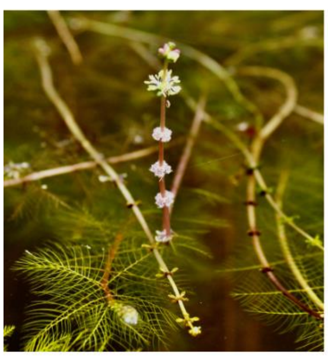
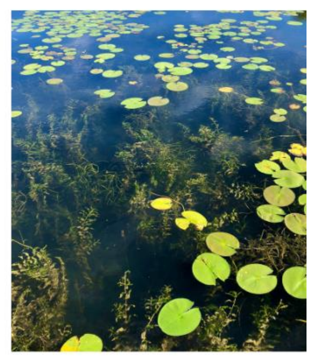
LONG-TERM MANAGEMENT PLAN

FOR SUBMERSED AQUATIC VEGETATION AT CHAUTAUQUA LAKE, NY





2024 - 2028

NC STATE UNIVERSITY

Aquatic Plant Management Program

Long-Term Management Plan for Submersed Aquatic Vegetation at Chautauqua Lake

2024-2028

Prepared By:
North Carolina State University
Aquatic Plant Management Program
Raleigh, NC 27695

Submitted To:
Chautauqua Lake Partnership
Bemus Point, NY 14712

June 2024

NC STATE UNIVERSITY
Aquatic Plant Management Program

Table of Contents

Chautauqua Lake Background

Overview and Historical Perspective

Chautauqua Lake sits in the southwestern corner of the State of New York, approximately 50 miles east of Erie, Pennsylvania and 75 miles south of Buffalo, New York. The Towns of Chautauqua, Ellery, Ellicott, Busti, and North Harmony share shoreline space in addition to the Villages of Lakewood, Bemus Point, Celeron, and Mayville.

Chautauqua Lake history dates to 1679 when European explorers documented "a little lake six or seven miles south of Lake Erie, the mouth of which opens southeastward". By the 1800's, Chautauqua Lake's waters were heavily used to connect trade between the Great Lakes and the Mississippi River. During this time, Chautauqua Lake and the surrounding watershed suffered from overfishing and deforestation, likely due to bountiful lands and lack of regulations.

Tourism began to boom around Chautauqua Lake by the late-1800's. Some of the first lake houses, hotels, and community gathering areas were established during this time. Major attractions included The Chautauqua Institution, a unique center for arts and education, which was founded in 1874. Amenities such as the Bemus Point Ferry and various operating steamboats also served as a destination for tourists while simultaneously supporting further expansion and growth around the lake.

In the more recent past, Chautauqua Lake has continued to serve as a picturesque backdrop supporting a bustling community. The lake provides a multitude of ecosystem services, and therefore, the overall function and sustainability of the ecosystem should be conserved and managed.

Major Ecosystem Services of Chautauqua Lake

Ecosystem services can be defined as the direct and indirect benefits that humans receive from natural processes. These services can be divided into three categories: 1) provisioning, 2) regulating and supporting, and 3) cultural. Chautauqua Lake provides services from all of these groups.

Provisioning

Provisioning environmental services are those that provide direct benefits back to individuals. Chautauqua Lake is classified as a Class A water source in the State of New York. As such, it supplies water for drinking, food preparation, primary and secondary contact recreation, and fishing.

Regulating and Supporting

Regulating and services are those that allow the ecosystems to support themselves through natural processes. At Chautauqua Lake, these include nutrient cycling and sequestration, water filtration, flood and erosion mitigation, and maintenance of habitat for fish and wildlife. These services are often overlooked due to the silent impact that they have within an ecosystem, however, they are powerful and important factors that allow the Chautauqua Lake ecosystem to be sustained for many years to come.

Cultural

Among all of the types of ecosystem services, cultural services may be the most apparent to humans due to the direct impact that we gain from them. Cultural services at Chautauqua Lake include recreational activities such as fishing, boating, sailing, swimming, camping, snowmobiling, wildlife watching. Additionally, tourism is a major cultural service. Chautauqua Lake is a popular destination for tourists and locals alike who are interested in exploring a destination with rich history, unique community and educational opportunities, and beautiful natural areas. Some significant resources to note include the Chautauqua Institution, Long Point State Park, the Chautauqua Belle Steamboat, the National Comedy Center, downtown Bemus Point, and the Lucille Ball Desi Arnaz Museum.

Chautauqua Lake Stakeholders

The value of Chautauqua Lake has not been overlooked by local and state communities. These stakeholders include town and state municipalities, non-profit organizations, local businesses and citizens, among others. These groups have invested in Chautauqua Lake and work towards protecting and conserving the natural resource and include:

- Chautauqua County Department of Planning and Economic Development
- Chautauqua County Soil & Water Conservation District
- Chautauqua Institution
- Chautauqua Lake Association
- Chautauqua Lake Fishing Association
- Chautauqua Lake Partnership
- Chautauqua Lake and Watershed Alliance
- Chautauqua Watershed Conservancy
- New York State Department of Environmental Conservation (NY DEC)
- Towns of Busti, Chautauqua, Ellery, Ellicott, North Harmony
- Villages of Bemus Point, Celeron, Lakewood, Mayville

In 2019, a Memorandum of Understanding was enacted and signed by several of these entities to unify goals and efforts related to Chautauqua Lake's management. The Memorandum of Understanding is "a statement of the intent of all participants to work collaboratively and in good faith to achieve a common goal of an ecologically and economically healthy lake." This statement is place until at least 2024 with hopes of future commitment to collaboration.

Current Inventory of Chautauqua Lake

Physical Conditions

Chautauqua Lake is a naturally-formed freshwater waterbody in Western New York. Covering 13,156 acres with 42.5 total miles of shoreline, this lake is the 10th largest within the State of New York. Chautauqua Lake is situated within Chautauqua County and share shoreline with the Towns of Chautauqua, Ellery, North Harmony, Ellicott, and Busti and the Villages of Mayville, Bemus Point, Celeron, and Lakewood (NYSDEC 2023). In 2022, Chautauqua County's population was estimated to be just over 126,000 people (US Census Bureau 2023). Chautauqua County is a rural area rich in agricultural and natural lands. Generally, the land use around Chautauqua Lake is classified as open or low intensity development, wetlands, or forested space (USGS 2016). There are seven public access points to the Chautauqua Lake. Additionally, seven marinas, five public parks, and several public swim beaches at the lake.

Chautauqua Lake is part of the Ohio River Basin, in which water flows from Western New York, down through the Allegheny and Ohio Rivers before flowing into the Mississippi River, and eventually the Gulf of Mexico. The name 'Chautauqua' is a Native American term that can be translated to "a bag tied in the middle", a phrase that accurately describes the general shape of the lake. Chautauqua Lake is divided into a North and a South Basin, as well as a short "Narrows" section that connects the two. The North Basin has an average depth of 26 feet and maximum depth of 75 feet. Morphologically, the South Basin is much different with an average depth of 12 feet and maximum depth of 26 feet (NYSDEC & The Cadmus Group, 2012). Water levels at Chautauqua Lake can be controlled by the Warner Dam, located at the outlet of the Lake's South Basin.

Water Quality

The New York Department of Environmental Conservation Citizens Statewide Lake Assessment Program (NY DEC CSLAP) has been monitoring Chautauqua Lake surface waters for over 30 nearly consecutive years. The most recent 2022 reports indicate that the trophic state, or overall biological condition, is 'Mesotrophic' (moderate nutrient level) in the North Basin, and "Eutrophic' (high nutrient level) in the South Basin. Despite this difference, both the North and South Basins of Chautauqua Lake have elevated levels of phosphorus in their surface waters that exceed the guidance provided by the State of New York. Additionally, measured total phosphorus levels are displaying a strong significant positive long-term trend within the Chautauqua Lake dataset (NY DEC CSLAP 2022a,b). These trends, along with other water quality parameters, have contributed to Chautauqua Lake's water quality status of "impaired" that have been documented for parts of the Lake in the recent past (NYSDEC 2022).

Elevated phosphorus levels in Chautauqua Lake may be exacerbated through the process of eutrophication. All lake ecosystems experience a natural aging process in which their basins fill with material generated through erosion, atmospheric deposition, or internal processes (NHDES 2019). The timing of this process is different for every unique lake system, and can be influenced by basin structure, watershed characteristics, and other physical and ecological processes. This natural progression can be interrupted and enhanced through additional human interactions to the waterbody. This phenomena is called cultural eutrophication, which can be defined as "the acceleration of the natural process of lake aging and increased fertility by human activities" (Mattison et al. 2003).

According to the 2012 Total Maximum Daily Load (TMDL) for Phosphorus in Chautauqua Lake report, the major sources of phosphorus in Chautauqua Lake are of both natural and anthropogenic causes and differ between the North and South Basins. These contributors include internal loading, groundwater, and point sources such as wastewater treatment plants (NYSDEC & The Cadmus Group, 2012). Other sources include agricultural runoff, urbanization and development runoff, and residential septic systems (NYSDEC & The Cadmus Group, 2012).

Submersed Aquatic Vegetation

Efforts to monitor the aquatic vegetation community at Chautauqua Lake began in 1937. At this time, 34 aquatic plant species were present, including 12 species of native pondweeds (*Potamogeton spp.*). During this effort, curly-leaf pondweed (*Potamogeton crispus*) was recorded. Eurasian watermilfoil (*Myriophyllum spicatum*) was found at Chautauqua Lake over 40 years later in 1982 (Chautauqua Lake Macrophyte Management Strategy, 2016). Over time, a total of 60 species of aquatic plants species have been recorded at Chautauqua Lake since initial investigations took place (Table 1).

Table 1. Compilation of all aquatic plant and algal species recorded at Chautauqua Lake over time. The most recent year that the species were documented in the lake is listed in the 'year' column. Data sourced from reports submitted by North Carolina State University (NCSU 2020 – 2023), SUNY Oneonta (Casey and Lord 2022), Racine-Johnson Aquatic Biologists (Rooney et al. 2021), and Solitude Lake Management (Solitude Lake Management 2017 – 2019).

Submersed

Scientific Name	Common Name	Year
Ceratophyllum demersum	Coontail	2023
Eleocharis baldwinii	Spikerush	2019
Elodea canadensis	Common Waterweed	2023
Elodea nutallii	Western Waterweed	2023
Fontinalis sp.	Water Moss	2023
Heteranthera dubia	Water Stargrass	2023
Lemna trisulca	Ivy-Leaved Duckweed	2023
Megladonta beckii	Water Marigold	1975
Myriophyllum sibericum	Northern Watermilfoil	1937*
Myriophyllum spicatum	Eurasian Watermilfoil	2023
Myriophyllum tenellum	Slender Watermilfoil	1937
Najas flexilis	Slender Naiad	2023
Najas guadalupensis	Southern Naiad	2023
Najas minor	Brittle Naiad	2023
Potamogeton amplifolius	Largeleaf Pondweed	2023
Potamogeton berchtoldii	Berchtold's Pondweed	2018
Potamogeton crispus	Curly-Leaf Pondweed	2023
Potamogeton diversifolius	Water Thread Pondweed	1937
Potamogeton epihydrus	Ribbon-Leaf Pondweed	1937
Potamogeton foliosus	Leafy Pondweed	2023
Potamogeton gramineus	Variable Pondweed	2008
Potamogeton hillii	Hill's Pondweed	2021
Potamogeton illinoensis	Illinois Pondweed	2019
Potamogeton natans	Floating Leaf Pondweed	2019
Potamogeton perfoliatus	Heart Pondweed	2018
Potamogeton praelongus	Whitestem Pondweed	2023
Potamogeton pulcher	Spotted Pondweed	2019
Potamogeton pusillus	Small Pondweed	2023
Potamogeton richardsonii	Clasping-Leaf Pondweed	2023
Potamogeton robbinsii	Robbins Pondweed	2023
Potamogeton spirillus	Spiral-Fruited Pondweed	2018
Potamogeton vaseyi	Vasey's Pondweed	1937
Potamogeton zosteriformis	Flatstem Pondweed	2023
Potamotegon nodosus	Long-Leaf Pondweed	2013
Ranunculus aquatilis	White Water Crowfoot	2020
Ranunculus longirostris	Stiff Water Crowfoot	1937
Ranunculus trichophyllus	Threadleaf Crowfoot	2022
Stuckenia pectinata	Sago Pondweed	2023
Utricularia purppurea	Purple Bladderwort	2018
Utricularia vulgaris	Common Bladderwort	2023
Vallisneria americana	Wild Celery	2023
Zannichellia palustris	Horned Pondweed	2021

* Undocumented reporting of *M. sibericum* by NCSU, Solitude Lake Management, and NYDEC in 2022

Floating-Leaved

Scientific Name	Common Name	Year
Brasenia schreberi	Watershield	2021
Lemna minor	Small Duckweed	2023
Nuphar advena	Yellow Pond Lily	2016
Nuphar varigata	Spatterdock	2023
Nymphaea odorata	White Water Lily	2023
Spirodela polyrhiza	Great Duckweed	2021
Trapa natans	Water Chestnut	2023
Wolffia columbiana	Watermeal	2021

Emergent

Scientific Name	Common Name	Year
Alisma subcordatum	Water Plantain	2023
Justicia americana	Water Willow	2023
Polygonum amphibium	Water Smartweed	2008
Scirpus acutus	Hardstem bulrush	2023

Algae

Scientific Name	Common Name	Year
Chara vulgaris	Chara	2023
Lyngbya sp.	Benthic Filamentous Algae	2023
Nitella flexilis	Nitella	2023
Nitellopsis obtusa	Starry Stonewort	2023
Tolypella sp.	Stonewort	2015
Various Species	Filamentous Algae	2023

Differences in the aquatic vegetation community over time may be attributed to changes in species composition through the introduction of non-native species to the ecosystem. The United States Geological Survey lists 246 non-native species that have been documented within the State of New York (USGS 2023). With this, it is understood that New York supports the fourth-most largest population of nonindigenous aquatic species within the United States, following Texas (297), California (427), and Florida (450) (USGS 2023). Of these species, 57 are classified as aquatic or wetland plants. Of those, 4 are present in Chautauqua Lake: *Myriophyllum spicatum* (Eurasian watermilfoil), *Potamogeton crispus* (curly-leaf pondwed), *Trapa natans* (water chestnut), and *Najas minor* (brittle naiad).

As defined by the New York Prohibited and Regulated Species regulation (6 NYCRR Part 575; July 2014), non-native species are understood to pose a risk to ecosystems in public waters of the State and can cause ecological and economic harm to the environment. Control of these species should be prioritized to reduce risks associated with the local ecosystems in which they invade, as well as the uninvaded waters in which they could be introduced. With this, Chautauqua Lake should continue to be monitored for non-native species that have not yet been introduced to the waterbody but are present in surrounding waterbodies in New York including *Hydrilla verticillata* (hydrilla), *Hydrocharis morsus-ranae* (frogbit), *Nymphoides peltata* (yellow floating heart), and *Cabomba caroliniana* (fanwort).

Today, Chautauqua Lake supports a diverse community of aquatic macrophytes. In 2022, 30 species were documented and included submersed, floating-leaved, emergent, and macroalgal species (NCSU 2022). The establishment and development of vegetation in aquatic ecosystems are highly influenced by both intraspecific (same species) and interspecific (different species) competition and through external environmental factors. Due to this, long-term aquatic plant management plans should consider aquatic plant communities as a whole to ensure that ecosystem balance is maintained. The following species comprise the majority of Chautauqua Lake's submersed aquatic vegetation community.

Eurasian Watermilfoil (*Myriophyllum spicatum*)

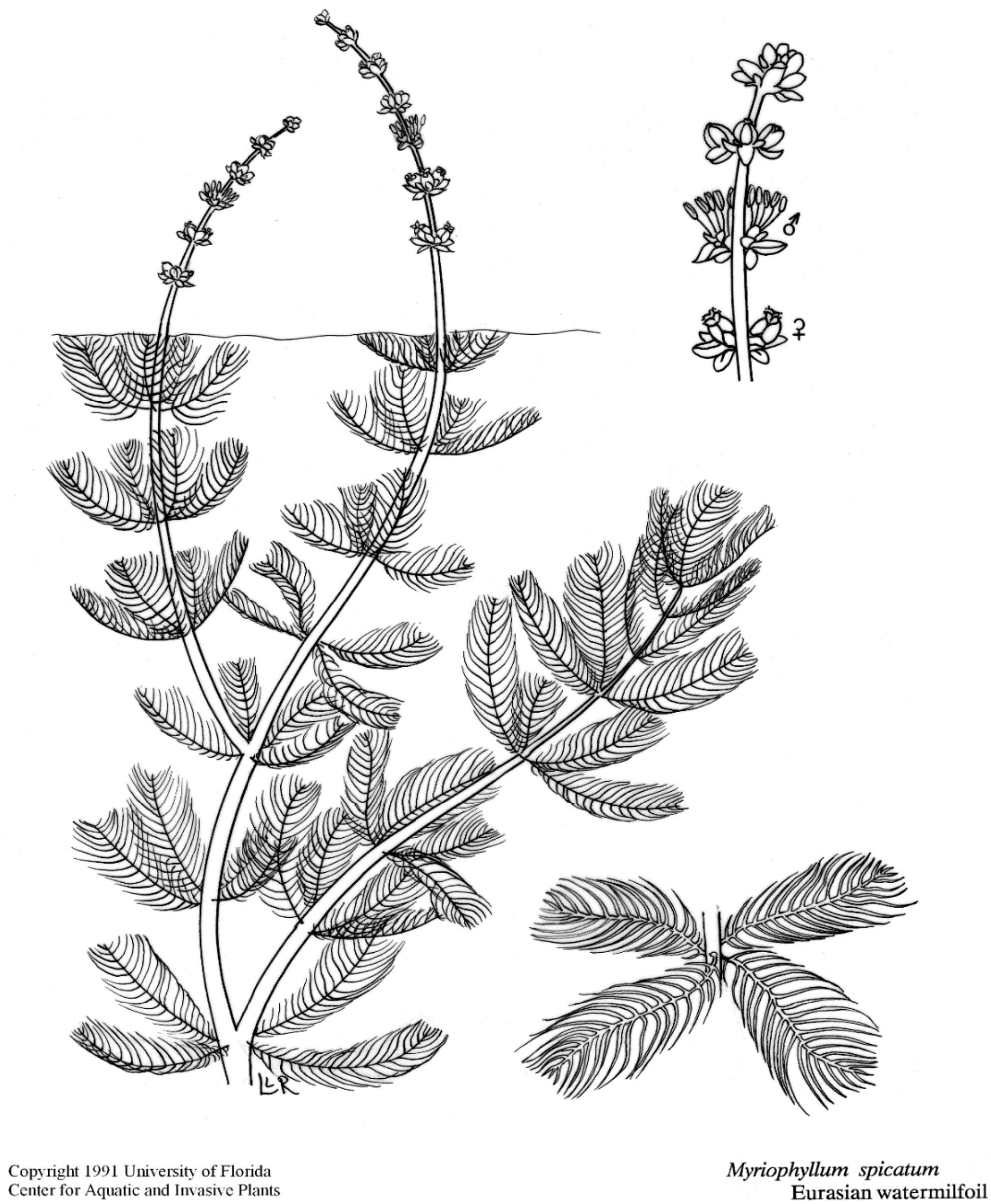


Figure 1. Eurasian Watermilfoil (*Myriophyllum spicatum*) line drawing.
Source: University of Florida Center for Aquatic and Invasive Plants.

Botanical Description

Myriophyllum spicatum has feathery leaves arranged in whorls around a long, flexible stem. Stems can range from green to red in color and can grow up to 4 m long (Grace and Wetzel, 1978). Branching of the stems often occurs at the surface of the water column and can form dense canopy cover, an unusual growth habit when compared to other native aquatic plants (Aiken et al. 1979). The number of leaflet pairs along the dissected leaf is an important factor for proper identification. *M. spicatum* has 13+ pairs while other species in the *Myriophyllum* genus will have fewer (<12) pairs. Flowers of *M. spicatum* are arranged on an emergent spike where staminate (male) flowers appear on the top and pistillate (female) flowers form at the base. *M. spicatum* can reproduce via seeds, fragmentation, and vegetative growth.

Phenology

Sprouting from overwintering root crowns occurs in the spring (late April/Early May), after ice-out and when water temperatures begin to warm. Rapid growth occurs from the time of sprouting to approximately mid-July. Flowering occurs between late July and early August in the Northeast. After flowering, auto-fragmentation occurs in which stems weaken near the tips and eventually break off sections that develop their own root system and can become established as a new plant elsewhere in the waterbody. Fragments of *M. spicatum* stems that are broken due to unnatural causes such as boating and mechanical harvesting can also develop into new plants as well. Senescence of aboveground *M. spicatum* biomass occurs around November.

Ecological Benefits and/or Impacts

Due to the canopy-forming growth habit, *M. spicatum* has the ability to shade out other species of submersed vegetation that occupy lower regions of the water column. Ultimately, this decreases biodiversity in water resources over time. Additionally, it has been determined that *M. spicatum* makes for poor fish habitat due to low structural complexity of stems and leaves (Dibble et al. 1997). *M. spicatum* has been designated as an Aquatic Nuisance Species in the State of New York and is listed as a Prohibited Invasive Species (6 NYCRR Part 575, September 2014).

A 2010 assessment by the New York State Office of Invasive Species Coordination ranks *M. spicatum* as ‘very high’ for invasiveness with a relative max score of 100.0 (New York Invasive Species Council, 2010). This rating is determined through a process of evaluating species ecological and biological characteristics, distribution potential, and management implications*. M. spicatum* received the highest relative max score of all species assessed and is followed by Japanese knotweed (*Fallopia baldschuanica*) (97.94), autumn olive (*Elaeagnus umbellata*) (94.0), common reed grass (*Phragmites australis*) (92.0), and water thyme (*Hydrilla verticillata*) (91.4).

Curly-leaf Pondweed (*Potamogeton crispus*)

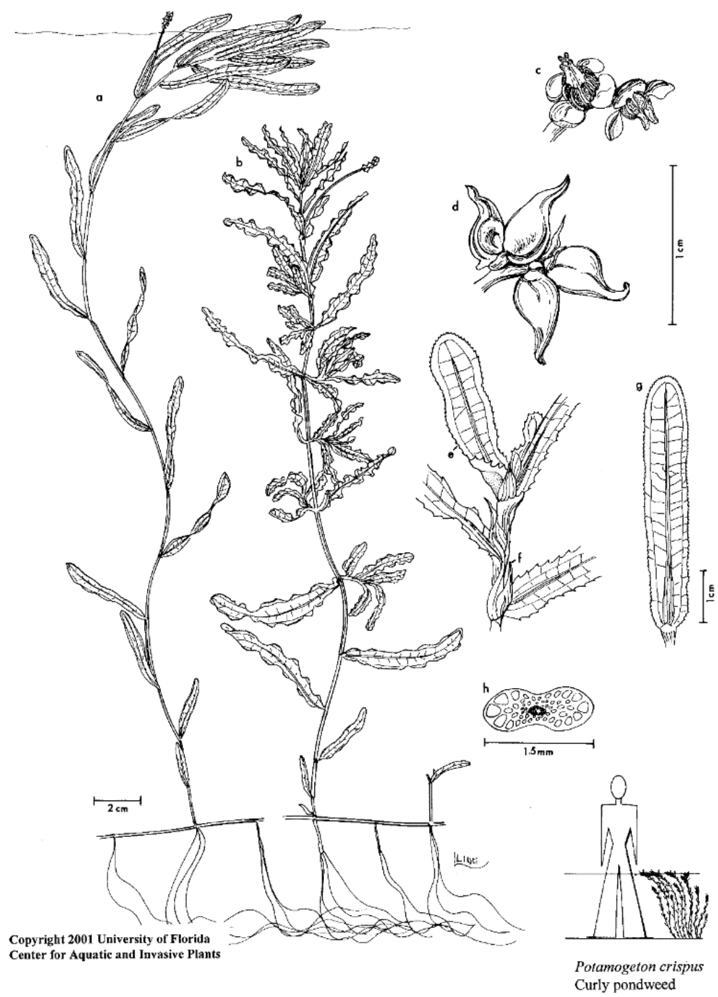


Figure 2. Curly-leaf Pondweed (*Potamogeton crispus*) line drawing.
Source: University of Florida Center for Aquatic and Invasive Plants.

Botanical Description

Potamogeton crispus is a submersed species that is distinguishable from other pondweed species by distinctly wavy or crinkled leaf margins (edges). Leaves are arranged alternately along a long, flexible stem and have a prominent midvein through their center. Stems of *P. crispus* can grow up to 3 m long depending on environmental conditions. Reproduction of *P. crispus* is primarily through the production of turions (winter buds) that are formed in the leaf axils at the apices of stems. *P. crispus* can produce significant rhizomatous growth throughout the growing season.

Phenology/Life Cycle in Chautauqua Lake

The life cycle of *P. crispus* is unique among aquatic plants in the Northeast. Prolific vegetative growth occurs in early to late spring and most biomass senesces in the summer. It is understood that these growth phases depend on water temperature and light availability (Turnage et al., 2018). Peak biomass production usually occurs in mid- to late-spring when water temperatures are between 10 – 15°C and light availability is fairly low. Peak stem elongation rates have been reported to be 4.2 cm day^{-1} $plant^{-1}$ for *P. crispus* (Kunii 1982). Turions are formed (5 – 13 per shoot) and inflorescences emerge during this period. 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 at which they sprout small, narrow leaves. The turions remain in this form throughout the winter while water temperatures remain below 10°C. Some turions may remain dormant for multiple seasons (Wolf 2020).

Ecological Benefits and/or Impacts

P. crispus is a non-native species in New York and has a widespread distribution throughout the state. This species thrives in cool climates and exhibits aggressive growth habits early in the growing season. The timing of peak biomass production often lines up closely with the timing of the beginning stages of biomass production for other native aquatic plant species, thus impacting their establishment and growth potential. *P. crispus* is often documented in shallow, phosphorus-rich lakes where Total Phosphorus levels measure between 50 and 100 µg/L (Heiskary and Valley 2012). It has been observed that the natural summer die-off of *P. crispus* is often followed by algal blooms, which can be attributed to nutrient release from decaying plants along with other factors such as changes in ecological food webs and summer climate characteristics (Heiskary and Valley 2012).

Coontail (*Ceratophyllum demersum*)

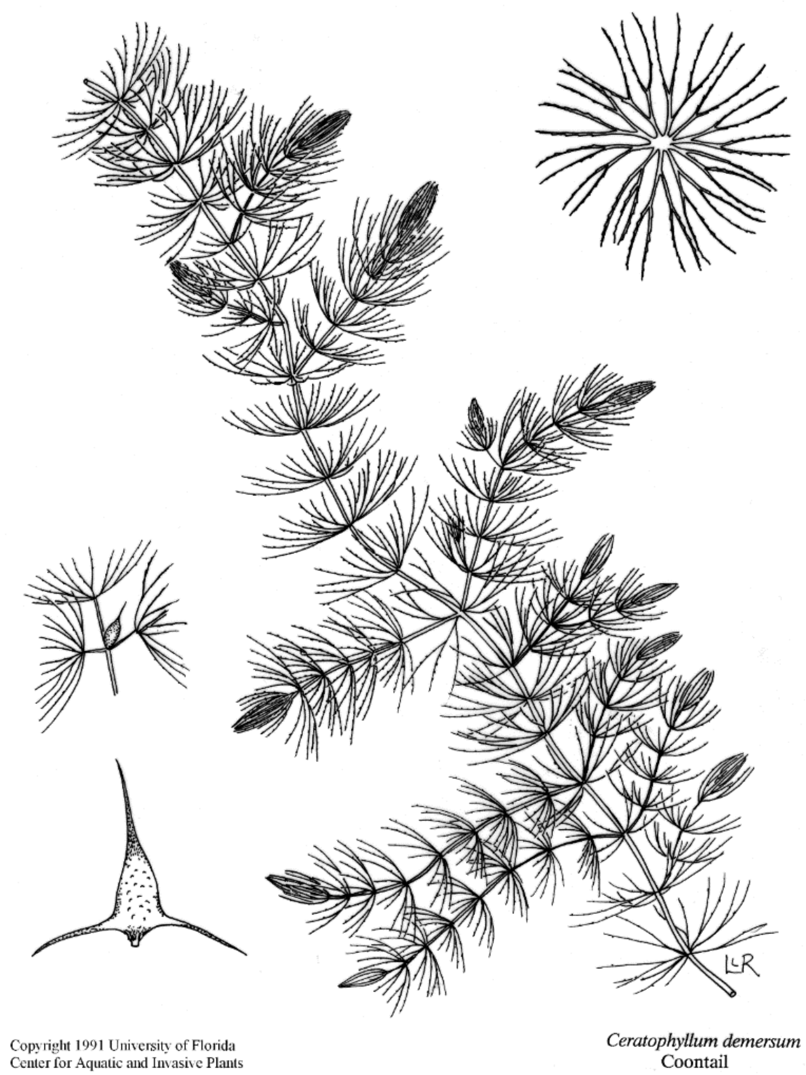


Figure 3. Coontail (*Ceratophyllum demersum*) line drawing.
Source: University of Florida Center for Aquatic and Invasive Plants.

Botanical Description

Ceratophyllum demersum is a free-floating, rootless submersed aquatic plant. Dichotomously dissected leaves are toothed and arranged in whorls around the stem.

Due to the presence of teeth along the leaves, the plant feels rigid and rough to the touch. Leaf whorls are often bunched tightly at the tips and spaced farther apart along the main stem, which can become quite long depending on water depth and other environmental conditions (up to 6 m). Branching is common along the stem, and branches occur at 90 degree angles. Flowers are formed but they are very small and difficult to see with the human eye. Occasionally, achenes (fruit) are produced and dispersed through water currents. The main method of reproduction for *C. demersum* is through fragmentation and winter bud (turion) production.

Phenology/Life Cycle in Chautauqua Lake

The active growth phase for *C. demersum* occurs June – July (Fukuhara et al. 1997). Flowering and achene development occurs July – September. The plants go through an auto-fragmentation stage towards the end of the growing season (September). In late fall, winter turions are formed at the tips of fragmented stems which lay dormant in sediments until waters warm in the spring.

Ecological Benefits and/or Impacts

C. demersum provides suitable fish habitat and has also been documented as an important species for water quality improvement. Yanran et al. (2012) suggest that a 20% coverage of *C. demersum* is optimal to restore water quality of eutrophic lakes. This species can grow to nuisance levels, especially in systems with high nutrient loads. Due to the rootless growth form, *C. demersum* collects nutrients directly from the water column, therefore, sites with high nutrient inputs generally sustain dense populations of this species. High biomass production of *C. demersum* can shade out bottom-dwelling species and form dense monocultures throughout the water column.

Water Stargrass (*Heteranthera dubia*)

Figure 4. Water Stargrass (Heteranthera dubia) line drawing.
Source: Jeanne R. Janish - University of Washington Press

Botanical Description

Heteranthera dubia is characterized by long, robust stems and flat, linear, grass-like leaves. Leaves have parallel veins but lack a distinct midrib. Stems often have creeping roots at the nodes and can grow up into the saturated shoreline sediments via emergent growth. Flowers of *H. dubia* are yellow, solitary, and often hidden within the plant's stem and leaf biomass when growing densely. Flowers have a distinct 6-pointed star-like shape. Seed production is minor, and as such, the primary reproduction method of *H. dubia* is through vegetative means and the production of dormant buds (Hollingsworth 1966). *H. dubia* lacks a prominent mid-rib that can be seen in narrow-leaved pondweed species that otherwise have a similar resemblance.

Phenology/Life Cycle in Chautauqua Lake

H. dubia overwinters via viable stem and root fragments and seeds. Sprouting usually occurs when water temperatures reach 8ºC in the spring. Seasonal growth and development of *H. dubia* appears to be slower than that of other submersed plants, but can become dominant by early fall and shade out low-growing species. Dispersal throughout the growing season can occur via fragmentation of stems. Flowering occurs in July - August and mature seeds overwinter in submersed sediments. Biomass senescence occurs when water temperatures fall below 10ºC (November) (Horn 1981).

Ecological Benefits and/or Impacts

Due to branching and leaf morphology, *H. dubia* provides complex habitat for submersed aquatic organisms. It has been documented as a species with high wildlife value for higher-level aquatic fauna, such as ducks and wading birds (Stuzenbaker 1999). This native species is well-distributed throughout the US and is considered to be an important species for aquatic restoration projects.

Wild Celery (*Vallisneria americana*)

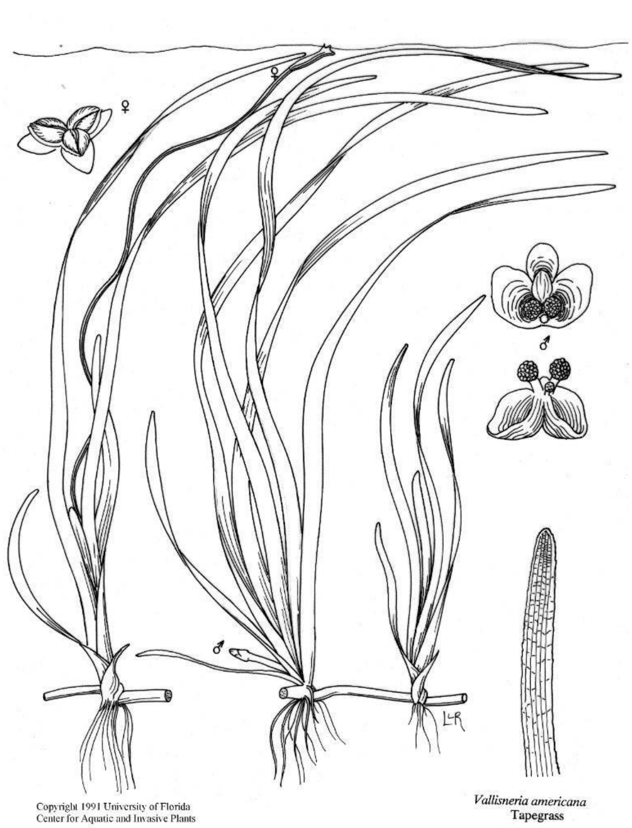


Figure 5. Tapegrass (*Vallisneria americana*) line drawing.
Source: University of Florida Center for Aquatic and Invasive Plants.

Botanical Description

Vallisneria americana is a submersed species with a basal growth form. Leaves are linear or ribbon-like in shape, grow up to 3 m long, are relatively thin, and are often about 2.5 cm wide. The leaves of *V. americana* have parallel venation with 3 – 5 longitudinal veins surrounding a distinct midvein. Leaf tips are rounded. The aboveground biomass of *V. americana* arises from stolons and can quickly colonize an area in water depths up to approximately 5 m. *V. americana* is dioecious, meaning that male and female flowers are produced on separate plants. Flowers arise on either spathes at the base of the plant (male) or at the tip of a long, spiraled stalk (female).

Phenology/Life Cycle in Chautauqua Lake

V. americana begins biomass production in spring when water temperatures reach 10-14°C. Biomass continues to develop throughout the growing season on individual plants, as well as though the production of daughter plants via stoloniferous growth. In the Upper Mississippi River, peak biomass of *V. americana* has been observed in September. Around this same time, *V. americana* begins to develop male and female flowers on separate plants. Male inflorescences can consist of 2,000 individual microscopic flowers (Korschgen and Green 1988). These flowers break out of a spathe and float to the surface of the water column where they disperse. Floating female flowers may intercept these structures, and as such, become pollinated and begin developing fruit. Fruits reach maturity in late summer and release seeds that settle on the lake bottom. Germination characteristics of these seeds is difficult to study, but primary investigations have reported that germination is increased in oxygenated conditions and warm water temperatures (>22°C) (Jarvis and Moore 2008). *V. americana* also produces overwintering buds (turions) that remain dormant through the winter months and germinate in early spring. These turions generally account for more biomass production in successive growing seasons when compared to seeds (Korschgen and Green 1988).

Ecological Benefits and/or Impacts

V. americana has been documented as an important native submersed aquatic plant species in freshwater ecosystems across the United States. So much so, that it has often been propagated and intentionally planted in restoration or revegetation projects across the country. This species is capable of strong shoreline stabilization and erosion mitigation through the formation of dense root structures and creeping stoloniferous vegetative growth. It is also a nutritious food source for aquatic organisms as it is rich in minerals and crude protein (Korschgen and Green 2008). Additionally, *Vallisneria* provides habitat and cover for invertebrates and fish, facilitating diversity in aquatic ecosystems (Korschgen and Green 2008). Exotic and hybrid invasive *Vallisneria* populations have recently been reported in the US (Gorham et al. 2021).

Native Pondweed Species (*Potamogeton sp.*)

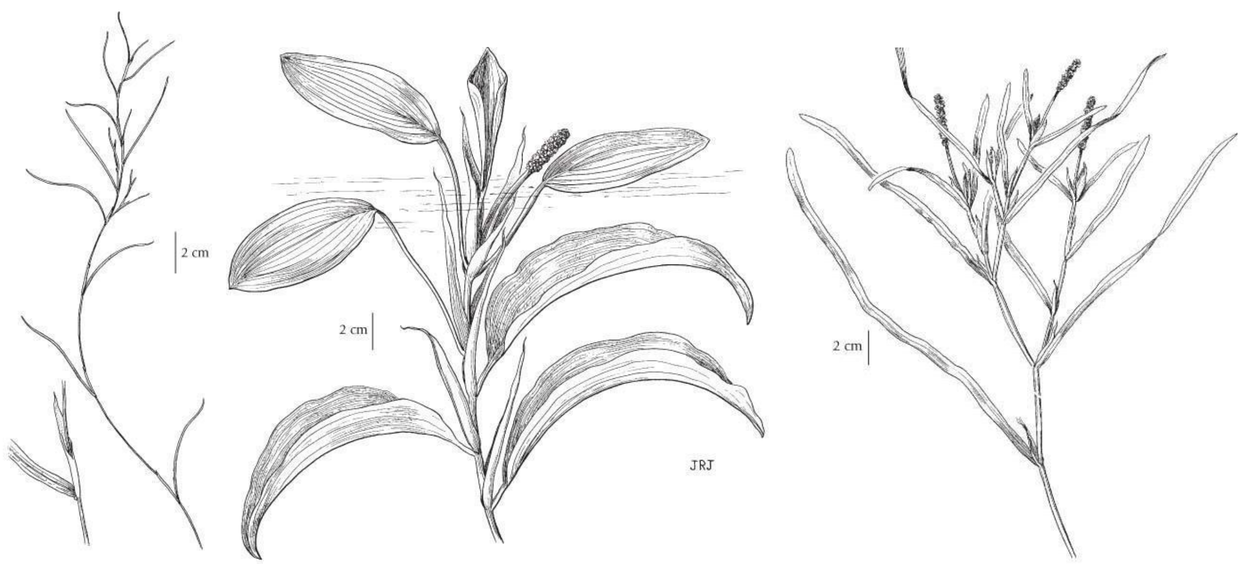


Figure 6. *Potamogeton* species from left to right: *P. pusillus, P. amplifolius, P. zosteriformis*.
Source: Illustrated Flora of British Columbia

Botanical Description

There is a diverse community of native pondweed species present in Chautauqua Lake. These include *Potamogeton praelongus* (white stem pondweed), *P. zosteriformis* (flat stem pondweed), *P. pusillus* (small pondweed), *P. foliosus* (leafy pondweed), *P. robbinsii* (Robbins' pondweed), and *P. amplifolius* (large-leaf pondweed). While there are many morphological differences between these species, they share common features as well. These include alternate leaf arrangement, presence of a stipule, and presence of leaf midveins (Haynes and Holm-Nielsen, 2003; Wiegleb and Kaplan, 1998). Most *Potamogeton* species can grow from rhizomes and turions (winter buds), and several are able to reproduce through seed production (Muenscher 1936).

Phenology/Life Cycle in Chautauqua Lake

Most native *Potamogeton* species in Chautauqua Lake are warm season plants, meaning that the timing of their major growth and reproduction phases occur in the early to late summer months. In a study of Otsego Lake (NY), Harman (1974) noted that peak biomass of *P. richardsonii*, *P. illinoensis, P. zosteriformis*, and *P. pusillus* occurred in July and was greatly reduced by August and September. Note that this is a stark difference when compared to the life cycle of the non-native *Potamogeton cripsus* that also occurs in Chautauqua Lake.

Ecological Benefits and/or Impacts

Native *Potamogeton* are a significant component of the Chautauqua Lake ecosystem. Some species, such as *P. pusillus* and *P. foliosus* are often found growing in the shallow shoreline regions of the Lake and provide important habitat for small biota, serve as a food source for fish and waterfowl, and assist with shoreline stabilization. Other pondweed species, including *P. praelongus, P. zosteriformis, P. robbinsii*, and *P. amplifolius* are often distributed in the deeper portion of the Lake's littoral zone (Harman 1974). Sustaining a high diversity of these species may allow for increased variety of cover for large or mature fish, fostering diversity within those species as well.

Waterweeds (Elodea sp.)

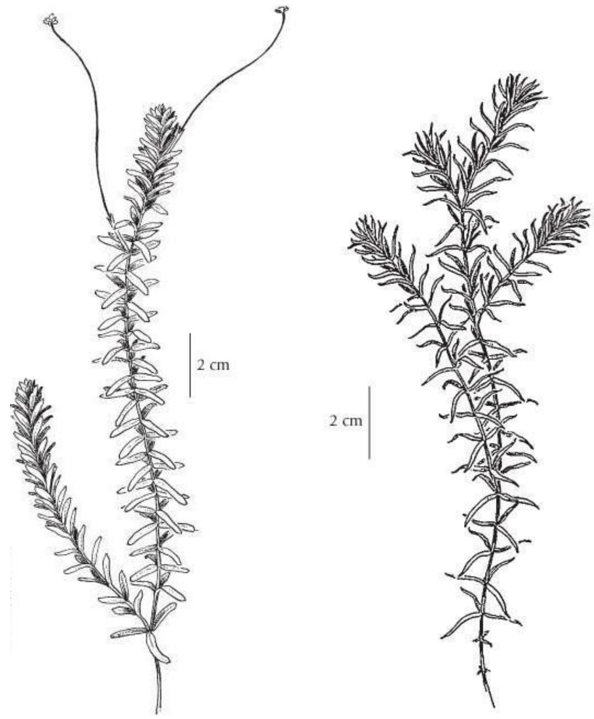


Figure 7. *Elodea Canadensis (left) and Elodea nuttallii (right)*
Source: Illustrated Flora of British Columbia

Botanical Description

Two species of *Elodea* have been documented in Chautauqua Lake: *E. Canadensis* and *E. nuttallii*. These two species are morphologically very similar as they both grow completely submersed in the water column, have leaves arranged in whorls of three along long, flexible stems, and have smooth or slightly serrated leaf edges. The main difference between the two species is the width of their leaves as *E. canadensis* exhibits comparatively wider leaves. As with all aquatic plants, environmental factors can influence features such as leaf width, making the distinction between these two species difficult to an untrained eye. Stems of *E. canadensis* can grow to an average length of 1.2 m or a maximum length of 2.5 m (Wishah and Morningstar, 2023).

Phenology/Life Cycle in Chautauqua Lake

Elodea can overwinter in cool climates through the production of vegetative propagules of condensed shoot tissue. Generally, these propagules remain dormant throughout the winter, although *E. canadensis* has been documented to be able to slowly grow in the presence of ice cover (Bowmer et al. 1995). Spring growth begins when water temperatures reach 10°C and maximum growth has been recorded in 25°C water. Flowers of *Elodea* are wind and/or water-pollinated as pollen is released and floats along the water surface until it makes contact with a floating female flower. However, viable seed production is rare, especially for *E. canadensis*. Generally, *Elodea* species require moderate to high light conditions, and can be outcompeted by canopy-forming species including *M. spicatum*, as documented in Lake George (Boylen et al. 1999), or through the formation of dense algal blooms.

Ecological Benefits and/or Impacts

Elodea species are beneficial in aquatic plant communities as they increase availability of food and habitat for aquatic organisms at low trophic levels, which in turn, feeds life at the top of the food web (Wishah and Morningstar, 2023). Both *E. canadensis* and *E. nuttallii* are widespread native aquatic species in the United States and can be found in a variety of aquatic ecosystems including lakes and ponds as well as rivers and streams.

Naiads (*Najas* sp.)

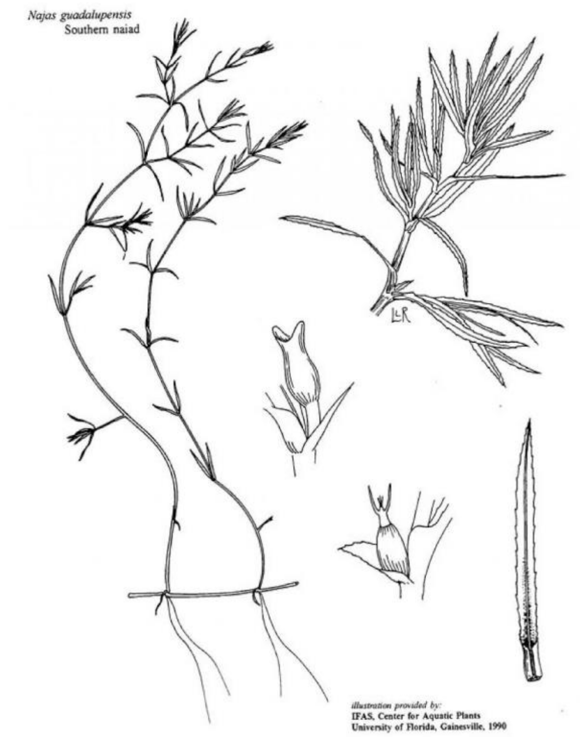


Figure 8. Southern Naiad (*Najas guadalupensis*) line drawing
Source: University of Florida Center for Aquatic Plants

Botanical Description

There are three naiad species documented in Chautauqua Lake. Two are native, *Najas flexilis* and *N. guadalupensis*, and one is non-native, *N. minor*. All three species share common morphological traits including completely submersed stems and leaves, opposite leaf arrangement, and slender leaf shapes. *N. minor* exhibits long, recurved, rigid leaves with obviously serrated edges that keep their shape when held out of water. Alternatively, the leaves of *N. guadalupensis* and *N. flexilis* are flexible and thin with minute serrations along their edges.

Phenology/Life Cycle in Chautauqua Lake

Najas species primarily reproduce and overwinter through seed production in Chautauqua Lake (Les et al. 2015). Seeds are produced in the warm summer months and may remain dormant for up to three years before sprouting. Warming water temperatures trigger sprouting in the spring and biomass production increases throughout the summer months.

Ecological Benefits and/or Impacts

Seeds produced by *Najas* species provide a food source for waterfowl in aquatic ecosystems (Les et al 2015). Seeds can be carried on fragmented plants and dispersed throughout a waterbody. As such, while this dispersal method could be beneficial for native *Najas* species, it also has significant implications for the spread of the non-native *N. minor* within a waterbody. *N. minor*, also commonly referred to as “brittle naiad”, can prolifically fragment due to the rigid, yet fragile, structure of the plant stems and leaves. This strategy should be considered when determining management options.

Macroalgae

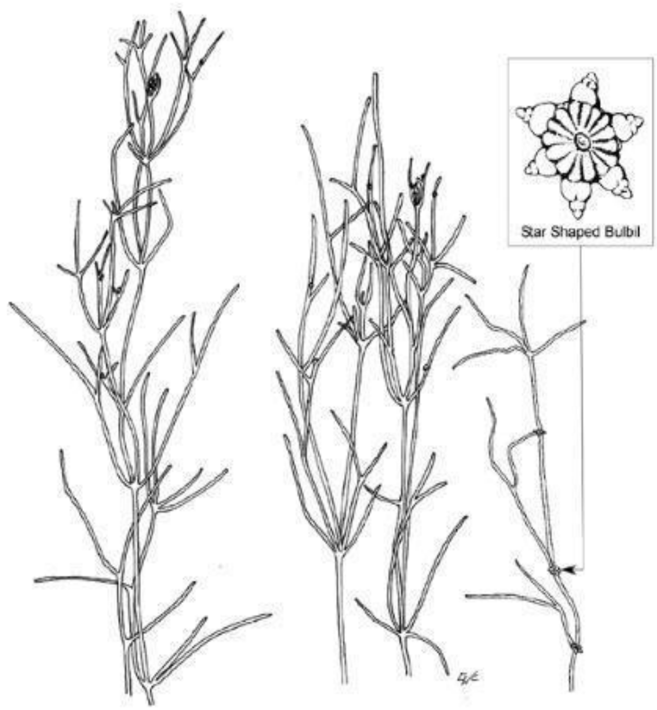


Figure 9. Starry Stonewort (*Nitellopsis obtusa*) line drawing
Source: Pullman and Crawford (2010)

Despite having the overall appearance of a submersed aquatic plant, macroalgae species lack true vascular systems and are therefore a functionally unique group of freshwater organisms. Chautauqua Lake supports multiple species of macroalgae, both native and non-native. Native genera include *Chara spp*. and *Nitella spp.* Native macroalgal species fill a similar role to native submersed aquatic plants, as they can provide food to higher-level organisms. Identification of native macroalgae to a species level often requires use of a microscope to examine minute features of reproductive structures.

Recent monitoring surveys at Chautauqua Lake have documented the non-native *Nitellopsis obtusa* (starry stonewort). *N. obtusa* can be distinguished from native macroalgae by the observation of evenly divided leaf tips and production of star-shaped bulbils. Where it has been studied in the United States*, N. obtusa* can exhibit fast growth rates, prolific reproduction through fragmentation and bulbil formation, and high biomass production. These traits allow this non-native macroalgal species to have a competitive advantage over other submersed species.

Primary Producers

Algae, in both macroscopic (seen with the human eye) and microscopic (best observed under a microscope) are major contributors to Chautauqua Lake's aquatic ecosystem. Like plants, algae are considered to be primary producers, as many species are able to convert sunlight and nutrients into oxygen and usable forms of energy. Despite having relatively simple cellular structures, algae have become highly adapted for growth and survival under a wide range of environmental conditions.

There are several groups, or phyla, of algae that often exist in aquatic ecosystems. Chautauqua Lake supports a diverse community of algae, including several macroalgal species (discussed above) and many planktonic or filamentous microalgal species. The cyanobacteria are a group that are frequently noted in freshwater resource management, as many species within this phylum can produce toxins that are harmful to humans, our pets, and other organisms including fish, birds, and mammals. Additionally, many cyanobacterial species can produce unwanted water taste and odors that disrupt local economies through decrease of recreation and contamination of drinking water supplies. Harmful algal blooms (HABs) occur when colonies of these species grow out of control, most often due to excess nutrient availability in the system, elevated water temperatures, and other disturbances, and as such, accelerate the impacts that cyanobacteria can have on a system.

A Harmful Algal Bloom Action Plan has been developed for Chautauqua Lake by the New York State Department of Environmental Conservation (NYDEC). Chautauqua Lake has been listed as a priority lake impacted by HABs in the State of New York and is annually monitored by the State to confirm the presence of harmful algae. This monitoring program has confirmed that some of the HABs that have occurred at the lake have contained high levels of toxins and their presence has led to several public beach closures since its initiation. Species composition of HABs at Chautauqua Lake generally consists of the cyanobaceteria *Gleotrichia* in early and mid-summer and shifts to *Microcystis* and *Aphanizomenon* towards the end of the growing season (Brown 2022). NYDEC staff have confirmed that algal blooms have been a common occurrence at Chautauqua Lake for many years. Between 2019 and 2022, NYDEC has documented blooms generally occur between July and October and have been reported as many as 92 times in a single season (Figures 10 & 11). The Action Plan cites priority actions that should be addressed within the Chautauqua Lake Watershed, including the implementation of source nutrient management practices, increased monitoring and sampling efforts, and investigating nutrient mitigation strategies (NYSDEC 2018).

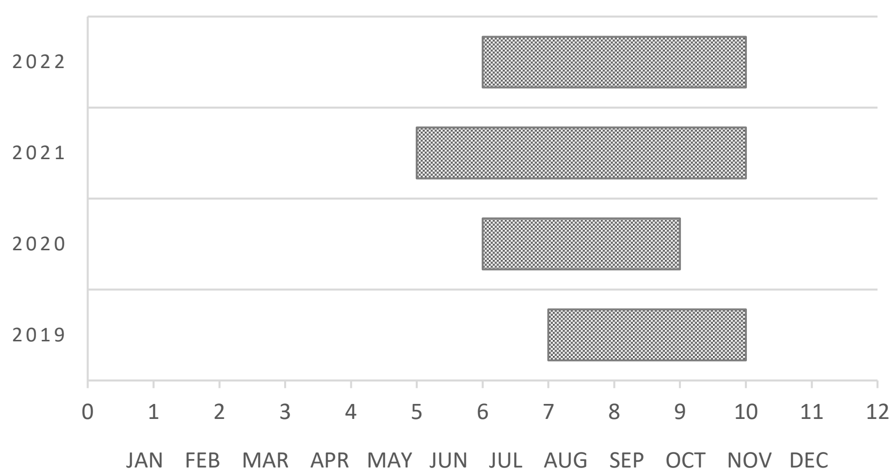


Figure 10. Annual HAB occurrence at Chautauqua Lake based off of the first and last month in which HABs were reported by NYDEC from 2019 – 2022. Data accessed from the NY Open Data Portal and was provided by NYS Department of Environmental Conservation.

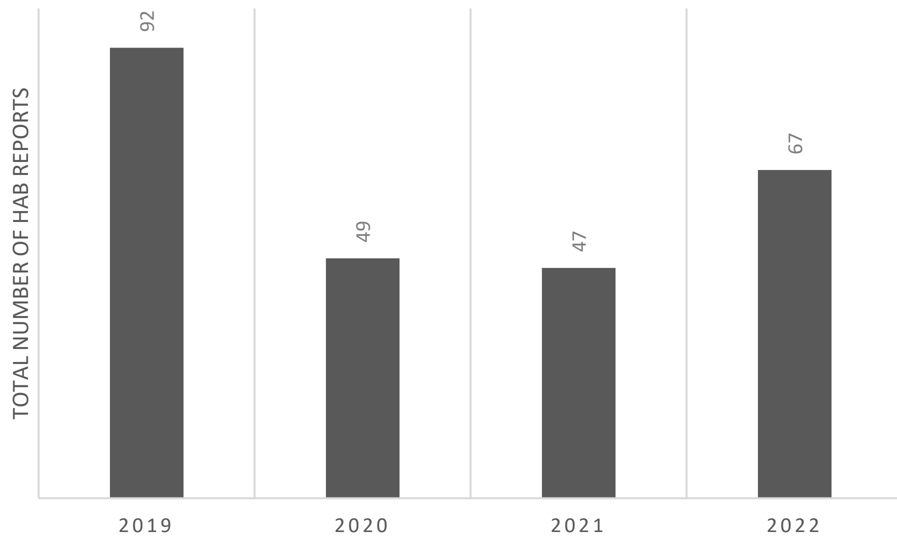


Figure 11. Total number of reported HABs by NYDEC at Chautauqua Lake from 2019 – 2022. Data accessed from the NY Open Data Portal and was provided by NYS Department of Environmental Conservation.

Primary Consumers

In a freshwater ecosystem, primary consumers are those organisms that are classified as herbivorous and feed on the primary producers (plants and algae) within a system. Due to this position in the food web, primary consumers are essentially able to control energy and nutrient availability at a foundational level. In lakes, most primary consumers are various species of zooplankton, microscopic animal-like organisms.

Larger macroinvertebrates can also be classified as primary consumers, as these organisms directly interact with primary production through shredding, collecting, and grazing on plant material. These organisms include the aquatic life forms of nymphs, midges, weevils, beetles, thrips, and moths. A strong community of primary consumers can have a strong influence on water quality and nutrient availability at higher trophic levels, as well as the distribution and extent of plants and algae in the trophic level beneath them.

The primary consumer population in Chautauqua Lake has been strategically monitored through periodic reviews over the past 22 years. A recent monitoring effort quantified the presence of invertebrate herbivores of Eurasian watermilfoil at 15 long-term sample sites at Chautauqua Lake. It was determined that the two main species of interest, *Euhrychiopsis lecontei* and *Acentria ephemerella*, a weevil and moth, respectively, have declined in presence and abundance over time (Rooney et al., 2023). Other invertebrate herbivore species that have been documented in the lake include *Cricotopus myriophylli* (midge), *Mectopsyche albida* (Walker) (caddis), and *Setodes grandis* (cadis) (Rooney et al., 2023).

Fishery

Chautauqua Lake supports a robust and diverse fishery. Major fish species within the community include Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Muskellunge (*Esox masquinongy*), Walleye (*Sander vitreus*), Perch (*Perca sp.*), Crappie (*Pomoxis sp.*), Bullhead (*Ameiurus sp.*), Pumpkinseed (*Lepomis gibbosus*), and Bluegill (*Lepomis macrochirus*), among others (Table 2). Most of these species are sustained through natural reproduction, however, an annual fall stocking of muskellunge fingerlings has been conducted by NY DEC since 2011 (NY DEC 2023). The stocked muskellunge are primarily sourced from eggs field-collected from Chautauqua Lake's established muskellunge population and reared at the NYSDEC Chautauqua Fish Hatchery located near the Village of Mayville.

In 2014, NY DEC Fisheries Biologists conducted a series of surveys to monitor the fish population in the lake. Through this effort, it was revealed that 22% of collected muskellunge likely were naturally produced in the lake. This number may be overestimated due to additional unmarked stocking events. Further, electrofishing monitoring found that pumpkinseed, yellow perch, brown bullhead, and largemouth bass were the most abundant species at the time of the survey. Catch rates and fish morphological features did not differ between North and South Basin sampling largemouth bass, smallmouth bass, and walleye (Legard 2015).

Table 2. Chautauqua Lake Fish Spawning Characteristics (according to Lane et. al. 1996). Species listed in Red rely on vegetative cover.

Species	Depth (m)	Cover	Substrate	Temperature (°C)	Type
Largemouth Bass	0 - 2	Vegetation	Sand, Silt, Clay	14 - 21	Nest
Smallmouth Bass	0 - 2	Boulders, Docks, Logs	Rubble, Gravel	13 - 24	Nest
Muskellunge	0 - 2	Vegetation, Stumps, Logs	Silt, Clay	8 - 18	Broadcast
Walleye	0 - 5+		Bedrock, Cobble, Gravel, Hard-pan Clay	4 - 12	Broadcast
Yellow Perch	0 - 5+	Rocks, Brush, Debris	Gravel, Sand	7 - 22	Broadcast
Pumpkinseed	0 - 2	Vegetation	Gravel, Sand	13 - 29	Nest
Bluegill	0 - 5	Vegetation	Gravel, Sand	19 - 27	Nest
Black Crappie	0 - 5	Vegetation, Stumps, Rocks	Gravel, Sand, Silt	16 - 26	Nest
White Crappie	0 - 5	Banks, Brush, Stumps	Clay, Hard-pan Clay	14 - 23	Nest
White Perch	0 - 5	Any	Any	11 - 15	Broadcast
White Bass	0 - 5+		Rock, Boulder, Cobble, Rubble, Gravel	13 - 26	Broadcast
Brown Bullhead	0 - 2	Logs, Tree Roots, Boards, Debris	Sand, Silt, Clay	14 - 29	Nest
Yellow Bullhead	0 - 2	Logs, Tree Roots, Boards, Debris, Vegetation	Sand, Silt	n/a	Nest
White Sucker	0 - 2		Gravel	6 - 23	Broadcast
Common Carp	0 - 2	Vegetation	Silt	17 - 28	Broadcast
Rock Bass	0 - 2	Under Rocks, Logs	Cobble, Rubble, Gravel	14 - 24	Nest
Longnose Gar	0 - 1	Vegetation, Cladophora (Algae)	Sand, Silt	19 - 29	Broadcast
Golden Shiner	0 - 2	Vegetation, Organic Debris, Filamentous Algae	Sand, Silt	20 - 27	Broadcast

An Annual Fall Walleye Survey conducted by the New York State Department of Conservation Bureau of Fisheries has documented the walleye population at Chautauqua Lake for nearly 20 years. A 2019 report has indicated that the walleye population is now strong and self-sustaining at Chautauqua Lake after efforts to revitalize the fishery were conducted in 2012 (NY DEC Bureau of Fisheries Technical Brief TB919108, 2019).

Rare, Threatened or Endangered Species

With any management plan, consideration of rare, threatened, or endangered species is crucial for determining sensitive environmental areas. Previous reviews of the Chautauqua Lake ecosystem by the New York Natural Heritage Program have documented seven species of concern within the ecosystem from 1980 - Present (Table 3; New York Natural Heritage Program 2024).

Table 3. Species of concern at Chautauqua Lake

Category	Scientific Name	Common Name
Reptiles	*Apalone spinifera*	Spiny Softshell Turtle
Birds	*Haliaeetus leucocephalus*	Bald Eagle
	Gavia immer	Common Loon
Freshwater Mussels	*Actinonaias ligamentina*	Mucket
	Utterbackia imbecillis	Paper Pondshell
	Ligumia nasuta	Eastern Pondmussel
	Ptychobranchus fasciolaris	Kidneyshell

Review of Management Tools and Methods

Comprehensive management plans for freshwater systems usually integrate a variety of tools and methods. This often allows for implementation of both short and long term strategies and also ensures that management success can be achieved through multiple perspectives and forms of effort. Many management tools can build and reinforce one another such that synergistic relationships can be formed and allow for sustainability through future years. For example, in North Carolina reservoirs, a common management practice for *Hydrilla verticillata*, a Federal Noxious Aquatic Weed, is to incorporate use of both biological and chemical control options. Aquatic herbicide applications provide relatively fast, seasonal control of *Hydrilla* biomass and the biological control option (triploid grass carp) maintains control over the span of multiple years. This is an example of Integrated Pest Management (IPM) and is a commonly used approach by managers of both aquatic and terrestrial systems in the United States. IPM must also use management techniques that are appropriate and effective for the system being managed.

IPM strategies combine the use of cultural, mechanical, biological, and chemical tools. In aquatic systems, the implementation of these strategies are often closely connected to broader ecosystem processes. Therefore, the timing and scale to which each is applied is an important factor in management plan design.

Physical/Cultural

Generally, cultural control methods are those that alter the environment in such a way that can prevent the growth of aquatic plants. All aquatic plants generally require water, light, and nutrients to survive. Therefore, alterations of water quality, light availability, water level, or accessibility of nutrients can influence the growth and reproductive success of many aquatic plant species. These methods are generally not selective for management of specific species and require careful planning to ensure that off-target impacts are minimized.

Additionally, cultural control methods can include education and public awareness initiatives. With an increased understanding of aquatic plant ecology, a local community can have an impact on the preventing the introduction and spread of invasive species.

Nutrient and Watershed Management

The watershed that surrounds a waterbody has a major influence on water quality and nutrient enrichment to aquatic ecosystems. Limiting nutrient runoff within the watershed will ultimately reduce phosphorus and nitrogen availability that aquatic plants use for growth and reproduction. Nutrient release from the following sources within a watershed should be monitored and strategies should be implemented to keep them on-site:

- Agricultural runoff
- Lawn fertilizer
- Yard Waste
- Animal Waste
- Septic Waste
- Soil Erosion

Additional nutrient mitigation efforts could include application of phosphorus-sequestering products or planted buffer zones.

Benthic Barriers

Installation of benthic barriers can help reduce aquatic plant growth by providing a physical barrier and blocking light from reaching the sediment surface. Benthic barriers are essentially large, sinkable plastic or organic fabrics that cover large areas to prevent plant growth. These are non-selective and will impact any plants or non-plant organisms that are covered by the barrier. Once installed, benthic barriers can provide season-long control of aquatic plants. However, this technique requires maintenance to ensure that debris build-up does not occur on top of the installed barrier and that barriers do not dislodge. This option is often preferred when managing a small, localized infestation but generally not preferred for large, widespread plant control. Benthic barrier material and installation costs can be expensive – up to $50,000/acre.

Education

Increasing educational outreach and public awareness for invasive species prevention and management techniques can help with prevention of invasive species introductions and movement across waterbodies. Boat launch stewards, boat inspections, informational signage, social media posts, or newsletter articles can all be effective at spreading the message of the importance of aquatic plant management and other lake stewardship efforts.

Mechanical

Mechanical control methods include those that involve machinery and other physical means of direct weed removal. These options are often included in weed management plans at the beginning or intermediate phases of control efforts as they can be effective at removing dense plant growth and stabilizing water quality through the physical removal of nutrient-rich biomass.

Harvesting

Harvesting is a widely-utilized tool for aquatic plant management. Equipment for mechanical harvesting techniques can vary in size and design, but all have similar mechanisms for submersed aquatic plant removal. Generally, aquatic vegetation cutter boats are equipped with a sharp cutting device, such as a sickle-bar or shredder, and paddle wheels which allow for movement overtop dense aquatic plant canopies. As these vessels move over vegetation in, or on top of, the water column, they cut their stems at approximately 5 feet below the water's surface and in swaths of over 10 feet wide. Cut biomass is then brought into the vessel through a conveyor belt system and stored until it can be unloaded onto transport barges or brought to a shoreline disposal zone.

Hydro-raking is another form of mechanical harvesting that can be deployed for aquatic vegetation management in lake systems. Mechanical raking vessels are fitted with a hydraulic arm with a rake attachment that is able to physically pick up and carry organic matter out of a lake with a directed purpose. The design of hydro-rakes allow them to reach biomass in deeper water depths (up to 10 feet) than most harvesting vessels

(Solitude Lake Management 2023). However, unlike harvesting vessels, hydro-rakes are not able to store their collected biomass. Instead, the material can be transported to a shoreline disposal zone and removed entirely from the system.

Mobitrac™ units are a relatively new option for mechanical aquatic plant management. These are small, amphibious vehicles that can be equipped with several attachment options and accomplish a variety of tasks within a waterbody including aquatic plant cutting and collecting, as well as excavating and dredging (Mobitrac USA, 2023). Due to their small size, these vessels can be useful for shoreline management areas where larger mechanical management options may be limited by access. The design and small size of these rake harvesters may make them more effective for invasive plant removal, but less efficient on scale. Rake harvesters may be used to the sediment, which is typically not an operational method for cutter harvesters.

Two negative attributes of mechanical harvesting are fragmentation and bycatch. Due to the nature of mechanical techniques, some level of fragmentation is unavoidable. Risk of spread of submersed invasive macrophytes by fragmentation should be considered and containment used where possible. Due to the life cycle of curly leaf pondweed, it should not be fragmented near the time of senescence (approximately June) as every plant fragment will have biological cues to produce turions.

Bycatch can be a significant issue with mechanical harvesting and likely varies with harvesting technique. Haller et al. 1980 stated "*Three block-net samples in dense hydrilla indicated fish standing crops (mean ± SD) of 205,000 ± 35,000 fish/hectare and 460 ± 30 kg/hectare. The estimated loss of fish to mechanical harvesting represented 32% of fish numbers and 18% of fish biomass. Fish most susceptible to mechanical removal with hydrilla were juvenile sportfish and smaller species. The monetary replacement value of the fish lost was estimated at over $6,000/hectare.*" Serafe et al. 1994 reported short term decreases in fish density and biomass with later recovery after hydrilla harvesting in the Potomac River, Maryland. Engel (1990) found 3 million macrointervebrates removed per harvest in Wisconsin. As well as a loss of about 25% of fish fry per year with greater losses from July harvest than June.

Hand Removal & Diver Assisted Suction Harvesting

Hand removal of problematic aquatic plants can be a good selective option for management efforts in appropriate situations. Due to the intensive effort that hand removal requires, this is another option that is best suited for small, localized management of specific aquatic weeds but can slightly scaled up on an operational level when suitably equipped. Diver Assisted Suction Harvesting (DASH) can be a form of the hand pulling technique. In this method, SCUBA equipment is utilized to allow divers to work underwater for extended periods of time and long suction hoses are used to deliver hand-pulled submersed weeds into a vessel where they are collected for disposal. This technology allows for high species selectivity and can be implemented over multiple acres of growth per day.

Dredging

The physical removal of submersed sediments and associated aquatic plant biomass is called dredging. During a dredging project, sediment is relocated from the lake bottom to a shoreline or transport vessel and moved out of a system. Due to the nature of this type of work, dredging has non-selective impact and can have long-term implications on aquatic ecosystems, such as the composition of benthic organisms. This method is often used for navigation or flood control purposes as it can directly alter the bathymetric design of a waterbody. Dredging has multiple indirect impacts on aquatic plant growth as it may decrease sediment nutrient availability as well as increase water depth, thus decreasing space availability in a waterbody's littoral zone. It is crucial that planning and monitoring efforts accompany dredging activities due to the potential water quality and larger ecosystem issues that could arise from this activity. Dredge spoil must also be disposed of properly. Significant sediment deposits may be present with Chautauqua Lake and dredging could be potentially used to remediate those deposits. A separate plan should evaluate sedimentation and potential benefits if desired.

Biological

Native aquatic vegetation is naturally managed through biological processes in freshwater ecosystems. Due to their position at the bottom of the food chain, aquatic plants serve the primary producers and are depended upon by primary consumers that are unable to make their own energy to survive. Primary consumers in lake ecosystems can include snails, insects, turtles, fish, and birds, among others. Non-native aquatic plant species are unknown to these consumers and are often a lesser-preferred option for food. This means non-native species frequently have no natural suppression of growth, which ultimately gives them a competitive advantage over native plant species.

Biological control agents are organisms that have the ability to inhibit or restrict the growth and/or reproduction of a target species of interest. These biological control organisms often are sourced from the native range of the target species and have evolved alongside of each other in order to achieve natural suppression. In aquatic plant management, biological control agents often consist of fish (triploid grass carp) and herbivorous insects (weevils, midges, beetles, moths, etc.). Triploid grass carp have been used extensively for hydrilla control in reservoirs, however, grass carp are not compatible with desirable submersed plant communities. The process of discovering and studying potential biological control agents is extensive and time-consuming. It is important that these organisms are host-specific and are able to tolerate the environmental conditions in the region in which they are introduced to.

Milfoil Invertebrate Herbivores

Eurasian watermilfoil has a few invertebrate herbivore species that feed on stems and flowers of the submersed plant, which in turn, slows or stops growth and reproduction. One species in particular, *Euhrychiopsis lecontei* (milfoil weevil), has been relatively well studied as a biocontrol agent in the United States. This weevil selectively feeds only on milfoil species. The larval stage impacts growing milfoil stems by mining directly into their tissue. This reduces milfoil's ability to maintain a fast relative growth rate and development of reproductive structures. Weevil density is an important factor in their ability to significantly reduce milfoil biomass. Havel et al. (2017) reported that sustained populations of at least 1 weevil per EWM stem may be necessary for adequate results, but Jester et al. (2000) reported that augmenting populations to 4 weevils per stem “may cause a decline” in lake EWM populations. Newman and Inglis (2009) reported 300 weevils per square meter provided control in mesocoms.

Mechanical harvesting of submersed aquatic plants has been found to negatively impact weevil density because the removal of milfoil meristems directly disrupts weevil ecology. Other causes for declines in milfoil weevil densities include predation by fish and overall reduction of milfoil through other control methods. Milfoil weevils complete their life cycle relatively quickly, but require warm water temperatures (20-25°C) to do so. In general, invertebrate herbivores will not completely eradicate a pest plant population over time and require sustained long-term milfoil biomass in order to maintain their population levels (Figure 12). Reports of field efficacy from the milfoil weevil are mixed with a typical result of some suppression of milfoil, but not control.

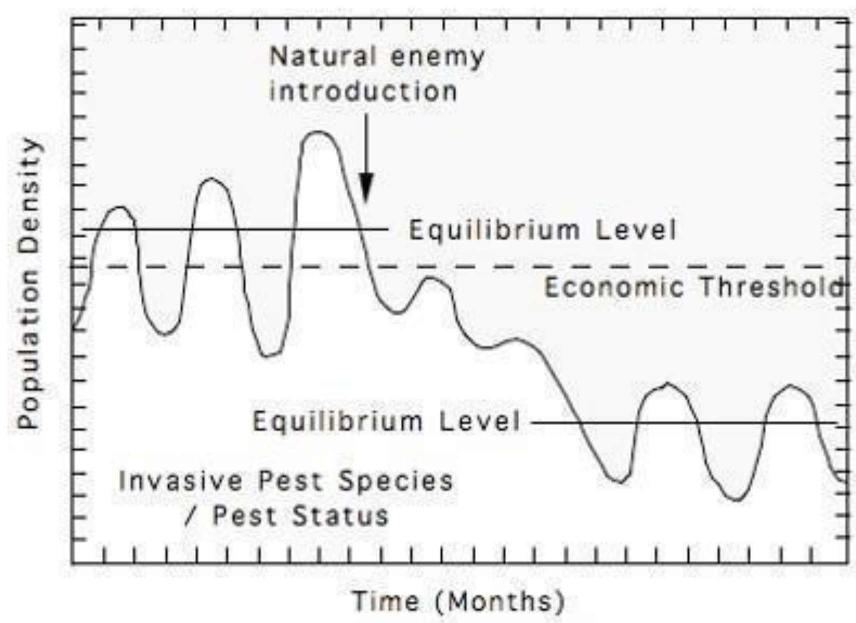


Figure 12. Theoretical overview of biocontrol dynamics in relation to pest populations over time. *Source*: University of California Division of Agriculture and Natural Resources

Chemical

Aquatic herbicides can be a valuable tool in an integrated aquatic plant management plan. Each aquatic herbicides must be registered through the United States Environmental Protection Agency (EPA) as well as NYDEC with registrants generating the necessary data for aquatic use approval. During this process, the EPA evaluates chemical characteristics of the herbicides such as their toxicology, longevity, and potential off-target impacts. As explained by Madsen (2000), after thorough screenings, the EPA rejects any product that may have a one in a million chance of causing significant damage to humans or the environment. As of 2023, there are 16 active ingredients that have been EPA-approved for use in aquatic systems. This is a small fraction of all of the active ingredients that have been approved for use in other systems in the United States.

Registered products must have a detailed label that outlines instructions for legal use practices and application methods. Once accepted by the EPA, individual States, including New York, often have additional requirements for product registration and regulate their use through permitting.

Like all pesticides, aquatic herbicides can be classified by their mechanism of action, or the pathway in which they impact plant function and control susceptible species. These pathways target specific aspects of plant growth at a tissue or cellular level and inhibit vital processes such as enzyme formation, photosynthesis, and growth regulation. Herbicides can further be categorized as either ‘contact’ or ‘systemic’. This refers to their mobility within a plant after application. Contact herbicides impact plant tissue that has directly come into contact with herbicide solution. Contact herbicide symptomology on plants may be observed within hours to days post-treatment. Systemic herbicides are absorbed through plant tissues and are translocated within the plant. Symptomology from ‘systemic’ herbicides is generally slower as it takes time for the product to translocate through plant biomass and rapid action prohibits translocation.

Aquatic herbicide selection requires careful consideration of physical, chemical, and ecological site conditions. These conditions should be matched with characteristics of active ingredients and to ensure that all product label restrictions are followed. Below, we discuss details of the most frequently used aquatic herbicide active ingredients in New York State (NYSDEC 2005). It should be noted that most aquatic herbicides are labeled as “restricted use” in the State of New York and have special local need labels. These labels should be consulted for specific site requirements and regulations for their use in New York.

2,4-D

Many forms of 2,4-D are used in terrestrial systems, while only 2 are approved for aquatic use. These include the butoxyethanol ester and the dimethlamine salts. Formulations of 2,4-D include liquids, emulsifiable concentrates, soluble concentrates, and granules. 2,4-D is a systemic herbicide with some selectivity in aquatic settings. This herbicide targets aquatic weed growth through growth regulation. The half-life of 2,4-D in aquatic systems has been measured to last from 10 – 50 days and depends on microbial activity, hydrolysis, and photolysis processes (MA Department of Agricultural Resources, 2017A).

Copper products

There are various copper algaecides and herbicides available for aquatic use. These may include copper sulfate or formulated copper products containing actives such as chelated copper. The coppers are generally active on algae and may control certain plants such as hydrilla. Copper has rapid, contact activity on algae and sensitive plants with symptomology visible within 24 hours. When applied as a pesticide, “copper rapidly partitions to suspended algae and particulates and the majority (>90%) of applied copper is transferred to sediments within 2 days” (Willis and Bishop 2016). Copper sulfate is typically the most inexpensive form of copper, but may be more toxic to non-target organisms and slightly less efficacious on target algae or plants. For this reason, only formulated copper products would be recommended. Formulated copper products may be effective for control of starry stonewort.

Diquat

Diquat is a fast-acting contact herbicide that is generally non-selective. Water quality can play a major role in efficacy of diquat treatment as it binds quickly to suspended sediments in the water column, resulting in inactivity. Therefore, sites where water turbidity is high should be avoided for diquat use. Treatment with diquat is generally recommended early in the growing season reduce aquatic plant growth when biomass is low. Follow-up treatments may be necessary at later points in the growing season. The half-life of diquat is relatively quick in aquatic systems, even when turbidity is low, and decreases to undetectable levels 7 – 14 days after treatment (MA Department of Agricultural Resources, 2017B). In the State of New York, use of diquat products should follow a special local needs label and meet additional requirements (cannot be combined with copper products, must be sprayed to lake surface, and cannot be applied in water depths of 3 feet or less). Diquat is not currently considered for use in Chautauqua Lake.

Endothall

Two derivatives of endothall are approved for aquatic use: endothall potassium salt and endothall amine salt. Generally, the potassium salt of endothall is primarily used to target submersed aquatic plants and the amine salt is applied for algae control. Endothall has been classified as a contact herbicide due to relatively fast activity but has been observed to have some systemic behaviors in several submersed aquatic plants including Eurasian watermilfoil (Ortiz et al. 2019). The mode of action for endothall has recently been documented as a serine/threonine protein phosphatase inhibitor (Ortiz et al. 2019). Endothall does not bioaccumulate in the environment and can degrade rapidly in the environment (within 7 days) especially through microbial processes in aerobic conditions (MA Department of Agricultural Resources, 2017C).

Florpyrauxifen-benzyl

Florpyrauxifen-benzyl is the most recently-approved active ingredient labeled for use in waterbodies in the United States. It is a synthetic auxin, regulating plant development and growth. Florpyrauxifen-benzyl is a selective, systemic herbicide option that is highly effective at controlling *Myriophyllum* (milfoil) species at low use rates. Native submersed aquatic plants are generally not as susceptible to treatment of florpyrauxifen-benzyl, and in some cases, have also been noted to increase in abundance in treated sites (Vermont Agency of Natural Resources, 2022). Additionally, florpyrauxifen-benzyl has low toxicity to fish and other aquatic organisms. Similar to other systemic herbicides, the slow plant response to florpyrauxifen-benzyl treatments may be preferred in sites that are susceptible to post-treatment oxygen depletion. Despite being a new option for use in aquatic systems, florpyrauxifen-benzyl has been successfully utilized in many US waterbodies including those in New York, New Hampshire, Massachusetts, Vermont, and Maine.

Flumioxazin

An additional relatively new active ingredient available for aquatic applications is flumioxazin. This chemical is fast-acting and controls aquatic vegetation on contact. Flumioxazin inhibits protoporphyrinogen oxidase (PPO), meaning that it disrupts cell membranes and ultimately causes necrosis to plant tissues (Richardson et al., 2008; Selden, 2015). Flumioxazin is formulated in granular and liquid forms and can be applied to target either submersed plants or emergent plants. Flumioxazin is highly sensitive to water pH and should not be applied when pH is greater than 8.5. At this level, flumioxazin breaks down quickly and remains active in the water column for less than one day. When pH is low (<7) flumioxazin remains active for four to five days (Wisconsin Department of Natural Resources, 2012).

Fluridone

Fluridone is a slow-acting systemic aquatic herbicide that can selectively control several submersed and floating aquatic plants. Formulations of fluridone include both liquid and granular forms with ‘slow release’ technology. Effective fluridone treatments require longer contact times than other herbicides, so it is not recommended for sites with high water movement. Additionally, treatment with fluridone should occur when plants are in an active growth phase to ensure maximum uptake and translocation. Typically, plant control is observed 30 – 90 days after exposure to fluridone in aquatic environments, and this control can be sustained with minimal regrowth of treated plants later in the growing season. This slow activity may be preferred in sites with high biomass that are susceptible to post-treatment oxygen depletion.

Triclopyr

Triclopyr is a systemic herbicide with relatively fast-acting properties that can be applied to submersed, floating, and emergent aquatic weeds. Generally, dicot plants including Eurasian watermilfoil, are more susceptible to treatment with triclopyr when compared with monocot grasses and sedges. In addition to selectivity advantages, triclopyr also requires a relatively short contact time when compared to other systemic options (ESNR Corporation, 2007).

Table 4. Major SAV species at Chautauqua Lake and associated sensitivities to chemical, physical, and biological controls and their associated costs. Costs for site-specific management activities at Chautauqua Lake should be determined through a detailed analysis and could be included as a future Addendum to this Management Plan (Modified from Lynch 2009 and NYSFOLA 2009).

		Chemical							
Scientific Name	**Common Name**	**2,4-D**	**Copper***	**Diquat**	**Endothall**	**Florpyrauxifen-Benzyl**	**Flumioxazin**	**Fluridone**	**Triclopyr**
Myriophyllum spicatum	Eurasian Watermilfoil	X	X	X	X	X	X	X	X
Nitellopsis obtusa	Starry Stonewort	-	X	X	X	-	-	-	-
Potamogeton crispus	Curly-leaf Pondweed	-	X	X	X	-	X	X	-
Ceratophyllum demersum	Coontail	X	X	X	X	X	-	X	-
Elodea sp.	Elodea	-	X	X	-	-	X	X	-
Heteranthera dubia	Water Stargrass	X	X	X	X	-	-	X	-
Najas sp.	Naiads	-	X	X	X	-	X	X	-
Potamogton sp.	Native Pondweeds	-	X	X	X	-	X	X	-
Vallisneria americana	Wild Celery	-	X	X	X	-	-	X	-
	Estimated Cost	*~$500- $3,000/acre depending on product/formulation and site characteristics*							

		Biological	Mechanical / Physical				
Scientific Name	**Common Name**	**Milfoil Weevils**	**Benthic Barriers**	**Dredging**	**Hand Removal**	**Mechanical Harvesting**	**Nutrient Management**
Myriophyllum spicatum	Eurasian Watermilfoil	X	X	X	X	X	X
Nitellopsis obtusa	Starry Stonewort	-	X	X	X	X	X
Potamogeton crispus	Curly-leaf Pondweed	-	X	X	X	X	X
Ceratophyllum demersum	Coontail	-	X	X	-	X	X
Elodea sp.	Elodea	-	X	X	-	X	X
Heteranthera dubia	Water Stargrass	-	X	X	-	X	X
Najas sp.	Naiads	-	X	X	-	X	X
Potamogton sp.	Native Pondweeds	-	X	X	-	X	X
Vallisneria americana	Wild Celery	-	X	X	-	X	X
	Estimated Cost	***Milfoil Weevils:*** *~$1,000/acre*	***Materials and Installation:*** *~$20,000/acre*	***Dredge with spoil removal:*** *~$40,000/acre*	***Hand Removal*** *: ~$500/acre* ***Suction Harvesting*** *: ~$20,000/acre*	***Equipment*** *: >$200,000* ***Operation*** *: ~$500/acre*	*Highly variable depending on specific program goals*

Plant Response Time	**Fast** *(Days)*	**Moderate** *(Weeks to Months)*	**Slow** *(Years)*

Review of Past Management Techniques

Active aquatic plant management methods began at Chautauqua Lake in 1952 when mechanical harvesting begun. Mechanical harvesting efforts have continued annually at the lake since that time, marking over 70 consecutive years of work. These efforts have been overseen by the Chautauqua Lake Association. A combination of equipment has been used for this work and includes large harvesters, and more recently, Mobitracs. Large harvesters are able to cut and collect vegetation up to 5 feet below the water's surface and in swaths ranging from 7' – 11'. Mobitrac vehicles are amphibious and are mainly utilized for shallow shoreline efforts. This system has removed millions of pounds of aquatic vegetation from the lake on an annual basis (Figure 13). Since 2017, the mechanical harvesting season has consistently occurred from late May through late August at Chautauqua Lake (Figure 13). Over the course of a growing season, harvesting intensity at the lake has gradually increased to a peak harvest period in late July (Figure 14).

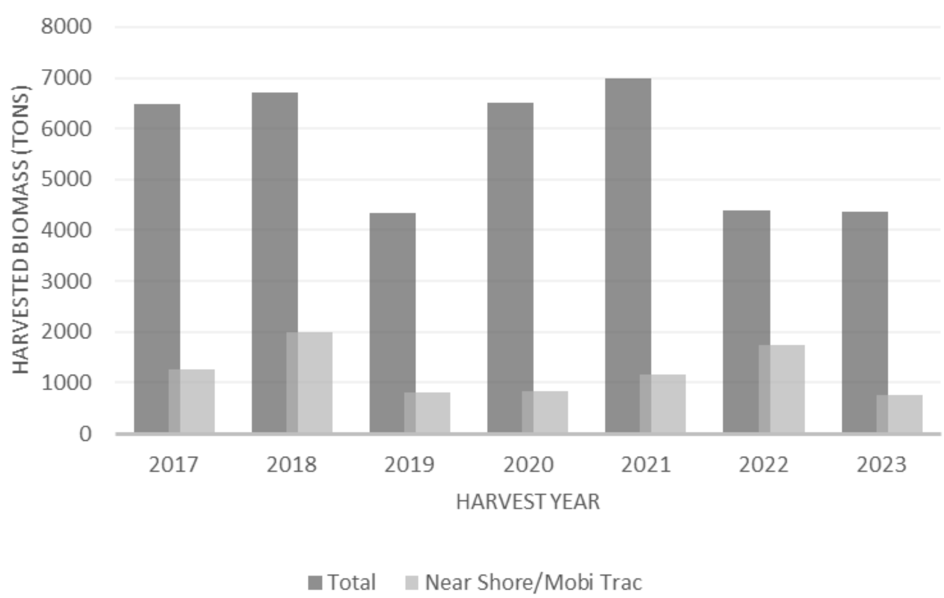


Figure 13: Reported harvested biomass from mechanical harvesting efforts at Chautauqua Lake since 2017. Solid line represents total harvested biomass (tons) and is the sum of all harvesting efforts per harvest year. Dashed line is the representative tonnage of plant material harvested by near shore and/or Mobi Trac efforts per harvest year. Data provided by Chautauqua Lake Association's Activity Reports (2017 – 2023).

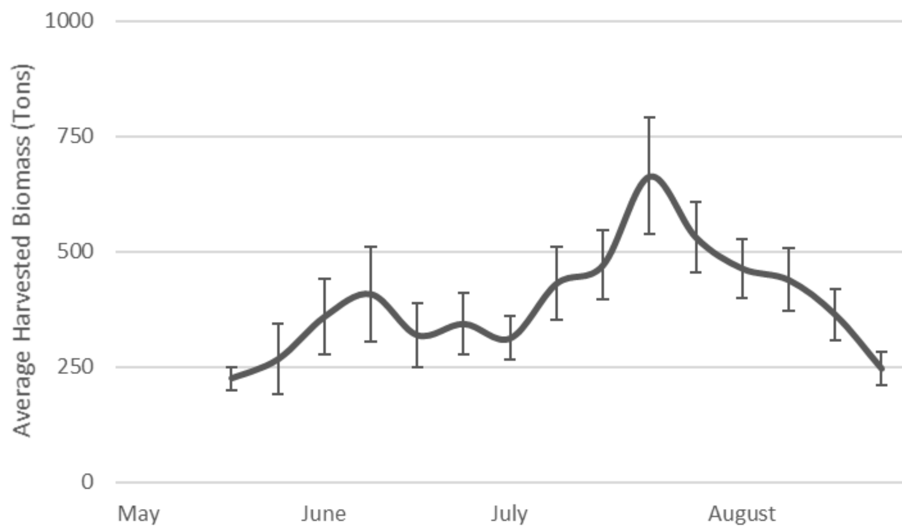


Figure 14: Mean weekly harvested biomass at Chautauqua Lake over a single season reported during 2017 – 2023 seasons. Bars represent ± SE. Data provided by Chautauqua Lake Association's Activity Reports (2017 – 2023).

With the exception of tracking biomass removal over time, limited information is available on total acreage harvested, species composition of harvested biomass, and subsequent impact to the sustained aquatic plant community at Chautauqua Lake. Due to the resurgence of submersed aquatic plant biomass within the lake from year to year, mechanical harvesting efforts appear to act well for temporary maintenance of the waterway over time, but cannot be relied upon as a long-term management strategy.

Milfoil biocontrol agents were introduced to the Lake in the early 2000's, however little information is available about the rates and species that were stocked. Monitoring of these populations in Chautauqua Lake has occurred. As of 2023, species presence includes *Euhrychiopsis lecontei* (weevil), *Acentria ephemerella* (moth), *Cricotopus myriophylli* (midge), *Nectopsyche albida* (Walker) (caddis), and *Setodes grandis* (small caddis) (Rooney et al. 2023). While these species remain present in Chautauqua Lake, the herbivore density has declined over time at most surveyed sites (Rooney et al. 2023).

Chemical aquatic plant control methods began in 1955. Products applied to the lake have included sodium arsenate (1955 – 1961), 2,4-D (1965, 2017 - 2019), diquat (1965

– 1987), endothall (1981 – 2005; 2018 – 2023), and florpyrauxifen-benzyl (2020 – 2023). Chemical methods have targeted curly-leaf pondweed and Eurasian watermilfoil growth. Since 2020, 567 acres of Eurasian watermilfoil have been treated with ProcellaCOR EC, and just over 500 acres of curly-leaf pondweed have been treated with Aquathol K. The integration of chemical, biological, and mechanical control methods have resulted in a reduction of Eurasian watermilfoil acreage in Chautauqua Lake over time in the recent past (Figure 15).

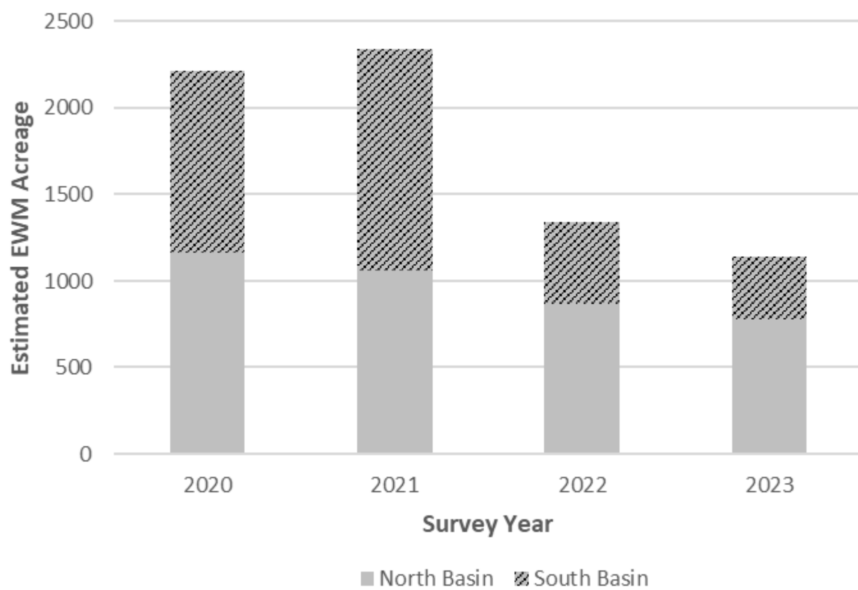


Figure 15. Estimated acreages of Eurasian watermilfoil (EWM) in the North and South Basin of Chautauqua Lake from 2020 – 2023. Acreages were calculated based on annual whole lake point-intercept and hydroacoustic biovolume data.

In his paper *Changes in Submersed Macrophytes in Chautauqua Lake, 1937 – 1975*, Nicholson (1981) analyzes aquatic plant community variation over time at Chautauqua Lake and discusses the influence of past management techniques on both native and non-native aquatic plant species. It was noted that native pondweed species abundance experienced the most change as a response to both herbicide and mechanical harvesting work. At the time, chemical treatments were largely comprised of diquat use, a fast-acting contact herbicide. It was noted that native pondweed was susceptible to diquat exposure due to tall stems at the top of the water column and cited implications of targeting curly-leaf pondweed late in the growing season, after turion formation occurred. Nicholson (1981) also examined implications of mechanical harvesting on native pondweed growth, where it was observed that native pondweed was highly vulnerable to decreases in abundance from cutting due to the inability to regenerate through sexual reproduction [due to cutting of flowers prior to maturity], the failure to be able to fully regrow after cutting, and their long stems that occupy much of the water column. This work emphasizes the need to consider non-target impacts and highlights the need for selective techniques in order to maintain a diverse and robust native plant community.

Looking Ahead: 5 Year Comprehensive Plan

Problem Assessment

According to recent monitoring efforts, the macrophyte community at Chautauqua Lake is largely composed of Eurasian watermilfoil in the summer and fall months, and curly-leaf pondweed in the spring. The presence of these invasive species can disrupt the overall ecosystem function and additionally impact the local fishery, water quality, and recreational opportunities at the Lake. Starry stonewort also represents an emerging threat.

Vision

The goal of this project is to achieve a balanced and sustainable aquatic ecosystem at Chautauqua Lake. Objectives include reducing the nuisance level of invasive species and maintaining or increasing the relative distribution of native species. Integrated management of invasive species is encouraged as well as monitoring of both invasive and non-native species. Implementation of this plan will be based on set priorities and will occur in defined stages to ensure that progress is completed according to a systematic design. Annual reviews should be conducted of the plan, management effectiveness, and lake surveys.

Whole-Lake Management Strategy

Chautauqua Lake is naturally divided into two sections, the North and South Basins. Studies have determined that, while connected, the physical differences between the two basins can influence dynamics of fundamental, underlying ecosystem processes (Smith et al. 2020). These physical differences likely directly influence the aquatic plant communities as well, and as such, management strategies may need to differ when comparing North and South Basin needs. However, it should also be recognized that decisions regarding lake management should be unified in a whole-lake approach to maximize effort from all entities.

The 2017 Chautauqua Lake Macrophyte Management Strategy delineates the lake into sub-sections based off of shoreline use and highlights the need to consider human interaction along with environmental sensitivities when developing management options. While this strategy is effective at assessing options for specific, small-scale situations, it shifts the strategy away from a viewpoint that should be centered on plant ecology in order to meet the primary goals of long-term macrophyte management.

Specific Goals

The goals of this long-term plan include:

- Reduce the nuisance level of Eurasian Watermilfoil and Curly-Leaf Pondweed in the Chautauqua Lake system.
- Identify control measures for Starry Stonewort in Chautauqua Lake.
- Encourage native submersed aquatic vegetation species diversity throughout the system, with particular focus on South Basin assembly
- Limit continued spread of non-native species in the Chautauqua Lake watershed
- Shift algal community away from cyanobacterial dominance
- Support the local fishery, especially the established game fish population

Plan Management

Stakeholder collaboration will be an important aspect of this plan, and as such, management decisions will need to be organized through a central entity. A Lake

Manager dedicated to coordinating and tracking this work could be a valuable asset for long-term success and goal achievement. This position would be responsible for coordinating long-term data collection and interpretation, communication and dissemination of information to the public, and prioritize decision making strategies based on consideration of current environmental data. A Lake Manager would also work directly with local and state agencies to obtain permits and closely monitor all vegetation management efforts at Chautauqua Lake throughout the growing season.

To provide support and oversight, the Lake Manager position should collaborate with an Executive Board comprised of elected individuals that represent the Chautauqua Lake community's diverse background and interests. This group should collaborate to review summarized lake data and trends to make informed and organized decisions regarding lake management.

Plan Review

To address the dynamic nature of long-term aquatic plant management projects, annual reviews of the management plan shall be conducted through a collaboration between the Lake Manager and the Executive Board to evaluate yearly outcomes, navigate forthcoming needs, and continue prioritization of management goals. The annual review should take place in the winter, such that necessary modifications can be put in place prior to the onset of the subsequent growing season.

Integrated Management Plan

This plan is divided into a sequential tiered system. Each tier builds upon each other, and as such, should be completed in the defined order. The plan will define and target long-term treatment areas, short-term management goals, and habitat protection areas. Long term treatment areas will be established in Tier 1 and managed beginning in Year 1 and continued on a yearly basis through the duration of this effort. These areas are ones that are of high priority and have sustained biomass over multiple growing seasons. Intensity of management on individual sites should decline over time. Tier 2 sites are those that contain sparse growth in susceptible areas and locations where moderate or dense biomass is recorded locations outside of Tier 1 sites. These sites will likely be introduced years 3 or 4, dependent on initial management gains. Lastly, Tier 3 sites are those that will require continued, small-scale management in Years 4 – 5 (Table 5).

This plan is built upon a combination of chemical and mechanical management efforts, while sustaining long-term biological management projects that have been ongoing at Chautauqua Lake as well. In general, chemical options are able to target specific, problematic sites and provide long-term solutions for the reduction of aggressive species within the ecosystem. Mechanical controls allow for short-term maintenance at sites where chemical treatments are not feasible. Biological controls will continue to suppress Eurasian watermilfoil growth in habitat protection areas and augmentation of those biological controls may be considered.

Definition of Priority Management Zones

Tier 1 Management Priorities

Long-term management sites include those that have sustained biomass of target aquatic plants over the span of multiple recent growing seasons. As such, these areas have demonstrated that they contain established biomass of target species that will be the most time-intensive to manage. These sites also likely act as source populations for continued spread throughout the lake. Tier 1 sites should also include those areas of the target species that occur within 100 feet of high use areas. High use areas of the lake may include public boat launches, marinas, and swim beaches. The inclusion of these zones will reduce spread of the target species within and out of the lake.

Tier 1 sites should be established in Year 1 and should continue to be monitored and managed throughout the duration of the 5 year plan. If biomass of target species is significantly reduced in any of these sites prior to the 5th year of management, then they will transition from active management to less intensive management with continued monitoring.

Tier 2 Management Priorities

Tier 2 sites are those that arise as a management need in Years 3 – 4. These sites will be delineated based off of annual survey efforts and will include regions of growth of the target species that were evaluated as moderate/dense or trace/sparse in regions of the lake that are susceptible to invasion. Susceptible areas are those that have soft sediments, low SAV biodiversity, and occur within 2 – 3 m water depths.

Tier 3 Management Priorities

Our goal is to reach a point by the end of this 5 year effort in which maintenance of target species management is reduced to isolated "spot treatments". Spot treatments should be contained to 15 acres or less and delineated as necessary based on annual survey results.

Habitat Protection Zones

Habitat protection zones will be limited to low-impact management. These sites will include areas of the lake where rare, threatened, or endangered species are located, have high overall biodiversity of submersed aquatic plants, or act as sensitive fish spawning sites as defined by the New York State Department of Environmental Conservation. Low impact options could include DASH and insect biocontrol. If possible, habitat protection zones will be rotated to allow for maximum depletion of invasive species with equivalent protection of critical habitat.

Management Area Characteristics

Table 5. Tiered management area focus over a 5 year timeframe

<table>
<tr><td>Year 1</td><td rowspan="5">Tier 1:
Long-term management zones
- Consistent documented EWM growth (delineated from Fall survey) and CLP growth (delineated from Spring survey)
- Any growth within 100 feet of High Use Areas</td><td rowspan="5">Habitat Protection Zones
Limited, low impact management
- Presence of rare, threatened or endangered aquatic plant species (delineated from Fall survey)
- High aquatic plant diversity areas (delineated from Fall survey)
- Sensitive fish spawning sites</td><td></td><td rowspan="2"></td></tr>
<tr><td>Year 2</td><td rowspan="4">Tier 2:
Short-term management zones
- New moderate/dense growth outside of Tier 1 sites (delineated during annual surveys)
- May require management for less than 4 consecutive years</td></tr>
<tr><td>Year 3</td><td rowspan="3">Tier 3:
Maintenance Management
- Spot treatments as needed outside of Tier 1 and Tier 2 areas
- Previously managed areas prior to development of long-term plan</td></tr>
<tr><td>Year 4</td></tr>
<tr><td>Year 5</td></tr>
</table>

Delineation of Management Zones

Priority management zones were determined through the analysis of recent monitoring results, combined with the integration of high-use and sensitive shoreline areas (Figures 16 & 17). Due to differences in water clarity between North and South regions of the lake, the littoral zone at Chautauqua Lake will be defined as regions where water depths were 12.5 feet or less in the North Basin, and 10 feet or less in the South Basin (Figures 18 & 19). This defined littoral zone at Chautauqua Lake will allow for a robust view of vegetation distribution and abundance potential and allow for improved detection of submersed vegetation in management areas. In any waterbody, the littoral zone serves as a foundation for all plant management-related activities as this region supports primary productivity in aquatic ecosystems.

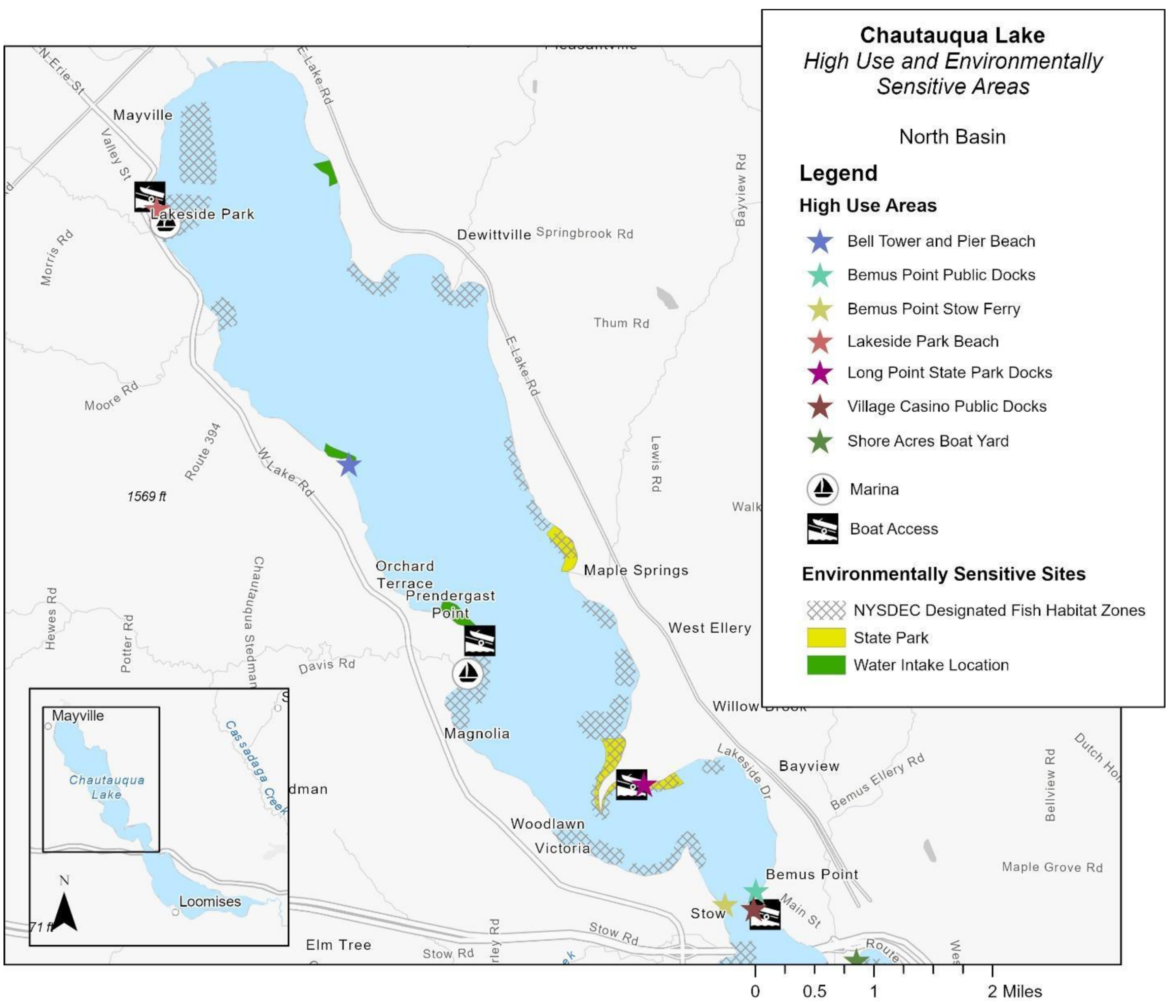


Figure 16. Major use and environmentally sensitive areas at Chautauqua Lake – North Basin

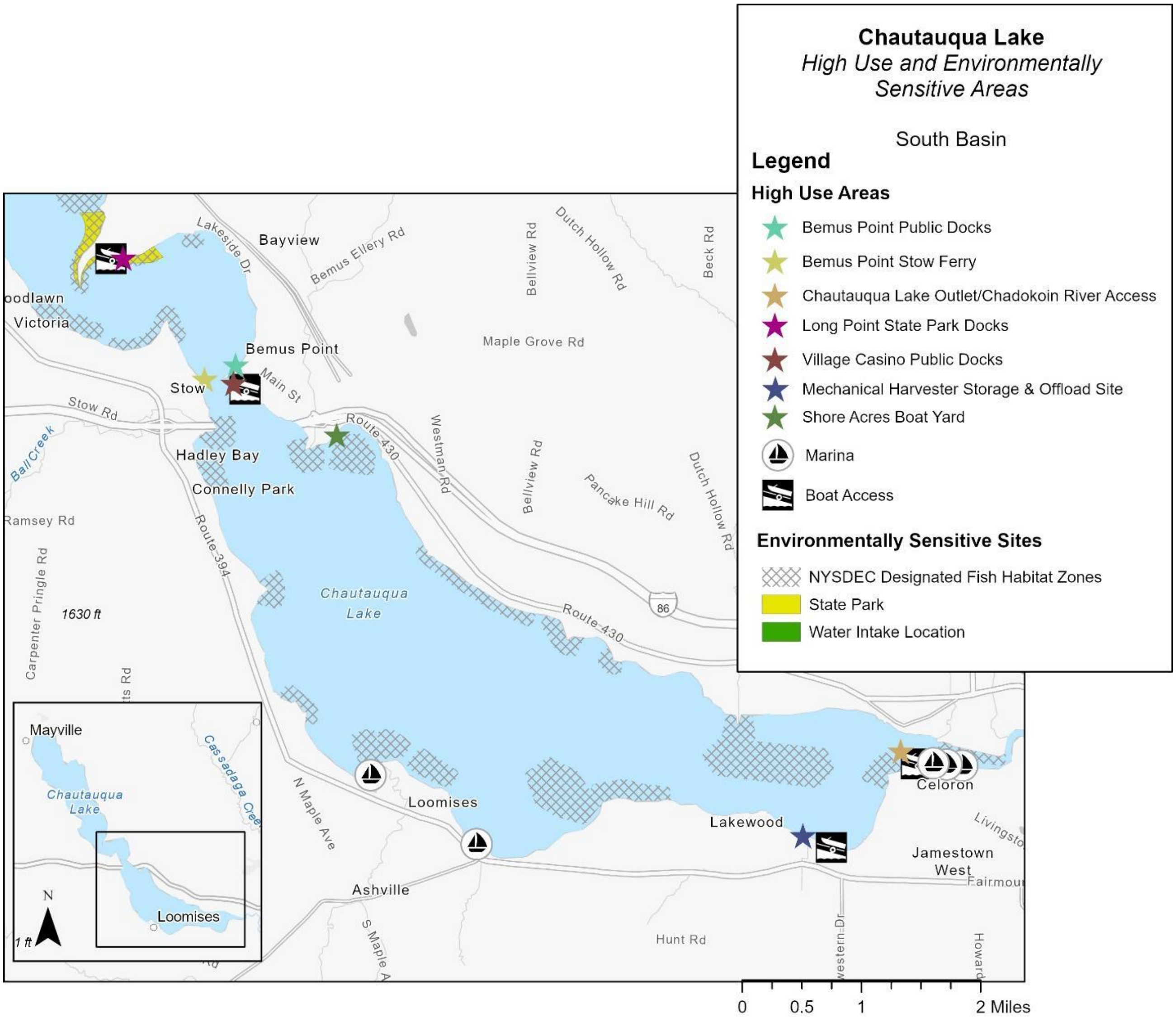


Figure 17. Major use and environmentally sensitive areas at Chautauqua Lake – South Basin

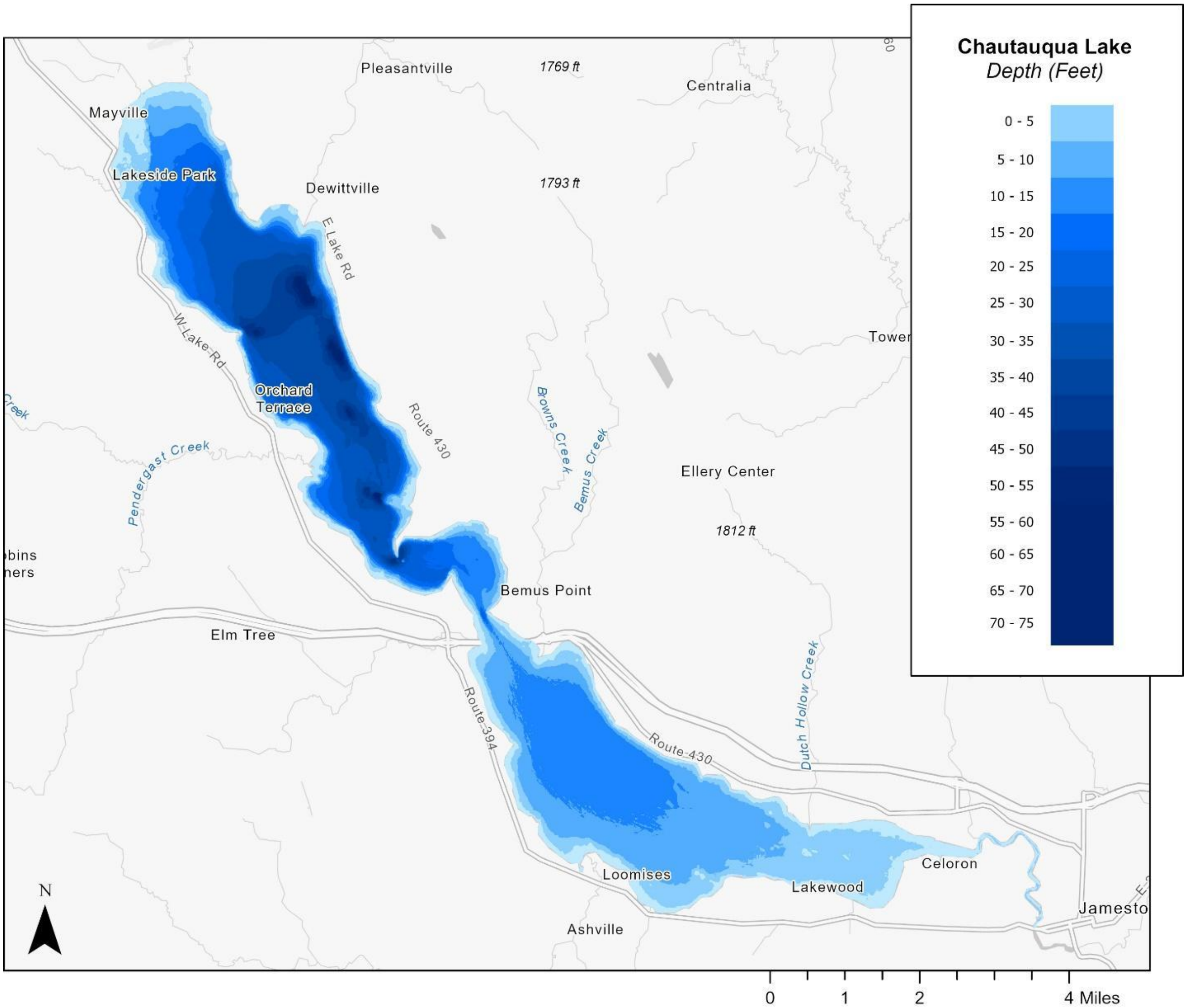


Figure 18. Chautauqua Lake Bathymetry. Data retrieved from CMap Genesis Social Map (administered through Biobase™) and supplemented with hydroacoustic data collected during aquatic plant surveys by North Carolina State University.

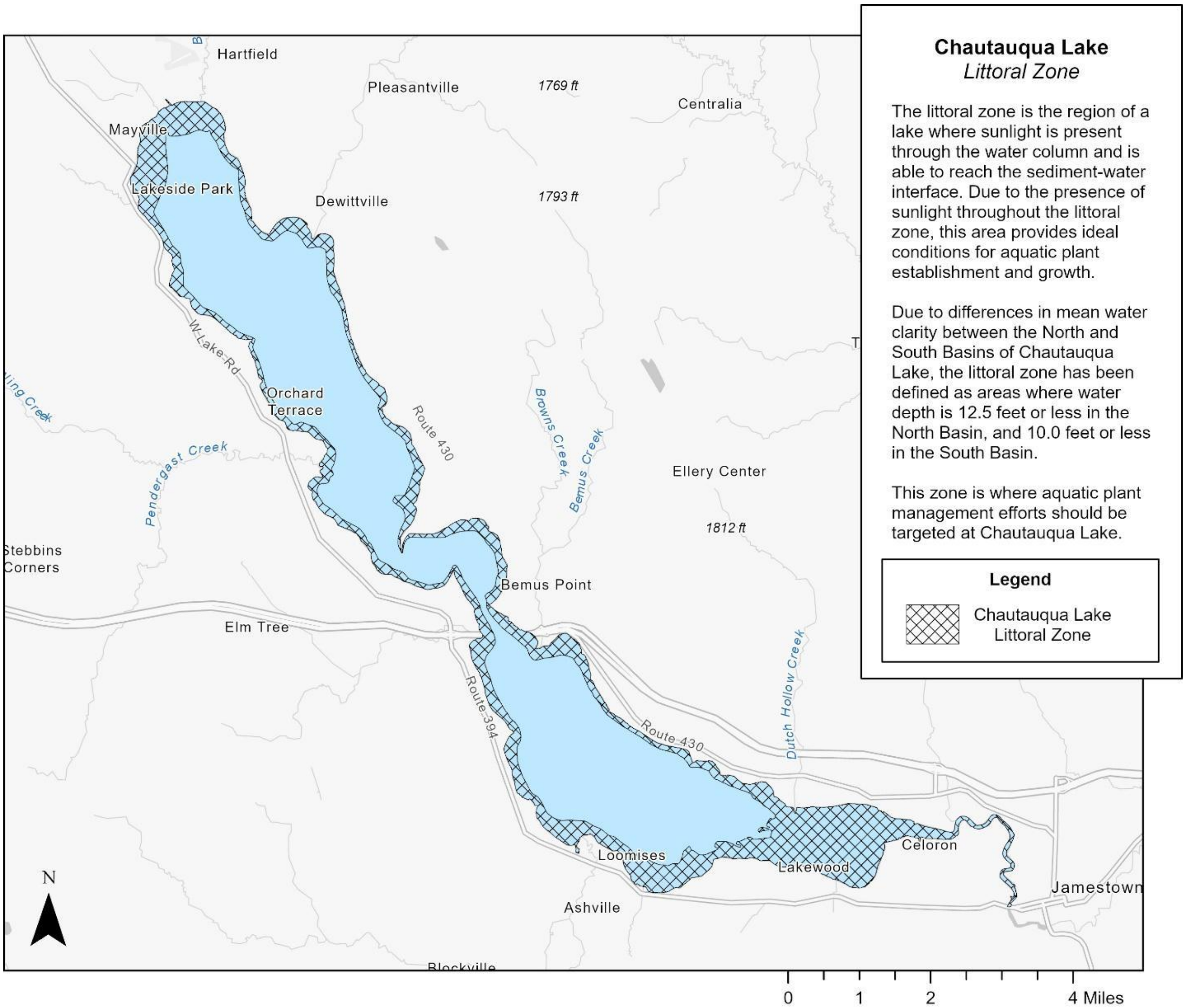


Figure 19. Defined littoral zone for Chautauqua Lake

Eurasian Watermilfoil

Persistent Eurasian watermilfoil (EWM) beds were determined through the analysis of recurrent monitoring efforts at Chautauqua Lake from 2020 – 2023 (Figure 20). Areas of Tier 1 management priority include zones in which EWM has been present for 3 or more consecutive years, emphasize areas where persistent EWM sites are present in clusters of sites of 4 or more, and are in close geographical proximity to high use areas. Tier 2 management priority include zones in which Eurasian watermilfoil has been present for 3 or more consecutive years, emphasize areas where persistent EWM sites are present in clusters of sites of 4 or more and may be in close proximity to high use areas. Tier 3 management priority include zones in which Eurasian watermilfoil has been present for 2 or more consecutive years, and emphasize areas where persistent EWM sites are present in clusters of sites of 4 or more (Figures 21 – 26).

Effort should be focused on these highlighted regions during management years. It should be noted that Tier 2 and 3 zones may be subject to change depending on environmental conditions in Years 2 – 5. Specific management areas within priority zones should be determined based off of most recent annual survey has been completed to confirm or deny current presence of biomass, and therefore, management need.

Our data reflect recent successes of targeted EWM management in several sites at Chautauqua Lake prior to 2024, including regions along the Ellery and Bemus Point shorelines. Due to this success and the lack of EWM in these areas over consecutive survey years (2020 – 2023), these zones are not highlighted as priority sites of concern at this time. However, these areas should still be included in the long-term plan, and as such, will be placed as Tier 3 sites for continued monitoring and management as necessary.

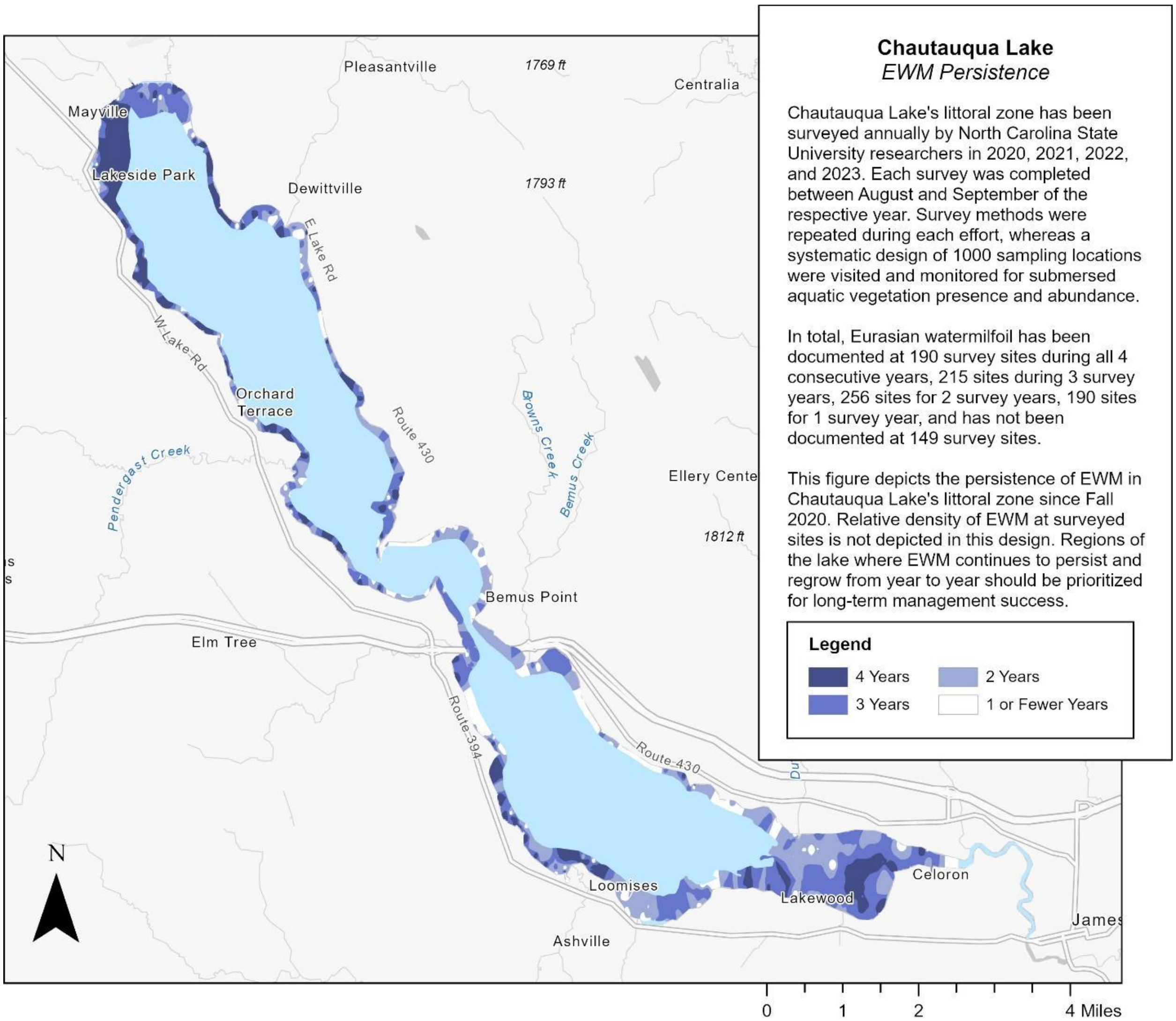


Figure 20: EWM Persistence in Chautauqua Lake as delineated by 2020 – 2023 survey efforts.

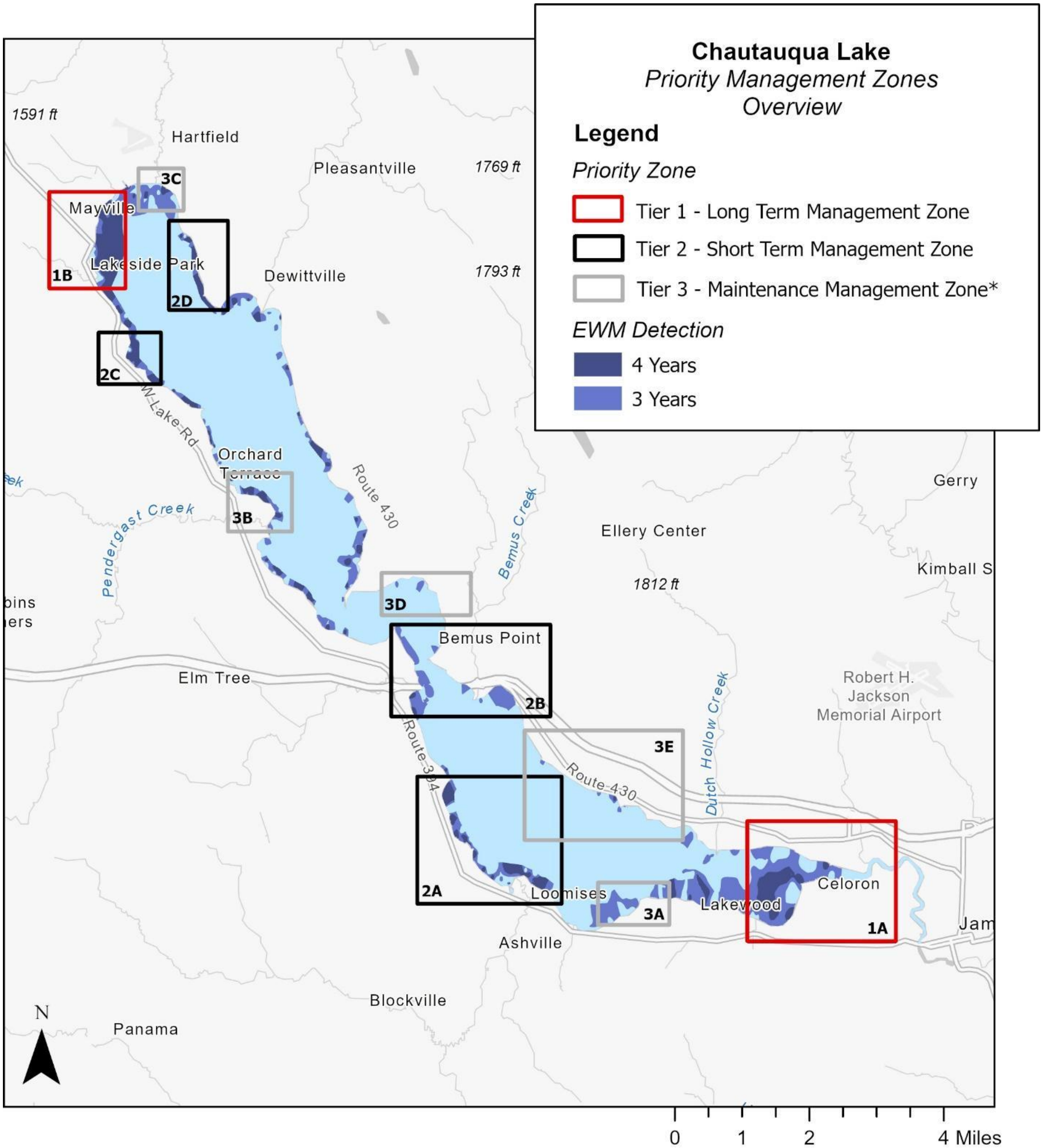


Figure 21. Overview of priority management zones at Chautauqua Lake

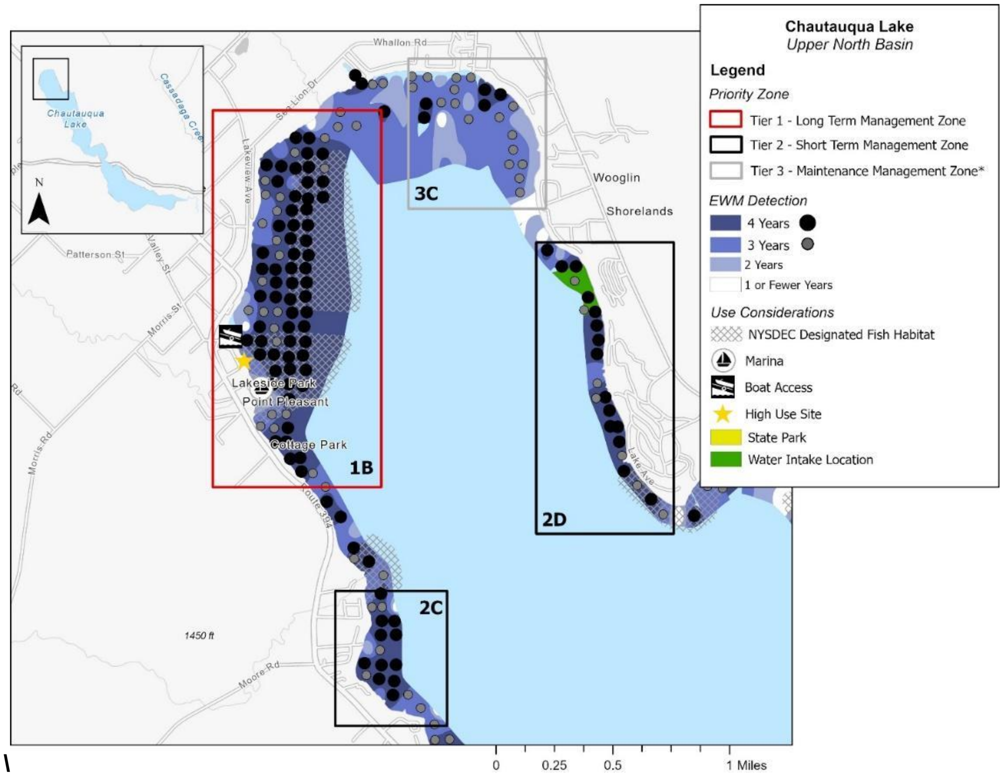


Figure 22: Priority Eurasian watermilfoil management zones in the Upper North Basin of Chautauqua Lake.

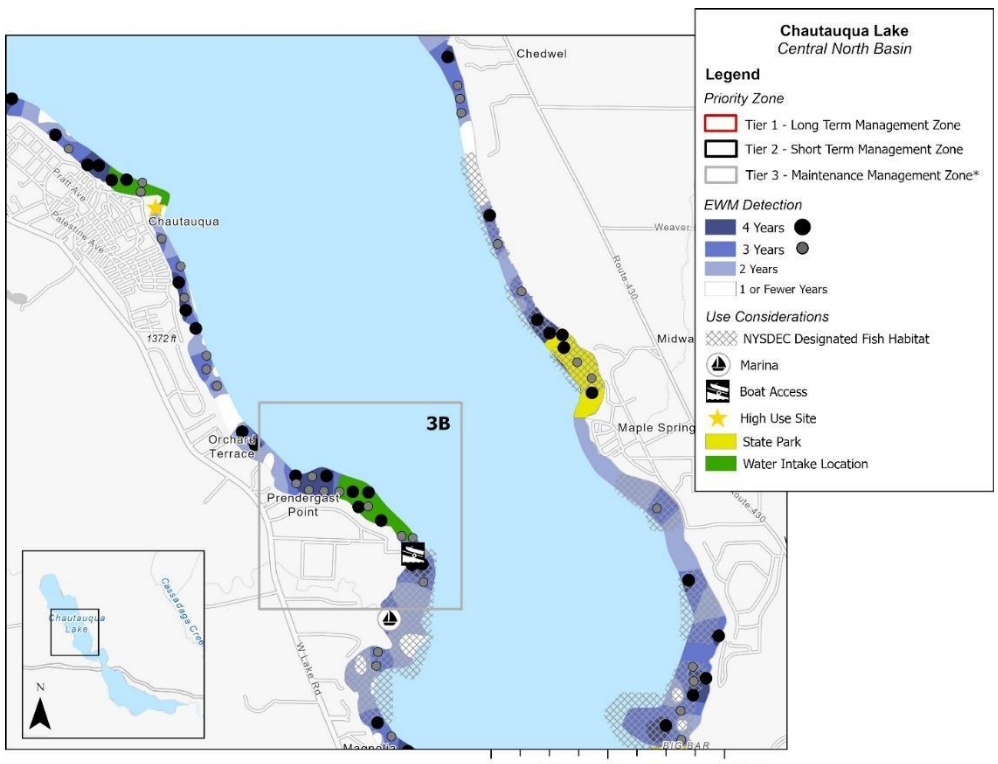


Figure 23: Priority Eurasian watermilfoil management zones in the Central North Basin of Chautauqua Lake.

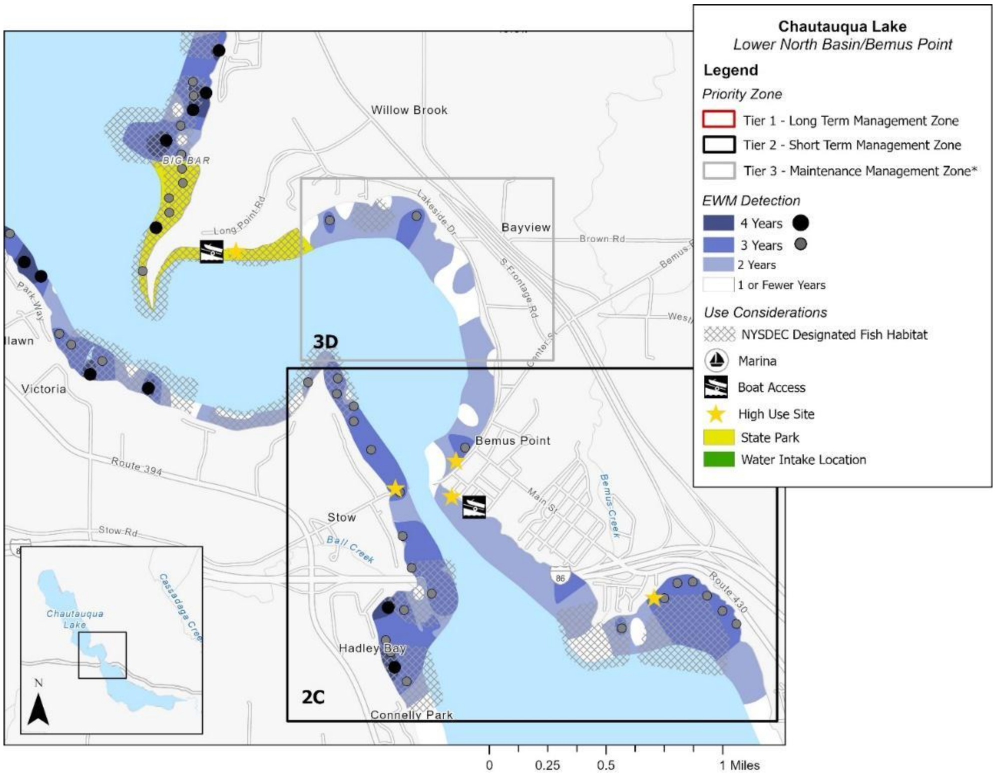


Figure 24: Priority Eurasian watermilfoil management zones in the Lower North Basin of Chautauqua Lake.

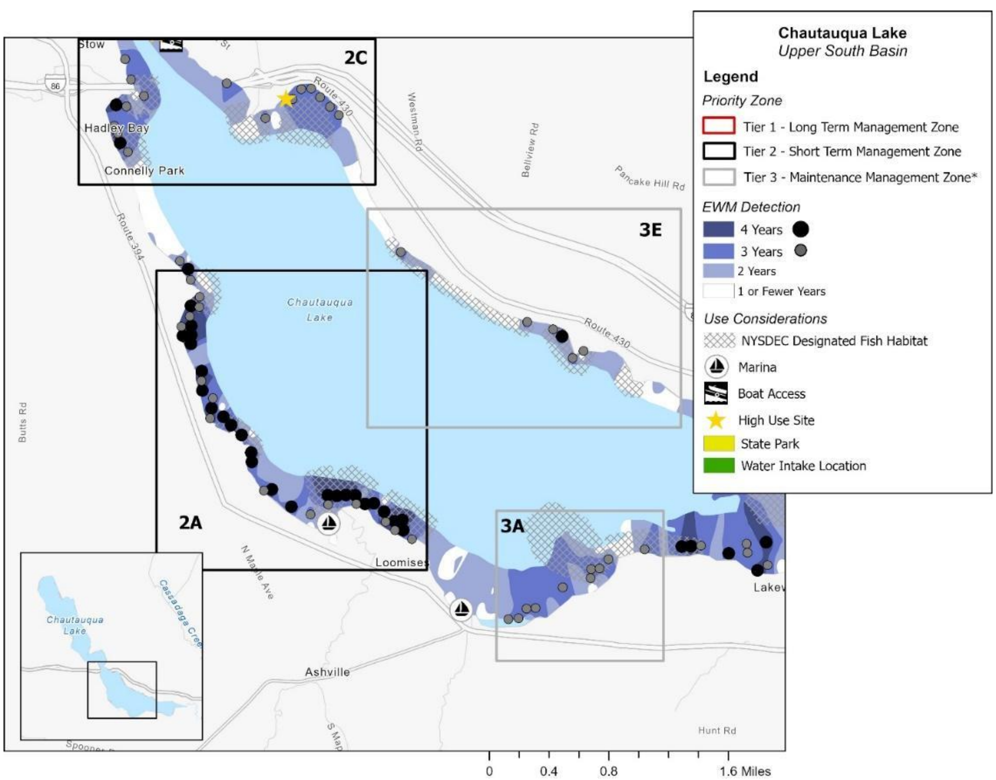


Figure 25: Priority Eurasian watermilfoil management zones in the Upper South Basin of Chautauqua Lake.

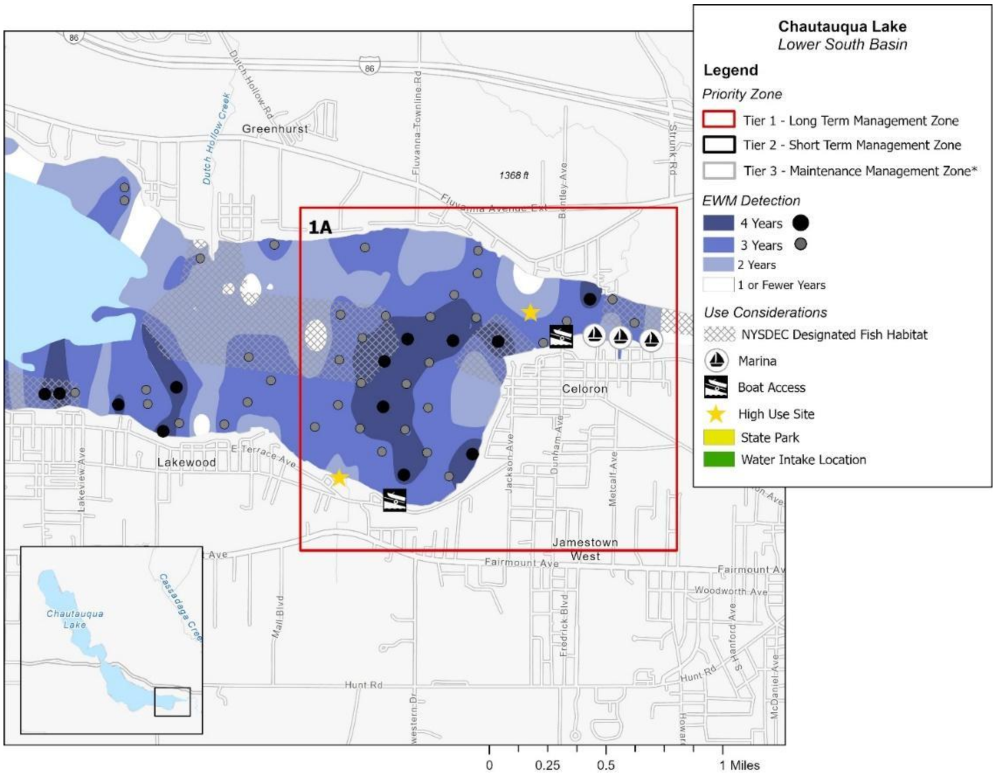


Figure 26: Priority Eurasian watermilfoil management zones in the Lower South Basin of Chautauqua Lake.

<u>Curly-Leaf Pondweed</u>

As of 2023, data on curly-leaf pondweed distribution and abundance at Chautauqua Lake is minimal, as the timing of annual Fall surveys are not able to capture the extent of curly-leaf pondweed biomass. Priority management zones for curly-leaf pondweed should be determined based off most recently acquired Spring monitoring data. These data may be captured by traditional point-intercept rake toss surveys, or through novel techniques such as UAV or satellite imagery.

<u>Starry Stonewort</u>

With the increase of starry stonewort within Chautauqua Lake as of the 2023 survey, the most recent survey results should be utilized to determine management zones. Further, all sites with starry stonewort presence should be targeted for long-term management while total acreage remains low (Figures 27 - 30).

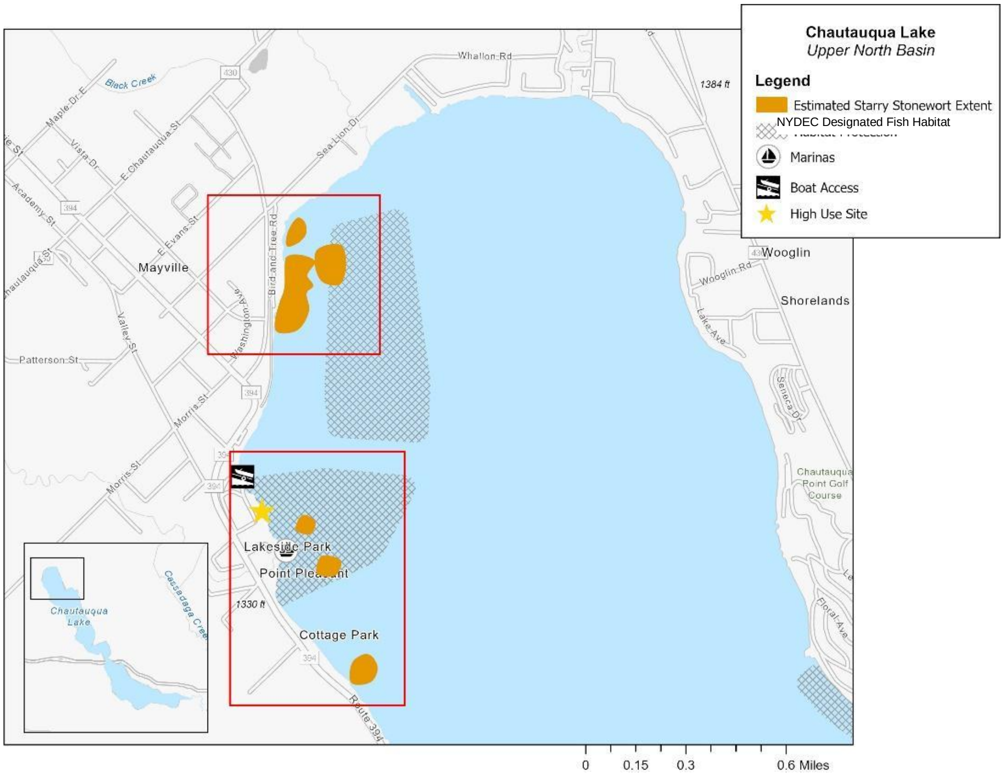


Figure 27: Priority starry stonewort management zones, boxed in red, in the Upper North Basin of Chautauqua Lake.

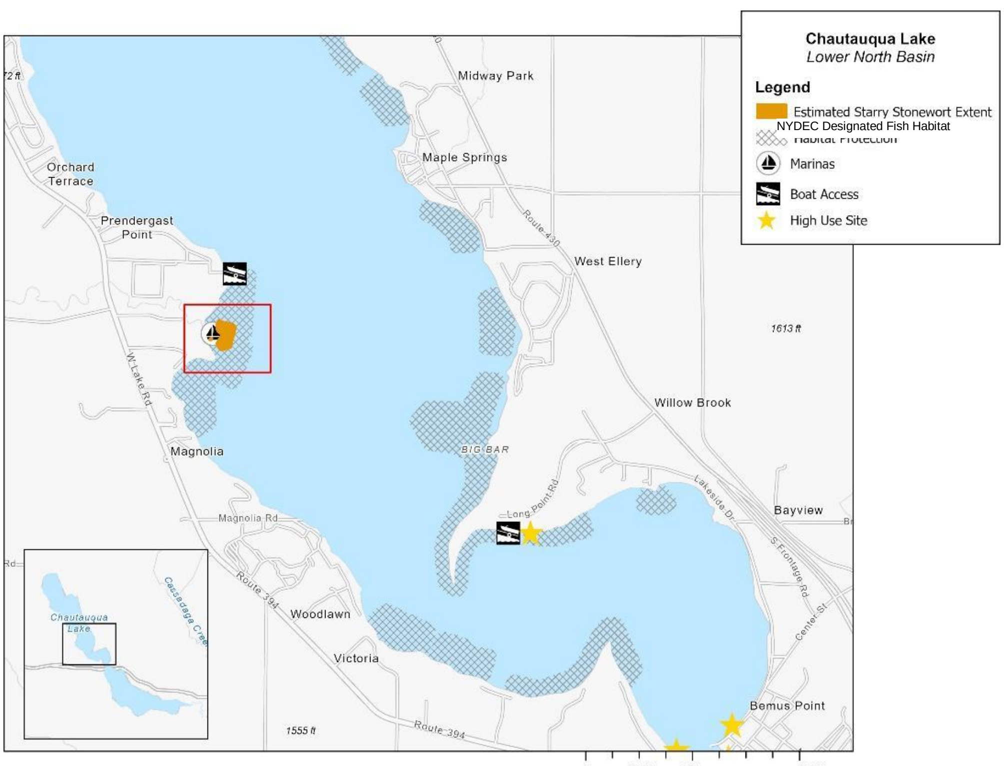


Figure 28: Priority starry stonewort management zones, boxed in red, in the Lower North Basin of Chautauqua Lake.

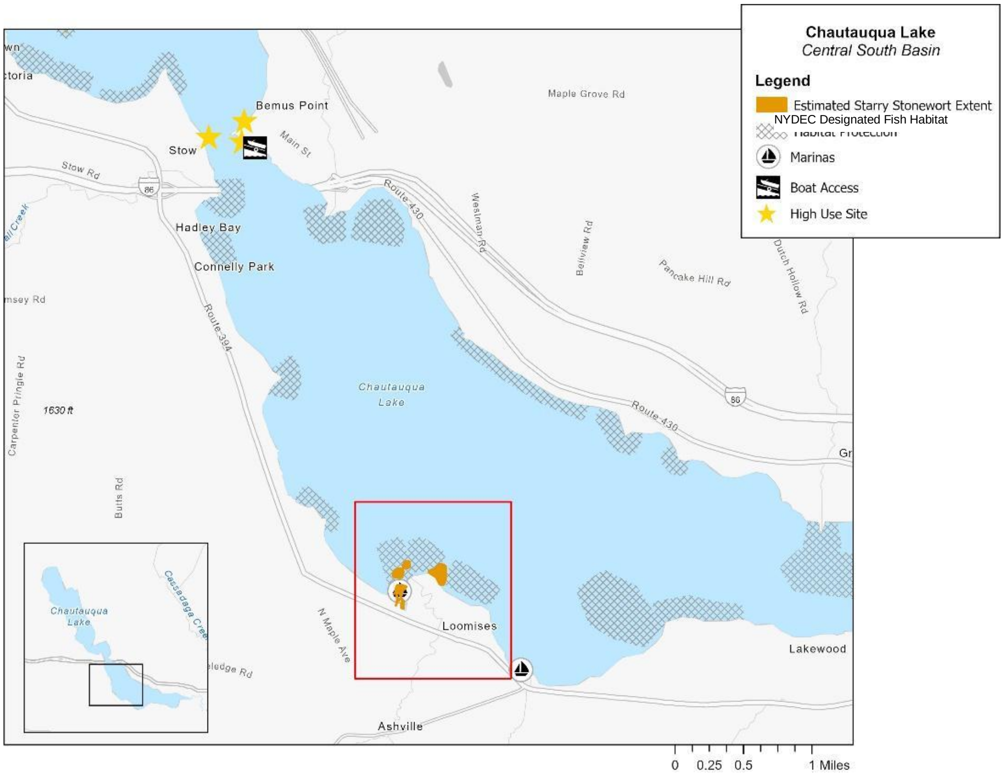


Figure 29: Priority starry stonewort management zones, boxed in red, in the Upper South Basin of Chautauqua Lake.

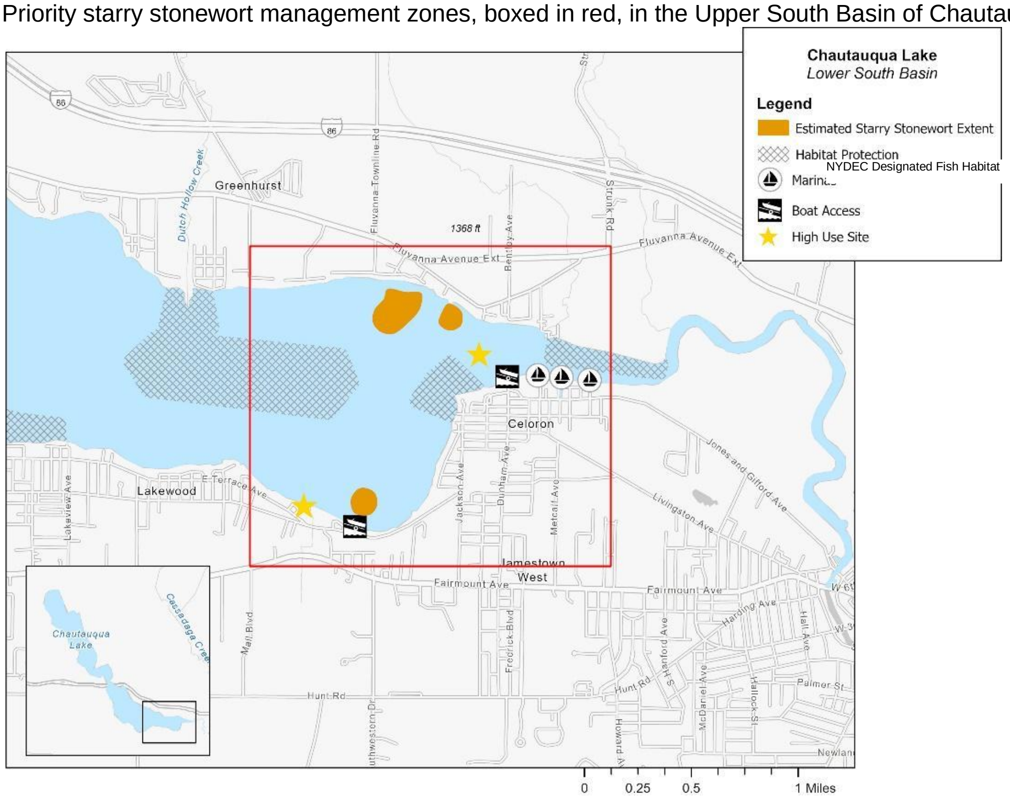


Figure 30: Priority starry stonewort management zones, boxed in red, in the Lower South Basin of Chautauqua Lake.

Annual Strategic Timeline

Strategic implementation of this plan not only spans work years, but also depends on the timing of critical management events in relation to the ecological factors of target and non-target species.

Curly-leaf Pondweed

Due to the unique growth pattern of curly-leaf pondweed, management efforts specifically for this species should occur early in the growing season. It is recommended that endothall (1 - 2 ppm) should continue to be used for chemical control of curly-leaf pondweed at Chautauqua Lake. Treatment with chemical controls should begin when the plants are at the start their active growth phase (Figure 28). This timing limits treated biomass, thus reducing Curly-leaf pondweed naturally senesces in June-July, and early season management reduces overall nutrient release into the water column and decreases this nutrient source for summer algal blooms. Additionally, the timing of early season management is critical for curly-leaf pondweed to limit turion production and future growth in subsequent years. Early-season chemical control should also limit off-target impacts as fewer macrophytes will be actively growing at this time. Lastly, this timing should have reduced overlap with spawning fish activity and allow more time for native plants to reclaim curly-leaf pondweed areas before spawn (Figure 29). Studies have documented that water temperature does impact overall efficacy of selected chemical controls but biomass is still reduced, especially with a long (12 + hour) exposure period (Netherland et al. 2000). So, ideal parameters for treatment include water temperatures at 5 – 10°C in sites that do not experience high water flow.

Summary of Management Events (specific timing to be based on water temperature):

- *March-April* – Management Zone Confirmation
- *April-May* – Application of Chemical Control and/or Mechanical Harvesting
- *May-June* – Post-treatment Assessment and survey for population extent delineation. No mechanical harvesting during flowering and turion formation.
- *September* – Turion Bank Sampling

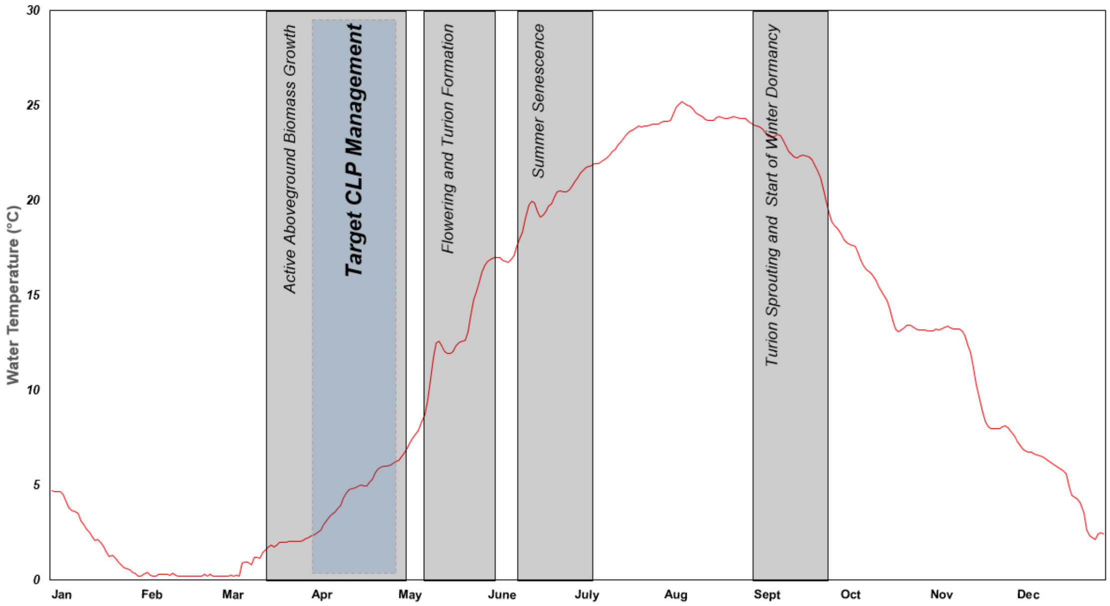


Figure 28. Phenology mapping of curly-leaf pondweed (CLP) based on seasonal water temperatures at Chautauqua Lake. Target management period is highlighted in blue.

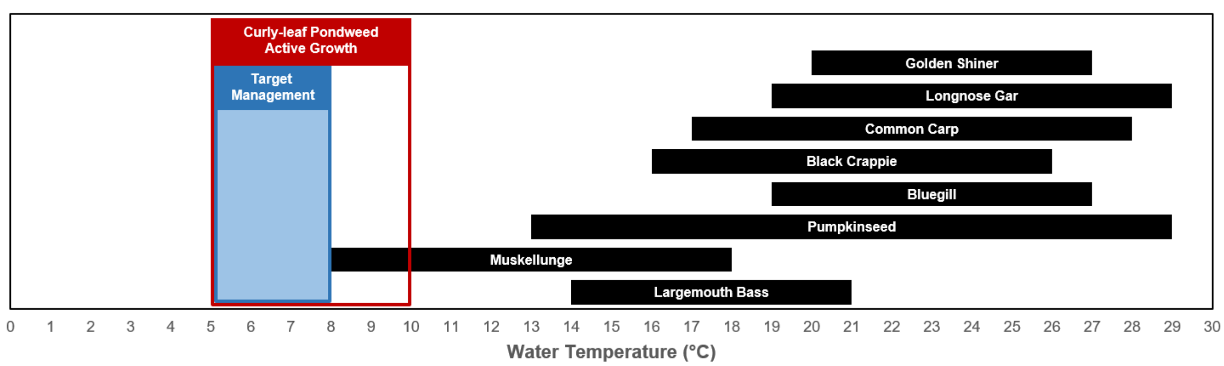


Figure 29. Target management period of curly-leaf pondweed specific management efforts in relation to fish spawning activity in Chautauqua Lake.

Eurasian Watermilfoil

Florpyrauxifen-benzyl (3 – 6 ppb) is highly effective for Eurasian watermilfoil control. This herbicide is selective for milfoil species, even at low (0.5 hour) exposure times, and should limit off-target impact to the diverse native plant community (Mudge et al. 2021). Ideal application timing is during the active growth phase but before peak biomass. Early treatment will limit the release of excess nutrients into the water column by reducing the amount of biomass that will be left to break down in the system.

Summary of Management Events:

- *June – Management Zone Confirmation*
- *July – Application of Chemical Control followed by Mechanical Harvesting*
- *August – Post-treatment Assessment & Survey for remaining population extent delineation*

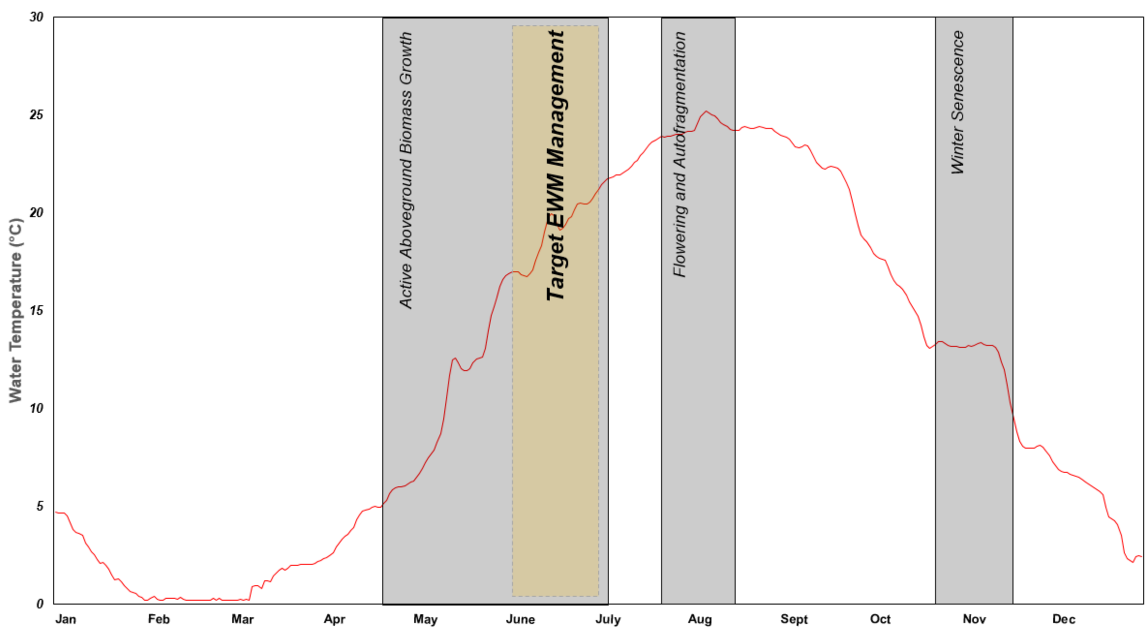


Figure 30. Phenology mapping of Eurasian watermilfoil (EWM) based on seasonal water temperatures at Chautauqua Lake. Target management period is highlighted in yellow.

Algae Management

Although algae and aquatic plants share similar roles in the environment, and are closely connected in aquatic ecosystems, algal and aquatic plant management tactics are quite different. The Harmful Algal Bloom Action Plan for Chautauqua Lake (NYSDEC 2018) outlines critical steps for reducing the presence and continual recurrence of algal blooms in the Chautauqua Lake system. Algal bloom dynamics are closely related to large-scale environmental conditions, such as nutrient loading, temperature, seasonality, water movement, and weather events. With this, algal management efforts should focus on watershed-level or lake-wide initiatives that aim to disrupt driving factors of the process of algal bloom formation when possible - in a proactive approach rather than a reactive approach.

Select algae management techniques, such as the use of algaecides, aeration, and nutrient sequestration technologies, may not be able to completely resolve long-term trends, but can provide temporary relief to localized regions of the lake. This option may be crucial to the mitigation of algal blooms that have the ability to interfere with lake uses such as swimming, boating, and fishing and pose a threat to human health.

It should be noted that dense algal bloom formations can negatively impact submersed aquatic plant distribution and abundance, mainly by blocking available sunlight. In Chautauqua Lake, algal growth has been observed growing directly attached to submersed aquatic plant biomass, as an epiphyte, as well as physically covering biomass, through benthic filamentous growth, which also could have negative consequences for plant health and diversity.

Introductions of non-native macroalgae, such as starry stonewort, require a shift in this standard algal management strategy. The ecological characteristics and life history traits of starry stonewort closely mimic those of a weedy, troublesome aquatic plant species by way of the overwhelming production of bulbils, or reproductive propagules, and fast vegetative growth rates (Larkin et al. 2018). With these features, starry stonewort has been able to outcompete some of the most problematic aquatic plant species, including Eurasian watermilfoil, in shallow, inland waterbodies (Ginn et al. 2021). Because starry stonewort growth and distribution does not fit into the classic definition of a harmful algal bloom, alternate management options for this species should be considered. If left alone, starry stonewort has the ability to disrupt the interconnected functions of Chautauqua Lake's ecosystem – thereby influencing the composition and diversity of the submersed aquatic plant and fishery communities and having a larger impact than the management practices themselves.

Eradication of starry stonewort has proven to be very difficult in systems where it is currently invading. Factors that have influenced the success of management efforts include early detection, aligning timing with phenological growth patterns, and integrated approaches that combine the utility of multiple strategies including chemical and mechanical control options (Glisson et al. 2018).

As of 2023, starry stonewort occupies a relatively small portion of Chautauqua Lake's littoral zone, but has begun to expand outside of isolated coves (starry stonewort presence was recorded at 13, 7, 12, and 24 surveyed sites in 2020 – 2023, respectively) and is now present at multiple sites within the main body of the lake. Management of starry stonewort should begin as soon as feasibly possible at Chautauqua Lake before distribution of the species continues to increase. It is recommended that all management options should be considered for this species at Chautauqua Lake, and that outcomes should be fully documented and reported to add to the current base of knowledge for starry stonewort management in the United States.

Starry stonewort has yet to be targeted for management at Chautauqua Lake. Due to this, there is a lack of a current knowledge base for effective site-specific control methods. North Carolina State University has recommended an operational-scale demonstration project that incorporates use of combinations of both copper-based algaecides and mechanical harvesting. Results of this work would help inform decisions for future long-term management.

General Guidelines

Mechanical Harvesting

Mechanical harvesting efforts at Chautauqua Lake may provide immediate relief to invasive and nuisance plant growth and can be a valuable tool for maintaining open surface water. A standardized approach to mechanical harvesting efforts should be followed:

- Continue small-scale or manual harvesting invasive or nuisance species in near-shore (< 3') management areas
- Ensure that at least 2 feet of SAV biomass remains in main lake (> 3') harvested areas (or 1 foot in High Use Areas)
    - Presence of aquatic plants is beneficial for nutrient uptake, sediment stabilization, habitat for small fish and macroinvertebrates. Due to this, mechanically harvesting plants below a 2 foot threshold could compromise the integrity of the beneficial native submersed plant population at Chautauqua Lake and influence the balance of higher trophic levels
- Examine harvested material in real time
    - Collect floating debris
    - Return harvested fish or other bycatch back to the lake when possible
- Harvest Area Priorities
    - Regions of the lake where mechanical harvesting occurs should be strategically organized. Priority level descriptions are provided in Table 6.

Table 6. Tiered priority classes for management of aquatic plant biomass through mechanical harvesting techniques at Chautauqua Lake

Priority Level	Description
High	• Access sites • Highly used areas (Parks, Hotels, Marinas) • Early season curly-leaf pondweed beds
Moderate	• Regions of the lake where water depth is 5 – 10’ • Recreational boating zones
Low	• Regions of the lake where water depth is greater than 10’
Restricted	• Habitat protection zones • Within 50’ of treatment zones (to prevent reintroduction of target species from fragmentation drift)

Chemical Controls

The use of chemical methods may provide long-term control of target non-native species at selected management sites when implemented appropriately. A standardized approach to chemical management should be followed:

- Treatment timing should be based on target life cycle. Target species as early in their life cycle as possible to inhibit reproduction and nutrient release.
- Streamline permitting process with municipalities to accomplish early treatment
- Refine treatment design and application based on available data

Biological Controls

It is recommended that monitoring of milfoil weevil populations and impacts to Eurasian watermilfoil be monitored periodically. This is especially important in Habitat Protection Zones where low-impact management is mandated. If weevil densities are low in these areas, additional stockings of 3,000 weevils per acre should be considered (Madsen et al. 2000). Note that reduction of overall Eurasian watermilfoil in the lake may impact biocontrol efficacy over time.

<u>Management Monitoring</u>

Monitoring sites at pre- and post-management time points should continue and data used to inform management decisions on an annual basis. For example, if results demonstrate that a treatment was ineffective at controlling curly-leaf pondweed in Year 1, then management operations the following year should be altered to obtain better control. Collected data should include:

- Aquatic Plant Community Ratings
    - Standardized Rake Tosses
    - Biovolume/Sonar Data
    - Total Abundance Estimation
    - Species Abundance Estimation
    - Overall Plant Health
- Water Quality
    - Nutrient sampling (Phosphorus, Nitrogen)
    - Physical profiles (Dissolved Oxygen, Temperature, pH, Chlorophyll-*a*)
- Algal Community
    - Species Composition
    - Species Abundance

Ongoing Research Needs

Despite the decades of scientific research that has been conducted at Chautauqua Lake, there are still many opportunities for research questions evaluated to benefit management of Chautauqua Lake's ecosystem. Improved understanding of management impacts should make management more efficient and non-target effects less pronounced over time. Research projects should provide results that may be applied directly into monitoring or management. Initial research questions may include:

Chemical Control

- Can algaecides or algaecides plus mechanical harvesting be used to manage starry stonewort and prevent bulbil expansion?
- Can florpyrauxifen-benzyl provide improved control of Eurasian watermilfoil in Chautauqua Lake with minimal non-target impacts when applied at specific timings or in consecutive years?
- Can endothall provide improved control of curly-leaf pondweed with minimal non-target impacts when applied at specific timings or in consecutive years?

Invasive Plant Biology

- What are curly-leaf pondweed turion dynamics and how quickly can the turion bank be depleted with management?
- What concentrations of nutrients are released from curly leaf pondweed natural senescence and does this release encourage summer HABs?
- How much spread or density increase occurs from “sparse” non-managed areas?

Chautauqua Lake Ecology

- Are the established fish management areas effectively increasing spawning and long-term success of the Chautauqua Lake fishery?
- Can fish management zones be shifted over time to following change in aquatic plant community structure (e.g. non-native vs. native species presence) to increase fishery productivity?

Monitoring and Permitting

- Can UAVs be utilized to provide rapid and efficient mapping of invasive species to allow streamlined permitting decisions?

Mechanical Harvesting

- Can mechanical harvesting or mechanical harvesting plus algaecides reduce starry stonewort bulbil production?

- Does extensive mechanical harvesting impact the seed production and distribution of native submersed species?
- How many seasonal passes with a mechanical harvester are necessary for submersed species suppression?
- What depth of a cutter blade effectively reduces biomass without compromising water quality and/or nutrient releases?

Aquatic Plant Management Resource Guides

<u>Biology and Control of Aquatic Plants: A Best Management Practices Handbook</u>
Lyn Gettys, William Haller, David Petty (eds.)
Aquatic Ecosystem Restoration Foundation

<u>Eutrophication and Aquatic Plant Management in Massachusetts</u>
Mark Mattson, Paul Godfrey, Regina Barletta, Allison Aiello
University of Massachusetts Water Resources Research Center

<u>Advantages and Disadvantages of Aquatic Plant Management Techniques</u>
John Madsen
US Army Corps of Engineers Aquatic Plant Control Research Program

<u>A Primer on Aquatic Plant Management in New York State (Draft)</u>
NYSDEC Division of Water

References

Barr TC and Ditomaso JM. 2014. Curlyleaf pondweed (*Potamogeton cripus*) turion control with acetic acid and benthic barriers. Journal of Aquatic Plant Management. 52: 31 - 38.

Beets J, Heilman M, Netherland MD. 2019. Large-scale mesocosm evaluation of florpyrauxifen-benzyl, a novel arylpicolinate herbicide, on Eurasian and hybrid watermilfoil and seven native submersed plants. Journal of Aquatic Plant Management. 57: 49 - 55.

Bowmer, KH, SWL Jacobs, GR Sainty. 1995. Identification, biology, and management of Elodea canadensis, Hydrocharitaceae. Journal of Aquatic Plant Management. 33: 13 – 19.

Boylen CW, LW Eichler, JD Madsen. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. Hydrobiologia. 415: 207 – 211.

Brown, KM. 2022. Investigation into the environmental drivers of microcystin and saxitoxin production in harmful algal blooms in Chautauqua Lake, NY. Master’sThesis, Bowling Green State University, Bowling Green, OH.

Casey J and PH Lord. 2022. Chautauqua Lake plant survey in August 2022. SUNY Oneonta Biological Field Station. Cooperstown, New York. 13326. Prepared for Chautauqua Lake Association. Lakewood, NY.

Catling PM and Dobson I. 1985. The biology of Canadian weeds. 69. *Potamogeton crispus* L. Canadian Journal of Plant Science. 65: 655 - 668.

Chautauqua County Department of Planning and Economic Development. 2016. Chautauqua Lake Macrophyte Management Strategy. Available at: https://planningchautauqua.com/wp-content/uploads/2017/03/Part-I-Final.pdf

Chautauqua Lake Association. 2017. Chautauqua Lake Association Work Performance Results for 2017. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2017/06/2017-ACTIVITY-REPORT-092517.pdf

Chautauqua Lake Association. 2018. Chautauqua Lake Association Work Performance Results for 2018. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2018/07/2018-ACTIVITY-REPORT-092318.pdf

Chautauqua Lake Association. 2019. Chautauqua Lake Association Work Performance Results for 2019. Lakewood, NY. https://chautauqualakeassociation.org/wp-content/uploads/2019/07/2019-ACTIVITY-REPORT-101519.pdf

Chautauqua Lake Association. 2020. Chautauqua Lake Association Work Performance Results for 2020. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2020/10/2020-Activity-Summary.pdf

Chautauqua Lake Association. 2021. Chautauqua Lake Association Work Performance Results for 2021. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2021/10/2021-Work-Report-SUMMARY.pdf

Chautauqua Lake Association. 2022. Chautauqua Lake Association Work Performance Results for 2022. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2022/12/CLA22_Full_WORK_REPORTS.pdf

Chautauqua Lake Association. 2023. Chautauqua Lake Association Work Performance Results for 2023. Lakewood, NY. Available at: https://chautauqualakeassociation.org/wp-content/uploads/2023/12/CLA23_Activity_Report_2023.pdf

Committee on the Status of Endangered Wildlife in Canada [COSEWIC]. 2005. COSEWIC assessment and update status report on the hill's pondweed (Potamogeton hillii) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. Vi + 19 pp. Accessed from: https://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_hills_pondweed_e.pdf

Dibble E.D., Killgore, K.J., and G.O. Dick. 1996. Measurement of plant architecture in seven aquatic plants. Journal of Freshwater Ecology. 11:311-318.

Engel S. 1990. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. J Aquatic Plant Management 28:41-45.

ESNR Corporation. 2007. Use of the aquatic herbicide triclopyr Renovate in the State of New York, supplemental environmental impact statement. Document Number 10746-001-310. Available at: https://www.dec.ny.gov/docs/materials_minerals_pdf/triclopyrseis.pdf

Fukuhara H., Tanaka T., and M. Izumi. 1997. Growth and turion formation of *Ceratophyllum demersum* in a shallow lake in Japan. Japanese Journal of Limnology. 58: 335 – 347.

Ginn, BK. EFS Dias, T Fleischaker. 2021. Trends in submersed aquatic plant communities in a large, inland lake: impacts of an invasion by starry stonewort (*Nitellopsis obtusa*). Lake and Reservoir Management.

Glisson WJ, Wagner CK, McComas SR, Farnum K, Verhoeven MR, Muthukrishnan R, Larkin DJ. 2018. Response of the invasive alga starry stonewort (Nitellopsis obtusa) to control efforts in a Minnesota lake. Lake and Reservoir Management.

Gorham SB, Seyoum S, Furman BT, Darnell KM, Reynolds LK, Tringali MD. 2021. Molecular detection of a non-native hybrid eelgrass, Vallisneria spiralis Linnaeus (1753) × V. denseserrulata Makino (1921), in the southeastern United States. Aquatic Botany, 175.

Grace, J.B., and R.G. Wetzel. 1978. The production biology of Eurasian watermilfoil (*Myriophyllum spicatum L*.): A review. Journal of Aquatic Plant Management. 16: 1 – 11.

Haller WT, JV Shireman & DF Durant. 1980. Fish Harvest Resulting from Mechanical Control of Hydrilla, Transactions of the American Fisheries Society, 109:5, 517-520, DOI: 10.1577/1548-8659(1980)109<517:FHRFMC>2.0.CO;2

Harman WN. 1974. Phenology and physiognomy of the hydrophyte community in Otsego Lake, NY. Rhodora. 76(808): 497 – 508.

Harms N., Grodowitz, M., and J. Kennedy. 2011. Insect herbivores of water stargrass (Heteranthera dubia) in the US. Journal of Freshwater Ecology. 26(2): 185-194.

Havel JE, SE Knight, KA Maxson. 2017. A field test on the effectiveness of milfoil weevil for controlling Eurasian watermilfoil in Wisconsin Lakes. Hydrobiologia. 800: 81 – 97.

Haynes RR and LB Holm-Nielsen. 2003. Potamogetonaceae. Flora Neotropica Monograph 85. New York Botanical Garden. Bronx, NY.

Heiskary S, and RD Valley. 2012. Curly-leaf pondweed trends and interrelationships with water quality. Minnesota Department of Natural Resources Investigational Report 558.

Hellquist, CB. 1984. Observations of Potamogeton hillii Morong in North America. Rhodora. 86:101-111.

Hollingsworth, EB. 1966. Water stargrass as an aquatic weed. Fayetteville: University of Arkansas Agricultural Experiment Station. Bulletin 705.

Horn, C.N. 1981. Life history of *Heteranthera dubia* (Jacq.) Macm. (water star-grass) (Pontederiaceae) with respect to seasonal and environmental effects on morphology. Clear Technical Report No. 214. The Ohio State University Center for Lake Erie Research. Columbus, OH.

Jarvis JC and KA Moore. 2008. Influence of environmental factors on *Vallisneria americana* seed germination. Aquatic botany. 88: 283 – 294.

Jester LL, MA Bozek, DR Helsel, and SP Sheldon. 2000. Euhrychiopsis lecontei distribution, abundance, and experimental augmentations for Eurasian watermilfoil control in Wisconsin Lakes. Journal of Aquatic Plant Management 38:88-97.

Korschgen CE and WL Green. 1988. American wildcelery (Vallisneria americana): ecological considerations for restoration. US Fish and Wildlife Technical Report 19. Washington, DC.

Kunii, H. 1982. Life cycle and growth of *Potamogeton crispus* L. in a shallow pond, Ojaga-ike. Botanical Magazine, Tokyo. 95: 109 – 124.

Laitala KL, Prather TS, Thill D, Kennedy B, Caudill C. 2012. Efficacy of benthic barriers as a control measure for Eurasian watermilfoil. Invasive Plant Science and Management. 5(2): 170 - 177.

Larkin DJ, AK Monfils, A Boissezon, RS Sleith, PM Skawinski, CH Welling, BC Cahill, KG Karol. 2018. Biology, ecology, and management of starry stonewort (*Nitellopsis obtusa*; Characeae): a red-listed Eurasian green algae invasive in North America. Aquatic Botany. 148: 15 – 24.

Les, DH, EL Peredo, NP Tippery, LK Benoit, H Razifard, UM King, HR Na, HK Choi, L Chen, RK Shannon, SP Sheldon. 2015. *Najas minor* (Hydrocharitaceae) in North America: a reappraisal. Aquatic Botany. 126: 60 - 72.

Legard, C. 2015. Chautauqua Lake status of fisheries 2014. New York State Department of Environmental Conservation Division of Fish, Wildlife, and Marine Resources, Bureau of Fisheries. Albany, New York. Available at: https://www.wewanchu.com/wp-content/uploads/2016/04/Chautauqua-Lake-status-of-fisheries-2014-Legard.pdf

Lynch Jr, WE. 2009. Chemical control of aquatic plants. The Ohio State University Extension, Agriculture and Natural Resources Fact Sheet A-4-09. Available at: https://medina.osu.edu/sites/medina/files/imce/AGNR/Handouts/A4_09_chemical%20control%20of%20aquatic%20plants.pdf

Madsen JD. 2000. Advantages and disadvantages of aquatic plant management techniques. US Army Engineer Research and Development Center, Vicksburg, MS.

Madsen JD, HA Crosson, KS Hamel, MA Hilovsky, CH Welling. 2000. Panel discussion: management of Eurasian watermilfoil in the United States using native insects: state regulatory and management issues. Journal of Aquatic Plant Management. 38: 121 – 124.

Massachusetts Department of Agricultural Resources. 2017A. Active Ingredient Fact Sheets: 2,4-D. Available at: https://www.mass.gov/doc/24-d/

Massachusetts Department of Agricultural Resources. 2017B. Active Ingredient Fact Sheets: Diquat Appendix. Available at: https://www.mass.gov/doc/diquat-appendix/

Massachusetts Department of Agricultural Resources. 2017C. Active Ingredient Fact Sheets: Endothall. Available at: https://www.mass.gov/doc/endothall

Mattson, MD, PJ Godfrey, RA Barletta and A Aiello. 2003. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J. Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. Available at: https://archives.lib.state.ma.us/bitstream/handle/2452/36454/ocn244301077.pdf?sequence=1

Menninger H. 2011. A review of the science and management of Eurasian watermilfoil: Recommendations for future action in New York State. Cornell University.

Mobitrac USA. 2023. Products. Web page. Available at: https://www.mobitrac-usa.com/products/

Mudge, C.R. 2013. Impact of aquatic herbicide combinations of nontarget submersed plants. Journal of Aquatic Plant Management. 51:39-44.

Mudge CR and LM Glomski. 2012. Impact of herbicide combinations on two biotypes of the submersed plant Vallisneria americana. APCRP Technical Notes Collection (ERDC/TN APCRP-CC-17). Vicksburg, MS. US Army Engineer Research and Development Center. http://ed.erdc.usace.army.mil/aqua/

Mudge, C.R., Sartain, B.T., Getsinger, K.D., and M.D. Netherland. 2021. Efficacy of florpyrauxifen-benzyl on dioecious hydrilla and hybrid water milfoil - concentration and exposure time requirements. US Army Corps of Engineers Engineer Research and Development Center. Aquatic Plant Control Research Program. EL TR-21-8.

Muenscher WC. 1936. The germination of seeds by Potamogeton. Annals of Botany. 50 (200): 805 – 821.

Netherland MD, JD Skogerboe, CS Owens, JD Madsen. 2000. Influence of water temperature on the efficacy of diquat and endothall versus curlyleaf pondweed. Journal of Aquatic Plant Management. 38:25-32.

New Hampshire Department of Environmental Services. 2019. Environmental Fact Sheet WB-BB-3: Lake Eutrophication. Concord, NH 03301. Available at: https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/bb-3.pdf

New York Natural Heritage Program. 2023. Online conservation guide for Potamogeton hillii. Available at: https://guides.nynhp.org/hills-pondweed/

New York Natural Heritage Program. 2024. Report on State-listed animals (Chautauqua Lake). Albany, NY.

New York State Invasive Species Council. 2010. Final report: a regulatory system for non-native species. Appendix H. Invasiveness Assessment Results – Plants. Available at https://nyis.info/wp-content/uploads/2018/07/Regulatory-System-for-Non-Native-Species.pdf

New York State Department of Environmental Conservation. 2023. Chautauqua Lake. Available at: https://www.dec.ny.gov/outdoor/9230.html

New York State Department of Environmental Conservation. 2022. New York State 303(d) List of Impaired Waterbodies. New York State Department of Environmental Conservation, Division of Water, Bureau of Water Assessment and Management. Available at: https://www.dec.ny.gov/chemical/31290.html

New York State Department of Environmental Conservation. 2018. Harmful algal bloom action plan Chautauqua Lake. Available at: https://extapps.dec.ny.gov/docs/water_pdf/chautauquahabplan.pdf

New York State Department of Environmental Conservation Bureau of Fisheries. 2019. Technical Brief #TB919108. 2019 Chautauqua Lake Annual Fall Walleye Survey. Available at: https://www.dec.ny.gov/docs/fish_marine_pdf/tb919108.pdf

New York State Department of Environmental Conservation Division of Water. 2005. A primer on aquatic plant management in New York State. Available at: https://www.dec.ny.gov/docs/water_pdf/ch6apr05.pdf

New York State Department of Environmental Conservation Citizens Statewide Lake Assessment Program. 2022. Chautauqua N CSLAP Site 33 – 2022 Sampling Season Results Available at: https://www.dec.ny.gov/data/IF/CSLAP/2022_CSLAPreport_CHAUTAUQUA%20N%20CSLAP%20SITE%2033(0202CHA0122).html

New York State Department of Environmental Conservation Citizens Statewide Lake Assessment Program. 2022. Chautauqua S CSLAP Site 33.1 – 2022 Sampling Season Results. Available at: https://www.dec.ny.gov/data/IF/CSLAP/2022_CSLAPreport_CHAUTAUQUA%20S%20CSLAP%20SITE%2033.1(0202CHA0122).html

New York State Department of Environmental Conservation and the Cadmus Group. 2012. Total Maximum Daily Load (TMDL) for Phosphorus in Chautauqua Lake, Chautauqua County, NY. Available at: https://www.dec.ny.gov/docs/water_pdf/tmdlchautlk12.pdf

Newman RM and WG Inglis. 2009. Distribution and abundance of the milfoil weevil, Euhrychiopsis lecontei, in Lake Minnetonka and relation to milfoil harvesting. Journal of Aquatic Plant Management. 47: 21 – 25.

[NCSU] North Carolina State University. 2020. Chautauqua Lake monitoring program submersed aquatic vegetation survey results - August 2020. Prepared for Chautauqua Lake Partnership, Bemus Point, NY.

[NCSU] North Carolina State University. 2021. Chautauqua Lake Monitoring Program Submersed Aquatic Vegetation Survey Results - August 2021. Prepared for Chautauqua Lake Partnership, Bemus Point, NY.

[NCSU] North Carolina State University. 2022. Chautauqua Lake Monitoring Program Submersed Aquatic Vegetation Survey Results - August 2022. Prepared for Chautauqua Lake Partnership, Bemus Point, NY.

[NCSU] North Carolina State University. 2023. Chautauqua Lake monitoring program submersed aquatic vegetation survey results - August 2023. Prepared for Chautauqua Lake Partnership, Bemus Point, NY.

NYSFOLA. 2009. Diet for a small lake: the expanded guide to New York State lake and watershed management. New York State Federation of Lake Associations, Inc.

Nicholson, SA. 1981. Changes in submersed macrophytes in Chautauqua Lake, 1937 – 1975. Freshwater Biology. 11: 523 – 530.

Ortiz MF, SJ Nissen, CJ Gray. 2019. Endothall behavior in *Myriophyllum spicatum* and *Hydrilla verticillata*. Pest Management Science. 75: 2942-2947.

Pullman GD and G Crawford. 2010. A decade of starry stonewort in Michigan. Article. Lakeline Magazine. North American Lake Management Society.

Raj AV, and P Jamwal. 2020. How do excess nutrients cause problems in lakes? Insight Article #5: Centre for Social and Environmental Innovation, ATREE.

Richardson RJ, RL Roten, AM West, SL True, and AP Gardner. 2008. Response of selected aquatic invasive weeds to flumioxaxin and carfentrazone-ethyl. Journal of Aquatic Plant Management. 46: 154 – 158.

Rooney MK, VM Covert, and RL JohnsonLake summer 2021 status of Chautauqua Lake's aquatic macrophytes community and associated invertebrates. Racine Johnson Aquatic Biologists. Ithaca, NY.

Rooney MK, RL Johnson, NC Rutkowski. 2023. Insect herbivore monitoring in Chautauqua Lake 2023. Rooney's Aquatic Biologists. Groton, New York 13073.

Selden G. 2015. Aquatic herbicide mode of action and use implications. Southern Regional Aquaculture Center. Publication Number 3602.

Serafy JE, RM Harrell & LM Hurley. 1994. Mechanical Removal of Hydrilla in the Potomac River, Maryland: Local Impacts on Vegetation and Associated Fishes, Journal of Freshwater Ecology, 9:2, 135-143, DOI: 10.1080/02705060.1994.9664440

Skogerboe, J.G., and K.D. Getsinger. 2001. Endothall species selectivity evaluation: southern latitude aquatic plant community. Journal of Aquatic Plant Management. 39:129-135.

Smith CS and Barko JW. 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management. 28: 55 - 64.

Solitude Lake Management. 2023. Harvesting, dredging & hydro-raking: which solution is best? Web Page. Available at: https://www.solitudelakemanagement.com/harvesting-hydro-raking-mechanical-solution-best/

Solitude Lake Management. 2019. 2019 delineation of aquatic vegetation in Chautauqua Lake. Worchester, NY.

Solitude Lake Management. 2018. 2018 delineation of non-native macrophytes and other submersed aquatic vegetation (SAV) in Chautauqua Lake. Shrewsbury, MA.

Sprecher, S.L. 1994. Herbicide concentration/exposure times: effects on nontarget plants. Proceedings, 29th Annual Meeting, Aquatic Plant Control Research Program. Vicksburg, MS. pp. 51-58.

Stuzenbaker, C.D. 1999. Aquatic and wetland plants of the western gulf coast. TPWD Press, Austin.

Turnage, G, JD Madsen, RM Wersal. 2018. Phenology of curlyleaf pondweed (Potamogeton crispus L.) in a southeastern United States: a two-year mesocosm study. Journal of Aquatic Plant Management. 56:35-38.

United States Geological Survey. 2016. Land Cover, New York. National Land Cover Database. Cornell University Geospatial Information Repository. Available at: https://cugir.library.cornell.edu/catalog/cugir-009031

United States Geological Survey. 2023. Nonindigenous Aquatic Species: Species Lists by State. Web Page. Available at: https://nas.er.usgs.gov/queries/statesearch.aspx

Vermont Department of Environmental Conservation. 2022. Permitting aquatic herbicide projects in Vermont. Lakes and Ponds Management Protection Program. Available at: https://dec.vermont.gov/sites/dec/files/wsm/lakes/ANC/docs

Wiegleb, G and Z Kaplan. 1998. An account of the species of Potamogeton L. (Potamogetonaceae). Folia Geobotanica. 33: 241 – 316.

Willis BE and WM Bishop. 2016. Understanding fate and effects of copper pesticides in aquatic systems. Journal of Geoscience and Environmental Protection. Vol 4.

Wisconsin Department of Natural Resources. 2012. Flumioxazin chemical fact sheet. DNR PUB-WT-971. Madison, WI. Available at: https://dnr.wisconsin.gov/topic/lakes/plants/factsheets

Wishah, L., and C.R. Morningstar, 2023, *Elodea canadensis*: U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL. Available at: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2843

Wolf, T. 2020. 2.4 Curlyleaf Pondweed. *In* 4th Edition Biology and Control of Aquatic Plants: A Best Management Practices Handbook. Lyn A. Gettys, William T. Haller and David G. Petty, editors. Pg 39-42.

Yanran D., Chenrong J., Wei, L. Shenghua, H., and W. Zhenbin. 2012. Effects of the submerged macrophyte Ceratophyllum demersum L. on restoration of a eutrophic waterbody and its optimal coverage. Ecological Engineering. 40:113 – 116.