WATER CHESTNUT MANAGEMENT
GUIDANCE & FIVE-YEAR MANAGEMENT PLAN
FOR THE SUDBURY, ASSABET, & CONCORD RIVER WATERSHED

February 2017
Revised August 2024

OARS

ACKNOWLEDGEMENTS

This Guidance and Plan document was produced in 2017 by OARS through the "Planning and Guidance for Water Chestnut Management in the SuAsCo Watershed" project. We would like to thank the members of the project's Technical Advisory Committee who contributed their time and ideas to this document. It has been revised in 2024 with input from members of the Aquatic Invasives Management Subcommittee (AIMS) of the SuAsCo Cooperative Invasive Species Management Area (CISMA), with special thanks to Michele Grzenda (Conservation Director, Lincoln), Becca Solomon (Conservation Agent, Ashland), and Kara Sliwoski (Program Manager, DCR Lakes and Ponds). We are grateful to the Fleetwing Charitable Family Foundation for its support for this revised edition.

This work was prepared by OARS staff, and any errors or omissions are OARS' responsibility. The Guidance is intended as a living document, and we will endeavor to keep it up to date with the help of its readers and users.

EXECUTIVE SUMMARY

Rivers, lakes, and ponds across the Commonwealth of Massachusetts are being choked by invasive water chestnut (*Trapa natans*). The result is degraded ecology and habitat value, loss of recreational value, and the high cost of management efforts. It can be challenging to figure out how to effectively manage water chestnut due to diverse approaches to permitting, cost, evolving management methods, and the effects of a shifting climate. This Guidance provides the latest research and management experience compiled for Conservation Commissions, communities, researchers, and other stakeholders to use in developing effective management approaches and plans. The document reviews the control options and permitting needs for each option and provides model language for permitting under the Wetlands Protection Act for use by both applicants and Commissions. It includes a 5-year Water Chestnut Management Plan, 2024–2029 for the Sudbury, Assabet, and Concord rivers watershed, as well as extensive references. It is intended to be a living document.

OARS 3 Rivers
August 2024

Executive Director
Matt Brown

Report Design
Sarah Kwan

On the Cover
Community water chestnut pull in Billerica, 2023 along the Concord River.

Technical Advisory Committee 2015/2016
Tom Largy (Wayland Surface Water Quality Committee)
Ron Chick (Framingham resident)
Frank Lyons (Hop Brook Protection Association)
Judy Schmitz (DEP Wetlands Circuit Rider, Central Region)
Lealdon Langley (DEP)
Michael Stroman (DEP)
Tom Flannery (DCR Lakes and Ponds)
Michele Girard (MACC—Massachusetts Associations of Conservation Commissions)
Eileen McGourty (US F&W)
Delia Kaye (Concord Natural Resources)
Dave McKinnon (Lincoln Conservation Dept)
Amber Carr (SuAsCo CISMA, by phone)
Jeff Castellani (Aquatic Control Technology)
Alison Field-Juma (OARS)
Sue Flint (OARS)
Jessica Furbeck (OARS)

Water Chestnut clogging the Talbot Mills Dam Impoundment along the Concord River in Billerica, Sept 2024, Photo Credit: Sterling Worrell

CONTENTS

TABLES & FIGURES

APPENDICES

The water chestnut genus *Trapa* is currently classified in the *Lythraceae* family (integrated taxonomic information system, 2016). Previously water chestnut was classified as a separate family, *Trapaceae* (Crow and Hellquist, 2000; muenscher, 1944) or *Hydrocaryaceae* (gleason and cronquist, 1963), with one genus, *Trapa*. There are between 2 and 11 species listed by various sources under the *Trapa* genus, the most common being *T. Natans* and *T. Bicornis*. The two-horned *T. Bispinosa* was documented in 2014 in the tidal potomac river in virginia (Sweany, 2023). The focus of this literature review is *T. Natans* l., which is invasive in north america. *Trapa* species should not be confused with the edible corms of the "chinese water chestnut" (*Eleocharis Dulcis*) commonly used in asian cuisine. Water chestnut is listed as a prohibited plant in massachusetts and trade is banned (Wong, 2023).

HISTORY

Water chestnut, *Trapa spp*., is an annual aquatic plant native to temperate and tropical Europe, Asia, and Africa. Archeological records suggest that *Trapa natans* was once widespread in northern Europe, but it is now nearly extirpated from the region (Hummel and Kiviat, 2004; Karg, 2006). Recently, due to increasing average temperatures across Europe, water chestnut populations have begun to spread in Germany, Poland, and Ukraine, reclaiming some habitat that was once lost (Walusiak *et al.*, 2023). *T. natans* is still an important agricultural product in China and India where the nuts are used in a variety of dishes (Kundu and Joshi, 2012). Although reportedly an important food in early European history, the nuts of *T. natans* are not known to be consumed in North America except by squirrels and other wildlife (Hummel and Kiviat, 2004).

While accounts vary, most agree that *Trapa natans* was introduced to North America in Middlesex County, Massachusetts, in the 1870s (Countryman, 1978). By 1874, the plant was cultivated in the Asa Gray Botanical Garden at Harvard University in Cambridge, Massachusetts. Louis Guerineau, the gardener at the botanical garden, introduced it to Fresh Pond and several other ponds in Cambridge, Massachusetts, as an ornamental (Davenport, 1879). Davenport reported personally bringing nuts to Minor Pratt in Concord, Massachusetts, where they placed the nuts and plants in a pond near the Sudbury River, remarking "but that so fine a plant as this, with its handsome leafy rosettes, and edible nuts, which would, if common, be as attractive to boys as hickory nuts now are, can ever become a

Figure 1: Water chestnut, Sudbury River, Framingham, 2016

'nuisance' I can scarcely believe." In 1886, Father J. Hermann Wibbe independently introduced the plant to Sanders Lake (now Collins Lake) near Schenectady, New York (Countryman, 1978). Over the last 150 years, water chestnut spread from Sanders Lake down the Mohawk River into the Hudson River and from eastern Massachusetts across the region. It was first documented in the southern end of Lake Champlain in the early 1940s (Countryman, 1970) in a tributary to the Chesapeake Bay, Maryland, in 1955 (Allen and Strain, 2013) and in Quebec, Canada by 1998, and in the Connecticut River system in 1999.

Water chestnut has been observed in 18 rivers and 96 lakes within 17 of the 33 major watersheds in Massachusetts (Wong, 2023).

Although T. natans had been in the Sudbury and Concord

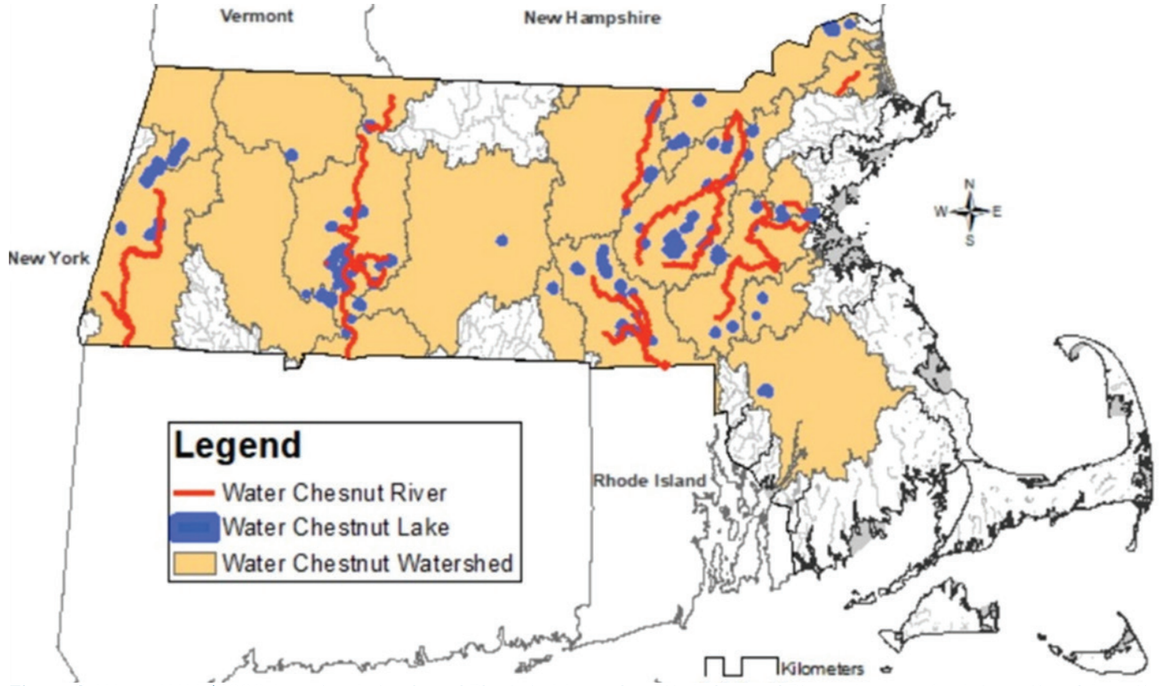


Figure 2: Wong, W.H. (2023. Invasive Animals and Plants in Massachusetts Lakes and Rivers: Lessons for International Aquatic Management (1st ed.). CRC Press. [*link*]

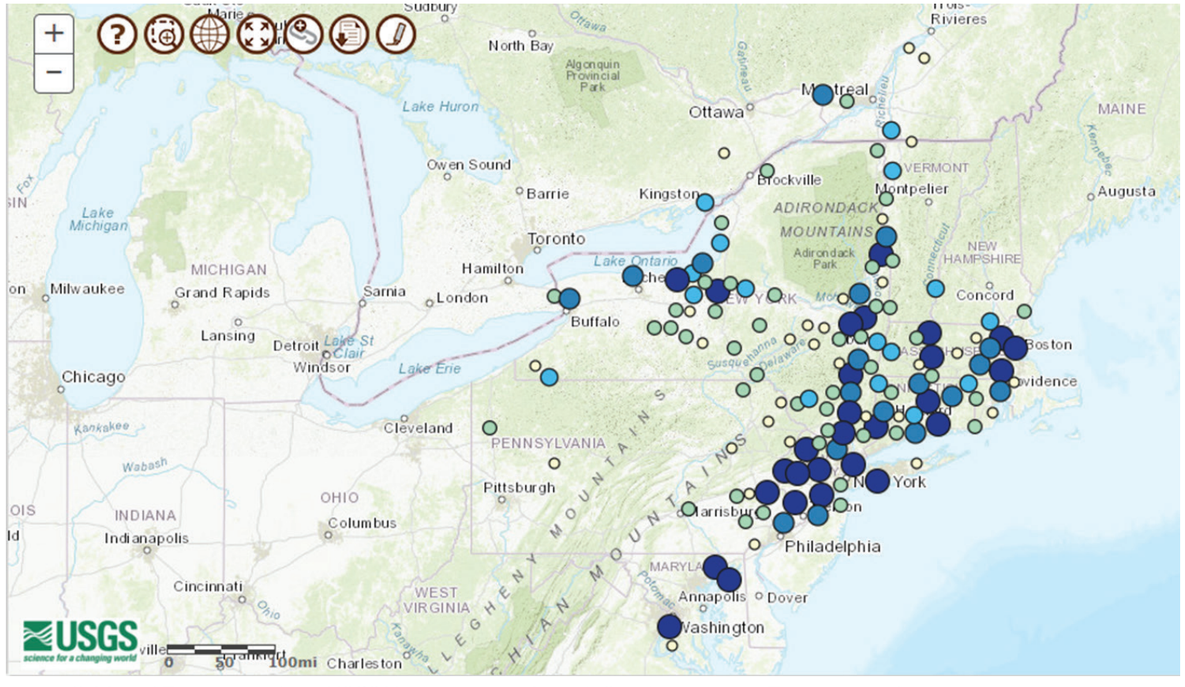


Figure 3: Map of *Trapa natans* from USGS Nonindigenous Aquatic Species database. The number of records does not imply species abundance. The map represents collection records only and may not reflect the actual distribution of estimated populations.

Rivers since 1886, it was reported to grow suddenly to nuisance proportions by 1945. (Eaton, 1947) reported "the still more spectacular explosion of the … water chestnut (*Trapa natans*) that took place in our part of the river [Sudbury River from Fairhaven Bay to Concord Village] summer before last and which continued during this past summer. … last summer it so multiplied in our stretch that no water at all was to be seen, except along the thread of the stream." Eaton attributed the explosion of both *Trapa* and *Lemna* (duckweed) on the Sudbury to the increase in "alkaline sewage wastes," as measured by soluble nitrates in the river. The plant continues to spread along waterways and in lakes and ponds through accidental introductions. Efforts to control the plant followed in the wake of these introductions and have been ongoing for several decades. Populations have been documented from Kentucky to Quebec (EDD Maps, 2024).

The lesson from this history and current efforts is that water chestnut, like any highly adaptable invasive species, is incredibly hard to eliminate entirely. Smaller infestations with intense management may be eliminated, but larger infestations may only be manageable, as complete eradication may not be possible. The goal of this Guidance and Plan is to assist in long term, committed management that restores ecological health and recreation, reduces spread, reduces the cost of management, and engages the community for the long run.

BIOLOGY

ANATOMY

Trapa natans is easily identified by its distinctive floating rosettes of leaves. The leaves on the water surface are alternate, green, and triangular with a toothed edge, a glossy upper surface, and a lower surface covered with soft hairs. The floating leaves form rosettes from 10" to 15" in diameter by late July (Groth *et al.*, 1996; OARS, 2013) with leaves surrounding a central stem, kept afloat by petioles with air bladders. Small white flowers are borne in axils of the floating leaves. The fruits are large woody nuts with four sharp, recurved barbs. Below the water surface is a cord-like stem 2–5 meters long with feathery, leaf-like structures in opposite pairs along the stem. These plume-like structures are variously considered stipules, leaves, or adventitious roots. Further down the stem are black feathery roots which reach down into the soft sediment. Each stem may produce several branches, each terminating in a rosette (Crow and Hellquist, 1983; Crow and Hellquist, 2000; Gleason and Cronquist, 1963; Muenscher, 1944).

LIFE CYCLE & HABITAT

Trapa natans is an annual plant, growing each year from seed (nut) and dying back by the end of the growing season. Most nuts sink to the bottom of the water body where they were produced. The nuts overwinter in the soft sediment and germinate the bed of *T. natans* at that site the following year or years (Hummel and Kiviat, 2004).

A portion of the seeds produced each year germinate in the following spring, the remainder accumulates and creates a seed bank; seeds in the sediments are viable for up to 10–15 years (Methe *et al.*, 1993; T. Largy, pers. comm.). To germinate, seeds must have a period of dormancy at cold temperatures (< 8°C) (Kurihara and Ikusima, 1991; Des Jardin, 2015); they germinate in the spring when water temperatures reach about 12°C. Des Jardin (2015) found that seeds germinate fastest at moderately warm temperatures (17–19°C) but will germinate at a range of water temperatures from 10°C to 24°C, and the final overall germination rate was found to be unaffected by these temperature ranges. Contradicting earlier reports that the plants require full sun, Des Jardin (2015) also reported that they are tolerant of partial shade.

In eastern Massachusetts, seeds typically germinate in May, with the first flat leaves reaching the water surface by early to mid-June, forming the floating rosette. Though it is important to note that with a changing climate and increased temperatures, this growing schedule is anticipated to shift moving forward.

The roots of the plant are anchored in the sediment. Secondary branches and rosettes appear from the time the first leaves reach the surface until the first nuts are set (usually late July), at which point the number of rosettes per plant stabilizes (Groth *et al.*, 1996). Each plant may branch to produce up to 10-15 rosettes. Leaves are produced from the meristem (growing tip of the stem) throughout the growing season as the stem elongates. Submersed leaves drop early and are replaced by pairs of fine, dissected leaves along the stem (Hummel

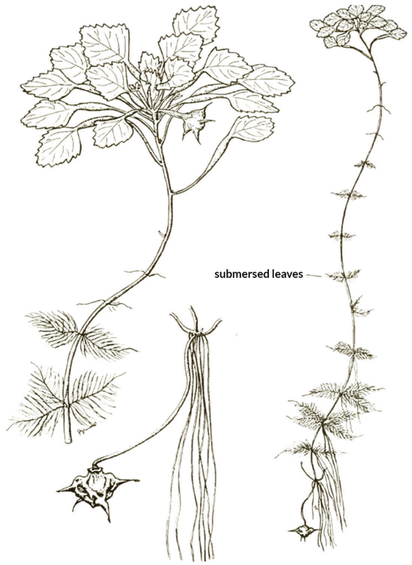


Figure 4: *Trapa natans* from: Crow & Hellquist, 1983, Used with permission by Milne Special Collections and Archives Dept, University of New Hampshire, Durham, NH.

and Kiviat, 2004). Small four-petal, white flowers are borne singly in the axils of floating leaves from late June to September (Hummel and Kiviat, 2004). Pollination occurs via self-pollination, cross-pollination, or by insects. Kadono and Schneider (1986) reported that the flowers are most often visited by beetles and true bugs (*Coleoptera* and *Hemiptera*).

After fertilization, the peduncle holding the flower bends down into the water where the one-seeded green nut forms. Each rosette may produce 10–15 nuts (O'Neill, 2006). The plant continues to bloom and fruit into the fall or when cold temperatures end the season (S. Flint, pers. observation). When the seeds are mature, usually by early August, the nuts start to fall off and sink to the bottom of the water body and lodge in the sediment. The outer fruit layer of the nut disintegrates quickly to reveal a hard, black, woody nut with sharp barbed spikes. Although nut production is reduced, a rosette separated from its root can continue to produce nuts (Methe *et al.*, 1993) and a stem can branch and form new rosettes by mid-August if the main stem is broken earlier in the summer (S. Flint, pers. observation). Ultimately each germinating nut could produce up to 300 new nuts in a single season.

Water chestnut thrives in slow moving, nutrient-rich fresh water of ponds, lakes, and rivers with muddy bottoms (Takamura *et al.*, 2003). The plant prefers pH of 6.7–8.2 and tolerates salinity up to 0.1% and alkalinity of 12–128 mg/L calcium carbonate (Crow and Hellquist, 1983). It rarely grows where the substrate is low in organic matter or there is a swift current; the stems are weak, and the plant is lightly rooted in the sediments by thin roots and the empty nut hull. It can survive in tidal freshwater marshes, such as the Hudson River (Coote *et al.*, 2001) and can grow in depths up to 5 meters but is most abundant in water around 2 meters deep (Muenscher, 1944).

Plant density affects many aspects of water chestnut growth and vigor since they compete for two-dimensional water surface space rather than three-dimensional canopy space like terrestrial plants. *Trapa natans* in initially low-density plots (5–15 rosettes/square meter) are larger, more productive, and longer-lived than plants in high density plots (>100 rosettes/square meter). Compared with plants in high density plots, low-density plants can have 5 times more rosettes and 8–10 times the biomass (Groth *et al.*, 1996). Groth *et al.* reported that the largest plant from low-density plots bore 27 rosettes, while the largest from high density bore only five rosettes. In addition, low-density plants showed practically no mortality until the entire plant senesced in September, whereas rosettes of plants at high-density suffered continuous mortality, particularly to the secondary rosettes, through the growing season (Groth *et al.*, 1996).

Two-horned water chestnut (*T. bispinosa*) is a distinct species of the *Trapa* genus that was first documented in the United States in 2014 in the tidal Potomac River in Lorton, Virginia (Sweany, 2023). *T. bispinosa* is very similar to *T. natans* in appearance, forming floating rosettes and nuts, however *T. bispinosa* has a red coloration on the underside of its leaves and its nuts have only two spines (Chorak *et al.*, 2019). When it was initially discovered in 2014, *T. bispinosa* was mistaken for *T. natans*, it was only after genetic research in 2019 that the distinction was made. In 2022, *T. bispinosa* was discovered to have spread from the Potomac to many other waterbodies in Maryland and Virgina (Sweany, 2023). *T. bispinosa* has the same invasive potential as *T. natans*, and forms almost identical dense floating mats. Although it has only been documented in Virginia and Maryland, care should be taken to identify plants suspected to be *T. natans* to ensure it is not a cryptic invasion of *T. bispinosa*.

Trapa natans Identification Photos

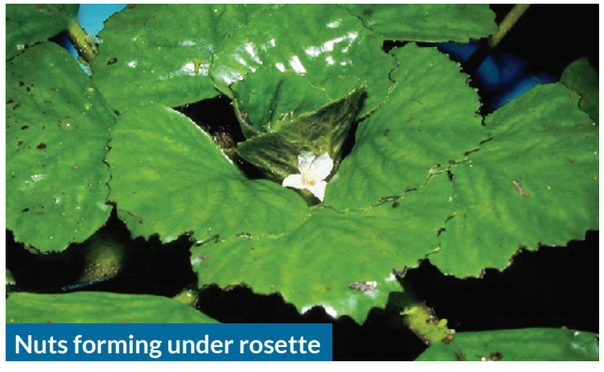
Dry nut

Nut sprouting—with roots and underwater leaves

Mature nut—late August

Mature nut—bisected

Flower on short peduncle



Nuts forming under rosette

Underwater leaves—late August

Underwater leaves—late August

Rosette close up—new leaves from center

Nuts forming under rosette

Petioles with air bladders—late August

Petioles—bisected

Immature nut—early July

Immature nut—bisected

Large rosette with secondary rosette—July 20

Volunteer water chestnut pull—July 15

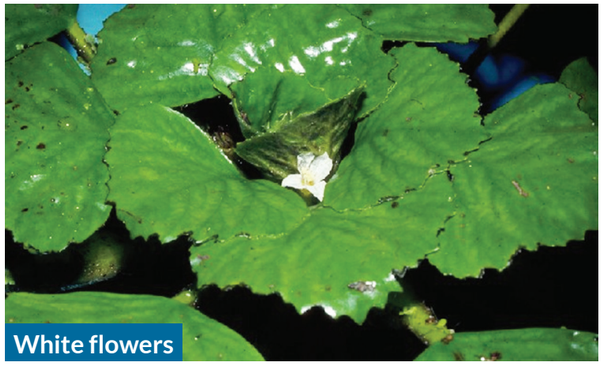
Trapa natans and *Trapa bispinosa* comparison


Trapa natans


Trapa bispinosa— photo credit: Kevin Heffernan, DCR, VA


Green underside


Red underside


White flowers


Pink flowers


Four spines

Two spines

NATURAL ENEMIES

In water chestnut's native range there are a number of natural enemies that could potentially be harnessed to control *T. natans* populations in North America. Field surveys identified 17 species (including insects, mollusks, fungi, and other pathogens) in Asia and 7 insects in Western Europe feeding on *Trapa* species. Several were investigated further: *Galerucella nymphaeae* L. (water lily beetle), *Galerucella birmanica* (beetle), and *Nanophyes japonica* (weevil) (Ding and Blossey, 2005). Of these, *G. birmanica* was the most damaging to water chestnut and the most promising for biological control (Pemberton, 1999; Pemberton 2002; Ding *et al*., 2006a; Ding *et al.*, 2006b). A North American beetle, *Pyrrhalta nymphaeae*, has also been reported to graze on *Trapa natans* in the Hudson River, but not extensively enough to inhibit nut production (Schmidt, 1986).

Research by Dr. Bernd Blossey at Cornell University's Department of Natural Resources and the Environment demonstrated that feeding by *G. birmanica* "is likely to reduce *T. natans* population growth rates in North America" (Blossey *et al.*, 2018) and has promise as a potential biological control for water chestnut. Host specificity is key to approval of any biological control agent, and the beetle was found to also feed on the non-target plant water shield (*Brasenia schreberi*). However, this was found to present a low level of risk to water shield (Simmons and Blossey, 2023).

Simmons and Blossey conclude that their "findings suggest that widespread and safe biocontrol of *T. natans* in North America appears promising if *G. birmanica* is granted release approval by regulatory agencies." As of 2023, *G. birmanica* was restricted to a quarantine facility and had not been approved for release by the US Department of Agriculture (Wong, 2023). *G. calamarensis* and *G. pusilla* beetle species are currently used widely for biocontrol of purple loosestrife to which they are host-specific (Shelton, 2024).

DISPERSAL

Initially the greatest dispersal vector of *T. natans* in New England was intentional human introduction (Hummel and Kiviat, 2004; Les and Mehrhoff, 1999). *T. natans* has been listed as a nuisance or noxious species in 11 states, including Massachusetts, although not at the federal level. As a result, intentional spread has likely stopped. However, nuts can still be distributed due to human activity by getting caught on nets, boats, construction equipment, and in excavated sediment.

The sharply barbed nuts can cling to the feathers of waterfowl (MISC, accessed 2019) and the fur of animals, which may also play a role in their dispersal, as well as in sediment washed downstream in floods. Propagation downstream can also occur by rosettes with nuts breaking off the stem and floating with the current to populate a new area with suitable substrate.



Figure 5: Canada geese forage in and spread water chestnut; Water chestnut on the edge of dam, Billerica, Sept. 2016
Photos: Nancy Rybicki, USGS; OARS

IMPACTS

ECOLOGICAL IMPACTS

Water chestnut can cover nearly 100% of the water surface, intercepting over 95% of sunlight (Caraco and Cole, 2002). The floating mats of vegetation shade out other submerged plants and can create large diurnal changes in the dissolved oxygen concentration in the water column (Kornijów *et al.*, 2010). A study of dense water chestnut beds in a tidal section of the Hudson River reported dissolved oxygen values below 2.5 mg/L occurring up to 40% of the time in August and varying with tidal cycle (Caraco and Cole, 2002). Areas that are not flushed by tides may have longer periods of anoxic (depleted oxygen) conditions.

Despite reducing the dissolved oxygen in the water essential to fish and other aquatic life, the impacts of dense water chestnut beds on macroinvertebrate and fish communities are varied (Schultz and Dibble, 2012). Studies of *T. natans* and native *Vallisneria* beds in the Hudson River found macroinvertebrate communities of different compositions (Feldman, 2001; Strayer *et al.*, 2003; Teixeira *et al.*, 2014; Kato *et al.*, 2016). Strayer reported that the abundance of macroinvertebrates in the *Trapa* beds was higher than in *Vallisneria* beds. Kornijów *et al.* (2010) reported that water chestnut beds studied supported a rich community of macroinvertebrates, despite the common occurrence of hypoxia. Yuan *et al.* (2021) found that removal of *Trapa* can significantly improve local water quality in the growing season: the concentrations of nutrients (total and dissolved nitrogen, total and dissolved phosphorus) were much lower and the biomass of aquatic macrophyte community was significantly increased. They noted that removal of one invasive plant may allow other invasive plants to flourish.

Low species richness is often the result of these conditions, and the monoculture of plants covering a large water surface area can diminish available wildlife food and habitat (Wong, 2023.). Several studies of fish abundance and species composition in water chestnut beds report that although fish do inhabit the beds, the species in greatest abundance are those with a wider tolerance for adverse conditions. (Pelczarski, 1990) reported that the abundance of fish in water chestnut beds in the Hudson was lower than reported in other vegetation types, but both adult and juvenile fourspine stickleback and carp were present in both beds. (Coote *et al.*, 2001) found young-of-the-year blueback herring using some beds. Most of the fish and macroinvertebrates studies in North America have been done on the tidal sections of the Hudson River; additional studies in non-tidal rivers are warranted.

Water chestnut, like other large beds of aquatic plants, slows current velocity which leads to deposition of sediments. It has been shown to accumulate copper and cadmium in its roots, shoots, leaves and nuts (Sweta *et al.*, 2015). Water chestnut (whole plants) harvested from the Sudbury River at Framingham, Mass., showed concentrations of cadmium and selenium above common soil concentrations; mercury, a major contaminant of sediments in the Sudbury River, was not detected and other contaminants tested were at low levels (OARS, 2013, pers. comm.). The fate of accumulated metals after water chestnut decomposes is unknown (Hummel and Kiviat, 2004).

PUBLIC HEALTH IMPACTS

Dense acres of water chestnut can also have health impacts. Each acre of water chestnut can create over 15 cubic yards of organic matter that settles to the bottom of ponds. These dense areas encourage the proliferation of mosquito larvae that are sheltered by the rosettes. In a study done by Kelly and Henley (1996) in the Lakes District on the Charles River, it was found that even during several years of drought, mosquito larvae were abundant in areas of high-water chestnut density and infrequent or missing in all other areas. After a young local girl got very sick with the mosquito-borne virus Eastern Equine Encephalitis (EEE), it was a major factor in Hop Brook Protection Association's decision to take more aggressive measures in treating and managing water chestnut.

IMPACTS ON RECREATION & AESTHETICS

There is universal agreement that *T. natans* severely affects the recreational use of water bodies by creating impenetrable mats of vegetation that make the river inaccessible to boating, swimming, and fishing. The sharp barbed nuts can penetrate shoes and gloves and pose a hazard to swimmers and beach goers. (Charles River Watershed Association, n.d.; Connecticut River Watershed Council, n.d.; Mystic River Watershed Association, n.d.; Nashua River Watershed Association, n.d.; Robinson, 2002).

Figure 6: Water chestnut on Billerica impoundment, 2008

The decaying vegetation at the end of the growing season, or as a result of herbicide treatment, can create odors. In August 2016, a large mat of rotting water chestnut washed up against the dam on the Nashua River in Pepperell, its strong odor bringing notice in the local press: "The Nashua River flowing over the dam and underneath the Main Street Bridge stinks where a dense mat of bright green vegetation slowly dying to brown floats at the top of the dam." (Nashoba Valley Voice, 2016). The loss of open water can significantly change the scenery and aesthetic beauty of a water body. These impacts can, in turn, impact real estate values (Robinson, 2002).

ECONOMIC IMPACTS

Water chestnut management is a lengthy process. With established seed viability extending up to (and potentially over) 15 years, water chestnut plants must be continuously removed before they drop their nuts in order to eventually exhaust the seed bank. Since removal or treatment must be continued for several consecutive years (at least three), management can become quite expensive, depending on the chosen technique. Herbicides must be applied by a licensed company. Companies often require multiple site visits and treatment days, and must submit permitting, all of which adds to the cost. Mechanical harvesters are expensive in their purchase, their operation, and upkeep.

MANAGEMENT CONSIDERATIONS

An optimal management plan for controlling water chestnut will vary by the size of the infestation, the type of water body managed, any special characteristics of the site (e.g., rare species present or source water protection), the length of time managed, and the resources available for management. Unlike many invasive plants, water chestnut is strictly an annual. The most important aspects of successful water chestnut management are commitment to at least 15 years of active adaptive management, ongoing monitoring, and long-term maintenance. Below, the most commonly used considerations for managing water chestnut are listed. Each of these techniques may be suitable as part of an overall adaptive management effort at different times and different locations. Several considerations should be noted when determining the best management method.

Dams. The slow-moving water behind dams tends to deposit nutrient rich beds of sediment that provide the conditions for water chestnut to become established. Removal of a dam will often clear populations directly upstream as sediment containing the nuts are left above the water line and seed banks dry out in the post-dam environment. Seeds that are still under the water are often unable to survive due to increased velocity of flow and lack of sediment to root in. Although dam removal is not an easy process, it is an effective way of controlling water chestnuts in the impounded waters above the dam and gives ecosystem benefits that extend beyond invasive plant control as well as preventing further spread of the plants below the dam.

Nutrients. Excessive aquatic plant growth is promoted by nutrient-rich water. Efforts at water chestnut management should be accompanied by systematic efforts to reduce nutrient inputs to the water body. This may be done by reducing and treating stormwater runoff, fixing or eliminating failing septic systems, eliminating runoff of lawn fertilizer, reducing nutrients in effluent from wastewater treatment facilities, and other means depending on the sources of nutrients. However, no amount of watershed or nutrient management will control aquatic plant growth (Wagner, 2004). Water chestnut itself is a significant contributor to pond nutrients, as they die and settle to the bottom each year. In a pond, this reservoir is not going to disappear through dilution, as it's recycled and added to each year. In some watersheds, such as Hop Brook in Sudbury, these in-pond nutrient reservoirs are much larger than contributions from external sources (runoff, septic, etc.). Dredging is usually prohibitively expensive, but dam removal provides an effective solution.

Succession. Aquatic ecosystems should be managed as complex ecosystems with a goal of maintaining a healthy, diverse system that will continue to evolve. This will require protecting and encouraging native aquatic and riparian plants while discouraging invasive plants. A holistic approach is needed due to the high possibility of other invasive aquatic plants taking the place of water chestnut once it is removed. If sufficient nutrients are present, succession will happen. Whether the subsequent overgrowth is invasive or native species, the result may not be that different from a water chestnut infestation – blocking sunlight, fall die-offs with odors, and increasing nutrient load with ponds becoming shallower.

Persistence. Due to the easy spread of the nuts and the long period of viability in the sediments, the most attainable goal may be "management" over the long term rather than "control." This requires consistent action over many years to reduce the initial infestation and monitoring thereafter to remove any new infestations before they get too large to manage. Early detection and removal is by far the best approach.

Timing. Water chestnut plants must be removed before they drop their nuts if management efforts are to succeed. In the Sudbury, Assabet, and Concord rivers watershed, this means removal from early June to end of July—a relatively short window. This means that contractors must fulfill all their contracts expeditiously, which may not always be possible. The exact timing will depend to some degree on the water depth and temperature that year. Although advantageous due to the small size of the plants, a very early treatment or harvest may necessitate a second round if there is regrowth. Consistent opportunistic hand pulling by paddlers can be quite effective.

The key to water chestnut control is early detection. It is of utmost importance to remove new patches of water chestnut before they become unmanageable by hand. When new patches are reported and removed in a timely fashion, large infestations can be avoided. This saves both effort and money.

Several sources have detailed discussions of treatment methods suitable for all invasive aquatic plants (Gettys *et al.*, 2014; Mass. EOEA, 2004; Wagner, 2004) and the level of adoption of different methods has evolved significantly over the past five years. This discussion is intended as a general guide; detailed Standard Operating Procedures and guidelines should be consulted in preparation for starting any management project. The "guidelines" listed for each option here are primarily drawn from The Practical Guide to Lake Management in Massachusetts (Wagner, 2004).

Climate change. Climate change is having an important influence on many invasive species. Mean surface temperatures have increased globally by ~0.7 °C per century since 1900 and 0.16 °C per decade since 1970. Most of this warming is believed to result from increases in atmospheric concentrations of greenhouse gases produced by human activity, especially carbon dioxide. The increase in temperature and flooding and an extended growing season can facilitate the spread and establishment of invasive species, creating new opportunities for them to become invasive. Increasing carbon dioxide levels can speed up the growth of those species that can take advantage of it (Ziska, 2022). Climate change may challenge the way we perceive and consider nonnative invasive species: some will be more impacted than others, new nonnative species are likely to become invasive, and native species are likely to shift their geographic ranges into novel habitats (Finch *et al.*, 2021)

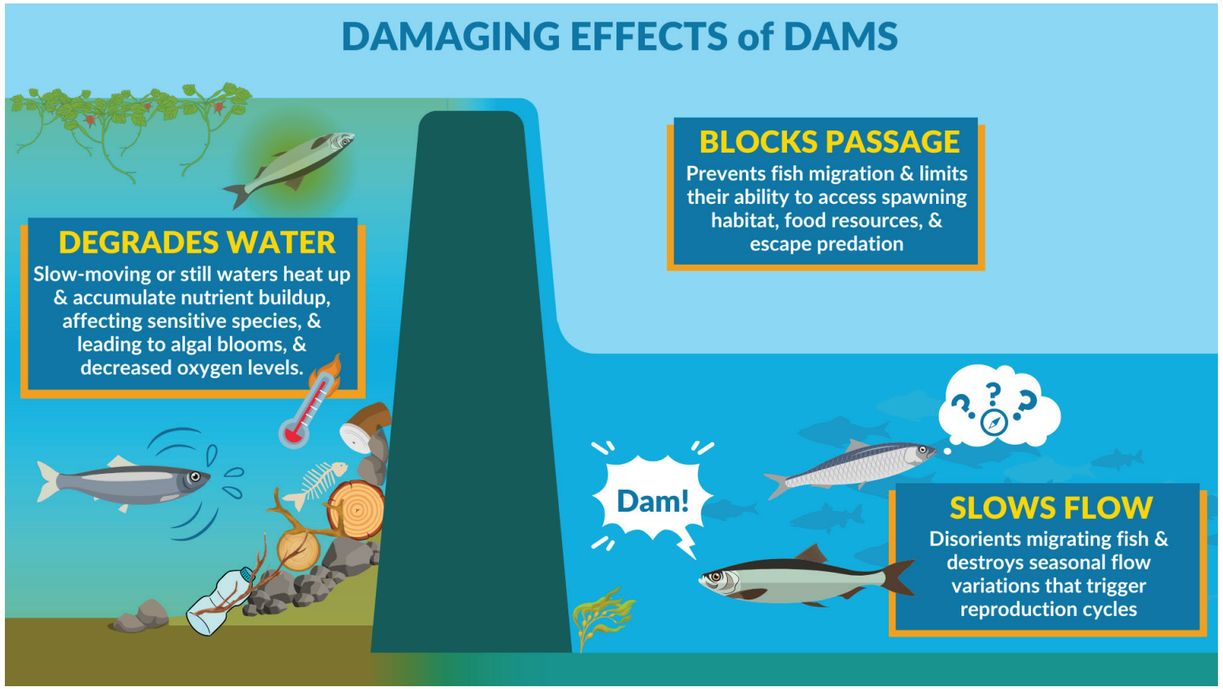


Figure 7: Damaging effects of dams

Table 1: Water Chestnut Control Options

Type	Mode of action	Advantages	Disadvantages	Potential permitting	OARS'/SuAsCo Watershed Method Experience
Hand-pulling	Physical removal of plants before seeds drop (June-July depending on conditions; hand-pulling from small boats).	Highly selective control; limited impact to non-target organisms; good for shallow sites; removes plants from water column; can involve volunteers (lower cost).	Not good for large, dense infestations; labor intensive.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP.	Used very successfully to remove new and small infestations.
Herbicide **Imazamox (ClearcastTM)**	Imazamox: Systemic, absorbed through leaves, stems, and roots. Binds with an enzyme found only in plants, and not found in humans or other mammals, birds, fish or insects.	Apply to leaves at surface only; limited toxicity; rapid action; can be somewhat selectively applied; breaks down quickly. Application in moving water (rivers and streams) is problematic for herbicides injected into the water column.	Short-term water use restrictions after application; increased oxygen demand from decaying vegetation. Other herbicides e.g., SonarTM (fluridone) and triclopyr are less effective. Consistent control by 2-4 D is documented but it is more toxic.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; license to apply chemicals from MassDEP.	ClearcastTM is widely used in the watershed and successful when applied properly. This is now the main form of control for larger infestations. Other herbicides have seen little use.
Mechanical Harvesting	Physical removal of plants before nuts drop; requires mechanical harvester, conveyor, and truck or skidsteer and potential dumpster.	Capable of removing large/dense infestations; removes plants from waterbody.	Minimally selective; not useable in shallow sites; fragmentation may spread other invasives; may impact aquatic fauna; requires larger access or use of crane; higher cost than hand-pulling.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP.	Short-term benefit and expensive, concerns about spreading other invasives through fragmentation, generally being replaced by Clearcast.
Hydroraking	Physical removal of plants before seeds drop; requires hydrorake, barge, and truck and skidsteer and potential dumpster.	Capable of operating in shallower areas than mechanical harvester, removes stump and debris.	Minimally selective; very disruptive in areas applied; may generate high short-term turbidity; fragmentation may spread other plants; requires larger access or crane.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP.	Is not used very often for water chestnut. Concerns about spreading other invasives through fragmentation, expense.
Drawdown	Winter drawdown to kill nuts by freezing; summer drawdown to kill emerging vegetation before seeds set; timing and duration are critical.	Low cost; opportunity for shoreline cleanup or structure repair; needs outlet control.	Non-selective; very disruptive; alteration of flows downstream during drawdown & refill periods; more information needed on effectiveness of summer drawdown.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP.	Is not used very often for water chestnut. This method does not kill the nuts which are protected within the sediment.
Dredging	Sediment removal to reduce seed bank, reduce nutrient recycling, increase water depth.	Removes the soft sediments, deepens the waterbody, effective on all rooted plants.	Non-selective; very disruptive; alteration of flows during management; potential release of sediment; high cost.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; 401 Water Quality Certificate from DEP; Chapter 91 and/or 401 permit from ACOE.	Not used often for the control of water chestnut. Very expensive and sediment may build back up over time undoing the benefit. Very effective in the short term but disruptive to the waterbody.
Benthic Barriers	Placement of barrier or bottom cover to prevent growth of rooted plants.	Effective on growth of rooted plants in limited areas or to create access lanes; complete elimination of plants in area.	Non-selective; High cost of installation and maintenance; not suitable for large areas; difficult to install.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP.	Is not used very often for the control of water chestnut.
Biological Control: Herbivorous insects	Introduction of insects that feed selectively on water chestnut.	Research on *Galerucella birmanica* ongoing; potentially very selective control; lower cost of application and potentially long-term control achieved.	Involves introduction of non-native species; more research and federal approval needed.	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; permit to import and release biological control agents if bred out-of-state USDA Animal and Plant Health Inspection Service.	Not yet available. Research and permitting for biological control is a slow process. Not a management strategy at this stage.

Abbreviations: ACOE, Army Corps of Engineer; DEP, Department of Environmental Protection; NHESP, Natural Heritage and Endangered Species Program; WPA, Wetlands Protection Act (and applicable local wetlands bylaws).

HAND-PULLING

Pulling water chestnut out by hand can be done easily. The technique is well suited for working in shallow water, controlling new and small infestations, selective control where they are intermixed with other wetland or aquatic plants, or long-term maintenance when an infestation has been brought under control with other techniques. It is often used in combination with herbicide treatment and subsequently for long-term management after treatment has brought the population down to a manageable level. Because minimal training and equipment is needed, hand-pulling is well suited for volunteer efforts, which can help build community investment in long-term management of the problem (Mass. DCR, 2007). Organized group pulling events work well for larger patches and individual volunteers can be encouraged. The technique is not suited for large-scale efforts when the target plants occur in dense and extensive beds.

The most efficient approach is to pull out the entire plant at the beginning of the season, when the rosettes have just reached the surface. You may, however, have to repeat this later to catch nuts that germinated later or are in the deeper water. Because the plants grow and sprout branches quickly, the earlier they are removed, the less plant biomass needs to be pulled into the boats and disposed of onshore. Late in the season a single plant will contain many rosettes over a foot wide and is far larger and heavier and is likely to disturb more sediment.

Quantify your removal whenever possible. One technique is to count the number of rosettes in one basket, and then count the number of baskets.

Figure 8: Water Chestnut Tallying and Pulling, Framingham (2016); Corporate Team building (2021), Community Pull, Billerica (2023)

Guidelines

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Identify the access points (boat launch and plant off-loading), disposal site(s), and disposal method (e.g., composting above the floodplain or drying and incineration).
- Inform Conservation Commission and receive appropriate permits as needed (see *permitting* section).
- Train all participants on plant identification, boating safety, harvesting techniques, and proper plant disposal. Supply safety equipment: PFDs, bailers, and gloves. Set up a sturdy and safe off-loading point (e.g., a small dock is ideal), a wheelbarrow and tarps are useful. Work from canoes, kayaks or small boats, using well-draining containers (e.g., laundry baskets) to collect the plants.
- Tally amount of water chestnut removed.
- Early in the season when the plants have just reached the surface and are very small, gently pull up the entire plant including the roots, if possible.
- Once the plants have longer stems and may have multiple attached rosettes, break the stem off just above the root to avoid pulling up sediment; at this point the roots can safely be left undisturbed. The full stem should be removed to avoid later re-sprouting and branching.
- Late in the season, care should be taken to only remove the rosette to avoid dropping mature seeds.
- Multiple pulls (early and late) in a season should be done to ensure full removal.
- Conduct follow-up monitoring in the same and following seasons.

Figure 9: Sign at boat access for volunteers

MECHANICAL HARVESTING & HYDRORAKE

"Aquatic weed harvesters are like lawnmowers for aquatic weeds." Aquamarine describes their mechanical harvesting process thus: "aquatic plant harvesters are hydraulically driven with reciprocating knives mounted on the harvesting head to cut the aquatic vegetation. The vegetation is then transferred onto the conveyor system located on the closed deck barge. The storage conveyors are gradually filled up with tightly packed plants and this harvested biomass is then transferred to the shoreline or into a dump truck via a shore conveyor" (Aquamarine, n.d.).

While mechanical harvesting is faster (0.2–0.6 acres per hour) than hand pulling and requires fewer people (Wagner, 2004), it has not been highly effective in controlling water chestnut. Significant amounts of time can be involved shuttling to and from to offload the weeds, it can be challenging to find a suitable launch and offloading site, and often a crane is needed to lower the harvester into a river from a bridge. Harvesters generally need a minimum of 2–3 feet of water depth. Weed harvesters have two major drawbacks: they cut off the rosettes, which may allow resprouting from the stem and the need for a second cutting later in the season; they also cut up other aquatic invasive plants, such as milfoil, that can propagate from fragments and spread, becoming a larger long-term problem once the water chestnut has been removed.

Hydroraking is not generally considered effective for water chestnut control but may be useful for other invasive plants found in Massachusetts. It involves the equivalent of a floating backhoe; the tines of the rake are pulled through the sediment, uprooting plants, sediment and debris. SOLitude describes their hydrorake: "The hydro-rake can best be described as a floating barge upon which is mounted a backhoe with several different size and functioning rake attachments. The hydro-rake can operate in water as shallow as 1.0–1.5 feet and can remove nuisance vegetation and bottom debris from water depths ranging from 18 inches to 10 feet." Hydrorakes don't have on-board storage, so they deposit weeds either on-shore or require a barge. The hydrorake pulls the entire plant with roots out of the sediment and tends to stir up a lot of silt, some of which can be minimized by a skilled operator.

Figure 10: Water Chestnut Harvester & Conveyor, Sudbury River, 2014

Guidelines

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Identify the access points (harvester launch and weed off-loading), disposal site(s), and disposal method (e.g., composting or incineration).
- Receive appropriate permitting before the start of the project (see *permitting* section).
- Identify methods for minimizing turbidity during harvesting and implement when feasible.
- Develop a fragment control plan for non-target invasive species likely to spread by fragmentation (e.g., milfoil).
- Schedule harvesting to take place before nuts mature.
- Plan hand-pulling to work in tandem with harvesting for edge areas and areas of mixed invasive/native plants. Retrieve any cut rosettes before they float away.
- Avoid areas of known sensitive habitat during active use.
- Monitor collection of non-target fauna (e.g., fish, turtles).
- Quantify amount of water chestnut removed.
- Develop a harvester maintenance plan.

Weed Disposal for Hand-pulling and Mechanical Harvesting

Once harvested, the weeds (sometimes large volumes) must be disposed of by composting or incineration. The weeds may be piled near the harvest site but above the floodplain and allowed to dry for a few days to weeks before final disposal. The weight and volume of the pile will decrease significantly when it is allowed to drain and dry, making subsequent transportation and disposal much easier. The pile must be kept far enough from the water's edge to avoid washing back into the water in the event of heavy rain or flooding. Care in handling the piles is advisable, since the sharp-barbed nut husks of germinated plants commonly accompany the roots. Viable nuts are heavier than water and sink to the bottom. Floating nuts are husks of nuts that have already germinated and can penetrate rubber-soled shoes but cannot resprout.

Composting is usually the least expensive option when a suitable site can be found. Since the plant volume reduces tremendously when dry, landowners often allow composting on-site which is by far the easiest option. In an OARS' survey done October to December of 2015, of the towns reporting water chestnut harvesting in their area, most (13) reported composting, one reported incinerating, and the remaining towns (10) reported "do not know" because someone else was managing the harvesting (see Appendix I). In accordance with Massachusetts' Department of Agricultural Resources regulations (330 CMR 25.00) compost piles should be placed in such a way as to minimize odors, the drift of materials and risk to humans and the environment. Due to the presence of the sharp nuts, reuse of the compost is limited. Incineration as part of the municipal waste stream is sometimes used but is only efficient if the plants have had an opportunity to dry out naturally as much as possible prior to incineration.

Because of concerns about potential contamination, particularly mercury contamination, the heavy metal content of whole water chestnut plants from the Sudbury River was tested. Plants were pulled from the Fairhaven Bay and Saxonville impoundment sections of the Sudbury River, both areas suffering from significant mercury contamination. The samples were dried and sent for analysis by the Cornell Nutrient Analysis Laboratory. Mercury was undetectable in all samples (OARS, unpublished). The results were also compared with compost guidelines for application on food crops and reported typical soil levels (Brinton, 2000). Of the metals tested, cadmium, chromium, copper, manganese, nickel, selenium, and zinc exceeded the guidelines for application on food crops; only cadmium and selenium exceeded reported typical soil values (OARS, unpublished).

HERBICIDE TREATMENT

Several herbicides have been used to manage water chestnut. Herbicides can be classified by their chemical

family, mode of action, or time of application (e.g. pre-emergence or post-emergence). They can also be classified as "contact" or "systemic." Contact herbicides injure only the plant tissue that they come in contact with and are relatively fast acting (hours to days). Contact herbicides are applied in relatively high concentrations and have a short half-life in water. In contrast, systemic herbicides move from leaves into the roots and rhizomes and kill the plants within days to weeks; they are applied at lower concentrations (Haller, 2014; US Army Corps of Engineers, 2012). A surfactant is added to many contact herbicides to improve adhesion and absorption by the plant leaves. The surfactants are also chemicals and should be specified and assessed as well.

Herbicides have three names: a trade name, a common name, and a chemical name. The trade name is trademarked by the manufacturer and is specific for each formulation of the herbicide. The common name and chemical name are assigned by the American National Standards Institute and are unique to the active ingredient (US Army Corps of Engineers, 2012). For example, the active ingredient of Clearcast™, a trademark of BASF Corporation, is ammonium salt of imazamox, chemical name: 2-[4,5-dihydro-4-methyl-4-(1-methylethly)-5-oxo-1 H-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid (SePRO, 2015).

Aquatic herbicides must be registered with the EPA (under the Federal Insecticide, Fungicide, and Rodenticide Act) and the Massachusetts Department of Agricultural Resources and approved for legal use in Massachusetts. The Massachusetts Pest Product Registration (Mass. DAR, 2016a; Mass. DAR, 2016b) currently lists nine herbicide formulations specifically approved for control of water chestnut in Massachusetts: Aquacide Pellets (2,4-D), Arsenal (imazapyr, isopropylamine salt), Clearcast (imazamox), Habitat (imazapyr, isopropylamine salt), Navigate (2,4-D), Navitrol DPF (triclopyr), Renovate Max G (combination 2,4-D and triclopyr), Renovate OTF (triclopyr), and Sculpin G (2,4-D).

In the past, the most widely used herbicide had been 2,4-D (Hummel and Kiviat, 2004; Poovey and Getsinger, 2007; Kishbaugh, 2014; Rector *et al.*, 2015). More recently other chemicals have been used. Since Clearcast was approved for control of water chestnut, imazamox has been used with initial good results (Nemecek and DeHollander, 2014; DeHollander, pers. comm.). SOLitude Lake Management reported using Clearcast and Renovate Max G to clear water chestnut in several small ponds in Fairfax, Virginia (SOLitude, 2016). The Perkiomen Watershed Conservancy reports using a combination of Habitat and Rodeo (glyphosate) to successfully clear a section of water chestnut on Perkiomen Creek (pers. comm.).

Clearcast has been very effective when applied to the Saxonville impoundment on the Sudbury River in Framingham. Following two years of successful treatment, the Hop Brook Protection Association has seen great improvements in the ponds along Hop Brook in Sudbury. Clearcast is also being used by the US Fish and Wildlife Service (USFWS) to manage water chestnut in the Sudbury River in the Great Meadows National Wildlife Refuge; they had previously tried to manage it by mechanical harvesting for several decades.

After 24 years of mechanical harvesting and unable to keep up with growth using one harvester, Oswego County Soil and Water Conservation District turned to a combination of methods including treatment with a variety of herbicides and hand-pulling to control water chestnut on the Oswego River and in the district. In 2004–2005, they expanded chemical treatments with special use permits from the New York Department of Environmental Conservation for Aqua-Kleen (granular 2,4-D), Rodeo (glyphosate), and Weedar 64 (2,4-D) at sites in Oneida Lake, Oneida River, Ox Creek and the Seneca River to compare the effectiveness of the herbicides. They reported that results using 2,4-D and glyphosate on large patches of water chestnut were "erratic at best." In 2009–2013, they attempted undercutting without weed removal in conjunction with chemical treatments. In 2012–2016, large patches of water chestnut in the Oswego and Seneca rivers were treated using Clearcast. By 2016, the over-220 acres of water chestnut were reduced to about 20 acres and Clearcast treatment was combined with hand-pulling to control the remaining population on the Oswego River (J. DeHollander, pers. comm.; DeHollander, 2015; The Nature Conservancy, 2012; Nemecek and DeHollander, 2014).

General guidelines for chemical control

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Identify waterbody and downstream water uses that may be impacted.
- Inventory aquatic biota with emphasis on sensitive species.
- Develop treatment plan including does, areas treated, expected alteration of plant community, follow-up activities, and notifications about any water use restrictions.
- Apply and receive all applicable permits before the start of the project (see *permitting* section).
- Application must be done by a licensed applicator.
- Quantify area cleared of water chestnut.
- Monitor effectiveness and results, with emphasis on oxygen and nutrient levels if more than 10% of the waterbody area is treated.

2,4-D

2,4-D is a somewhat selective, systemic, broadleaf herbicide used to control a variety of submersed and floating aquatic plants. It has been registered by the US EPA for use in aquatic environments since 1959 (US Army Corps of Engineers, 2012). The chemical prevents the elongation of stems and roots, keeping tissues juvenile. Depending on the form, the compound acts like the plant hormone auxin, affecting cell wall plasticity and nucleic acid metabolism in plants.

Amine and butoxy-ethyl ester formulations in liquid and granular formulations of 2,4-D can be used against water chestnut effectively (US Army Corps of Engineers, 2012; Rector *et al.*, 2015). These go by the trade names of Navigate (2,4-D ester) and Platoon, DMA-4, and CleanAmine (liquid 2,4-D amine) (ACT, 2015). The liquid amine formulation of 2,4-D is typically used to control both emergent and submersed plants, and granular butoxy-ethyl ester formulation is used for submersed plants only (ACOE 2012). Though widely used as a water chestnut herbicide, updated regulations lowered the allowable dose concentration for 2,4-D, and it may be less effective on water chestnut (pers. comm.). All 2,4-D products are prohibited in Zone II wellhead protection areas due to toxicity and concerns about migration into groundwater (Aquatic Control Technology, 2015a).

Clearcast

Clearcast is a liquid herbicide containing the ammonium salt of imazamox. It is active on many submerged, emergent, and floating broadleaf and monocot aquatic plants, applied as a foliar (onto the leaves) spray on emergent or floating plants, or applied directly to the water to control submerged plants. A foliar application of Clearcast with a surfactant is used to treat water chestnut. Clearcast is absorbed by the plants' leaves and stems where it binds to an enzyme only found in plants. Binding to this enzyme causes the plant to break down and die shortly thereafter. Water & Wetland applies Clearcast via an airboat to minimize their disturbance. It should be noted that control will be reduced if spray is washed off foliage by wake, wave action, or rain, and repeat applications are often necessary. Clearcast is mixed onboard, about 0.75–1 gallon is used per acre of treatment (Gosselin, pers. comm.).

The study of Clearcast for aquatic vegetation management began in 2004, with aquatic Experimental Use Permit (EUP) programs conducted in some 16 states starting in 2006, and the treatment of up to 4,750 acres per year. Clearcast received full EPA approval in 2008 (AECOM, 2009). In the spring of 2015, the Massachusetts Department of Agricultural Resources registered Clearcast for controlling vegetation in and around aquatic sites and terrestrial non-crop sites (Aquatic Control Technologies, 2015a).

Figure 11: Before (2015) and after (2024) treatment with Clearcast, Saxonville, photo credit Ron Chick

Triclopyr

Triclopyr is a selective systemic herbicide and auxin mimic that has been shown to be effective on water chestnut (Poovey and Getsinger, 2007). Although triclopyr is not as effective as 2,4-D, it can be used in public waters where 2,4-D use is not allowed (Netherland, 2014). Liquid and granular formulations of triclopyr amide are available to control submersed, floating and emergent dicotyledonous (and some broadleaf monocotyledonous) aquatic plants (Wagner, 2004; US Army Corps of Engineers, 2012). Humans have been found to absorb less than 2% of a dose of triclopyr when absorbed through the skin (NPIC fact sheet).

DRAWDOWNS

Winter drawdowns are not generally used to control water chestnut because the nuts are likely to survive in the sediments (Wagner, 2004). Summer drawdowns have been used occasionally to control water chestnut. To be effective, a summer drawdown should be conducted after late May/early June when the nuts have sprouted, and water levels are drawn down far enough to dry the sediment and kill the vegetation. Summer drawdowns used in the Concord Impoundments of the Concord River to improve habitat for migrating birds were effective in reducing the water chestnut (see Concord Impoundments below). Drawdowns can be cost effective, depending on the ability to control water levels in the section of interest, but may have broad negative impacts on other plant and animal species. Recolonization from nearby areas may be rapid, depending on species, and the response of macrophyte species is quite variable (Wagner, 2004). Summer drawdowns have the potential to affect nearby wells and fire-fighting ponds, which could be critical during the lower-flow summer months. The rules for drawdowns may change due to concerns about the impact of low water levels on non-target species (Gosselin, 2023).

Guidelines

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Evaluate the potential risks to non-target flora and fauna.
- Apply for and secure permitting from local Conservation Commission.
- Limit the drawdown to 3 feet or contract the Mass. Division of Fish and Game for help evaluating impacts of a greater drawdown.
- Keep outflow during drawdown below 4 cfs/square mile of watershed; once the drawdown is achieved, match outflow to inflow.
- Quantify area cleared of water chestnut the following season.
- Monitor water levels and water quality during the drawdown and monitor the recovery of the waterbody.

DREDGING

Sediment dredging has been used successfully for weed control, but its utility is limited to areas that will not rapidly re-accumulate sediment. *The Practical Guide to Lake Management in Massachusetts* (Wagner, 2004) includes an extensive discussion of conventional wet, conventional dry, and hydraulic dredging. Dredging can control water chestnut by physically removing its seed bank along with the soft sediment that supports its growth, by removing nutrients and internal loading stored in the sediment, and/or increasing the depth of the water body. Dry dredging involves drawing down the waterbody to expose the sediment, controlling inflows during the process, and using conventional excavation equipment. Wet dredging may involve a partial drawdown (especially where water level control is limited) and use of specialized excavation equipment. Conventional wet dredging creates considerable turbidity and requires steps to limit downstream movement of the sediments and to de-water dredged sediments before they are removed for disposal. Hydraulic dredging involves a suction type of dredge to remove a slurry of sediments. The slurry is pumped into a containment area to remove excess water. Hydraulic dredging can work well for large volumes of sediment in areas that cannot be drained and that contain relatively few rocks and stumps.

Permitting requirements and costs for dredging are generally higher than for other management options. Permitting required may include: Wetland Protection Act and local wetlands bylaw permits, MEPA review, Chapter 91 permit, 404 permit through Army Corps of Engineers, and the 401 Water Quality permit through the Massachusetts Department of Environmental Protection (MassDEP) for projects involving dredging greater than 100 cubic yards of sediment.

Guidelines

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Project planning should address: reasons for dredging, volume and nature of material to be dredged, any protected resources, equipment access, disposal site or use/sale of material, site bathymetry, flow management, dredging methodologies, regulatory process, and costs.
- Apply for and receive all applicable permits (see *permitting* section).Conduct all work in accordance with permit conditions.
- Achieve depth or substrate limitation (depending on project goals).
- Restore or rehabilitate all access, temporary containment, and final disposal areas.
- Monitor containment area, downstream flows, and water quality during dredging.
- Monitor recovery of the waterbody.

BENTHIC BARRIERS

Benthic barriers are used to prevent growth of rooted aquatic plants by limiting light and disrupting growth of all the rooted plants in the application area (Mass. DCR, 2007). Barriers may be clay, silt, sand, gravel, or sheets of artificial material (e.g., polyethylene, polypropylene, fiberglass, or nylon) manufactured to be negatively buoyant. Because of the expense, difficulty of application, non-selectivity, and need for maintenance, benthic barriers are usually used in limited areas and in areas without significant current or waves, limiting their use to lakes and ponds.

Guidelines

- Map the distribution of water chestnut and non-target species before treatment and identify the boundaries of the work area.
- Select a barrier with properties consistent with the project goals and site features.
- Apply for and receive all applicable permits (see *permitting* section).
- Install and anchor the barrier so that it is stable in response to waves, currents, and billowing up from sediment gases.
- Post the area to inform potential users of the barrier's presence.
- Leave in place for at least a month, check for movement and sedimentation.
- Quantify area cleared of water chestnut
- Monitor the barrier's effectiveness and plant community before and after installation.

BIOLOGICAL CONTROLI

"Successful biological control depends on the ability of host-specific herbivores to suppress populations of their host plant" (Ding *et al.*, 2006b). Biological control agents can kill the target plants outright or damage them thus limiting their reproduction or ability to compete with other plants. Research on *Galerucella birmanica* as a biological control for water chestnut is ongoing (see Natural Enemies, above). Any biological control agent must be thoroughly studied for host-specificity and effectiveness and approved for use by the US Department of Agriculture and individual states. A Plant Protection and Quarantine (PPQ) 526 permit from the USDA is required to transport biological controls across state lines and for release into the environment. Researchers have filed a technical advisory group petition, which is the last step before approval. However, these petitions take time and approval may not be coming soon. At this time, there are no biological controls available for use in MA that are effective and approved for water chestnut control.

FUNDING

At the state and federal level, most funding for water chestnut control comes through annual budget appropriations or Environmental Bond funding to the Massachusetts Department of Conservation and Recreation (DCR) or US Fish and Wildlife Service (USFWS). MassDEP does not currently have funding for circuit riders for invasives control. At the local level, municipal budgets have provided funds, sometimes drawing on Community Preservation Act money. Local land trusts and watershed organizations have been able to secure funds through grants, donations, and environmental penalties. Volunteer contributions in surveying and hand-pulling are invaluable.

Possible grant programs for invasives control include: Section 106 of the Clean Water Act (EPA), Section 319 of the Clean Water Act—Healthy Watershed Initiative, and DCR matching funding for areas abutting or sharing DCR land.

PERMITTING FOR CONTROL EFFORTS

Current permitting information is based on the 2014 Wetland Protection Act (WPA) Regulations. In December 2023, the Massachusetts Department of Environmental Protection (MassDEP) proposed revisions to the WPA regulations and the Water Quality Certification (WQC) regulations. Additional regulatory revisions are planned in the Fall of 2024. Some of these revisions may streamline permitting for invasive species management. Updated regulations are expected to be promulgated in 2025.

LEGAL STATUS

In Massachusetts, the sale, planting, transport, and traffic in water chestnut is specifically banned by Massachusetts general law Title XIX Ch. 128 Sec. 20A (Commonwealth of Massachusetts, 2016) and water chestnut is on the Massachusetts Prohibited Plant List (Mass. EOEEA, 2016). The Massachusetts Invasive Plants Advisory Group (MIPAG) lists water chestnut as a "Category 1" early detection priority species; Category 1 species should be reported and eradicated if found anywhere in Massachusetts (MIPAG, 2011). The Massachusetts DCR Lakes and Ponds Program lists water chestnut on their Rapid Response List.

In 1949, New York State enacted a law prohibiting the planting, transporting, transplanting, or trafficking of water chestnut seeds or plants in any manner that would cause its spread or growth. The National Invasive Species Act of 1996 specifically mentioned *Trapa natans* as a species of concern but imposed no restrictions or penalties (Hummel and Kiviat, 2004). Currently, it is not on the federal noxious weed list. As of 2016, *Trapa natans* is listed as a "noxious weed" in 11 states, including Massachusetts (USDA, 2016).

RESPONSIBLE PARTIES

Control of aquatic invasives is not legally mandated, and, thus, not the responsibility of any agency or municipality. Various groups have taken the lead in managing aquatic invasive plants, depending on ownership/management, municipal involvement, and the existence of lake or watershed associations. For example, DCR, through their Lakes and Ponds Program, manages invasives on DCR-owned properties and has taken the lead in Massachusetts to provide information and training to support control efforts statewide. DCR's Division of Water Supply Protection manages invasives in the water supply reservoirs, including the Sudbury Reservoir (Mass. DCR, 2010). USFWS takes the lead managing water chestnut on the Sudbury River within the Great Meadows National Wildlife Refuge in coordination with the Towns of Lincoln, Sudbury, and Concord, and the Concord Land Conservation Trust. Outside of the state parks and reservations, control of invasive plants is largely a function of local desire to protect and maintain the resource. Watershed organizations, lake and pond associations, and local conservation departments have often taken the lead.

PERMITTING IN MASSACHUSETTS

A key guide to the permitting process is DEP's *Guidance for Aquatic Plant Management in Lakes and Ponds as it Relates to the Wetlands Protection Act* (Langley *et al.*, 2004), available on the DEP website. This guide is specific to lakes and ponds but can generally be applied to rivers as well. Another key resource is *Protecting Wetlands and Open Space: MACC's Environmental Handbook*, which is available on-line for a fee. The local Conservation Commission will be involved due to the Wetlands Protection Act and local wetlands bylaws. It is highly recommended that anyone considering water chestnut control discuss their proposed activities as early as possible with their Conservation Commission so that they, or the conservation agent, may advise on the best approach. Where MassDEP has a Wetlands Circuit Rider they are a great resource for applicants and Commissions alike.

All water chestnut control projects fall under the permitting requirements of the Massachusetts Wetlands Protection Act (MGL Ch. 131, Sec. 40) primarily because they may "alter" (change the condition of) "land under water" and may also require approval under local wetlands bylaws/ordinances. "Alterations" include sedimentation, flow patterns, vegetation, or the physical, biological or chemical condition of the water. In some cases, "bordering vegetated wetlands" may also be affected. Some Conservation Commissions have determined that minor hand-pulling efforts to remove water chestnut plants that do not significantly disturb the sediment may go ahead without permitting. Where large equipment may need to access the waterbody, projects may also alter "banks" or "floodplains" or other resource areas, potentially creating erosion or sedimentation. Herbicide application requires permitting. Plants removed by harvesting (whether by hand or machine) will need to be disposed of properly. See Figure 12 describing the permitting process. All forms and instructions for filing under the Wetlands Protection Act can be found at [*link*]. Sample permitting is provided in Appendix II.

Water chestnut control projects may also fall under other regulations. The scale, site location, funding sources, and methods will define the regulatory requirements. Permitting can take several months so it should be started during the winter for the following summer. For projects that will require obtaining funding and an Order of Conditions and any other permits, getting started the preceding fall is advisable.

Under the Wetlands Protection Act, water chestnut control may be considered an "Ecological Restoration Limited Project." Such a project must meet the definition: "a project whose primary purpose is to restore or otherwise improve the natural capacity of a Resource Area(s) to protect and maintain the interests identified in M.G.L. c.131 § 40, when such interests have been degraded or destroyed by anthropogenic influences" (310 CMR 10.04). To be considered a "Limited Project," the activity must exceed the thresholds for the three resource areas shown in table 2, below. If it is less than those thresholds, it goes through the same process as any other project under the Act.

Table 2: Thresholds for filing "Limited Projects"

Resource Area	Threshold for Wildlife Habitat Evaluations in Inland Resource Areas
Bank	50 linear feet or 10% of Bank on the property, whichever is less (310 CMR 10.54(4)(a)(5))
Land Under Waterbodies and Waterways (LUW)	5,000 square feet or 10% of LUW on the property, whichever is less (310 CMR 10.56(4)(a)(4))
Bordering Land Subject to Flooding (BLSF)	5,000 square feet or 10% of BLSF presumed significant for wildlife habitat, whichever is less (310 CMR 10.57(4)(a)(3))

Source: MACC (2015), p. ST 6.4.

The project *cannot* be Dam Removal, Freshwater Stream Crossing Repair and Replacement, Stream Daylighting, Tidal Restoration, Rare Species Habitat Restoration, or Restoring Fish Passageways. These six project types are considered "Ecological Restoration Projects" and require a different form (Form 3A) and process [310 CMR 10.13 (2–7)].

Under the "Limited Project" type, the applicant must show that a project improves the natural capacity of a specific resource area. This includes projects proposed primarily to enhance fisheries habitat, address eutrophication, or increase dissolved oxygen or improve overall water quality in a water body. Ecological Restoration Limited Projects fall into five categories; #5 is "Other Restoration Projects." According to the MACC Handbook (2016, p. 18.7.4), this category applies to projects designed "to enhance biodiversity through the removal and/or management of invasive species and through native plantings. It can also be used to justify removal of aquatic nuisance vegetation and thinning or planting of vegetation to improve habitat value." DEP's Guidance (2004, p. 1) notes that "projects involving removal of aquatic nuisance vegetation must demonstrate that the vegetation is a 'nuisance' to the interests of the act." Water chestnut, as a non-indigenous invasive plant species, fits the definition of nuisance vegetation.

As an Ecological Restoration Limited Project, the environmental impacts are reviewed at two levels: the local Conservation Commission, which has jurisdiction under the Wetlands Protection Act and any local wetland bylaw/ordinance, and the Massachusetts Environmental Policy Act (MEPA) Unit, which has jurisdiction over state-funded or state-authorized projects of a certain size or scope. Mass DEP may choose to review projects as part of the Wetlands Protection Act but generally only get involved if the project is appealed to DEP. If there are rare species in or adjacent to the waterbody, approval for control actions will be needed from the Natural Heritage and Endangered Species Program (NHESP). Other agencies and approval programs may apply, depending upon the features of the waterbody (e.g., naturally large enough to be a statutory Great Pond), its location (e.g., in an Area of Critical Environmental Concern), or its uses (e.g., as a water supply) (ENSR, 2005; Langley *et al.*, 2004). Provided there is no discharge of dredge or fill materials, the federal Clean Water Act (Section 404) should not apply. The Clean Water Act's Sec. 401 Water Quality Certificate should not be required for the same reason unless a herbicide is used.

Conservation Commissions may be willing to administratively approve small-scale hand pulling efforts. However, organized larger-scale hand-pulling may significantly disturb sediment (resource area = "land under water") and generate quite a lot of pulled material and may need to be reviewed through a Request for Determination of Applicability (RDA) or Notice of Intent (NOI). This is at the discretion of the Conservation Commission so meeting with the Conservation Agent well in advance of any planned work is advisable. Some Commissions accept RDAs for organized hand-pulling. After holding a public meeting, the Commission may issue a negative Determination (thus not requiring a Notice of Intent). They may include a provision that DCR's Standard Operating Procedures are used (Mass. DCR, 2007), and other conditions as needed. This process enables the Commission to confirm that proper methods are being used for the hand-pulling and disposal of the weeds. If a positive Determination is issued, the next step is for the applicant to submit a Notice of Intent.

There were differences of opinion about permitting hand-pulling among the towns responding to OARS' survey question posed in 2015: "What type of permitting would be needed for hand-pulling?" (see Appendix I). The Request for Determination should probably be used more frequently than it is currently because it provides information to the Conservation Commission and provides a record in case of local complaints or concerns. Using equipment such as harvesters and hydrorakes to remove water chestnut, on the other hand, will generally need permitting through an Order of Conditions.

Table 3: Survey Response

Permitting for Hand pull (49 responses)	Number
Administrative or none	13
Request for Determination	18
Order of Conditions	12
Emergency Order	2
Unsure	4

To obtain an Order of Conditions, the applicant must submit a Notice of Intent that specifies the scale and scope of the project, location(s), and equipment and disposal methods. The forms for the Limited Project are the Wetlands Protection Act (WPA) Form 3 (Notice of Intent) and Appendix A (Ecological Restoration Limited Project Checklists). The Limited Project application requires submitting a plan, a determination letter from the Natural Heritage and Endangered Species Program (if there is an endangered plant or animal species habitat mapped in that area), and publication in the Environmental Monitor [*link*], and abutter notification. While there is a fee for the filing for most applicants, town departments are exempt from the fee.

If the project does not exceed these thresholds for a Limited Project (Table 2), a regular Notice of Intent without Appendix A is appropriate. This can be filed electronically and does not need publication in the Environmental Monitor. It does require abutter notification. The Order of Conditions may be written to cover similar efforts elsewhere in the municipality if so requested in the Notice of Intent. In this case, it is preferable to have one town entity or person designated as the coordinator who can delegate the work to other groups, departments, consultants or individuals in order to maintain accountability and compliance with the Conditions. This is often a municipal department, such as Public Works.

The Order of Conditions should include erosion control at the location where equipment is put in the water, proper plant disposal, and minimizing disruption of bottom sediments, particularly where they may be contaminated. Areas with contaminated sediment may also need permits from the local Board of Health, or DEP and EPA. These aspects should be thought through in advance by the applicant and included in the Notice of Intent where possible. Orders of Conditions may be issued for 3–5 years and be extended upon request an indefinite number of times. Applicants and Commissions should review the *Guidance for Aquatic Plant Management in Lakes and Ponds as it Relates to the Wetlands Protection Act* (Langley *et al.*, 2004). Useful procedures are described in DCR's *Standard Operating Procedures: Using Hand Pulling and Benthic Barriers to Control Pioneer Populations of Non-Native Aquatic Species, A Guide for Volunteers* (2007, on the DCR website), and in the much more detailed document *Final Generic Environmental Impact Report: Eutrophication and Aquatic Plant Management in Massachusetts* (Mass. EOEA, 2004), available on the EOEEA website.

Herbicide application to water bodies or aquatic plants requires permitting under the Wetlands Protection Act through a Notice of Intent. The MassDEP WM04 Chemical Application License grants approval to apply chemicals for the control of nuisance aquatic vegetation in accordance with authority granted to the MassDEP by Massachusetts General Laws c. 111, s. 5E. Herbicide licenses are issued by MassDEP. Using Form BRP WM 04 is also required to apply chemicals for the control of nuisance aquatic vegetation in waterways. The herbicide must be applied by a licensed applicator. No herbicide license is required for treating a privately-owned pond with a single owner from which there are no flowing outlets, although this activity will still require approval from the Conservation Commission.

Drawdowns or dredging permitting is more complex. Typically, a study is done first to determine what native species are present and how dredging will affect them. This requires the Department of Fish and Game to look at the proposed location and ensure it will not be harmful. An Order of Conditions will be required from the local Conservation Commission. Restrictions may then be put on the extent of drawdown and dredging and other elements of the project. The Army Corps of Engineers must also issue a permit under the Clean Water Act, Section 404 which requires a permit before dredged or fill material may be discharged into waters of the United States. Depending on the amount of material dredged, a Section 401 Water Quality Certificate from MassDEP may also be required.

Additionally, if there are time-of-year restrictions in a coastal water body, or the project will affect a diadromous (migratory) fish run, a determination from the Division of Marine Fisheries is required. Work that generates silt, or involves dredging of over 100 cubic yards, also has specific requirements. These requirements are spelled out in the Wetlands regulations at 310 CMR 10.11 and 10.12 and must be met.

Because water chestnut control always requires several years of continuous work, it is advisable for the applicant to seek an Order of Conditions for the maximum duration, 5 years, and that provides for adaptive

Request for Determination of Applicability (RDA)

An RDA is made to the Conservation Commission to determine whether the proposed work requires filing a Notice of Intent and issuance of an Order of Conditions, or not. In this case, the question is not whether the work is in a resource area, as by definition it is in "land under water," but rather whether the proposed work will affect the resource such that it needs a more complete review and Order of Conditions under the Act or a local bylaw/ ordinance to ensure protection of resource areas. An applicant can skip the RDA and go directly to filing a NOI if they prefer. The applicant uses WPA Form 1. There are instructions on the same web page. There is no fee or abutter notification under the state Wetlands Protection Act, although local bylaws/ordinances may require one or both. The applicant must pay for a legal notice of the application in a local newspaper that is published at least five days prior to the hearing. The Conservation Commission can advise regarding placing the public newspaper notice. The RDA should include a narrative describing the work to be done and at least a sketch plan showing the areas where removal is proposed, along with any other proposed activity.

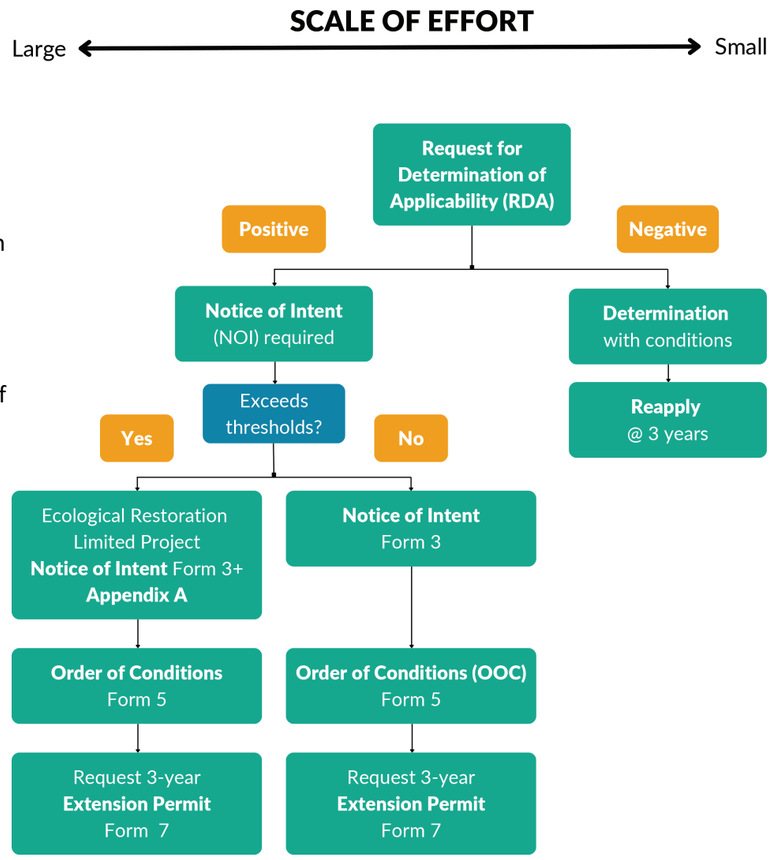


Figure 12: Wetlands Protection Act Permitting Flow Chart

Determination of Applicability

The outcome of an RDA filing will either be a positive or a negative Determination of Applicability, using Form 2. A *positive* Determination means that the applicant must file a Notice of Intent for the proposed work. A *negative* Determination means that the work does not require permitting and can be issued with or without conditions. While a Negative Determination with conditions has fewer procedural requirements, the commission retains the right to require an NOI if the conditions are not followed. Note, however, that no abutter notice and no public hearing is required for an RDA/Determination under the state Wetlands Protection Act (although local wetland bylaws may require abutter notification). So, the public doesn't get official notice, other than the request being listed on a Conservation Commission's agenda. Members of the public may feel uninformed if they subsequently observe control activities. A negative Determination expires after three years, after which a new RDA must be submitted. It cannot be extended. See sample RDA in Appendix II.

Possible conditions could be

1. Before invasive plant management begins, a site visit shall be conducted to review work and inspect the erosion control barrier.
2. A report shall be submitted annually and/or after the project has been completed documenting that the work has been conducted in accordance with all conditions of this Determination of Applicability.
3. Invasives shall be disposed of at an appropriate off-site location or covered with a tarp and "cooked."
4. Hand-pulling of invasives is permitted site-wide in perpetuity.

Notice of Intent (NOI)

Applicants for Ecological Restoration Limited Projects use WPA Form 3 plus Appendix A for the NOI. Appendix A is an Ecological Restoration Limited Project Checklist that "guides the applicant in determining if their project is eligible to file as an Inland or Coastal Ecological Restoration Limited Project" MACC, 2016, p. 18.7.4). Applicants for Ecological Restoration Projects (not "limited"), such as larger dredging projects, use an Ecological Restoration NOI form, WPA Form 3A, instead.

Before filing an NOI for an Ecological Restoration Limited Project, an applicant must: (1) submit notification to the Environmental Monitor 14 days prior, and (2) if the project will occur within "Priority Habitats of Rare Species" (shown on the most recent Estimated Habitat Map of State-listed Rare Wetlands Wildlife as yellow cross-hatching, [*link*] the applicant must receive a written determination from the Natural Heritage and Endangered Species Program (NHESP) that Preliminary Massachusetts Endangered Species Act Review has been met (see 310 CMR 10.11). Similarly, if the project will occur within "Estimated Habitats of Rare Wildlife" (shown on the same map as yellow cross-hatching), the applicant may receive a written determination from NHESP as to whether or not the project will have long- or short-term adverse impacts.

Additionally, if there are time-of-year restrictions in a coastal water body, or the project will affect a diadromous (migratory) fish run, a determination from the Division of Marine Fisheries is required. Work that generates silt, or involves dredging of over 100 cubic yards, also has specific requirements. These requirements are spelled out in the Wetlands regulations at 310 CMR 10.11 and 10.12 and must be met.

Because water chestnut control always requires several years of continuous work, it is advisable for the applicant to seek an Order of Conditions for the maximum duration, 5 years, and that provides for adaptive management. Adaptive management allows adjustment of the control method based on the actual conditions. This approach should include annual monitoring and reporting to the Conservation Commission. The Commission could approve any adjustment of the control approach, e.g., moving from mechanical to hand harvesting when population densities are significantly reduced. An adaptive management approach will be more effective and save time and money over permitting one single approach without monitoring and adjustment. See sample NOI in Appendix II.

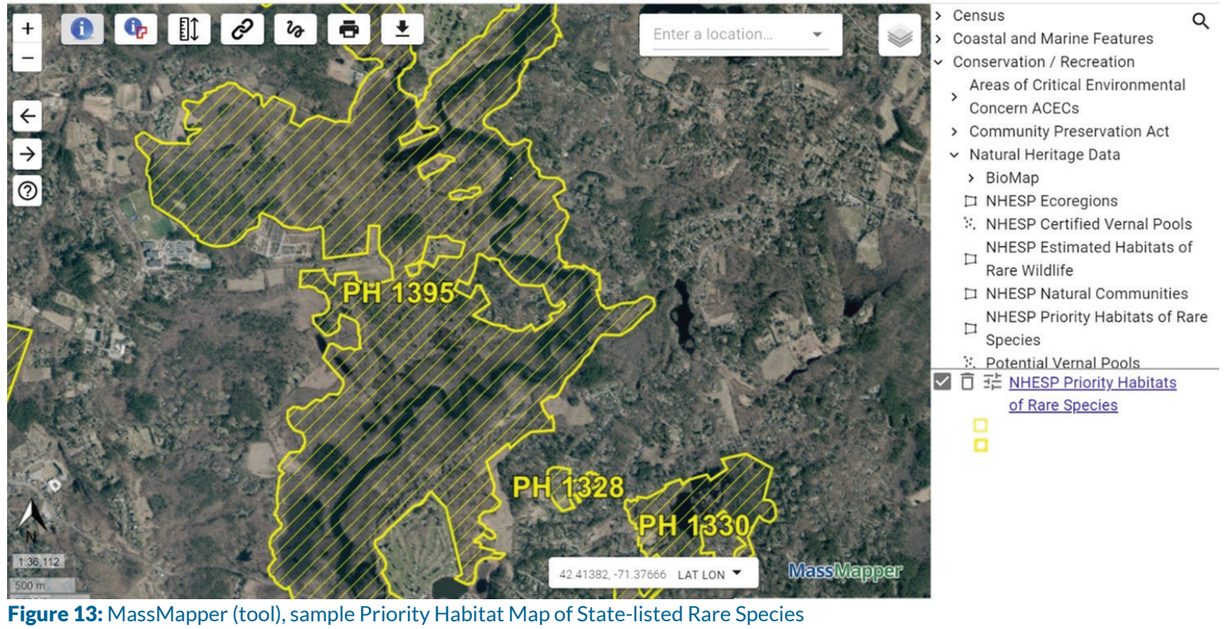


Figure 13: MassMapper (tool), sample Priority Habitat Map of State-listed Rare Species

Order of Conditions (OOC)

Orders of Conditions use WPA Form 5; these can be issued for a maximum 5-year duration and can be extended upon request. As noted above, there are many advantages to requesting the Order of Conditions be valid for a 5-year period since managing invasive plants is a long-term project. The Commission will likely require monitoring and reporting; therefore, it would be helpful to include a reporting schedule that is in sync with the seasonal growth patterns of the plant and the work to be performed. See sample OOC for mechanical harvesting in Appendix II.

WATER CHESTNUT IN THE SUDBURY, ASSABET, & CONCORD WATERSHED

The Sudbury, Assabet, and Concord watershed lies within Middlesex and Worcester Counties in eastern Massachusetts, some 20 miles west of Boston. The watershed drains an area of 399 square miles, flowing generally north into the Merrimack River at Lowell. Ten of the river miles along the Sudbury and Concord rivers lie within the boundaries of Great Meadows National Wildlife Refuge, established to protect the outstanding waterfowl habitat associated with the extensive riparian wetlands. Twenty-nine miles of free-flowing sections of the Sudbury, Assabet, and Concord rivers are federally designated "Wild and Scenic Rivers" recognizing their outstanding ecology, history, scenery, recreation values, and place in American literature.

DISTRIBUTION OF WATER CHESTNUT

As described earlier, water chestnut was introduced to the watershed in the late 1870s and had expanded to nuisance proportions in the Sudbury River by 1945. Today water chestnut has been documented in all three mainstem rivers, and observed in many ponds, lakes and tributary streams of the watershed.

In 2013, 2014, and 2016 OARS mapped the extent of water chestnut infestation throughout the length of the Assabet, Sudbury and Concord rivers and several ponds of the watershed. This was funded through the SuAsCo Cooperative Invasive Species Management Area (CISMA) from a natural resources damages payment from the Nyanza Superfund site on the Sudbury River in Ashland. See Appendix III for 2016 maps of the watershed (on-line version). These surveys showed a spread of the plant from the initial long-term concentrations on the Sudbury and Concord rivers

MANAGEMENT HISTORY

Sudbury River

The Sudbury River from Route 27 in Wayland downstream to Fairhaven Bay in Lincoln/Concord have been impacted by a heavy infestation of water chestnut for over 25 years. By 1998, Fairhaven Bay was reported to be almost completely closed by a thick mat of water chestnut plants inhibiting recreation and changing the ecological conditions in the bay. However, management over the past five years in several sections has shown great success.

Despite decades of mechanical harvesting, sections of the Sudbury River are still impacted by water chestnut. USFWS, in collaboration with other stakeholders, now manages water chestnut on the Great Meadow National Wildlife sections of the Sudbury River with Clearcast and hand-pulling. In 2022 and 2023, two treatments of Clearcast were made each year between Sherman's Bridge and Route 27. This has had a noted effect on reducing the water chestnut populations, but more years of successful treatments are needed to bring the population down to a level that can be managed by hand-pulling exclusively (Koch, pers. comm.).

Since 2001, water chestnut control in the Sudbury River's Fairhaven Bay (on the Lincoln/Concord line) has been jointly managed by a collaboration between USFWS, the towns of Concord and Lincoln, and Concord Land Conservation Trust. Hand-pulling has been the primary method used to remove water chestnut in Fairhaven Bay since 2012. Despite its history as a hotspot for water chestnut, Fairhaven Bay is now reportedly clear, although patches remain upstream to Route 27. This is due to consistent and long-term work.

A large infestation of water chestnut in the Saxonville Impoundment of the Sudbury River in Framingham came to OARS' attention with the first full watershed mapping in 2013. Local residents reported that the population had grown explosively in the previous few years, and they had brought their concerns to the Framingham Conservation Commission. An estimated 30 acres of the 56-acre impoundment were completely covered with water chestnut in 2016 (OARS, unpublished). After permits had been obtained, a private contractor was employed to apply Clearcast each year. Following seven years of applying Clearcast three times during the growing season, residents say the impoundment looks the best it ever has. The city hopes to move more to hand-pulling in 2024 (Portelli, pers. comm.).

The upstream-most population of water chestnut on the Sudbury River documented in OARS' 2016 survey was in the Mill Pond off Pinehill Road in Ashland. No known management has been started yet.

Sudbury Reservoir

The Sudbury and Foss Reservoirs are the emergency water supply for the DCR/ Massachusetts Water Resources Authority water supply system. The main sources of water are the Quabbin Reservoir, Wachusett Reservoir, and Ware River. The Sudbury Reservoir flows into the Foss Reservoir which enters the Sudbury River in Framingham just below Framingham Reservoirs #3 (Foss) and #1 (Stearns). In 2006, DCR in collaboration with Massachusetts Water Resources Authority (MWRA), conducted a plant survey of the Sudbury Reservoir. The survey identified a pioneer infestation of water chestnut in the extreme northern end of the reservoir, with the two largest patches each 30 to 40 feet in diameter (Mass. DCR, 2010). Since 2006, Aquatic Control Technology (now SOLitude Lake Management) has been hired to manage aquatic weeds in the Sudbury Reservoir by hand-pulling.

Assabet River

Starting in 2008, OARS has organized volunteer (public and corporate) hand-pulling events on the Assabet River in Stow, Maynard, and Acton nearly every summer. Community and corporate hand-pulling events have also been organized in Acton, Concord, Lincoln, Framingham, and Billerica. For several summers OARS hired a Rapid Response team to pull out all pioneer infestations in all three rivers where other efforts were not already underway. The towns of Westborough, Hudson, and Stow have supported this and OARS' ongoing volunteer-based efforts. Water chestnut populations in the sections that have been consistently pulled have been reduced, but not eliminated since hand-pulling has not been thorough enough to remove all the water chestnut in any year. There has also been a group of landowners who abut the Assabet who have been removing and controlling populations of water chestnut on their own for many years. This community effort has been crucial in keeping the Assabet clear of new infestations. Maps of the Gleasondale area illustrate some reduction in water chestnut in the area that has been consistently managed..

Figure 14: Assabet River Water Chestnut Survey, Gleasondale, 2013

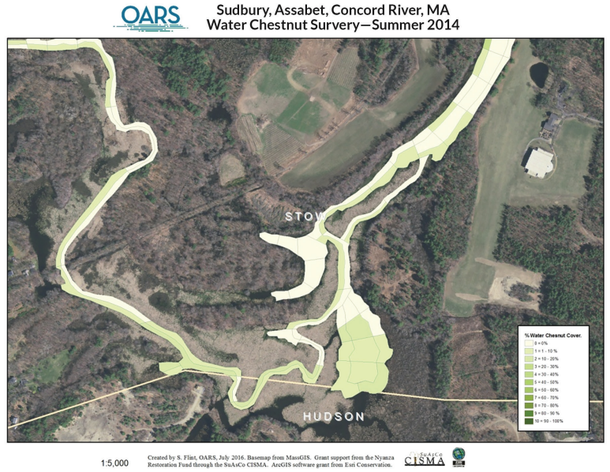


Figure 15: Assabet River Water Chestnut Survey, Gleasondale, 2014

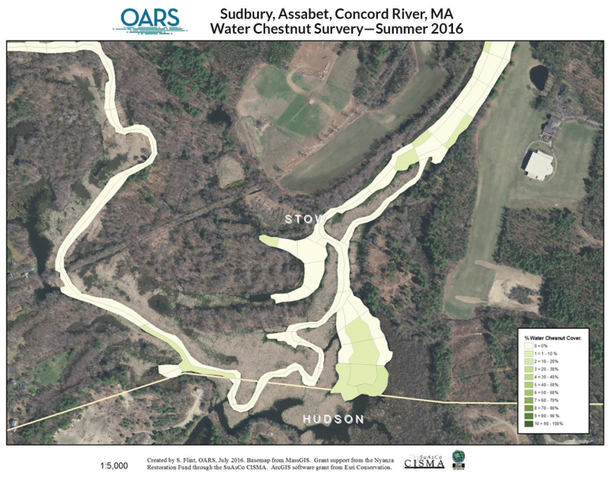


Figure 16: Assabet River Water Chestnut Survey, Gleasondale, 2016

Concord River

Concord Impoundments

The Concord Unit of the Great Meadows National Wildlife Refuge consists of two shallow impoundments along the Concord River. These are managed by USFWS as "moist soil management units" for the benefit of migrating birds between 2000 and 2013. Alternate impoundments were drawn down each year from late May until early fall. The drawdowns appeared to reduce the amount of water chestnut significantly in the impoundments, but only when sediment dried out and was left with no standing water; plants were observed to survive during a drawdown if the pool was not drawn down completely (McGourty, pers. comm., 2016). Since 2013, management of the impoundments has focused on habitat for Blanding's turtles, and they are no longer drawn down in the summer. OARS' 2016 survey documented water chestnut in one basin of the impoundments (Figure 16); a considerable population of lotus is also now growing in the impoundments. USFWS is developing a new management plan for the unit in 2024.

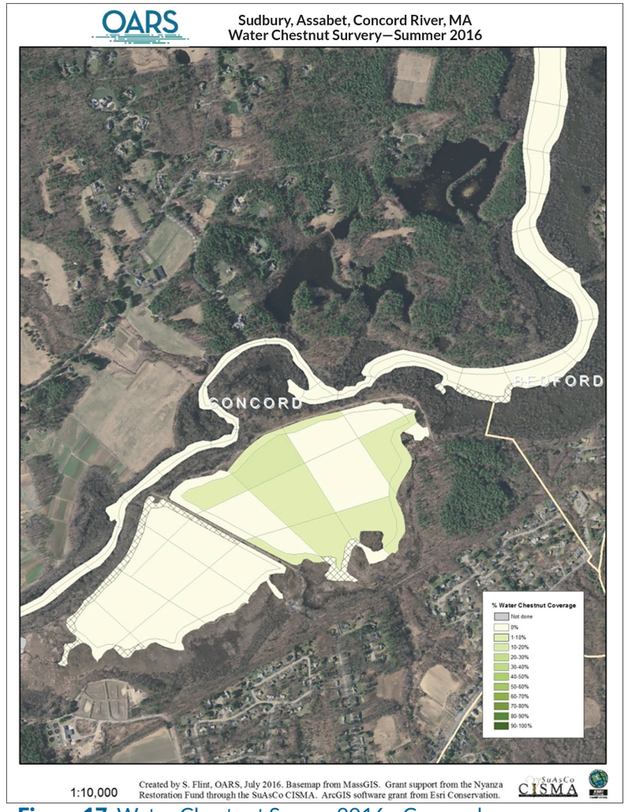


Figure 17: Water Chestnut Survey 2016—Concord Impoundments

Billerica Mill Pond Impoundment

The impoundment created by the Talbot Mills dam in Billerica has been a water chestnut hotspot for more than 15 years, with an estimated 8 acres of 100% cover surveyed in 2016. OARS held a volunteer water chestnut pulling day on the Billerica impoundment in June 2008. However, the population was already well-established, and it rapidly became obvious that a much more intensive effort would be required to have any impact. No further work has been done in this impoundment, and water chestnut remains a significant problem. By mid-summer this section is often completely covered by water chestnut except for a narrow path down the thread of the stream. The dam is scheduled for removal in 2025 which is expected to largely eliminate the water chestnut problem. During removal, a silt screen will be put in place to stop water chestnut seeds from spilling downstream and prevent further spreading.

OARS has worked with community volunteers and a property owner for several years upstream of the dam where water chestnut has been spreading. OARS' Rapid Response team removed emerging populations for several years along the length of the river. The town of Billerica has supported this work and OARS' continuing volunteer pulls.

Ponds

Ice House and Robbins Mill Ponds, Acton

The Town of Acton began managing water chestnut in Ice House Pond, an impoundment of Nashoba Brook, in 1948 using herbicides, including mixtures of 2,4-D, and tricholopicolinic acid (Picloram). The town dredged the pond in 1995 to remove the severe infestation of water chestnut, which was effective for several years. By 2011, the plant had returned, and the first volunteer hand-pulling was organized. In 2012 the hand-pulling involved 30 local volunteers and ten boats and was designated a "community service project." In 2014, Ice House Pond had very few plants and the effort moved to Robbins Mill Pond, also an impoundment of Nashoba Brook in Acton. In 2015 it became clear that more intensive work was needed. That year Town Meeting approved a Community Preservation Act (CPA) grant of $36,000 for three years of mechanical harvesting on both ponds. Mechanical harvesting was conducted in 2015. Drought conditions in 2016 made water levels too low for the harvester, therefore, SOLitude Lake Management was hired to conduct hand-pulling in both ponds (Abe, pers. comm., 2016). Robbins Mill Pond remained clear in 2023. However, a significant quantity (some 16,400 plants) was hand pulled from Ice House Pond by 42 volunteers in September 2023.

Heard Pond, Wayland

Heard Pond in Wayland, which is connected to the Sudbury River during floods, has been undergoing management for water chestnut for more than 20 years. The Wayland Surface Water Quality Committee (WSWQC) reported that mechanical harvesting removed about 600 tons of water chestnut plants in the first year of harvesting. The quantities of water chestnut plants harvested declined sharply year to year from 2003 until 2013, when only 691 plants were harvested (Aquatic Control Technology, 2015b). The WSWQC hoped that the water chestnut seed bank in the sediment was close to being exhausted, given that published seed viability time frame of seven to twelve years. However, the 2016 season saw about 50,000 plants harvested, with still some plants left unharvested in a very shallow "hot spot" area. Apparently, the seed bank in the pond sediment was still large, despite fourteen years of largely complete shoreline-to-shoreline harvesting in the pond, calling into question the published ranges for seed viability. The WSWQC noted that in years when the spring was colder and high water persisted into June, many fewer plants emerged, while 2016 was a remarkable year, with very low water levels from May onward, which may have resulted in the pond water warming more quickly.

Hand-harvesting has continued to be the main form of management in Heard Pond. Water chestnut populations have decreased since 2017, when just over 10,000 plants were collected. In 2022 a total of only 696 plants were collected (SOLitude Lake Management, 2022).

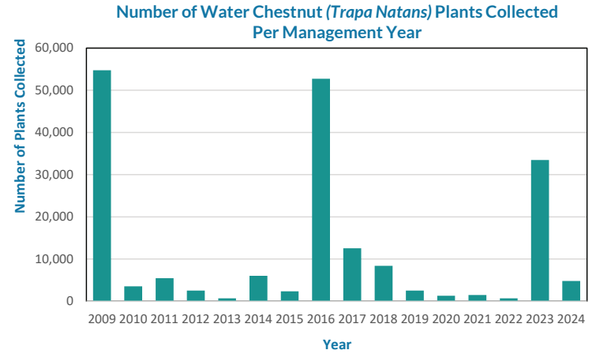


Figure 18: Number of Water Chestnut *(Trapa natans)* Plants Collected Per Management Year

Hop Brook Ponds

The Hop Brook ponds (Stearns Mill, Carding Mill, Grist Mill and Hager Ponds) are impoundments of Hop Brook, which run into the Sudbury River in Wayland. Hop Brook is heavily eutrophic, receiving the treated effluent from the Marlborough Easterly Wastewater Treatment Facility near its headwaters. Stearns Mill, Carding Mill, and Grist Mill ponds all have large populations of water chestnut covering over 45 acres combined (estimated from OARS 2016 survey; Hager Pond was not surveyed). Hop Brook

Protection Association (HBPA), in collaboration with USFWS, harvested water chestnut mechanically and by hand between 2000 and 2018. Mechanical harvesting was largely unsuccessful and the switch to using Clearcast was made in 2020. When applied correctly, Clearcast has been extremely successful at managing the water chestnut within the ponds. As populations continue to decline with repeated herbicide treatment, HBPA hopes to move to hand-pulling as their primary method.

Warner's Pond, Concord

Warner's Pond was created in the 1800s by damming Nashoba Brook, a tributary to the Assabet River, to power a sawmill, then a pail factory. Today the pond is shallow and eutrophic. In 1997 OARS (then the Organization for the Assabet River) conducted an aquatic plant survey of Warner's Pond, reporting the presence of water chestnut as well as Eurasian milfoil and fanwort. In 1999 Aquatic Control Technology surveyed the pond, again reporting water chestnut, milfoil, and fanwort as the primary invasive aquatic weeds. Mechanical harvesting and hydroraking were conducted in 2005 but discontinued over concerns of spreading the milfoil and fanwort through fragmentation. The Town of Concord initiated hand pulling to control water chestnut in 2004, which continues on an annual basis with community participation. In 2011 and 2012, the pond was surveyed and treated with the herbicide Sonar (fluridone) to control milfoil and fanwort (ESS Group, 2012). In 2012, a comprehensive Watershed Management Plan was completed, and the town had a dredging feasibility study for a limited area of the pond prepared (Kaye, 2016). After finding the cost of dredging was far too high, the town commissioned a study to determine the best alternative for restoring ecological health and recreational opportunities. The study considered no action, modified dredging, and dam removal. The Alternatives Analysis Report (EA, 2023) recommended dam removal as the preferred alternative.

WATER CHESTNUT MANAGEMENT PLAN, 2024–2029

GOALS

Vision: a watershed with a healthy, diverse, and resilient ecosystem. The overall goals for managing water chestnut in the Sudbury, Assabet, and Concord River watershed (SuAsCo) are to reduce existing populations of water chestnut to levels that can be controlled with minimal effort, prevent re-infestation in managed sections, and to prevent the establishment of infestations in new areas. To work toward these goals, we propose the following objectives and actions over the next five years. Implementation will depend on funding and leadership.

ACTION PLAN

OBJECTIVE 1. Establish a Watershed-Wide Water Chestnut Task Force

OARS facilitates the Aquatic Invasive Management Subcommittee (AIMS), originally named the Water Chestnut Task Force, to oversee implementation of this management plan. AIMS is a subcommittee of the SuAsCo Cooperative Invasive Species Management Area (CISMA). AIMS' founding members were those already involved in water chestnut management in the watershed: USFWS, towns of Concord, Lincoln, Acton, and Framingham (now City), and the Concord Land Conservation Trust, OARS, Wayland Surface Water Quality Committee, and Hop Brook Protection Association. Additional members now include DCR, Mass Audubon, Friends of Saxonville (Framingham), National Park Service, and the towns of Ashland, Hudson, and Sudbury. This subcommittee meets every spring and fall to coordinate management efforts by these stakeholders, encourage monitoring and logistical support from towns, share updates on control techniques, research, and funding sources, and collaborate on outreach and education materials and efforts. AIMS' goals are:

- Implement the Action Plan.
- Recruit additional members from other watershed towns, state and local agencies, and lake/pond associations.
- Every five years or more frequently if needed, review and revise this Management Plan to adapt its methods and recommendations to changes in field conditions, including the effects of ongoing management, and any new research or management options.
- AIMS may help to organize applications for funding for regional planning and implementation, leveraging the water chestnut management strategy outlined here.

OBJECTIVE 2: Establish Watershed-Wide Monitoring & Reporting

Develop a watershed-wide water chestnut monitoring and reporting system to provide current plant distribution information for control program planning and evaluation, and to provide early detection of new infestations.

- Encourage use of the reporting app developed by OARS through signs, handouts, community outreach, and social media.
- Seek funding to update mainstem river surveys of existing infestations periodically in early summer (before management) to monitor changes: progress in management, potential spread at the margins of existing infestations, and the development of new infestations.
- Look into the feasibility of using drones to map sections of river, including funding and methods to analyze the imagery.
- Create and give presentations to Conservation Commissions on how water chestnut can be effectively monitored, reported, and managed. Update Conservation Commissions about water chestnut work being done in the watershed.
- Assess the feasibility of contributing to other web-based water chestnut reporting systems, including state-wide invasive species databases under development and/or the SuAsCo CISMA website. Integrate mainstem surveys and town-based surveys for consistent reporting and evaluation.

OBJECTIVE 3: Control Existing Populations

Control existing populations of water chestnut by supporting ongoing efforts, expanding efforts to control other areas identified by monitoring, and utilizing the Weed Warrior program. Work to completely clear sections of rivers or ponds to test established seed viability ranges. Encourage volunteers through both Weed Warriors and the community to pull water chestnut early in the season to prevent the seeds from maturing.

OBJECTIVE 4: Outreach & Local Participation

Encourage local and individual participation by making outreach and education materials widely available and promoting participation in CISMA's Weed Warriors program.

- Implement the Action Plan.
- Encourage use of the reporting app developed by OARS through signs, handouts, community outreach, and social media.
- Continue to support and encourage the use of the Weed Warriors program under the SuAsCo CISMA, which educates and trains volunteers on proper water chestnut removal technique.
- Update the water chestnut information available on CISMA's and OARS' websites.
- Develop water chestnut informational handout for the general public. Distribute handouts where river users are likely to be reached (e.g., local libraries and businesses, visitor centers).
- Facilitate communication with towns and stakeholder groups. Organize meetings with town/city Conservation Commissions or other stakeholder groups to: encourage town-based monitoring (see Obj. 2), encourage direct assistance with transport and disposal of harvested plant material (see Obj. 6), and discuss consistent permitting of control efforts (see Obj. 4).
- Support community and corporate hand-pulling events.Use social media and e-newsletters to share opportunities for volunteering and the results.

OBJECTIVE 5: Consistent Wetland Permitting of Control Efforts

Collaborate with the Massachusetts Association of Conservation Commissions (MACC) and other stakeholders to disseminate water chestnut management permitting information and this Guidance.

- Organize meetings with town Conservation Commissions (see Objective 3) to discuss how water chestnut can be effectively managed and the municipal role in implementing this Plan.
- Encourage towns with water chestnut in multiple waterbodies to: identify someone (or an organization) to oversee water chestnut pulling in the town; facilitate compliance as needed under the Wetlands Protection Act and local bylaws to allow hand-pulling by small groups and individuals under supervision of a coordinator. Hand pulling should follow standard Mass. Lakes and Ponds operating procedures for pulling and disposal.

OBJECTIVE 6: Prevent & Control New Infestations

Prioritize management of new or "satellite" patches of water chestnut.

- Use the reporting system via a QR code on the signs to monitor the spread of water chestnut.
- Monitor waterbodies throughout the watershed for

new or expanding populations of water chestnut that could be managed by hand-pulling (Objectives 2 and 6).
- Maintain water chestnut signs posted at boat ramps in good condition. Support "Aquatic Hitchhiker" messaging at boat ramps: Clean, Drain, Dry.
- Provide financial support to provide seasonal staff or organize volunteer events.
- Support and encourage municipal and volunteer efforts to control new water chestnut patches in tributaries, lakes, and ponds.
- Cross-post calls for volunteers to help with hand-pulling events throughout the watershed.

OBJECTIVE 7: Contribute To Research On Effective Controls

Support research on effective biological and chemical control of water chestnut.

- Actively seek and/or support grants for research on the effects of water chestnut populations on habitat (e.g., macroinvertebrate and fish populations, competition with native plants, succession of invasive plants), and on biological, chemical, and other controls in the watershed.
- Encourage research into new ways of monitoring and reporting water chestnut within the watershed.
- Continue monitoring for *T. bispinosa* to reduce the risk of a cryptic invasion.
- Participate, where possible, in research on *Galerucella birmanica* being conducted at Cornell University.
- Encourage thorough pre- and post-treatment surveys of areas treated with herbicides or biological controls and reporting of the results.
- Communicate research and management results via websites, newsletters, and newspaper articles.

Table 4: River Sections and Management

Section Description	Access points & distance	Total area (acres)	Est. area WC cover (2016 survey, updates)	Management History	Management Actions recommendation	Leadership
A1 Impoundment of the Assabet River, Westborough (335 acres)	Mill Road boat ramp, Westborough	335	Sparse cover across 57 acres, worst in southern section mixed with other species.	First documented in 2014, OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Continue hand-pulling; very labor intensive.	Westborough
Assabet River from A1 Imp. to Chapin Road, Hudson	Various		0 acres	OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor	OARS
Assabet River Impoundment, Hudson (22 acres)	Library parking lot canoe put-in, Hudson	22	Sparse cover across 2 acres; other aquatic biomass severe, eutrophic	First documented in 2012, hand-pulling since 2012. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed	OARS, Hudson
Assabet River between Main Street and Cox Street, Hudson (14 acres)	Cox Street canoe put-in, Hudson	14	Sparse cover across 1 acre	Hand-pulling since 2014. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	OARS, Hudson
Assabet River Gleasondale Impoundment, Stow (20 acres)	Canoe access Cox Street, Hudson, or Gleasondale Road private access, Stow	20	Previously areas of dense cover, now sparse across 4 acres	Hand-pulling since 2008. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	OARS, Stow
Assabet River between Gleasondale Road and Sudbury Road, Stow (40 acres)	Sudbury Road canoe put-in, Stow	40	Sparse cover across 8 acres	Hand-pulling since 2008. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	OARS, Stow
Assabet River between Sudbury Road & White Pond Road, Stow/ Maynard (incl. Crow Island area) (70 acres)	Private access at Crow Island Air Field, Stow; White Pond Road boat ramp, Maynard	70	Previously widespread and dense but now sparse cover over 3 acres	Hand-pulling since 2009. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	OARS, Stow
Assabet River, Ben Smith Impoundment, Maynard (18 acres)	White Pond Road boat ramp, Maynard	18	Sparse cover over 9 acres	Hand-pulling since 2009. OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	Maynard
Assabet River Powdermill Impoundment, Maynard/Acton	Private access at Powdermill dam, Acton	25	Was sparse cover over 13 acres and 3 acres moderate, now mostly clear	Hand-pulling since 2015; OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	Maynard and Acton
Assabet River from Rte 62, Acton, to confluence, Concord	Rte 62 canoe put-in, Acton, Pine Street, Concord; Lowell Road Concord		0 acres	OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor	OARS
Cedar Swamp, Area of Critical Environmental Concern (ACEC)	Headwaters of Sudbury River, Westborough. Limited canoe access at Fruit Street, Hopkinton		No data	None	Assess and develop plan if needed	DCR

Section Description	Access points & distance	Total area (acres)	Est. area WC cover (2016 survey, updates)	Management History	Management Actions recommendation	Leadership
Sudbury River, from Cedar Swamp to Ashland	Canoe access at Fruit Street, Hopkinton		None	None	Assess.	
Sudbury River Mill Pond, Ashland	Canoe access at Mill Pond Park, Pinehill Rd, Ashland	12	Sparse–moderate cover over 7 acres.	None	Initiate hand-pulling effort, monitor	Ashland
Sudbury River, Framingham Reservoir #1	DCR access at Winter Street dam, Framingham	126	Was 70 acres sparse cover, 21 acres moderate cover, 10 acres heavy cover.	None	Continue herbicide treatment and initiate hand-pulling when appropriate	Mass. DCR
Sudbury River, Saxonville Impoundment, Framingham	Centennial Avenue access, Framingham	39	Was 30 acres heavy cover; 8 acres sparse. Now mostly clear.	Hand-pulling in 2013–present; herbicide 2017–2023.	Monitor and hand-pulling as needed by volunteers/ teams	Framingham, Friends of Saxonville
Sudbury River from Saxonville to Rte 27, Wayland	Little Farms Road, Framingham canoe access and Route 20 boat ramp, Wayland	18	Was 8 acres sparse cover; 1-acre moderate cover.	OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/ teams	Framingham? Wayland?
Sudbury River from Route 27 to Route 117	Route 27 boat ramp, Wayland; Sherman Bridge Road, Wayland	158	Sparse cover over 75 acres; 15 acres of moderate to heavy cover.	Mechanical harvesting and hand pulling; herbicide started 2022.	Continue herbicide treatment and follow up with hand-pulling when feasible.	USFWS
Sudbury River from Route 117 to Sudbury Road, Concord (includes Fairhaven Bay area)	Route 117 canoe access, Lincoln; Sudbury Road, Sudbury	115	Was sparse over 41 acres; 4 acres moderate-heavy. Fairhaven Bay now largely clear, large patches at Route 2.	Mechanical harvesting and hand pulling.	Continue hand-pulling.	Concord Land Conservation Trust, towns of Lincoln and Concord
Sudbury River from Sudbury Road to Lowell Road, Concord	Lowell Road boat ramp, Concord	50	11 acres sparse cover.	Mechanical harvesting and hand pulling; OARS Rapid Response monitored and pulled emergent plants 2016–2021.	Monitor and hand-pulling as needed by volunteers/teams.	Concord Land Conservation Trust, Town of Concord
Concord River from Lowell Road, Concord to Pollard Street, Billerica	Lowell Road boat ramp, Concord; Route 225 boat ramp, Bedford		Was 0 acres. Now dense patches along edges.	OARS Rapid Response monitored and pulled emergent plants 2016–2021. Large volunteer pulls begun 2022.	Monitor and intensive hand-pulling by volunteers/ teams.	OARS, Town of Billerica
Concord River, Talbot Mills dam impoundment, Billerica	Private access off Faulkner Street, Billerica	16	8 acres heavy cover.	None	Dam removal. Other option is herbicide.	Town of Billerica
Concord River, Lowell Street, Billerica to Lowell	Muldoon Park, Billerica Street, Lowell		0 acres in 2016; scatted emergent along shoreline.	OARS Rapid Response monitored and pulled emergent plants 2016–2021. Volunteer pulls.	Assess management options in conjunction with Billerica Impoundment.	Billerica, Lowell, OARS
Heard Pond, Wayland	Pelham Island Road, Wayland	90	Sparse cover scattered over 39 acres	Mechanical harvesting from 2003 to 2009; hand-pulling from 2007 to 2023.	Continue hand-pulling.	Wayland Surface Water Quality Committee
Hop Brook Ponds (Stearns Mill, Carding Mill, Grist Mill ponds), Sudbury	Various access points	99	61 acres moderate/heavy cover; 8 acres sparse cover (some areas not surveyed).	Mechanical harvesting 2000–2018; hand pulling and chemical treatment 2020–2023.	Continue chemical Treatment then move to hand-pulling.	Hop Brook Protection Association
Ice House and Robbins Mill Ponds, Acton			Had dense coverage. Mostly clear in 2023 after pulling.	Chemical treatment (1948–), dredging, hand-pulling, and mechanical harvesting.	Hand-pulling; further treatment to be determined.	Acton

REFERENCES

Abe, B. (2016). Town of Acton Natural Resources Department, Acton, Mass. Pers. comm., Nov. 2106.

AECOM (2009). Use of Aquatic Herbicide Imazamox Clearcast® in the State of New York Supplemental Environmental Impact Statement. Final AECOM, Inc. September 2009 Document No.: 00760-245-310. Retrieved from www.dec.ny.gov/docs/materials_minerals_pdf/imazamoxseis.pdf on October 25, 2016.

Allen, J. and D. Strain (2013). Aquatic invasive species water chestnut in the Chesapeake Bay. Maryland Sea Grant Brief. Retrieved from www.mdsg.umd.edu/sites/default/files/files/Water%20chestnut_AIS%20brief_PI-2013-05.pdf

Aquamarine (n.d.). Aquatic Weed Harvesters. Retrieved from www.aquamarine.ca/aquatic-weed-harvesters/

Aquatic Control Technology (2005). Warner's Pond Management Plan Summary. Retrieved from www.concordma.gov/pages/ConcordMA_NaturalResources/WarnersPond2004ReportACT.pdf

Aquatic Control Technology (2015a). 2015 Baseline Assessment Sudbury River Survey Findings and Management Recommendations. Prepared for Town of Framingham.

Aquatic Control Technology (2015b). 2015 Summary Report Water Chestnut Harvesting, Heard Pond, Wayland, MA.

Brinton, W. F. (2000). Compost Quality Standards & Guidelines: Final Report. Prepared for: New York State Association of Recyclers. Retrieved from compost.css.cornell.edu/Brinton.pdf

Caraco, N. F., and J. J. Cole (2002). Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. Ecological Applications, 12 (5), 1496–1509

Charles River Watershed Association (n.d.). Retrieved from www.crwa.org/canoeing-for-clean-water

Chorak, G.M., L. Dodd, N. Rybicki, K. Ingram, M. Buyukyoruk, Y. Kadono, Y. Y. Chen, and R.A. Thum, Cryptic introduction of water chestnut (Trapa) in the northeastern United States, Aquatic Botany, Volume 155, 2019, Pages 32–37, ISSN 0304-3770, https://doi.org/10.1016/j.aquabot.2019.02.006(https://www.sciencedirect.com/science/article/pii/S0304377018302298)

Commonwealth of Massachusetts (2016). General Laws. Part I, Title XIX, Ch 128, Section 20A. Retrieved from https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIX/Chapter128/Section20A

Connecticut River Watershed Council (n.d.). Retrieved from www.ctriver.org/get-involved/stopping-an-invasive-species-water-chestnut/

Coote, T.W., R.E. Schmidt and N. Caraco (2001). Use of a Periodically Anoxic *Trapa natans* (water-chestnut) Bed by Fishes in the Hudson River. Section IV: 20pp. In: J.R. Wladmand & W.C. Nieder (Eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 2000. Hudson River Foundation, NY.

Cornell Chronicle (2016). Herbicides can't stop invasive plants. Can bugs? August. Retrieved from www.news.cornell.edu/stories/2016/08/herbicides-cant-stop-invasive-plants-can-bugs

Countryman, W.D. (1978). Nuisance Aquatic Plants in Lake Champlain. Prepared by Aquatec, Inc. for the Eutrophication Task Force. Lake Champlain Basin Study. New England River Basins Commission, Burlington, Vermont.

Countryman, W.D. (1970). The history, spread and present distribution of some immigrant aquatic weeds in New England. Hyacinth Control J. 8: 50–52. Retrieved from www.apms.org/japm/vol08b/v8p50.pdf.

Crow, G.E. and C.B. Hellquist (2000). Aquatic and Wetland Plants of Northeastern North America: Volume One Ptericophytes, Gymnosperms, and Angiosperms: Dicotyledons. The University of Wisconsin Press. Pp. 206–207.

Crow, G.E., and C.B. Hellquist (1983). Aquatic Vascular Plants of New England: Part 6. Trapaceae, Haloragaceae, Hippuridaceae. Station Bulletin 524. New Hampshire Agricultural Experiment Station University of New Hampshire, Durham, NH. Retrieved from www.library.unh.edu/digital/object/agbulletin:0485.

Davenport, G. E. (1879). *Trapa natans.* Bulletin of the Torrey Botanical Club, 6 (58): 352. Stable URL: www.jstor.org/stable/2476842.

DeHollander, J. (2016). Oswego County Soil and Water Conservation District, Fulton, NY. Pers. comm.

DeHollander, J. (2015). 2014 Oswego County Water Chestnut Control Program. Report of Oswego County Soil and Water Conservation District, Fulton, NY. Retrieved from www.sleloinvasives.org/wp-content/uploads/2014/04/Oswego-County-Special-Project-Report-2014-PDF.pdf.

Des Jardin, K. (2015). Water Chestnut: Field Observations, Competition, and Seed Germination and Viability in Lake Ontario Coastal Wetlands. Environmental Science and Biology Theses. Paper #98.

Ding, J., and B. Blossey (2005). Impact of the Native Water Lily Leaf Beetle, *Galerucella nymphaeae* (Coleoptera: Chrysomelidae), Attacking Introduced Water Chestnut, *Trapa natans*, in the Northeastern United States. Environmental Entomology, 34 (3): 683–689. DOI: 10.1603/0046-225X-34.3.683.

Ding, J., B. Blossey, Y. Du, and F. Zheng (2006a). *Galerucella birmanica* (Coleoptera: Chrysomelidae), a promising potential biological control agent of water chestnut, *Trapa natans*. Biological Control 36(1):80–90.

Ding, J., B. Blossey, Y. Du, and F. Zheng (2006b). Impact of *Galerucella birmanica* (Coleoptera: Chrysomelidae) on growth and seed production of *Trapa natans*, Biological Control, 37 (3): 338–345. Retrieved from www.sciencedirect.com/science/article/pii/S1049964405003373.

EA Engineering, Science and Technology, Inc. (2023). Warner's Pond Alternatives Analysis Report, Concord Massachusetts. Prepared for the Town of Concord. Warwick RI.

Eaton, R. J. (1947). Lemna minor as an aggressive weed in the Sudbury River. Rhodora, 49 (583): 165–171. New England Botanical Club, Inc. DOI: http://www.jstor.org/stable/23303808.

EDDMapS (2024). Early Detection and Distribution Mapping System. Distribution maps, Water Chestnut (Genus Trapa). Retrieved from www.eddmaps.org/distribution/.

ENSR (2005). Rapid Response Plan for Fanwort (Cabomba caroliniana) in Massachusetts. Retrieved from www.mass.gov/eea/docs/dcr/watersupply/lakepond/downloads/rrp/fanwort.pdf.

ESS Group (2012). Warner's Pond Watershed Management Plan. Prepared for Town of Concord Division of Natural Resources. Concord, Mass.

Feldman, R. (2001). Taxonomic and size structures of phytophilous macroinvertebrate communities in Vallisneria and Trapa beds of the Hudson River, New York. Hydrobiologia 452 (1): 233–245. DOI: 10.1023/A:1011903315998 (Abstract only).

Finch, D.M. *et al.* (2021). Effects of Climate Change on Invasive Species. In: Poland, T.M., Patel-Weynand, T., Finch, D.M., Miniat, C.F., Hayes, D.C., Lopez, V.M. (eds) Invasive Species in Forests and Rangelands of the United States. Springer, Cham. https://doi.org/10.1007/978-3-030-45367-1_4.

Gettys, L.A., W.T. Haller, and D.G. Petty, Eds. (2014). Biology and Control of Aquatic Plants. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia. Retrieved from www.aquatics.org/bmp%203rd%20edition.pdf.

Gleason, H.A., and A. Cronquist (1963). Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Willard Grant Press. Boston, Mass. P. 496.

Gosselin, C. (2024). Water and Wetland, Inc. Grafton MA, pers. comm.

Groth, A.T., L. Lovett Doust, and J. Lovett-Doust (1996). Population density and module demography in *Trapa natans* (Trapaceae), an annual, clonal aquatic macrophyte. American Journal of Botany, 83 (11): 1406–1415. Retrieved from www.jstor.org/stable/2446095.

Haller, W.T. (2014). Appendix B: Aquatic Herbicide Application Methods. In: Gettys, L.A., W.T. Haller, and D.G. Petty (Eds.). 2014. Biology and Control of Aquatic Plants. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia. Retrieved from www.aquatics.org/bmp%203rd%20edition.pdf.

Hop Brook Protection Association (2004). 2004 Harvesting Report. Retrieved from www.hopbrook.org/id36.htm.

Hummel, M. and E. Kiviat (2004). Review of world literature on water chestnut with iImplications for management in North America. J. Aquat. Plant Manage., 42: 17–28. Retrieved from www.apms.org/japm/vol42/v42p17.pdf.

Integrated Taxonomic Information System (2016). Online Database: Trapa L. Retrieved from www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=27169.

Kadono, Y. and E.L. Schneider (1986). Floral biology of *Trapa natans* var. japonica. Bot. Mag. Tokyo 99: 435. DOI:10.1007/BF02488722.

Karg, S. (2006). The water chestnut (*Trapa natans L.*) as a food resource during the 4th to 1st millennia BC at Lake Federsee, Bad Buchau (Southern Germany). Environmental Archaeology 11(1): 125–130. DOI: 10.1179/174963106x97106.

Kato, Y., J. Nishihiro, and T. Yoshida (2016). Floating-leaved macrophyte (*Trapa japonica*) drastically changes seasonal dynamics of a temperate lake ecosystem. Ecol. Res., 31: 695. DOI:10.1007/s11284-016-1378-3 (Abstract only).

Kaye, D. (2016). Concord Natural Resources, Concord, Mass. Pers. comm., November.

Kelly, R., and D. Henley (1996). Water chestnut and culex mosquitoes. East Middlesex Control Project. Northeastern Mosquito Control Association. Retrieved from http://www.nmca.org/paper17a.htm.

Kishbaugh, S.A. (2014). Chapter 15.6: Water Chestnut. In: Gettys, L.A., W.T. Haller, and D. G. Petty (Eds.). Biology and Control of Aquatic Plants. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia. Retrieved from www.aquatics.org/bmp%203rd%20edition.pdf.

Koch, S. (2023). Eastern Massachusetts NWR Complex. US Fish and Wildlife Service, pers. comm.

Kornijów, R., D.L. Strayer, and N.F. Caraco (2010). Macroinvertebrate communities of hypoxic habitats created by an invasive plant (*Trapa natans*) in the freshwater tidal Hudson River. Fundam. Appl. Limnol., Arch. Hydrobiol., 176 (3): 199–207. Retrieved from www.caryinstitute.org/sites/default/files/public/reprints/Kornijow_2010_FAL.pdf.

Kundu, M. and R. Joshi (2012). Production Technology of Water Chestnut (*Trapa natans L.*). Indian Agricultural Research Institute, Division of Fruits and Horticultural Technology, New Delhi. Retrieved from www.krishisewa.com/articles/production-technology/142-chestnut.html.

Kurihara, M., and I. Ikusima (1991). The ecology of the seed in *Trapa natans* var. *Japonica* in a eutrophic lake. Vegetatio, 97 (2): 117–124. Retrieved from www.jstor.org/stable/20046091.

Langley, L., L. Rhodes, and M. Stroman (2004). Guidance for Aquatic Plant Management in Lakes and Ponds as it Relates to the Wetlands Protection Act. Department of Environmental Protection, Bureau of Resource Protection, Wetlands/Waterways Program. Retrieved from www.mass.gov/eea/docs/dep/water/laws/a-thru-h/alkguide.pdf.

Largy, T. (2016). Wayland Surface Water Quality Committee. Pers. comm., October.

Les, D.H. and L.J. Mehrhoff (1999). Introduction of nonindigenous aquatic vascular plants in southern New England: a historical perspective. Biological Invasions, 1: 281–300.

Mass. DCR (2007). Standard Operating Procedures: Using Hand Pulling and Benthic Barriers to Control Pioneer Populations of Non-Native Aquatic Species, A Guide for Volunteers. Mass. Department of Conservation and Recreation, Lakes and Ponds Program. Retrieved from www.mass.gov/eea/docs/dcr/watersupply/lakepond/downloads/sop2007.pdf.

Mass. DCR (2010). Aquatic Invasive Species Assessment and Management Plan. Mass. Department of Conservation and Recreation, Office of Watershed Management. Retrieved from www.mass.gov/eea/docs/dcr/watersupply/watershed/2010aismgtplan.pdf.

Mass. DAR (2016a). Aquatic Vegetation Management. Mass. Department of Agriculture. Retrieved from www.mass.gov/eea/agencies/agr/pesticides/aquatic-vegetation-management.html,

Mass. DAR (2016b). Mass. Department of Agriculture, Pesticide Product Registration Information. Retrieved from www.kellysolutions.com/ma/showproductsbypest.asp?Pest_ID=PCGABBA01.

Mass. EOEA (2004). Eutrophication and Aquatic Plant Management in Massachusetts Final Generic Environmental Impact Report. Massachusetts Executive Office of Environmental Affairs. Retrieved from www.mass.gov/eea/docs/dcr/watersupply/lakepond/downloads/main-geir.pdf.

Mass. EOEEA (2016). Massachusetts Prohibited Plant List. Executive Office of Energy and Environmental Affairs. Retrieved from www.mass.gov/eea/agencies/agr/farm-products/plants/massachusetts-prohibited-plant-list.html.

MACC (2015). Protecting Wetlands and Open Space: MACC's Environmental Handbook (First On-Line Edition). Massachusetts Association of Conservation Commissions, Belmont, Mass. Available through www.maccweb.org/ehandbook.html.

McGourty, E. (2016). Eastern Mass. National Wildlife Refuge Complex, US Fish & Wildlife Service, pers. comm.

Methe, B.A., R.J. Soracco, J.D. Madsen, and C.W. Boylen (1993). Seed Production and Growth of Waterchestnut as Influenced by Cutting. J. Aquat. Plant Manage., 31: 154–157. Retrieved from www.apms.org/japm/vol31/v31p154.pdf.

MIPAG (2011). Massachusetts Invasive Plant Species: Early Detection Priorities. Massachusetts Invasive Plants Advisory Group. Retrieved from www.massnrc.org/mipag/docs/EarlyDetectionMIPAG.pdf.

MISC, 2019. Teaming up to Tackle Two-horned Trapa: A Highly Invasive New Species of Water Chestnut. Maryland Invasive Species Council, Annapolis MD. Retrieved from https://mdinvasives.org/iotm/july-2019/.

Muenscher, W.C. (1944). Aquatic Plants of the United States. Comstock Publishing Company, Inc. Cornell University, Ithaca, New York. Pp. 274–276.

Mystic River Watershed Association (n.d.) www.mysticriver.org/water-chestnut.

Nashoba Valley Voice (2016). August 30. Ayer, Mass. Retrieved from www.nashobavalleyvoice.com/pepperell_news/ci_30307299/whats-that-smell-pepperell.

Nashua River Watershed Association (n.d.). Retrieved from www.nashuariverwatershed.org/what-we-do/protect-water-and-land/invasive-species-overview/plants-water-chestnut.html.

Nemecek, R. and J. DeHollander (2014). Chemically Treating Water Chestnut (*Trapa natans*) in a River System. Presented at Eastern Lake Ontario Invasive Species Symposium, June 11, 2014.

Netherland, M.D. (2014). Chapter 11: Chemical Control of Aquatic Weeds. In: Gettys, L.A., W.T. Haller and D.G. Petty, Eds. Biology and Control of Aquatic Plants. A Best Management Practices Handbook. Third Edition. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia. Retrieved from www.aquatics.org/bmp%203rd%20edition.pdf.

OARS (2013). Report to CISMA: Mapping Water Chestnut in the Sudbury, Assabet, and Concord River System. October 31. OARS, Concord, Mass. Retrieved from www.cisma-suasco.org/sites/default/files/uploads/OARS-report-to-CISMA%20final.pdf.

O'Neill, C.R. Jr. (2006) Water Chestnut (*Trapa natans*) in the Northeast. New York Sea Grant Invasive Species Factsheet Series: 06-1, Brockport, NY.

Pelczarski, K. (1990). Evaluation of a Pop Net for Sampling Fishes from Water-Chestnut Beds in the Tidal Hudson River. A Report of the 1990 Tibor T. Polgar Fellowship Program. Hudson River Foundation, NY.

Pemberton, R.W. (1999). Natural enemies of Trapa spp. in Northeast Asia and Europe. Biological Control 14: 168–180.

Pemberton, R.W. (2002). Chapter 3: Water Chestnut. In: Van Driesche, R., B. Blossey, M. Hoddle, S. Lyon, & R. Reardon. Biological Control of Invasive Plants in the Eastern United States. USDA Forest Service Publication, FHTET-2002-04. Retrieved from www.invasive.org/weedcd/pdfs/biocontrol.pdf

Poovey, A.G. and K.D. Getsinger (2007). Subsurface Aapplications of Triclopyr and 2,4-D amine for control of water chestnut (*Trapa natans L*). J. Aquat. Plant Manage., 45: 63–66. Retrieved from www.apms.org/japm/vol45/v45p63.pdf

Portelli, D. (2023). Conservation Commission, Framingham MA, pers. comm.

Pransky, G. (2023). Hop Brook Protection Association, Sudbury MA, pers. comm.

Rector, P.R., P. J. Nitzsche, and S.S. Mangiafico (2015). Temperature and herbicide impacts on germination of water chestnut seeds. J. Aquat. Plant Mange., 53: 105–112.

Robinson, M. (2002). Water Chestnut: An Exotic Invasive Aquatic Plant *Trapa natans.* Massachusetts Department of Conservation and Recreation, Lakes and Ponds Program. Retrieved from: www.mass.gov/eea/docs/dcr/watersupply/lakepond/factsheet/water-chestnut.pdf.

Schmidt, K. (1986). The Life History of the Chrysomelid Beetle Pyrrhalta nymphaeae (Galerucienae) on Water Chestnut, *Trapa natans* (*Hydrocariaceae*), in Tivoli South Bay, Hudson River, NY. In J.C. Cooper (Ed.) Polgar Fellowship Reports of the Hudson River National Estuarine Sanctuary Program. Hudson River Foundation, NY.

Schultz, R. and E. Dibble (2012). Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: The role of invasive plant traits. Hydrobiologia, 684: 1–14.

SePRO Corporation (2015). Safety Data Sheet: Clearcast. Retrieved from www.sepro.com/documents/Clearcast_MSDS.pdf.

Shelton, A. Biological Control: A Guide to Natural Enemies in North America. Cornell University, College of Agriculture and Life Sciences, Ithaca, NY. Retrieved from https://biocontrol.entomology.cornell.edu/weedfeed/Galerucella.php on 2-22-2024.

Simmons, W., and B. Blossey (2023). Host plant phylogeny does not fully explain host choice and feeding preferences of *Galerucella birmanica*, a promising biological control herbivore of *Trapa natans*. Biological Control, 180 (2023) 105201.

SOLitude Lake Management (2016). Case study: Water Chestnut Controlled with Clearcast & Renovate Max G. Fairfax, Virginia. Retrieved from www.solitudelakemanagement.com/lake-and-pond-management-success-stories-and-case-studies.

Strayer, D.L., C. Lutz, H.M. Malcom, K Munger, and W.H. Shaw (2003). Invertebrate communities associated with a native (*Vallisneria americana*) and an alien (*Trapa natans*) macrophyte in a large river. Freshwater Biology, 48 (1): 1938–1949. DOI: 10.1046/j.1365-2427.2003.01142.x/abstract (Abstract only).

Sweany, A.G. (2023). "Two-horned *Trapa*." ARCGIS Storymaps, August 21, 2023. Two-horned Trapa (arcgis.com).

Sweta, K. Bauddhb, R. Singha, and R. P. Singha (2015). The suitability of *Trapa natans* for phytoremediation of inorganic contaminants from the aquatic ecosystems. Ecological Engineering, 83: 39–42. Retrieved from DOI:10.1016/j.ecoleng.2015.06.003.

Takamura, N., Y. Kadono, M. Fukushima, M. Nakagawa, and B.O. Kim (2003). Effects of aquatic macrophytes on water quality and phytoplankton communities in shallow lakes. Ecol Res., 18, 381. doi:10.1046/j.1440-1703.2003.00563.x (Abstract only).

Teixeira, M.C., M.P. Budd, and D.L. Strayer (2014). Responses of epiphytic aquatic macroinvertebrates to hypoxia. Inland Waters 5: 75–80. DOI: 10.5268/IW-5.1.764.

The Nature Conservancy (2012). SLELO-PRISM Special Project. Oswego County 2012 Water Chestnut Control Program. Retrieved from www.sleloinvasives.org/wp-content/uploads/2012/09/Oswego-County-Special-Project-Water-Chestnut-Control-Report-PDF.pdf.

US Army Corps of Engineers (2012). Aquatic Herbicides. Retrieved from www.glmris.anl.gov/documents/docs/anscontrol/AquaticHerbicides.pdf.

USDA (2010). Federal Noxious Weed List. US Department of Agriculture. Retrieved in 2024 from https://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/weedlist.pdf.

USDA (2024). The PLANTS Database. National Plant Data Team, Greensboro, NC. Retrieved from www.plants.usda.gov/core/profile?symbol=TRNA.

Wagner, K. (2004). The Practical Guide to Lake Management in Massachusetts, A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Mass. Executive Office of Environmental Affairs. Retrieved from: www.mass.gov/eea/docs/dcr/watersupply/lakepond/downloads/practical-guide.pdf.

Walusiak, Edward, Wojciech Krztoń, Elżbieta Cieślak, Magdalena Szczepaniak, and Elzbieta Wilk-Wozniak (2024). Native recovery or expansive threat? Past and predicted distribution of *Trapa natans* L. s. l. on northern limit of species' range. Handout for species management. Ecological Indicators 158: 1470–160. 10.1016/j.ecolind.2023.111349.

Wong, D. (2023). Water Chestnut (*Trapa natans*). Chapter 14 in Invasive Animals and Plants in Massachusetts Lakes and Rivers: Lessons for International Aquatic Management, Wai Hing Wong, Editor. Taylor & Francis, London.

Yuan C., *et al.* (2021). Long-term effects of the harvesting of *Trapa natans* on local water quality and aquatic macrophyte community in Lake Erhai, China. Front. Environ. Sci. 9:706746. doi: 10.3389/fenvs.2021.706746.

Zheng, F., Y. Du, A. Wang, and J. Xu (2008). Effect of temperature on the demography of *Galerucella birmanica* (Coleopter: Chrysomelidae). Insect Science 15: 375–380. DOI: 10.1111/j.1744-7917.2008.0024.x (Abstract only).

Ziska, L.H. (2022). Plant Invasions, Rising CO2, and Global Climate Change. In Global Plant Invasions, Clements, D.R., M.K. Upadhyaya, S. Joshi, and A. Shrestha (eds). Springer, Cham. https://doi.org/10.1007/978-3-030-89684-3_4.

APPENDIX I: RESPONSES TO OARS/MACC ON-LINE SURVEY

Town Conservation Commissions were surveyed about water chestnut management and permitting in October to December of 2015. The Massachusetts Association of Conservation Commissions distributed a request for survey responses via email to their members. Not all respondents answered all questions.

51 towns responded: Ayer, Berlin, Braintree, Brewster, Burlington, Concord, Danvers, Dedham, Dennis, Dudley, East Longmeadow, Foxborough, Freetown, Grafton, Hadley, Holyoke, Hopkinton, Lanesborough, Leverett, Lincoln, Littleton, Marlborough, Maynard, Medfield, Medford, Millbury, Millis, Needham, New Bedford, Newton, Northampton, Northborough, Northbridge, Norton, Norwell, Pembroke, Pepperell, Pittsfield, Randolph, Rehoboth, Shirley, South Hadley, Stow, Sturbridge, Sudbury, Topsfield, Westfield, Weston, Westwood, Wilmington, and Worcester.

1. DO ANY OF YOUR MUNICIPALITY'S WATERBODIES CONTAIN WATER CHESTNUT PLANTS?

Reporting water chestnut	51 responses
Yes	24
No	9
Uncertain	18

2. IF YES, WHAT TYPES OF WATERBODIES? (SELECT ALL THAT APPLY)

Water Chestnut Locations	24 responses
River / stream	4
Pond / Lake	12
Both	8

3. IF YES, HOW WOULD YOU RATE THE INFESTATION(S)? (SELECT ALL THAT APPLY)

Infestation Size	24 responses
Small or Emerging	4
Established	10
Extensive or Full	9
Not Certain	1
Both	8

4. DOES YOUR MUNICIPALITY HAVE A LOCAL WETLANDS PROTECTION BYLAW OR ORDINANCE?

Have wetland bylaw?	51 responses
Yes	42
No	9

5. DOES YOUR MUNICIPALITY HAVE A CURRENT MANAGEMENT PLAN FOR WATER CHESTNUT REMOVAL?

Management Plan	49 responses
Yes	9
No	38
Not Sure	2

6. WHO IS RESPONSIBLE FOR MANAGEMENT OF WATER CHESTNUT? (SELECT ALL THAT APPLY)

Who is responsible for management	24 responses
ConsCom	6
State/Federal Agency	6
Local association	8
No one/NA	4

7. WHAT TYPE OF PERMITTING WOULD BE NEEDED FOR HANDPULLING? (SELECT ALL THAT APPLY)

Permitting for Handpull	49 responses
Administrative or none	13
Request for Determination	18
Order of Conditions	12
Emergency Order	2
Unsure	4

8. WHAT TYPE OF PERMITTING WOULD BE NEEDED FOR USE OF HARVESTERS OR HYDRORAKES? (SELECT ALL THAT APPLY)

Management Plan	49 responses
Permitting for harvester/ hydrorake	47 responses
Request for Determination	1
Order of Conditions	42
Administrative	1
Unsure	3

9. WHAT TYPE OF PERMITTING WOULD BE NEEDED FOR USE OF HARVESTERS OR HYDRORAKES? (SELECT ALL THAT APPLY)

Responsible for disposal & method (41 responses)	41 responses
State/federal agency take care of disposal, some don't know where it goes, others report composting	6
Conservation commission/ Town DPW with composting on public or private land	13
No one or Not Applicable	12

APPENDIX II: SAMPLE WETLANDS PROTECTION ACT PERMITTING (ON-LINE VERSION ONLY)

REQUEST FOR DETERMINATION OF APPLICABILITY (RDA)

WPA Form 1: For hand pulling [*link*]

NOTICE OF INTENT (NOI)

WPA Form 3 and Appendix A: For mechanical harvesting, inland *[link*]

NOTICE OF INTENT (NOI)

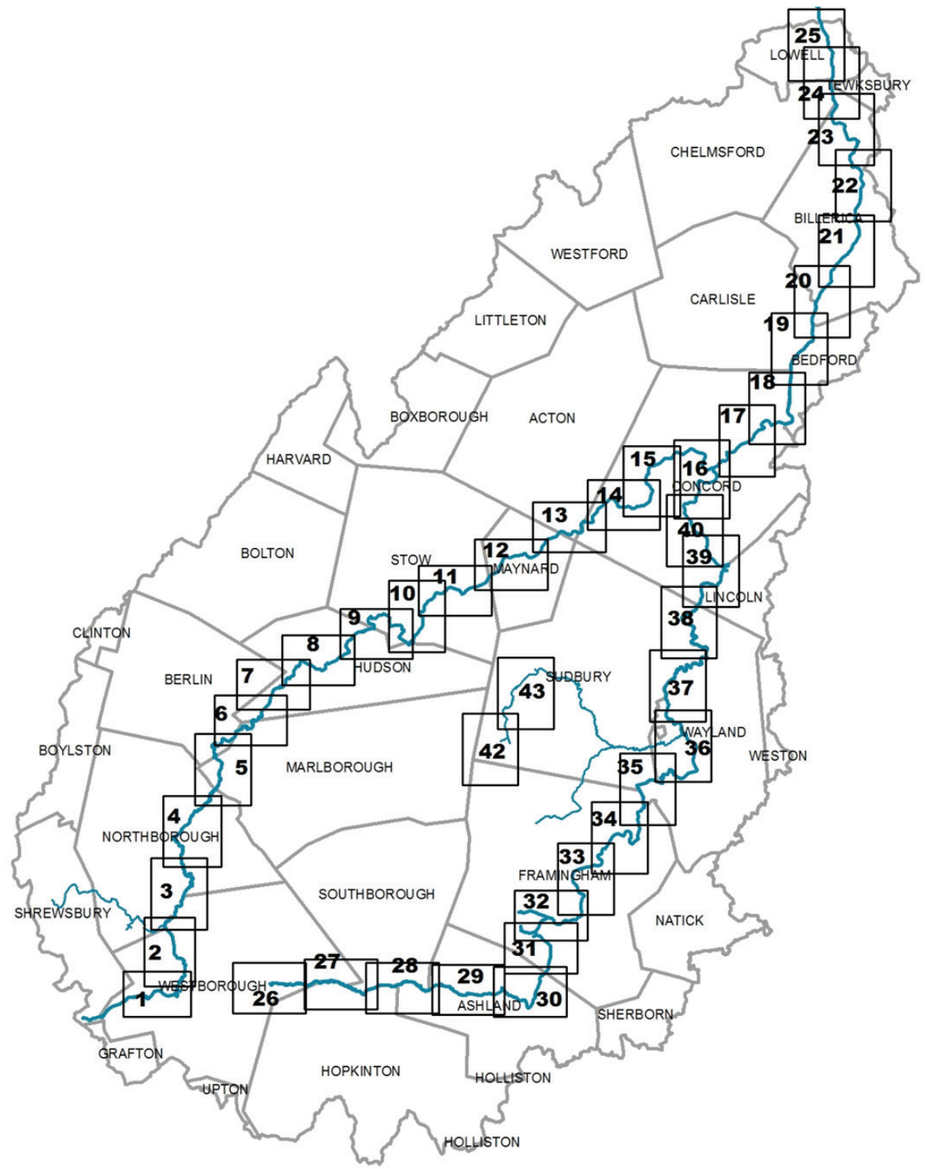
Sample Notice of Intent for Chemical Treatment [*link*]
Sample Notice of Intent for Mechanical Harvesting [*link*]

APPENDIX III: WATER CHESTNUT MAPS: OARS' 2016 SURVEY

Map Key for 2016 Water Chestnut Survey Maps [*link*]

OARS

Sudbury, Assabet, Concord River, MA
Water Chestnut Survey—Summer 2016—Map Key



1:204,593

Created by S. Flint, OARS, July 2016. Basemap from MassGIS. Grant support from the Nyanza Restoration Fund through the SuAsCo CISMA. ArcGIS software grant from Esri Conservation.

SuAsCo CISMA

OARS
WATERSHED ORGANIZATION FOR THE SUDBURY
ASSABET & CONCORD RIVERS
23 Bradford Street, Concord, Massachusetss 01742

Community Water Chestnut Pull, Sept. 2024, Acton