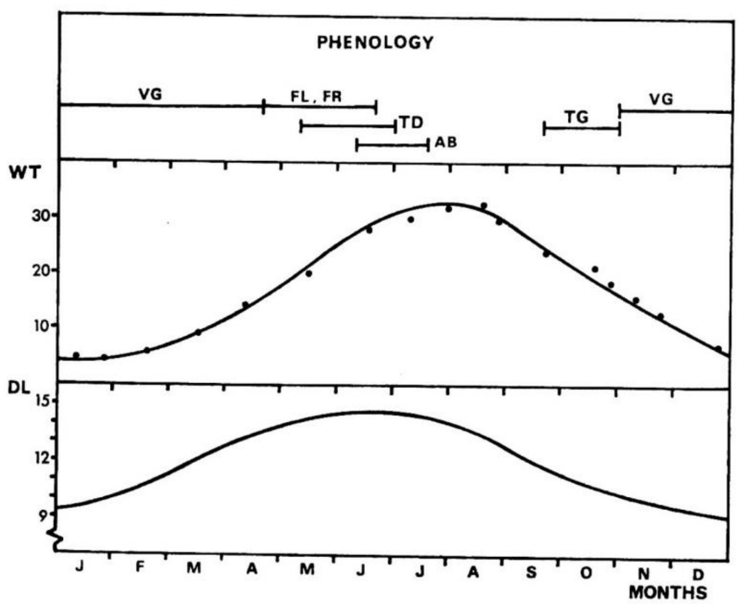

Fig. 9. Phenology of *P. crispus* with emphasis on the formation and germination of turions. The horizontal bars indicate important periods in the development of the plant (upper). The water temperature (WT, °C) curve is derived from the field data (middle) and day length (DL, hrs from 1977–1978) curve is based on the Chiba Prefecture Meteorological Tables. VG, vegetative growth; FL, flowering; FR, fruiting; TD, turion development; AB, turion abscission; TG, turion germination.

(Figure Source: Sastroutomo et al. 1979)

Preferred Environmental Factors for Growth

P. crispus appears to favor environments with high alkalinity and nutrient availability. In fact, because of this, it is often used as an indicator of eutrophication or pollution within waterbodies (Bolduan 1994). It is often found in relatively shallow water (1 to 3 m) when compared to other SAV species such as *Myriophyllum spicatum* (Eurasian watermilfoil) and *Elodea canadensis* (Common waterweed) (Nichols and Shaw 1986). Generally, it is fairly cold water dependent as many of its phenological cues, such as turion sprouting, appear to rely on water temperature (Bolduan 1994). Day length is also an important factor in *P. crispus* turion ecology. It is understood that turion development occurs when day length exceeds 12 hours and sprouting is initiated when day length falls below 12 hours.

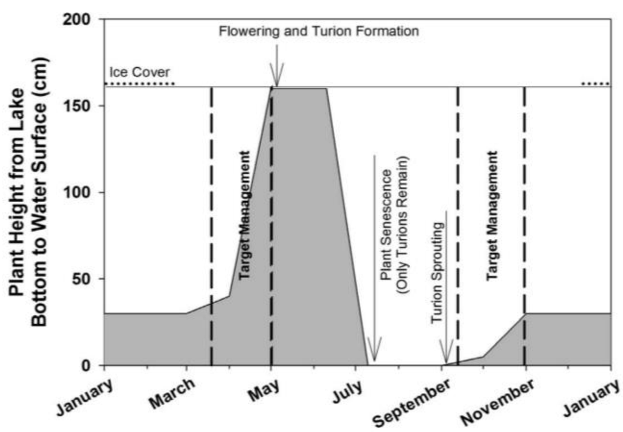

Figure 3. Conceptual diagram based on curlyleaf pondweed phenology for timing management based on seasonal phenology (adapted from Turnage et al. in press).

(Figure source: Wersal and Madsen 2018)

Management Options

Curly leaf pondweed management options include chemical (multiple herbicides) as well as mechanical/physical options such as harvesting, benthic barriers, and drawdowns (Barr and Ditomaso 2014; Catling and Dobson 1985).

II. Species Overview: Eurasian Watermilfoil *(Myriophyllum spicatum)*

Distribution/History

The native range of *Myriophyllum spicatum* (Eurasian watermilfoil, EWM) covers regions in Europe, Asia, and Northern Africa (Smith and Barko 1990). The first record of *M. spicatum* in the United States occurred in the Chesapeake Bay region in 1902 (Nichols 1975). Today, *M. spicatum* has been found in nearly all of the US states and multiple Canadian provinces. *M. spicatum* has aggressive growth habits and has been deemed "detrimental" to the aquatic ecosystems in which it invades (Aiken et al. 1979). In New York, *M. spicatum* has been documented in 54 of 62 counties (Menninger 2011). It has been consistently recorded in Chautauqua Lake since 1972 (Johnson 2019).

Identification

M. spicatum is a submersed aquatic macrophyte that is commonly found in freshwater lakes, ponds, streams, and rivers. Like other watermilfoil species, *M. spicatum* is characterized by its feathery leaves, long, slender stems, and inconspicuous flowers. Proper identification of *M. spicatum* requires close consideration of its leaves, which are arranged in whorls of 3 - 5 around its stem, and have 12 - 21 leaflet pairs. Look-alike species, such as *M. sibiricum* (Northern watermilfoil), usually do not have as many leaflet pairs in comparison to *M. spicatum*. It is also important to note that *M. spicatum* is able hybridize with other watermilfoil species in waterbodies where they co-exist and confirmation of such hybridization is nearly impossible without laboratory analysis (Grafe et al. 2015).

Life Cycle

The life history of *M. spicatum* is fairly equivalent to that of other perennial SAV species. In the Northeast, *M. spicatum* shoots grow rapidly throughout the spring and summer months and tend to die back in the fall leaving only root crowns to persist throughout the winter (Aiken et al. 1979). Regrowth of *M. spicatum* shoots has been observed to be in response to warming water temperatures and often occurs in early spring. Peak biomass production occurs after the flowering periods that occur in mid-June and late summer (Nichols 1975). After peak development, *M. spicatum* often undergoes an autofragmentation period in which stems weaken and release fragments that are able to develop adventitious roots and can continue to grow and reproduce as a separate individual elsewhere within a waterbody (Nichols 1975). This mode of vegetative reproduction is a high contributor to the long-term success of *M. spicatum* populations as portions of stems that are detached via unnatural activities such as boating and mechanical harvesting can continue to survive and reproduce as well. In addition to fragmentation, *M. spicatum* can also reproduce through the production of viable seeds and axillary vegetative buds (Nichols 1975). Axillary buds are usually formed in late winter and early spring (Aiken et al. 1979).

Preferred Environmental Factors for Growth

M. spicatum is tolerant of a wide range of aquatic environments. Some of the major factors that influence the growth of M. spicatum include water clarity, water temperature, carbon availability, water nutrient levels, and sediment texture. Generally, freshwater environments with high light attenuation, warm water temperatures, high nutrient availability, fine, mucky sediments favor the growth of *M. spicatum* (Smith and Barko 1990).

Management Options

Common management techniques for *M. spicatum* include chemical (multiple herbicides) and mechanical/physical options (harvesting, benthic barriers, and drawdowns) (Beets et al. 2019; Laitala et al. 2012; Menninger 2011; Smith and Barko 1990). The milfoil weevil (*Euhrychiopsis lecontei*) has also been released as a biological control agent but results are not consistent across lakes (Havel et al. 2017).

III. Overview of Chautauqua Lake Survey Strategies

Littoral mapping is crucial for risk assessment of plant invaders, quantifying aquatic bionetwork changes, and providing sound considerations for water resource conservation, management, and stewardship. Over the past many decades, managers have honed several protocols for assessing and quantifying submersed aquatic vegetation (SAV). Though many surveying techniques are well-established (Madsen 1999; Schneider et al. 2004; Gunn et al. 2010), *in situ* point-intercept sampling protocols remain the industry standard for describing spatiotemporal trends in macrophyte presence, abundance, distribution, and richness in North America. Combining point-intercept practices with computer-based programs, such as geographic information system (GIS) (eg. ArcGIS; QGIS), has further increased the performance of mapping techniques, from survey design to analysis. Likewise, advances in hydroacoustic technology have further improved traditional boat-based SAV assessments, providing a passive method for recording water depth and plant structure while conducting point-intercept surveys.

However, there are limits with both methodologies, as assessments require a skilled workforce (correct species identification and boating proficiency) and there can be subjectivity among surveyors, which may lower survey accuracy and efficiency. Likewise, these methods require considerable labor and time inputs, as the extent of waterway evaluations are well correlated with the precision, spatial coverage, and time-length spent evaluating each sampling location. However, combining hydroacoustic methods with point-intercept surveys helps alleviate many of the hindrances found between both survey methods using a complementary survey process (Valley et. al 2015).

Point-intercept Methods

This survey technique may be designed in a random or systematic manner, with survey points distributed throughout the known littoral zone for whole-lake assessments (Madsen and Wersal 2017). The sampling device used often employs a double sided hard-tine rake attached to a rope 30’ or greater in length. Using a GPS navigation system and established survey points, a surveyor tosses the sampling device, allows the rake to hit lake-bottom, then retrieves the plant material collected on the rake. Based upon survey demands, a series of quantitative and qualitative in-field recordings may occur. These recordings include SAV species occurrence, percent rake cover, and local plant abundance.

The primary benefit of point intercept surveys includes ease of implementation under most management programs, and with appropriate design, provides a general assessment of plant community dynamics (Madsen and Wersal 2017). While the point-intercept method is industry standard for evaluating lakewide SAV, plant morphology and phenology can result in varying rake estimates per species. Further, a two-sided rake has a finite area to capture plant material; therefore, a maximum threshold exists for plant biomass among dense rake estimates. Likewise, lower growth form species, like Slender Naiad, might not receive a rake composition estimate as high as prolific growing plants like Eurasian Watermilfoil and Coontail, especially among densely populated plant beds.

Hydroacoustic Methods

Over the past 20 years, researchers and lake managers have increasingly incorporated hydroacoustic (echosounding) techniques to support lakewide and localized macrophyte surveys. Hydroacoustic monitoring uses active SONAR scans to measure the physical properties of a water column to evaluate depth and locate submersed objects. Numerous studies have revealed valuable implications for utilizing hydroacoustic technology (Valley and Drake 2005; Howell and Richardson 2019) to estimate submersed plant structure, littoral growth, and quantify management outcomes over time. The increased use of these systems results from improved availability and cost-efficiency of consumer-grade hydroacoustic technology, and cloud-based post-processing convenience.

One advantage of hydroacoustic mapping is the ability to provide a repeatable, non-destructive monitoring opportunity for management applications and ecological growth patterns (Madsen and Wersal 2017; Howell and Richardson 2019). Furthermore, hydroacoustic monitoring can assist in formulating recommendations for herbicide treatments along with evaluation of management tactics. Due to the minimal training requirements, managers can easily train employees to use this system in only a few minutes. However, there are a few limitations involving hydroacoustic survey monitoring, including the inability to accurately assess shallow regions (< 3’ depths) or regions of topped-out vegetation due to boat obstruction.

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