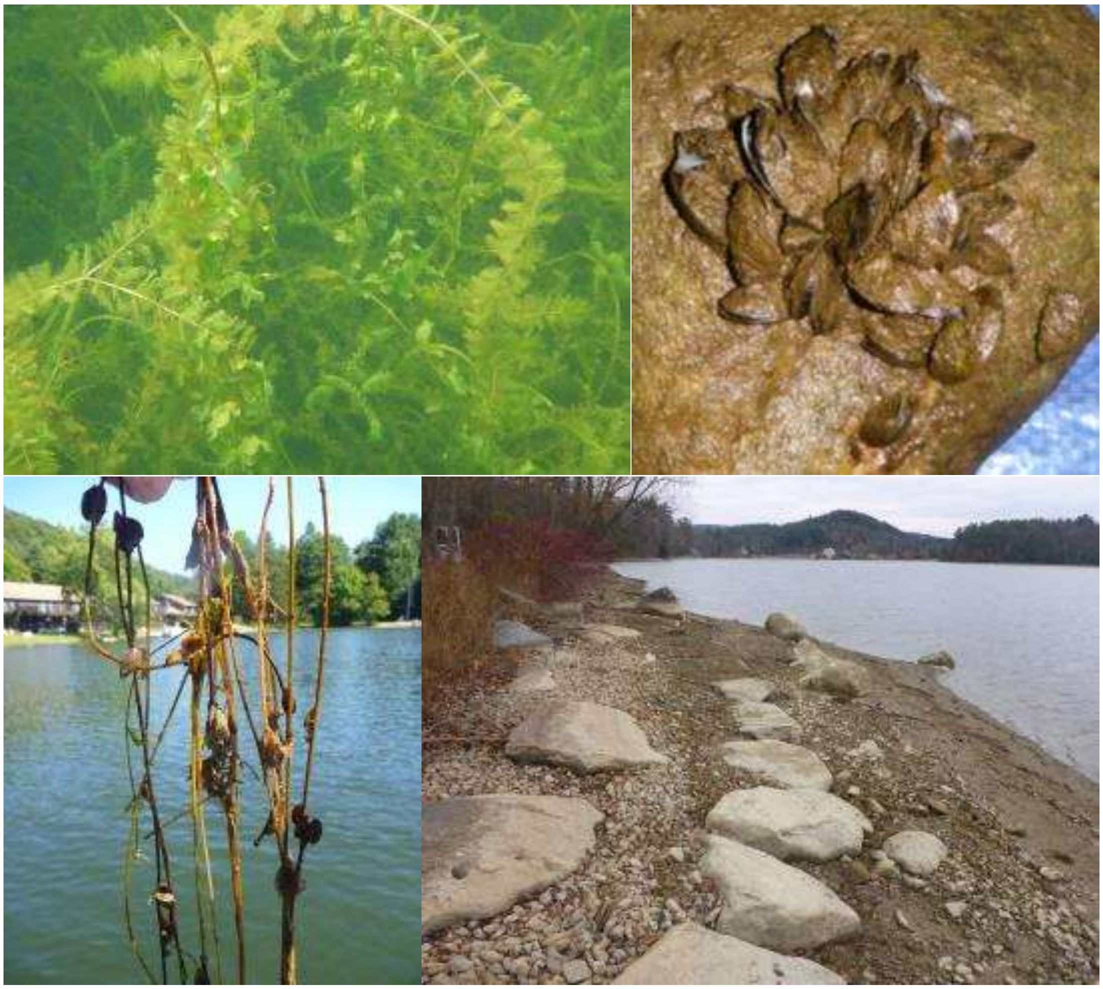
Laurel Lake Drawdown

Summary Report: 2010-2017



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Executive Summary

Laurel Lake has been subject to a 3 foot drawdown each winter since 2010-2011 for the control of zebra mussels and Eurasian watermilfoil in shallow water, although drawdown was not conducted in the winter of 2017-2018. Greater control is needed and desired, but the drawdown has been limited to 3 feet by the permitting system. Monitoring has been conducted over 8 years so far, resulting in a database that provides both baseline conditions for comparison among years and investigative studies to answer questions that relate to additional management planning. This report provides a detailed accounting of activities undertaken and the results through 2017.

Zebra mussels invaded Laurel Lake about a decade ago and the rapid response plan in place in Massachusetts was not followed. Zebra mussels have been allowed to proliferate and represent a major threat to the Housatonic River, downstream impoundments, and other area lakes. Boat ramp inspections and use of a wash station limit spread by boats, but only on a part-time basis. The Housatonic River has received larval zebra mussels from Laurel Lake, two impoundments downstream in Connecticut have become infested, and there is great concern for Candlewood Lake, which receives diverted water from the Housatonic River. Laurel Lake is a Great Pond under state statute and is therefore technically owned by the Commonwealth of Massachusetts, although the dam is under private ownership. The Laurel Lake Preservation Association (LLPA) has assumed primary responsibility for lake management, but has limited funds and authority.

Most hard substrate in Laurel Lake that is suitable for colonization by zebra mussels is in water <5 ft deep, but scattered rocks and logs provide some substrate in deeper water and zebra mussels grow on plants, mainly Eurasian watermilfoil, which can be dense in water up to 14 ft deep. The 3 ft drawdown controls zebra mussels over slightly less than two thirds of the hard substrate area in the lake and about half of the possible plant growth area. A 5 ft drawdown would increase the affected area, but zebra mussels are found to about 30 ft of water depth.

The macrophyte community includes 37 identified species, 33 of which are higher plants and 4 of which are forms of macroalgae. Only about 8 species are common, however, with water celery (*Vallisneria americana*) most frequently encountered and Eurasian watermilfoil (*Myriophyllum spicatum*) providing the greatest individual biomass. A variety of species from the pondweed family also present high density in patches, with the invasive spiny naiad (*Najas minor*) increasing in abundance in shallow water since drawdown commenced. The area covered by plants is extensive in water between 4 and 14 ft deep, but the portion of the water column filled by plants averages <50% over that area. Overall plant cover and biovolume have not changed significantly since drawdown was initiated.

Native bivalve mollusks have been greatly reduced in abundance in Laurel Lake by zebra mussels, which colonize the shells of the two species known from this lake. The native snail community is dominated by three species, most abundant of which is *Amnicola limosa*, a common member of the Hydrobiidae family. Laurel Lake also hosts a population of the state listed *Marstonia lustrica*, also a hydrobiid snail, known only from this lake and Stockbridge Bowl in Massachusetts, which represents the northeastern end of its range. This snail is not on the endangered list in any other state or at the federal level, but is rarely abundant, and represents an average of just over 1% of the shallow water snail community in Laurel Lake. Recently deceased snails of all types in the drawdown zone represent a small portion of the total community based on late summer surveys. There is no evidence that the drawdown has harmed any species of snail in Laurel Lake.

The watershed of Laurel Lake was divided into four contributing drainage areas and examined for sources of pollution. Three distinct areas of potential concern and two areas of secondary concern were identified, but no sampling or other follow up has been conducted, as all areas are private property and the LLPA has no jurisdiction over them. Modeling of nutrient loading from the watershed suggests moderate inputs of phosphorus and nitrogen with predicted average in-lake concentrations that closely match available actual data (phosphorus at 20 ug/L, nitrogen at 600 ug/L). Those concentrations are borderline in terms of the potential to support algae blooms. Overall, however, the watershed does not appear to represent a major threat to Laurel Lake on a short-term basis, and the watershed does not influence invasive plant or zebra mussel abundance, the primary problems in Laurel Lake. Zebra mussels are known to foster cyanobacteria blooms, and may be more influential in the occasional and mild Laurel Lake blooms than nutrient concentrations.

Field water quality data indicate generally desirable conditions with moderate to high water clarity on all sampling dates and oxygen suitable for all aquatic life until at least 30 ft of water depth. There is low oxygen in deep water, but this is a largely natural phenomenon in most area lakes. Data for pH, conductivity, turbidity and chlorophyll-a suggest desirable water quality from the perspective of all designated uses. Laurel Lake is on the impaired waters list for invasive species, oxygen and phosphorus, but only the invasive species impairment appears justified.

Recommendations have been made every year that include details for the conduct of drawdown, investigating alternative means of zebra mussel and milfoil control, and increased town involvement to further watershed assessment. From a technical perspective, the most effective control of zebra mussels would involve either an expanded drawdown or use of molluscicides, both of which could have significant impacts on non-target organisms. However, experiments have demonstrated that no more than a week of exposure would be needed to kill all zebra mussels by drawdown, so the impact would be temporary and potentially a one-time event. At the very least, a 5 ft drawdown would provide increased control of invasive species.

The fundamental problem in addressing zebra mussels in Laurel Lake is that local conservation commissions, the MA DEP and the NHESP are all bound by laws intended to protect aquatic habitats from harm without requiring that a solution be approved for addressing a serious issue that threatens not just Laurel Lake but other aquatic resources in multiple states. Within the constraints of the legislation and regulations those agencies are charged to uphold, they are not able to support most proposed solutions because of non-target impacts. What is needed is a cooperative effort by all interested parties to develop a solution even if it has some undesirable impacts, with the intent of a multi-year ecological restoration of Laurel Lake. Convening a group representing all relevant parties to discuss options and possible solutions is recommended. The LLPA and WRS have called on the Secretary of the Office of Energy and Environmental Affairs to take a leadership role in this effort, but have received no response after months of waiting. The Lenox Conservation Commission rejected a formal request to renew the Order of Conditions for the 3 foot drawdown in 2017, requiring a full reapplication process that the LLPA declined to enter. So there has been no drawdown in the winter of 2017-2018 and future management is uncertain.

This report is a cumulative review of all monitoring and management efforts since 2010. It is expanded from past annual reports, including new data and being revised to reflect any additional revelations from data analysis and regulatory discussion.

Introduction and Drawdown Features

Laurel Lake (Figure 1) has suffered use impairment in the past from elevated nutrient levels, related algal blooms, invasive plant species, and most recently from the invasive zebra mussel. Water quality in recent years has been acceptable for all uses, but invasive species remain a serious problem. The Laurel Lake Preservation Association (LLPA), a group of homeowners and interested lake users, has sought various means of managing the lake, with drawdown viewed as potentially very advantageous in the effort to control both invasive Eurasian watermilfoil and zebra mussels. After a protracted application and hearing process, an Order of Conditions was granted in the fall of 2010 by the Lee and Lenox Conservation Commissions for a 3 foot drawdown to be conducted beginning in the winter of 2010-2011. After review by the Conservation Commissions, the drawdown was repeated in 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016 and 2016-2017.

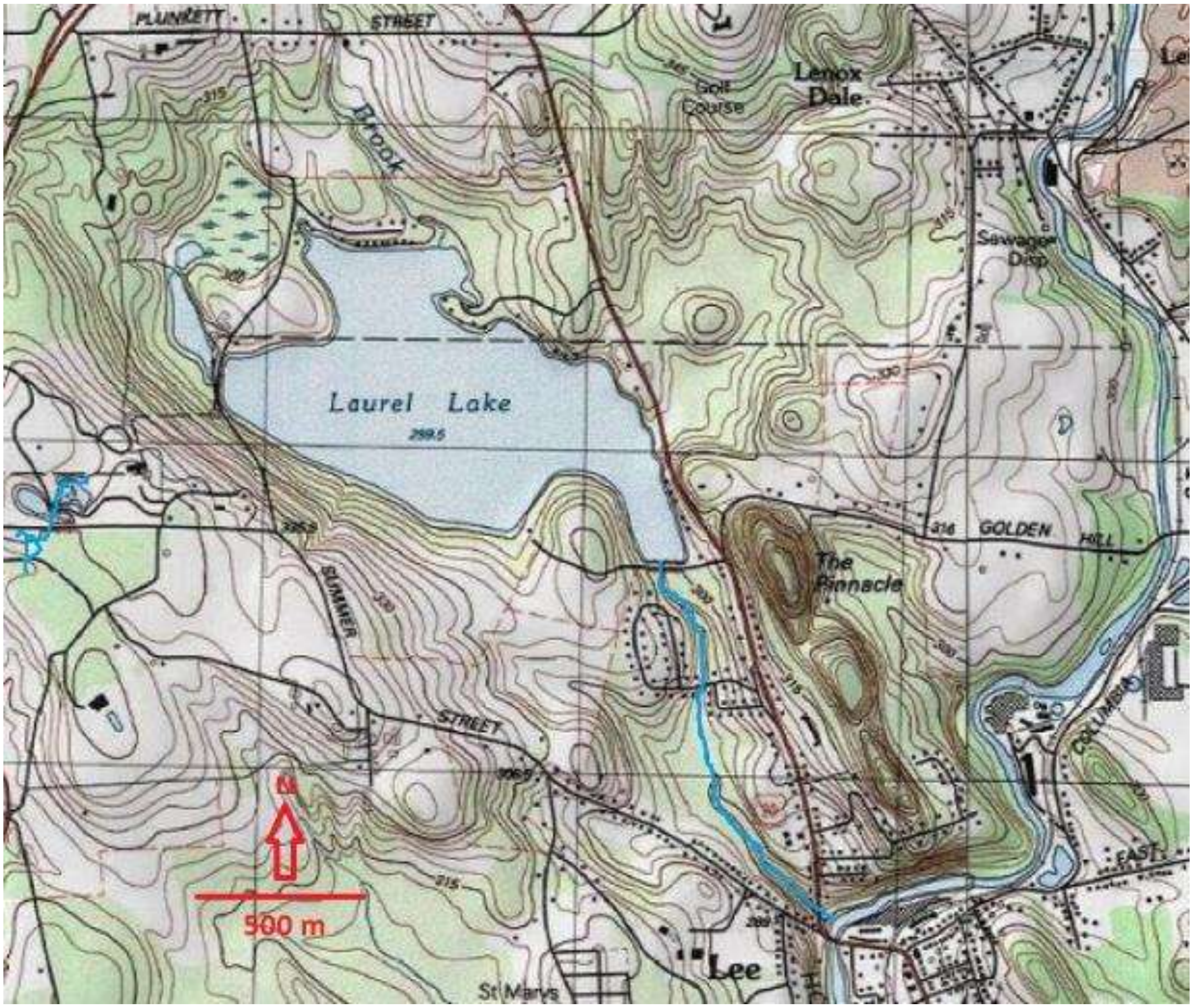
WRS was retained by the LLPA to direct relevant studies and assist in fulfilling the conditions outlined in the Orders of Conditions issued by the Conservation Commissions of Lee and Lenox and governing the drawdown. Specific conditions covered in this report relate to assessment of sediment features, evaluation of the plant community, inventory of zebra mussels and other mollusks, and investigation of watershed land use and nutrient loading. Field work was conducted in 2010 through 2017. Experiments on necessary duration of exposure to kill zebra mussels have also been conducted. Studies have been intended to provide baseline conditions over time for comparison and targeted investigations that might shed light on options for lake management with the least potential for damage to non-target populations.

Annual reports of findings have been submitted to the LLPA and the Towns of Lee and Lenox, with a focus on the conservation commissions as the groups regulating management of Laurel Lake under provisions of the Massachusetts Wetlands Protection Act (WPA). Meetings have been held with each conservation commission to verbally report findings and seek input on next steps. More recently, involvement of state environmental agencies has been sought to seek a lasting solution to the zebra mussel problem, but with no response. The Lenox Conservation Commission declined a request to renew the permit for the 3 foot drawdown from the LLPA in summer 2017, citing “new information” that led that commission to require a complete refiling and hearing process. The LLPA has declined to enter such a process through 2017. The Lenox Conservation Commission further denied a Certificate of Compliance for the drawdown project, claiming that certain provisions of the Order of Conditions were not met. The LLPA and WRS dispute that finding and hold this document to represent complete compliance and additional effort over and above that required by the permit.

Outflow from Laurel Lake at full pool elevation is through a spillway to Laurel Brook, which travels south for approximately one mile before discharging to the Housatonic River in Lee. Drawdown is facilitated by piped outflow from a separate structure in the dam. Two 12-inch drain valves in the outlet structure drain to the brook and are utilized during the drawdown activity. Additionally, a 12-inch pipe leads to a defunct mill complex on the Housatonic River, which has a 10 inch drain valve allowing water flow to the river. Maximum drawdown based on pipe placement is about 5 feet. The dam is controlled by a private party that has cooperated with the LLPA on drawdown since 2010.

Drawdown was conducted in each of the winters of 2010-2011 through 2016-2017, with a target water level decrease of 3 feet (36 inches). Drawdown of only 30 inches was achieved by the start of December 2010 (Figure 2A), the ending date for active drawdown progress, and refill

Figure 1. Laurel Lake in Lee and Lenox, Massachusetts.



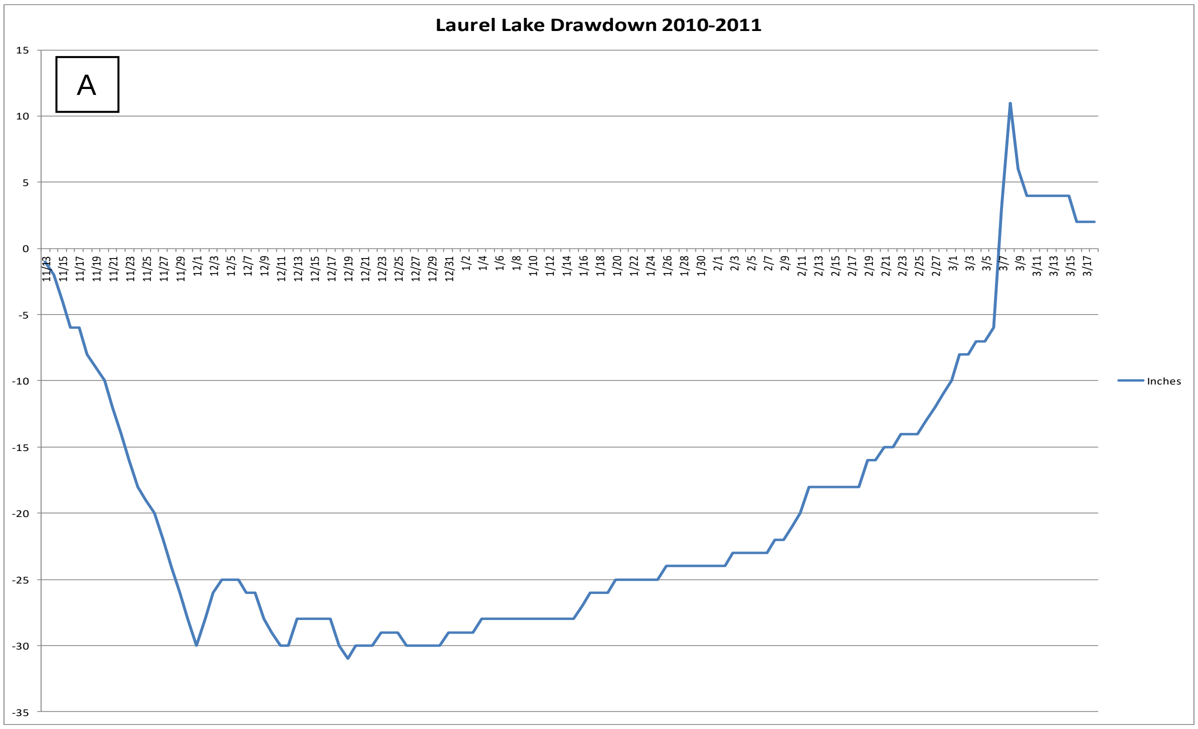
was achieved in early March of 2011. A drawdown of 36 inches was achieved by December 1 of each subsequent year (Figures 2B-G).

Drawdown may appear to start early in some years, but the lower water level in fall of those years occurs naturally due to low inflow and continued evaporation and groundwater outflow. Piped outflow has begun on November 1st each year of drawdown. Water level fluctuations have been observed during the drawdown period in most years, as the outlet pipe system cannot handle the range of possible inflows to Laurel Lake, but exposure of the target area has been achieved for multiple weeks at a time.

The date of complete refill has varied between early March and late April. The start of refill is primarily controlled by the date of ice out, although a thaw or rainstorm in late winter can overrun the capacity of the outlet pipe to maintain the drawdown. The start of refill has ranged from late January in 2011 to mid-March in 2015. Time to refill has ranged from 2 to 7 weeks and

Figure 2. Overwinter water level in Laurel Lake from 2010-2017.

(Values given in inches relative to the spillway elevation)



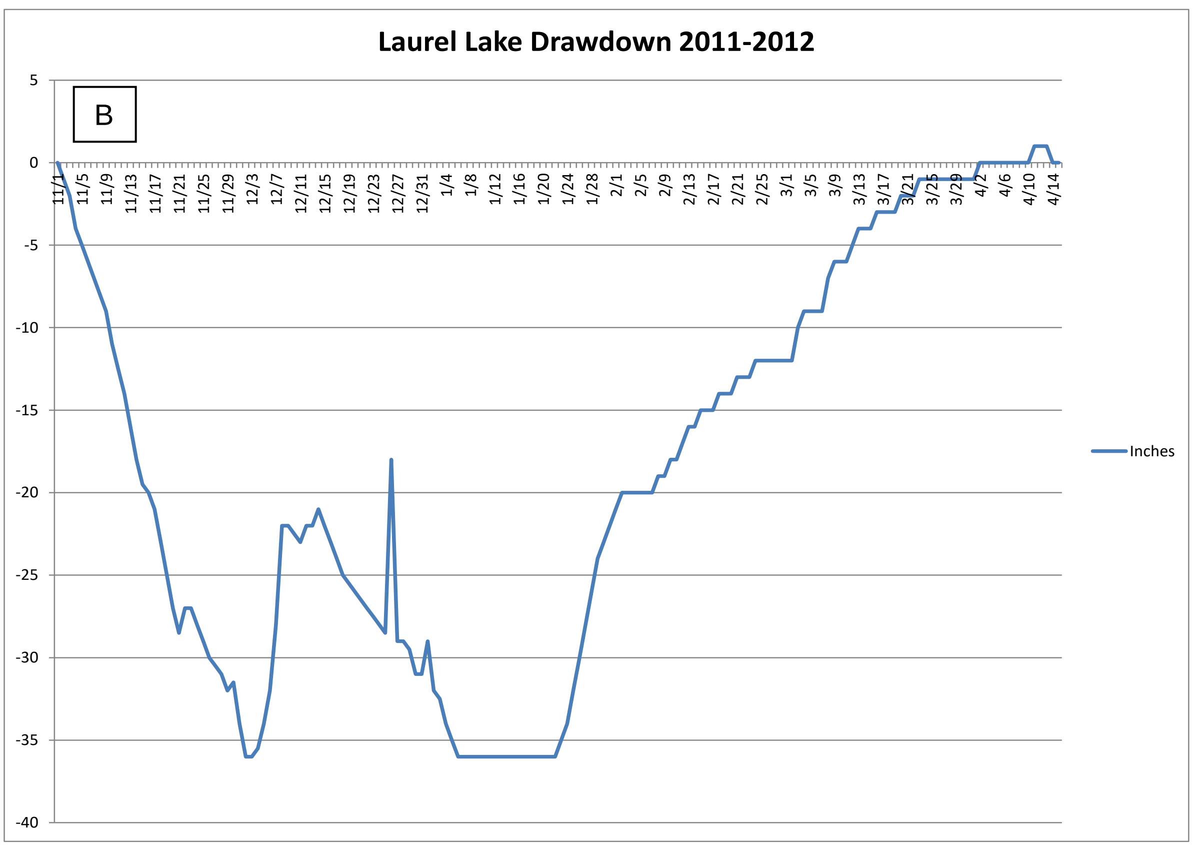
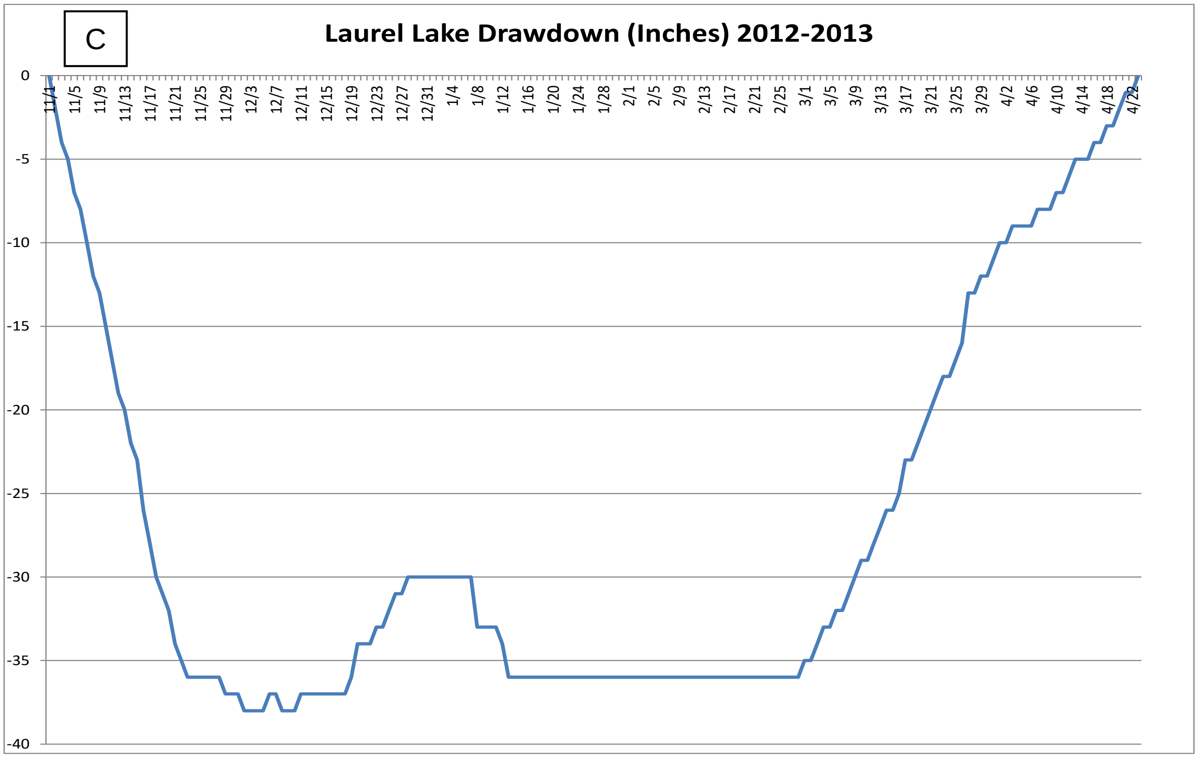


Figure 2. Overwinter water level, continued.



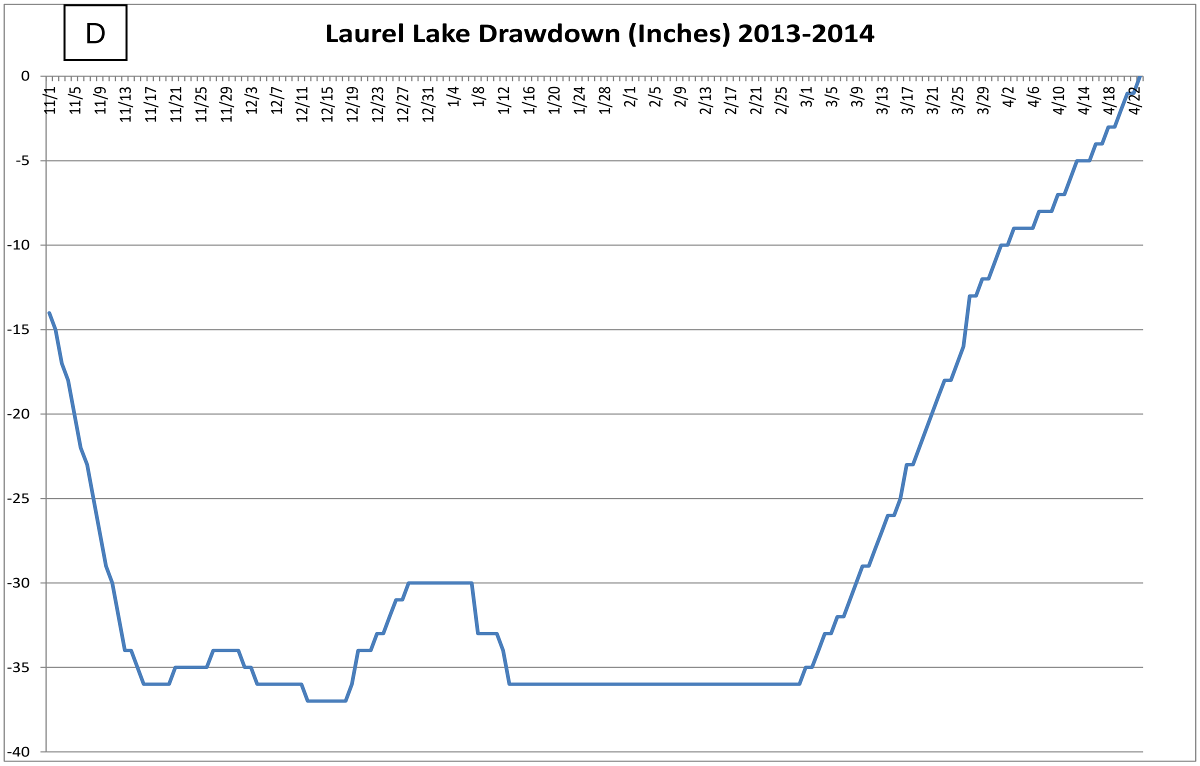
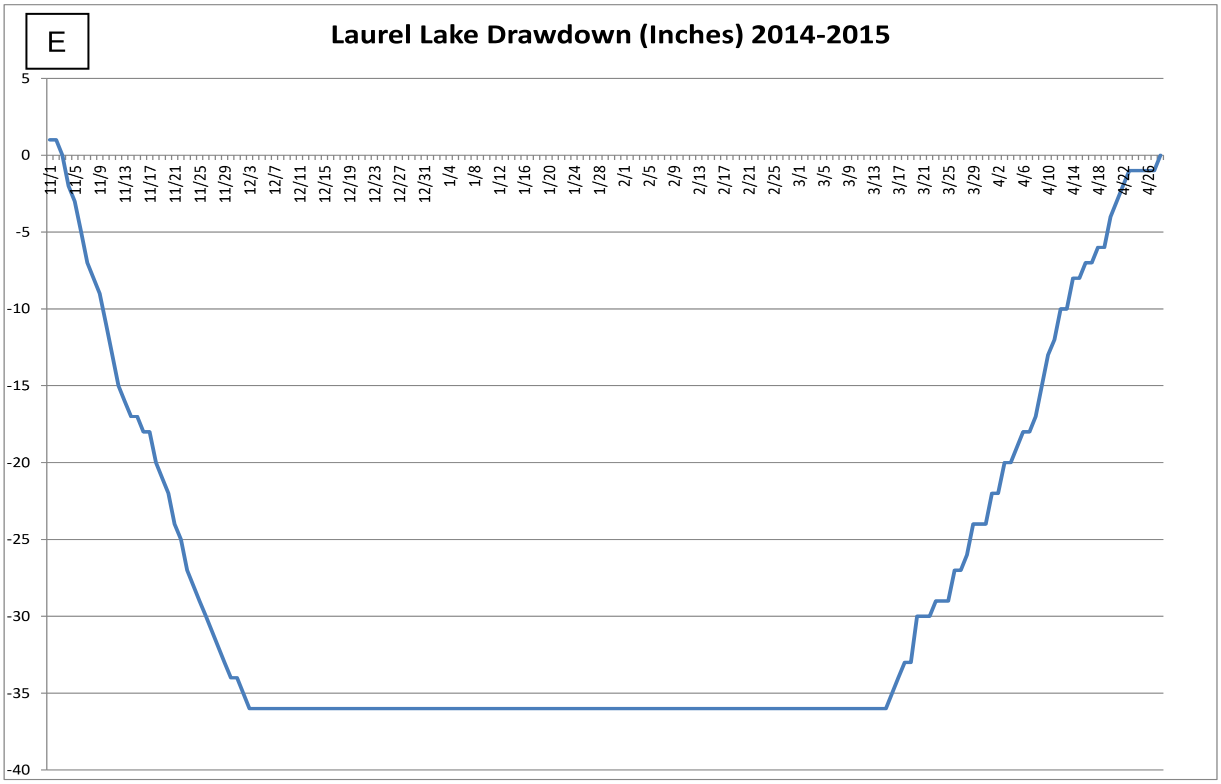
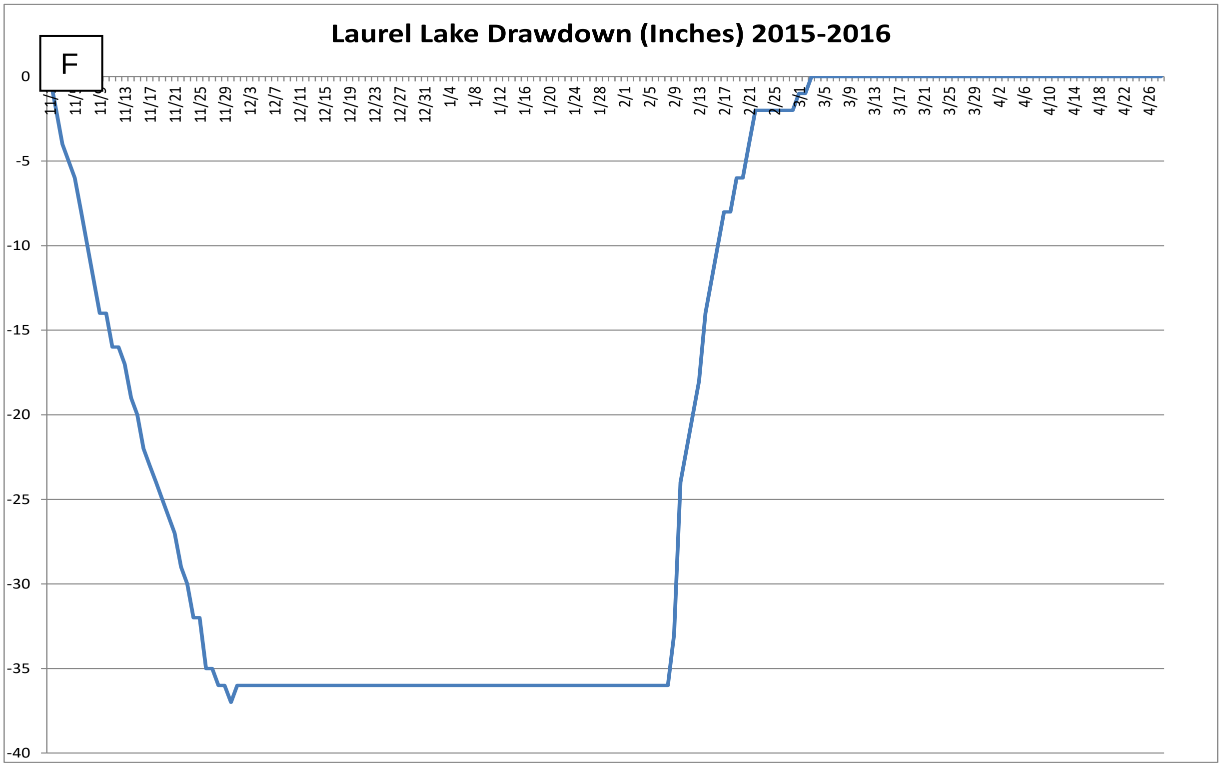
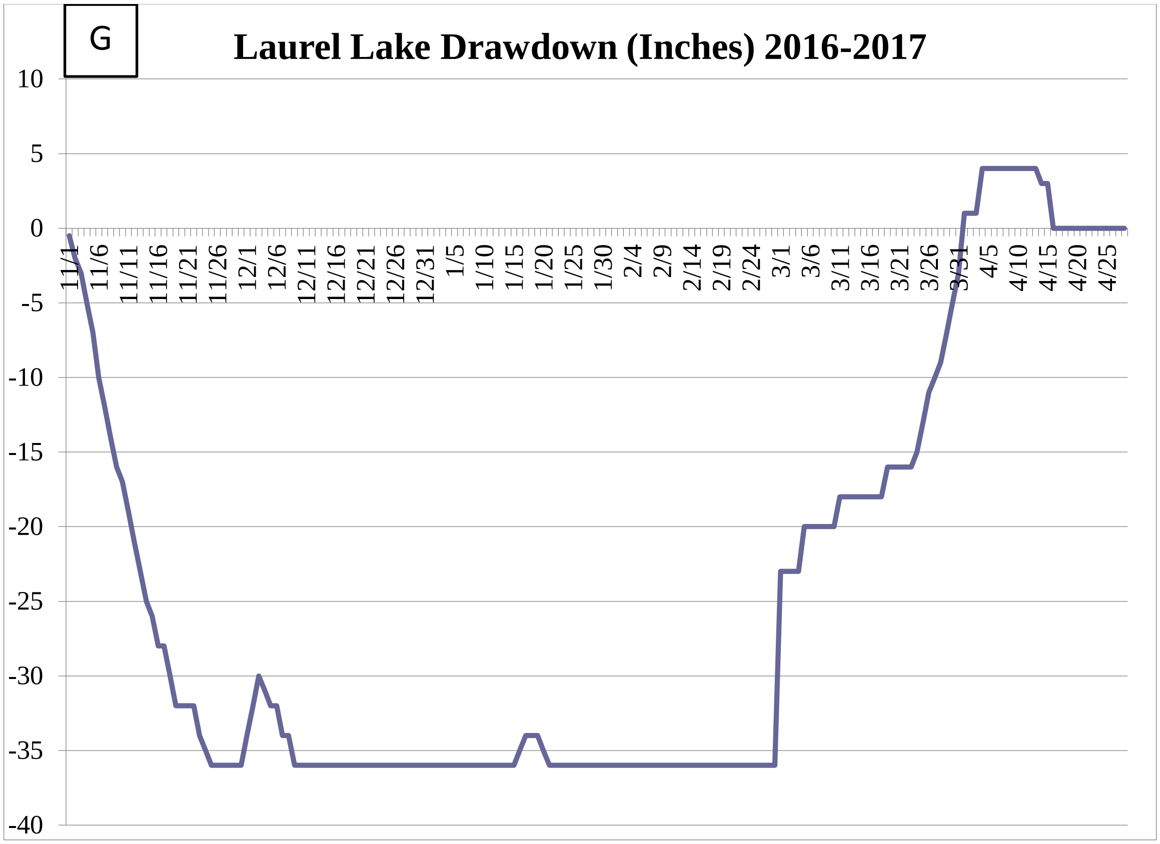


Figure 2. Overwinter water level, continued.







is weather dependent. Refill in 2011 overshot the full level by almost a foot due to a large storm when the lake was nearly full (Figure 2A). High water levels have not been observed in other years after refill until 2017, when wet weather at the time of refill completion caused the water level to rise an additional 5 inches. During refill there is still flow in Laurel Brook, mainly from seepage at the dam. The valves controlling pipe flow can be adjusted to let out some water during refill, but there is no required minimum flow to Laurel Brook as a consequence of the historic operation of the mill and related water rights.

The data provided here are not required by any agency of the Commonwealth (e.g., DEP, NHESP, DFW, DCR), but rather are generated in support of compliance with the conditions of permits issued by the Conservation Commissions of Lenox and Lee, in consultation with the LLPA, with the intent of guiding future management of Laurel Lake within the constraints of time and budgets. This report provides an update on all activities through December 2017, representing 7 years of drawdown experience and related lake studies at Laurel Lake.

Study Approach

Assessment of drawdown results has been largely adaptive, with little input on proposed monitoring in the permitting phase and adjustment to respond to questions that arose as data were collected. At this point we have 7+ years of varied monitoring data, enough to make reasonable statements about drawdown results and to recommend possible future courses of action.

A set of 34 transects were originally established around the perimeter of Laurel Lake, extending from shore to beyond the photic zone, with emphasis on the area <8 ft deep, the likely maximum impact zone for a drawdown, based on up to 5 ft of water level lowering and up to 3 ft of ice depth (Figures 3 and 4). These transects were surveyed for sediment features, plant species and density, and the density of zebra mussels and other mollusks at depths up to 8 ft in 1 ft increments in 2011. The desire of the Lenox Conservation Commission to have data for greater depths and at least two surveys per year resulted in use of only the even numbered transects in 2012, to accomplish the desired expansion within the budget.

An analysis of information loss with decreasing transect number was conducted to guide future monitoring, and indicated no significant loss from halving the number of transects. An additional transect was added on the upstream side of the causeway, also at the request of the Lenox Conservation Commission. So there are currently 18 transects that are surveyed at depths of 0-2, 2-4, 4-6, 6-8, 8-10, 10-12 and 12-14 ft (a compromise between expansion of data collection and cost control). A few transects are in areas where water does not achieve the complete range of surveyed depths, but most extend to 14 ft. Data from 2011 at 1 ft depth increments were converted into the new format to allow comparison with 2012- 2017 data.

Sediment was assessed in 2011 by remote video viewing system from the boat or simply by looking over the side of the boat in shallow water, as clarity is almost always excellent in Laurel Lake. Sediment features were recorded as a combination of sediment types, which included rock, cobble, gravel, sand, muck and clay. Multiple sediment types were listed for any plot, in order of abundance. Frequencies for each 1 ft water depth increment were set up as a percentage presence for each sediment type. Debris, such as sticks, logs, cans or other materials not considered natural inorganic sediment were not recorded quantitatively, but observations were made. Samples were collected from three locations (Figure 4) for analysis of total solids, organic content, and iron-bound phosphorus. The expanded sediment assessment for sediment type to a depth of 14 ft was conducted in 2012, and additional but less quantitative assessment has been conducted since then when looking for zebra mussels in deeper water.

Plants were assessed by remote video viewing system from the boat or simply by looking over the side of the boat in shallow water. A pole with grappling hook was used to collect specimens for identification where necessary. Plants were identified to species level wherever possible. Overall plant cover was assessed in each plot at each 1 ft depth increment along each transect in the first year and at 2 ft vertical depth increments thereafter. Assessment of data indicated that there was no loss of valuable information with this change in depth interval. Cover was recorded as either 0 (no plants), 1 (1-25% cover in 2 dimensions, looking down on the plot), 2 (26-50% cover), 3 (51-75% cover) or 4 (76-100% cover). Biovolume was assessed as the portion of the water column filled with plants, using the same approach (0=no plants, 1=1-25% of volume filled, 2=26-50%, 3=51-75%, and 4=76-100%). Plant species present in each plot were recorded as trace (t, a single to just a few plants), sparse (multiple plants but not abundant), moderate (numerous plants, but not dominant), and dense (very abundant, dominant

Figure 3. Study transects on a bathymetric map of Laurel Lake.

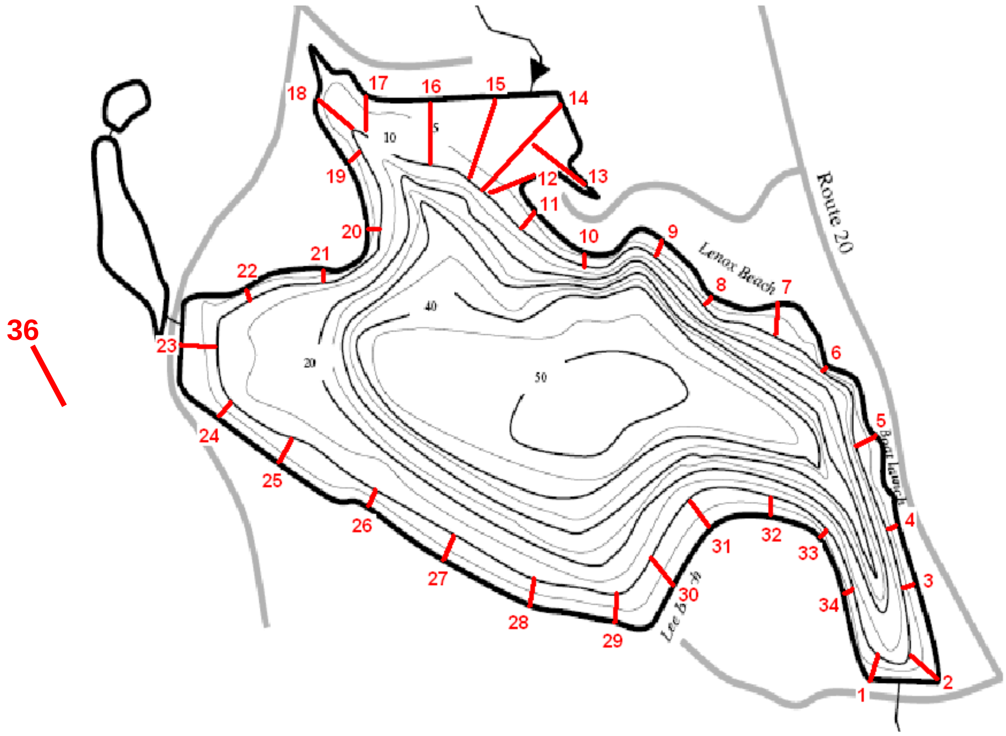


Figure 4. Study transects and sediment sampling locations on an aerial image of Laurel Lake.

component of assemblage). Assessments were completed at least twice each year (late spring and late summer) from 2012 through 2015 but only once in late summer in 2016 and 2017.

Peripheral emergent wetlands in the Berkshires tend to be resistant to impacts from winter drawdown, but interest by the conservation commissions in possible impacts led to the establishment of ten wetland plots of 2 m by 2 m in September 2011, marked by white PVC pipes placed in the two targeted wetland areas. The eastern wetland, located in Lenox off Sargent Brook Road, is a red maple swamp with a variety of trees, shrubs and herbaceous vegetation. Plots were chosen to reflect the diversity of vegetation in this area. The western wetland, located across Laurel Lake Road from the lake and just north of the open water area that flows under the causeway, is an expansive cattail marsh. While less diverse than the red maple swamp, plots were also selected to cover the range of vegetation found there.

Locations (Figure 5) were recorded by global positioning system. Photodocumentation was obtained at the time of installation, but no further vegetative analysis was conducted in 2011. The wetlands were visited in August, just to get an initial sense for conditions, but analysis in 2012 was conducted on September 15th, as the plots were established in September 2011 and it was intended that they be photodocumented at the same time each year. No follow up documentation was conducted as a function of budgetary limitations and lack of detectable changes in 2012. Detecting changes has a low probability and any changes would not necessarily be attributable to drawdown, but the plots were set up and documented in case later assessment proved necessary. With no comment by any regulatory agency, we dropped that aspect of monitoring after 2012.

A survey of zebra mussels in the drawdown zone was conducted in early December 2010. As the drawdown was only 30 inches, assessment of conditions out to the normal 2 ft water depth contour was conducted that year. This survey was repeated in December of each year after the initiation of the drawdown through 2016. In the absence of drawdown in 2017-2018, no December survey of the drawdown zone was conducted. Two plots of 0.25 m^2 were assessed for zebra mussel density by direct count in each of two depth intervals at each of the designated transects, with plots at 0-2 ft and 2-3 ft (relative to full pool level) within the 3 ft drawdown zone. Recently dead snails and bivalves other than zebra mussels were also assessed by direct count.

During the non-drawdown period, mollusks were assessed by remote video viewing system from the boat or simply by looking over the side of the boat in shallow water. Mollusks were observed in roughly 1 X 1 m plots, with substrate and plants examined for the presence of zebra mussels, two other mussel species listed for the lake, and any snail species encountered (about 6 species are commonly found in the lake). The focus was on zebra mussels, and identifying small snails (many species are <5 mm in longest dimension) proved difficult with the underwater videocamera, although obvious specimens on plants were recorded.

Zebra mussels, the only molluscs found to be abundant, were recorded when present as trace (1-5 per square meter), sparse (6-50 per square meter), moderate (51-200 per square meter) or dense (>200 per square meter). In general, trace levels were characterized by just an occasional zebra mussel observed on a plant or piece of gravel, while sparse levels typically involved scattered zebra mussels near the base of plants, most often Eurasian watermilfoil.

Figure 5. Location of emergent wetland plots near Laurel Lake.

Moderate to dense concentrations of zebra mussels were associated with sticks, logs, or rocks. Dense ratings always involve rocks or wood as substrate. Assessments were conducted twice a year from 2011 through 2015, in June and August or September, with a quantitative survey in only late summer in 2016 and 2017. The December survey counted zebra mussels in survey plots, but also characterized abundance with the trace-sparse-moderate-dense categorization system.

In the summer of 2015 an experiment was conducted by a student to determine when zebra mussels colonized substrates. Artificial substrates were placed in the lake in early July and checked weekly into September. In fall of 2015 an experiment was conducted by another student to determine how long zebra mussels must be out of water to be killed. Rocks with zebra mussels on them were collected from the lake and exposed to air at temperatures above freezing for varying amounts of time, then returned to lake water. The number of live zebra mussels at the start and end of the exposure period was counted. This experiment was repeated in fall of 2016 by WRS staff with slightly different exposure times and the addition of sub-freezing temperatures at the end for surviving zebra mussels.

A more definitive assessment of snails was conducted in June 2012 and 2013, using a dip net to capture snails over a 30 second period at each transect in the 0-2, 2-4 and 4-6 depth intervals. Surveys were conducted in June and August 2014 and August 2015 through 2017, with composited samples from 0-6 ft to make one sample for each of 7 randomly chosen transects.

Zooplankton, phytoplankton and water clarity have been characterized in association with most surveys, but analysis of 2012 samples suggested that the larval stages of zebra mussels (veligers) are not evenly abundant all summer long. Consequently, weekly samples were collected between June and mid-September of 2013 to further check veliger distribution over time. Just under 1000 liters of water were filtered through a plankton net, the concentrate was preserved, and the sample was examined microscopically for veliger presence as well as other types of zooplankton. Zooplankton samples were also collected in April, June and August of 2014 and in June and August of 2015 through 2017.

The watershed had been previously delineated, but a check of the overall boundary and differentiation into major subwatersheds was accomplished in June 2011 by field survey (driving and walking). Land uses were acquired from aerial photos and were checked in the field. Loading was estimated in accordance with the Lake Loading and Response Model (LLRM). Data available from past sampling were used for calibration. A more detailed assessment of watershed conditions was conducted in December 2012. The parcels delineated in 2011 as warranting further investigation were visited and an evaluation of pollution potential was made. No samples were collected and no blatant trespassing was committed, but a better picture of watershed conditions and probable pollutant loading sources was gained.

Sediment Assessment

Sediment conditions included various mixes of rock, cobble, gravel, sand, muck and clay, usually with one to two forms dominating a plot. Patterns over the assessed transects from shallow to deep varied by sediment type (Figures 6 and 7, the same data expressed two ways), but was consistent with expectations based on observation at Laurel Lake and many other waterbodies. Cobble and gravel decrease with depth and are not major components overall, although they can be locally abundant in shallow water. Sand is a dominant component of the sediment, increases from 0 to 3-4 ft of water depth, then decreases. Silt, including organic and inorganic forms, is also a dominant component, and increases with water depth. Rock is slightly more abundant in the shallowest water, but is present at low levels at all surveyed depths, usually as occasional boulders or outcrops. Visible clay was not a significant factor in the Laurel Lake sediments, but inorganic fine particles were abundant from lab testing.

Sticks and logs were not recorded quantitatively as substrate, but were present in about the same proportions as rock. Woody debris was present at all depths surveyed, with a somewhat erratic pattern, and nearly disappeared at greater depths (>15 feet). Much of the woody debris tends to move over time, with sticks and logs moving both away from and toward shore. Wood that has washed ashore is sometimes covered with zebra mussels of a wide range of sizes, indicating multiple years at a depth where zebra mussels can survive all year.

Cobble and gravel are virtually absent at depths of 8 ft or more, leaving occasional rocks as the most viable substrates for zebra mussels in deeper water. As zebra mussels achieved densities greater than sparse on only rock or wood, the limited availability of these substrates appears to limit zebra mussel density. The relative abundance of cobble, gravel and to a lesser extent sand in the shallowest water will limit plant density and affect the species present. The shallow sediment features are a function of lake history (natural lake enhanced by a dam) and past drawdowns (natural and human induced).

Figure 6. Sediment features of Laurel Lake expressed as percent of total in separate bars for each sediment type.

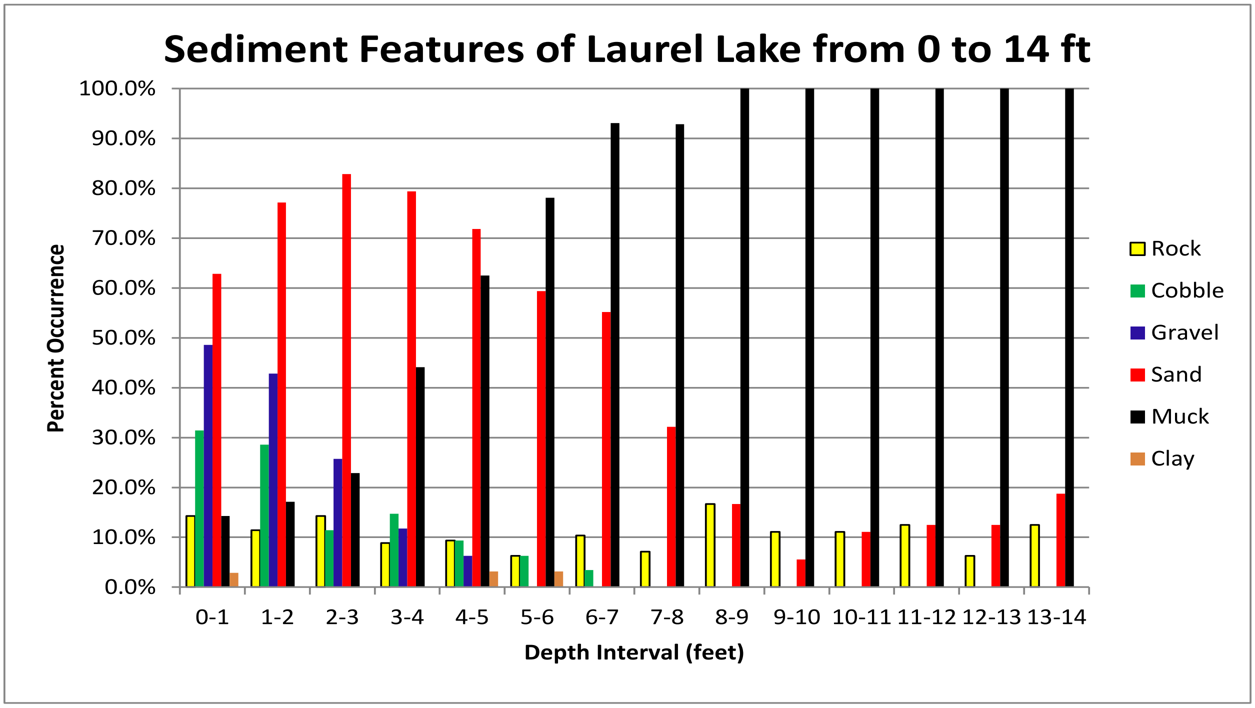
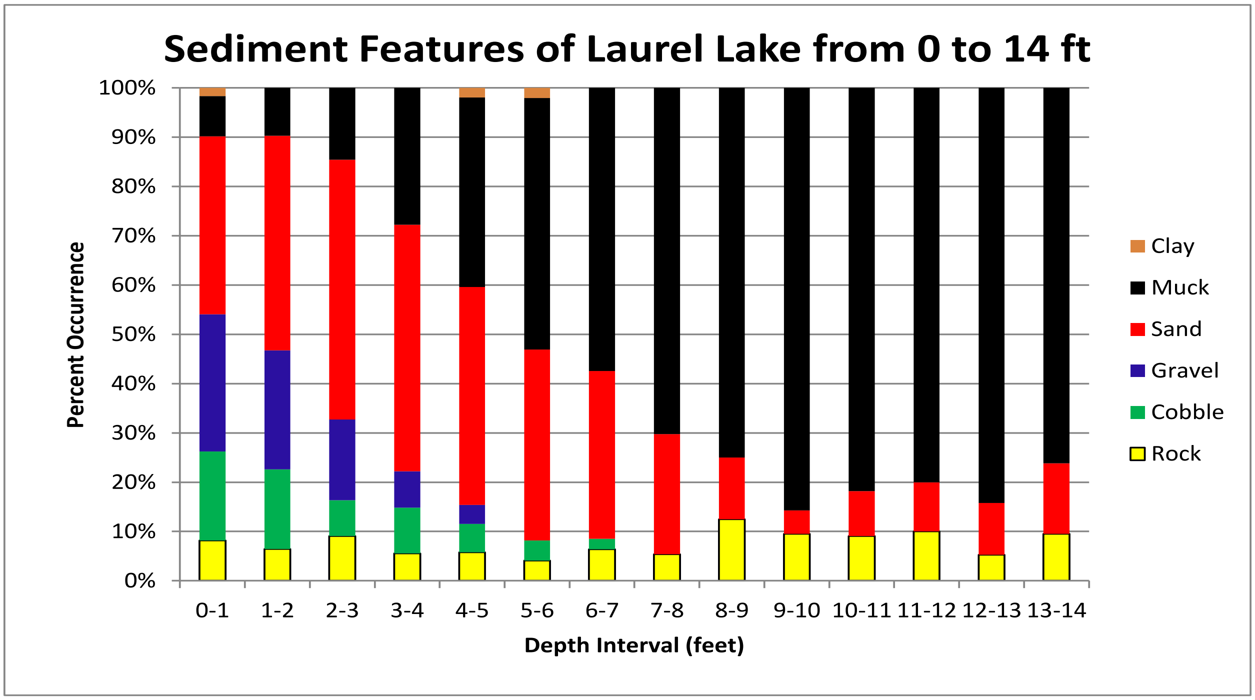


Figure 7. Sediment features of Laurel Lake expressed as percent of total in combined bars.



The accumulation of fine sediment with increasing water depth is observed in nearly all lakes in New England, but the depth at which fine sediment becomes the dominant substrate component is usually a function of sediment slope and any drawdowns (which tend to move soft sediment toward deeper water). Fine sediment becomes the dominant sediment type at water depths between 5 and 7 ft, and remains dominant into the deepest parts of Laurel Lake. The fine sediment in Laurel Lake is a mix of organic and inorganic particles, with inorganic silts more common, based on lab testing (Table 1).

Rock, gravel and woody debris that are more common as peripheral substrates are far more favorable to zebra mussel colonization than the fine sediments found in deeper water. Consequently, between about 7 ft of depth (where “hard” substrate becomes scarce) and the depth at which plants disappear, a range of 12 to17 ft of water depth, zebra mussels are found mainly on plants. As many plants die back for the winter, most notably the pondweeds (*Potamogeton* spp), zebra mussels are largely found on two species that tend to overwinter as mature plants: Eurasian watermilfoil and water celery. In shallow water, zebra mussels are most common on rocks and cobble, with some on gravel and rooted plants. The veligers settle on any substrate, but the resultant mussels do not survive on annual plants beyond that initial year.

When one walks on the exposed lake bottom during drawdown, the surface is largely a mix of rock, gravel and sand, but the substrate is not especially solid. There is considerable ground water seepage around most of the pond, and especially on the south side, so while the upper sediment dewaters, there is water not too far below the surface. There may be additional draining over the winter, but freezing is probably a more important mechanism for plant control. Solar inflection over six years of drawdown has moved coarser particles upward, making the surface rockier, even if there is finer, softer sediment underneath. This enhances habitat overall, as rocky substrate is not common in Laurel Lake except near the periphery, but it does increase attachment sites for zebra mussels. The substrate does not look appreciably different than when the project began in 2010, however, so the change is not major to date.

Note that based on the three sediment samples collected (Table 1, locations in Figure 4), the solids content of Laurel Lake sediment was higher than average for Massachusetts lakes and was higher at greater depth, which is somewhat unusual. Organic content decreased with depth, also not typical in Massachusetts. The fine sediment base of Laurel Lake is more inorganic than organic. Iron-bound phosphorus, a form often released under low oxygen conditions, was generally low (<100 mg/kg) and also decreased with water depth. High calcium content of area soils is known and would explain the observed pattern; organic levels are highest in shallow water where plants are abundant, but calcium based particles dominate the fine sediment and bind much of the sediment phosphorus in the lake, making it unavailable to algae.

Table 1. Sediment characterization for Laurel Lake.

	Station		
Feature	LL-Sed 1	LL-Sed 2	LL-Sed 3
Sample depth (m)	6.0	4.5	3.0
Total Solids (%)	66.0	33.2	34.1
Volatile Solids (%)	9.0	14.1	20.7
Iron-bound P (mg/kg)	<19.0	48.0	73.2

Aquatic Plant Assessment

The rooted plant community of Laurel Lake is fairly diverse, but includes several invasive species. The list of species for Laurel Lake from all available sources (Table 2) includes 37 species of macrophytes, although Chlorophyta (filamentous green algae), Cyanophyta (filamentous blue-green algae), *Nitella* and *Chara* (macroalgae) are not higher plants. Four species are invasive forms. *Trapa natans* (water chestnut) was found in the outlet cove and pulled in 2011, but was later found on the upstream side of the causeway in 2012 and reported to the DCR for action; water chestnut remains upstream of the causeway as of September 2016, but has not expanded its coverage. Spiny naiad appears to be increasing in abundance, especially in the Lenox portion of the lake. Curlyleaf pondweed is present but not abundant during summer; this species tends to peak in spring then decline by early summer, limiting its impact on recreation and possibly lake ecology. Eurasian watermilfoil remains the most problematic invasive species, and is one of the most abundant plants in the lake.

The plant assemblage can be characterized several ways, as a total plant community or as individual species over space. Only a few species have been found at more than 20% of surveyed sites, and about 8 species form the base for most assemblages in Laurel Lake. Eurasian watermilfoil, noted above, can be abundant, as are water celery, chara, chlorophyta (green algae mats), several species of pondweed, and common naiad. Spiny naiad (aka European naiad or minor naiad, *Najas minor*) became more abundant during this monitoring period, with a distinct increase in 2015 through 2017 relative to prior to 2015, but exceeded an overall frequency of 20% only in 2016.

Cover (portion of the bottom covered in two dimensions, looking down from above) varies greatly and generally increases to a depth of about 8 ft, then declines (Figure 8). There are few plants in water deeper than 14 ft and none deeper than 17 ft. Cover tends to be lower in late spring than late summer, simply as a function of growing season effects. High cover is not a problem for most aspects of lake ecology or recreational pursuits, unless most of that cover occurs at the surface, as with water lilies. However, high biovolume impairs habitat for many organisms and interferes with recreation. While biovolume is locally high in some areas (the large cove on the north side in Lenox, along the causeway, and patches of milfoil in various parts of the lake), overall biovolume (Figure 9) is not extreme and has not varied greatly among years for the lake overall. Average biovolume in Laurel Lake reaches a value close to 2 at 6-8 ft water depth, meaning that no more than 50% of the water column is filled. Eurasian watermilfoil (*Myriophyllum spicatum*) reaches maximum density in about 10 ft of water in Laurel Lake. Certainly there are specific locations with higher biovolume, some of which merit management, but overall the lake does not experience excessive rooted plant growth, as much of it is too deep for plant growth.

For the most commonly encountered species, frequency patterns vary over depth (Figures 10-17). Chara is most common in shallow water while milfoil is more common in deeper water, and water celery and most pondweeds have a peak at an intermediate depth. Common naiad and chara appeared to increase in shallow water between 2011 and 2012, a possible consequence of drawdown; these are seed producers known to be resistant to drawdown impact. However, this trend was reversed in 2013 and 2014 after the seemingly successful drawdowns of 2012-2013 and 2013-2014. Spiny naiad has increased in abundance over the monitoring period, and while it is not a dominant species all over the lake, it can fill the water column in some shallow locations in late summer. This invasive species is favored by drawdown and may continue to increase in shallow water where the substrate is not sand or coarser material.

Table 2. Plant species from Laurel Lake.

Scientific Name	Abbreviation	Common Name
Brasenia schreberi	B schreb	Watershield
Ceratophyllum demersum	C dem	Coontail
Chara vulgaris	Chara	Chara, muskgrass
Chlorophyta mats	Chloro	Filamentous green algae
Cyanophyta mats	Cyano	Filamentous blue-green algae
Eleocharis acicularis	Eleo acic	Spikerush
Elodea canadensis	El can	Waterweed
Eriocaulon aquaticum	Erio aq	Pipewort
Gratiola neglecta	Grat neg	Hedge hyssop
Lemna minor	Lem min	Duckweed
Myriphyllum spicatum	My spic	Eurasian watermilfoil
Naja flexilis	N flex	Common naiad
Najas minor	N minor	Spiny naiad
Nitella flexilis	Nitella	Nitella, stonewort
Nuphar variegata	N var	Yellow water lily
Nymphaea odorata	N odor	White water lily
Polygonum punctatum	Poly	Smartweed
Pontederia cordata	P cord	Pickerelweed
Potamogeton amplifiolius	P ampli	Bigleaf pondweed
Potamogeton crispus	P crisp	Curlyleaf pondweed
Potamogeton epihydrus	P epi	Bronze pondweed
Potamogeton foliosus	P fol	Foliose pondweed
Potamogeton gramineus	P gram	Graminoid pondweed
Potamogeton illinoensis	P ill	Illinois pondweed
Potamogeton natans	P nat	Heartleaf pondweed
Potamogeton praelongus	P prae	Boattip pondweed
Potamogeton pusillus	P pus	Thinleaf pondweed
Potamogeton richardsonii	P rich	Claspingleaf pondweed
Potamogeton robbinsii	P rob	Robbins pondweed
Potamogeton zosteriformis	P zos	Flatstem pondweed
Ranunculus flabellaris	Ran flab	Water crowfoot
Spirodela polyrhiza	Spir poly	Big duckweed
Stuckenia pectinata	Stuc pec	Sago pondweed
Trapa natans	Trapa nat	Water chestnut
Utricularia macrorhiza	U mac	Bladderwort
Vallisneria americana	V am	Water celerty
Wolffia columbiana	Wolf col	Watermeal

Figure 8. Plant cover in Laurel Lake, 2011-2017.

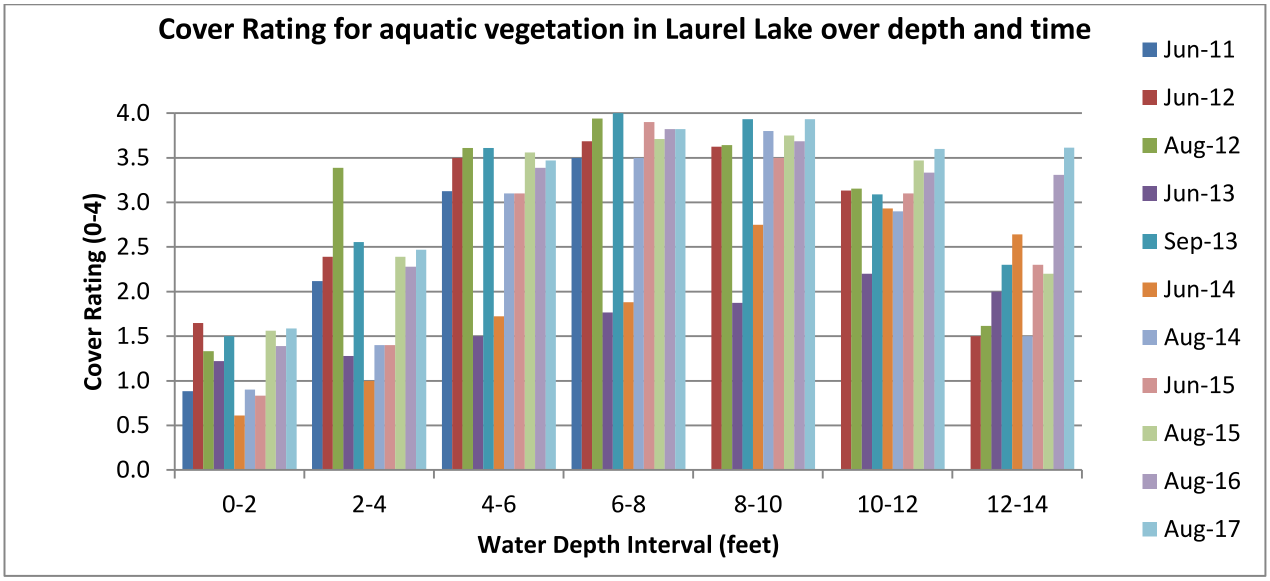


Figure 9. Plant biovolume in Laurel Lake, 2011-2017.

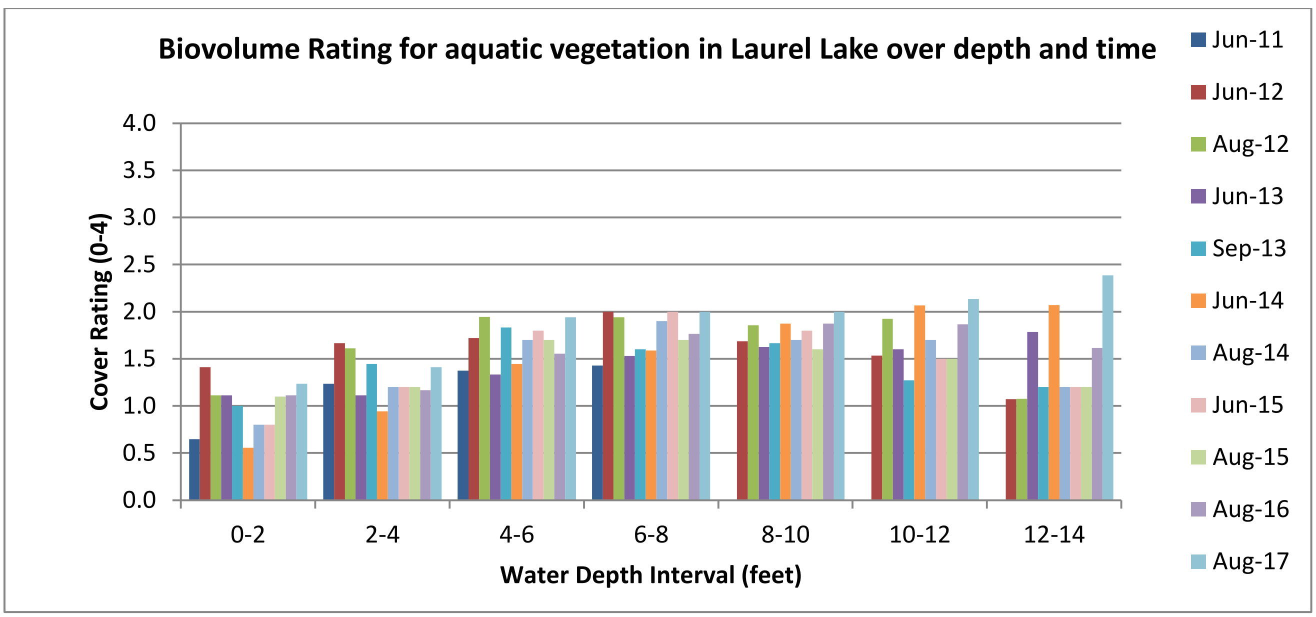


Figure 10. Frequency of chara in Laurel Lake.

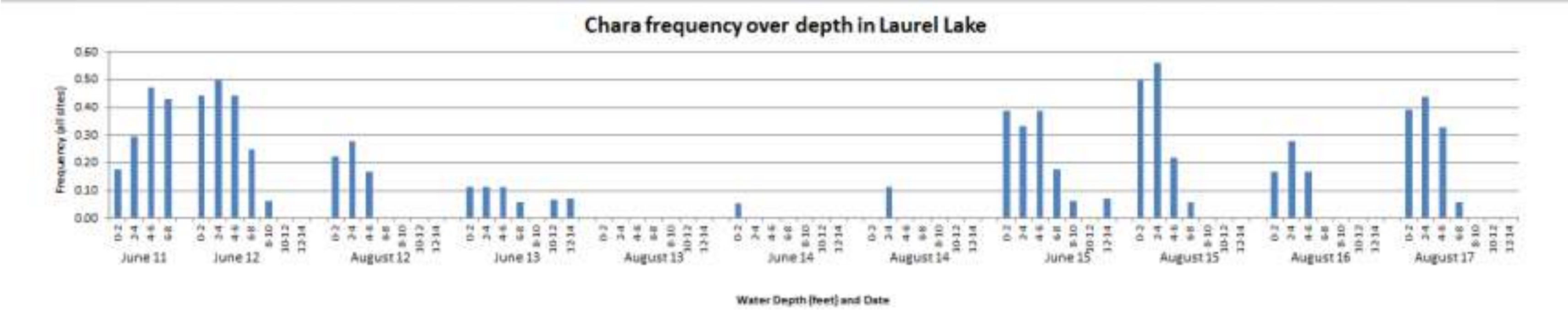


Figure 11. Frequency of filamentous green algae in Laurel Lake.

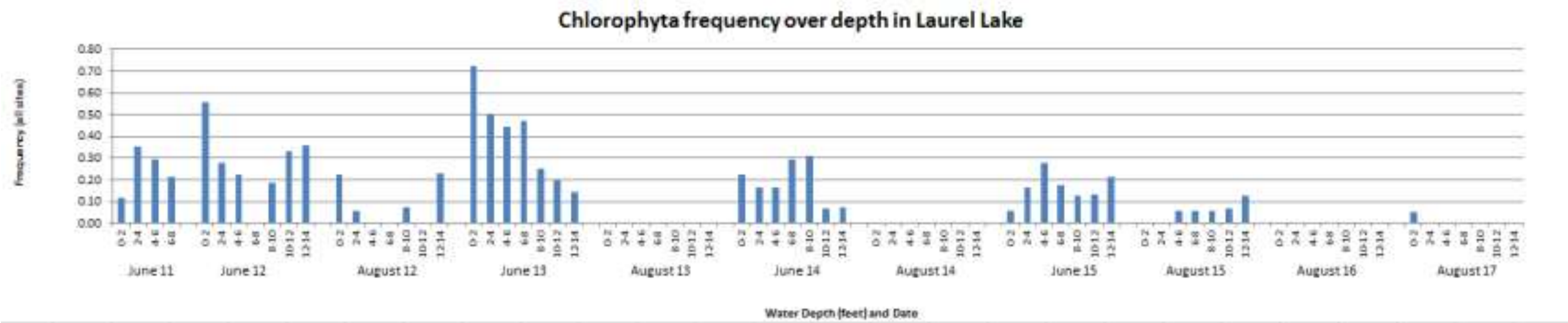


Figure 12. Frequency of Eurasian watermilfoil in Laurel Lake.

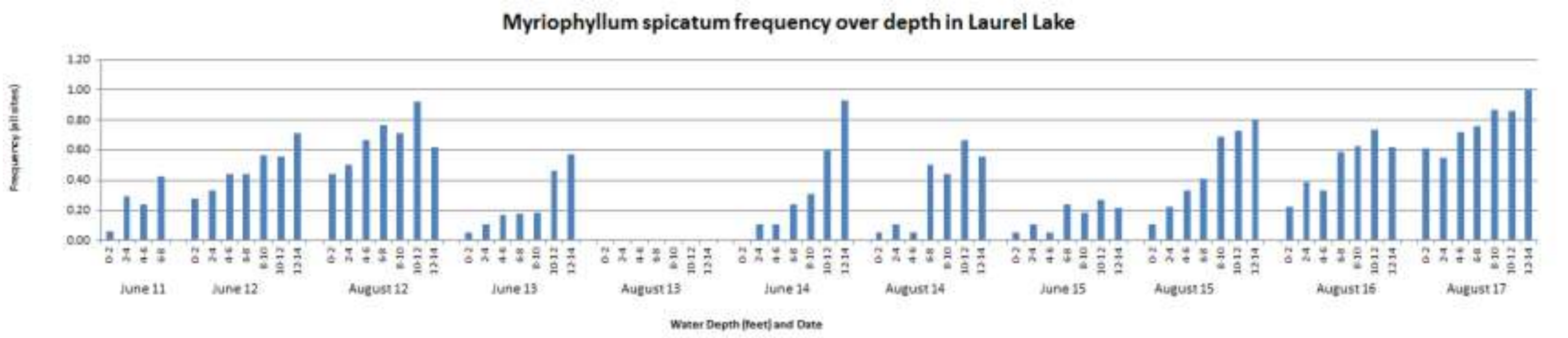


Figure 13. Frequency of common naiad in Laurel Lake.

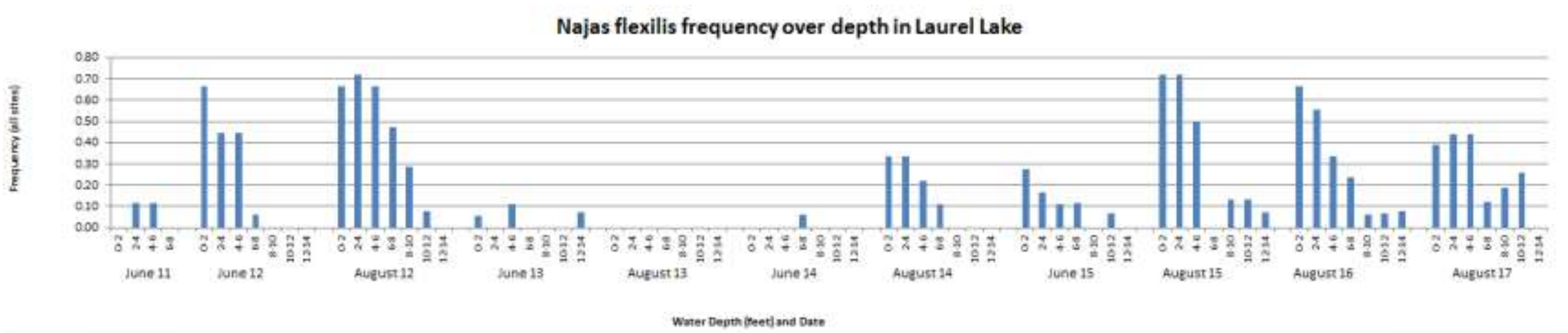


Figure 14. Frequency of graminoid pondweed in Laurel Lake.

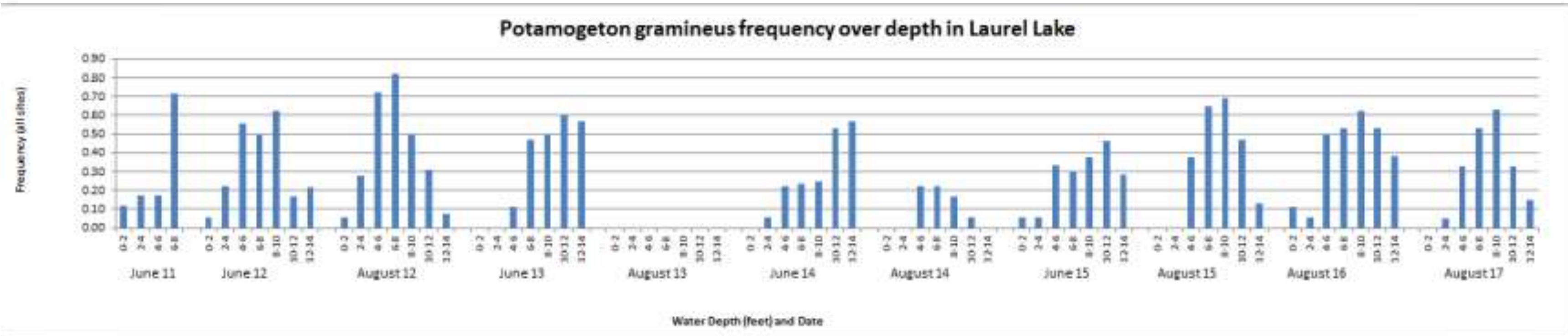


Figure 15. Frequency of flatstem pondweed in Laurel Lake.

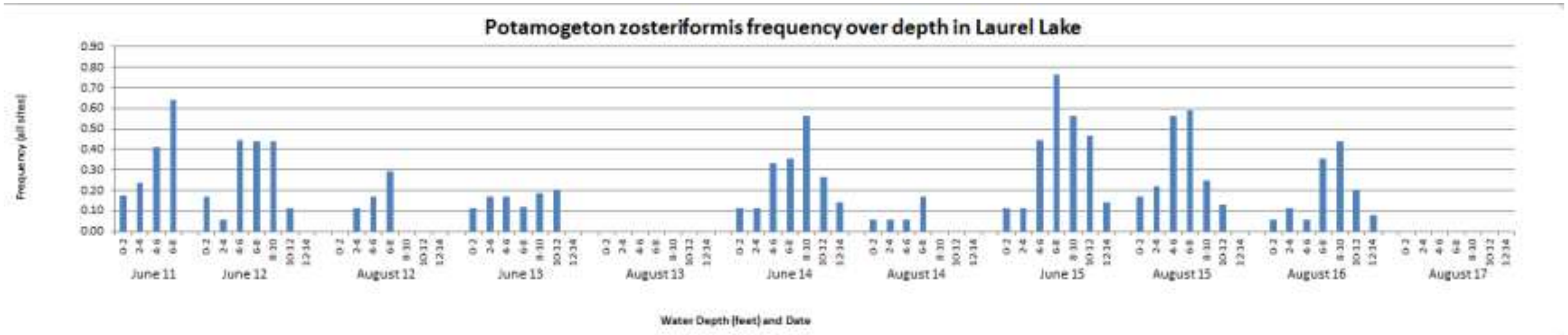


Figure 16. Frequency of sago pondweed in Laurel Lake.

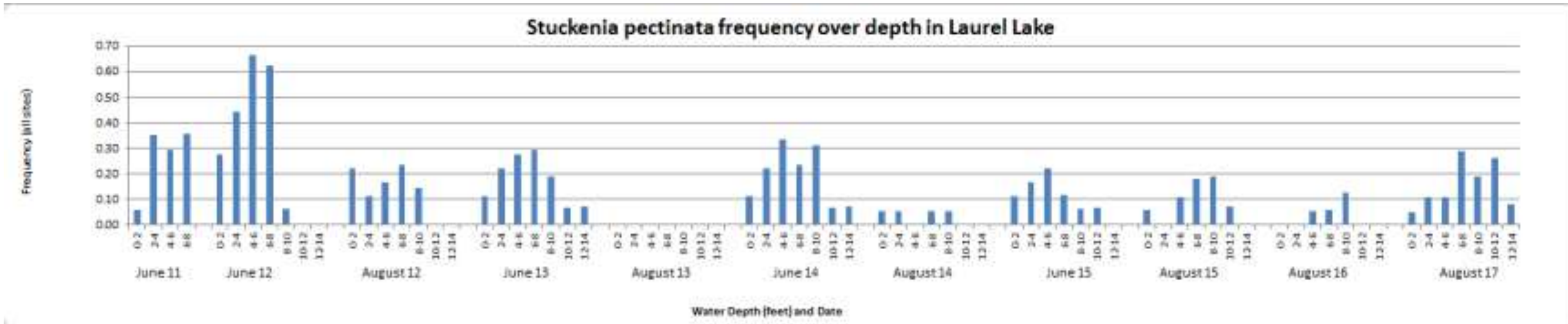


Figure 17. Frequency of water celery in Laurel Lake.

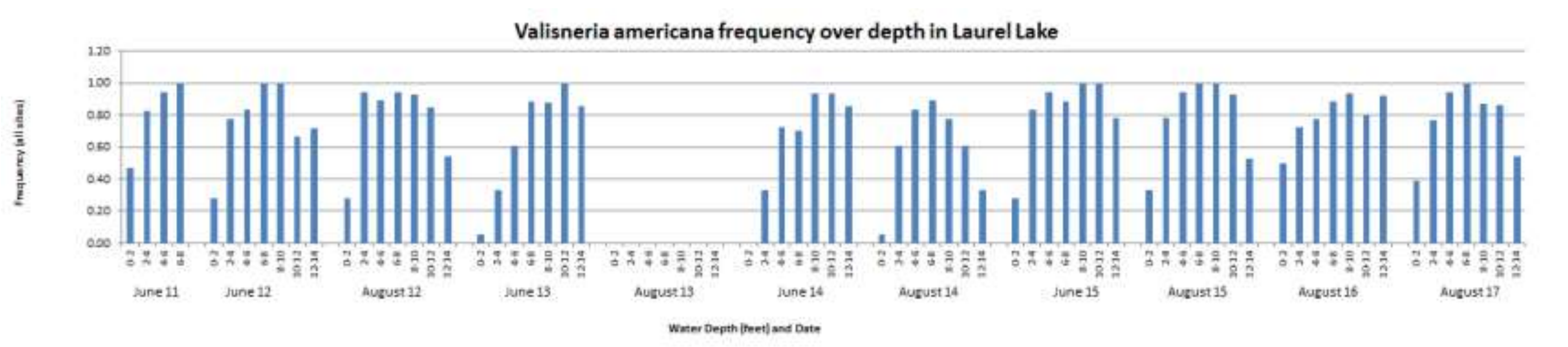
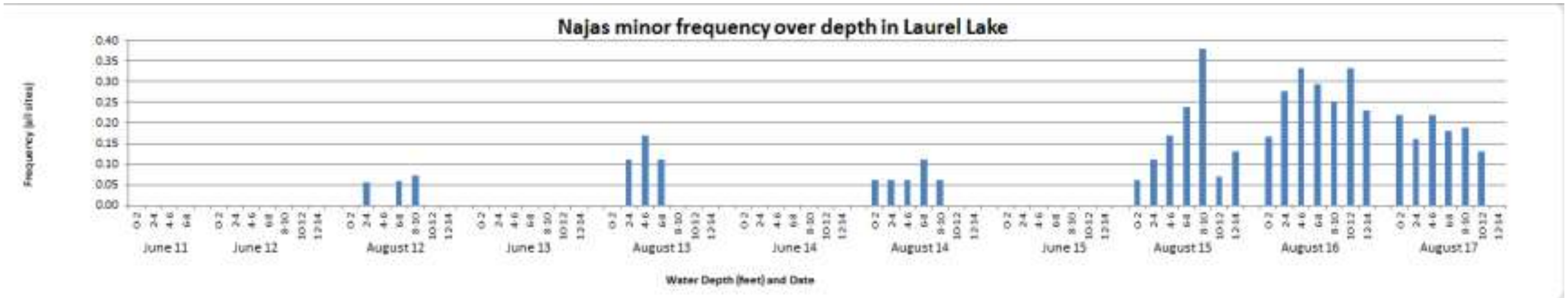


Figure 18. Frequency of spiny naiad in Laurel Lake.



Note that frequency and abundance are not the same; chara and water celery are two of the most frequently encountered plants, but do not create biovolume ratings >1 (no more than 25% of the water column is filled). Plants that create substantial biovolume include milfoil and some of the pondweeds, but none filled more than 50% of the water column on average (although small areas of greater biovolume were encountered). Spiny naiad also formed substantial biovolume in shallow water, but never at depths >4 feet.

Milfoil is the primary plant of concern in Laurel Lake, an invasive species that achieves localized high densities in water up to about 12 ft deep. There could be dense patches in shallower water, but ice formation and more recently drawdown tend to minimize the density of perennial plants like milfoil in shallow water. Milfoil was clearly depressed in shallow waters following very successful drawdowns in 2012-2015 (Figure 12). These results would be expected based on the ecology of Eurasian watermilfoil and the degree of exposure offered by the drawdowns. Milfoil is observed to recolonize shallower areas over the course of the summer, but is largely eliminated from the affected zone by drawdown each winter. Drawdown results were adequate in 2016, but there was more milfoil in shallower water by August than usual as a result of an early ice out and early onset of the growing season. That trend continued in 2017, something observed in many other Berkshire County lakes.

Growths of the invasive spiny naiad appear to be increasing in shallow water but are found at nuisance densities only in the eastern half of the Lenox (northern) cove, with some larger patches in the causeway bay of Laurel Lake. Drawdown will tend to favor this species, which is a seed producing annual. The distribution of most other species suggests that drawdowns of up to 5 feet will not have a major impact on the plant community; other species are either resistant to drawdown or have their peak abundance in water at least 8 ft deep. Water celery may be influenced by the drawdown based on shallow water frequency (Figure 17), but is quite abundant at depths of 6 to 14 ft.

Coverage, biovolume and general taxonomic assemblage maps were generated in 2011 (Figures 19-21). The patterns look much like those from the ESS studies of previous years, and have changed little over the monitoring period except for the increase in spiny naiad in two areas (Figure 22). A substantial portion of the lake is devoid of plants as a consequence of light limitation at greater depth. Yet the sometimes dense fringe interferes with recreation and in some cases habitat in the zone between 6 and 12 feet deep and in a few areas in shallower water (e.g., the east and west corners of the northern cove, in Lenox). The pattern of dominant plants in 2012 was not appreciably different from that observed in 2011, and the pattern in 2013 through 2017 differed from those of 2011 and 2012 mostly in the dominance of spiny naiad in the eastern portion of the Lenox cove (Figure 22 vs. Figure 21). Localized variation is to be expected, but at the scale of the maps provided, there is substantial consistency among years.

Aquatic plant communities are not usually static; shifts over space and time are to be expected, especially with many seed producing annual species where distribution can vary among years. Yet the Laurel Lake plant community is relatively stable, with certain areas exhibiting elevated plant densities in each survey and only a few substantial shifts in species composition over time. The drawdown helps to minimize plant growth in shallow water, although some species (e.g., naiads) thrive after drawdowns where the substrate is suitable (a limited area in Laurel Lake). The current 3 ft drawdown is not deep enough to affect more than a small peripheral fringe area around the lake, and much greater drawdown would be needed to impact Eurasian watermilfoil over its complete distribution or even to the depth at which peak densities occur. However, a drawdown of 5 ft could impact milfoil out to depths of about 7-8 ft in a year with historically normal ice thickness, yet would leave substantial stands of plants in water up to 14 ft deep.

Figure 19. Plant cover in Laurel Lake, 2011-2017.

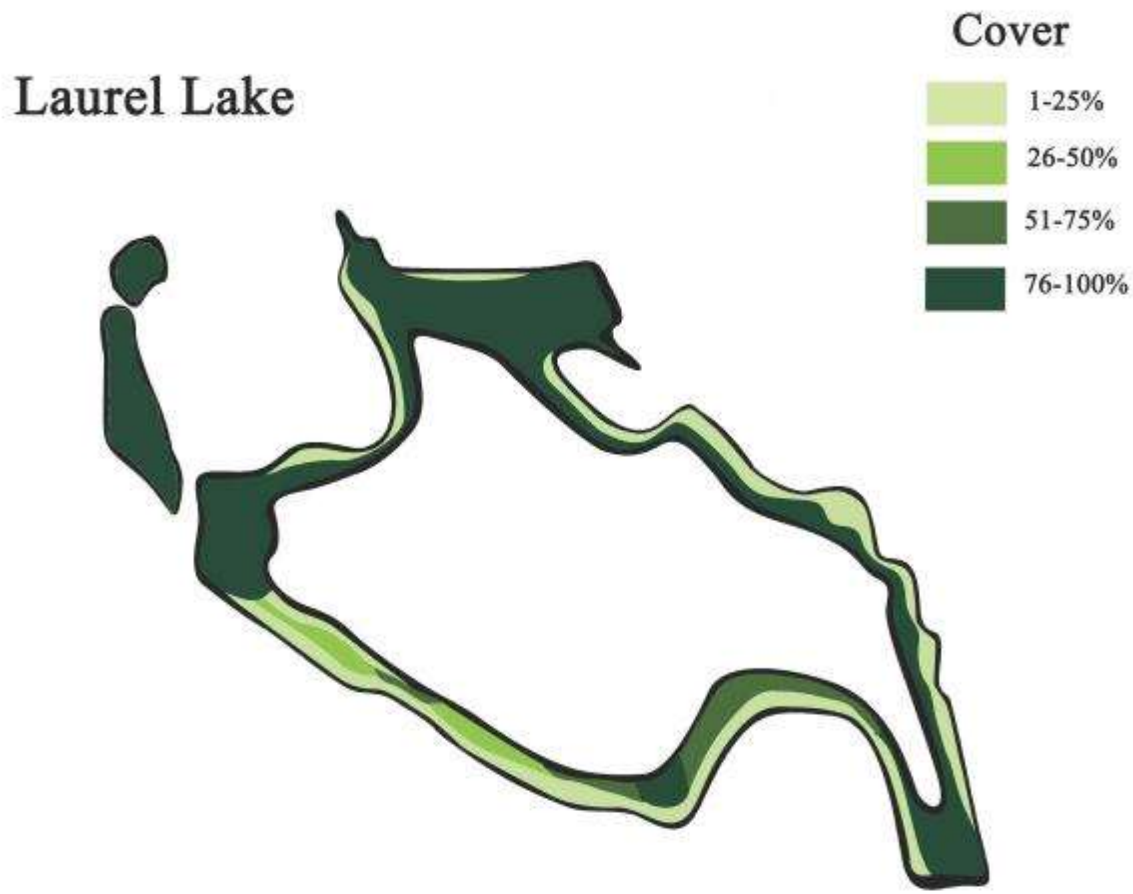


Figure 20. Plant biovolume in Laurel Lake, 2011-2017.

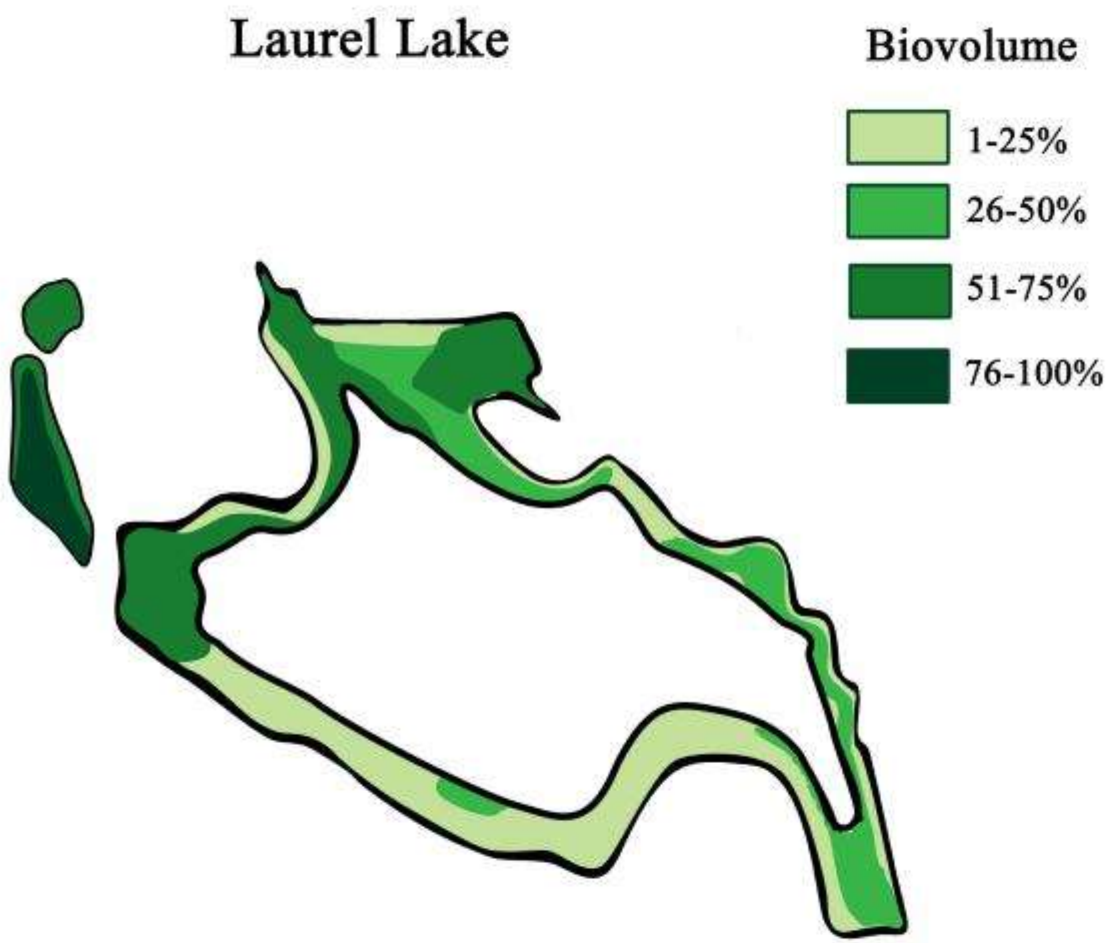


Figure 21. Dominant plants in Laurel Lake in September 2011 and August 2012.

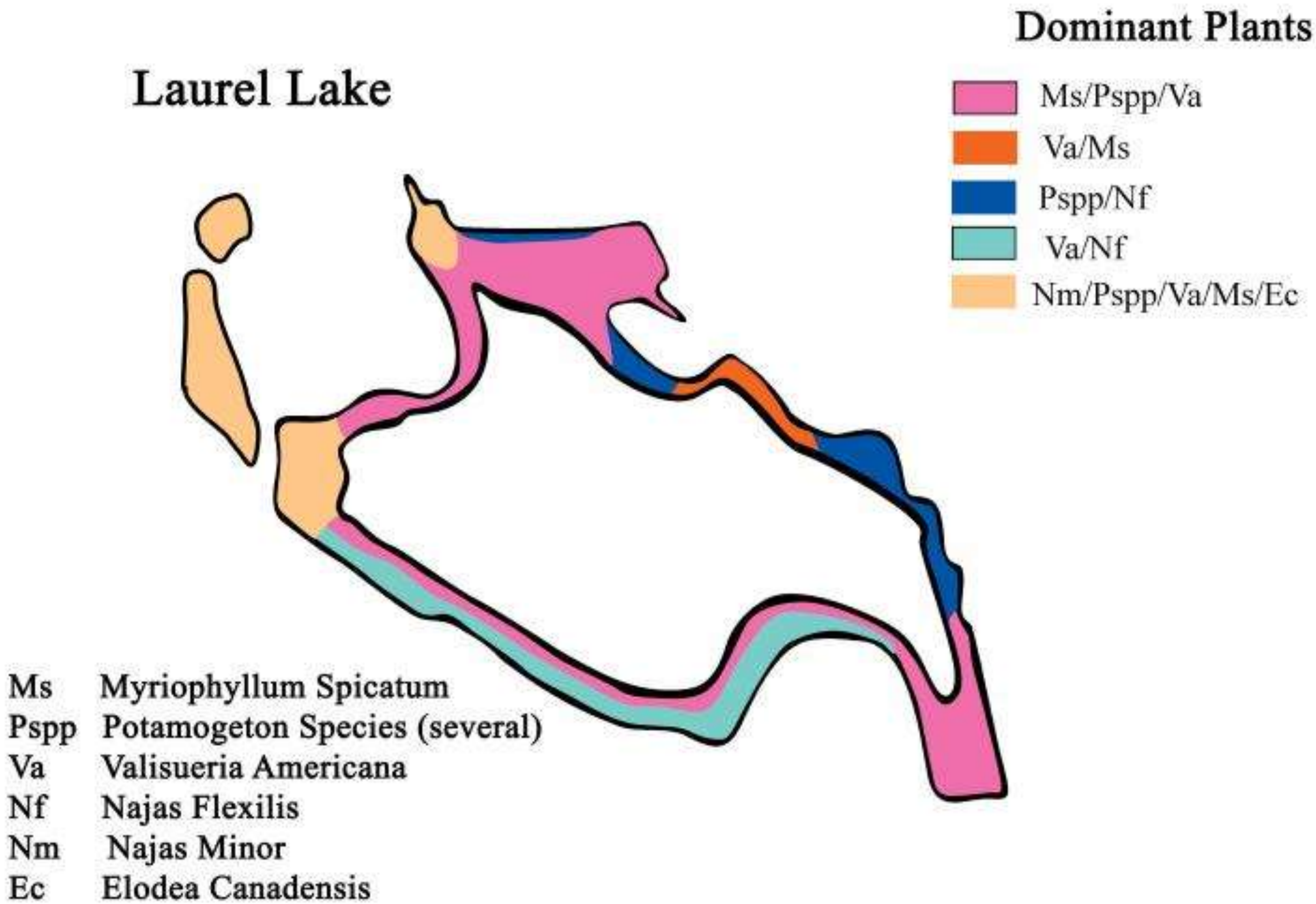
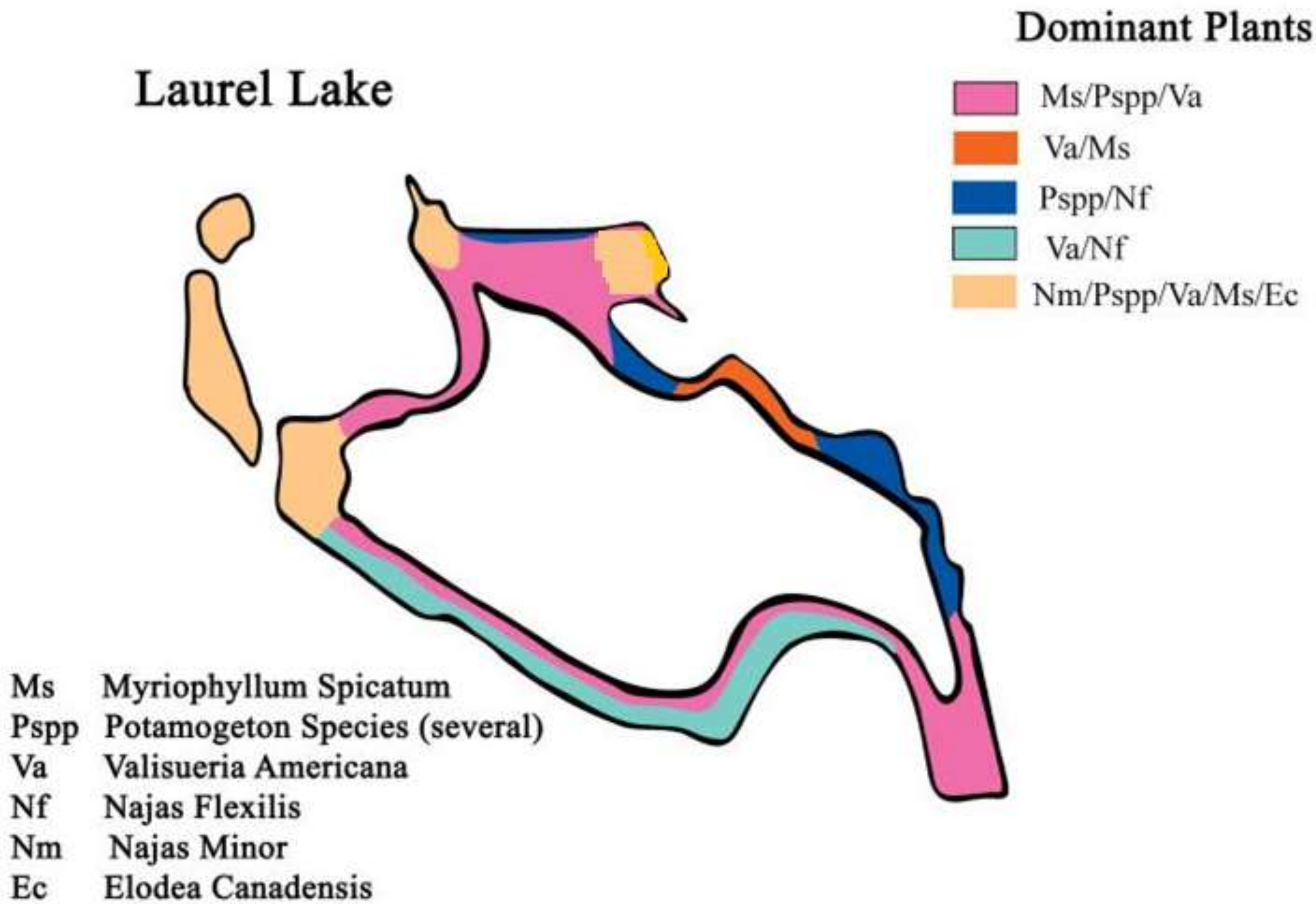


Figure 22. Dominant plants in Laurel Lake in September 2013 and August 2014 through 2017.



Invertebrate Assessment

Aside from zebra mussels, bivalve mollusks are relatively scarce in Laurel Lake. It was considered worthwhile to collect data for other mollusks during the zebra mussel survey, as at least two additional mussels, *Elliptio complanata* (eastern Elliptio) and *Pyganodon cataracta* (eastern floater), are listed for Laurel Lake. A few specimens of each were observed in surveys during 2011 and 2012. Few were alive, and all were colonized by zebra mussels (Figure 23). No live bivalve mollusks other than zebra mussels were detected in 2013 or 2014 over two surveys each year (June and August/September) and only a single small Elliptio was found in the December 2015 survey, with none detected since then. This is not a function of drawdown, as much of the surveyed area is deeper than can be affected by the drawdown. Zebra mussels are eliminating other mussel species.

A variety of snails are found in Laurel Lake from the families Physidae, Lymneidae, Planorbidae, Hydrobiidae, and Viviparidae. The visual method applied for bivalve mollusk evaluation is not especially well suited for quantitative surveys of snails, so more detailed surveys were conducted at the 0-2, 2-4 and 4-6 depth intervals at all transect locations in 2012 and 2013, counting all collected snails from 30-second dip net collections. Two surveys were completed in 2014 and one in each of 2015 through 2017, but with samples from 0-6 ft composited for each of 7 transects. Zebra mussels were also collected and counted in these surveys.

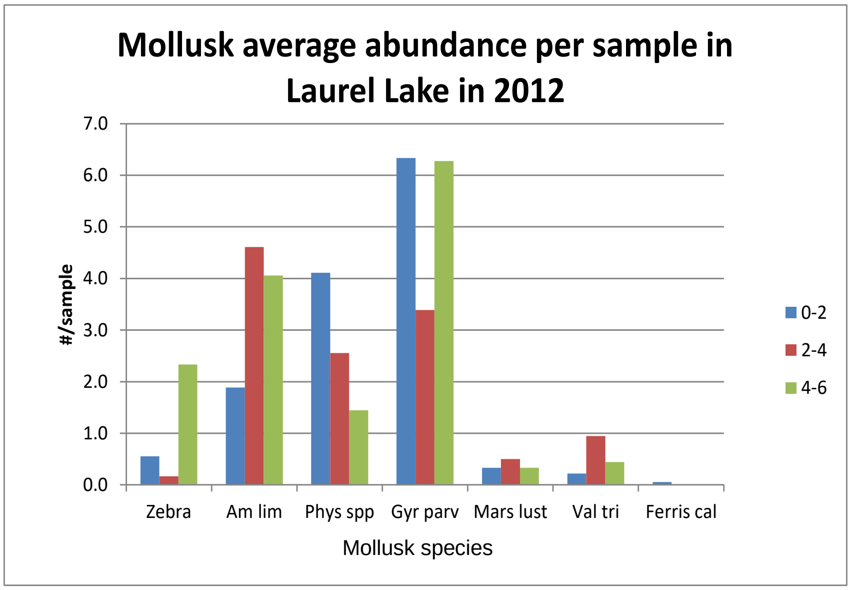
A total of 10 snail species have been listed from a survey of drifting plant material or shoreline rack material performed by MA DEP, but only 6 species were encountered in 106 samples collected by WRS in 2012 and 2013, plus the zebra mussels. The same 6 species were found in 2014 through 2017 samples plus zebra mussels and an occasional fingernail clam (Sphaeriidae). The primary snails in Laurel Lake are species of *Amnicola, Gyraulus, Helisoma, Physella* and *Valvata*, all common snails in Massachusetts. *Amnicola limosa* is the most abundant species, but *Valvata tricarinata* is sometimes more numerous in individual samples. *Viviparus georgianus* was also observed in the lake, but was not collected in samples. *Viviparus* is a large snail but is not found on vegetation or rocks, which is where most samples were collected. The average abundance of each species (Figures 24-26) suggests that only the zebra mussels, which are non-motile as adults, are distinctly impacted by the drawdown, although there has been a decline in *Gyraulus*, a planorbid snail, since 2011 that remains unexplained.

Looking at overall abundance of mollusks in shallow water over the last five years, there has been an overall increase that is largely related to increases in the genus *Amnicola* and lesser increases in the genera *Valvata* and *Helisoma* (Figure 27). However, samples were not collected at the same time in every year, and we would expect related variation, as more snails return to shallow water over the summer and reproduction increases their numbers. Based on the available data, drawdown may be causing some shifts in composition, but does not appear to be causing any mass decrease in snails in shallow water. This is consistent with the ecology of these snails, which is believed to include migration to muddier substrate in deeper water for the winter.

Marstonia lustrica, the Pillsbry spire snail and a state-listed (protected) species, averaged less than 0.5 per sample, or 3% of the total snail count in 2012. In 2013 *M. lustrica* averaged 0.1 per sample, or 1% of the total snail count in that survey. In June 2014 *M. lustrica* averaged 1.4 per sample, or 5.6% of the total snail count, while in August the density was 1.3 per sample, or 1.7% of the total snail count. In August 2015, *M. lustrica* density was 1.4 per sample, or 1.0% of the total snail count for that survey. In August 2016, M. lustrica density was 1.0 per sample, or

Figure 23. ***Pyganodon*** **shell colonized by zebra mussels.**

Figure 24. Mollusk abundance in Laurel Lake in 2012.



Zebra	Dreissena polymorpha
Am lim	Amnicola limosa
Mars lust	Marstonia lustrica
Val tri	Valvata tricarinata
Viv geo	Viviparus georganus
Phys spp	Physella species
Foss spp	Fossaria species
Gyr parv	Gyraulus parvus
Helis anc	Helisoma anceps
Ferris cal	Ferrissia californica
Micro dila	Micromenetus dilitatus

Figure 25. Mollusk abundance in Laurel Lake in 2013.

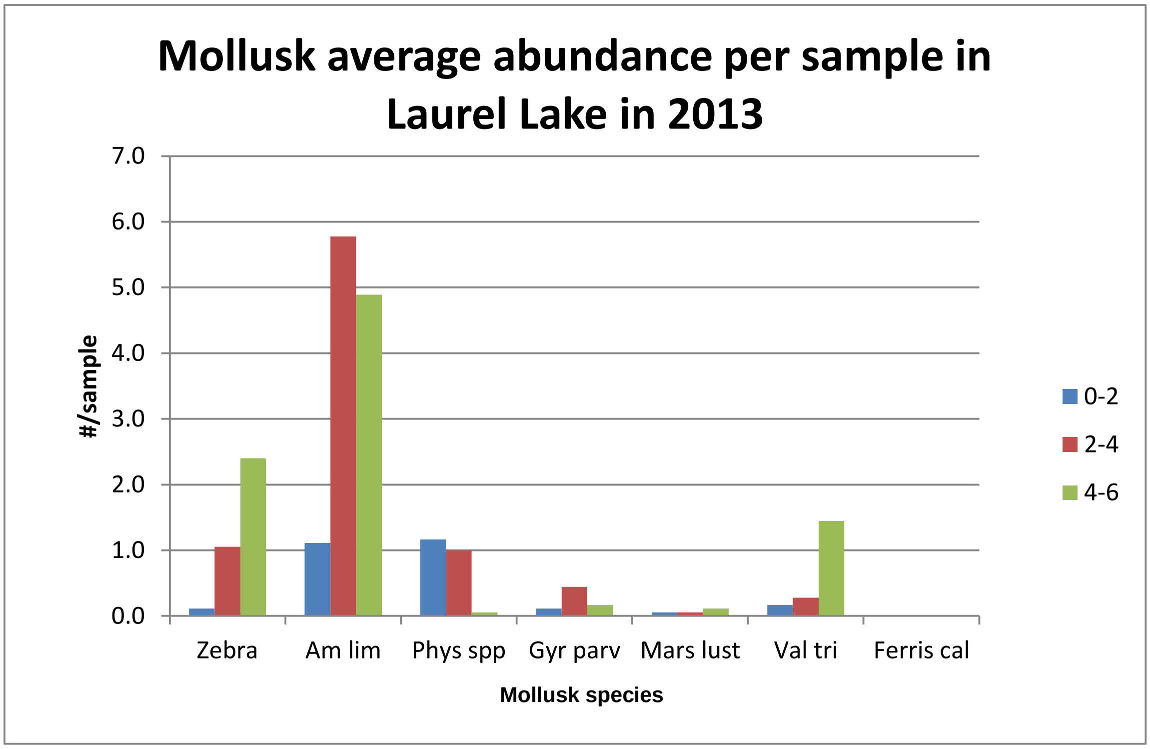


Figure 26. Mollusk abundance in 0-6 feet in Laurel Lake in 2014 to 2017.

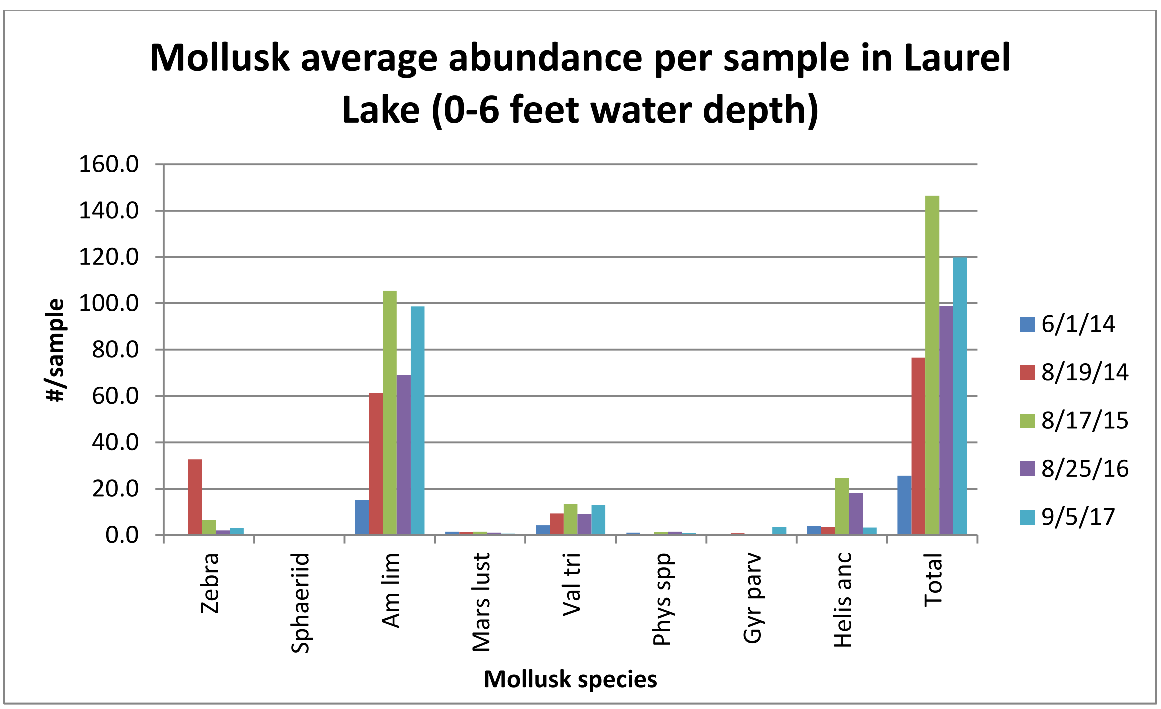


Figure 27. Snail abundance in Laurel Lake, 2012-2017.

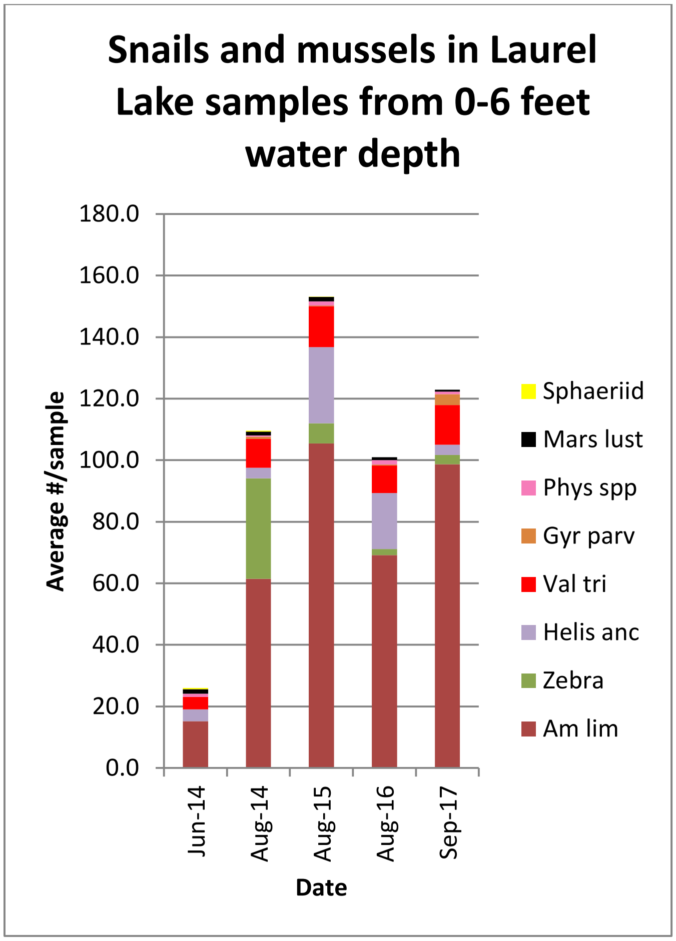
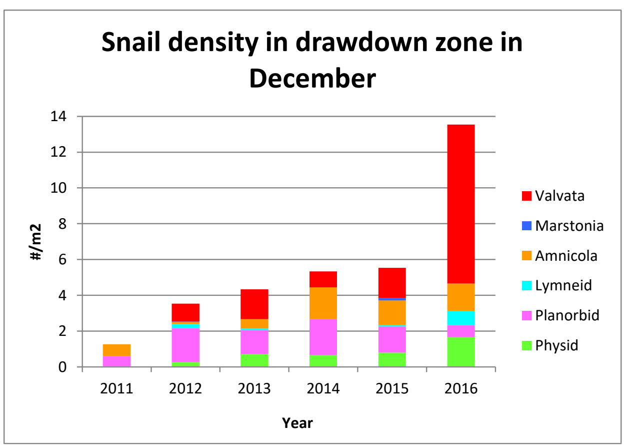
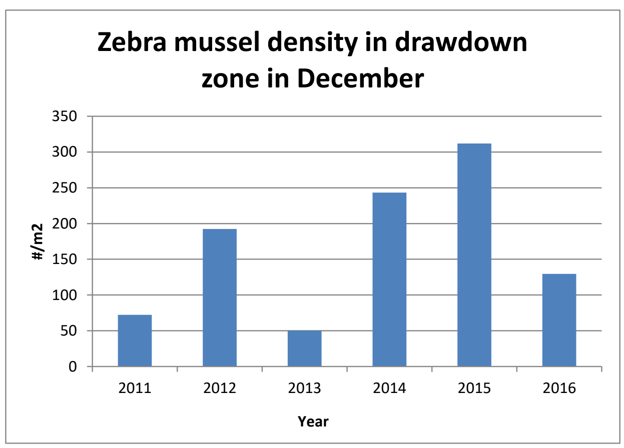


Figure 28. Recently dead snail and zebra mussel density in the drawdown zone.





1.0% of the total snail count. In September 2017, M. lustrica density was 0.6 per sample, or 0.5% of the total snail count.

Note that the number of snails per survey varies, so both actual number per sample and % of total are relevant and will vary. The Pillsbry spire snail is a minor component of the Laurel Lake snail community, with 4-10 specimens found in each survey. Much greater variation in other snail populations accounts for the variation in the portion of the total snail count represented by *M. lustrica*. At the low numbers encountered, it cannot be concluded that there is any impact from drawdown, positive or negative.

The abundance of *Marstonia lustrica* in Laurel Lake represents a similar percentage of the snail population observed in Stockbridge Bowl, the other Massachusetts lake known to support this species, but far less than suggested by the two NHESP/DEP samples of debris from Laurel Lake. *Marstonia lustrica* would appear to remain a rare species even when conditions are favorable. It was believed to prefer *Chara* as a summer substrate based on distribution in past surveys; *Chara* is abundant but not dominant and rarely dense in Laurel Lake, although drawdown tends to favor greater *Chara* abundance. *M. lustrica* has been believed to migrate into deep water for winter, when *Chara* dies back, so drawdown would not represent a major threat to this species.

Yet at such low densities in very few northeastern lakes, not enough is really known of the ecology of *M. lustrica*. Recent consideration by Tom Coote at Simon's Rock College, a snail researcher, suggests that *M. lustrica* may be more of a habitat generalist than previously thought, may not migrate far, and could even have a lifespan of only a year. It is on the northeastern end of its range in Massachusetts. It remains unclear why a political boundary (state border) is grounds for placing it on the protected list, as it is not a listed species in other states. It is also not at all certain that it is not present in other Massachusetts Lakes, as surveys have been limited and this species has not been abundant in the northeast.

Relatively few recently dead snails of all species have been found in the December survey of the drawdown zone through 2015, compared to counts in samples collected during summer at full pool water level. White "fossil" specimens are observed (snails eventually die and the shells often remain, bleaching white over several years) but these are not counted. Recently dead specimens that might have been casualties of the drawdown ranged from 1.3 to 5.5/m^2 in 2011-2015 (Figure 28). However, recently dead snails in the December 2016 survey increased to 13.5/m^2 as a result of a major increase in dead shells of *Valvata tricarinata* (8.9/m^2).

The survey methodology for summer snail sampling is a timed sampling and not keyed to an exact area, but is believed to be close to one square meter per sample; live snails per sample ranged from 34 to 41 in August 2014, 2015 and 2016. Recently deceased snails in December of the same years ranged from 5.3 to 13.5/m^2. In contrast, zebra mussels killed by the drawdown range from 129 to 310/m^2 for 2014-2016 (Figure 28). It is important to remember that snails can die of multiple causes, so finding non-fossil snails in the drawdown zone is not clear evidence of a drawdown impact. On the other hand, observation of no decrease in summer snail density in the drawdown zone is an indication of no significant negative impact of drawdown.

Zebra mussels were frequently found in the snail surveys, collected mainly from the base of plants, especially milfoil and water celery, and sometimes from rocks. In June 2012, zebra mussels averaged <0.5/sample in water <4 ft deep, the zone clearly impacted by drawdown, but increased to 2.3/sample in the 4-6 ft zone (Figure 24). In June 2013, zebra mussels averaged 0.1/sample in water <2 ft deep, 1.1/ sample in water 2-4 ft deep, and 2.4/sample in water 4-6 ft deep (Figure 25), similar to 2012 results except for more zebra mussels in the 2-4 ft zone in 2013. In June 2014, after a very effective drawdown (water level held, cold winter, no lasting snow until late January), there were no zebra mussels found in samples composited for water depths of 0-6 ft (Figures 26 and 27). The August 2014 sampling yielded an average of 10.9 zebra mussels per sample, and all zebra mussels in those August samples were very small. No June survey was conducted in 2015 through 2017, but few zebra mussels were observed (the lake was visited, just without quantitative surveys). In the August 2015 snail survey, composited over 0-6 feet of water depth, zebra mussels averaged 2.2 per sample, all small in size. This is taken as evidence of reproduction from deeper water mussels over the summer with veligers settling in shallow water. Yet in the August 2016 survey, zebra mussels averaged only 0.7 per sample; veliger counts were also very low in 2016 (see plankton section). There were more zebra mussels in shallow water by December, but fewer than in 2014 or 2015 (Figure 28). The early September 2017 zebra mussel count in 0-6 ft of water averaged 3.0 per sample, more like 2015 than 2016.

Summer surveys for zebra mussels over a wider range of depths, in conjunction with rooted plant surveys, provide additional insight on zebra mussel distribution. Zebra mussel distribution was rated as absent ($0/m^2$), trace ($1\text{-}5/m^2$), sparse ($6\text{-}50/m^2$), moderate ($50\text{-}200/m^2$) or dense ($>200/m^2$) at 2 ft depth intervals out to 14 ft of water depth (Figures 29-35). Few truly dense plots were observed, mainly as a consequence of lack of suitable substrate. Zebra mussels were nearly absent in water <2 ft deep in June 2011 after having been found in trace to moderate quantities in those same areas in December 2010 (Figure 29). The reduction was not quite as dramatic between December 2011 and June 2012, and may reflect the mild winter, but the impact of drawdown is apparent in comparison to zebra mussel population features in deeper water (Figures 32-35). The decline in shallow water between December 2012 and June 2013 is quite striking with no zebra mussels found in water <2 ft deep at the end of spring 2013 (Figure 28). A similarly striking comparison is offered by the December 2013 and June 2014 zebra mussel assessments and by those for December 2014 and June 2015. Likewise, zebra mussels were common in December 2015 but virtually absent in water <4 ft deep in June 2016. The same holds true for comparison of December 2016 vs. June 2017. The drawdown clearly impacts zebra mussel abundance around Laurel Lake in water <6 ft deep. Note that no zebra mussels were found upstream of the causeway; continual inflow at that point may be responsible.

The gradual increase in zebra mussels over the summer in shallow water is evident in all years of monitoring (Figures 29-31), with moderate to dense patches found by December when such densities are virtually absent in June. The biggest increase is in the fall, with veligers released in July and August settling and forming small adult zebra mussels in August and September. Even with growth between September and December, nearly all zebra mussels in shallow water are small to medium in size. Clearly the drawdown has an impact on the exposed zebra mussels, but the effect is temporary. Abundance increases over the summer, although not to an extreme level and with high variability. Even where zebra mussel densities qualify as “dense” by counts in December, the actual biomass and coverage of substrates is not high relative to other infested lakes in other states. The lack of drawdown in late 2017 is expected to foster increased shallow water zebra mussel abundance in 2018, but densities were low as of September 2017.

Zebra mussel density in Laurel Lake is not high overall. During the summer, the most common trace and sparse ratings correspond mostly to zebra mussels on plants, nearly all within a foot of the substrate on stems. When sticks or rocks were present in water deeper than 2-4 ft, zebra mussels often colonized these to a greater density, but on a per square meter basis, these only

Figure 29. Zebra mussel abundance in 0-2 ft of water.

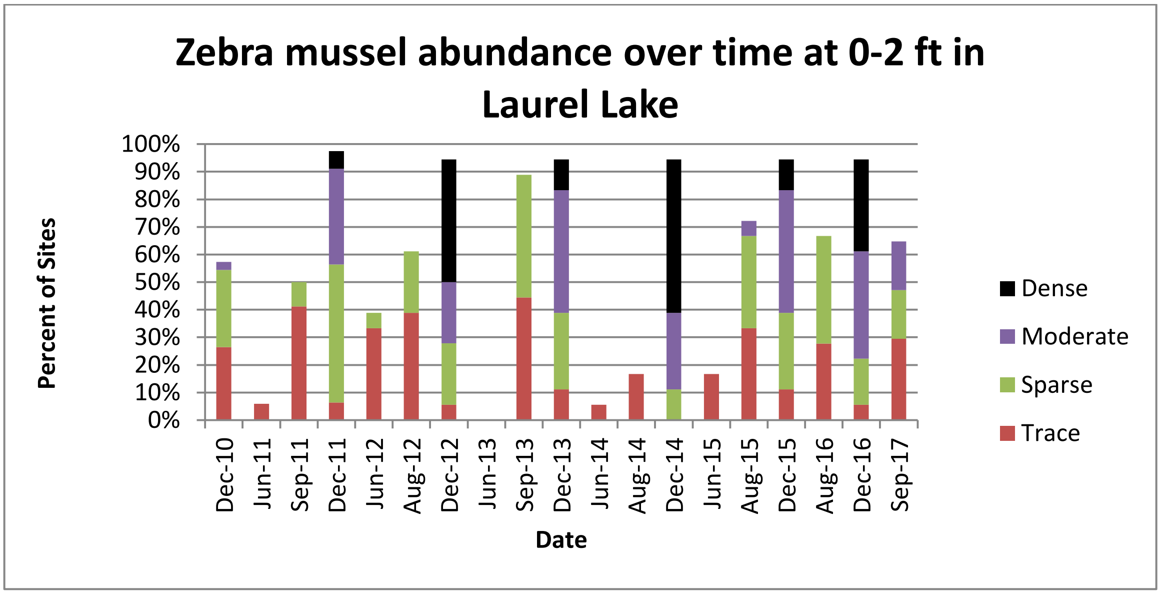


Figure 30. Zebra mussel abundance in 2-4 ft of water.

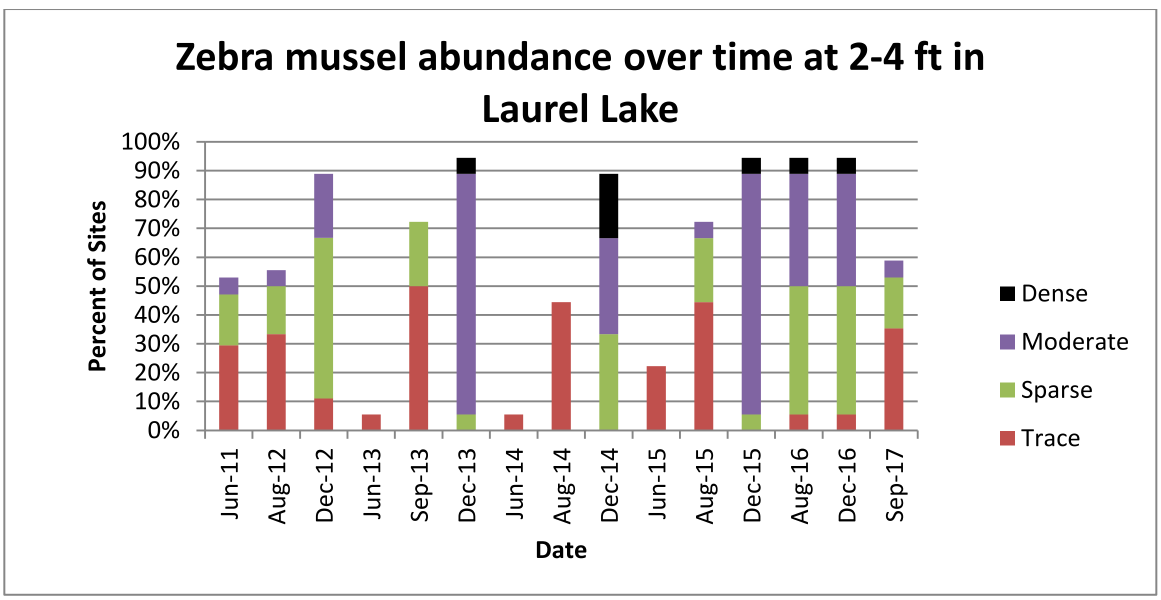


Figure 31. Zebra mussel abundance in 4-6 ft of water.

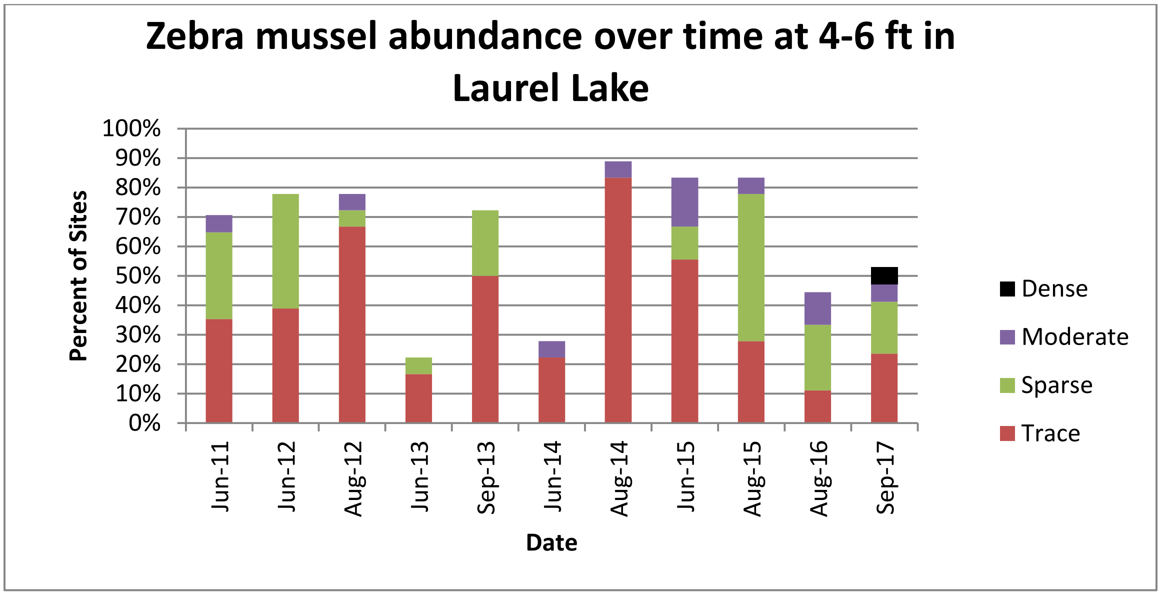


Figure 32. Zebra mussel abundance in 6-8 ft of water.

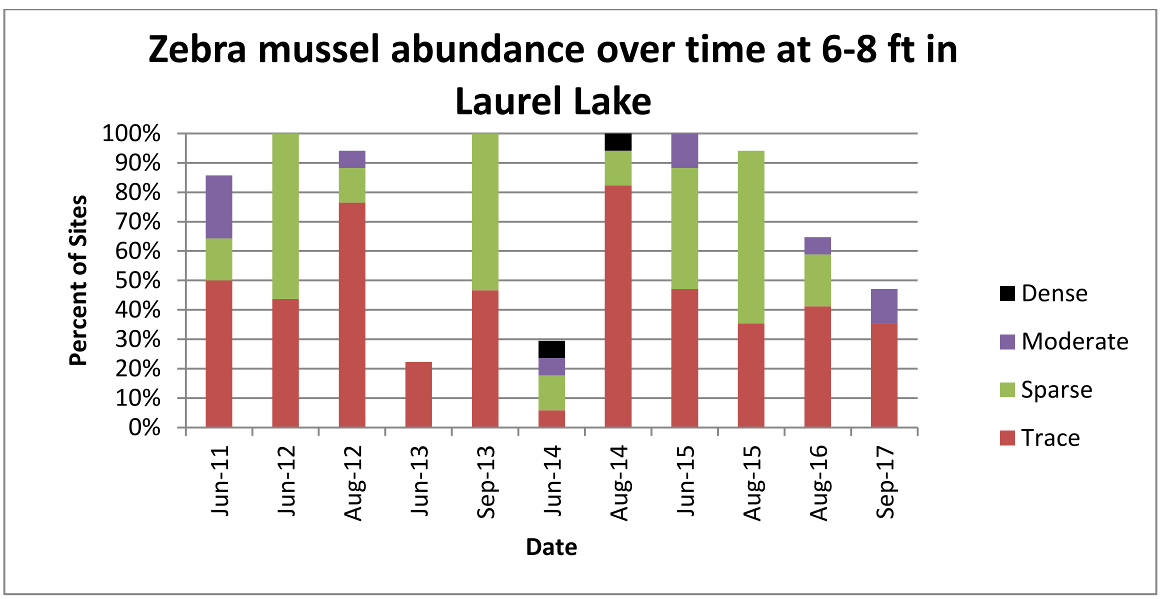


Figure 33. Zebra mussel abundance in 8-10 ft of water.

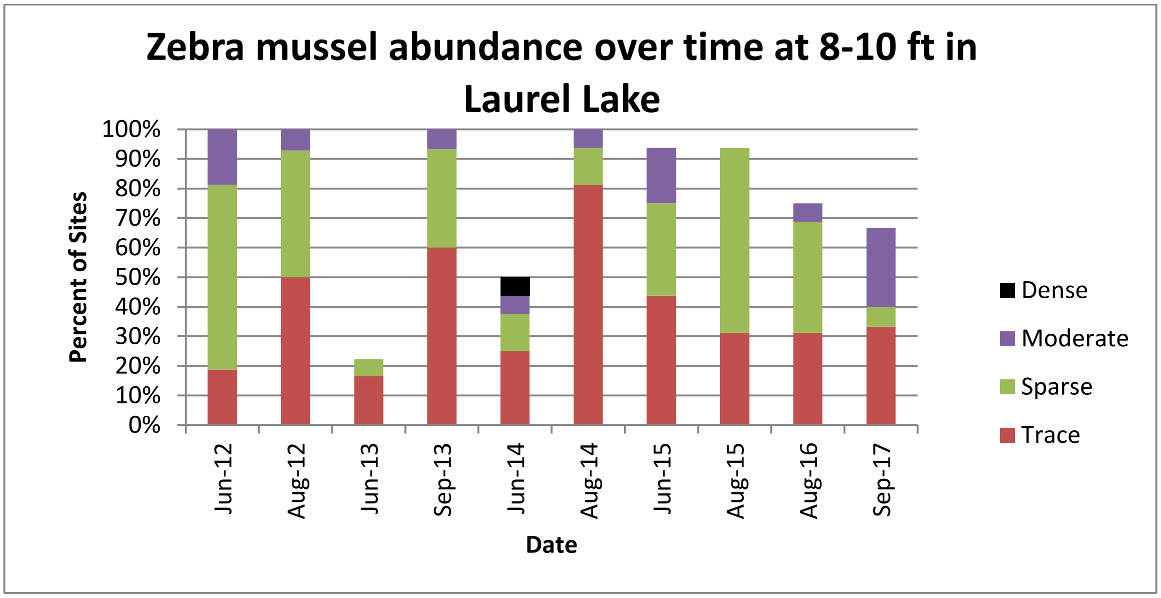


Figure 34. Zebra mussel abundance in 10-12 ft of water.

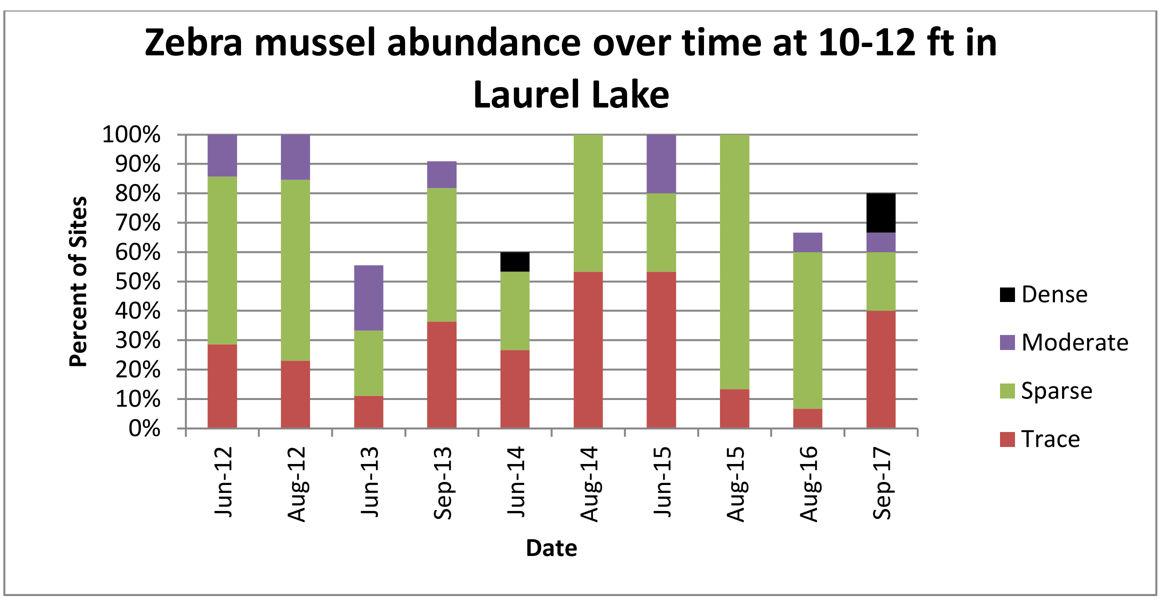
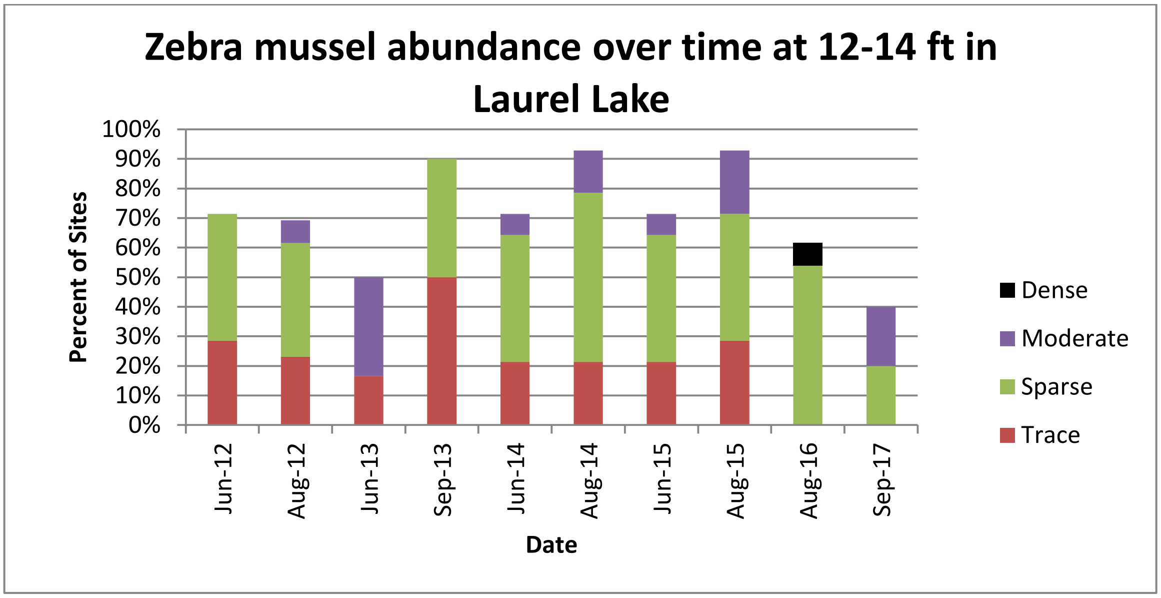


Figure 35. Zebra mussel abundance in 12-14 ft of water.



occasionally amounted to more than a moderate rating for the site overall. Substrate appears to be the major limiting factor in Laurel Lake, now coupled with the drawdown, which affects the zone with the greatest amount of substrate suitable for zebra mussels.

Even in late summer, zebra mussel density is low overall. From shore to water depths of 5 to 6 ft there are only small to medium zebra mussels scattered on rocks. In the zone of primary plant growth (6 to 14 ft), zebra mussels include mostly medium sized individuals scattered along the bottom 1-2 ft of milfoil and water celery, although in 2014 WRS personnel noticed many very tiny zebra mussels (very recently settled veligers) on the upper leaves of most species of plants. These mussels apparently do not survive, as most of those plants die back in the fall. Individual rocks or sticks beyond the zone of plant growth may be densely colonized, but most of the substrate is fine silt without live zebra mussels. Low oxygen in water >30-35 ft deep prevents zebra mussels from developing a mature population beyond that depth, but available suitable substrate appears to be the major limiting factor at shallower depths. Yet the small percentage of lake area represented by hard substrate and overwintering portions of perennial plants deeper than the drawdown zone and above the level of summer anoxia harbors a zebra mussel population large enough to keep recolonizing shallower zones though released veligers.

Photographs from the monitoring period help document conditions and processes in Laurel Lake. In spring the drawdown impact zone, which extends to at least 5 feet of water depth and may extend to 6 feet with a cold winter and 3 feet of ice along with the 3 foot drawdown, is largely clear of zebra mussels, while areas deeper than 5-6 feet may be extensively colonized where the substrate is suitable (Figure 36). In deeper water, rocks are colonized to the maximum extent and larger zebra mussels can be found all year (Figure 37). This limited deep water population of zebra mussels is likely to be the main source of veligers in the lake. Further

Figure 36. Zebra mussels on vertical wall just north of boat ramp, June 2014.

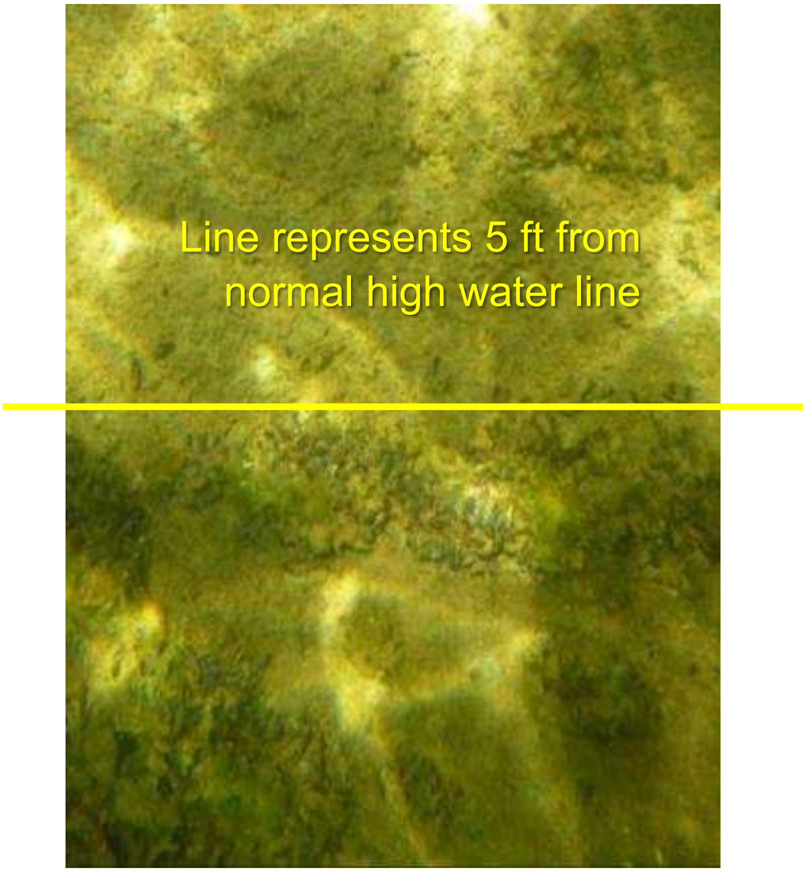


Figure 37. Zebra mussels on rocks in deeper water, April 2014.

Figure 38. Zebra mussels on the base of milfoil stems, June 2012.

Figure 39. Zebra mussels on overwintering plant stems, April 2014.

Figure 40. Snails on plant stems, April 2014.

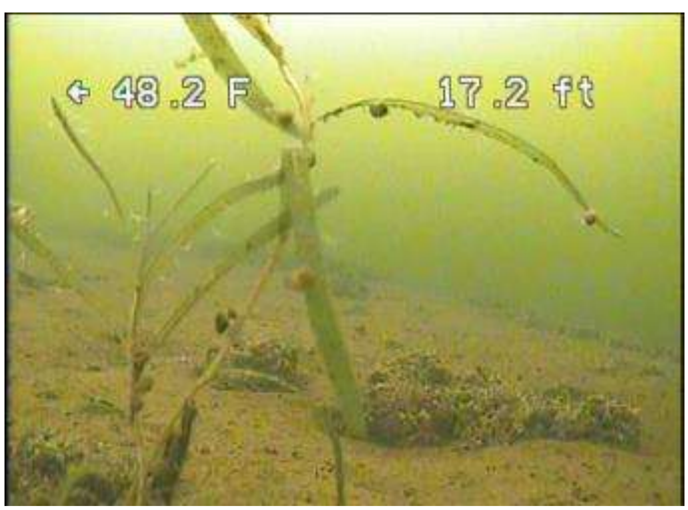


Figure 41. Zebra mussels on exposed substrate during December 2014.

investigation of veliger abundance has been conducted as part of the plankton assessment and is described in that section of this report.

During the growing season, zebra mussels can be found on plants, with larger ones found near the base of Eurasian watermilfoil (Figure 38). Examination of early spring conditions (Figure 39) indicates that these zebra mussels overwinter on the surviving basal stems of the milfoil. Small zebra mussels may be found higher on milfoil and on other plant species in late summer, after veligers have been produced and settle, but these appear to die with the plants in fall and winter. In contrast, most snail species are found on annual plants, like *Potamogeton* (Figure 40), but do not require such substrate for winter survival. Veligers settling in shallow areas in late summer produce clusters of small zebra mussels on suitable substrate, as illustrated by exposed rocks during the December 2014 survey (Figure 41).

Considering the available substrate based on sediment and plant surveys conducted by WRS over the last 7 years, the portion of that substrate associated with each functional depth zone and potentially impacted by a drawdown of 3 to 5 ft can be estimated (Table 3). Between 61 and 65% of all hard substrate is impacted by the current 3 ft drawdown, while a 5 ft drawdown would be expected to impact 69 to 72% of hard substrate habitat for zebra mussels. The current 3 ft drawdown impacts 40 to 48% of the available plant habitat for zebra mussels, although it should be remembered that the density of zebra mussels achieved on plants is much less than what can be sustained by hard substrates (rocks and wood). A 5 ft drawdown would impact 57 to 67% of suitable plant habitat. This leaves about 22% of hard substrate habitat unaffected in 8 to 14 ft of water and a little less than 7% of hard substrate in water 14 to 30 ft deep. In other words, drawdown up to 5 ft will not affect about 29% of possible hard substrate habitat for zebra mussels. About 33% of possible plant habitat for zebra mussels occurs below the maximum depth of influence by drawdown, with almost all of that between 8 and 14 ft of water depth. If zebra mussels are to be controlled, all lake area to a depth of at least 30 ft must be affected.

Table 3. Portion of substrate suitable for zebra mussels impacted by drawdown.

Drawdown	Impact Depth	Total % Hard Substrate	Total % Plant Habitat
3	5	60.7%	40.1%
3	6	64.9%	48.4%
5	7	69.3%	57.3%
5	8	71.6%	66.9%
Habitat	8 to 14	21.7%	30.20%
	14 to 30	6.7%	2.90%

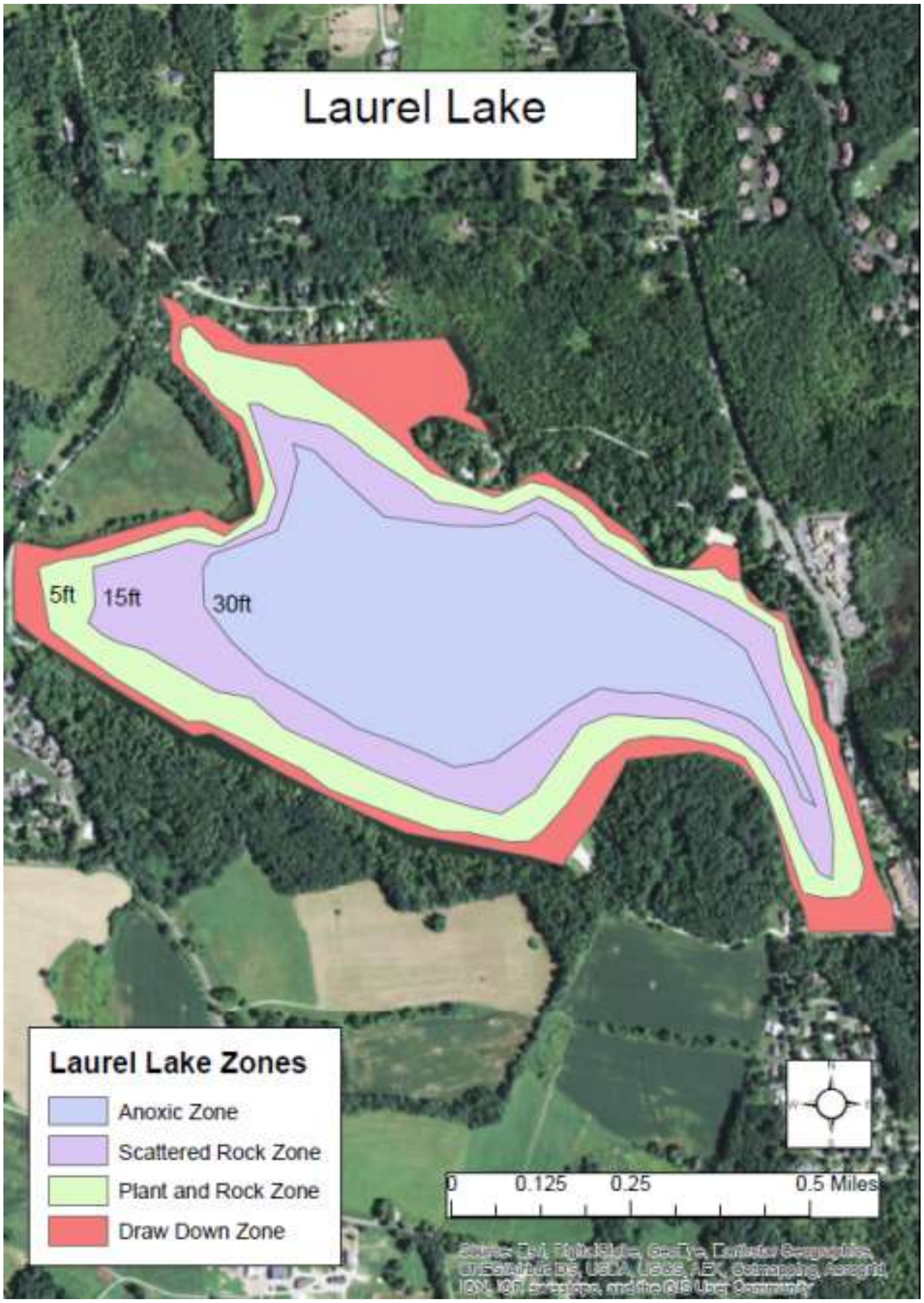
However, the drawdown of 3 ft greatly reduces zebra mussel abundance in the nearshore zone, where interactions with people are greatest, most notably at both town beaches. A drawdown to 5 ft would extend that influence significantly, but not without possible trade-offs, particularly with regard to refill time in a dry late winter/early spring. Control of invasive Eurasian watermilfoil would greatly reduce attachment points, further limiting the abundance of zebra mussels. The drawdowns have been effective in minimizing zebra mussel and milfoil density in shallow water into September. Zebra mussel density increases by the end of fall, and milfoil is present in many shallow areas by the end of summer, so drawdown must be repeated annually to maintain the current level of control in Laurel Lake.

To put the zebra mussel habitat zones into perspective, Figure 42 was developed from GPS and underwater camera assessment in June of 2016. The drawdown impact zone, out to about 5 ft of water depth, covers about 30 acres. This zone has few zebra mussels between December and August as a consequence of drawdown, but is gradually recolonized in late summer and fall as veligers produced in deeper waters drift and settle in this area.

The plant and rock zone, from 5 to 15 ft of water depth and covering an area of about 38 acres, contains some hard substrate and the bulk of the rooted plant growth, with zebra mussels colonizing rocks and mainly the stems of milfoil in this zone. Drawdown may impact the shallow edge of this area when ice formation is thick, with some effects observed to a water depth of 6 ft, but most of this area is unaffected by drawdown and harbors a permanent zebra mussel population. Zebra mussels on rocks in this area exhibit a wide size range, with many larger specimens. Rooted plants, mainly milfoil, support small to moderate sized zebra mussels on their stems, usually within a foot of the sediment. It is not clear why zebra mussels do not grow much higher on those stems, but it could be a function of annual dieback of much of the upper growths or inability of the thinner stems to support the weight of zebra mussels.

Beyond the 15 ft water depth contour, plant abundance declines rapidly to zero, but there are still scattered rocks that are colonized by zebra mussels to a depth of about 30 ft, beyond which

Figure 42. Zebra mussel habitat zones in Laurel Lake



oxygen stress limits zebra mussel survival. The 15-30 ft water depth interval represents an area of about 39 acres. WRS surveyed these areas, hoping that rocks might be unevenly distributed and some localized control of zebra mussels might be possible. However, while there are a few areas of more concentrated rocks, such as directly off the boat launch in 15 to 30 ft of water, there are enough rocks in each area within the 15-30 ft zone to warrant attention. The area deeper than 30 ft represents 64 acres of Laurel Lake. There were no zebra mussels observed by WRS on rocks deeper than 30 ft of water depth, although MA DCR divers report zebra mussels to depths of up to 35 ft.

Two experiments were conducted in 2015 by high school students as part of coursework, with input from DCR and WRS, and supplement the observations above. The first experiment, by Ben Greeley of Philadelphia, PA (whose family has a summer home closer to Laurel Lake), examined colonization of zebra mussels on artificial substrates placed at various depths along a line at two locations in the lake. He found very few zebra mussels on those substrates until September, but colonization was then substantial. Previous observation and tracking of veliger concentrations suggest that colonization is generally a late summer event. It may have been later in 2015 than normal, but we rarely see small zebra mussels on plants or substrates in the drawdown zone before late August. Ben Greeley was interested in what types of substrates might be colonized and if transfer among lakes might be facilitated, but the primary conclusion relevant to management of zebra mussels in Laurel Lake appears to be that veligers are not produced evenly throughout summer and colonization of "new" substrates (including annual plants and rocks previously exposed during drawdown) occurs no earlier than August.

The second experiment was conducted by Tom Canto of Wilbraham, MA and was a test of the duration of exposure necessary to kill zebra mussels. Rocks with zebra mussels attached were harvested from the lake. One set of rocks was left in a pan of water as a control, while others were pulled out of the water and left to dry at temperatures above freezing for up to 4 days. Exposed rocks with zebra mussels were then put back in water and the percent survival was recorded. The key conclusion was that zebra mussels died after no more than 4 days out of water. This means that a deeper drawdown for the purpose of killing zebra mussels would not have to last all winter, or even more than a week.

The colonization experiment by Greeley was consistent with plankton assessments and field monitoring results, but the survival experiment by Canto had no specific corroboration other than knowing that a whole winter of exposure killed zebra mussels, so the survival experiment was repeated in fall 2016 by WRS staff. The experiment was conducted under moderately controlled temperature, which was relatively constant at slightly above freezing (Figure 43). Other than for the control group, which remained in lake water, exposure time varied between 48 and 164 hours (Figure 44). Survival was roughly linear vs. time, with about 91% survival in the control group, 50% survival after 48 hours (2 days) of exposure, and no surviving zebra mussels after 140 hours (just under 6 days) of exposure. The slope of the mortality line was not as steep as in the 2015 experiment, but it is evident that zebra mussels do not survive for more than a week when exposed to air at cold temperatures above freezing.

At the end of the experiment, the control group was exposed to freezing temperatures and did not survive for more than a day. The duration of exposure for complete zebra mussel control is therefore fairly short (<1 week), and may be very short if the temperature is below freezing.

This opens the possibility of a very short term drawdown that could kill all the zebra mussels in Laurel Lake while having lesser impact on other aquatic biota. Fish could move into remaining open water, although some stranding is to be expected. There is indication that many snails would survive a short term drawdown, and few plants would be affected if the drawdown was conducted in late fall or early winter. An extreme, but short duration drawdown could set the stage for a true ecological restoration program at Laurel Lake. While some impact will be unavoidable, recovery is entirely possible and removal of zebra mussels appears possible.

Figure 43. Temperature record during zebra mussel exposure experiment

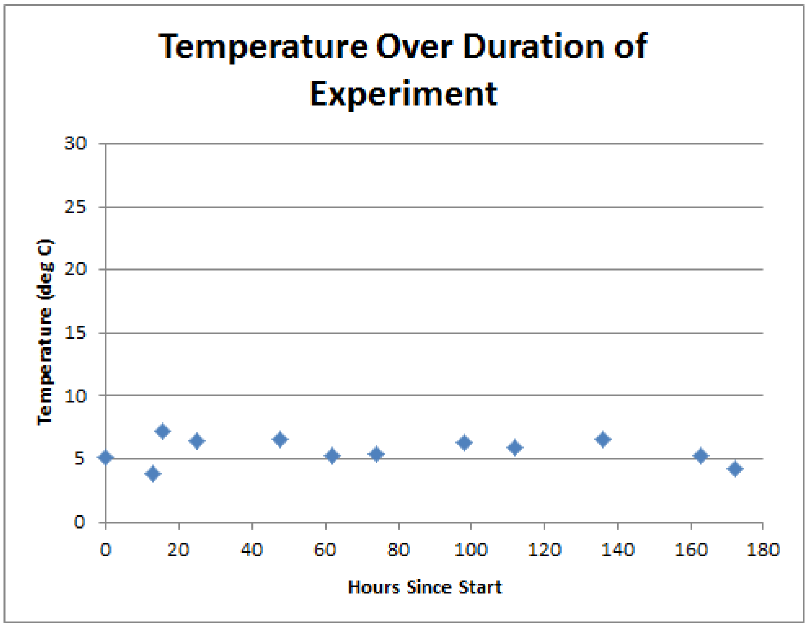
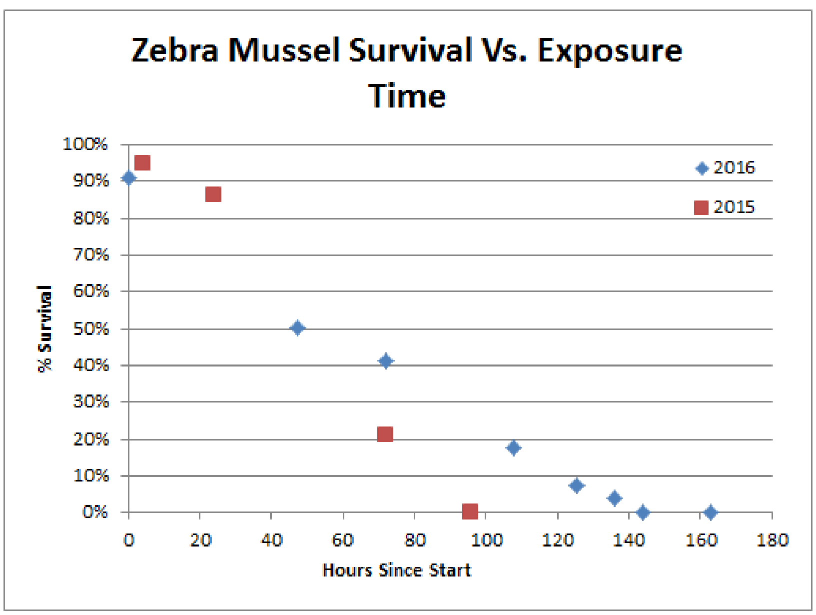


Figure 44. Zebra mussel survival after varying exposure to air



Water Quality and Plankton Assessment

The need for watershed management may be indicated by in-lake water quality. Water quality features that could be assessed in the field were evaluated during summer surveys (Table 4). Visibility was above average for Massachusetts lakes at 4 to 7 m (13 to 23 ft). The pH is slightly basic and conductivity is moderate, typical of Berkshire County lakes. The temperature – dissolved oxygen profile suggests that the boundary between upper and lower water layers during summer stratification is at about 6 m (20 ft), but ecologically significant oxygen depression is not encountered until deeper than 9 m (30 ft), much better than for many stratified Massachusetts lakes.

There was an oxygen peak at the boundary between water layers in 2012, indicative of an accumulation of algae, but peaks were weaker or not observed in 2013-2017. Turbidity is not elevated except near the bottom, where particles tend to accumulate and where the instrument may stir up the bottom to some extent. While protective measures are always appropriate, there is no obvious need to curtail watershed inputs to improve water quality. The low oxygen in the deepest water is a natural phenomenon. It can be exacerbated by human activities, but oxygen profiles from Laurel Lake are better than most lakes in western Massachusetts and show few signs of strong human impact. Reduced watershed inputs would be unlikely to increase deep water oxygen for many years.

Algae samples (Table 5) were collected in June, July and August of 2012, and suggest that the oxygen peak is a function of the blue-green *Aphanocapsa*, but this is not a problem species (not a taste and odor or toxin producer). Overall, the algal community was fairly innocuous. There are some species that can form blooms, but there is no strong indication of any water quality problem. No problem blue-green algae (more properly, cyanobacteria) were found in any sample in 2012.

In 2013 samples were collected weekly from mid-June to mid-September as part of more detailed plankton evaluation aimed at zebra mussel veliger detection and indication of overall conditions with respect to plankton assemblages. Water clarity was slightly lower than in 2012, and more potential problem cyanobacteria were observed; there was a surface bloom on the final sampling date, September 11th, although it was not severe. The most abundant alga through most of the summer was the chyrsophyte *Dinobryon*, which is generally associated with colder waters and is not a problem species in recreational lakes.

Algae were sampled on three dates in 2014, late April, mid-June and mid-August. A mix of diatoms, green algae, golden algae and cyanobacteria were observed, but none were especially abundant. Some problem cyanobacteria were observed, but did not form surface scums on the days when sampling occurred. Water clarity remained high. Only one sample was collected in late summer of 2015, 2016 and 2017, and revealed a limited mix of algae at low densities; water clarity was high on the 2015, 2016 and 2017 sampling dates.

Overall, algae data suggest that the lake is in relatively desirable condition, but that there is potential for blue-green blooms. These are most often promoted by excessive phosphorus with a lesser amount of nitrogen, resulting in a low N:P ratio that favors cyanobacteria (blue-green algae) over other forms. While the watershed is the ultimate source of nutrients, elevated levels of P at low N:P ratios is often a sign of internal recycling (P being released from anoxic sediments with much less release of N). Additionally, zebra mussels have been linked to increased cyanobacteria, most likely as a function of nutrient releases from those mussels and

Table 4. **Field water quality in Laurel Lake in 2012 - 2017.**

Laurel Lake, Lee/Lenox MA									
	Depth	Temp	DO	DO	Sp. Cond	pH	Turbidity	Secchi	CHL
Date	meters	°C	mg/l	% Sat	µS/cm	Units	NTU	meters	µg/l
6/28/12	0.1	22.5	9.4	109.7	244	7.8	0.6	5.8	
	2.0	22.3	9.3	108.9	244	7.8	1.0		
	4.0	22.2	8.9	103.1	244	7.8	1.3		
	6.0	13.7	14.3	140.0	251	7.8	1.5		
	8.0	10.9	8.7	79.8	254	7.2	1.0		
	10.0	9.1	2.2	19.1	255	6.7	2.0		
	12.0	8.0	0.4	3.1	258	6.5	2.0		
	14.0	7.8	0.1	0.5	260	6.5	2.0		
08/21/12	0.1	24.9	8.4	103.5	252	8.6	0.6	6.1	
	2.0	24.9	8.6	105.3	252	8.6	0.5		
	4.0	24.8	8.5	104.5	252	8.6	0.6		
	6.0	18.2	11.8	127.3	260	8.5	0.7		
	8.0	12.1	4.9	46.5	280	7.8	1.4		
	10.0	9.9	2.1	18.6	282	7.7	1.2		
6/19/13	0.2	19.8	11.4	126.4	287	8.8	0.4	4.0	
	2.0	19.6	11.5	127.5	288	8.9	0.4		
	4.0	17.5	9.9	105.1	290	8.4	0.4		
	6.0	14.0	11.1	108.8	300	8.5	0.4		
	8.0	9.1	11.0	96.6	302	8.1	0.4		
	10.0	6.6	6.1	50.0	312	7.7	0.4		
	12.0	5.4	1.4	11.0	322	7.4	0.4		
	14.0	5.0	0.4	3.5	335	7.1	1.5		
9/11/13	0.3	22.0	9.1	105.3	472	8.3	0.6	5.2	
	3.0	21.7	9.2	105.6	472	8.4	0.2		
	6.0	20.4	9.0	101.3	492	8.3	0.1		
	9.0	10.0	4.8	43.4	549	7.6	0.1		
	12.0	6.5	0.3	2.3	578	6.8	6.8		
	15.0	5.7	0.0	0.0	602	6.0	6.1		
4/29/14	0.1	10.6	11.2	102	468	7.1	2.0	4.3	
	2.0	10.5	11.6	106	468	7.9	1.9		
	4.0	9.5	11.7	104	467	8.0	2.2		
	6.0	9.0	11.6	102	468	8.1	2.2		
	8.0	7.4	10.6	90	479	7.9	2.2		
	10.1	4.8	10.1	80	507	7.7	2.7		
	12.0	4.1	6.2	48	538	7.5	3.5		
	14.1	3.8	2.8	21	575	7.3	4.5		
	15.8	3.8	0.0	0	651	6.0	7.6		

	Depth	Temp	DO	DO	Sp. Cond	pH	Turbidity	Secchi	CHL
Date	meters	°C	mg/l	% Sat	µS/cm	Units	NTU	meters	µg/l
6/19/14	0.1	21.5	9.5	108.6	403	8.1	1.6	6.8	
	3.0	21.3	9.6	109.4	403	8.1	2.7		
	6.0	12.4	11.9	113.3	400	8.0	2.5		
	9.0	6.8	7.1	58.8	425	7.4	2.5		
	10.0	5.7	5.0	40.7	441	7.3	2.7		
	11.1	5.0	1.6	12.9	453	7.2	3.3		
	12.3	4.4	0.7	5.4	463	7.1	3.7		
	13.0	4.2	0.3	2.3	465	7.1	4.8		
	14.1	4.1	0.0	0.3	472	7.0	6.5		
8/19/14	0.2	22.6	8.9	103.9	358	8.0	2.6	4.8	
	3.0	22.0	8.8	101.5	357	8.4	3.2		
	6.0	16.3	7.1	73.5	420	8.1	2.8		
	9.0	8.5	3.5	30.3	447	7.8	3.1		
	10.0	7.4	1.7	14.4	457	7.7	3.3		
	11.0	6.5	0.8	6.5	470	7.6	3.8		
	12.0	5.9	0.1	0.8	481	7.5	5.8		
	13.0	5.6	0.0	0.0	488	7.3	7.7		
	14.0	5.4	0.0	0.0	495	7.1	7.7		
	15.0	5.2	0.0	0.0	503	7.0	7.0		
8/17/15	0.1	22.0	9.1	104.1	365	8.0	1.5	6.7	
	3.0	21.2	9.0	103.1	367	8.0	1.8		
	6.0	14.0	9.3	90.2	360	7.8	2.0		
	9.0	7.2	8.8	72.8	388	7.5	2.0		
	10.0	5.9	6.0	48.1	402	7.3	2.7		
	11.0	5.2	3.8	29.9	412	7.2	3.0		
	12.0	4.6	1.2	9.3	422	7.1	3.4		
	13.0	4.3	0.8	6.2	423	7.1	4.5		
	14.0	4.1	0.0	0.3	426	7.0	5.5		
	15.0	4.1	0.0	0.0	434	7.0	6.8		
9/7/16	0.0	23.85	9.2	111.1	486	8.4	2.2	6.5	1.6
	1.0	23.75	9.2	110.8	486	8.4	2.3		1.7
	2.0	23.66	9.2	110.4	486	8.4	2.6		1.8
	3.0	23.64	9.1	109.5	486	8.4	2.6		1.8
	4.0	23.61	9.1	109.3	488	8.4	2.7		1.8
	5.0	23.59	9.2	110.0	485	8.4	2.7		1.7
	6.0	22.1	8.8	102.5	505	8.3	2.7		2.3
	7.0	17.26	8.0	84.8	523	8.2	2.8		2.0
	8.0	14.35	6.4	63.2	523	8.1	2.8		2.0
	9.0	11.77	3.7	34.9	529	8.0	2.9		1.6
	10.0	9.97	1.3	11.5	525	7.8	3.1		2.5

	Depth	Temp	DO	DO	Sp. Cond	pH	Turbidity	Secchi	CHL
Date	meters	°C	mg/l	% Sat	µS/cm	Units	NTU	meters	µg/l
7/21/17	0.0	27.2	9.4	120.6	501	8.13	3.1	5.1	3.1
	2.0	26.9	9.4	120.1	501	7.88	3.2		1.1
	4.0	23.9	9.0	108.7	504	7.53	3.2		5.4
	6.0	15.0	10.6	106.7	506	7.35	3.4		2.9
	8.0	9.8	9.7	86.8	503	7.13	3.8		3.1
	10.0	7.1	6.8	57.0	507	6.91	4.9		4.5
	12.0	6.2	2.0	16.1	508	6.79	6.4		4.0
	14.0	5.6	0.4	3.2	518	6.72	10.2		2.2
	14.8	5.5	0.4	3.4	530	6.82	9.0		1.4
9/5/17	0.2	20.7	9.1	103.3	527	8.1	2.4	7.0	1.5
	1.0	20.6	9.1	103.1	527	8.1	2.5		1.6
	2.0	20.5	9.1	103.0	527	8.0	2.5		1.9
	3.0	20.2	9.2	103.3	527	7.9	2.5		1.9
	4.0	20.1	9.0	100.9	527	7.6	2.6		3.0
	5.0	20.0	8.9	99.5	531	7.5	2.6		2.8
	6.0	19.5	9.7	107.4	528	7.2	2.7		3.4
	7.0	15.6	9.4	95.4	559	7.1	2.8		3.7
	8.0	11.4	7.3	67.7	565	7.0	3.0		4.4
	9.0	9.4	6.1	53.6	559	7.0	3.1		5.2
	9.0	9.4	6.6	58.7	559	7.0	3.0		5.0
	10.0	8.0	3.6	30.8	561	6.9	3.3		4.9
	11.0	7.1	1.6	13.6	561	6.9	3.8		4.1
	12.0	6.7	0.8	6.2	562	6.9	4.2		4.1
	13.0	6.2	0.5	3.9	570	6.9	5.9		2.9
	14.5	5.9	0.5	4.2	586	6.9	8.1		2.4

an inability to filter out the more buoyant algae, most of which are cyanobacteria. There is no indication from the algae data that the watershed is a major force in current water quality conditions in the lake on a daily to seasonal basis. This does not negate the value of watershed management for long term lake protection, but does suggest that watershed management is not a pressing need to solve existing lake problems.

Zooplankton samples were collected in June and August of 2012 (Table 6). Individual densities and biomasses were moderate in June and low in July, consistent with predation effects by young of the year fish and other planktivorous fish like sunfish and perch. Rotifers were most common in June and small cladocerans were most abundant (although not common) in August. No zebra mussel veligers were detected in the June sample, but almost 3 per liter were found in August. This suggests a substantial reproductive potential by zebra mussels and is consistent with the fall increase in small mussels noted in late 2011 and 2012. Yet the density of veligers is low in relation to other studies of zebra mussels, ranging from Minnesota to Vermont, where concentrations have ranged from 2 to 200 per liter of lake water. While 3/L represents a large number when considering the whole lake volume, it does not suggest a high magnitude zebra mussel population or elevated reproduction encountered in most other infested lakes; this is also consistent with findings for Laurel Lake, where attachment points are limited and overall density of zebra mussels is at the low end for infested lakes.

In 2013 zooplankton samples were collected weekly with the intent of more detailed characterization of zebra mussel veliger densities. Veligers were never abundant, however, and could not even be detected by the normal analysis procedure. Examination of more material did

![WRS]

Table 5. Phytoplankton in Laurel Lake in 2012 - 2017.

	PHYTOPLANKTON ABUNDANCE																						
	Surface	7m	Surface	Surface	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Epilimnion	Surface	Surface	Surface	Surface	Surface	Surface
TAXON	06/28/12	07/03/12	07/27/12	08/21/12	6/19/13	6/26/13	7/3/13	7/10/13	7/17/13	7/24/13	7/31/13	8/7/13	8/14/13	8/21/13	8/26/13	9/4/13	9/11/13	04/29/14	06/19/14	08/19/14	08/17/15	9/7/16	7/21/17
BACILLARIOPHYTA																							
Centric Diatoms																							
Aulacoseira					x																		
Stephanodiscus																		x	x	x			
Araphid Pennate Diatoms																							
Asterionella																		x					
Fragilaria/related taxa	x	x	x	x											x			x		x		x	
Synedra								x										x		x			x
Tabellaria					x																		
Biraphid Pennate Diatoms																							
Cymbella																		x					
Navicula/related taxa	x		x															x	x				
Nitzschia			x	x																			
CHLOROPHYTA																							
Flagellated Chlorophytes																							
Pandorina			x																				
Coccoid/Colonial Chlorophytes																							
Ankistrodesmus		x																					
Botryococcus	x																						
Crucigenia	x	x				x	x		x	x	x	x	x	x					x	x			
Elakatothrix	x	x									x								x			x	
Oocystis	x	x							x		x								x		x		
Pediastrum													x										
Schroederia																							x
Sphaerocystis				x					x	x	x	x	x	x								x	x
Tetraedron	x																						
Desmids																							
Mougeotia						x	x												x				
Spirogyra																			x				
Zygnema																			x				
CHRYSOPHYTA																							
Flagellated Classic Chrysophytes																							
Chromulina																							x
Dinobryon			xx	x	xx	xx	x	x	x	x	x	xx	xx	x				x		x	x	x	xx
Mallomonas	x		x	x														x	x	x		x	x
Synura			xx	x							x	x	x	x					x				
Non-Motile Classic Chrysophytes																							
Other Non-Motile Classic Goldens	x	x																					
CRYPTOPHYTA																							
Cryptomonas	x	x	x	x				x	x	x		x				x	x		x	x	x		
CYANOPHYTA																							
Unicellular and Colonial Forms																							
Aphanocapsa	x	xx	x	x						x			x	x	x	x			x			xx	
Chroococcus			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x
Gomphosphaeria	x	xx																		x	x		x
Microcystis										x	x	x	x	x	x	x	xx		x	x			x
Filamentous Nitrogen Fixers																							
Anabaena					x	x								x					x				
Filamentous Non-Nitrogen Fixers																							
Lyngbya				x	x								x	x	x	x	x			x			
EUGLENOPHYTA																							
Trachelomonas	x	x																					
PYRRHOPHYTA																							
Ceratium													x		x	x	x						x
Peridinium			x	x			x						x		x	x	x					x	x

Table 6. Zooplankton in Laurel Lake in 2012 - 2017.

	ZOOPLANKTON DENSITY																								
TAXON	6/28/12	8/21/12	9/15/12	6/19/13	6/26/13	7/3/13	7/10/13	7/17/13	7/24/13	7/31/13	8/7/13	8/14/13	8/21/13	8/26/13	9/4/13	9/11/13	4/29/14	6/19/14	7/18/14	8/19/14	6/26/15	8/17/15	6/14/16	8/25/16	9/5/17
PROTOZOA																									
Ciliophora	X			X	X					X			X	X					X						
ROTIFERA																									
Asplanchna	X	X				X	X					X	X			X		X		X	X	X	X		
Conochilus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	XX	X	X	XX	X	X
Filinia																									X
Kellicottia	X			X													X				X	X	X		X
Keratella	X					X															X				X
Polyarthra			X		X	X						X												X	
COPEPODA																									
Copepoda-Cyclopoida																									
Cyclops	X	X	X	X	X			X	X		X	X		X	X						X	X	X	X	
Mesocyclops	X	X	X	X	X	X	X		X	X	X	X		X	X		X	X	X	X	X	X	X	X	X
Copepoda-Calanoida																									
Diaptomus	X	X	X	X	X		X		X	X	X	X	X	X	X	X	XX	X	X	XX	X	X	X	XX	XX
Other Copepoda-Nauplii	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
CLADOCERA																									
Alona																							X		
Bosmina	X	X	X			X	X	X	X	X	X	X	X	X	X				X	X		X	XX		
Chydorus	X																							X	
Ceriodaphnia								X	X		X		X	X		X	X		X	X	X	X	X		X
Daphnia ambigua	X	X		X	X	XX	XX	X	XX	XX	XX	X	X	X	X	X	X	XX	XX	XX	X	X		XX	XX
Daphnia galeata	X			X	X	X	X																		
Diaphanosoma																							X		X
OTHER ZOOPLANKTON																									
Chaoborus																X					X			X	
Chironomidae																							X		
Ostracoda											X	X	X												
Dreissena polymorpha veligers	<0.01/L	2.9/L	<0.01/L	<0.01/L	<0.01/L	<0.01/L	<0.01/L	<0.1/L	<0.1/L	<0.01/L	<0.01/L	<0.1/L	<0.1/L	<0.01/L	<0.01/L	<0.01/L	<0.01/L	<0.1/l	1.9/L	0.85/L	<0.01/L	2.0/L	<0.02/L	<0.01/L	<0.01/L

detect early stage veligers on 4 dates, but at very low densities. Some low level of reproduction is indicated in July and August, and may be consistent with lower adult zebra mussel densities in 2013.

Zooplankton samples were collected on four dates in 2014, late April and near the middle of June, July and August. Samples were collected from 3 locations (off boat launch, at deepest point, and off causeway) and composited to provide more material for examination. No veligers were observed in late April, and very few were detected in June, but densities were estimated at 1.9/L in July and 0.85/L in August. As in 2013, these are low densities relative to other infested systems, but represent a large number of veligers that can colonize shallow areas previously impacted by drawdown or go downstream to the Housatonic River.

Sampling in 2015 and 2016 was conducted at two sites (off boat ramp and central deep hole) on two dates (June and August). No veligers were found in the June 2015 samples, while the average for the August samples was 2.0/L. No veligers were found in the 2016 samples. Zooplankton were sampled only in early September of 2017, and no zebra mussel veligers were detected. Certainly veligers were produced in 2015, 2016, and 2017, just at low levels not detectable by the analysis applied. The reasons for variable veliger production are not known, but generally low production appears associated with a relatively small population of zebra mussels, held in check by limited substrate and drawdown.

Other zooplankton comprised a moderately diverse assemblage that included rotifers, copepods and cladocerans. *Daphnia*, the large-bodied, filter-feeding zooplankton that are valuable for both algae removal and fish food, achieved peak abundance in late spring or early summer and was detectable through the summer; this is rather unusual in New England lakes, but is highly desirable. More often, *Daphnia* are consumed by small fish that hatch in June and disappear by late July. Food resources appear to favor elevated *Daphnia* reproduction and predation pressure is not intense, suggesting a balanced or gamefish-dominated fishery. Overall, the zooplankton community of Laurel Lake is in a desirable condition, except for the presence of zebra mussel veligers.

Wetland Plot Evaluation

In over 20 years of assessing the impacts of drawdowns on adjacent lakes in the Berkshires, no impacts distinctly attributable to drawdown have been detected. The most commonly cited potential impact is land slumping relating to drying of the wetland soils, a condition that might be expected to sufficiently change habitat to allow different plants and animals to become dominant. This is a factor in wetland change in some geographic areas, but the “tightness” of the soils in most of the Berkshire region limits drying. Wetland soils are often frozen for just a few inches from the surface and remain moist below that level. Some changes in wetland vegetation and habitat are to be expected over time, either directionally as material is deposited and the wetland ages, or randomly in response to extreme weather events, trees falling over, or other episodic events. Yet detecting any changes from drawdowns has been elusive. Despite this long-term observation, conservation commissions often ask for monitoring, given logical concern over possible wetland impacts and their duty under the Wetlands Protection Act. We have moved over time from detailed quantitative vegetative inventories to photodocumentation to keep costs manageable, and at Laurel Lake all designated wetland plots (Figure 5) have been photographed twice (2011–2012, Figure 45).

Figure 45. Emergent wetland plot photodocumentation, Sept. 2011 and 2012


2011 GPS 162 2012

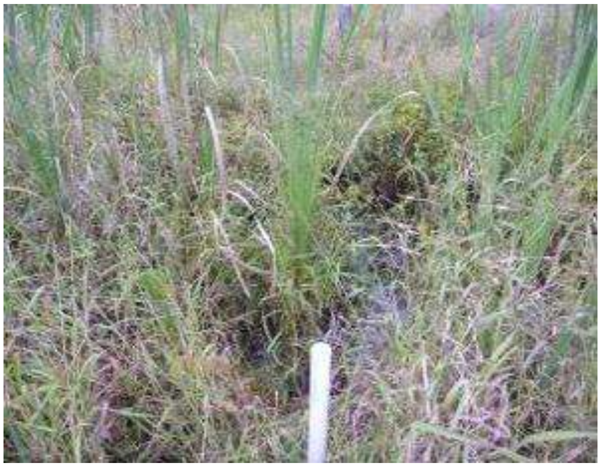

2011 GPS 163 2012


2011 GPS 164 2012

Figure 45. Wetland plot photos (continued)


2011 GPS 165 2012


2011 GPS 166 2012




2011 GPS 167 2012 (post lost, location not exact)

Figure 45. Wetland plot photos (continued)


2011 GPS 168 2012


2011 GPS 169 2012


2011 GPS 170 2012

Figure 45. Wetland plot photos (continued)

2011 GPS 171 2012 (post lost, location not exact)

Two posts were lost in 2012, at sites 167 and 171, both in the western wetland, making matching photos more difficult to obtain, although GPS reading allowed us to get close. Other pairs are closer in view, but we did not always get exactly the same position or scale. Despite being shot at the same time of year, there are differences in growing season features evident; the 2011 photos show more vegetation dying off, while the dates are only five days from being exactly one year apart. Considering that the horizontal distribution of annual plants varies from year to year, there are no obvious shifts in the vegetation in the designated plots, although slight differences are evident. The paired images do not indicate substantial changes in habitat value for wetland animal species.

Changes in wetland features from anything short of a catastrophic event like a major flood are likely to be slow. We would not expect major shifts between two consecutive years, and monitoring can be performed less frequently without loss of important monitoring information. Further documentation of wetland plots has therefore not been conducted.

Watershed Evaluation

Watershed management is a desirable part of lake management, but does not have substantial bearing on the problems experienced in Laurel Lake, namely invasive rooted plants and zebra mussels. Neither the invasive plants (Eurasian watermilfoil, spiny naiad) nor the zebra mussels are caused by watershed features or activities, and no amount of watershed management will aid their control in the lake. Laurel Lake has exhibited very desirable water clarity over the last 6 years and oxygen is adequate to a depth of >30 ft, about as deep as one can expect in Berkshire lakes. Nevertheless, developing a watershed management plan is desirable and the LLPA has an interest in providing such a plan. However, cost and jurisdictional issues limit the ability of the LLPA to generate a complete plan; proper planning would involve extensive sampling on private property, creating issues of both expense and access. The approach pursued to date has been more along the lines of the MA DEP publication entitled Surveying a Lake Watershed and Preparing an Action Plan, itself based on a 1997 publication by the State of Maine, minus substantial interaction with landowners. The watershed was viewed from virtually every public road within it, possible problem areas were identified, and these areas were investigated further, to the extent possible without permission to walk entire properties and collect water samples for testing.

The first cut analysis was performed in 2011 annual and is updated here as Figure 46. The original effort held up, in that no additional problem sites were found in a fall 2012 assessment. However, most of the sites identified in 2011 were eliminated as major sources. All could benefit from improved site management practices, but there were no obvious problems or violations of known laws or ordinances at most sites. An itemized review of parcels is provided in Table 7. The primary problem areas at this time are High Lawn Farm, the Fox Hollow Complex and the Rt 20 corridor; each is close to the lake and has obvious pollution sources with inadequate runoff controls. Of secondary interest are the Sargent Brook Road and Bramble Lane residential areas, which appear to have limited runoff issues but could be contributing from septic systems. Other areas are either not major sources (e.g., Schermerhorn Park, fields south of Plunkett Street), have adequate detention facilities on-site or between the source and the lake (e.g., Cranwell, Immaculate Heart Seminary, Kimball Farms), or are far enough from the lake to allow substantial attenuation of loads.

High Lawn Farm is a dairy operation that grows most of its own feed and uses the manure generated by the cows as fertilizer on the fields. Many of the fields drain to the lake through multiple small channels with just a steep wooded slope as a buffer, offering minimal attenuation potential. Nutrient inputs from this operation could be very high, and the logical next step would be storm water sampling to corroborate expected loading. Additionally, sediment inputs could be high during winter and spring, as there do not appear to be cover crops on the corn fields. Sampling should therefore be conducted in all seasons to adequately characterize loading, and would include forms of phosphorus, forms of nitrogen, and turbidity or suspended solids.

Fox Hollow is a multi-faceted cluster housing community including Lakeside Condo Trust (44 units situated on a slope draining to the lake), a timeshare and condo group, The Ponds at Foxhollow (west of the condos and draining into the area just west of the causeway), and the Enlighten Next World Center (at the old Foxhollow estate building). There is extensive lawn area and relating landscaping, all of which appear to be fertilized. There is an extensive storm water drainage system, directing water to the slope upgradient from the lake. Nutrient input could be high, and the logical next step would be storm water sampling to corroborate expected loading. Sampling in spring and summer would be most important, but seasonal sampling to match

Figure 46. Potential pollution problem parcels in the Laurel Lake watershed.

Table 7. Watershed pollution hotspot investigation results

Location (See Fig 37)	Description	Hypothesized water quality issues	Investigative conclusions
1	**South Drainage**		
1A	High Lawn Farm	Agricultural runoff, use of manure for fertilizer, sediment during non-growing season	Definite potential for impacts; minimal buffer zones, close to lake, steep slopes, no cover crops in winter, drainage channels to lake
1B	Fox Hollow complex	Urban runoff, fertilizer use	Definite potential for imapcts; managed landscape with extensive drainage systems lead to lake
2	**West Drainage**		
2A	Church and fields off Rt 7	Urban and/or agricultural runoff	Minimal impact potential; no apparent drainage system, adequate buffer zones, fields mostly fallow
2B	Edith Wharton Estate	Fertilizer runoff	Minimal impact potential; adequate buffer zones, drains to large wetland system
2C	Sargent Brook Road residential area	Urban runoff, septic system inputs	Limited potential impact; area not very large, no obvious excessive use of fertilizer, no direct drainage systems to lake, some septic system impact potential
3	**Sargent Brook (North) Drainage**		
3A	Kimball Farms cluster development	Urban runoff, fertilizer use	Minimal impact potential; far from lake, limited unnatural landscape area, drainage systems lead to detention areas
3B	Immaculate Heart Seminary	Urban runoff, fertilizer use	Minimal impact potential; far from lake and stream system, but direct observations very limited
3C	Schermerhorn Park (fields)	Agricultural runoff	Minimal impact potential; fallow fields, not agricultural, very limited runoff potential
3D	Cranwell driving range and part of golf course	Fertilizer runoff	Limited potential impact; no direct drainage systems to streams, far from lake, but fertilizer use over substantial area bears scrutiny
3E	Fallow fields south of Plunkett Street	Agricultural runoff	Minimal impact potential; fallow fields, not agricultural, very limited runoff potential
3F	Bramble Lane residential area	Urban runoff, septic system inputs	Limited potential impact; area not very large, no obvious excessive use of fertilizer, no direct drainage systems to lake, some septic system impact potential, but some properties are sewered
4	**East Drainage**		
4A	Portion of Cranwell golf course	Fertilizer runoff	Minimal impact potential; area not that large, large buffer zone, extensive wetland before lake
4B	Rt 20 corridor	Runoff from impervious surfaces	Distinct impact potential; drainage systems direct to lake, vehicle related inputs

assessment of High Lawn Farm would be appropriate. Phosphorus, nitrogen and turbidity or suspended solids should be assessed at a minimum.

The Route 20 corridor is a stretch of largely impervious surface along the east side of the lake and with one main input point to the lake near the boat launch and a few smaller input points. The intermittent stream from the east (Area 4 in Figure 46) also enters near the boat ramp, complicating separation of inputs. Vehicular contaminants, including metals and hydrocarbons, wash off of Route 20. Fertilizer and other contaminants from adjacent residential properties are also likely to be contributed through the Route 20 drainage system. Given the limited differential elevation between the road and the lake in the boat launch area, there are few options for detaining or processing runoff in this area. Some sampling of runoff would be advised to verify the level of contribution, with testing of phosphorus, nitrogen and turbidity or suspended solids, but if the load is significant it will take some creative engineering to reduce inputs.

The Sargent Brook Road and Bramble Lane residential areas are older developments with smaller lots and mostly summer homes. A few are year round residences, but use of these areas is only intense during the summer. Most lawns are not highly landscaped and most do not show signs of any appreciable fertilization. There is no known piped drainage system with discharge to the lake, although runoff may reach the lake by overland, diffuse routes during larger storms. Over half the properties on Bramble Lane are tied into the Lee sewerage system, with the remainder on septic systems. The seasonal use pattern for most systems minimizes inputs and soils in this area have substantial adsorptive capacity for phosphorus, but there is also considerable rock and shallow depth to groundwater, so inputs to the lake are possible but undocumented. Education of residents to minimize residential property impacts is advised, and has been performed to some extent by the LLPA. There isn’t really a stream or discharge to be sampled, but it would be possible to sample the groundwater where it enters the lake with Littoral Interstitial Porewater (LIP) samplers to assess possible septic system inputs. Testing would include dissolved phosphorus, nitrate and ammonium nitrogen, and dissolved iron.

Other potential source areas either turned out to have very low potential to generate contaminants (e.g., Schermerhorn Park, the fields south of Plunkett Road, and the church and fields off Route 7) or far enough from the lake and with enough detention capacity in between to limit inputs. The large wetlands west of the causeway and east of Route 20 provide considerable purification potential, while a large wetland augmented by beaver dams north of Plunkett Street provides substantial detention in the Sargent Brook drainage area. Some of the more recent developments, like Kimball Farms, have detention facilities on-site. Attention should be paid to property management at the developed sites; fertilization practices should be examined and both structural and non-structural pollution control practices should be considered. However, the overall contribution from these sites does not appear substantial. To corroborate this assessment, sampling during high flow events at the causeway, the Sargent Brook inlet, and upstream of the culvert under Route 20 (avoiding associated storm water pipes) should be conducted to assess maximum loads. Phosphorus, nitrogen and turbidity or suspended solids should be assessed.

Only after a sampling program as identified above can a complete watershed management plan be developed, but we have narrowed the focus considerably, and it would be possible now to enter into discussions with the owners of key land parcels about access, sampling, and potential management adjustments. No further assessment has occurred, based on budget limitations.

While field assessment has been limited, WRS undertook a modeling exercise to evaluate likely loading to Laurel Lake based on available data and information. The watershed was divided into 4 drainage areas (Figure 46) and land use in each was characterized (Table 8). Export coefficients were applied to generate loads of water, nitrogen and phosphorus (Table 9) through the Lake Loading Response Model, developed in part by WRS personnel and applied in TMDL work for New England states and the federal government. Based on those calculations, a series of empirical equations are applied within the model to predict average phosphorus and nitrogen concentrations. The important lake features, calculated through the model, are listed in Table 10; phosphorus and nitrogen mean values from available data are an exact match for the predicted values.

Using this model, we can project other lake conditions, such as water clarity as Secchi transparency or algae abundance as chlorophyll-a. Actual values for water clarity are higher than predicted by the model, while measured chlorophyll-a concentrations are lower than suggested by the model. The amount of actual data are limited, but the results suggest that conditions are at least as good as predicted by the model, and those conditions are acceptable for all designated uses of Laurel Lake. There is no reason why Laurel Lake should be on the impaired waters list for Massachusetts for any water quality feature other than possibly low oxygen in deep water, a common and largely natural phenomenon. Impairment by invasive species would be a reasonable listing. However, the 2014 Massachusetts impaired waters list includes Laurel Lake as needing a TMDL on the basis of invasive species, oxygen and phosphorus, although the rationale is not clear from the listing.

Table 8. Laurel Lake watershed land use

	BASIN 1	BASIN 2	BASIN 3	BASIN 4
LAND USE	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)
Urban 1 (LDR)	10.1	4.4	0.8	10.5
Urban 2 (MDR/Hwy)	0.0	2.4	9.3	0.0
Urban 3 (HDR/Com)	0.4	39.9	62.1	19.8
Urban 4 (Ind)	0.8	21.8	9.7	0.0
Urban 5 (P/I/R/C)	0.4	0.8	28.2	17.7
Agric 1 (Cvr Crop)	35.5	21.4	35.1	7.7
Agric 2 (Row Crop)	0.0	0.0	0.0	0.0
Agric 3 (Grazing)	0.0	2.4	0.0	0.0
Agric 4 (Feedlot)	0.0	0.0	0.0	0.0
Forest 1 (Upland)	23.8	86.7	90.7	96.4
Forest 2 (Wetland)	0.0	0.0	0.0	0.0
Open 1 (Wetland/Lake)	0.0	10.5	0.0	0.4
Open 2 (Meadow)	0.0	1.6	14.9	0.0
TOTAL	71.0	191.9	250.8	152.4

Table 9. Predicted loads of phosphorus, nitrogen and water to Laurel Lake

DIRECT LOADS TO LAKE	P (KG/YR)	N (KG/YR)	WATER (CU.M/YR)
ATMOSPHERIC	14.0	453.7	844580
INTERNAL	27.8	55.6	0
WATERFOWL	4.0	19.0	0
SEPTIC SYSTEM	1.1	26.7	1519
WATERSHED LOAD	142.6	4618.8	3565816
TOTAL LOAD TO LAKE	189.5	5173.7	4411915
TOTAL INPUT CONC. (MG/L)	0.043	1.173	

Table 10. Predicted and measured Laurel Lake features

	PHOSPHORUS			
SYMBOL	**PARAMETER**	**UNITS**	**DERIVATION**	**VALUE**
TP	Lake Total Phosphorus Conc.	ppb	From in-lake models	20
KG	Phosphorus Load to Lake	kg/yr	From export model	189
L	Phosphorus Load to Lake	g P/m2/yr	KG*1000/A	0.271
TPin	Influent (Inflow) Total Phosphorus	ppb	From export model	43
TPout	Effluent (Outlet) Total Phosphorus	ppb	From data, if available	20
I	Inflow	m3/yr	From export model	4411915
A	Lake Area	m2	From data	698000
V	Lake Volume	m3	From data	5100000
Z	Mean Depth	m	Volume/area	7.307
F	Flushing Rate	flushings/yr	Inflow/volume	0.865
S	Suspended Fraction	no units	Effluent TP/Influent TP	0.466
Qs	Areal Water Load	m/yr	Z(F)	6.321
Vs	Settling Velocity	m	Z(S)	3.403
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.568
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)	0.518
	NITROGEN			
SYMBOL	**PARAMETER**	**UNITS**	**DERIVATION**	**VALUE**
TN	Lake Total Nitrogen Conc.	ppb	From in-lake models	600
KG	Nitrogen Load to Lake	kg/yr	From export model	5174
L1	Nitrogen Load to Lake	g N/m2/yr	KG*1000/A	7.41
L2	Nitrogen Load to Lake	mg N/m2/yr	KG*1000000/A	7412
C1	Coefficient of Attenuation, from F	fraction/yr	2.7183^(0.5541(ln(F))-0.367)	0.64
C2	Coefficient of Attenuation, from L	fraction/yr	2.7183^(0.71(ln(L2))-6.426)	0.91
C3	Coefficient of Attenuation, from L/Z	fraction/yr	2.7183^(0.594(ln(L2/Z))-4.144)	0.97

Detailed Conclusions from Seven Years of Study

Substrate

1. Substrate is coarsest (rock and gravel) near the shore and grades to sand and then finer silt with distance from shore. Silty sediment dominates at water depths greater than about 7 ft and affects plant and zebra mussel distribution.
2. Larger rocks are present throughout the lake, but represent <10% of substrate in areas <14 ft deep and only about 1% of substrate in deeper areas. However, rocks support dense zebra mussel populations to depths of at least 30 ft, below which low oxygen during summer restricts colonization.
3. Cobble (smaller rocks) represents slightly less than 20% of substrate near the shoreline and decline to negligible abundance in water >7 ft deep. Cobble supports dense zebra mussel populations if not exposed to drawdown.
4. Gravel (very small rocks) is also most abundant near the shoreline (20-25%) but declines to negligible levels in water >5 ft deep. Gravel supports zebra mussels, but not at more than moderate densities.
5. Sand is moderately abundant in water <8 ft deep and still present in water up to about 14 ft deep, but does not support appreciable densities of zebra mussels.
6. Silty sediment is present throughout the lake, but becomes the dominant substrate in water >6 ft deep and does not support zebra mussels.
7. Woody debris is present throughout the lake but represents <1% of substrate. Yet woody debris in <30 ft of water often exhibits moderate to dense zebra mussel populations.
8. Rooted aquatic plants can grow to substantial density to depths of 14 ft. Zebra mussel veligers settle on all plants and appear to attempt to colonize them, but the annual cycle of most plants does not support zebra mussels outside of summer and early fall. Only a few plant species, most notably Eurasian watermilfoil and to a lesser extent water celery, overwinter in a vegetative state and support zebra mussels older than a few months.
9. Exposure of substrate and rooted plants through drawdown kills associated zebra mussels within a week, but those substrates are colonized the following summer by settling veligers (zebra mussel larvae). Repeated drawdown is necessary to keep substrates free of live zebra mussels.

Aquatic Plants

10. Thirty seven species of aquatic macrophytic plants are listed for the lake; 8 of which were encountered in at least 20% of all surveyed plots. Four invasive species have been recorded for the lake, but only *Myriophyllum spicatum* (Eurasian watermilfoil) is abundant lakewide at this time. *Najas minor* (spiny naiad) is increasing in abundance, however, and is favored by drawdown, leading to dense growths in shallow areas with silty sediment, mainly in the northern cove in the Lenox part of the lake and near the causeway at the western end of the lake. Invasive *Trapa natans* (water chestnut) and *Potamogeton crispus* (curlyleaf pondweed) are minor components of the plant community at this time.
11. *Vallisneria americana* (water celery or tapegrass) was the most frequently observed plant, but rarely achieved high biovolume, as it does not project upward far from the bottom. Lower frequency but higher biovolume was associated with Eurasian watermilfoil and several pondweed species (*Potamogeton* spp. and *Stuckenia pectinata*), which can grow to the surface from depths of up to 12 ft in Laurel Lake.
12. Plant growth increases with silt coverage in shallow water until light becomes limiting at 14 to 17 ft of water depth. However, different species peak in abundance at different depths, creating a mosaic of assemblages and plant densities in Laurel Lake.

13. Cover is substantial in 4 to 12 ft of water; about 75% of the bottom in that depth range is covered by plants on average, and represents valuable habitat for many aquatic and water dependent species. By itself, cover is not a recreational problem unless the species have floating leaves and cover most of the surface, which is very uncommon in Laurel Lake.
14. Highest plant biovolume values occur in 6 to 10 ft of water, but biovolume is similar between 4 and 12 ft of water depth. In general, biovolume is not excessive in Laurel Lake, with no more than 50% of the volume filled in any depth interval on average. However, there are localized areas where biovolume is excessive, and these areas tend to have Eurasian watermilfoil, spiny naiad, or sago pondweed as the dominant plant. High biovolume affects ecological interactions and creates recreational problems.
15. Lower density of plants in water 0 to 4 ft deep relates to both natural substrate and water level fluctuation. Drawdown of 3 ft extends its influence up to 6 ft of water depth from actual exposure and ice damage.
16. Drawdown favors annual species (seed and spore producers), such as *Chara* and the naiads, which appear to be increasing in importance in the shallow water of Laurel Lake. Density is not increasing overall, however; the same areas experience roughly the same plant density each year, just with shifting species composition.
17. Drawdown negatively impacts perennial species, most notably Eurasian watermilfoil. Yet with peak milfoil abundance in water >6 ft deep, this species cannot practically be controlled by drawdown in Laurel Lake. Drawdown keeps perennial species from becoming abundant in the zone affected by drawdown, which is up to 6 ft of water depth with the 3 ft drawdown.
18. Plant community composition and abundance are somewhat variable among years, as much of the community is re-established from seeds each spring, but the depth limits on growth are similar each year and a fringe of aquatic plants forms in the same area around the lake. Other than the apparent increase by spiny naiad and possibly *Chara*, there have been no major changes in the overall features of the plant community of Laurel Lake over at least the last 6 years.
19. Eurasian watermilfoil, and to a lesser extent water celery, provide year round plant substrate for zebra mussels. Continued attachment by zebra mussels at distances up to about 2 ft off the lake bottom has been observed. Zebra mussel density is not more than moderate, but populations supported by perennial plants represent a source of veligers that can colonize shallow water habitats each year.

Invertebrates

20. Zebra mussels invaded the lake in 2008 or slightly earlier, making Laurel Lake the first documented lake in Massachusetts to have this invasive species.
21. The most suitable substrate for zebra mussels is in shallow water; most zebra mussels in water >6 ft are restricted to scattered rocks or logs and the base of plants, mainly Eurasian watermilfoil, keeping overall densities relatively low in deeper water. Zebra mussels are restricted to scattered rocks and logs in water between 15 and 30 ft deep, where oxygen is sufficient but suitable substrate is very limited, and are absent below about 30 ft due to low oxygen during summer, although some colonization of rocks is reported to 35 ft.
22. The drawdown is clearly limiting zebra mussels in water <5-6 ft, with substrates in water <3 ft exposed and ice damage over areas between 3 and 5-6 ft deep, depending on the winter weather and ice thickness. Extending the drawdown to 5 ft would extend the impacts to water depths up to 8 ft, the zone with the greatest substrate suitability, but would not address all areas of zebra mussel colonization.
23. Zebra mussels colonize shallow areas during late summer, suggesting production of veligers in at least July and August, but the maximum detected veliger abundance is near the low end of the range reported for other infested northern lakes and densities in most

samples are non-detectable. The largest colonization period appears to be in September, resulting in many more small zebra mussels in shallow areas during December surveys than August or September surveys and making winter drawdown important to conditions the following spring.

24. Laurel Lake supports a diverse invertebrate fauna, with many larval forms of insects present, but the focus of most studies on lakes with drawdowns is on mollusk populations. Limited mobility and endangered status of so many species makes them the logical target of assessment.
25. Bivalve molluscs other than zebra mussels are uncommon in Laurel Lake. Two species of larger mussels (Unionidae) are reported from the lake and both were found in 2012, but most individuals were dead and all shells were colonized by zebra mussels; no live specimens of Unionid bivalves have been found since 2014. Tiny fingernail clams (Sphaeriidae) are present but uncommon in Laurel Lake.
26. A total of 10 snail species are reported from Laurel Lake, but 3 species of snails represented the vast majority of the individuals collected in surveys conducted in 2012-2016. *Amnicola limosa*, *Valvata tricarinata* and *Helisoma anceps* are the most common snail species encountered.
27. *Marstonia lustrica*, a species protected under MESA, was uncommon and represented <1 to 6% of all snails sampled on any given day, with an average of 2%. The number of *M. lustrica* found averages just over 1 per sample. There is no evidence of any negative impact of the drawdown on *M. lustrica*, but at such low densities, detecting an impact is difficult.
28. Surveys in June and August/September indicate higher snail densities in water <6 feet deep in late summer, consistent with recruitment from movement into shallow water and reproduction. Overall snail density appears to be increasing in shallow water since drawdown began. While it is premature to declare this a benefit of drawdown, it cannot be concluded that the drawdown is hurting the overall snail population, and an increase in recently dead snails in December is likely related to increased snail abundance during summer. Different species of snails may be differentially impacted, but there are no major shifts.

Water Quality

29. Water quality in Laurel Lake appears generally acceptable for all designated uses. We monitored only features that can be measured in the field, including water clarity, temperature, oxygen, pH, conductivity and turbidity, but few problems were indicated.
30. Laurel Lake suffers oxygen depression in water deeper than 30 ft and depletion in water deeper than about 35 ft by late summer, but this leaves most of the lake area and volume suitable for fish and other wildlife habitat, and anoxia in deep water is a natural phenomenon in most thermally stratified lakes.
31. Water clarity is moderate to high. Elevated nutrient levels will produce lower water clarity in nearly all instances, so acceptable levels of phosphorus and nitrogen are suggested. Zebra mussels may improve clarity by filtering water, but are known to encourage buoyant blue-green algae blooms. Mild blue-green blooms have been observed, but conditions remain acceptable for contact recreation and other sensitive lake uses.

Plankton

32. Spring and summer phytoplankton consist of a mix of common species, mostly within the algae groups of diatoms, greens, goldens and blue-greens. Some problem blue-greens have been observed in some years, but are rarely dominant. Most forms can be consumed by zooplankton and support the open water food web.

33. Phytoplankton biomass is generally low to moderate, suitable for supporting a desirable food web that includes many fish and wildlife species. Excessive fertilization is not indicated.
34. Zooplankton composition includes representatives of the three major zooplankton groups, rotifers, copepods and cladocerans, with the desirable cladoceran *Daphnia* often dominant.
35. Zooplankton biomass is moderate, but remains moderate with *Daphnia* present through most summers. This is desirable in terms of grazing on algae to maintain high water clarity and for supporting small fish populations which prefer *Daphnia* as a food source. Balanced panfish and gamefish populations are indicated.
36. Zebra mussel veligers are not encountered before July, and reach peak densities of <1-3/L in August. This is lower than the reported range of veliger densities for all other northern lakes and is likely a function of limited suitable substrate for colonization leading to less expansive and dense reproducing zebra mussel accumulations.

Adjacent Wetlands

37. In a very limited study focusing on photodocumentation of wetland plots, no striking changes were observed, but none would be expected over the monitoring timeframe in response to drawdown.
38. There is no evidence that the adjacent wetlands are susceptible to influence from drawdown, but photodocumentation of marked plots with known GPS coordinates could allow future assessment if concerns exist.
39. It may be advisable to examine wetland features, with 7 drawdowns having been conducted between 2010 and 2017. If there have not been obvious changes in that time, it seems unlikely that drawdown will be a major influence on these wetlands.

Watershed

40. Examination of the watershed of Laurel Lake from online imagery and visual field assessment suggests up to 13 possible problem land parcels, but only a few represent likely significant threats at this time. Follow-up water quality assessment for runoff from those parcels is desirable to advance any watershed management prioritization and planning, but such effort is beyond the jurisdictional and budgetary means of the LLPA.
41. Watershed management is an integral part of lake management, and despite the prevalence of problems in Laurel Lake that cannot be addressed through watershed management, efforts to control inputs and protect the long-term quality of the lake are warranted. A complete watershed management plan cannot be developed without access to and sampling on private property, but watershed investigation has identified three high priority parcels and two areas of secondary importance that could be further assessed. Neither Lenox nor Lee has taken any action in this regard.
42. Modeling of the watershed suggests an annual phosphorus load of 190 kg/yr and a nitrogen load of 5174 kg/yr. Predicted average concentrations of 20 ug/L for phosphorus and 600 ug/L for nitrogen closely match available data for the lake. These are borderline concentrations that may facilitate algae blooms at times, but are not excessive and are generally appropriate for multi-use lakes where fishing is an important lake use.
43. Watershed management will not solve either of the most pressing in-lake invasive species problems in Laurel Lake: Eurasian water milfoil and zebra mussels. Control of these species requires an in-lake solution. While watershed management is always a desirable component of overall lake management, it has a lower priority at Laurel Lake based on current water quality and the nature of defined problems at the lake. In-lake action should not be delayed because of any perception of watershed management needs.

Drawdown

44. Experience elsewhere has demonstrated large changes in lake ecology and negative impacts on recreation and other uses as a result of zebra mussel invasions. A rapid response plan for zebra mussels was in place at the state level and MA DCR was prepared to implement it, but other agencies intervened and discussion of options over an 18 month period yielded no action. The LLPA initiated efforts to actually address the infestation, gaining approval for the 3 ft drawdown that has been conducted in each of the last 7 years. This action is not sufficient by itself to eliminate zebra mussels, but represents an affordable first step that produces considerable benefit for minimal cost. Drawdown was not conducted in winter of 2017-2018, as the Lenox Conservation Commission rejected a request to renew the Order of Conditions.
45. A 3 ft drawdown has been conducted in each winter since 2010-2011, into 2017; 7 drawdowns have been completed as of this report, although no drawdown is currently underway. Laurel Lake has reached full pool level in March or April of each year after 2 to 7 weeks of refill time, including a very dry winter-spring period (2011-2012). The drawdown reached only 30 inches by December 1st in the first year, but has reached 36 inches in all other years. However, the initiation of refill, usually timed with ice-out, has been late in some years, leading to later achievement of full pool elevation. The lake should be full within a month of ice-out in nearly all years, and refill should commence with ice out.
46. The 3 ft drawdown exposes 12.3 acres of the 173 acre lake (7%), but this represents a disproportionately high amount of zebra mussel habitat. Between 61 and 65% of all hard substrate is within the zone of influence of the drawdown (including ice thickness, about 30 ac). Between 40 and 48% of all possible plant habitat for zebra mussels is also affected by the 3 ft drawdown.
47. The impact on zebra mussels in the drawdown zone of influence is striking. Rocks in water shallower than 5 ft have very few or no live zebra mussels in June after a drawdown, while rocks in water deeper than 7 ft are largely covered with larger zebra mussels. Veligers produced by zebra mussels in deeper water settle on shallow water substrates by fall each year, and many small zebra mussels are found in December surveys, but the drawdown eliminates these zebra mussels each winter when conducted.
48. The impact on the plant community is less striking. Eurasian watermilfoil is rare in the drawdown zone but often abundant in deeper water. Seed producing annual plants appear in the drawdown zone every summer, but plant density overall is reduced somewhat over what is observed in 6 to 10 ft of water. It is not clear that plant density would be higher in the drawdown zone without the drawdown, but the drawdown is likely to add to the effects of coarser substrate and natural water level fluctuation. There has been an increase in spiny naiad, an invasive plant favored by drawdown, in several shallow areas, but those areas have had dense plant growths for many years as a function of shallowness and less coarse substrate than most of the lake in the 0 to 4 ft depth range.
49. Large mollusks within the drawdown zone would be likely to be harmed by exposure, but there are few large mollusks left in Laurel Lake, and the shells of dead mussels of the family Unionidae are found covered in zebra mussels. The two species known for the lake, *Elliptio complanata* and *Pyganodon cataracta,* are not state-listed, protected species, but one might wonder if the reaction to the zebra mussel invasion would have been more responsive if protected large mussels were present.
50. The ecology of most snails in Laurel Lake is believed to involve overwintering in water deeper than where ice contacts sediment, so major drawdown impacts would not be expected. Surveys in August and December suggest that recently dead snails found in the drawdown zone represent a small portion of the summer population. No significant decrease in the overall snail population has been indicated. There might be slight shifts in relative

abundance of snails, but the snail community remains vibrant and no impacts can be directly attributed to drawdown.

51. One state-listed snail species, *Marstonia lustrica*, is present at low densities in Laurel Lake. There is no evidence of any substantial change in abundance as a result of drawdown, but as a rare species, densities are relatively low and changes are not easy to quantify.
52. Drawdown appears to have no measureable effect on water quality, and conditions have remained suitable for all designated uses of Laurel Lake during the 5 year period covered by this report.
53. Increasing the drawdown to 5 ft would extend the potential impact zone to 8 ft of water depth. This would impact 69 to 72% of hard substrate and 57 to 67% of available plant habitat for zebra mussels. Large, reproducing zebra mussels would remain in deeper water to continue to provide veligers to recolonize shallower water habitats, necessitating drawdown each year, but the threat to both in-lake conditions and downstream habitats would be reduced. Further drawdown does not appear to pose a major direct ecological threat, but there would be an increased probability of late refill each spring that could impact fish and wildlife populations.
54. Zebra mussels exposed by drawdown die in less than one week, much quicker if the temperature is below freezing. An increased drawdown that attained a deeper target for only a week would be sufficient to kill zebra mussels in that zone, after which the water level could be returned to the 3 ft level or refill could be continued. The risk of late refill could be minimized while maximizing inexpensive control of zebra mussels.
55. Killing Eurasian watermilfoil by exposure is most effective at sub-freezing temperatures, but with very cold weather the necessary duration of exposure can be just a few days. This opens the possibility of enhanced control of Eurasian watermilfoil as well as zebra mussels at minimal cost if the drawdown can be timed to match up with very cold conditions.
56. Techniques additional to shallow drawdown will be needed to address Eurasian watermilfoil and zebra mussels more completely in Laurel Lake. Options include hand pulling, suction harvesting, benthic mat deployment and herbicide application for milfoil, each of which is expensive and some of which have potential impacts on non-target organisms that create permitting issues. For zebra mussels, application of molluscicides, deployment of benthic barriers, or having divers physically crush them offer the greatest potential, but non-target impacts are also a concern. A short duration but very deep drawdown (30-35 ft) during cold weather could dramatically reduce milfoil and zebra mussels and could be part of an overall ecological restoration project at Laurel Lake.

Recommendations

Recommendations have been offered in most annual reports, but in the absence of direction from any regulatory agency the LLPA and WRS have determined next steps in management and monitoring each year. Available budget has been used as judiciously as possible to provide a combination baseline monitoring and investigative studies that would advance our knowledge of the situation in Laurel Lake and inform management decisions. The 3 foot drawdown has been repeated each winter until 2017-2018 but no other actions have been permitted or taken. Other management recommendations have included:

1. Expand the drawdown to the greatest depth that can be supported based on technical feasibility and non-target impacts – A 5 ft drawdown is possible with the existing outlet structure, but it would also be possible to pump the lake lower in a one-time effort to expose and kill all zebra mussels. Non-target impacts represent issues for the permitting process with any increase in drawdown.
2. Consider alternative control options for zebra mussels – The primary alternative to drawdown for widespread and economical control of zebra mussels would be a copper treatment that would have non-target impacts that represent issues for the permitting process.
3. Consider alternative control means for Eurasian water milfoil – Milfoil could be controlled with herbicides or some form of harvesting; complete control in any one year is unlikely, necessitating a multi-year approach. A greater drawdown for zebra mussel control would also impact milfoil, but would be unlikely to eliminate it. However, if a one-time treatment as with a systemic herbicide or deep drawdown was permitted, more localized and less obtrusive follow up methods such as hand harvesting or benthic barriers could be applied.
4. Town government should take the lead in addressing watershed management concerns - The LLPA has taken watershed management as far as it can with no authority over private land in the watershed. The Towns of Lee and Lenox should arrange for sampling and evaluation of inputs from noted potential problem parcels and follow up as warranted to reduce nutrient and sediment inputs. The withholding of a compliance certificate by the Lenox Conservation Commission because it believes that the LLPA should do more with watershed management is counterproductive.

With regard to further 3 foot drawdowns, they should commence on November 1st each year as they have, and refill should be initiated at ice out of each year. The target would be to achieve full pool elevation one month after ice-out, but this could require initiating refill sooner than ice-out if the snowpack is light and no major storms are forecast, and may present an unacceptable safety risk. Note that the April 1 deadline often applied to drawdown in Massachusetts is not appropriate for the Berkshires and may be counterproductive; the focus should be on the start date for refill and achieving full pool within a month after ice-out, rather than on an arbitrary date that has minimal ecological or management meaning in this geographic area.

An additional area of concern is the discharge of untreated outflow from Laurel Lake during at least August and September, which represents a risk to downstream aquatic habitats, as veligers are discharged and can settle in the Housatonic River or its impoundments. At least two power supply impoundments in Connecticut have become infested; these infestations have not been traced definitively to Laurel Lake, but are a likely consequence of veliger discharge from Laurel Lake. Additionally, inflow from the Housatonic River to Candlewood Lake in Connecticut is impacted by the threat of zebra mussels and limits the use of drawdown for milfoil control in that lake as well as power production from its outlet.

If the water level in Laurel Lake was dropped just a few inches to a foot by early August (which happens naturally in some years), the overflow could be entirely by pipe, which would allow for treatment to kill veligers. Use of chlorine, followed by injection of sodium thiosulfate to inactivate the chorine before entry to the Housatonic River, would be one way to minimize risk to downstream systems. Use of carbon dioxide was also proposed by the CT DEEP to kill veliger and protect CT waters downstream, but failure to negotiate an agreement with MA regulatory agencies prevented advancement of that approach. A water level up to a foot below normal full pool from August through October would not interfere significantly with any recreational pursuits or habitat functions in Laurel Lake, but could afford the opportunity to minimize downstream impacts.

The fundamental problem in addressing zebra mussels in Laurel Lake is one of regulatory inertia. Local conservation commissions, the MA DEP and the NHESP are all charged with upholding laws intended to protect aquatic habitats from harm, but there are no proactive provisions that allow the process to seek solutions. Rather, these agencies respond to proposals from other groups, and weigh them based not on whether or not they solve a pressing problem, but on whether or not impacts on non-target organisms are acceptable. From the perspective of these agencies, within the constraints of the legislation and regulations they are charged to uphold, they are not able to support most proposed solutions because of non-target impacts.

What is needed is a cooperative effort by all interested parties to support a solution even if it has some undesirable impacts, with the intent of a multi-year ecological restoration of Laurel Lake. Convening a group representing the LLPA, the Conservation Commissions of each town, the DEP, the DCR, the DFW and the NHESP to discuss options and possible paths forward is recommended. The LLPA and WRS have called on the Secretary of the Office of Energy and Environmental Affairs to take a leadership role in this effort, but have received no response after months of waiting.

If no cooperative effort is advanced in the first quarter of 2018, it is recommended that the LLPA seek a 5 ft drawdown for 2018-2019 as the greatest drawdown supported by the current outlet structure and no indication to date that this represents a significant negative impact on any aspect of Laurel Lake. The recommended monitoring plan for 2018 would be no different than for recent years, including a qualitative check on the lake in June, quantitative surveys in August, and a zebra mussel and snail assessment in the drawdown zone in December (if a drawdown is conducted). This plan may be altered if there is regulatory direction intended to advance better management of Laurel Lake. It may be necessary to seek an superceding order of conditions from the MA DEP is the Lenox Conservation Commission will not approve drawdown. However, it will be essential to get review by the NHESP prior to any submission to either conservation commission, as an increase to 5 ft may raise concerns based on recent interactions between the NHESP and the Town of Stockbridge over drawdown of Stockbridge Bowl, the only other lake in MA known to harbor a *Marstonia lustrica* population. Yet failure to make a concerted effort to better control zebra mussels in Laurel Lake represents an ongoing threat to other lakes in the area and even downstream into CT, suggesting that environmental protection is not being well served and raising the spector of litigation over damage to other aquatic systems.