Zebra Mussel (*Dreissena polymorpha*) Ecology and Control: A Plan for Early Detection and Rapid Response to Prevent Successful Invasion of Onota Lake (Pittsfield, MA)

Prepared for the Lake Onota Preservation Association (LOPA)

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Problem Statement

The zebra mussel (*Dreissena polymorpha*) is an invasive mollusk that is rapidly spreading in the U.S. and causing great harm to waterbodies in which it becomes established. Onota Lake is highly vulnerable to zebra mussel invasion and colonization because of its habitat, water chemistry, location, and recreational boating usage. Boats frequently enter Onota Lake after having been in lakes and rivers with known zebra mussel infestations in New York, Connecticut, Massachusetts, Vermont, and elsewhere. Routine monitoring in September 2023 by MA Department of Conservation and Recreation (MADCR) using environmental DNA (eDNA) resulted for the first time in a positive finding of zebra mussel DNA in a sample collected near the Onota Lake public boat launch. Although this DNA could be from non-living zebra mussel material, the possibility that it could be from living, reproducing zebra mussels in the lake warrants immediate action.

Zebra mussel populations have been established for more than a decade in water bodies near the Berkshire region, including the Hudson River, St Lawrence, and Mississippi drainages in NY. Nearby Laurel Lake (Lee and Lenox, MA) was infested by 2009, and is currently the only Massachusetts lake with a confirmed zebra mussel infestation. The Housatonic River (to which Laurel Lake drains), and the Green River (which has a confluence with the Housatonic River in Great Barrington, MA) are also now infested. Zebra mussel colonies observed downstream through Connecticut in the Housatonic River basin are threatening other lakes and have already infested some. For example, an infestation was recently confirmed in Lake Candlewood (CT), which draws water from the Housatonic River to refill in spring after winter drawdown.

Infestation by zebra mussels has been known to cause many adverse effects in lakes through their alteration of the physical, chemical, and biological components of the lake ecosystem. Negative impacts on ecology and recreation can be substantial, potentially affecting property values, recreational usages, and the municipal tax base. Ecological effects include alteration of energy flows through the aquatic food web, with subsequent changes in species composition and abundance. Very few species benefit from zebra mussels as a food source, while many species experience adverse impact from habitat modification and loss of food sources. Although average water clarity may increase as a function of zebra mussel filtering, blooms of buoyant cyanobacteria are promoted. Zebra mussels will colonize the shells of larger mussels and kill them. Recreation is hindered, as the sharp shells can cut on contact with human skin. Intake pipes, moorings, and boats can be colonized by zebra mussels, impairing use. Control over boat entry or departure from the lake becomes important, with inspection and cleaning, to meet the state mandate to avoid transport of invasive species.

Preventing an invasion and reacting quickly to any detection of zebra mussel in Onota Lake is critical to preserving the health of Onota Lake. Once established, the elimination of zebra mussels from Onota Lake will be impossible with currently available technology without unacceptable collateral impacts. The significant threat of serious damage to Onota Lake from a successful invasion warrants application of the precautionary principle (Persson 2016, Sepulveda et al., 2023), by which precautionary action to avert the threat is warranted even if the evidence for an invasion is not entirely conclusive. This principle has been applied in decision-making regarding environmental threats worldwide and is appropriate due to the likelihood of a catastrophic outcome from successful colonization should action be delayed.

The presence of living zebra mussels in Onota Lake has not been confirmed as of this writing, but the positive eDNA sample collected on September 9 (at the boat launch) could be an early warning of a developing infestation. At a minimum, this finding highlights Onota Lake's vulnerability to zebra mussel infestation, and the need for a plan should an infestation be confirmed in the short term or in the future.

Protecting Onota Lake from the potentially catastrophic impacts of a zebra mussel infestation requires short-term and long-term plans. The short-term plan is critical to immediately follow-up on the September 2023 eDNA finding. Because invasion potential is high, and eradication is not likely after a population is established throughout a lake of Onota's size, these plans must address (1) detecting zebra mussel at an early and localized stage of invasion, (2) responding rapidly, with appropriate eradication techniques, to any early detection of zebra mussels, and (3) avoiding introduction of any life stage of zebra mussels to the lake.

This document details short-term and long-term plans for early detection and rapid response based on the state of the science. Relevant background information and supporting references follow these plans.

Short-Term Plan to Follow Up on eDNA Detection in September 2023 Sample

Zebra mussel DNA was detected in one of four samples collected on September 9, 2023 by Stantec biologists, under contract to MA DCR. The positive finding occurred only in the sample collected near the public boat launch. Samples collected at three other locations (fishing pier, deeper location out from boat launch, and lake outlet) were negative for zebra mussel DNA. No juvenile or adult zebra mussels were found in several visual searches (wading, diving, underwater camera, view scope) conducted following the eDNA detection. The positive sample collected at the boat launch in September 2023 was the first occurrence of zebra mussel DNA in any Onota Lake sample collected annually since eDNA monitoring began in 2020. However, the 2023 sampling was the first time that a separate sample was collected at the boat launch; in previous years water collected from several locations was composited to form a single Onota Lake sample.

The finding of zebra mussel DNA at the boat launch in September 2023, and not at the other three locations in the lake indicates that if there are living zebra mussels in the lake, this is an early stage of infestation that is limited to the vicinity of the boat launch. These factors are highly conducive to eradication if treatment is conducted prior to further spread. Avoidance of spread out of the localized boat launch area is critical and requires the following actions in the spring of 2024: (1) early detection with additional eDNA testing and (if detected), (2) rapid response in the form of treatment of the affected while eradication of a small colony is still possible. Zebra mussel reproduction occurs when waters warm in the spring, and every female zebra mussel can produce more than a million eggs per season. Thus, failing to eradicate the early invasion when it is limited to the boat launch area puts the entire lake at risk and eliminates the possibility of eradication in a lake the size of Onota.

Repeat eDNA sampling in April and May of 2024 is required to determine whether or not the zebra mussel DNA found in September 2023 emanated from living zebra mussels in Onota Lake, and whether or not the infestation is limited to the boat launch area. Thus, locations within the boat launch area as well as elsewhere in the lake should be sampled. Sampling during the warmer months is important because of the greater possibility of 'false negative' findings in winter. Follow-up eDNA sampling was done in February 2024 by Stantec under contract to MA DCR. All samples were negative for zebra mussel DNA, however 'false negatives' are highly likely during cold weather. It is critical to conduct repeat eDNA sampling in the spring when zebra mussels are more active and eDNA is more likely to detect living zebra mussels. Ideally, repeat eDNA sampling would be conducted both in April, prior to intensive reproduction, and in May, when zebra mussel reproduction typically occurs. A detection prior to reproduction would enhance the likelihood of successful eradication of an early-stage, spatially limited infestation.

Treatment to eradicate zebra mussels at the boat launch should be conducted as soon as possible after eDNA detection in the spring or early summer of 2024. Because zebra mussels are very prolific (females can release more than one million eggs in a season), any delay required to actually find living zebra mussels is likely to allow further spread throughout the lake and eliminate the opportunity to confine, treat, and eradicate at the boat launch.

Treatment with the copper molluscicide EarthTec QZ is recommended; it is the most effective copper product registered for zebra mussel control, both in Massachusetts and federally. Treatment will require obtaining the necessary permit(s), curtaining off the boat launch area (approximately 1-3 acres in size), and applying the molluscicide. The permit must be obtained in advance of eDNA detection to avoid any delay in treatment after positive eDNA findings.

The curtained-off and treated area should be tested for zebra mussel DNA after treatment and retreated until 100% mortality is achieved as demonstrated by two negative eDNA findings and absence of any life stage of living zebra mussels. Retesting should occur 1 -2 weeks post treatment. The amount of time post treatment required to attain 100% mortality is not known but is anticipated to be as little as two weeks and possibly as long as a month (Hammond and Ferris 2019).

While there could be some collateral damage to other organisms within the treatment area (see further details in section on 'Evaluation of Adverse Impacts from Zebra Mussel Control by Molluscicides'), these are expected to be minimal and far less harmful to any species populations than would an irreversible lake wide invasion (detailed in above 'Evaluation of Adverse Effects section and elsewhere in background information). Further, the regulations under the Wetlands Protection Act generally call for recovery of any impacted area within two years where an impact has been allowed to facilitate projects that have overall benefit to the interests of the Act but may have some adverse effect on an individual interest.

Proposed Longer-term Onota Lake Plan for Prevention, Early Detection and Rapid Response

Even if zebra mussel eDNA is not detected in the spring of 2024, the detection in September 2023 highlights Onota Lake's vulnerability to zebra mussel invasion, and the importance of advance planning to attempt avoidance of irreversible ecological harm in the future. The following actions longer-term actions are recommended:

Prevention:

1. Enhance the established boat inspection program for boats entering Onota Lake
    a. Ensure coverage for the full boating season, starting at least by May (when zebra mussels start reproducing), and continuing through September (when reproduction peaks in some lakes).
    b. Increase coverage by monitors during the season, especially on weekends, holidays, and other busy periods.
2. Provide a washing station at or near the public ramp.
3. Encourage installation of a wash station at the marina.
4. Educate boaters regarding the necessity of and methods for inspection and decontamination of boats and gear
5. Educate the fishing public regarding need to inspect and clean gear and avoid bait bucket introductions, including when ice fishing.

Early detection:

1. Determine distribution of potential zebra mussel habitat throughout the lake. Map hard and soft substrates out to a depth where soft substrate is almost exclusively dominant or oxygen is <2 mg/L during late summer from past monitoring, whichever is shallower. This will inform monitoring program decisions and allow estimation of locations and total area that might have to be addressed.
2. Use eDNA to detect the possible presence of zebra mussel.
    a. Samples should be collected at the boat ramp (most likely point of introduction), near the marina (another possible introduction location), near the outlet, and potentially at several additional locations around the lake where hard substrate is most available for colonization.
    b. Samples collected in the vicinity of the boat launch should extend out to the fishing pier, rocky habitat just north of boat launch, and include a

    range of depths out (lakeward) from launch to allow for delineation of colonization, should eDNA sampling result in a positive finding.
    c. Such sampling should occur in spring (May) and late summer (September) at a minimum.
3. Conduct visual searches at boat launch, outlet, and marina as well as other zones of suitable habitat.
    a. Search by wading and (or) boat (the latter with view scope or underwater camera).
    b. Conduct diving searches at least once per season
    c. Record absence or presence of zebra mussels, estimate density if present, and note average size of any individual zebra mussel detected.
4. Educate the public regarding zebra mussel identification; encourage vigilance and the reporting of any findings (specimens, photographs)
5. Confirm any positive eDNA results.
    a. Conduct a repeat eDNA sampling where the original positive sample was collected.
    b. Conduct visual searches by diver or snorkeler focused on (and branching out from) the location of the positive sample collection.
6. If repeat eDNA sampling and (or) visual searches are positive, delineate the approximate location of colonies, and document the size of zebra mussel and density of colonies.
    a. Consider additional spatially distributed eDNA sampling to document the spatial extent of potential infestation.
    b. Conduct general visual search of all suitable habitat in the vicinity of the positive eDNA or location of the original colony observed.
    c. Where zebra mussels are confirmed to be present, swim transects recorded by GPS perpendicular to shore, the first transect passing through the sampling point where the eDNA detection occurred and other transects initiated along shore in both directions until no zebra mussel are found between shore and the deepest plausible extent of colonization (soft substrate or low oxygen). Then swim transects parallel to shore and perpendicular to the initial transects, covering the area from shore to the deepest point of plausible colonization, until no zebra mussel are encountered. This will set the boundary of known zebra mussel infestation if zebra mussels are found.

<u>Treatment</u>

1. Characterize biological resources in the zebra mussel-colonized area in preparation for permitting to eradicate zebra mussel. If permits have been granted in anticipation of zebra mussel detection, such characterization could be a condition of those permits prior to and following zebra mussel eradication effort. This does not need to be an exhaustive survey, but should note the types of plants, invertebrates, and fish present, and any overlap with Priority Habitat. Physical features that may affect sequestration needs should also be noted.
2. Obtain necessary permit(s). It may be expeditious to obtain a permit prior to actual zebra mussel detection, so that treatment is not delayed.

a. Permitting will include an Order of Conditions issued by the Conservation Commission and approved by MassDEP under the Wetlands Protection Act and may also include a License to Apply Chemicals (WM04) issued by MassDEP, depending on the control technique chosen.
b. If the target area includes any area mapped as Priority Habitat under the Massachusetts Endangered Species Act as administered by NHESP, a separate permitting process will be necessary, and the allowable techniques may be limited.
c. It is possible that a permit under Chapter 91, pertaining to structures in a Great Pond, would also be needed for any sequestration of the target area.

3. Sequester the infested area with a curtain or equivalent means as soon as possible after delineation. Some areas with limited water exchange might be addressed without sequestration; in that case some testing (most likely a dye test) would be necessary to demonstrate water exchange low enough to ensure successful control without more extensive collateral damage to non-target organisms.
4. Attempt to eradicate zebra mussel in the target area by physical destruction and/or application of an approved molluscicide,
    a. Physical destruction could be effective if small, distinct colonies are located, but there is always a risk of missing individuals.
    b. An approved molluscicide can be very effective, covers more area more efficiently, and is a logical follow up to any but the smallest physical intervention.
        i. The copper molluscicide EarthTec QZ is recommended; it is the most effective copper product registered for zebra mussel control federally and in Massachusetts and is relatively inexpensive.
        ii. The biopesticide Zequanox can be considered when it is permitted in MA.
        iii. New products for invasive species control come to market periodically and may be approved for use in Massachusetts through proper channels at the state level; permits may cite use of only approved techniques and products but should not unnecessarily restrict control approaches.
5. Perform visual inspection and, if none are found, eDNA analyses in the target area after treatment to document zebra mussel eradication.
6. Re-apply control measures as necessary until two negative eDNA results are obtained. Remove the sequestration barrier after two negative eDNA results are obtained.
7. Continue early detection monitoring. Conduct eDNA and visual search monitoring at least 2 times per year (May and September).

Zebra Mussel Identification, Distribution, and Relation to Other Mussels

Zebra mussels are small mollusks with a yellowish to brownish or grayish shell shaped like the letter “D” in cross-section. The shell of the zebra mussel normally contains both dark and light-colored stripes, giving the mollusk its name (Figure 1), although some zebra mussel shells may be a solid brownish or grayish color. Adult zebra mussel can reach a length of two inches but are usually less than one inch in greatest dimension. Very small (<1/4 inch) zebra mussel tend to be dark, often gray, but maintain the “D” shape with the flat side attached to the substrate. Unlike most freshwater mussels, the zebra mussel grows in clusters containing numerous individuals.

Zebra mussels are believed to have come from eastern Europe in ballast water in cargo ships. They were first discovered in North America in 1988 (in Lake St. Clair near the Great Lakes). Once in North America, zebra mussels have continued to spread, mainly by smaller watercraft and downstream flow.

Zebra mussels can be transported in any life stage from infested locations to other water bodies. Early stages can be transported in boats, bait buckets, bilge water, live wells, and anywhere that water pools. Juvenile and adult zebra mussels can be transported similarly, as well as by attachment to boats and boat trailers, plant fragments, ropes, wood, fishing gear, and any other surface to which they have become attached.

Within Massachusetts, zebra mussel are known only from Laurel Lake and the Housatonic River drainage basin downstream of Laurel Lake. zebra mussel are in the mainstem of the Housatonic River and also in the Green River in Great Barrington, which drains to the Housatonic River and may be subject to backflow during high flows in the Housatonic River. No genetic studies have been conducted to determine if the zebra mussel in Massachusetts are all from the same source. The threat of import via boats is ever present, and there are zebra mussel in the Hudson River and various lakes in the Hudson River valley. The potential for zebra mussel to be moved among waterbodies is very high. Successful invasion is not guaranteed with every contaminated boat that enters a lake, but the risk is very real and preventive measures are strongly recommended.

A close relative, the invasive quagga mussel (*Dreissena rostriformis bugensis*) is similar to the zebra mussel, having less of a “D” shape, being somewhat larger on average, and having the stripes and general shell color fade toward the narrow end of the shell where the two halves are hinged (Figure 2). zebra mussel and the related quagga mussel are the only freshwater mollusks that can attach to solid objects, including rocks, logs, docks, boats, and various water intake pipes and instruments. The quagga mussel has not been found in Massachusetts but has been detected in a few locations in New York and Pennsylvania.

A third invasive mollusk, the Asian clam (*Corbicula fluminea*) (Figure 3) is becoming widespread in Massachusetts and neighboring states but does not cluster like zebra mussels and individuals are largely buried in organic to sandy sediment. Asian clams are found in many eastern Massachusetts lakes and were recently found to be widely distributed in Onota Lake (see Appendix II in Lake Onota Preservation Association 2022

Annual Monitoring Report, available at Documents and Reports • LOPA - Lake Onota Preservation Association [onotalake.com]).

These invasive mollusks should not be confused with larger native mollusks, some of which are common in the Berkshires and a few of which are protected species under the Massachusetts Endangered Species Act. The most common mollusks in Berkshire lakes (Figure 4) include eastern elliptio (*Elliptio complanata*), eastern floater (*Pyganodon cataracta*), and eastern lampmussel (*Lampsilis radiata*). These are the only native mussels found in Onota Lake; none are protected species. Except for the youngest individuals of the native bivalve mussels, which are usually buried in mud or sand, these mussels are all much larger than zebra mussel and will be found singly, not in tight clusters as will zebra mussels.

A family of very small freshwater clams, the Sphaeriidae, or fingernail clams (Figure 5), are native to Massachusetts and are found in Onota Lake. Fingernail clams might be confused with Asian clams, but the Asian clams tend to be larger and have thicker shells. Neither looks anything like a zebra mussel.

Figure 1. Zebra mussels

Figure 2. Zebra mussel (left) vs. quagga mussel (right)

Figure 3. Asian clams

Figure 4. Eastern elliptio (top), eastern floater (middle), and eastern lampmussel (bottom)

Figure 5. Sphaeriid clams

Zebra Mussel Ecology and Life History

Zebra mussels are the subject of a Rapid Response Plan prepared for MA DCR by ENSR Corporation in 2005 and a chapter in a 2023 book on invasive species in Massachusetts by MassDEP's David Wong. zebra mussels typically live 3 to 5 years, but some specimens have lived as long as 15 years. Zebra mussels prefer water with salinity below 4 parts per thousand, summer water temperatures between 17 and 23°C, pH levels between 7.4 and 9.0, a calcium concentration of at least 20 ppm with increased preference up to 125 ppm, and dissolved oxygen of at least 8 ppm. While water quality preferences may control abundance, zebra mussels can survive in water of lower quality. They can survive elevated turbidity levels, having been found in waters with 40 to 200 NTU, but a large population will filter the water and greatly reduce turbidity. Survival in water with oxygen as low as 2 mg/L is also possible, but the highly organic substrate that tends to cause low oxygen is also not suitable for zebra mussel colonization. Onota Lake offers favorable physical and chemical conditions for zebra mussels in at least the upper 30 feet of lake depth in the south basin of the lake.

While zebra mussels can survive a range of environmental conditions, pH and calcium concentration appear to limit the reproductive capacity of a population. Consequently, susceptibility to zebra mussel invasion is largely evaluated based on pH and alkalinity (which reflects calcium concentration). However, zebra mussels are known to adapt to aquatic ecosystems with chemical parameters outside of the ideal range, so low susceptibility is not a guarantee that no infestation will occur.

Zebra mussels reach sexual maturity after one or two years and exhibit external fertilization (eggs and sperm expelled from the zebra mussel and mixed in the surrounding water). Spawning typically begins when the water warms above 54^{o}F (12°C), can occur throughout the spring and summer, and has been known to peak when temperatures exceed 63^{o} $^{-}$ 64^{o}F (17° -18°C). Female zebra mussels are very fecund and may produce 30,000 eggs per reproductive cycle, translating to more than one million eggs per spawning season. Larvae, called veligers, are planktonic for a few weeks but will eventually (thought to be1-5 weeks) become hard-shelled juveniles that will settle and attach to substrates. Zebra mussels are not selective when they settle, attempting to colonize whatever substrate on which they land, but successful colonization generally requires a “hard” substrate like rocks or logs. Plants, ropes, buoys, pilings, and other structures may be colonized, but density will be limited by the surface area available. Younger zebra mussel can grow on top of older zebra mussel, resulting in giant colonies called druses.

The ability of zebra mussels to filter large amounts of water increases clarity and increases the volume of the lake available for photosynthesis. Despite potentially increased photosynthesis, zebra mussels tend to shift the flow of energy in the aquatic system to benthic pathways. Each individual can filter between 1 and 2 liters of water per day. During filtration, desired food particles are consumed while other particles are discarded on the bottom of the waterbody as pseudofeces, pellets that are not resuspended in the water column. This shift of energy to benthic resources will affect habitat suitability for many organisms.

Zebra mussel filtration will directly remove filterable phytoplankton while excretion can alter nutrient ratios in the water column in lakes. Resultant conditions tend to favor buoyant cyanobacteria. Many cyanobacteria initiate growth at the sediment-water interface on organic sediments not colonized by zebra mussels but exposed to more light as a function of zebra mussel filtration of the water column. Those cyanobacteria accumulate excess phosphorus within cells, then develop gas pockets in cells that cause fully formed filaments and colonies to rise in the water column. These large, buoyant particles are resistant to zebra mussel filtration and can become the dominant phytoplankton in affected lakes. Resulting undesirable cyanobacteria blooms can produce toxins that are harmful to people and animals, triggering beach and waterbody use restrictions.

Zebra mussel filtration will increase average water clarity and is likely to foster increased rooted plant and algal mat growth in the nearshore zone. Benthic productivity in shallow water tends to increase, at least temporarily, but loss of larger mollusks (family Unionidae, the larger freshwater mussels) occurs as zebra mussels colonize their shells. The penetration of light to the bottom in deeper (15-30 ft) water often stimulates development of cyanobacteria at the sediment-water interface. Man of those cyanobacteria can form gas pockets in cells and rise in the water column, creating blooms that resist removal by zebra mussel filtration.

Shifts in food resource quantity and quality will affect zooplankton, which will in turn affect the small fish that depend on zooplankton as a food resource. Wong (2023) provides a review of ecological impacts. Any reduction in small fish may affect larger fish, with reduced gamefish abundance likely as a function of less available food. Benthic feeding fish may increase, especially if they can feed on zebra mussels, but only a few freshwater fish species include zebra mussels in their diet. Crayfish can eat smaller zebra mussels, but grazing has been found to be inefficient and of limited value in control. Muskrat have been found to collect and eat larger zebra mussels in Laurel Lake in Lee and Lenox, but the value of zebra mussels as a food resource in the aquatic environment appears limited. Zebra mussel infestation can therefore be a major restructuring force in the aquatic community. However, while the initial impacts of zebra mussel infestation are usually substantial, impacts are not consistent over time and long-term effects are not easily predictable. Impacts in lakes will tend to be more severe than in rivers, where flowing water is a strong influence on aquatic ecology.

Zebra Mussel Detection

Zebra mussel discoveries may be made by state agencies or consultants performing routine sampling, recreational scuba divers, water utilities performing routine maintenance or addressing a fouling issue, dock maintenance crews, observant shoreline walkers and the fishing public, or swimmers entering the water. Since zebra mussels were found in Laurel Lake in 2009, more surveys intended to find zebra mussels have been conducted on Berkshire lakes considered susceptible to zebra mussel invasion based on pH and calcium content of the water. These focused surveys have usually involved a diver visually surveying the substrate in targeted areas, usually near boat ramps, other human use areas, inlets, and the outlet.

With the advances in eDNA testing in the last decade, assessments have also been made by this approach, which allows detection from genetic material in the water from just a water sample. Because dilution is a factor in eDNA studies, samples are collected from target areas most likely to harbor zebra mussels, much as with visual surveys. The time commitment is much less, and eDNA can potentially detect zebra mussel invasions while they are still small, localized, and vulnerable to eradication or control measures. The results of eDNA are generally expressed as presence or absence, but recent advances in eDNA testing now allow somewhat more quantitative assessment.

Visual surveys are often used as follow up to positive eDNA findings to confirm the presence of living zebra mussels and to characterize the extent of any zebra mussel invasion more fully. However, it is important to recognize that time is of the essence in zebra mussel control, and waiting until zebra mussels can be detected by visual surveys can limit or prevent options for any rapid response to eradicate any initial infestation before it spreads. The point of early detection is to facilitate rapid response and targeted eradication to avoid harm to the Onota Lake ecosystem. Treatment based on eDNA evidence alone corresponds with the ‘precautionary principle’ (Persson 2016, Sepulveda et al., 2023). This principle argues for action despite uncertainty when inaction can result in grave or irreversible environmental damage. Follow up assessment should be performed but is not necessarily essential to moving forward with management actions.

There are multiple methods for conducting a visual survey depending on the objective of the survey. To quantify the extent of a zebra mussel invasion, it is important to be as thorough as time, money and manpower allow. The rapid response plan for zebra mussels in Massachusetts developed in 2005 recommended the following steps when conducting a survey of a known zebra mussel invasion; these are modified slightly here for clarity and through experience:

1. Acquire a suitable map of the waterbody with water depth contours.
2. Use the taxonomic information supplied here or supplementary information from taxonomic guides to identify zebra mussel. If zebra mussel are detected and individuals can be collected, seek confirmation from a qualified source such as MassDCR or MassWildlife.
3. Concentrate the survey in areas with suitable hard substrates for attachment. An initial survey with an underwater video system (Aqua Vu, Marcum, or equivalent) is helpful for defining the distribution of hard substrate in the lake, but it will generally decline with increasing water depth.
4. Using diving, snorkeling, or an underwater video system, survey target areas. The use of repeatable transects from shoreline to deeper water is advised for routine surveys, creating a record over time for the same areas. The spacing of transects will be largely a function of the distribution of suitable substrates. The depth to which transects extend would be to the depth at which soft sediments are exclusively dominant or oxygen is <2 mg/L by summer water quality surveys. The area of any boat ramp or other plausible input point should be included.
5. Mark the position of any zebra mussel detection by global positioning system (GPS). Note the abundance of zebra mussel at any site they are found. Note the size of any zebra mussel, ranging from newly established shells (<1/4 inch) to older individuals (often close to 1 inch).
6. Where zebra mussel are found, survey that area along transects perpendicular to the established shore to deep water transect to determine the extent of the infestation, further noting the position, abundance, and size of any detected zebra mussel.
7. Where zebra mussel have been preliminarily detected by eDNA, more focused surveys can target the area where zebra mussels are believed to be present. These surveys will still benefit from established transects and use of GPS, but it may be appropriate to visually survey the entire bottom in smaller areas where positive eDNA results have been obtained.
8. If conditions are suitable, wading parallel to shoreline may allow initial detection over a greater area with less effort. Hard substrate (rocks, woody debris, and structures) tends to be at a maximum very close to shore but below the depth of normal water level fluctuation (usually 1-2 feet). Visual observation in that zone has the highest probability of detection zebra mussel and can inform or supplement any transects from shore to deeper water.

Because the effort and expense involved in surveys following the guidance above can be substantial, and since there is no guarantee that not finding zebra mussel means there are none in the lake, alternative early detection approaches have been sought. Certainly, the simple shoreline survey, conducted by volunteers wading in shallow water and looking for zebra mussel on hard substrates is an economical method with a high probability of detection if zebra mussel are present at any but the lowest abundance.

However, no visual survey will cover all possible substrate. Plankton tows and eDNA offer alternatives.

Plankton tows using a net with mesh openings of <80 um (0.08 mm or 0.003 inches) can collect the larval veligers of zebra mussel. zebra mussel are very fecund, putting hundreds of thousands of veligers into the water per female each breeding season, dependent on temperature but roughly mid-May through September. Plankton tows can filter hundreds of liters of water, concentrating the veligers if present. Microscopy allows detection of the veligers and some quantification of abundance if the amount of water filtered is recorded. Net tow samples from Laurel Lake, with moderate density populations of zebra mussel on only a fraction of the substrate, have never yielded more than 2 veligers per liter of water, but lakes in other states with dense zebra mussel infestations over large areas have produced dozens to >100 veligers per liter of filtered water. Some commercial labs are set up for this analysis and while it may cost several hundred dollars per sample, only a few samples are needed each summer to document presence or absence of zebra mussel. The problem with this approach is the need for veligers at all, indicating that reproduction is occurring. Also, false negatives are likely if the zebra mussel population is not already substantial. The best rapid response will occur before significant reproduction is initiated.

The use of eDNA is predicated upon the uniqueness of DNA from any species, the ongoing shedding of DNA into the water by organisms (e.g., feces, various body coatings, dead organisms), and the ability of lab tests to detect that DNA at very low levels by amplification techniques. The main process used is quantitative polymerase chain reactions, or qPCR. The steps in the process include collection of a water sample, concentration of that sample by filtering (in the field or lab), laboratory amplification of target eDNA, and detection. Amplification is accomplished by what are called primers, short DNA sequences added that will, if the DNA sequence for which they are coded is present, make copies of that sequence and increase its abundance in the sample. The detection step involves addition of another DNA sequence, called a probe, that will fluoresce when it finds a match in the sample. The emitted light indicates that DNA from the organism targeted by the primer was present in the sample.

The release of eDNA is affected largely by metabolism, which in turn is most affected by temperature, with warmer temperatures increasing metabolism and release of eDNA. Persistence of eDNA is affected by temperature, light, and other environmental variables. The persistence of eDNA in the aquatic environment is limited, usually a matter of a few days after material is added to the water column from the organism, but if the organism remains present, more eDNA will be added and detection could be possible at any time. Yet the presence of eDNA does not guarantee that the source is still alive, and the qPCR method does not provide reliable estimation of how abundant the target organism is in the subject lake.

Various additional techniques have been developed to enhance detection and quantification of target organisms but are not all in common use. The presence of eRNA (related to DNA, but indicative of active cellular processes) indicates living specimens of the target organism. Metabarcoding allows detection of multiple species from a single sample and can facilitate some sense of relative abundance. The use of this technology in aquatic assessment and management is increasing and developing rapidly, offers powerful tools, but is still subject to sampling and processing issues and cannot tell us exactly where the zebra mussels are in the lake.

The pros and cons of options for detecting and quantifying zebra mussel in lakes are summarized in Table 1. Each survey option has advantages and disadvantages. Use of eDNA offers the best chance of early detection but follow up with some kind of visual survey is advisable to locate zebra mussels for possible management action. As noted previously, however, the risk of waiting until an eDNA detection can be confirmed visually is that containment and eradication may be compromised by any delay in management actions. Net tows may also provide early detection but in the early invasion stage the density of veligers will be very low and require extensive sampling. Visual surveys cover a range of options with cost increasing with more extensive and accurate coverage. Yet at the earliest stage of invasion, visually finding zebra mussels can be challenging, making eDNA the best early detection strategy.

Zebra Mussel Control Options

Control of any invasive species involves three separate but related efforts: prevention of invasion, rapid response with intent to eradicate, and maintenance with intent to limit abundance with little expectation of eradication. Clearly the prevention of an invasion is the preferred option, but this approach suffers from some limitations. Perhaps most problematic is the organization, effort, and funding necessary to prevent a problem that has not yet occurred. Inspection of boats entering a lake has proven effective, but inspecting all boats that enter is nearly impossible, and very few boat ramps even have inspectors present. Cleaning boats is also known to be effective, but very few launching facilities have cleaning stations. Preventing downstream movement of veligers from upstream sources would require chemical treatment of flows that would carry substantial cost and would be expected to kill non-target organisms as well. Prevention is a very important element of invasion control that is not getting the support it needs at the state or local level.

Rapid response with the intent to eradicate invaders hinges on early detection, just covered in the preceding section. Detected before distribution is widespread in a lake, techniques to eradicate the invading species are available and affordable, and localized application will minimize impacts to non-target organisms. Rapid response is mostly hindered by regulatory delays, and this document is provided in support of permitting to shorten the timeframe for effective rapid response. Getting necessary permits in advance of a possible invasion seems prudent. Acquiring the necessary permits where an invasion seems likely may be essential to effective rapid response.

Table 1. Options for zebra mussel detection and quantification

Technique	Description	Advantages	Disadvantages
Wading survey	Visual assessment in shallow water	Inexpensive; covers area most likely to have hard substrate; allows precise location and quantification	Does not cover deeper areas; obstructions may compromise survey
Snorkeler survey	Visual assessment in shallow to moderate depth water	Inexpensive; covers more area than wading survey; allows closer inspection of substrate; allows precise location and quantification	Does not cover deepest areas; cannot cover 100% of substrate in larger area
Diver survey	Visual assessment in shallow to deep water	Covers all possible colonization areas, allows close inspection of substrates and collection of specimens, allows precise location and quantification	Expensive for thorough survey; cannot cover 100% of substrate in large area.
Video survey from boat	Visual assessment in shallow to deep water	Less expensive than using divers. Can cover all possible target areas. Allows precise location and quantification.	Limited by video resolution and control of instruments at depth; cannot collect specimens.
Plankton tows	Lab assessment from net tow sample	Allows analysis of likely presence of zebra mussels by capture of veligers. Is relatively inexpensive.	Does not indicate where the adult zebra mussels are located; multiple samples needed per year; only provides semi-quantitative assessment of abundance; requires microscope and training; may not detect veligers in water bodies with low densities; likely not suitable for early detection.
eDNA	Lab assessment from filters through which lake water has been passed.	Allows determination of likely presence of zebra mussels by genetic evidence. Is relatively inexpensive. Tool for early detection while there is still time to eradicate or control and before invasion gets out of hand.	Does not indicate exactly where adult zebra mussels are located. Considerable additional sampling may be needed to narrow down likely infestation areas. Does not provide specimens or accurate estimate of abundance. Requires specialized lab work.

Maintenance to control an invasive species once in the lake but beyond the initial invasion stage would utilize mostly the same techniques as rapid response with intent to eradicate, but at the scale of the whole lake or a major portion of it. At such scale, those techniques are either less effective or have significant adverse impacts on non-target organisms that may prevent permit acquisition. Any overlap between an area targeted for management action and species listed for protection under the Massachusetts Endangered Species Act may create permitting problems. Additionally, the Wetlands Protection Act lays out eight interests that have to be considered in any lake project, including pollution prevention and habitat protection that can limit control of invasive species at larger scales. Some degree of invasive species control is usually possible, but eradication has been elusive.

Actual methods to kill zebra mussels when detected fall into three categories: physical, chemical, and biological. Options are discussed here without consideration for specific application in Onota Lake, which will be addressed in the next section on developing a plan for Onota Lake.

Physical control:

Manual destruction or removal – Physically destroying zebra mussels with a hammer or other blunt object is possible but very tedious on more than the smallest scale. Smaller rocks with zebra mussels on them could be removed from the lake until the associated zebra mussels have died, but many rocks, woody debris items, and structures cannot be moved by a diver. Physically removing the zebra mussel from the substrate is very difficult on account of the strength of the byssal threads used to anchor the shell onto the substrate. On a small scale, manual elimination of zebra mussels may be practical, as with a very early invasion detection in a limited area, but the potential for complete removal is limited by visual detection of zebra mussels to be destroyed.

Drawdown – Desiccation or freezing can be effective means to kill zebra mussels. Research at the USACE Research Station in Mississippi (Ussery and McMahon 1995) found that most zebra mussels died within a week of exposure at 60 F, even with 100% humidity, and none survived more than 22 days. Further, Ussery and McMahon (1995) found that larger (native) bivalve mussels survived exposure much longer, limiting non-target impacts. Research at Laurel Lake by WRS Inc. (WRS 2018) found that all zebra mussels died within a week when exposed to air at an average temperature of 43 F, and in about two days in below-freezing temperatures. Drawdown could indeed eliminate all exposed zebra mussels.

Laurel Lake, the only lake in Massachusetts with zebra mussels, has been subjected to a 3-foot drawdown each winter since 2010-2011. Zebra mussels at depths <5 feet are controlled; the 3-foot drawdown exposes about 18 acres while the ice in the 3- to 5-foot zone disrupts zebra mussels in another 12 acres, amounting to <18% of the total lake area but resulting in about 61% of all hard substrate in the lake being impacted and about 40% of the plant growth zone where zebra mussels attach to milfoil plants being affected. Zebra mussels are clearly less abundant in the drawdown impact zone and zebra mussels present in that zone are much smaller (meaning younger, having colonized since the last drawdown) than specimens found in deeper water. Yet it would require at least a 30-foot drawdown to expose all zebra mussel habitat in Laurel Lake. Thus, drawdown in Laurel Lake functions as a control mechanism rather than an eradication tool.

The problem with sufficiently deep drawdown to expose all zebra mussel habitat in many lakes is that many other organisms may be impacted. However, for drawdowns <3 feet, research in Massachusetts has not detected many significant adverse impacts among the many possible effects evaluated (Carmignani 2020), even with drawdown lasting all winter. Native mussels will be at risk, but then they will be at greater risk lakewide if zebra mussels become established. Some changes in insect fauna have been observed, but those have not affected the fish community in measurable ways. Peripheral substrate may get more coarse (fine particles move offshore, leaving gravel and rock), and that would actually enhance habitat for zebra mussels, but also improves the probability of killing exposed zebra mussels.

Yet a drawdown to kill all zebra mussels in any lake would undoubtedly have to be much greater than 3 feet, exposing many organisms of limited mobility and crowding more mobile organisms into a small remaining volume of water. The largest drawdown in Massachusetts is about 8 feet and this would not be enough to expose all hard substrate in any Berkshire County lake that is susceptible to zebra mussels. Achieving a drawdown deep enough to expose all zebra mussels would require pumping or siphoning, as no lake in Massachusetts is known to have a dam capable of gravity outflow to such depths. Drawdown could be a partial solution or maintenance method for minimizing zebra mussels in nearshore zones and would impact a disproportionately large fraction of possible zebra mussel habitat but does not appear to be practical as an eradication technique as a consequence of serious logistic and permitting problems.

Thermal treatment – Zebra mussels can be killed with hot water, with a minimum temperature of 37 C (100 F), which can be a valuable aspect of pressure washing watercraft before entering or just after leaving a lake. Yet achieving high temperatures in the lake itself is neither practical nor safe for non-target organisms.

Other – Other physical control techniques that have been used experimentally by industry and utilities include radiation, mechanical filtration, removable substrates and complete re-design of systems in critical areas. None of these appears particularly applicable for overall lake use. Physical control techniques may be practical on a small scale but are likely to be very expensive, less effective, and/or not permittable in the regulatory system on a larger scale.

Chemical control:
The Army Corps of Engineers published a “Zebra Mussel Chemical Control Guide” in 2000 and updated it in 2015 (Glomski 2015). This guide includes information about various chemical treatments used to combat zebra mussel infestations and much of the following information was gleaned from that document.

Chlorine and related anti-fouling chemicals – Public utilities that experience problems due to zebra mussel biofouling of pipes may use oxidizing chemicals to clear the fouling. Chlorine gas, hypochlorite, chlorine dioxide, peroxide, ammonia, oxamine 6150, bromine, and potassium permanganate are among the chemicals applied to kill zebra mussel. Some toxic compounds can be incorporated into paint or other coatings used on surfaces where zebra mussel colonization must be prevented, but most actions involve dosing chemicals into pipes or tanks to kill zebra mussels. Chlorine, peroxide, and various pesticides can be effective and can be used with limited risk inside water treatment facilities. However, the potential negative effects of chlorine and other chemicals used to kill zebra mussels in the aquatic environment may be great if applied in open water. There are no known chemical controls suitable for use against zebra mussels in an open environment that will not kill at least some non-target organisms at the concentrations necessary to kill zebra mussels.

Copper products – Copper has long been used as an algaecide and is toxic to many aquatic organisms. There are many copper formulations, with differences relating to various additives, most intended to enhance uptake or maintain the compound in solution longer. Some formulations have been found to be effective against zebra mussels at concentrations that limit impacts to other non-target organisms, although some collateral damage may be unavoidable.

Copper is toxic to many aquatic organisms. It disrupts cellular membranes and inhibits multiple metabolic pathways. Used as a molluscicide for zebra mussel control, the early life stages of zebra mussels are significantly more susceptible than adults to most copper products. Concentrations as low as 0.2 mg/L for 24 hours or 0.4 mg/L for 3 hours are expected to kill 99% of zebra mussel veligers, whereas it can take as much as 2 mg/L for 96 hours to kill a similar percentage of adult zebra mussel. The difference in sensitivity is partly due to the ability of adult zebra mussels to detect copper and close their shells, but adults do seem to be more resistant to copper toxicity. Temperature plays a significant role in copper toxicity with increasing temperature increasing toxicity and lowering the dose needed to kill zebra mussels.

EarthTec QZ and Natrix are copper products registered as molluscicides for use in Massachusetts at this time. Each can be applied at up to 1 mg/L as copper to half of the entire target waterbody; treatment of the other half must wait at least two weeks. Yet substantial control of zebra mussels has been reported for each at lower concentrations. EarthTec QZ in particular is reported to provide nearly complete kill of zebra mussels at concentrations as low as 0.03 mg/L, although that requires multiple applications over at least a month. Laboratory studies found that application at 0.1 mg/L as copper can eliminate zebra mussels in under two weeks without expected major non-target impacts; this has not yet been confirmed with field studies.

Hammond and Ferris (2019) report elimination of zebra and quagga mussel veligers and adults from a 30-acre quarry lake in Pennsylvania after 40 days with multiple treatments with EarthTec QZ that totaled 0.44 mg/L cumulatively as copper. Copper at as high as 0.3 mg/L was detected during treatment and background levels for copper were not attained until 76 days after treatment, but the extra time with copper in solution was viewed as insurance that all zebra and quagga mussels would be eliminated. Monitoring using eDNA confirmed elimination of zebra and quagga mussels in that quarry lake for several years.

Review of zebra mussel control efforts (Dahlberg et al. 2023) revealed 33 projects as of 2023. Monitoring data were found to be inadequate for proper evaluation of all aspects of project performance, but major reductions in zebra mussel abundance with copper treatments were common. Complete eradication occurred less than 10% of the time, likely because, in many cases the target area was not the entire lake. Complete eradication within the target area was achieved about two thirds of the time.

Biological control:

Predator introduction or augmentation – Augmenting or introducing natural predators and species-specific diseases or parasites may be considered but is not likely to result in the eradication of a zebra mussel infestation. The change in ecosystem dynamics due to introductions of new organisms or the augmentation of present organisms may be detrimental to the overall health of the ecosystem in some cases, so care must be taken with this approach. Necessary permitting for the addition of any vertebrate species in Massachusetts will likely prevent introductions.

Certain fish species, like freshwater drum and common roach (a non-native species), prey upon zebra mussels effectively. Some waterfowl, including diving ducks, eat zebra mussels, as do muskrat. Crayfish will also consume at least smaller zebra mussel. However, with most biological predator-prey interactions, cycles of abundance and scarcity are typically set up and eradication is unlikely; predators either switch to alternative food resources, emigrate, or die off before prey are eliminated. Some measure of control can be achieved, but in many cases, it has been nominal and cycles of abundance and scarcity create undesirable variation in lake conditions.

Zequanox – Zequanox is a biological pesticide composed of dead cells of the bacterium *Pseudomonas fluorescens*, a microorganism found in soil and cultured for this purpose. The cells contain natural compounds that, when ingested, are lethal to zebra and quagga mussels during all life stages. Chemicals such as chlorine may be sensed as threatening, causing valve closing and avoidance, while Zequanox is perceived as a non-threatening food source and readily consumed. Susceptibility increases with water temperature, with more than 90% mussel mortality at temperatures >57 F. Substantial mortality is achievable even in very cold waters, but 100% mortality is rarely observed.

Toxicity to non-target organisms has been minimal in most trials, but fish and other mussels may experience some toxicity at the maximum label rate (200 mg/L). Application rates near 50 mg/L are used in longer term control projects and represent less risk to non-target organisms. Typically, Zequanox is applied to the target waters twice per month during the zebra mussel spawning season.

The primary problem with Zequanox is that it dissipates rapidly from unconfined areas of application and associated dilution has rendered partial lake treatments ineffective without long-term (i.e., several months) confinement (Luoma et al. 2019). Zequanox has been used in enclosed systems such as water tanks and has potential for sequestered areas of lakes as part of a rapid response plan. Whole lake treatments have apparently not been attempted. Zequanox is not currently permitted in MA.

Summary:
Physical, chemical, and biological control methods for zebra mussels exist and while most have shown success on small scales, none has proven reliable at the whole lake level. Consequently, successful zebra mussel control at this time requires early detection and rapid response that addresses smaller areas. Confining such areas with curtains or other sequestering devices can maximize effectiveness and minimize non-target impacts on a lake wide basis. Some collateral damage within the target area may have to be accepted to achieve successful eradication, and retreatment may be necessary for a complete kill. However, any harm to organisms due to treatment within a small, contained area of the lake will be far less than the lake wide ecological disruption (including harm to fish and native mussel populations) expected invasion should inaction at an early stage allow for a successful, and likely irreversible, zebra mussel invasion. At this time, copper-based molluscicides are the most effective treatment that is permitted in MA.

Evaluation of Adverse Impacts from Zebra Mussel Control by Molluscicides

Impact of zebra mussel control actions on non-target organisms is often the primary concern of regulatory entities and well-meaning citizens and organizations. Although current laws prohibit the importation of invasive species, there are no statutes requiring action against those invasive species once they arrive. Massachusetts regulations prohibit actions thought to have significant adverse impacts on public interests such as protected (state-listed rare and endangered) species, fish and wildlife habitat, water quality, water supply, and shellfisheries. Consequently, the regulatory system is focused on preventing harm and does not prioritize remediating harm that has been done or minimizing the impacts of an invasion once it has occurred.

The use of a molluscicide, most likely Earthtec QZ, to eradicate zebra mussels if and when they show up in a small, treatable portion of Onota Lake, is predicated upon the following important assumptions: (1) that successful colonization of zebra mussels in Onota Lake will result in irreversible ecological and economic harm, (2) failure to eradicate an early invasion of a small area will likely result in lake wide spread, (3) widespread colonization of the lake could not be eradicated or controlled without collateral damage, and (4) preventing irreversible harm to Onota Lake by treating a small localized area is more important that protecting every organism in that treatment zone. Essentially, the overall impact of a full-scale zebra mussel in the lake portends far greater irreversible harm than would the loss of a few individuals of any given population within the localized treatment area. Any zebra mussel eradication is proposed to occur in areas without state-listed species. (Their occurrence would add a layer of permitting that could pose challenges to the proposed program, butthis basic premise of the precautionary principle may hold true for state listed species, if those species could be impacted by zebra mussels.)

Onota Lake, like Laurel Lake, has three species of native mussels, none which are state listed Importantly, the populations of these same three species of native mussels in Laurel Lake have been virtually eliminated by the zebra mussel invasion of Laurel Lake. The zebra mussels are not expected to directly impact state-listed plant species or the protected bald eagle in Onota Lake, but indirect impacts are possible (e.g., competition from invasive macrophytes, decline in pelagic fish populations). For other species not afforded protection under the Massachusetts Endangered Species Act, significant impacts are determined mainly from their relation to the interests of the Wetlands Protection Act. Fish and wildlife habitat, shellfisheries, and aspects of water quality are the most relevant interests. Given the potential for zebra mussels to strongly alter the ecology of a lake, prevention of zebra mussel establishment should be viewed as protective of Wetland Protection Act interests.

It must be acknowledged that copper, at the likely prescribed application rate, can be toxic to some aquatic organisms. At 0.1 to 1.0 mg/L, the most likely dose range, most algae and many zooplankton are susceptible to copper toxicity. Most rooted plants are not strongly impacted; some loss of Chara or Nitella (both actually macroalgae and not vascular plants), is to be expected, but the typical pondweeds and milfoil (both invasive and native, including one state listed species in a small portion of the lake) are not particularly susceptible to copper at the anticipated rate. Impacts on invertebrates are variable depending on dose and application frequency. Many larger mussels, including the native species found in Onota Lake, have been found to be resistant to copper toxicity, while most snails have proven more susceptible. Aquatic insect larvae, crayfish, and certain other benthic invertebrates have exhibited varied susceptibility, generally higher than for fish but dependent on other water quality features such as pH and temperature. There could indeed be some mortality of invertebrate species at a copper dose of 0.1 to 1.0 mg/L within any treatment area, but complete loss of invertebrates is very unlikely at the expected dose.

Fish also exhibit varying susceptibility to copper but are generally more tolerant than invertebrates, especially to short term exposure. In an evaluation of several decades of fishkill investigations, MassWildlife staff did not find evidence of any kills attributable to copper applications, but most of those applications were close to the 0.1 mg/L lower threshold of any planned treatment of any small area of Onota Lake. Lab data from products studies suggests a wide range of susceptibility, ranging from 0.02 mg/L for rainbow trout to 108 mg/L for golden shiner. Again, pH and temperature are important variables, with circumneutral pH and colder water limiting impacts.

Chronic toxicity effects can be expected at lower copper concentrations, but those effects are based on longer duration exposure than expected for zebra mussel control. Lasting impacts on individual organisms would be very difficult to document, and lasting impacts on whole lake populations will be negligible.

There is no expectation that all aquatic organisms will experience mass mortality in any confined treatment area within Onota Lake, but it is reasonable to expect some mortality for those more sensitive species. Disallowing treatment, however, does not necessarily protect those species populations, as the impacts of a full-scale zebra mussel invasion will affect habitat and food resources for many organisms. It is essential to maintain a big picture view of proposed treatments and to look at the overall impact of a zebra mussel invasion on the interests of the Wetlands Protection Act, rather than trying to protect every last individual of any aquatic species within the lake.

Even with substantial mortality of non-target organisms in any treated area, the size of that area and portion of the population of any species involved will be very small relative to the overall lake area or population. Consider that Lake Onota covers 617 acres to a maximum depth of 66 feet and an average depth of 22 feet. The most likely target treatment area, the area around the public boat launch where the one positive eDNA result was obtained, covers about 1 acre at a maximum depth of about 15 feet and an average depth of about 6 feet. That most likely treatment area therefore represents 0.16% of the lake area and 0.04% of the lake volume. Even considering just littoral zone (the area shallower than about 15 feet where oxygen is plentiful, plants grow, and benthic life is most diverse), the boat launch area targeted for possible treatment represents 0.5% of littoral zone area or volume. This is a very tiny fraction of the lake and represents a minimal portion of biological resources.

The regulations under the Wetlands Protection Act generally call for recovery of any impacted area within two years where an impact has been allowed to facilitate projects that have overall benefit to the interests of the Act but may have some adverse effect on an individual interest. For phytoplankton and zooplankton, which occupy most of the water column of Lake Onota, the removal of any physical barrier (a curtain to sequester the target area is likely to be in place during treatment) will result in mixing and recovery of any lost organisms within a few days. Recolonization of any areas by invertebrates from adjacent or even farther parts of the lake would be expected within the normally allotted timeframe, probably much faster. Fish would be free to move into the area immediately and would be expected to do so.

Other lake projects with impacts on some part of the lake have been monitored and in general there has been no issue with recovery within two years. No vascular plant mortality is expected from a copper treatment, but recovery within two growing seasons is normally observed for non-target plants with herbicide treatments. Aluminum treatments to control the release of phosphorus from bottom sediments have sometimes smothered invertebrates under the floc that forms and settles, yet recovery is observed within a couple of years. Zooplankton have been impacted by some copper treatments but have routinely recovered from resting stages that germinate within a year. No fish mortality has been recorded in Massachusetts from copper treatments, so there is no expectation of any lasting effect on fish populations. These example projects typically impact a larger portion of target lakes than that proposed in Lake Onota and yet are routinely permitted under the Wetlands Protection Act.

While there may be some copper residual in the sediment within the treated area, that copper will have reacted and been rendered inert. No physical change in the substrate will occur. Studies of long-term, annual or more frequent applications of copper to control algal nuisances have struggled to find any long-term impacts from applied copper. Minor reductions in benthic invertebrate abundance and diversity have been found in just a few studies, and these included copper treatments over as much as 50 years. The proposed project is much more transient and focused on a very small area; it will not result in high copper accumulation in the lake.

In comparison, consider the potential impacts of a zebra mussel invasion. One need look no farther than Laurel Lake for a comparison. Rocks and logs beyond the drawdown zone are covered with zebra mussels, extending out to a depth of about 30 feet, although more than half the hard substrate habitat is in water <5 feet deep. Cyanobacteria bloom frequency appears to have increased over the last 15 years. Except on late summer when cyanobacteria can dominate, water clarity is higher and plant density has increased, most notably that of invasive Eurasian watermilfoil which grows at greater depth than most native species. Native mussels have been nearly eliminated by zebra mussels colonizing their shells; it is rare to find a live Elliptio or Pyganodon. Pilings, floats, platforms, ropes, mooring buoys, and anchors must be removed each year to avoid permanent colonization by zebra mussels. A boat washing station is in place at considerable cost but is not manned continuously and boats are undoubtedly transporting veligers out of the lake on occasion. Overflow to the Housatonic River has fostered colonization in the river and in Candlewood Lake in CT, which draws water from the Housatonic River. Fishery data have been collected by MassWildlife but not made public, so fish impacts have not been made known.

Other than impacts to listed species under the Massachusetts Endangered Species Act, all potential adverse impacts from the proposed treatment can be allowed under the Wetlands Protection Act to enhance and protect the interests of that Act. No treatment is proposed in any Priority Habitat, so listed species are not at risk. Any negative impacts from treatment to eradicate zebra mussels would occur over a such a tiny portion of the lake as to be negligible at lakewide scale and recovery is expected within a year or two if any such impacts occur. Waiting to treat until zebra mussels have expanded into more of the lake will make an eradication project, if even feasible, much more difficult to permit due to expanded non-target impacts. The time to act is as soon as possible after zebra mussels have been detected in the lake.

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