RAPID RESPONSE PLAN FOR CURLYLEAF PONDWEED (*Potamogeton crispus*) IN MASSACHUSETTS

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Species Taxonomy and Identification

Curlyleaf pondweed (*Potamogeton crispus* or CLP) is an aquatic perennial plant with a flattened stem, and can reach 1 meter in length. Roots are fibrous, and from slender rhizomes. All leaves of CLP are submerged, and arranged alternately on the stem. The leaves are sessile, oblong to broadly linear, 3-8 centimeters long, and 5-12 millimeters wide. Each leaf has wavy edges, margins that are finely toothed, and three main veins. CLP produces turions during the spring. The turions can be up to 5 cm in length, and consist of three to seven small leaves that project from the stem. Flowers are produced on a flowering spike that protrudes from the surface of the water. Flowers are tiny, with 4 petal-like lobes, and 1-3 cm in length. The fruit of curlyleaf pondweed is 4-6 mm long, including a 2-3 mm beak, with a ridge on the main part of the seed.

According to Crow and Hellquist (2000), the following taxonomic characteristics are used to identify curlyleaf pondweed:

- Leaves lax, not conspicuously 2-ranked, lacking basal lobes.
- Stipules completely free or with only a few adnate to leaf base.
- Submersed leaves broadly linear-oblong to lanceolate to elliptic to subcircular, 10-75 mm wide
- Leaf margins are conspicuously toothed; stem flattened; fruit beak 2-3 mm long; winter buds commonly present and extremely hard.

Figure 1. Photographs of curlyleaf pondweed taken from www.wvu.edu

Species Origin and Geography

CLP is native to north Africa, India, the Middle East, Australia and Europe, from Portugal to Turkey and France to Italy. In the United States it is reported from all states except Alaska, Hawaii, Maine and South Carolina. The first collection of CLP in the United States was in Wilmington, Delaware in 1860. In Massachusetts, the first recorded specimen was collected in 1880 near Arlington. The likely pathways for introduction include the fish hatchery industry and the aquarium trade.

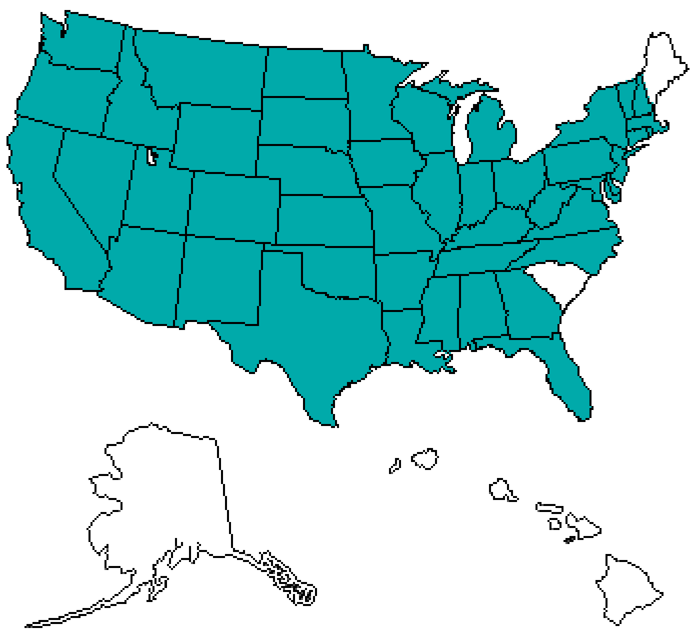


Figure 2. Map indicating the present range of curlyleaf pondweed in the United States. This map was taken from the USACE website. http://el.erdc.usace.army.mil

Species Ecology

Curlyleaf pondweed grows rooted in the mud of lakes, ponds, rivers, streams, reservoirs, and springs. It can grow in a wide range of water conditions, including but not limited to clear water, turbid water, polluted water, alkaline water and brackish water (Stuckey 1979; Crow and Hellquist 2000). CLP grows in very low light, and at very low temperatures (Jian et al. 2003). The life cycle of CLP begins in autumn as the turions germinate. It continues to grow during winter months, even under the ice, and maximum growth occurs in April-May, earlier than most other aquatic plants. Flowers and fruits are produced in spring, and dense mats of CLP can form at the surface of the water during this time. By mid-late June, when most other aquatic plants are in their peak growing season, the majority of CLP has died off, and may spark algae blooms. It is rare to see any substantial CLP growths after the end of June. CLP survives as turions in the lake sediment starting in July (Sastruotomo 1981; Tobiessen and Snow 1984; Nichols and Shaw 1986). Once curlyleaf pondweed is established, regrowth and colony formation can occur from rhizomes.

Detection of Invasion

CLP can enter lakes with flow, boats and birds, so the logical places to look first are the mouths of tributaries, boat ramps and areas of higher bird concentrations. While mature CLP growths may become dense and more obvious, new infestations may be less obvious and often require underwater examination for early detection. CLP is typically found in shallow waters (<10 ft deep) and is likely to be visible from a boat with a viewing tube or by snorkeling. Use of an underwater video system (Aqua-Vu or equivalent) can be very helpful in scanning large areas of variable depth, but is more expensive and not usually necessary for detecting early invasion unless the water is very turbid.

Sources may not be obvious, but the pattern of occurrence observed during early detection may provide useful clues. Appearance near boat ramps suggests boats as vectors, while appearance in more remote areas with no direct access or inflows suggests birds as the source. Where growths are detected near the mouth of a tributary, it would be appropriate to check the next upstream waterbody or the stream bed itself if conditions are suitable for rooted plant growth.

There are multiple methods of plant survey, and no truly standardized technique. The object is to be as thorough as time and trained manpower allow, to maximize detection probability. To detect a suspected invasion, or simply to monitor for possible invasion, consider the following steps:

1. Acquire a suitable map of the waterbody, showing shoreline features and reference points, and preferably with water depth contours.
2. Use the taxonomic information supplied here, or supplementary information from taxonomic guides, plant keys, or herbarium sheets to identify CLP.
3. CLP is most easily detected and identified in spring, during its peak growing season.
4. Ideally, space transects around the waterbody, extending from shore to the end of plant growth, with one transect per defined shoreline segment, determining transect location with GPS or readily identified shoreline features. Segments should be of roughly equal length, but this can be based on actual shoreline, straight distance across the water, land use or other features of concern or interest, or encompassed waterbody area. Be sure to cover all boat launch, swimming, inlet, bird congregation, key habitat and intake areas, and any other key access points.
5. Priority can be given to transects of key concern, either based on likely invasion points (access points) or potentially threatened resources (intakes, swimming areas, key habitat) if the number of transects is too great for the manpower and time resources available, but recognize the limitations this will impose on invasion detection.
6. Using a boat with a viewing tube or underwater videocamera, or employing snorkeling or SCUBA gear, examine the plant community along transects between the shore and the maximum depth of plant growth (typically <20 ft, often <10 ft). Note presence/absence of

CLP and extent of coverage and density where CLP is encountered. Record observations for 2 ft water depth intervals, with each observation representing either a defined area within the depth range or the length of the transect between depth intervals (typically 0-2 ft, 2-4 ft, 4-6 ft, and so on). GPS is particularly useful for both transect and point location for future reference.

7. Tabulate all data in a manner that facilitates future comparisons, typically in a spreadsheet or GIS format. Evaluate presence of any CLP, extent of coverage and density, and pattern of occurrence. Map the distribution of CLP in the waterbody for visual reference.
8. Repeat the survey at least once every 3 years (about the time for an invasion to have a detectable impact), and preferably every year to allow the earliest possible detection.

Species Confirmation

Although CLP is relatively easy to identify, unless the invasion is discovered by individuals trained in plant taxonomy, samples should be sent to competent taxonomists for confirmation. In Massachusetts, the Department of Conservation (DCR), the Department of Environmental Protection (DEP), the Massachusetts College of Liberal Arts (North Adams, specifically Dr. Barre Hellquist), and the University of Massachusetts at Amherst (UMASS) have the expertise to assist in plant identification. Many consulting and lake management firms also possess this expertise, but it will be the responsibility of the DCR to determine where specimens should be sent. Therefore, the DCR at 617-626-1411 or 617-626-1395 should be the first point of contact.

Key steps in confirming an invasion include:

1. Collect complete specimens of the suspected CLP; root systems are less critical for this species, but it is helpful to know that the whole stem has been harvested, and removal of the root crown is necessary for plant control. Place the specimen in a clear container with water for easy viewing (clear 2-L soda bottles without labels work well); keep chilled. Alternatively, specimens can be pressed on a sheet of appropriate (absorbent) paper, covered with wax paper and a stack of books or other suitable weight (an actual herbarium press is useful if available).
2. Contact the DCR representative at 617-626-1411 or 617-626-1395 and inform him/her that a suspected occurrence of CLP has been detected in the waterbody. The DCR contact will assess past records for the waterbody and will instruct the caller where to send a sample for confirmation, if warranted.
3. As soon as possible, preferably within 2 days, send specimens to the identified DCR representative for confirmation, or to a taxonomic expert as designated by the DCR contact. Note in writing that the enclosed specimen is believed to be CLP and include the name of the waterbody, the approximate location in the waterbody (a map is helpful) with water depth and any other site-specific observations, the date and time of collection, and the name, address, phone number and email for the collector or sender.
4. The DCR will confirm the identification or provide an alternative identification either directly or indirectly through a recognized taxonomist, and will be responsible for notifying all

appropriate agencies, municipalities and citizen groups either potentially affected or responsible for follow-up actions.

Quantifying the Extent of Invasion

Gaining effective control of CLP depends on detecting all growths, as this species can expand rapidly. The initial discovery may be made during a routine mapping exercise, but mapping approaches suitable for overall plant assemblage characterization (e.g., point intercepts on a grid or transects) may not be appropriate for thorough coverage of recent invasions. Where a growth is detected, it is likely that expansion in the first growing season will be by root crowns, rhizomes, so viewing each discovered growth in concentric circles moving outward from the apparent center will best facilitate mapping of the growth. Detection of additional growths is best accomplished by a thorough visual inspection of the newly infested area, either using tightly spaced transects radiating out from the first discovered growth or focused in the direction of likely current or wind transport.

If the waterbody is large, effort may have to be limited to the most likely locations for invasion. In this regard, examination of any existing plant maps may be helpful. Look for areas of suitable depth (<20 ft, with emphasis on areas 2-10 ft deep) and substrate (moderately organic and silty), known plant and bottom disturbance (marinas, boating lanes, windswept shallows), and plant assemblages of lower density and/or lesser canopy formation.

Evaluation of recent CLP growths should focus on extent of coverage and degree of dominance. Biovolume or biomass measures are useful but time consuming and are not critical to combating new infestations. Careful stem counts are helpful in assessing the efficacy of possible controls, but are also time consuming. An estimate of stems per unit area and the area covered is more valuable in assessing potential controls for new growths. With regard to dominance, it is important to note other species present, as the presence of protected species and the relative abundance of seed producers vs. vegetative propagators are important to planning management actions. A list of plant species with an approximation of the percent of the community each represents is appropriate.

Assessing the rate of expansion may not be necessary if the invasion is detected early and prompt control actions are implemented. However, where CLP has been present for more than a single growing season, information on the rate of expansion may be helpful in planning a control strategy and in garnering support for rapid action. Isolated plants are likely to signal the first year of growth, while scattered plants are likely to represent the second year of growth and well established beds will normally be more than two growing seasons old.

Useful steps in quantifying the invasion include:

1. Use the data generated by the transect method in the section on Detection of Invasion to get a first impression of the extent of invasion, preferably in mapped format. Where CLP is

discovered in multiple locations, look for spatial patterns that suggest either transport from the earliest infestation or invasion from multiple sources.

2. If a discovered growth is in a definable cove, examine the entire cove, or at least that portion with a water depth <10 ft.
3. If a discovered growth is associated with a boat ramp, check a suitable area (typically 1-2 acres) associated with that ramp, and check other ramps if present.
4. Where growths occur near a tributary mouth, check area maps for upstream ponds or impoundments on the offending stream and any other tributary and investigate where possible CLP sources seem most likely.
5. When the new growth appears associated with areas of bird congregation, check all such areas in the waterbody.
6. In all cases, note which areas have established beds vs. scattered plants vs. a single plant or just a few stems.
7. Identify all other plants in association with CLP growths, to the limit of areas likely to be targeted for control. Follow the protocols for species confirmation where specimens of unknown identity are encountered, paying particular attention to possible protected species or other invasive species.

Species Threat Evaluation

New plants grow rapidly in the early spring months and reach maximum biomass by mid to late June. CLP forms dense monocultures that prevent the growth of more desirable native species, and reduce species diversity. Monospecific stands of CLP can negatively affect wildlife, and can alter the predator/prey relationships as well as the overall ecology of an aquatic ecosystem.

There are some benefits of CLP growths. CLP is an excellent food source for coots and ducks, and may harbor large numbers of macroinvertebrates (Catling and Dobson 1985). Hafez et al. (1992, 1998) stated that CLP can remove toxins from water, including phenol, cesium, cobalt and cerium. However, the majority of issues associated with CLP infestations are negative. Impacts on aquatic environments are similar to those observed for other invasive species. Dense growths of CLP impedes flow in irrigation canals (Catling and Dobson 1985), may cause lake anoxia (Catling and Dobson 1985), depletes the water nutrients (Catling and Dobson 1985), can cause eutrophication (MN DNR 2002), and interferes with recreation (MN DNR 2002). However, as this species becomes abundant earlier in the growing season than most other plants and declines by early summer, impacts are localized in time and are separate than those of most other nuisance species.

Potential spread within the waterbody is governed by the physical features of the waterbody (especially water depth and substrate) and the level of activity of potential vectors of spread for CLP (especially boats, birds, flow and currents). CLP can grow on nearly any substrate, from rock to loose muck, although nuisance densities are less likely to be achieved on rocky to gravelly substrates. The depth range for CLP is from shore to about 20 ft, but in the vast majority of cases, nuisance growths are observed only between 2 and 10 ft. Boats and birds can actively transport CLP within a waterbody, and between waterbodies. The turions are a primary means of spread for CLP.

Potential spread outside the waterbody is mainly a function of surface outflow, birds and human activities. Overflow can carry viable plants, turions and seeds downstream to additional waterbodies. Birds may to carry seeds, either externally or in their digestive tract. The role of seeds in the spread of populations is unknown (Stuckey 1979), but even at low viability, this is a potentially important means of invasion. Studies have shown that aquatic macrophytes are commonly transported by humans, on boats and trailers (Johnstone et al. 1985, Bratager et al. 1996). Again, the turions represent a hardy propagule that can be transported great distances and remain viable.

All of these factors combine to create a site-specific level of threat. Of primary interest are how great an infestation may become, how readily it may be transmitted to new areas (both inside and outside the infested waterbody), what resources may be impacted to what degree, and what the potential is for eradication or control through rapid response to detection of an invasion. In evaluating the potential threat from a new CLP infestation in DCR parks on a case by case basis, the DCR staff will consider the following:

1. What portion of the waterbody could be colonized (estimate as the area with water depth <20 ft)?
2. What is the potential for dense bed formation (estimate as the area with softer sediments in water <10 ft deep)?
3. What is the potential for rapid (<3 years) spread of CLP (estimate as the common area from #1 and #2 above and not densely covered by native plants)?
4. What is the potential strength of vectors of internal CLP spread (boat traffic, flow, currents, open expanses vs. isolated coves)?
5. What is the potential strength of vectors of external CLP spread (trailered day-use boats, daily or seasonally mobile bird populations, outlets without screening)?
6. What resources and uses are potentially threatened (water supply, swimming, boating, fishing, aesthetics, sensitive or protected populations)?
7. What is the potential for eradication (based on extent and density of coverage, vectors of spread)?
8. What is the potential for confinement (based on extent and density of coverage, physical isolation of area affected, vectors of spread)?

By answering these questions, one can characterize the threat according to the following matrix, which can then govern the response to detection of an invasion:

FACTOR	YES	NO	THREAT EVALUATION	HIGH	MEDIUM	LOW
A large area could be affected			Extent and speed of possible infestation			
Plant density could be high						
Spread could be rapid						
Water supply may be impacted			Nature of possible impacts			
Swimming may be impacted						
Boating may be impacted						
Fishing may be impacted						
Aesthetics may be impacted						
Sensitive species may be impacted						
Protected species may be impacted						
Spread by water flow likely			Ability to spread			
Spread by birds likely						
Spread by boating likely						
Spread by other human activities likely						
Eradication is possible			Potential success of rapid response			
Confinement is possible						

Communication and Education

Once the presence of CLP has been confirmed, the town(s) in which the waterbody is situated should be notified, usually through the Conservation Commission, which will have a chairperson or an agent who is reachable through Town Hall. It would also be appropriate to notify all relevant stakeholder groups, but these need to be identified and many will not have a central clearinghouse contact for notification. Groups who should be informed about the infestation include any active lake association, shoreline property owners, boaters, anglers, swimmers, birdwatchers, and water suppliers. Notification through individual contacts is desirable but may be inefficient. Posting a notice in the local paper will help publicize the problem, but the notice may not receive widespread attention. Posting the waterbody at access points is perhaps the most effective approach, as it is the actual users that should be informed and warned to avoid spreading CLP.

It is desirable to post access points with warning signs even before an invasion, displaying a picture or drawing of CLP and asking waterbody users to be on the lookout for this invasive plant. Users, particularly boaters, should be asked to inspect their boats and any trailers prior to launching, and to remove any discovered plants with proper disposal in a manner that prevents the plant from reaching the waterbody. A local contact (name and phone number) for notification should be given, typically either a representative of the lake association or the town's Conservation Commission, or both. Users should be advised to mark the location where the plant was observed if at all possible, but not to pull it out unless they can get the whole plant, including the roots. As most users will not be diving or snorkeling, immediate, effective hand harvesting is probably not a realistic expectation.

After an invasion has been discovered, access points should be posted with a warning to users to avoid any action that could spread CLP. Again, a picture or drawing of CLP should be provided, and any known locations of the plant should be shown on a map of the waterbody. Users should be asked to notify a local contact if CLP is found in other areas not shown on the map, and to avoid motorized boating in areas with CLP. All boats, trailers, fishing equipment, bait buckets or other possible means of transport should be inspected and cleaned prior to leaving the waterbody.

Responsibility for control of CLP does not rest with any one entity under the laws of the Commonwealth of Massachusetts. Approval for control actions is governed by the Wetlands Protection Act, which always involves the town Conservation Commission and the Commonwealth's DEP. Approval for control actions may also involve the Division of Fisheries and Wildlife and/or the Natural Heritage and Endangered Species Program, both agencies of the Commonwealth, depending upon the resources in the waterbody (particularly if protected species are known from the waterbody). Other agencies and approval programs may apply, depending upon the features of the waterbody (naturally large enough to be a statutory Great Pond), the location of the waterbody (e.g., in an Area of Critical Environmental Concern), or the uses of the waterbody (e.g., as a water supply). However, none of these agencies is charged with controlling invasive species, and there is no legislation in Massachusetts that mandates control of CLP. The DCR has taken the lead in Massachusetts with regard to encouraging control of invasive species, and supports control efforts as its budget allows. However, outside of the state parks and reservations, control is largely a function of local desire to protect and maintain the resource.

For waterbodies within DCR parks, the following notification procedures are to be followed when a new infestation by CLP has been confirmed:

1. The DCR contact responsible for confirming the CLP invasion will notify the DCR Regional Director, Park Supervisor and any regional DCR contact charged with managing water resources. A single letter copied to each party is preferred. The letter should briefly state the problem and outline immediate control steps that are needed, indicating an expected date for a follow up visit by Lakes and Ponds Program staff to begin concerted control measures (see posting procedures below).

2. The DCR contact responsible for CLP invasion confirmation will also notify the DEP, the DFW and the NHESP in writing; a copy of the letter sent to DCR parties is sufficient. If a contact for an associated citizens' lake or watershed organization is known, notification should be given to that group as well.
3. The Regional Director or a designated park contact for local affairs will notify the town(s) in which the park and waterbody are situated. The appropriate parties within the town(s) to be notified may vary by town, but should include the Conservation Commission and either the Selectmen, Town Manager or Mayor, depending upon local government structure.

For waterbodies within DCR parks, the following posting procedures are to be followed when a new infestation by CLP has been confirmed:

1. All access points to the waterbody (e.g., boat launches, swimming areas, fishing piers or obvious shoreline fishing points) shall be posted with a photograph or drawing of CLP and a written notice that this invasive plant has been found in the waterbody.
2. Suggested language is as follows: Warning. Curlyleaf Pondweed (*Potamogeton crispus*) has been found in this waterbody. This invasive plant represents a threat to this waterbody and its users. Caution should be exercised to avoid the spread of this plant. Do not pick or remove this plant if you encounter it, and be sure all equipment brought to this waterbody is clean before leaving.
3. Include a contact name and phone number on all postings.

Quarantine Options

Both natural processes and human activities can spread CLP, both within an invaded waterbody and to other area lakes. Minimizing the spread of CLP may require some form of quarantine. Making the waterbody off limits to all users is an extreme action not typically justified for new growths that are likely to be limited in areal coverage. However, keeping people out of infested areas may be a valid option. This may be done by signage, buoys, or an actual sequestration curtain, with cost increasing dramatically in the listed progression.

Where the invasion is occurring at a boat ramp, closure of the ramp may be justified; this will both limit the spread of CLP and generate public awareness of the problem and a desire to take action against the CLP. A town may take such an action where the public welfare is deemed to be at stake for a boat ramp owned by the town, but it is not clear that such action is legal for private boat ramps, and towns do not have the authority to close ramps owned by the Commonwealth. Consult with private owners or the Public Access Board of Massachusetts when considering closure of a ramp not owned by the town.

Where the invasion is occurring in a swimming area, closure of that area will have much the same effect and limitations as for boat ramps. If the CLP growths are localized, it may be possible to partition off the infested area by moving the buoyed ropes that usually delimit swimming areas. If the growths are extensive, it may be appropriate to close the swimming area on the basis of public safety, so swimmers do not become tangled in the growths.

Possible expansion routes should be considered and addressed to the extent possible. It may be advisable to implement bird controls to limit bird contact with infested areas; scare tactics (e.g., flags or pinwheels on buoys, noisemakers) can be effective for short time periods, which may be all that is necessary for lakes with migratory populations. Greater effort may be needed for lakes with substantial resident bird populations, particularly in lakes with high populations of birds that consume CLP. If boating is allowed, it is advisable to set up a temporary wash station at any ramp; it may be necessary to staff it to maximize use compliance. At the very least, boats and trailers leaving the waterbody should be inspected and cleaned.

Where a CLP invasion is confirmed in a waterbody in a DCR park, the following quarantine steps will be evaluated and implemented as warranted:

1. Post access points with warnings to avoid the plant and/or certain areas of the waterbody; use marker buoys to identify infested areas.
2. Surround smaller infested areas with sequestration curtain or other enclosing materials that prevent spread and limit access.
3. Curtain off coves or other isolated areas to prevent CLP spread and limit access.
4. Use scare tactics or other approaches to limit bird use of the waterbody.
5. Set up a washing station and inspection point for boats taken out of the waterbody; require inspection and cleaning where needed.
6. Close any access point (e.g., boat ramp, beach, other points of active contact) in close proximity to CLP, where the potential for internal or external spread is considered high.
7. Close the waterbody to human use.

Early Eradication Options

Timelines for necessary action with regard to CLP invasions hinge on stopping the spread of this plant. Population expansion can occur throughout the growing season, so the sooner controls are implemented, the smaller the area that must be addressed. Once the growing season is over (late June), plants collapse and start to decompose. CLP survives as scattered turions in the sediment after the plants begin to decompose. Detecting and effectively removing CLP plants by physical means will therefore be much more difficult outside the growing season. Treatment of CLP growths must be undertaken in April-May, and must include removal of turions or prevention of their formation.

Management options that can be applied to invasive rooted plants are covered in The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, available on-line at http://www.mass.gov/dcr/waterSupply/lakepond/lakepond.htm and supplied to all towns in the Commonwealth by the DCR in 2004. A summary of control approaches is supplied, and many are applicable to the eradication of CLP. Brief descriptions of applicable techniques are provided below.

Hand Harvesting

Mode of action: Plants are removed by divers by hand; removal includes root crowns.

Probability of successful control: Where density is <500 plants per acre over a small number of acres, control can be complete. At higher densities or area of coverage, risk of incomplete harvest increases dramatically.

Potential non-target impacts: Limited; with training, divers recognize CLP and avoid other plants; risk to non-target plants increases as density of plant community increases. Temporary turbidity increases are expected.

Permitting needs: Can be approved without Order of Conditions under the Wetlands Protection Act through a Negative Determination of Applicability (WPA regulations deemed not to apply, as only the invasive plant is removed).

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage.

Range of costs: Often done by volunteers, but estimates from professional operations range from $100 to $500 per acre.

Other considerations: Effective hand harvesting requires careful planning and is more difficult that it may appear. It is especially important to collect the turions before they are dropped by the plant, which means hand harvesting under relatively cold water conditions prior to June.

Suction Harvesting

Mode of action: Plants can be pulled directly into the suction apparatus, but for best effect this is a suction aided hand harvesting operation, whereby hand harvested plants are fed into the suction tube and filtered out in an above-water chamber.

Probability of successful control: High potential for eradication at low to moderate densities of CLP; complete removal probability declines at higher densities.

Potential non-target impacts: May pull in non-target plants and plankton by suction, but effects localized and limited. Turbidity plume at surface from filtering chamber may be substantial.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act, but may be issued a Negative Determination of Applicability where risk to other species and turbidity is expected to be low.

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage.

Range of costs: $5,000 to $15,000 per acre, depending upon equipment features, contractor mobilization, CLP density, and total area to be harvested.

Other considerations: Turbidity may be unacceptable where a large area is suction harvested. May be helpful in collecting turions from surficial sediments, although resultant turbidity may be very high.

Mechanical Harvesting

Mode of action: Plants are cut with a cutting blade and collected for disposal elsewhere.

Probability of successful control: Moderate potential for eradication over multiple years at low to moderate densities of CLP; complete removal probability declines at higher densities. To be most effective, plants must be harvested before turion formation begins. If harvesting later, the depth of cutting must be very close to the sediment surface to collect turions attached to plants.

Potential non-target impacts: May cut and harvest non-target and native species, but effects localized and limited.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act, but may be issued a Negative Determination of Applicability where risk to other species is expected to be low (e.g., early season harvesting).

Monitoring needs: Critical to delineate target area and provide means to ensure harvester is staying on course.

Range of costs: $350 to $550 per acre, depending upon equipment features, contractor mobilization, and total area to be harvested. At very high densities these costs may be greater.

Other considerations: The harvester cutting depth is limited, typically to 5-10 feet. Mechanical harvesting more than a few inches above the sediment surface may not remove turions, so cutting must often be repeated over several seasons and may still not reduce growths the following year.

Rotovation

Mode of action: Basically large underwater rototillers. Knives penetrate the sediments and release roots crowns and other plant structures.

Probability of successful control: Rotovation can be used in water up to 20 feet, and can provide long-term control compared to mechanical harvesters or cutters. Rotivation must be practiced before turions are formed to have any lasting effect. Plant material may need to be harvested after being tilled from the bottom sediments.

Potential non-target impacts: Rotovation impacts all plants in the target area. Any native and desirable plants in the target area will also be impacted by the rototiller.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act.

Monitoring needs: Critical to delineate target area and provide means to ensure rototiller is staying on course. Will also need to monitor turbidity and if necessary provide turbidty controls.

Range of costs: $1500 to $4000 per acre for typical submergent operations.

Other considerations: This technique is not usually recommended for areas with new infestations and substantial amounts of native species, unless other options are limited. Tilling during fall or spring can increase the speed of the operation and impacts on non-target plants, due to reduced biomass on the bottom and the possible presence of mainly CLP.

Hydroraking

Mode of action: Plants and sediments are removed with the equivalent of a floating backhoe. In conjunction with a harvester, it can remove most forms of vegetation encountered in lakes.

Probability of successful control: Hydroraking is effective in the short-term and removes plants immediately. To be effective, plants must be harvested before turion formation begins.

Potential non-target impacts: Hydroraking is not selective and will remove native and non-target species in the harvest areas along with the target species. Typically there is high turbidity associated with hydroraking due to sediment disruption.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act

Monitoring needs: Critical to delineate target area and provide means to ensure hydroraker is staying on course. Will also need to monitor turbidity and if necessary provide turbidty controls.

Range of costs: $1500 to $4000 per acre for typical submergent operations.

Other considerations: This technique is applied on a very limited areal scale in the vast majority of cases, and is not expected to have a lakewide effect on non-target organisms or water quality.

Benthic Barriers

Mode of action: Covers target area with a porous or non-porous blanket, limiting light and physically stressing plants.

Probability of successful control: Usually completely eliminates live vegetation from covered area in 30 to 60 days.

Potential non-target impacts: All plants under the barrier will be killed. Some invertebrates are also killed, but many relocate. Fish find the barriers attractive for cover and foraging area, mainly a function of “edge effect” (creation of edges between plants and open water).

Permitting needs: Often approved through a Negative Determination of Applicability (provisions of WPA do not apply) where CLP is the main plant affected. Otherwise permitted with and Order of Conditions with possible restrictions where other species are at significant risk.

Monitoring needs: Careful delineation of areas to be covered is needed. Condition of plant community, especially root crowns of CLP, should be assessed prior to removal.

Range of costs: Materials typically cost $0.50 top $1.00 per square foot. With application and maintenance costs, expect $30,000 to $50,000 per acre. However, material can be re-used indefinitely, so costs are greatly reduced for subsequent applications.

Other considerations: To enhance performance, benthic barriers should be carefully anchored and periodically cleaned. To minimize hooks and lures getting caught in benthic barriers, mark location with labeled buoys. Barriers may present a safety hazard in swimming areas.

Water Level Drawdown

Mode of action: Lowered water level exposes plants and substrate to drying and freezing action. Ice damage may also be a factor. Where plants can be dried, frozen, or ripped up by ice action, CLP may be reduced in abundance, but impacts on non-germinated turions are negligible in most cases and regrowth the following year is probable. With many years of repeated drawdown, the turion supply may be exhausted and exposed substrate tends to be dominated by coarse sediment less hospitable to CLP invasion.

Probability of successful control: High for growing plants where drying, freezing and/or ice damage occurs. As this is a function of the weather pattern, uncertainty is high; about one out of three years provides effective drawdown conditions in Massachusetts. Where thick organic sediments, spring activity, or other factors limit freezing and drying, success will be lower. Staggered germination of turions over multiple years will limit success of a single year of drawdown.

Potential non-target impacts: Other plants that overwinter in vegetative forms are also likely to be harmed. Seed-producing plants may be stimulated. Some invertebrates (especially mollusks), amphibians (most likely frogs), reptiles (particularly wood turtles) and mammals (most probably beaver and muskrat) could be negatively affected. Effects on fish vary, depending upon timing and duration of drawdown and the interaction with feeding and reproduction. Direct water supply and water level in wells may be affected.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act, usually entailing a detailed review of the potential for non-target impacts.

Monitoring needs: Can be extensive. Pre- and post-implementation surveys are needed. Aside from effects on the plant community, effects on susceptible fauna may be required. Water supply must be monitored and a contingency plan is needed if supply is impaired. It should be assumed that at least three years of implementation will be needed to conduct a valid assessment of success and non-target impacts.

Range of costs: Where drawdown is facilitated by existing structures, costs are limited to permitting and monitoring, with potential for mitigation costs if impacts are unacceptable.

Other considerations: A very detailed evaluation of potential drawdown impacts is needed before attempting this technique. Issues of downstream flooding, refill time, and impacts on water supply and non-target organisms must be addressed.

Application of Fluridone

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, inhibiting the synthesis of carotenoid pigments. Lack of these auxiliary (protective) photosynthetic pigments causes susceptible plants to die slowly through reduced food production and damage by sunlight. Uptake must be nearly continuous over an extended period (>60 days preferred), necessitating extended exposure time.

Probability of successful control: Where adequate dose (>6 ppb, preferably 15 ppb) and exposure time (60-120 days) are maintained early in the growing season, CLP can be eradicated or greatly reduced in abundance. This has proven difficult to achieve, however, particularly in partial lake treatments. Use of slow release pellet formulations or sequestration of the target area with impervious curtains maximizes exposure time and limits dilution of the dose. Follow up actions, such as hand harvesting, are often necessary. This treatment will not affect the seeds or turions of CLP, however, so repeated applications may be needed to control growth

Potential non-target impacts: Susceptibility of other plants to fluridone varies widely, and lowering of the dose can maintain much of the native community. However, doses <6 ppb are unlikely to control CLP, and complete control is not typically achieved at <10 ppb, if then. Slow die-off of affected plants limits oxygen reduction. No impacts to fauna or humans are expected at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.

Monitoring needs: Normally the plant community is monitored before and after treatment. The concentration of fluridone is also commonly tracked on a weekly to monthly basis with an Enzyme Limited Immuno-Sorbent Assay (ELISA).

Range of costs: Costs range from $500 to $2,000 per acre, depending upon the form of fluridone applied, any necessary re-treatment to maintain dose, and any sequestration of the target area.

Other considerations: The combination of treatment timing, dose and exposure time is critical to success; the combination of achievable detention time and degree to which non-target plants must be protected will determine the potential for eradication or extended control.

Application of 2,4-D

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, killing susceptible plants by disrupting cellular growth. Uptake is fairly rapid, limiting necessary exposure time.

Probability of successful control: CLP is susceptible to 2,4-D, but a complete kill is rarely achieved. With adequate dose (around 1 ppm active ingredient) and contact time (1-3 days), CLP can be greatly reduced in abundance. Where dilution, flushing or other factors compromise dose and exposure, success declines.

Potential non-target impacts: Many other plants are susceptible to 2,4-D at doses and exposure times applied for CLP control. Rapid die off may reduce oxygen levels through decay. Most fauna are not affected at those doses, although toxicity has been observed in lab studies. It is considered a health risk to humans if consumed at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP. Application to waters used for drinking water supply, including surface waters with potential interaction with wells, is prohibited.

Monitoring needs: Normally the plant community is monitored before and after treatment. Special studies of other populations may be required by permit, depending upon the resources present.

Range of costs: Typically $300 to $800 per acre.

Other considerations: Not applicable for waterbodies with known interaction with water supplies (surface supplies or wells).

Application of Endothall

Mode of action: This contact herbicide inhibits respiration and affects only the parts of the plant with which it comes in contact. Results are fairly rapid, limiting necessary exposure time.

Probability of successful control: CLP is susceptible to endothall, and if treated before turions are formed, this can be an effective means of control. Some regrowth from unaffected roots is expected, but reproductive success can be minimized, potentially eradicating CLP over several treatments.

Potential non-target impacts: Many other plants are susceptible to endothall at doses and exposure times applied for CLP control. Rapid die off may reduce oxygen levels through decay. Most fauna are not affected at those doses, although toxicity has been observed in lab studies. Some use restrictions apply after treatment for a period of days.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.

Monitoring needs: Normally the plant community is monitored before and after treatment. Special studies of other populations may be required by permit, depending upon the resources present.

Range of costs: Typically $400 to $700 per acre.

Other considerations: Essential that treatment occur before turions are formed for maximum effect, meaning April and May.

Application of Diquat

Mode of action: This contact herbicide inhibits photosynthesis and affects only the parts of the plant with which it comes in contact. Results are fairly rapid, limiting necessary exposure time.

Probability of successful control: CLP is susceptible to diquat, and if treated before turions are formed, this can be an effective means of control. Some regrowth from unaffected roots is possible, but reproductive success can be minimized, potentially eradicating CLP over several treatments.

Potential non-target impacts: Many other plants are susceptible to diquat at doses and exposure times applied for CLP control. Rapid die off may reduce oxygen levels through decay. Most fauna are not affected at those doses, although toxicity has been observed in lab studies. Some use restrictions apply after treatment for a period of days.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.

Monitoring needs: Normally the plant community is monitored before and after treatment. Special studies of other populations may be required by permit, depending upon the resources present.

Range of costs: Typically $200 to $500 per acre.

Other considerations: Essential that treatment occur before turions are formed for maximum effect, meaning April and May.

Other Options

Other management options are not listed for one or more of the following reasons:

- impractical on a small scale
- not able to eradicate CLP
- not approved for use in Massachusetts

Recommended Options for Early Eradication

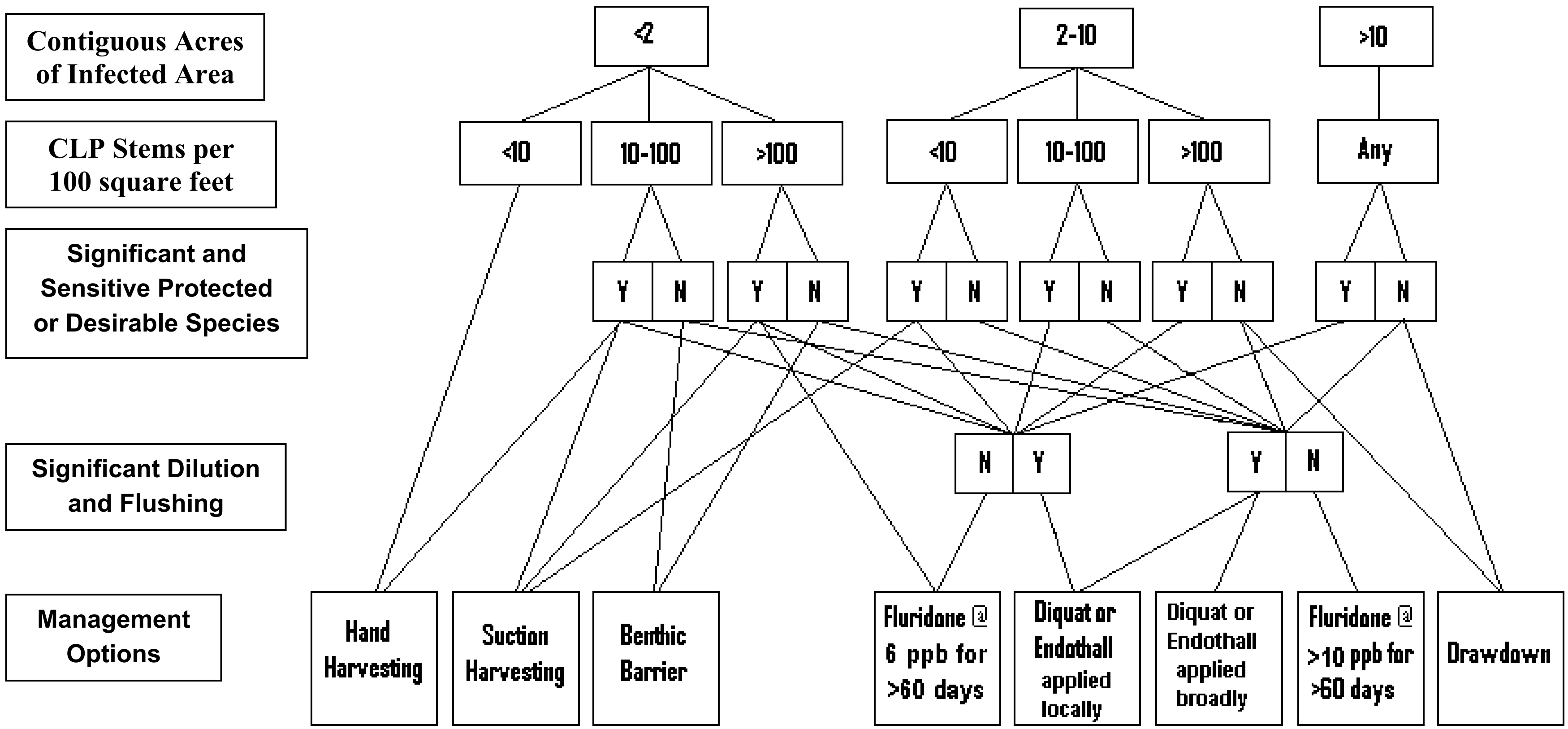
The most commonly recommended early actions are hand harvesting and bottom barriers, each of which has a high potential for success, low cost on a localized basis, and limited permitting needs. Where growths are too dense for effective hand harvesting and too extensive for cost-effective bottom barrier placement, suction harvesting should be considered. Drawdown, where applicable, is perhaps the most widely effective preventive control in cases where repeated invasion is expected or documented, but is not applicable in all cases. Early season use of fluridone is difficult in practice, but can be very effective if adequate exposure can be maintained. Use of diquat or endothall over multiple treatment can overcome dilution and flushing effects in some cases, and can be effective as well.

A graphic summary of rapid response actions is provided in Figure 3. Most rapid responses will involve sparse growths over a limited area or small, dense beds in a confined area. While the listed techniques may still be applicable after growths have become widespread, addressing them may not qualify as a rapid response, and additional considerations (e.g., impacts to non-target organisms on a lakewide basis) are likely to become more important in the permitting process. The selection pathways shown in Figure 3 represent logical choices based on general features of the aquatic system, and are not intended to provide infallible rules or inflexible options. Practitioners should use a careful process of option review based on site specific data when selecting a rapid response for CLP in any target lake.

Deciding Which Technique to Apply

The following decision tree is provided as an aid to evaluating control options. Thresholds for application are given as guidelines, not rigid rules. Individual circumstances may affect the choice of approach and outcome. Follow up monitoring is considered essential, and follow up control after an initial application is considered likely to be necessary.

Figure 3. Decision Tree for the Control of Curlyleaf Pondweed (*Potamogeton crispus*)



Notes: Hand harvesting and suction harvesting must include root system removal, and are best conducted before turions are formed. Benthic barrier should remain in place for 30 to 60 days. Fluridone use in spring may require flow control in target area. Choice of diquat or endothall is linked mainly to water uses. Drawdown use is dependent on many factors, including hydrology and use as a water supply. Moderate to dense growth over an extensive area (>10 acres) may not be appropriate for rapid response consideration.

Control of Established Infestations

This document deals mainly with early invasion and the new infestations that result, but it is important to note that older infestations, where the CLP has moved throughout the waterbody into all suitable habitats and probably become the dominant plant, can and should be addressed if continued invasion in the region is to be curtailed. The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, provides a review of all available techniques for combating invasive species infestations, and many of the management techniques and approaches may be applied to a CLP infestation. On a whole lake basis, herbicide treatment is the most cost-effective means for reducing CLP coverage and density to levels that can be controlled by physical techniques like hand harvesting or bottom barriers. Drawdown will reduce CLP in the drawdown zone, but it is rare that a waterbody can be drawn down enough to eliminate CLP without unacceptable impacts to non-target species. Techniques suitable for combating new growths are seldom practical or effective on a whole lake scale (e.g., hand harvesting, bottom barriers).

Maintenance techniques that limit the impact of CLP on waterbody uses, but do not typically result in elimination of CLP, include mechanical harvesting, hydroraking, and rotovation. The mechanical harvesting and yearly cutting will control CLP in the year of treatment. Continued yearly cutting of CLP before turions are produced has been shown to reduce abundance, and can slow or stop the spread of CLP to new areas in the infested waterbody.

Dredging can remove CLP along with all other plants and any remaining seeds or turions associated with the dredged sediment. The cost is extremely high, however, and resulting substrate conditions may still be hospitable to CLP growth. With much bare area to be colonized, invasive species such as CLP are likely to become dominant if more desirable species are not actively introduced. Only if dredging results in a water depth too great for effective colonization by CLP is it likely to be the only method needed to control CLP in the target area.

Grass carp can eliminate CLP (and indeed all other submersed plants) when stocked at sufficient density, but are not approved for use in Massachusetts at this time.

Prevention of Re-Infestation

Once an invasion has been repulsed through any of the above methods, it should be apparent that the waterbody is susceptible to CLP. As the cost of prevention is much less than the cost of rehabilitation of an infested waterbody, steps should be taken to reduce the risk of re-introduction of CLP. As CLP most often comes from a local source, control activity is encouraged on a watershed, multi-municipal or regional level. Working across political boundaries with limited funding is difficult, but represents the most sweeping opportunity to limit future invasions. Alternatively, and almost essential as a back-up, steps need to be taken at the individual waterbody to reduce the risk of re-introduction. Key steps may include:

- Education through the lake association or town for all users about the threat of CLP, how to avoid introducing it to the waterbody, how to identify it, and who to contact if it is found. See the other sections in this document for relevant information to be provided.
- Posting of all access points with signs warning of the threat, showing how to identify CLP, and urging that boats, fishing gear and other recreational equipment be cleaned before and after use in the waterbody. See the section on Communication and Education in this document.
- Provision of wash stations at boat ramps, and/or staffing of ramps with inspectors.
- Drawdown where applicable and permitted to minimize overwintering of introduced CLP.
- Monitoring of the plant community to detect CLP, with a focus on boat ramps and inlets.

Summary

1. Curlyleaf Pondweed (*Potamogeton crispus*) is an invasive plant normally identified by wavy edged leaves alternately arranged on the stem.
2. CLP is native to parts of Africa, Europe, Asia and Australia. It can be transported on boats or trailers, by birds, and with water flow.
3. CLP becomes locally abundant by rhizome expansion and turion formation. New turions germinate in the fall, and new plants grow through the winter. Seeds may be of limited importance in dispersal, but cannot be ignored completely in evaluating routes of new infestations or regrowth from seemingly eradicated populations.
4. CLP may create canopies that shade out other plant species. At high density it impairs recreational uses, and can have negative impacts on water supply and flood control. However, it reaches peak densities in the spring and is not typically a nuisance during summer.
5. CLP is most often detected in the early stages of infestation in water 2-10 ft deep by visual examination (viewing tube from boat or mask and snorkel). Look first in the vicinity of boat ramps, inlets, and areas of bird congregation. One effective long-term monitoring strategy involves setting up transects representing areas of the lake and searching at discrete depth intervals from shore to the maximum depth of plant growth.
6. When detected, map CLP coverage with notation of density as beds, scattered plants, or solitary stems. Be thorough with visual coverage of potentially infested areas. Record all other species present and their relative abundance. Confirm identification through the DCR.
7. Educate waterbody users by whatever means practical about the threat and presence of CLP. Posting of access points is useful in all cases. Signs should show how to identify CLP, urge that

all boats, trailers and other recreational equipment be cleaned before and after use in the waterbody, and provide a contact name and phone number for reporting or correspondence.

8. It is advantageous to quarantine infested areas until removal can be attempted. Closing beaches and boat ramps can be problematic, legally and practically, but can promote greater awareness and support for prompt action. Use of curtains or screens both to keep people out of an infested area and to keep CLP inside is desirable but expensive.
9. Eradication of CLP detected early in an invasion can be accomplished with hand harvesting, suction harvesting or benthic barriers. The herbicides fluridone, diquat and endothall are potentially effective on CLP. Drawdown can provide control over a period of years in the drawdown zone. Mechanical harvesting, hydroraking and rotovation can disrupt populations but usually do not result in longer term control. Hand harvesting and benthic barriers are often allowable without an Order of Conditions under the WPA, and can therefore be implemented most rapidly. Each method has benefits and drawbacks, and the specific circumstances will affect which option(s) can be applied. Because turions are resistant to most control methods, several applications of a given technique should be expected for control of CLP.
10. A range of additional options are available to combat later stage invasions. Those not mentioned as eradication options for new infestations have some feature that prevents effective, rapid use, but these techniques may have applicability under special circumstances.
11. Drawdown, where feasible, can act as a deterrent to invasion on an annual basis at a relatively low cost, through direct impact on invading CLP and by gradually altering the peripheral sediment features to make them less hospitable, but has many possible impacts on aquatic resources and requires a thorough evaluation in each case.
12. Once CLP has been removed after an invasion event, steps are necessary to prevent re-infestation. Education of waterbody users and ongoing monitoring to detect new CLP plants are critical components. It should be assumed that CLP will return, but it is far easier to address new growths than to combat a full infestation.

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