Pilot Zebra Mussel Monitoring in Deep Creek Lake:

2018 Summary of Findings

April 2019

Department of Natural Resources
Resource Assessment Service

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Larry Hogan, Governor

Jeannie Haddaway-Riccio, Secretary

Resource Assessment Service
Monitoring and Non-Tidal Assessment
580 Taylor Ave, C-2
Annapolis, Maryland 21401
410-260-8610 Phone
410-260-8620 Fax
dnr.maryland.gov

Report prepared by Julie Bortz
Julie.bortz@maryland.gov

Additional Telephone Contact Information:
Toll free in Maryland: 877-620-8DNR ext. 8540 OR
Individual unit/program toll-free number
Out of state call: 410-260-8540
Text Telephone (TTY) users call via the Maryland Relay

Cover Photo: Zebra Mussels *(Dreissena polymorpha)* (Photo credit : Seth Metheny)

ACKNOWLEDGMENTS

The Department of Natural Resources would like to thank Brookfield Renewable and the Deep Creek Watershed Foundation, Inc. for helping fund this project. Their current and continued commitment to this effort is greatly appreciated.

Suggested citation: Resource Assessment Service. 2019. Pilot Zebra Mussel Monitoring in Deep Creek Lake: 2018 Summary of Findings. Maryland Department of Natural Resources, 580 Taylor Avenue, Annapolis, Maryland 21401. DNR 12-043019-146.

Table of Contents

Executive Summary

Zebra mussels (Dreissena *polymorpha*) are small mollusks native to the Black and Caspian seas in Europe. These prolific, invasive mussels were first found in the United States in Lake St. Clair in 1988, and within a few years of their initial find, had spread to all five of the Great Lakes. Since their introduction into the United States, populations have spread throughout much of the country causing significant ecological and economic impacts.

Zebra mussels can be transported to a new waterbody via ballast/bilge water or attached to boat hulls, engines and propellers, as well as found on trailers and other equipment and gear. Once in a waterbody, adult zebra mussels can quickly reproduce, producing hundreds to thousands of microscopic planktonic larvae (also called veligers) that eventually attach to hard surfaces. Their ability to colonize and reproduce in the water column makes them very difficult to eradicate from an area once established.

Out of concern of a zebra mussel introduction into Deep Creek Lake, the Maryland Department of Natural Resources, in partnership with Brookfield Renewable Energy and the Deep Creek Lake Watershed Foundation initiated a Pilot Zebra Mussel Monitoring Study in 2018 at Deep Creek Lake, Maryland. The study was a multi-faceted approach conducted on Deep Creek Lake from May-October 2018. It consisted of water quality monitoring to determine the suitability of the lake for zebra mussel colonization as well as visual monitoring in an effort to determine the presence of the species in the lake.

Results of the 2018 effort found the following:

- Temperature, conductivity, dissolved oxygen and pH are within or near the preferred zebra mussel habitat range in the lake.
- Overall, Deep Creek Lake is thought to be at low risk for zebra mussel colonization due to low calcium and water hardness concentrations in the lake, as these factors are important for zebra mussel growth, reproduction and survival.
- No zebra mussels were found in the lake, at any location, during any of the 2018 visual surveys suggesting the species is not currently present in Deep Creek Lake.
- The 2018 monitoring effort should be continued in 2019 and 2020 to account for inter- annual variability in temperature and precipitation, which can affect water quality.
- Visual surveys should continue at a similar frequency, as in 2018, to ensure that no populations of zebra mussels exist in Deep Creek Lake.
- Additional monitoring, such as random dock surveys, as well as eDNA studies should be considered if determined to be appropriate and resource feasible.

Although water quality data collected at Deep Creek Lake in 2018, suggests that the lake has overall low habitat suitability for zebra mussel colonization and/or growth, conditions may not preclude zebra mussels from becoming established. Due to the potential damage an introduction could cause, water quality monitoring associated with this effort should be repeated for at least two additional years, with visual monitoring occurring seasonally or at least annually to allow for early detection of a zebra mussel introduction.

Introduction

Zebra mussels (Dreissena *polymorpha*) are small mollusks native to the Black and Caspian Seas in Europe. They were first found in the United States in Lake Saint Clair, Michigan in 1988. Within a few years of their initial find, zebra mussels had spread to all five of the Great Lakes (Benson et. al. 2018). Zebra mussels are an aquatic invasive species (AIS) of high concern in the United States largely due to their biology as well as the potential impacts of the organism. Concern over this species has led to stringent laws and procedures enacted by managers intended to protect water bodies from a zebra mussel introduction. As bivalves, zebra mussels are able to survive desiccation or drying for days; they can close their shells tight and survive out of water up to 10 days under certain weather conditions (Hoddle 2019). This makes it easy for zebra mussels to be transported from one waterbody to the next attached to boats or gear. Additionally, adult mussels are broadcast spawners, meaning when they reproduce, they send hundreds to thousands of larvae (called veligers) into the water column making the containment of established populations extremely difficult. Furthermore, these veligers can and will attach to any hard surface and have been shown to cause severe economic and ecological problems once established (Strayer 2009). Some direct impacts of an introduction include fouling boat hulls, clogging water intake pipes and covering rocky shorelines with jagged shells. Zebra mussels can cause impacts throughout the entire aquatic food chain. As filter feeders, they can rapidly deplete a water body of plankton, altering water quality and clarity causing cascading impacts throughout the food web, affecting native species of mussels and bivalves, reducing food for fish populations and affecting the aquatic plant populations as well as altering water chemistry (Benson et. al., 2018).

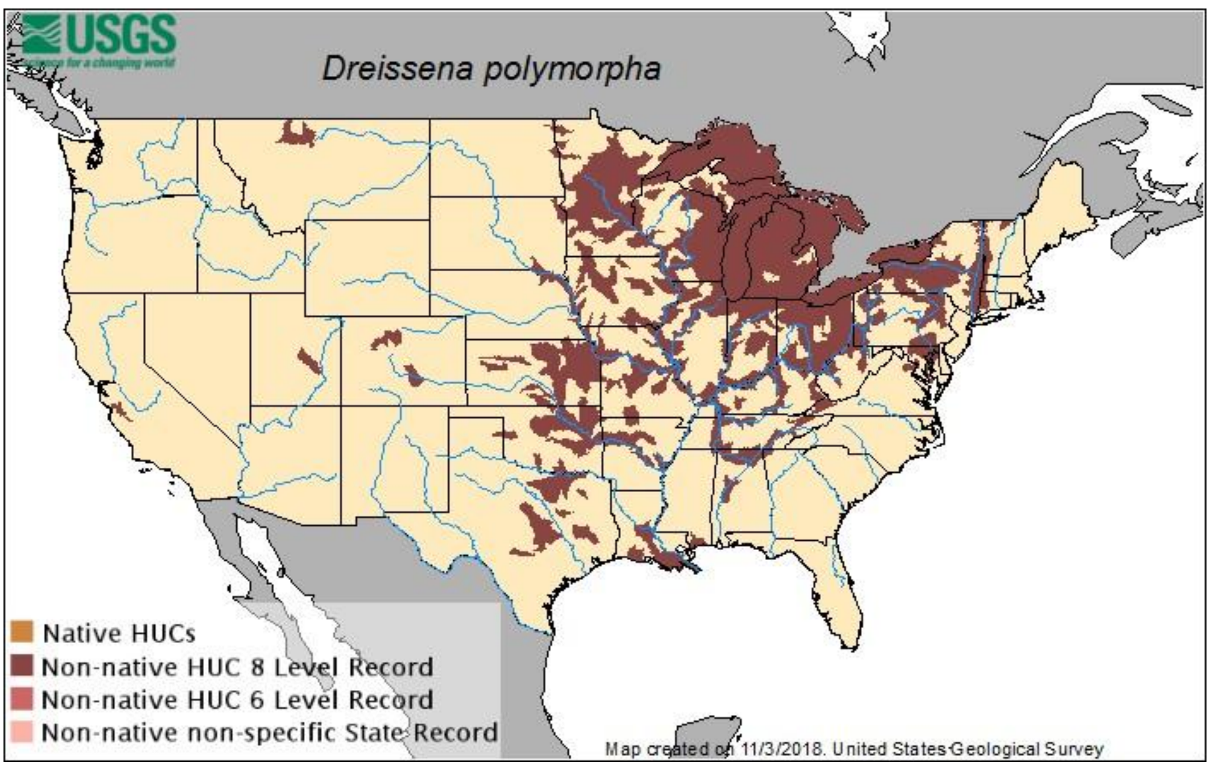


Figure 1: Map showing the known locations of zebra mussels (*Dreissena polymorpha*) as reported to the United States Geological Survey as of November 2018.
Source: nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=5

Since their introduction into the United States, populations have exponentially spread throughout much of the country in the past 20-30 years (Figure 1).While zebra mussels are found throughout the northeastern and central United States, in Maryland they are presently restricted to a small portion of the upper Chesapeake Bay, the Susquehanna River, and recently an inland quarry.
They were first found in the upper reaches of the Chesapeake Bay in 2007 and have since been found as far south in the Chesapeake Bay as Middle River near Baltimore, Maryland. In 2018, zebra mussels were confirmed to be established in an inland quarry in New Windsor, Maryland, 40 miles northwest of Baltimore. Regionally, they are found in portions of Virginia, Pennsylvania, and West Virginia. The closest location to Deep Creek Lake known to have zebra mussels is 45 miles away in the Monongahela River, West Virginia (Benson et. al. 2018). Given their common occurrence in neighboring states and water bodies and the high use of Deep Creek Lake by regional boaters, the likelihood of their introduction into Deep Creek Lake is high. The suitability of Deep Creek Lake for the establishment of a zebra mussel population remains questionable.

Zebra mussel biology
In general, zebra mussels prefer relatively cool, freshwater with ample food and calcium for shell growth. While habitat suitability is not an exact science, the United States Geological Survey (USGS) conducted a review of the scientific literature concerning habitat conditions and found that North American zebra mussel populations prefer an ideal salinity of 0 parts per thousand (ppt) with upper salinity tolerances thought to be a maximum of 4ppt (Benson et. al. 2018). Ideal temperature ranges are 20-25°C, but they can persist in waters up to 30-35°C for short periods of time. Zebra mussels tend to prefer slightly basic water with a pH ranging from 7-8.5, but have been found growing in waters with pH ranging as low as 6.6. Ideal calcium concentrations are thought to be as high as 40-55 mg/l, but North American populations have been found in waters with lower calcium concentrations. It's thought that North American zebra mussel populations need a minimum of 10 mg/L calcium to initiate shell growth and 25 mg/L to sustain growth (Benson et. al. 2018). However, some studies reported low suitability and medium risk for successful colonization of zebra mussels at calcium levels as low as 8.0 mg/L (Colorado Department of Public Health and Environment 2013). An unpublished study in Vermont found zebra mussels present in inland waters with mean calcium concentrations as low as 4 mg/L (Cohen 2005).

The literature remains widely varied as to the minimum thresholds for calcium concentrations, among other environmental conditions. The Colorado Department of Public Health and Environment (2013) created a table based on a study done by Mackie and Claudi (2010) that shows the suitability of zebra mussels to a long list of variables such as calcium, pH, alkalinity, hardness, dissolved oxygen, chlorophyll, total phosphorus, total nitrogen, water clarity as measured using secchi depth, temperature, conductivity, total dissolved solids, salinity, turbidity and total suspended solids. While all those parameters may be important, the majority of studies tend to suggest the parameters of most importance to determining zebra mussel habitat suitability include salinity, temperature, calcium concentrations and hardness as well as pH, conductivity and dissolved oxygen.

Deep Creek Lake Background and Water Quality Conditions

Deep Creek Lake is a man-made freshwater lake located in Garrett County, Maryland. The lake resulted from the damming of Deep Creek in 1925 for the purposes of hydro-electric power. Once the lake was created, development ensued along the shoreline and in the adjacent watershed with the majority of development happening after 1960. The lake still provides hydro-electric power via the dam, operated and maintained by Brookfield Renewable Energy, but has also evolved to be a four season resort destination for visitors from Maryland and nearby states. Visitors often originate from the Washington D.C and Baltimore metropolitan areas as well as the suburbs of Pittsburgh, Pennsylvania, Morgantown, West Virginia and the Ohio Valley to name a few. The lake has over 68 miles of shoreline with an average depth of roughly 22 feet. There are several shallow coves and fingers of the lake and the deepest point in the lake is located near the dam and is approximately 75 feet deep. Most of the development around the lake is residential with some commercial and agricultural land use (Fig. 2).

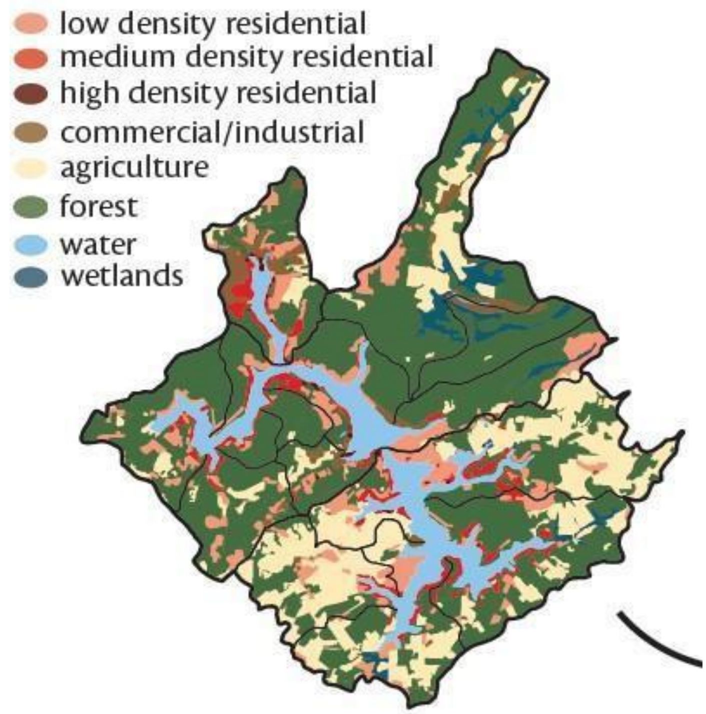


Figure 2: Deep Creek Lake watershed land use

The Maryland Department of Natural Resources (subsequently referred to as the Department) has conducted long-term water quality monitoring on Deep Creek Lake since 2009. This monitoring has occurred largely once a month (April-October) at select locations around the lake, with some locations being sampled both at the surface and at certain depths below the surface (Fig. 3). Water quality data from routine sampling by the Department suggests conditions in Deep Creek Lake appear to be suitable for zebra mussel establishment and growth with regard to temperature, salinity, conductivity, dissolved oxygen and pH. Important exceptions to the routinely available water quality data are calcium and hardness, which prior to 2018 were only sampled three times during 2009. The 2009 data (see Appendix E), collected from 14 locations during July, August and October 2009 suggest that Deep Creek Lake has low habitat suitability for zebra mussel survival based on calcium concentrations being <10 mg/L and water hardness concentrations under 30 mg/L (Benson et al. 2018).

Calcium and water hardness are essential for shell growth and thus thought to be important water quality parameters of interest in determining overall habitat suitability. It should be noted that the calcium and hardness levels, observed in the 2009 study, from some parts of the lake, during certain times of the year, were close to the low end of the suitability range (Benson et. al., 2018). Given that some studies have shown that North American zebra mussel populations may be able to tolerate conditions as low as 8 mg/L (Jones & Ricciardi, 2005), Deep Creek Lake may in fact have suitable conditions, albeit not necessarily ideal, for the establishment and growth of zebra mussels, in certain portions of the lake during certain times of year. Additionally, given that lake calcium levels could be increasing over time (Kaushal et al. 2013) and that certain areas where calcium levels could be higher due to underlying geology were not necessarily sampled in 2009, additional calcium and hardness sampling was, warranted moving forward, beginning in 2018.

2009-2016 Deep Creek Lake
Water Quality Monitoring Locations

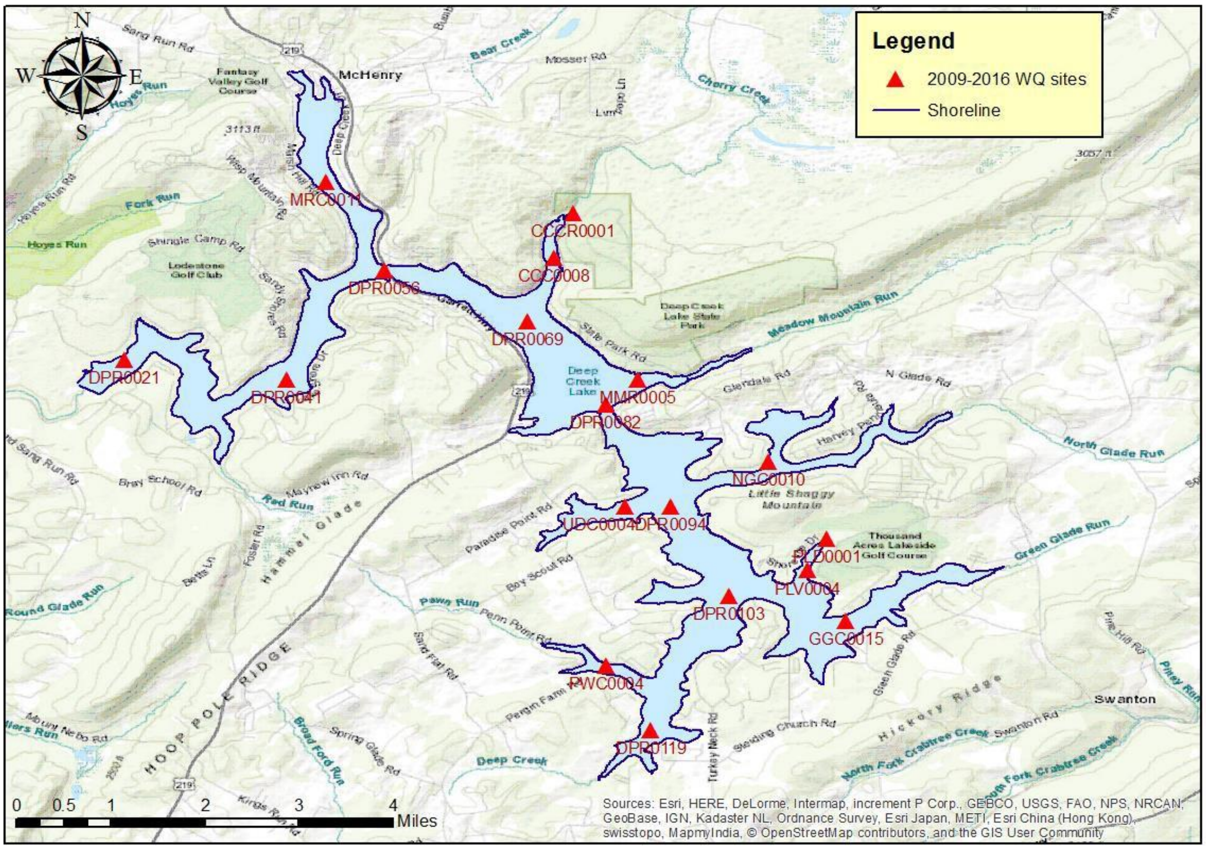


Figure 3. 2009-2016 Water quality monitoring locations at Deep Creek Lake, Maryland.

While water quality information provides a guideline by which to assess suitable habitat for zebra mussels, studies have shown that the species can often tolerate a wide range of environmental conditions. As such, it is reasonable to take the cautionary approach in assuming zebra mussels could survive – at least in some portions of Deep Creek Lake for at least some period of time, if they were introduced. However, based on the 2009 study and findings (Fig. 4), the majority of Deep Creek Lake may not offer preferable habitat for zebra mussels, given the low calcium and hardness concentrations. Therefore should a population(s) of zebra mussels be introduced into Deep Creek Lake, the likelihood of survival and reproduction of that population is unknown. If this were to occur, early detection would be critical. Additional calcium and hardness data will help direct future visual monitoring efforts to areas of the lake where habitat conditions might be more suitable to sustain a population of zebra mussels. In addition to monitoring these areas for the presence of zebra mussels, boat ramps remain the areas of the lake most likely to have the highest probability of occurrence and thus should remain a priority for visual surveys.

Since unintentional introductions via contaminated boats, trailers, gear or bilge water appear to be the primary mechanism of entry into a water body, education and outreach are important in helping defend against the spread of zebra mussels. In 2014, the Maryland Department of Natural Resources initiated a voluntary Boat Launch Steward Program at Deep Creek Lake to

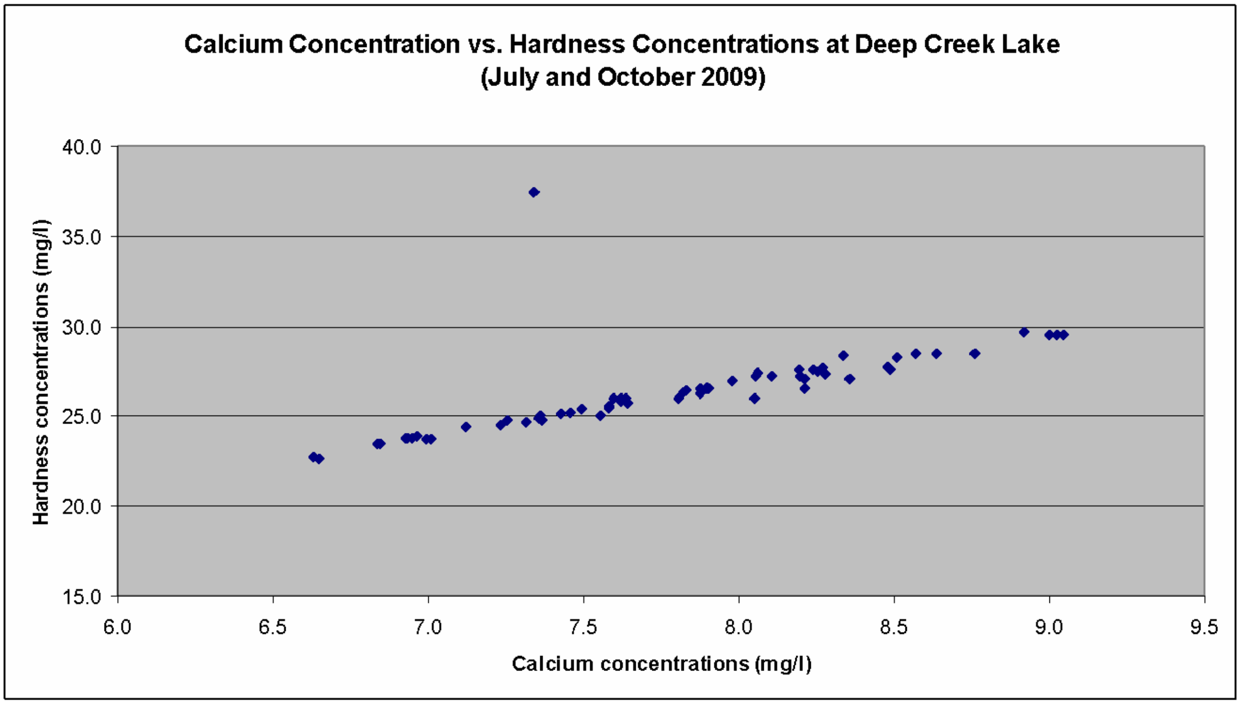


Figure 4. Calcium and Hardness data collected by the Maryland Department of Natural Resources from Deep Creek Lake during 2009.

provide aquatic invasive species education, outreach and prevention. This program was initiated following the finding of *Hydrilla verticillata*, a prolific, invasive aquatic plant that was found in various parts of the lake in the fall of 2013. The Boat Launch Steward Program offers voluntary inspections to incoming boats launching at the Deep Creek Lake State Park boat ramp. Since the program's inception in 2014, launch stewards have found several species of invasive plants on incoming boats. In 2016 and 2017, the launch stewards intercepted two boats carrying zebra mussels (one on June 4, 2016 and another on July 9, 2017). Neither of the boats launched after being informed of having zebra mussels attached. Although the launch stewards have been successful at reducing the threat of zebra mussel introduction into Deep Creek Lake, the risk of an introduction persists.

Rationale and Background

Eradication (when possible), population control, and other actions aimed at minimizing ecosystem damage and preventing further spread of an invasive aquatic species are often far more successful when an introduction is detected early – when populations are small and localized. In 2018, the Department initiated a monitoring study that utilizes a combination of visual surveys and water quality sampling to improve detection of new zebra mussel introductions into Deep Creek Lake and to further assess the suitability of the lake to zebra mussel establishment. Due to the presence of zebra mussels in Maryland and nearby states, this study focuses specifically on zebra mussel detection. The quagga mussel (*Dreissena bugensis*) is a closely related species with a similar invasive history that also poses a potential threat to Deep Creek Lake and other Maryland waters. Given the similarities of these two species in their life histories and habitat requirements, the protocols used in this study are likely to also be useful for quagga mussel detection and habitat suitability determination.

This monitoring study builds upon the Department's long-term comprehensive Deep Creek Lake water quality monitoring program and efforts by Brookfield Renewable (owners and operators of the dam) that have been ongoing since at least 2009. Brookfield Renewable has been conducting visual surveys and temperature monitoring monthly, for presence/absence of zebra mussels using zebra mussel monitoring plates hung at the water intake location**.** Brookfield Renewable submits an annual report of monitoring results to the Maryland Department of the Environment at the end of each year. Reports can be found at mde.maryland.gov/programs/Water/water_supply/Pages/DeepCreekLakePeriodicReports.aspx. To date, no evidence of zebra mussels in Deep Creek Lake has been reported by Brookfield Renewable.

Methods

A combination of water quality sampling and visual surveys were employed from May to October 2018 with the goal of evaluating habitat suitability for zebra mussels in Deep Creek Lake as well as visually surveying select areas for the presence/absence of zebra mussels. Eighteen locations throughout Deep Creek Lake were identified for water quality sampling (Fig. 5). Fourteen of those locations were additionally outfitted with zebra mussel monitoring plates and monitored once monthly from July to October 2018. Five of the 18 locations were additionally visually surveyed using SCUBA and/or snorkel/mask in July and again in October 2018 to assess presence/absence of zebra mussels in the lake. Table 1 shows the complete list of sampling locations as well as the monitoring techniques employed at each location and if those same sites were sampled in 2009.

Sampling Locations

A total of eighteen locations throughout Deep Creek Lake were identified for monitoring during 2018 (Fig. 5). Locations were chosen in part to replicate a similar effort the Department undertook in 2009 thus allowing for data comparison, as well as include additional locations of current importance or interest. Ten of the eighteen locations selected were previously sampled during the 2009 study, allowing for comparison of data collected in 2018 (Table 1). The remaining eight locations were selected to include areas where either zebra mussels might likely be introduced (i.e., boat ramps/commercial businesses) and/or shallow water cove locations with tributaries likely to have more suitable conditions (e.g., higher calcium) based on geology.

Water Quality Monitoring

Water quality sampling was conducted three times throughout the 2018 sampling season at 18 locations (Fig. 5; Table 1). At the four mainstem locations in Table 1 (DPR0082, DPR0056, DPR0021 and DPR0103) water quality sampling was conducted both at the water's surface (1.0 m below surface) and at the bottom and (1.0 m off bottom) for a total of 22 samples collected during each sampling event in the spring, summer and fall. Sampling occurred at each of the 18 locations on May 23, July 31, and October 23-25, 2018. Sampling dates in 2018 were attempted to align with the 2009 sampling dates to allow for better comparison across years and to account for seasonal changes in the amounts of precipitation.

Table 1. Chart showing each of the 2018 sampling locations name and study code, the type of location (nearshore, mainstem, boat ramp or other), if the site is a 2009 replicate study site, latitude and longitude, as well as what type of monitoring was conducted at each site.

Station code	Site type	2009 study site	GPS (N)	GPS (W)	Water Quality Sampling	Visual Surveys (SCUBA)	Visual monitoring (plates)
MMC6	Nearshore	√	39.511056	-79.2988528	√	no	√
GGC3	Nearshore	no	39.480256	-79.257275	√	no	√
DCC3	Nearshore	no	39.451671	-79.308681	√	no	√
PWC6	Nearshore	√	39.464949	-79.308667	√	no	√
CCC3	Nearshore	√	39.535347	-79.318152	√	no	√
AWC3	Nearshore	no	39.502871	-79.323433	√	no	√
PLV3	Nearshore	√	39.484107	-79.278704	√	no	√
HPC3	Nearshore	√	39.486316	-79.319378	√	no	√
GRC	Nearshore	no	39.536819	-79.3459861	√	no	√
DPR0082	Mainstem	√	39.507107	-79.3113183	√	no	no
DPR0056	Mainstem	√	39.528137	-79.344985	√	no	no
DPR0021	Mainstem	√	39.51442	-79.385305	√	no	no
DPR0103	Mainstem	√	39.477287	-79.2915633	√	no	no
SPRamp	boat ramp	no	39.515561	-79.313489	√	√	√
YCRamp	boat ramp	no	39.468583	-79.2937361	√	√	√
MRC6	boat ramp	no	39.55384	-79.355272	√	√	√
NGC6	boat ramp	no	39.499769	-79.27149	√	√	√
BRKDam	Dam	√	39.510244	-79.391713	√	√	√

At each sampling location, a one gallon whole water sample of lake water was collected from just below the water surface (0.5 m from the water surface for most sites, 1.0 m from surface at mainstem sites) using a submersible water pump, siphoning water into a one gallon plastic container. The siphoning hose was thoroughly rinsed before each sample, with water at the site, and each container was triple rinsed with sample water before being filled with lake water, capped and placed in a cooler on ice. Whole water samples were delivered on the same day to the University of Maryland Appalachian Laboratory in Frostburg, Maryland where they were filtered and analyzed for calcium and magnesium concentrations (mg/L) by flame atomic absorption spectroscopy. Once determined, hardness was calculated using both calcium and magnesium and the following equation:

Total Hardness = 2.497 * **Calcium Hardness** + 4.118 * **Magnesium Hardness**
(mg/L CaCO3) [Ca, mg/L] Mg, mg/L]

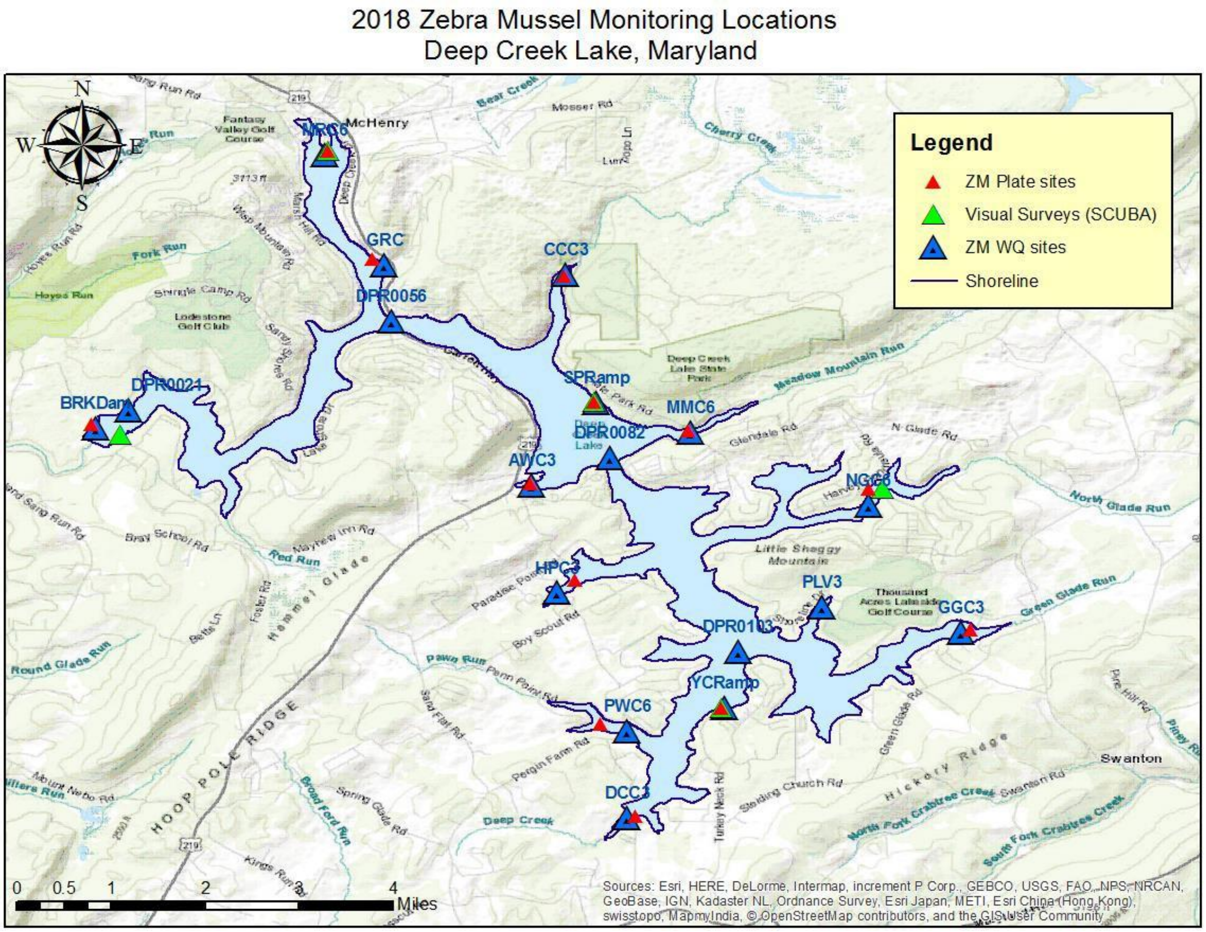


Figure 5. Zebra mussel monitoring locations for water quality, monitoring plates and visual surveys in 2018 at Deep Creek Lake, Maryland.

Laboratory results were analyzed to determine habitat suitability in the lake. At the same time whole water samples were collected, a YSI multi-parameter meter was used to measure various in-situ water quality conditions from both the surface and bottom sampling locations (at depths similar to water collection). Parameters measured included water temperature, turbidity, depth, conductivity, pH, dissolved oxygen and chlorophyll a. A weighted secchi disk was used to visually determine secchi depth (a measure of water clarity). Data were recorded and merged with additional data from the Deep Creek Lake long-term water quality monitoring effort, when available for each site, to provide for a greater suite of data for analysis.

Visual monitoring

Visual monitoring consisted of a combination of underwater visual surveys using certified SCUBA divers as well as zebra mussel monitoring plates. A total of fourteen sites (see Figure 6 red and green triangles) were planned for visual monitoring in 2018, however one site (PLV3) was not sampled in 2018 due to an inability to find suitable water depth at a dock to hang the monitoring plates. As such, thirteen locations were monitored in 2018 using zebra mussel monitoring plates. Five of those thirteen locations were also monitored using underwater SCUBA/snorkel surveys.

Visual surveys were initially planned to be completed at the same frequency as the water quality monitoring (spring, summer and fall). However, final approval for the pilot project was not obtained until late May 2018, so the first planned visual survey in mid May 2018 did not happen. Two sets of visual surveys were however conducted in 2018, the first was done on July 19, 2018 and the second on October 4, 2018. During each of the two visual surveys, five sites (NGR6, YCRamp, SPRamp, BRKDam, McH6) were sampled for a combined 30 minutes each using certified SCUBA divers. Two SCUBA divers surveyed roughly a 50 m area on either side of the GPS location, and visually inspected the underwater areas ranging in depth from 0.5 m to as deep as 5 m depending on the site. Efforts were made to focus on surveying hard surfaces such as docks, rocks, and other hard surfaces based on protocols established by the Pennsylvania Department of Environmental Protection's invasive mussel monitoring guide (seagrant.psu.edu/sites/default/files/2012zmbrochure.pdf). Survey start and stop time was monitored and any relevant information was recorded at the time of sampling. Additionally, electronic datasheets (dnr.maryland.gov/Invasives/Documents/ZM_report_form.xls) were completed for each site and will be archived at the Department's headquarters in Annapolis. An example of a hardcopy of the datasheet can be found in Appendix A. All five sites surveyed include the shoreline area near all of the major boat ramps on Deep Creek Lake as well as one site, BRKDam located near the dam. For safety reasons, the site BRKDam was surveyed on the shoreline across from the intake facility operated by Brookfield Renewable.

2018 Zebra Mussel Visual Monitoring Locations at Deep Creek Lake, Maryland

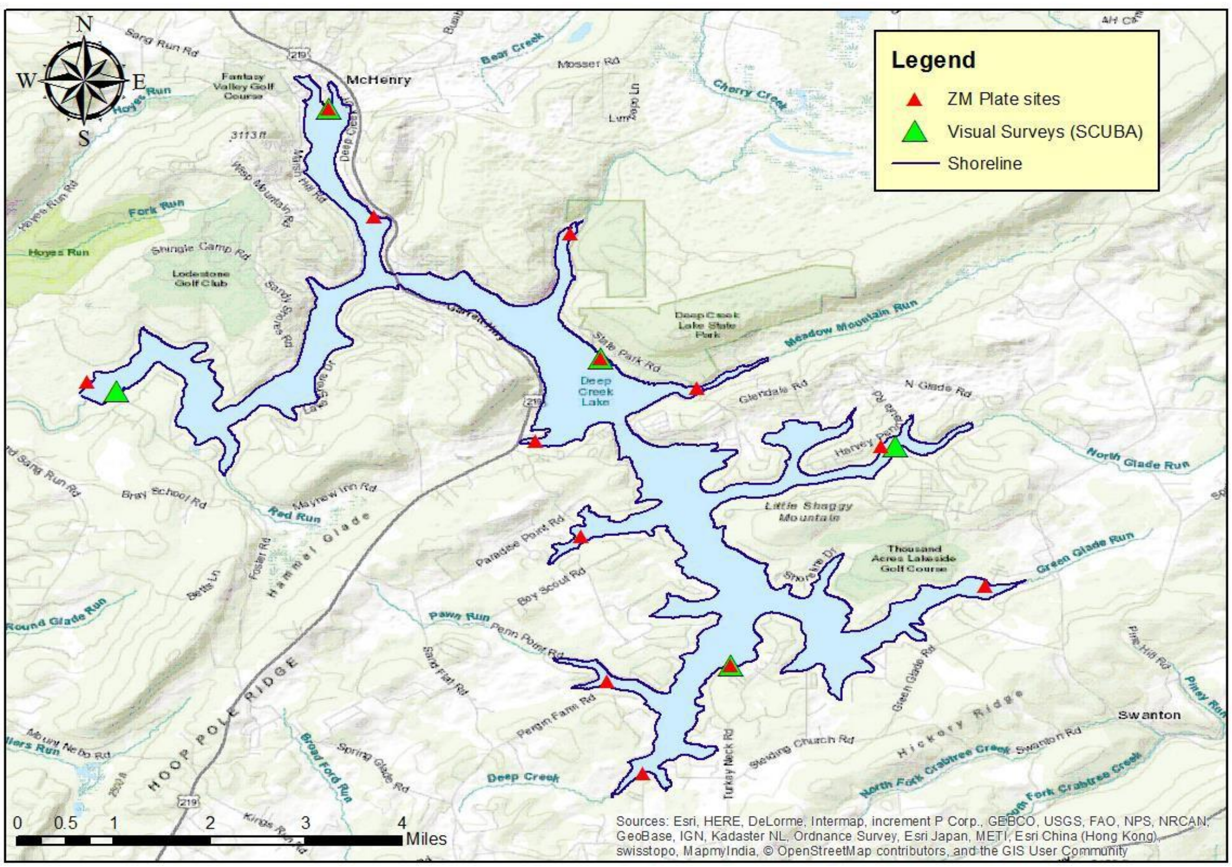


Figure 6. Map showing location of visual monitoring (plates and SCUBA surveys)

Additional visual monitoring using zebra mussel monitoring plates (see adjacent photo) was also conducted monthly from July to October 2018. A series of four hard PVC plates (each measuring 6” x 8”) were fashioned with 1/2” spacers along a long eyebolt and secured with a washer and nut. Each set of monitoring plates was deployed at one of the thirteen nearshore monitoring locations, usually suspended off a dock or nearby buoy using parachute chord attached to the plates. A small brick was suspended from the bottom of the plates, as a weight to keep the plates from moving due to wave energy. The date of plate deployment was recorded for each site; all plates were deployed by the end of July 2018. Monthly monitoring of the plates began in August 2018 and continued monthly through mid-October 2018 when they were retrieved. During each of the monthly visual plate inspections, plates were temporarily pulled from the water, visually inspected for any evidence of zebra mussel colonization by the Department and submerged back into the water.

Zebra mussel monitoring plates used in this study

Results and Discussion

Water Quality

Results of surface sampling are summarized only for water temperature, pH, dissolved oxygen and conductivity as those parameters appear to be more closely related to zebra mussel habitat suitability. A table showing all data collected for these variables at each site can be found in appendix C. Due to differences in water chemistry at shallow water cove locations compared to deep water mainstem locations (as reported by the Deep Creek Lake long-term water quality data) mainstem and cove locations were graphed separately but summarized collectively. When reviewing the data, it should be noted that data presented only represents discrete data taken at the time of sampling. While many of the sampled variables may naturally vary over the course of a 24 hour period, this variability is not addressed in this report as there continuous data are not available for each sampling location.

Water Temperature

Water temperatures at the sampled locations (surface only) ranged from 8.5°C to 26.8°C (see Fig. 7) across both deep water stations and the shallower coves during the sampling period (May-October 2018). It is possible that summertime temperatures may have exceeded the upper range (26.8°C), particularly in the shallow coves. Additionally, the shallow water coves likely exhibited substantially lower temperatures as well, especially during the winter months. This study however, focused only on water temperatures observed from the spring through the fall 2018.

A review of the literature suggests ideal temperature habitat for zebra mussels ranges between 10-26°C (Cohen 2005). Higher mortalities have been associated with upper temperatures ranging from 26-30°C and near total mortality when temperatures exceed 30°C for extended periods of time (Cohen 2005). Zebra mussels are stressed when temperatures fall below 10°C and near complete mortality as temperatures approach 0°C (Claudi and Mackie 1994, McMahon 1996).

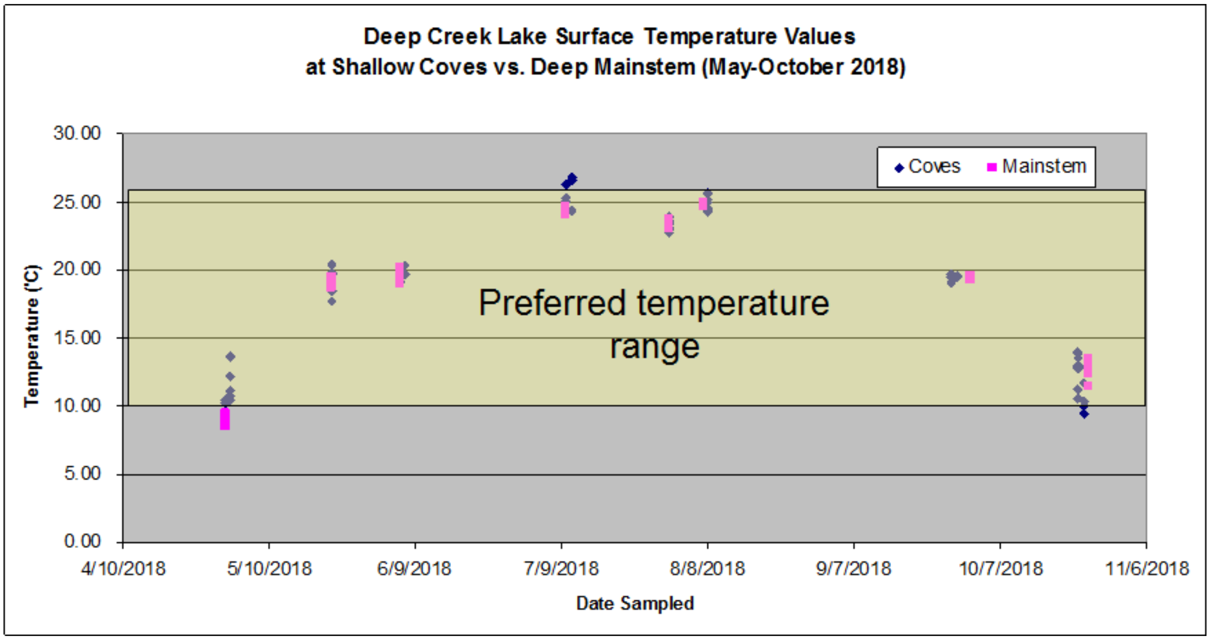


Figure 7. Zebra mussel preferred temperature ranges overlaid on top of actual observed temperature measurements at water quality sampling locations in Deep Creek Lake 2018.

With surface water temperatures in Deep Creek Lake ranging from 8.5°C to 26.8°C across both deep water stations and the shallower coves during the sampling period, it would suggest that Deep Creek Lake has suitable habitat for zebra mussels as observed from May-October 2018 (Fig. 7). It should be mentioned that the shallow portions and upper surface of Deep Creek Lake often freeze every winter. Lake ice can range from 24"-32" in depth (personal communication Eric Null 2018) which would suggest no growth could be sustained long term in the shallowest portions of the lake. Additionally the lake generally drops in elevation roughly 5 feet from the spring to the winter (from full pool of 2461 feet elevation in the late spring to as low as 2455 or 2456 feet elevation in the winter). Ice cover, combined with lake drawdown, would suggest that zebra mussels would not likely be able to survive in the lake over the long-term at spring and summer depths of 0-7 feet due to winter ice scouring and/or exposure. This creates a "habitat squeeze" from the surface down to a depth of ~7 feet. Additionally, a thermocline sets up during the summer months at a vertical depth of roughly 6-7 meters (personal communication Christine King 2018). While temperatures below that depth remain above freezing, the stratification of the water due to the thermocline precludes the mixing of oxygenated water at the surface with deeper water, causing dissolved oxygen conditions to drop below 4 mg/L at a depth of ~ 7 meters. Thus the impact of the thermocline on dissolved oxygen makes it is unlikely for zebra mussels to be found at depths below 6-7 m from the surface and creates a "habitat squeeze" from the bottom up. This would suggest that the combined impact of temperature and dissolved oxygen would limit zebra mussel habitat to lake water depths of 2 m – 7 m during the summer months.

Water pH

Water pH measurements at the sampled locations (surface only) ranged from 6.6-8.0 across both deep water stations and the shallower coves during the sampling period (Fig. 8). It is possible that pH values may have likely exceeded the observed 8.0 values in the summertime, at some sites, particularly in the shallow water coves in the when daytime productivity is greater; these higher values have been observed in the Deep Creek Lake continuous water quality monitoring efforts from 2016-2018 dataset (King 2018).

A review of the recent literature suggests pH ranges less than 7.3 and greater than 9.5 showed low to no zebra mussel survival (Cohen 2005). In Manitoba, BC, Sorba and Williamson (1997) found very low to low zebra mussel distribution potential at pH values of <6.5 and 6.5-<7.2, respectively and high distribution potential at a range from 7.5-8.7. Using ideal pH ranges of 7.5 - 8.7 (Sorba and Williamson 1998) for zebra mussel colonization and distribution, the observed readings from Deep Creek Lake would suggest the lake has at times moderate to high potential for zebra mussels but also low to moderate potential for zebra mussels as well. Pooling those findings suggests that Deep Creek Lake has moderate zebra mussel colonization potential with regard to pH.

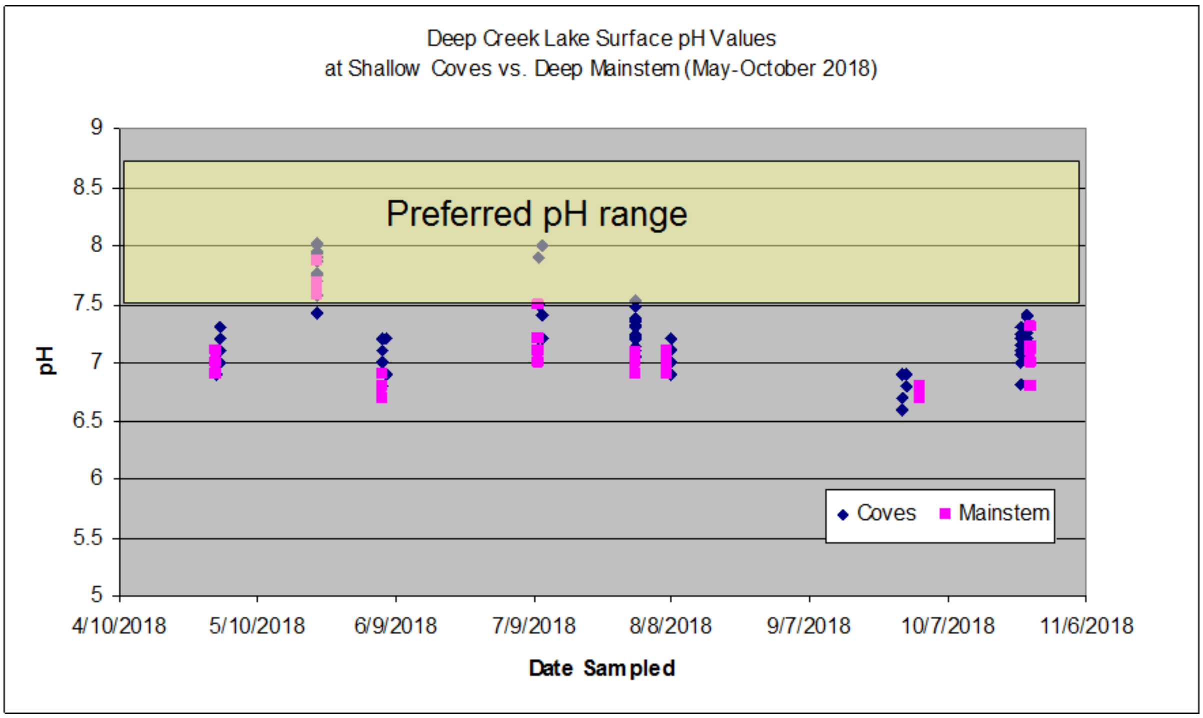


Figure 8. Zebra mussel preferred pH ranges overlaid on top of actual observed pH measurements at water quality sampling locations in Deep Creek Lake during 2018.

Dissolved Oxygen

Dissolved oxygen concentrations naturally vary over a 24 hour photo period due to diel changes in photosynthesis and respiration rates, largely of algae and aquatic plants. This diel fluctuation is most commonly observed closer to the water surface where light is more readily available. The data presented here are solely discrete measurements and do not reflect the natural diel fluctuation; instead dissolved oxygen concentrations are more likely indicative of normal conditions at the water's surface.

Dissolved oxygen measurements at the sampled locations (surface only) ranged from 7.1-11.5

mg/L across both deep water stations and the shallower coves during the sampling period (Fig. 9). It is likely that dissolved oxygen concentrations may have likely exceeded the observed values at some of the sites, particularly in the spring when temperatures were cooler as cold water can hold more oxygen. The observations graphed simply represent the surface dissolved oxygen concentrations; dissolved oxygen concentrations often decrease with increasing water depth during the summer months. Findings from the vertical profile measurements taken on behalf of the Deep Creek Lake long-term water quality monitoring dataset suggest dissolved oxygen concentrations generally decrease with water depth, with the highest values at the surface and slowly decreasing to a depth of roughly 6-7m during the summer months (King 2018). Below this depth, dissolved oxygen is limited and nears 0 mg/l suggesting zebra mussels could not survive at depths greater than 6-7 meters during the summer months due to low to no dissolved oxygen.

A review of the literature concerning ideal dissolved oxygen concentrations suggests low to no survival at concentrations less than 4 mg/L dissolved oxygen (Cohen and Weinstein 1998) and limited survival at levels as low as 6.0 mg/L (Sorba and Williamson 1997). Based on observed dissolved oxygen concentrations at Deep Creek Lake in 2018, it would appear as though Deep Creek Lake has suitable habitat for zebra mussels to a depth of 6-7 meters. At the few locations where bottom dissolved oxygen conditions were recorded, concentrations ranged from 0.2 mg/L – 10.7 mg/L from May – October suggesting at certain times of the year, bottom dissolved oxygen conditions would preclude zebra mussel establishment due to low or no dissolved oxygen.

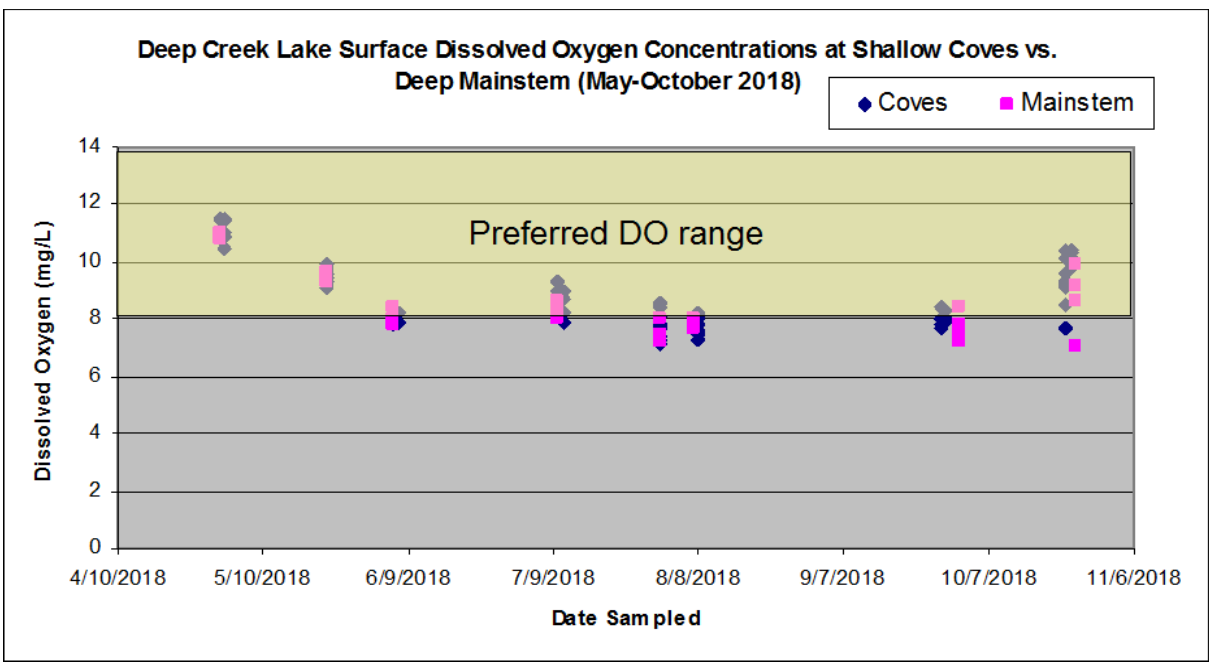


Figure 9. Zebra mussel preferred dissolved oxygen ranges overlaid on top of actual observed measurements at water quality sampling locations in Deep Creek Lake 2018.

Specific Conductivity

Conductivity is a measure of the ability of a substance to pass electrical current. In water, it is generally affected by the presence of dissolved ions such as chloride, phosphates and other dissolved constituents that carry and electrical charge (EPA 2012). Geology of nearby bedrock primarily dictates the natural conductivity of water, which once a baseline is established for a water body, any deviations in those levels might suggest the addition of pollutants (EPA 2012). Specific conductance is a measure of the amount of dissolved ions in the water with relation to temperature.

Specific conductance concentrations within Deep Creek Lake at the sampled locations (surface only) ranged from 72*µs/cm* to 98*µs/cm* across both the deep water mainstem stations and the shallower coves during the sampling period (see Figure 16). Observed specific conductance concentrations at the mainstem bottom locations ranged from 79-123*µs/cm* over the sampling period (Fig. 10). A review of the literature suggests preferred conductivity values of >83*µs/cm* demonstrate a high potential for zebra mussel distribution (Sorba and Williamson 1997). Another review found >82*µs/cm* suggested high risk of colonization (Illinois-Indiana Sea Grant, 2012). As the majority of 2018 Deep Creek Lake observations showed specific conductivity values near or above 82*µs/*cm, these values would suggest Deep Creek Lake has suitable habitat for zebra mussels with regard to specific conductance.

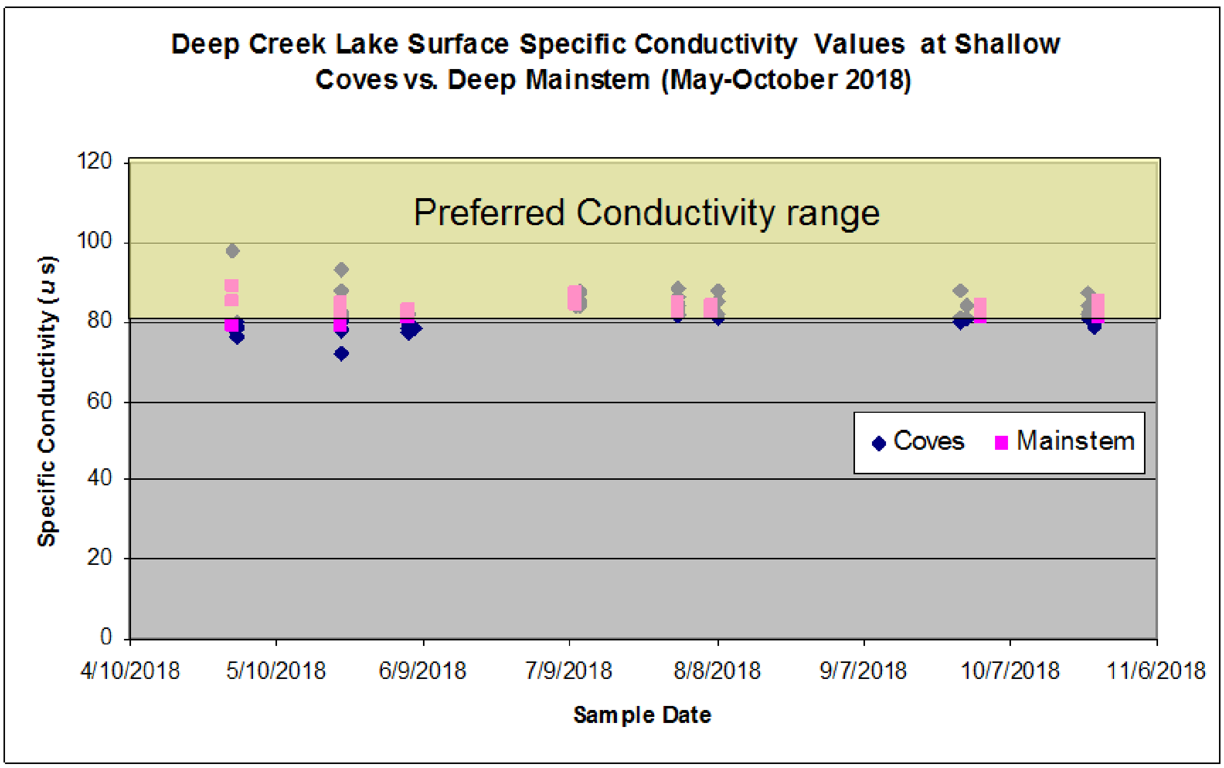


Figure 10. Zebra mussel preferred specific conductivity ranges overlaid on top of actual observed measurements at water quality sampling locations in Deep Creek Lake 2018.

Calcium

Calcium generally enters the water via the nearby geology, dissolving from rocks such as limestone, dolomite, calcite, gypsum, fluorite and marble. In water, calcium is usually found in dissolved form as either calcium carbonate ($CaCO_3$) or bound with sodium (Na) (Lenntech 2019). Calcium concentrations at the sampled locations in Deep Creek Lake ranged from 6.3 to

8.5 mg/L across all locations (surface and bottom) over the three sampling events in 2018. Calcium concentrations were generally the lowest in July and highest in October. Average calcium concentrations were 7.42 mg/L in May 2018, 7.08 mg/L in July and 7.44 mg/L in October (Fig. 11). A cumulative mean calcium concentration of 7.31 mg/L suggests Deep Creek Lake calcium concentrations are below the widely accepted 12-15 mg/L minimum calcium (Cohen 2005), but higher than the mean calcium concentrations of 4 mg/L and 6 mg/L found in unpublished records of two inland North American lakes (Cohen and Weinstein 2001) in regards to zebra mussel suitability. A 7.31 mg/L mean for Deep Creek Lake is close to the lower calcium threshold published by USGS (Benson et. al 2018) and the 8 mg/L levels found in the St. Lawrence River where zebra mussels were established (Jones & Ricciardi 2005). A few sites (MRC6, GRC and mainstem locations DPR01021 and DPR0056) were found to have calcium concentrations closer to 8mg/L in 2018 (Fig. 11). This suggests that conditions at these sites may support zebra mussel establishment at low abundance.

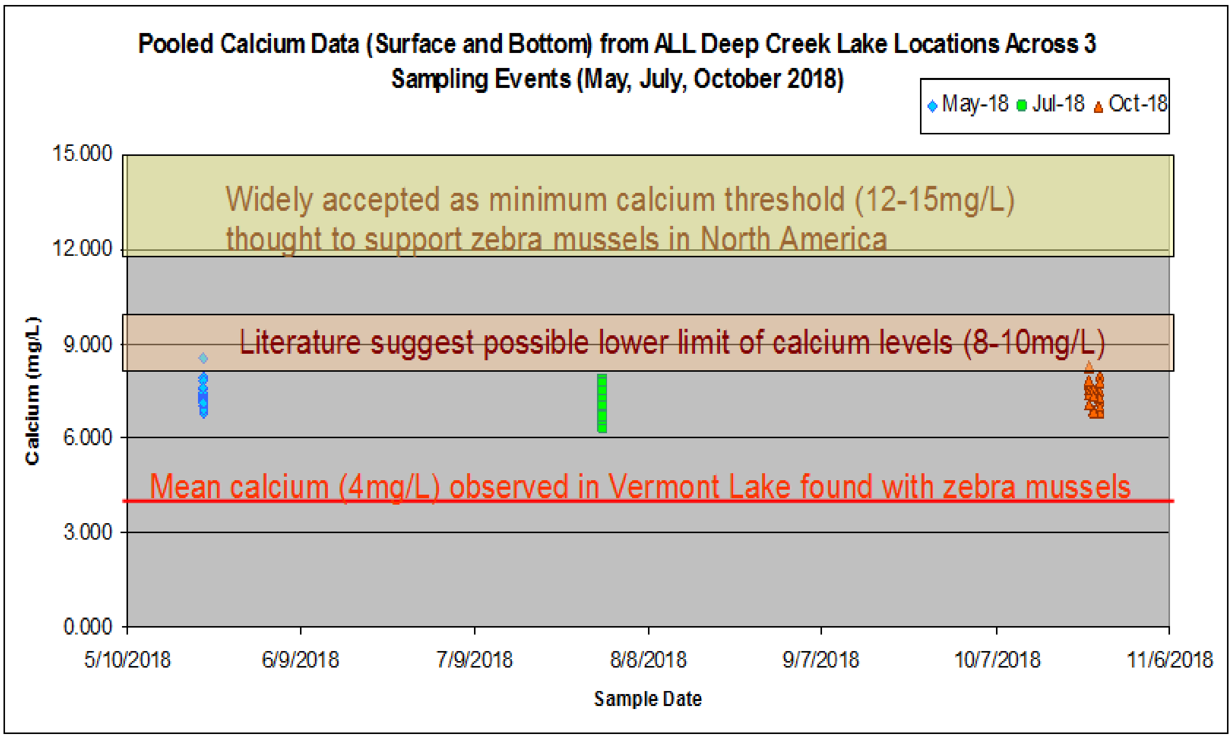


Figure 10. Actual calcium concentrations observed at water quality sampling locations in Deep Creek Lake during 2018. North American zebra mussel preferred calcium concentrations overlaid on top.

With regard to zebra mussels, a study by Strayer (1991) found most European lakes were hard (Calcium >20 mg/L) and most North American lakes were softer (<20 mg/l calcium) suggesting water hardness may limit zebra mussel distribution in North American lakes. While studies of European lakes have found higher calcium levels (above 20-40mg/L) usually provide more Suitable habitat for mussel colonization and survivability, studies of North American lakes suggest zebra mussels can and do survive in lower calcium concentrations between 12-25 mg/L (Cohen 2005). Most studies of potential zebra mussel distribution use values of 10, 12, or 15 mg/L as the minimum calcium threshold. However thresholds of 2, 7 and 9 mg/L calcium have also been used (Cohen 2005). A review of the literature suggest wide disparities in minimum calcium concentration requirements with some studies (Duke Power 1995, Cohen,

2005) suggesting zebra mussel growth is possible in waters with calcium concentrations as low as 2 mg/L. In general however, a minimum of ~25 mg/L calcium is assumed for European lakes whereas North American lakes can become established under lower calcium concentrations ranging from 12-15 mg/L (Cohen 2005). The difference in North American lake calcium requirements versus European lake requirements might be due to the origin of the population of zebra mussels, largely originating from the Caspian Sea (Cohen 2005). However it is evident that some North American populations of zebra mussels have been found in waters as low as 2 to 4mg/L (Duke Power 1995, Vermont DEC 1998). In summary, it appears challenging to identify clear minimum thresholds for calcium concentrations.

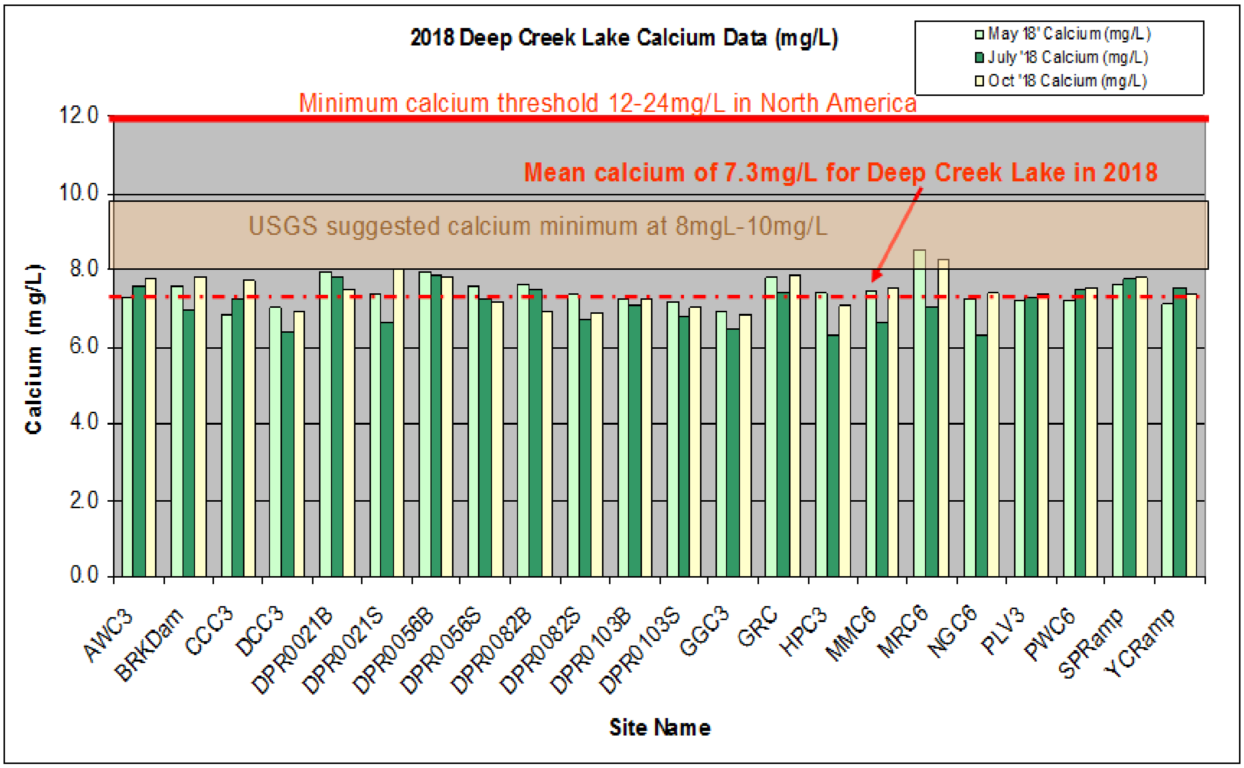


Figure 11. Site specific calcium concentrations observed at Deep Creek Lake in 2018. Suggested calcium concentrations for North American zebra mussel populations are overlaid on top of actual observed measurements at water quality sampling locations.

Water Hardness

Water hardness is caused by dissolved minerals found in water. Usually the dissolved forms of calcium and/or magnesium dissolve in water as it flows across or through limestone deposits. Both calcium and total hardness concentrations can vary with depth and time of year. There may be locally different concentrations of either calcium and/or hardness within the same water body due to differences in geology. While the literature suggests calcium concentrations being one of the key parameters in assessing potential zebra mussel distribution in a water body, water hardness may also be important. Cohen (2005) found that zebra mussel survival in higher calcium waters could be due to higher magnesium content rather than calcium (Cohen, 2005).

Deep Creek Lake water hardness concentrations were determined from measurements of calcium and magnesium. Total water hardness concentrations ranged from 21.5-27.1 mg/L across all sites (surface and bottom) over the three sampling periods (May, July, October 2018). Water hardness concentrations were generally the lowest in July and highest in October with May concentrations in between. Average water hardness concentrations were 24.4 mg/L in May 2018, 23.8 mg/L in July and 25.0 mg/L in October (Fig. 12) with a cumulative average hardness of 24.4 mg/L over the three sampling periods in 2018.

Total hardness less than 60 mg/L $CaCO_3$ is generally considered soft suggesting the waters in Deep Creek Lake are generally low in calcium and magnesium. A study cited by the Illinois-Indiana Sea Grant suggested total hardness concentrations of <46 mg/L are a low risk of zebra mussel colonization. A study done in South Carolina suggested 23 mg/L hardness was the minimum needed to even support poor growth of zebra mussels with 46 mg/L being the lower end of moderate growth (South Carolina Electric and Gas Company 1995). A summary of all three sampling events water hardness can be seen in Fig. 12. The red line at 23 mg/L total hardness indicates the minimum hardness needed to support even poor growth of zebra mussels (South Carolina Electric and Gas Company 1995). Other studies suggest minimum hardness concentrations of 46 mg/L are preferred for zebra mussel growth and use 30 mg/L as the lower threshold for zebra mussels (Colorado Department of Public Health and Environment 2013).

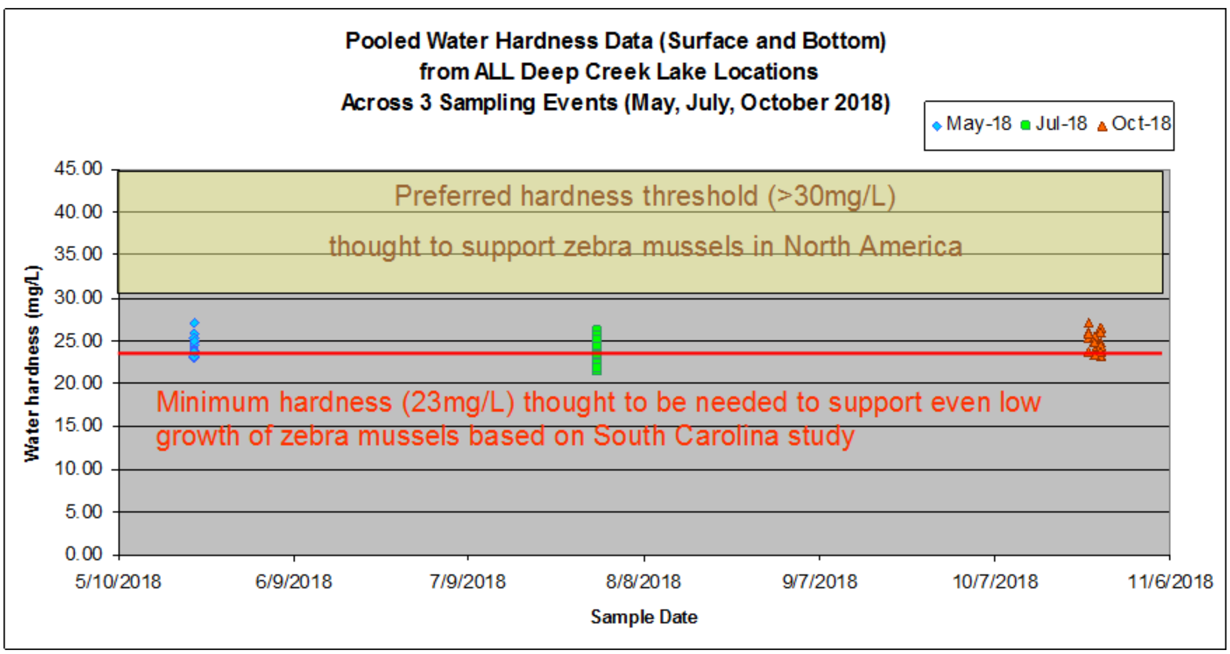


Figure 12. Actual hardness concentrations observed at water quality sampling locations in Deep Creek Lake during 2018. North American zebra mussel preferred hardness concentrations overlaid on top.

Using the above thresholds (23 mg/L hardness minimum and >30mg/L preferred), a review of the total hardness data for each location sampled in Deep Creek Lake in 2018 suggests that the majority of locations at some point in the year have reached and/or exceeded the minimum hardness concentrations needed to support poor zebra mussel growth. However, no locations in Deep Creek Lake demonstrated the minimum lower limit of the preferred total hardness concentrations (>30mg/L) to support zebra mussel growth. Hardness data, combined with calcium data suggests that should any zebra mussels be introduced into Deep Creek Lake, their survival and growth may be limited by calcium and/or total hardness concentrations.

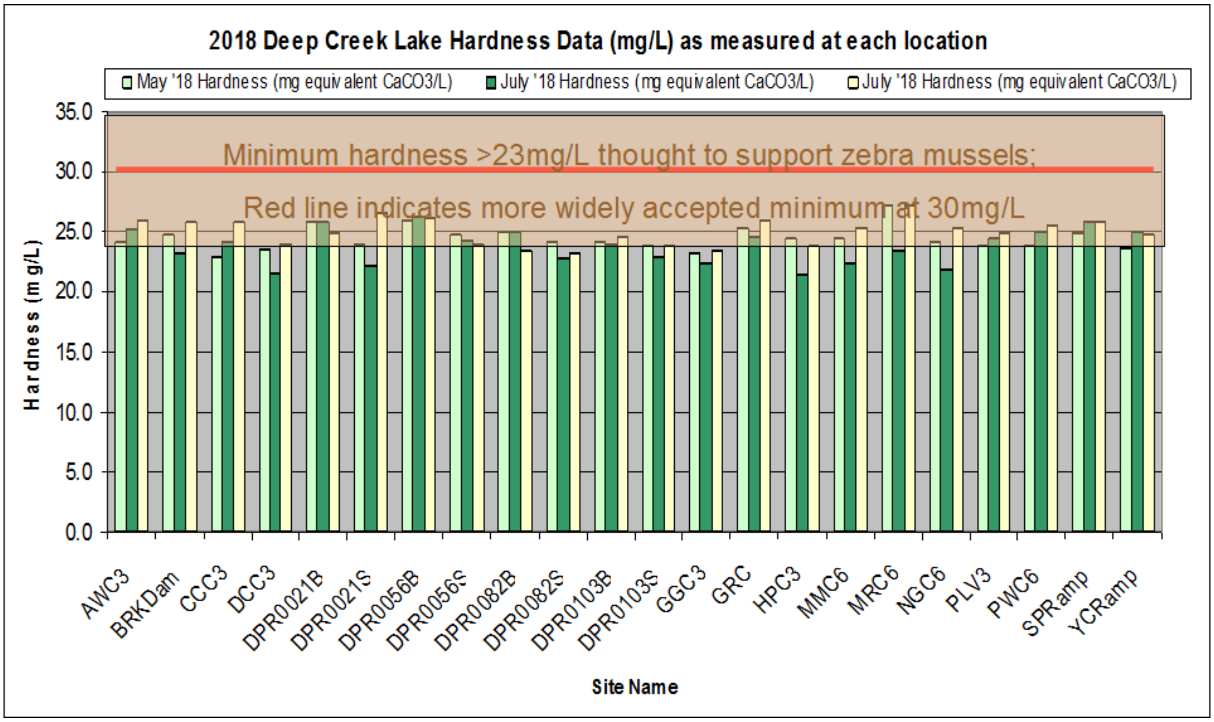


Figure 13. Site specific water hardness concentrations observed at Deep Creek Lake in 2018. *Suggested hardness concentrations for North American zebra mussel populations are overlaid.*

A summary of the findings (Table 2) concerning water quality in Deep Creek Lake as observed during the 2018 sampling season found the following ranges for the below environmental parameters measured as part of the Pilot Zebra Mussel Monitoring effort. Based on these data, Deep Creek Lake may be at low risk for zebra mussel colonization and survival due to low calcium concentrations. This does not mean Deep Creek Lake is unsuitable for zebra mussels, simply that calcium concentrations measured in 2009 and 2018 were lower than the desired level for zebra mussels in North America (Fig. 14). It should be noted that the 2018 year was an exceptionally wet year for the Mid-Atlantic region and this likely affected calcium

Table 2: Summary of water quality conditions observed in 2018 at Deep Creek Lake, Maryland.

	Hardness (mg/L)	Calcium (mg/L)	Specific Conductance (*µs/cm*)	DO (mg/L)	pH	Temperature (°C)
Deep Creek Lake (Surface and bottom)	21.5-27.1	6.3-8.5	72-123	0.2-11.5	5.6-8.0	6.4-26.8
Surface only	21.5-27.1	6.3-8.2	72-98	7.1-11.5	6.6-8.0	8.5-26.8
Bottom Only	23.9-26.23	6.9-7.9	78-123	0.2-10.6	5.6-7.6	6.4-20

concentrations. As such, additional monitoring may help assess annual variability in calcium concentrations in Deep Creek Lake. These findings only represent two years of data (for a combined total of 5-6 sampling events across both years) and may not be representative of the full range of conditions throughout the lake over time.

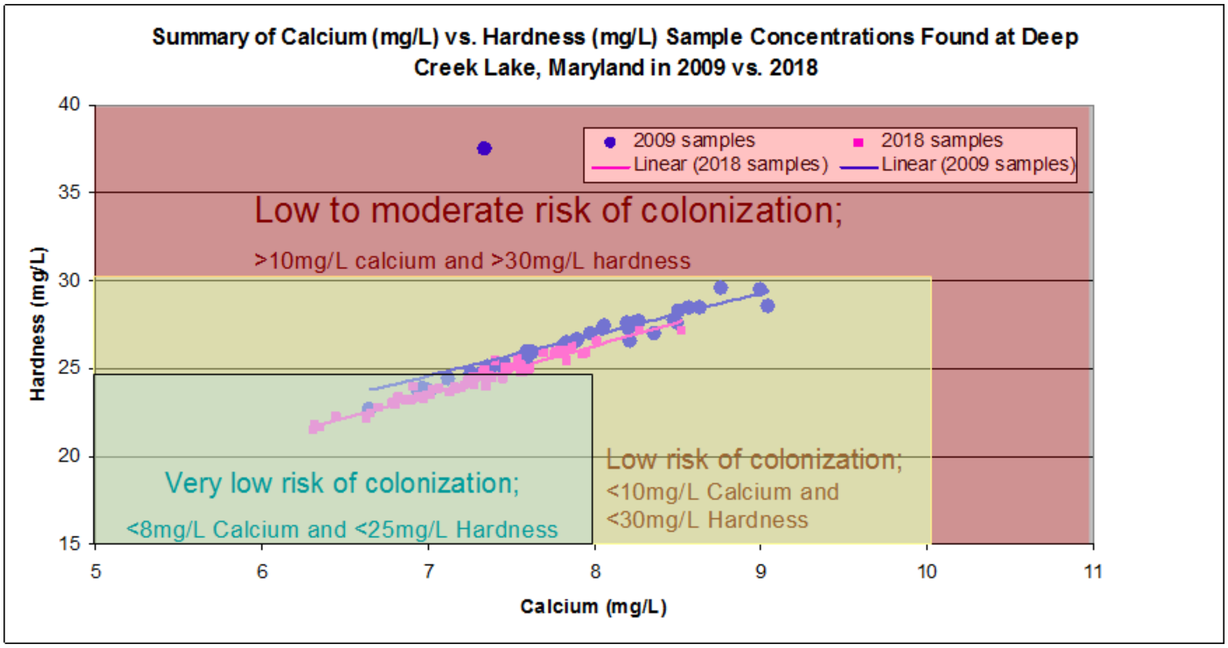


Figure 14. Calcium vs. water hardness concentrations observed at Deep Creek Lake in 2018 compared to 2009. *Suggested calcium and hardness concentrations for North American zebra mussel populations are overlaid on top of actual observed measurements.*

Visual Monitoring

Visual underwater surveys found no evidence of zebra mussels at any of the five visual monitoring sites. Thirty minute underwater surveys of all hard surfaces (docks, rocks, buoys, sand and silty surfaces as well) were conducted at each of the five locations (SPRamp, YCRamp, MRC6, NGC6 and BRKDam) twice over the course of the 2018 sampling season. SCUBA certified divers found no evidence of zebra mussels at any of those five locations during any of the surveys. Surveys were conducted on July 19 and October 4, 2018 at the five locations that represented four of the main boat ramps and a location near the dam (Table 3). No zebra mussels were found on any of the monitoring plates during the study period (Table 4).

Table 3. Visual monitoring (SCUBA surveys) results including site name, description, GPS coordinates and results of survey conducted in 2018.

Site Code	Location	Latitude ° North	Longitude ° West	July survey 19-Jul-18	October survey 4-Oct-18
SPRamp	NRP boat docks	39.515769	-79.31366	no ZM found	no ZM found
YCRamp	Yacht Club Swim area	39.468539	-79.294061	no ZM found	no ZM found
MRC6	Danger Buoy Ski Harbor	39.554408	-79.354625	no ZM found	no ZM found
NGC6	Mooring Buoy Sky Valley	39.502361	-79.269309	no ZM found	no ZM found
BRKDam	Southwest shoreline	39.510703	-79.3866	no ZM found	no ZM found

Table 4. Visual monitoring (zebra mussel plates) results including site name, description, GPS coordinates and results of survey conducted in 2018**.**

Site Code	Latitude °North	Longitude °West	Date Plates deployed	August check Aug 24-26, 2018	September check Sept 24-26, 2018	October Check and Retrieval October 10-12, 2018
MMC6	39.511321	-79.29914	7/26/2018	no ZM	no ZM	no ZM
GGC3	39.48069	-79.25575	7/31/2018	no ZM	no ZM	no ZM
DCC3	39.451923	-79.307425	7/31/2018	NA*	no ZM	no ZM
PWC6	39.46611	-79.31281	7/30/2018	no ZM	no ZM	no ZM
CCC3	39.535165	-79.318249	7/26/2018	NA **	NA **	no ZM
AWC3	39.50317	-79.32346	7/30/2018	no ZM	no ZM	no ZM
PLV3	DID NOT SAMPLE IN 2018			did not deploy plates in 2018		
HPC3	39.4884	-79.31662	7/30/2018	no ZM	no ZM	no ZM
GRC	39.537774	-79.34776	7/30/2018	no ZM	no ZM	no ZM
SPRamp	39.515769	-79.31366	7/19/2018	no ZM found	no ZM found	no ZM found
YCRamp	39.468539	-79.294061	7/19/2018	no ZM found	no ZM found	no ZM found
MRC6	39.554408	-79.354625	7/30/2018	no ZM found	no ZM found	no ZM found
NGC6	39.502361	-79.27149	7/19/2018	no ZM found	no ZM found	no ZM found
BRKDam	39.512291	-79.391138	7/19/2018	no ZM found	no ZM found	no ZM found

*plates appeared to have fallen off dock; found and re-hung on 8/29

**plates appeared to have fallen off buoy; searched for plates; did not find/replace

Conclusions

A review of recent literature concerning zebra mussel habitat requirements suggests wide disparities in habitat requirements (Cohen 2005). Additionally, there seems to be different results from different sources regarding what environmental parameters are most essential in determining habitat suitability. The Illinois-Indiana Sea Grant College published an online document (available at ilma-lakes.org/Artwork/zebra7.pdf) suggesting the key environmental parameters which determine colonization risk include temperature, calcium, total hardness, pH, dissolved oxygen, conductivity and water velocity. Their findings for low, medium and high risks for colonization are summarized in a chart in Table 5 and Deep Creek Lake values have been highlighted in yellow for the available measured parameters.

Table 5. Chart showing the low, medium and high colonization risk for each of the important environmental parameters to zebra mussel populations (source: ilma-lakes.org/Artwork/zebra7.pdf)

	Colonization Risk		
	Low	Medium	High
Sustained maximum summer water temperature 'C	9-18'C and 28-30'C	16-18'C or 25-28'C	18-25
Calcium (mg/l)	<20	20-25	>25
Total Hardness	<45	45-90	
pH	<6.6-7.2; >9.0	7.2-7.5 and 8.7-9.0	>7.5-8.7
Dissolved Oxygen (ppm)	<4-6	>6-<8	>8-10
Conductivity (uS/cm)	<22-36	36-82	>82
Water velocity (m/s)	<0.08-0.09 or >1.25	0.09-0.10 and 1.00-1.25	0.1-1.0

*Table modified from G. R O'Neill Jr. 1996 Zebra mussel impact and control. New York Sea Grant. Cornell University. Ithaca, NY

A review of Table 5, adjusted with the Deep Creek Lake conditions observed in 2018, suggest largely the lake has suitable conditions for zebra mussels. That said, concentrations of calcium and total hardness (needed for zebra mussel shell growth) show a low colonization risk suggesting calcium and hardness may be limiting factors to support zebra mussels in Deep Creek Lake. So although temperature, conductivity, dissolved oxygen and pH conditions may be suitable for zebra mussels, if calcium and hardness concentrations are too low, zebra mussels will not survive (SCEGC, 2001). At the same time, that study concluded that there were wide variations in defining those thresholds. They suggested minimum calcium thresholds of 3 mg/L is needed for survival, 7 mg/L for growth and 12 mg/L for reproduction and 25 mg/L calcium for massive infestations along with suggesting that temperature and pH can also be limiting parameters (SCEGC 2001).

After reviewing the literature, there is significant disparity in the results of studies aimed at trying to determine minimum requirements for zebra mussels as well as thresholds limiting zebra mussel survival. This suggests that multiple parameters are likely to contribute to the ability of zebra mussels to colonize, survive and reproduce in a water body and that this is complicated by the fact that these variables often change within a water body with location, depth and time of year. Cohen and Weinstein (1998) reviewed criteria for combining individual factor rankings using a potential distribution study in California and generated a chart to assess the potential for zebra mussels to become distributed (Table 6; Cohen 2005)

Table 6. **Criteria for Combining Individual Factor Rankings Used in a Potential Distribution Study in California (Cohen & Weinstein 1998)**

Overall Ranking	Calcium	pH	Temperature	Dissolved Oxygen	Salinity
High	at least one factor ranked High and neither ranked Low-to-no		each factor ranked High or Moderate		
Moderate	both factors ranked Moderate		each factor ranked High or Moderate		
Low-to-no	at least one factor ranked Low-to-no				

Based on the chart in Table 6, calcium, pH, temperature, dissolved oxygen and salinity are key variables to assessing potential distribution and that should one of those factors rank in the "low to no" range, it could limit the total potential of zebra mussel distribution. Using this as a guide and looking at the preferred habitat range for zebra mussels based on the preponderance of the literature, it would appear that calcium levels may be on the "low" range and would suggest Deep Creek Lake has an overall low potential for zebra mussel distribution.

In summary, based on the results of the 2018 Deep Creek Lake Zebra Mussel Monitoring Pilot Program, it is thought that Deep Creek Lake has suitable conditions for zebra mussels with regard to temperature, pH, conductivity and dissolved oxygen. However low calcium and hardness concentrations appear to be limiting and may not support extensive zebra mussel populations.

Potential future monitoring
While the data collected from Deep Creek Lake in 2018 suggest that the lake has overall low habitat suitability for zebra mussels (specifically due to low calcium and hardness concentrations), at least two years of additional water quality data would be beneficial to account for any seasonal or interannual variability, particularly with regard to calcium and hardness concentrations. So far, one additional year (2019) of monitoring is funded. The additional years of monitoring data is would be used together with the data described in this report to establish a baseline of calcium and hardness concentration at specified locations around the lake and enable the assessment of fluctuations or trends in those concentrations seasonally and/or over time. Having a combined three years of data would allow for more confidence in determining if Deep Creek Lake could support zebra mussels and also assessing the seasonal and temporal variability that may exist, specifically with regard to calcium and hardness concentrations. Additionally, 2018 was an exceptionally wet year (specifically, the wettest year on record in Baltimore, Maryland). As such, this increase in precipitation could have had an influence on the observed concentrations of calcium and magnesium concentrations observed in 2018.

Visual surveys, both underwater and using plates, found no evidence of zebra mussels at any location in 2018. Continued searches would be likely to provide an early warning if zebra mussels became established in Deep Creek Lake. Zebra mussel monitoring plates could continue to be deployed in April, checked monthly, and retrieved in October. Underwater visual surveys should be conducted at least once a year but preferably at a similar frequency as planned in 2018, three times over the year during optimal zebra mussel water temperatures (18-26℃). Colonization plates are a simple tool that can be used to check for presence/absence. However, underwater surveys are the preferred mechanism for assessing presence/absence of zebra mussels should resources become limiting. From a biological and logistical perspective underwater surveys are most effective if employed in mid-late May, mid-late July and mid-late September. These times should coincide with suitable water temperatures for zebra mussel growth.

Cherry Creek Cove could also be added to the locations surveyed via underwater sampling. During 2018, water samples for calcium and hardness were taken and a plate deployed in Cherry Creek Cove; however the site was not identified for underwater visual sampling. The reason for potential increased interest in Cherry Creek is that a lime doser is located on Cherry Creek operated by the Maryland Department of the Environment (MDE). Data collected by MDE from 1999 to 2010 (see Appendix B) suggests that the creek has experienced fluctuations in calcium concentrations possibly due to episodic pulses originating from the lime doser. That combined with the popularity of the cove for anchoring boats, may put that location at a potentially higher risk for a successful introduction of zebra mussels. Thus, underwater surveys and possibly more frequent (monthly) water samples analyzed for calcium may provide useful information from this location. If possible, monthly water sample analysis for calcium could be conducted on a more frequent (monthly) basis at a total of four mainstem surface locations (DPR0021, DPR0082, DPR0056, DPR0103), Cherry Creek Cove (CCC3) and possibly Gravelly Run Cove (GRC) and McHenry Cove (MCH6) as these locations demonstrated the highest calcium and/or hardness concentrations based on the 2009 and 2018 water quality sampling.

At the end of the boating season as local businesses are removing docks from areas around the lake for winter storage, a subset of docks could be inspected at the time of removal or more practically, at the location of storage. Dock floats and spud pipe poles could be inspected to check for the presence of zebra mussels. While this would not necessarily be an "early detection" tool, it would provide an additional, more randomized survey, to check for evidence of zebra mussels throughout Deep Creek Lake. Additionally, it could also be an educational tool that encourages the marinas and contractors that are removing docks every year to keep an eye out for invasive and suspicious organisms (like zebra or quagga mussels) that could be attaching to dock parts.

In addition to the monitoring survey described in this report, a pilot environmental DNA (eDNA) study was initiated in the fall of 2018 as part of an Aquatic Nuisance Species grant from the U.S. Fish and Wildlife Service. The goal of this pilot study is to determine the feasibility of using eDNA to detect several key aquatic invasive species of concern to include, but not limited to zebra mussels, hydrilla and various fish species. Environmental DNA is a promising technology that utilizes DNA sequencing techniques to detect ambient DNA (in the form of shed skin, feces, hair, etc.) of a target organism from water or sediment samples. The use of this technology in concert with traditional survey techniques as described in this report improves early detection of invasive species. The results of the first year of this pilot eDNA feasibility study were not available at the time of this report, but will likely be available to DNR some time during 2020. Should results be favorable for the continued use of this type of early detection monitoring, routine eDNA monitoring may be used to compliment this study.

It should be noted that all data (water quality and visual survey data) will be maintained by Department staff at the Lake Management Office (73 Brant Rd. Swanton, MD 21561).

References

Baker, P. and S. Baker. 1993. Criteria for estimating zebra mussel risk for non-invaded regions. Dreissena polymorpha Information Review (Zebra Mussel Information Clearinghouse, New York Sea Grant Extension, Brockport, NY) 4(4):4-8.

Benson, A.J., Raikow, D., Larson, J., Fusaro, A. , and Bogdanoff, A.K., 2018, *Dreissena polymorpha* (Pallas, 1771): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, nas.er.usgs.gov/queries/factsheet.aspx?speciesid=5, Revision Date: 2/13/2018, Access Date: 1/29/2019

Charlebois, Patrice M. "Zebra Mussels: Question and Answers for Inland Lake Managers." Illinois-Indiana Seagrant College. Sea Grant Publication HSG-01-20. Retrieved online January 2018 at iiseagrant.org/catalog/downlds_09/zmqas.pdf

Churchill, C.J., and Baldys, Stanley III, 2012, USGS Zebra Mussel Monitoring Program for North Texas: U.S. Geological Survey Fact Sheet 2012–3077, 6 p.

Cohen, A. N. and A Weinstein. 1998. The Potential Distribution and Abundance of Zebra Mussels in California. San Francisco Estuary Institute, Richmond, CA.

Cohen, A. N. and A Weinstein. 2001. Zebra Mussel's Calcium Threshold and Implications for its Potential Distribution in North America. San Francisco Estuary Institute, Richmond, CA.

Cohen, Andrew N. 2005. A Review of Zebra Mussels' Environmental Requirements. California Department of Water Resources. San Francisco Estuary Institute. Oakland, California. sfei.org/documents/review-zebra-mussels-environmental-requirements

Colorado Department of Public Health and Environment. 2013. Suitability of Colorado Lakes as Habitat for Invasive Mussels. Report accessed online February 2018. cpw.state.co.us/Documents/ANS/SuitabilityColoradoLakesasHabitatforInvasiveMussels.pdf .

Environmental Protection Agency. 2012. Water Monitoring and Assessment. Updated March 6, 2012. Retrieved January 10, 2019. archive.epa.gov/water/archive/web/html/vms59.html

Duke Power. 1995. Risk of Zebra Mussel Infestation in the Duke Power Service Area. Pamphlet produced by Aquatic Ecology Team/Environmental Division. Duke Power Company.

Haddon, David F. November 1995. S.C.E & G Vulnerability to Zebra Mussels. South Carolina Electric and Gas Company Environmental Services-Biology Division. Columbia, South Carolina.

Higgins, S.N., and J. Vander Zanden. 2010. What a difference a species makes: A meta-analysis of dreissenid mussel impacts on freshwater ecosystems. Ecological Monographs 80:179-196.

Hoddle, Mark S. Quagga *Dreissena rostriformis bugensis* and Zebra *Dreissena polymorpha* mussels. UC Riverside. Retrieved 1/29/19.

cisr.ucr.edu/quagga_zebra_mussels.html

Illinois-Indiana Sea Grant, 2012, Zebra mussel: U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. Revision Date: 9/25/2012, Access Date: 1/29/2019 nas.er.usgs.gov/queries/greatlakes/FactSheet.aspx?SpeciesID=5&Potential=N&Type=1&HUCNumber=DHuron,

Illinois-Indiana Sea Grant, 2005. "Aquatic Invasive Species-Zebra Mussel." Updated December 2005. Retrieved December 2018. in.gov/dnr/files/ZEBRA-MUSSEL.pdf.

Jones, L. A., & Ricciardi, A. (2005). Influence of physicochemical factors on the distribution and biomass of invasive mussels (Dreissena polymorpha and Dreissena bugensis) in the St. Lawrence River. Canadian Journal of Fisheries and Aquatic Sciences, 62, 1953-1962.

Kaushal, S.S., G.E. Likens, R.M. Utz, M.L. Pace, M. Grese, and M. Yepsen, 2013. Increased River Alkalinization in the Eastern U.S. Environmental Science & Technology 47:10302-10311.

King, Christine. December 2018. Personal Communications. Swanton, Maryland.

McMahon, R. 1996. The physiological ecology of the zebra mussel, *Dreissena polymorpha*, in North America and Europe. American Zoologist 36: 339-363.

Lenntech. 2019. "Calcium and Water". Retrieved Jan 10, 2019. lenntech.com/ro/water- hardness.htm

Mackie, G.L. and R Claudi. 2010. Monitoring and control of macrofouling mollusks in fresh water systems. CRC Press, Taylor & Francis Group, Boca Raton, FL.

MDDNR (Maryland Department of Natural Resources). 2016. Maryland Aquatic Nuisance Species Management Plan. Annapolis, Maryland. 77pp. + Appendices.

Null, Eric. December 2018. Personal Communications. Swanton, Maryland

Smits, J. and F. Moser (editors). 2009. Rapid Response Planning for Aquatic Invasive Species: A Maryland Example. Mid-Atlantic Panel on Aquatic Invasive Species. Maryland Sea Grant, National Oceanic and Atmospheric Administration, Publication Number UM-SG-TS-2009-01.

Strayer, D.L. 2009. Twenty years of zebra mussels: Lessons from the mollusk that made headlines. Front Ecol Environ 7:135-141.

U.S. Geological Survey. 2018. Nonindigenous Aquatic Species Database. Gainesville, Florida. Accessed 2/6/2018. nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=5

Vermont Department of Environmental Conservation 1998. Unpublished data on calcium levels and zebra mussel occurrence in Lake Champlain. Waterbury, VT.

Appendices

Appendix A: Sample Zebra Mussel Observation Form filled out after each visual survey

ZEBRA MUSSEL OBSERVATION FORM

OBSERVOR INFORMATION:

First name:	Julie		Last name:	Bortz	
E-mail:	julie.bortz@maryland.gov				
Area code and telephone:	301-387-4112				
Street address:	73 Brant Rd.				
City:	Swanton	State:	Md	Zip:	21561 - (extension)

OBSERVATION INFORMATION:

Date:	19-Jul-18	Time:	3:00 PM	Name of waterbody:	Deep Creek Lake, Maryland	
County:	Garrett	State:	MD			
Nearest town, road crossing or street name:				Swanton		
Location: **Either** decimal degrees	Latitude	39.50236100		Longitude	-79.27149000	
OR degrees-minutes-seconds	Latitude		(degrees)		(minutes)	(seconds) N
	Longitude		(degrees)		(minutes)	(seconds) W

Description of observation and its location (Found on outboard motor...). Describe the number of zebra mussels observed as: as Rare (1-10), Common (10-100), or Abundant (more than 100)

no zebra mussels found inside mooring buoys off Sky Valley swim area; searched 30min via diving; heaps of mystery snails found, no Hv; Pamp, Val, Sc, Ec, Ce, Ms, Ppu, lots of silt on rocks

If you find a suspected zebra mussel, take a picture and send it with your report form. Freeze it in a plastic bag or preserve it in a small bottle of rubbing alcohol so a DNR biologist can confirm the specimen.

Quagga Mussel
Dreissena rostriformis bugensis

- Shell: D-shaped and triangular, thin, fragile; smooth or shallowly ridged; solid light to dark brown or dark concentric rings; paler near hinge.
- Asymmetrical hinge line
- Attaches to hard surfaces

Zebra Mussel
Dreissena polymorpha

- Shell: D-shaped and triangular, thin, fragile; smooth or shallowly ridged; solid light to dark brown or striped.
- Symetircal hinge line; sits flat.
- Attaches to hard surfaces

Dark false mussel
Mytilopsus leuctophaeata

- Shell: Long and oval-shaped, thin, fragile; shallowly ridged; solid light to dark brown or black with irregular bands of color.
- Symetircal hinge line; does not sits flat.
- Attaches to hard surfaces
- Often found with barnacles.

Illustration courtesy of California Department of Water Resources

Please e-mail this completed form to: invasivemussels.dnr@maryland.gov

You should receive an e-mail confirmation that we received your data. Thank you for your assistance!

Appendix B: Data from the Maryland Department of the Environment (MDE) with regard to monitoring associated with the Cherry Creek Lime Doser

Figure 1. Site name, description and location of MDE's monitoring sites in support of the Lime Doser on Cherry Creek (Garrett County, Maryland)

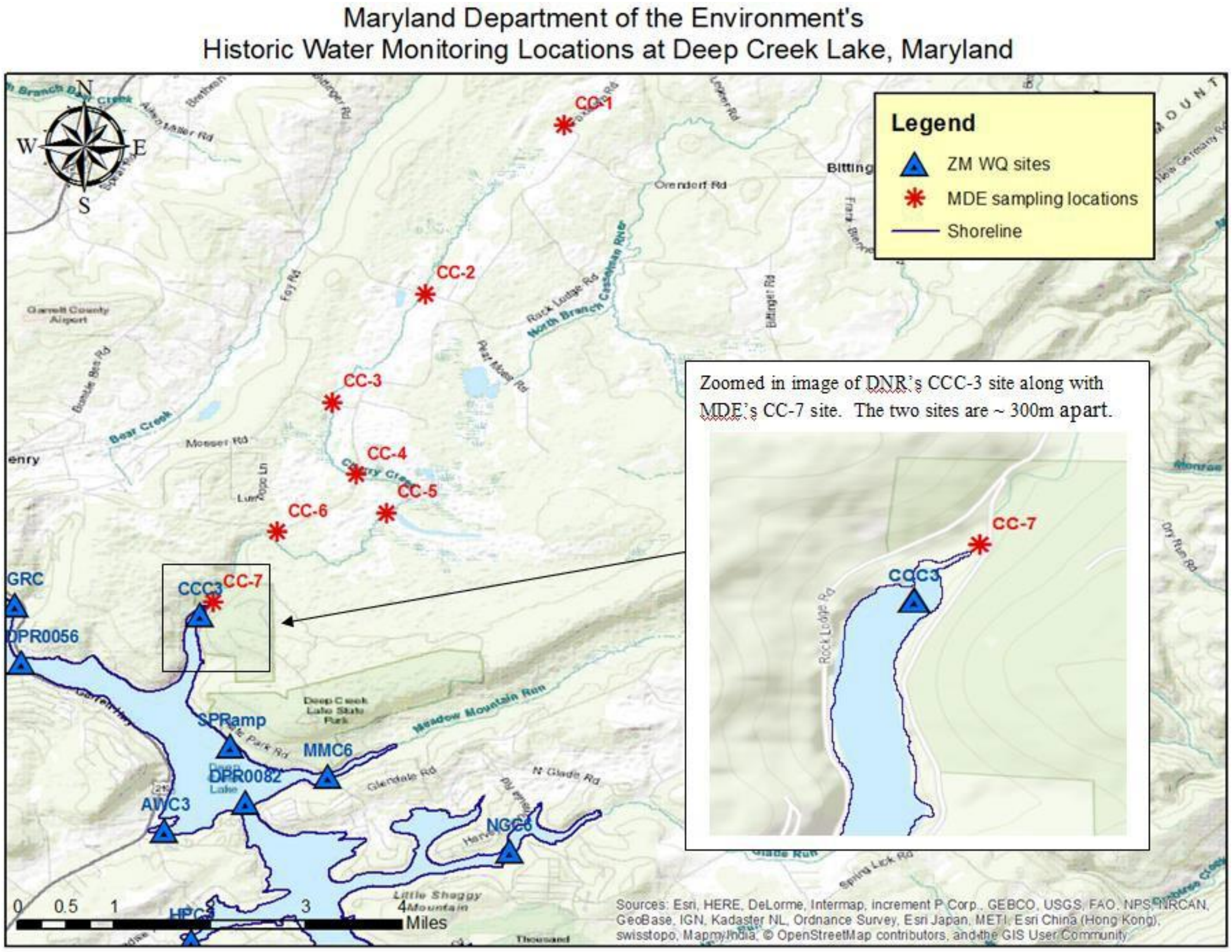
Site	Description	Latitude °N	Longitude °W
CC-1	Cherry Creek at culvert on Park Opel Road (headwaters)	39.609130°	79.263301°
CC-2	Cherry Creek at culvert on Accident-Bittinger Road	39.583668°	79.284192°
CC-3	Cherry Creek at culvert on Mosser Road	39.567341°	79.298152°
CC-4	Cherry Creek at Teets farm on Rock Lodge Road	39.556494°	79.294540°
CC-5	Cherry Creek at former Allegheny Mining site on Rock Lodge Trust Property	39.550756°	79.289950°
CC-6	AMD tributary to Cherry Creek at footbridge across from Limousin Ridge Road	39.547864°	79.306439°
CC-7	Cherry Creek at Cherry Creek Cove	39.537235°	79.316196°

Figure 2. Copy of raw data from site CC-7 (MDE's sampling location in Cherry Creek). This site is closest to DNR's water quality sampling location CCC3, located in Cherry Creek Cove, and monitored on behalf of the lake's long-term water quality monitoring dataset and the Zebra Mussel Monitoring Pilot Plan. The CC-7 site is in Cherry Creek and presumed to be flowing water under most conditions.

CC-7 Cherry Creek at Cherry Creek Cove 39.537235°, -79.316196°

Date	Field pH	Lab pH	Iron (mg/L)	Manganese (mg/L)	Suspended Solids (mg/L)	Acidity (mg/L)	Alkalinity (mg/L)	Aluminum (mg/L)	Calcium (mg/L)	Specific Conductance	Magnesium (mg/L)	Dissolved Solids (mg/L)	Sulfate (mg/L)	Zinc (mg/L)
4/22/2010	7.60	5.64	0.37	0.35	5	21.00	20.00	<0.10	5.88	107.0	2.40	83	42.00	<0.03
7/31/2008	7.50	6.23	0.19	0.98	18	11.00	14.70	<0.10	120.00	123.0	4.10	90	22.80	0.07
11/19/2007	7.10	6.04	0.39	0.27	2	19.20	5.40	<0.10	111.00	84.0	2.80	73	34.60	<0.03
8/27/2007	NA	6.60	2.54	0.46	<2	15.10	13.40	0.17	40.30	139.0	5.50	95	30.80	<0.03
5/23/2007	6.80	NA	0.74	0.30	3	NA	NA	0.74	85.00	92.0	20.90	72	30.60	<0.03
9/7/2006	6.97	6.93	0.68	0.29	2	0.00	126.70	0.10	150.00	208.0	11.10	153	67.10	0.03
5/18/2006	6.07	6.17	0.56	0.27	2	22.00	5.00	0.10	133.00	80.0	13.50	28	16.40	0.04
3/20/2006	7.31	6.08	0.36	0.49	2	11.00	6.00	0.10	57.40	87.0	23.00	60	28.00	0.06
2/2/2005	6.01	6.56	0.58	0.68	5	5.20	11.40	0.10	7.82	142.0	8.20	104	27.80	0.05
7/16/2003	6.70	6.72	4.10	0.73	6	19.30	10.20	0.36	4.83	131.0	1.60	84	25.20	0.04
11/19/2002	6.00	6.07	0.38	0.29	5	9.30	5.50	0.18	31.11	130.0	6.90	80	33.30	0.03
8/21/2002	6.90	7.32	1.15	0.12	4	0.00	33.90	0.03	25.90	197.0	6.50	138	50.40	0.03
5/22/2002	6.30	6.44	0.61	0.28	3	5.80	6.20	0.49	33.70	79.0	21.00	57	30.50	0.03
2/6/2002	6.60	6.48	0.52	0.40	2	4.70	6.00	0.10	18.10	94.0	1.30	61	30.90	0.03
10/29/2001	6.60	6.84	0.99	0.11	2	0.00	19.00	0.10	10.40	220.0	9.60	160	54.60	0.03
9/18/2000	6.81	6.96	1.96	0.08	2	0.00	26.60	0.10	38.80	218.0	19.60	135	33.30	NA
5/24/2000	n/a	5.16	1.37	1.07	6	22.20	2.70	0.32	65.20	68.0	9.40	53	20.80	NA
1/3/2000	5.53	5.92	0.35	0.91	2	48.20	9.90	0.17	53.80	86.0	81.30	52	33.90	NA
10/5/1999	6.55	6.55	0.03	0.34	17	14.20	15.40	0.10	192.30	174.0	14.20	175	102.10	NA
7/14/1999	5.90	6.06	0.13	0.16	2	11.90	5.60	0.10	22.00	113.0	23.00	96	47.60	NA
3/11/1999	5.90	5.78	0.25	1.25	5	0.00	4.90	0.60	37.28	92.0	10.00	68	36.80	NA

Figure 3. Map showing the location of MDE's sampling locations in Cherry Creek, along with a partial map of DNR's zebra mussel water quality monitoring locations.



Appendix C. 2018 Water quality data by date and site for each of the zebra mussel water quality monitoring locations in Deep Creek Lake, Maryland

DATE	SITE	Depth (m)	Temp (°C)	pH	ODO (mg/L)	Sp Cond (µS/cm)	Turbidty (FNU)	SECCHI (M)
5/1/2018	AWC3	0.5	10.20	7.1	11.5	98		
5/23/2018	AWC3	1.0	19.1	7.95	9.85	81.9	0.77	1.4
6/6/2018	AWC3	0.5	19.80	7.1	7.9	82		
7/11/2018	AWC3	0.5	24.30	7.4	8.2	88		
7/31/2018	AWC3	1.0	23.3	7.36	8.07	86.4	1.4	1.7
8/8/2018	AWC3	0.5	24.30	7.1	7.8	88		
9/27/2018	AWC3	0.5	19.00	6.6	7.7	88		
10/23/2018	AWC3	0.5	13.9	7	8.5	84	1.7	2.3
10/23/2018	AWC3	0.5	12.90	7.2	9.2	82		
5/2/2018	CCC3	0.5	10.80	7	10.5	79		
5/23/2018	CCC3	0.9	19.1	7.76	9.09	72	0.81	1.6
6/6/2018	CCC3	0.5	19.80	7	7.8	78		
7/11/2018	CCC3	0.5	24.40	7.2	7.9	87		
7/31/2018	CCC3	1.0	23.4	7.14	7.43	84.7	0.8	1.9
8/8/2018	CCC3	0.5	24.40	7	7.6	85		
9/27/2018	CCC3	0.5	19.50	6.7	7.8	81		
10/23/2018	CCC3	0.5	12.90	7.11	9.1	81		
10/23/2018	CCC3	1.0	12.9	7.1	9.1	81	1.3	2.0 c
5/2/2018	DCC3	0.5	11.10	7.3	11.5	76		
5/23/2018	DCC3	0.9	19.8	7.42	9.35	77.5	1.68	1.8
6/6/2018	DCC3	0.5	19.70	7	7.9	77		
7/11/2018	DCC3	0.5	26.60	8	9	84		
7/31/2018	DCC3	1.0	24	7.47	8.53	81.9	2.4	1.2
8/8/2018	DCC3	0.5	24.40	6.9	8	81		
9/27/2018	DCC3	0.5	19.10	6.9	8	80		
10/24/2018	DCC3	0.5	9.4	7.41	10.4	79	3	1.7
10/24/2018	DCC3	0.5	9.40	7.4	10.4	79		
5/2/2018	GGC3	0.5	13.60	7.2	10.9	80		
5/23/2018	GGC3	1.1	20.4	7.9	9.6	77.5	1.99	1.3
6/7/2018	GGC3	0.5	19.70	6.9	8.2	78		
7/11/2018	GGC3	0.5	26.80	8	8.7	85		
7/31/2018	GGC3	1.0	22.8	7.33	7.67	81.6	3.7	1
8/8/2018	GGC3	0.5	25.20	6.9	7.3	82		
9/27/2018	GGC3	0.5	19.70	6.7	8.4	80		
10/24/2018	GGC3	0.5	10.3	7.29	10.1	81	2.8	2
10/24/2018	GGC3	0.5	9.40	7.2	9.8	81		
5/2/2018	HPC3	0.5	10.40	7.1	11.4	79		
5/23/2018	HPC3	1.0	18.9	7.9	9.65	79.6	1.29	2.0
6/6/2018	HPC3	0.5	19.10	6.8	7.8	79		
7/10/2018	HPC3	0.5	25.10	7.5	9.3	84		
7/31/2018	HPC3	1.0	23.5	7.38	8.12	82.6	1.6	1.4
8/8/2018	HPC3	0.5	24.50	6.9	7.5	82		
9/28/2018	HPC3	0.5	19.50	6.9	8.3	81		
10/23/2018	HPC3	0.5	11.2	7.2	10.1	81	3.4	1.2
10/23/2018	HPC3	0.5	11.20	7.3	10.1	81		

DATE	SITE	Depth (m)	Temp (°C)	pH	ODO (mg/L)	Sp Cond (µS/cm)	Turbidty (FNU)	SECCHI (M)
5/1/2018	MMC6	0.5	10.40	6.9	10.8	78		
5/23/2018	MMC6	1.0	19	7.77	9.48	80	0.69	2.0
6/6/2018	MMC6	0.5	19.50	7.2	7.9	80		
7/10/2018	MMC6	0.5	25.30	7.2	8.5	87		
7/31/2018	MMC6	0.5	23	7.05	7.3	84	0.9	1.7
8/8/2018	MMC6	0.5	24.90	7.1	7.8	85		
9/28/2018	MMC6	0.5	19.50	6.9	7.9	84		
10/23/2018	MMC6	0.5	12.8	7.15	9.6	82	1.3	2
10/23/2018	MMC6	0.5	12.80	7.1	9.6	82		
5/23/2018	MRC6	1.0	19.7	7.7	9.27	93.2	1.11	2.0
6/6/2018	MRC6	0.5	20.10	7				
7/31/2018	MRC6	1.0	23.6	7.22	7.74	88.2	1.2	1.6
10/23/2018	MRC6	0.5	13.96	6.82	7.7	84	3.9	1.5
5/23/2018	NGC6	0.9	20.3	8	9.91	80.5	1.84	1.2
6/6/2018	NGC6	0.5	20.10	7				
7/31/2018	NGC6	1.0	23.4	7.33	7.12	83.3	2	1.2
10/23/2018	NGC6	0.5	10.5	7.24	10.4	84	3.3	1.6
5/2/2018	PLV3	0.5	12.20	7.1	11	78		
5/23/2018	PLV3	1.1	19.1	8.02	9.7	77.8	1.41	1.8
6/7/2018	PLV3	0.5	20.30	7.2	7.9	78		
7/10/2018	PLV3	0.5	26.30	7.9	9	84		
7/31/2018	PLV3	1.0	23.6	7.52	8.42	82.4	1.9	1.5
8/8/2018	PLV3	0.5	25.60	7.2	8.2	82		
9/28/2018	PLV3	0.5	19.60	6.8	8	81		
10/24/2018	PLV3	0.5	9.4	7.25	9.8	81	10.8	0.9
10/24/2018	PLV3	0.5	10.30	7.3	10.1	81		
5/23/2018	PWC6	1.1	18.6	7.74	9.67	77.8	1.93	1.8
7/31/2018	PWC6	1.0	23.4	7.3	7.81	82.3	2.1	1.4
10/24/2018	PWC6	0.5	9.97	7.39	10.32	80	3.2	1.6
5/23/2018	SPRAMP	0.7	18.5	7.94	9.33	81.2	0.48	2.2
7/31/2018	SPRAMP	1.0	23.1	7.2	7.65	84.2	0.4	1.8
10/23/2018	SPRAMP	0.5	13.52	7.06	9.1	82	2	2.4
5/23/2018	YCRAMP	1.2	19.8	8.01	9.54	78.2	1.24	1.1
7/31/2018	YCRAMP	1.0	23.3	7.35	7.25	82.5	1.3	1.7
10/24/2018	YCRAMP	0.5	11.66	7.32	9.8	81	2.3	1.4
5/23/2018	BRK Dam	1.0	17.7	7.57	9.39	82.6	0.29	3.4
7/31/2018	BRK Dam	1.0	23.9	7.24	8.12	83.9	0.3	2.3
10/23/2018	BRK Dam	1.0	12.9	7.16	9.2	82	1.2	1.8c
5/23/2018	GRC	1.0	19.7	7.86	9.64	87.6	0.82	2.0
7/31/2018	GRC	1.0	23.6	7.11	7.68	86.1	0.8	1.9
10/23/2018	GRC	0.5	13	7.1	9.3	87	1.1	2.2

DATE	SITE	Depth (m)	Temp (°C)	pH	ODO (mg/L)	Sp Cond (µS/cm)	Turbidty (FNU)	SECCHI (M)
5/1/2018	DPR0021	1.00	8.50	7.1	11	89		
5/23/2018	DPR0021	1.02	18.7	7.87	9.3	82.4	0.32	2.4
6/6/2018	DPR0021	1.00	19.00	6.9	8.4	82		
7/10/2018	DPR0021	1.00	24.10	7.1	8	86		
7/31/2018	DPR0021	1.00	23.7	7	8	83.9	0.5	1.7
8/7/2018	DPR0021	1.00	24.60	7	7.9	84		
10/1/2018	DPR0021	1.00	19.60	6.8	7.5	83		
10/25/2018	DPR0021	1.00	13.4	6.8	7.1	85	4.1	1.6
10/25/2018	DPR0021	1.00	13.40	6.8	7.1	85		
5/1/2018	DPR0056	1.00	9.10	7	10.9	89		
5/23/2018	DPR0056	0.99	19.3	7.65	9.62	84.6	0.76	2.0
6/6/2018	DPR0056	1.00	19.70	6.7	8	83		
7/10/2018	DPR0056	1.00	24.30	7	8	87		
7/31/2018	DPR0056	1.00	23.1	6.9	7.23	84.5	0.4	2.2
8/7/2018	DPR0056	1.00	24.60	6.9	7.7	84		
10/1/2018	DPR0056	1.00	19.50	6.8	7.8	84		
10/25/2018	DPR0056	1.00	13	7	8.6	84	1.5	2.4
10/25/2018	DPR0056	1.00	13.00	7	8.6	84		
5/1/2018	DPR0082	1.00	9.10	7	10.9	85		
5/23/2018	DPR0082 S	0.99	19.1	7.57	9.49	81	0.48	2.4
6/6/2018	DPR0082	1.00	19.60	6.7	8	82		
7/10/2018	DPR0082	1.00	24.10	7.2	8.2	86		
7/31/2018	DPR0082 S	1.00	23.2	7.01	7.45	83.3	0.9	1.8
8/7/2018	DPR0082	1.00	24.70	7	7.8	84		
10/1/2018	DPR0082	1.00	19.20	6.7	7.2	82		
10/25/2018	DPR0082	1.00	12.40	7.1	9.2	82		
10/25/2018	DPR0082 S	1.00	12.4	7.13	9.2	82	1.5	2.2
5/1/2018	DPR0103	1.00	9.50	6.9	10.8	79		
5/23/2018	DPR0103 S	0.96	19.4	7.67	9.57	78.7	0.94	1.9
6/6/2018	DPR0103	1.00	20.10	6.8	7.8	81		
7/10/2018	DPR0103	1.00	24.60	7.5	8.6	84		
7/31/2018	DPR0103 S	1.00	23.2	7.09	7.46	82.7	1.3	1.8
8/7/2018	DPR0103	1.00	24.90	7.1	8	82		
10/1/2018	DPR0103	1.00	19.40	6.8	8.4	81		
10/25/2018	DPR0103	1.00	11.40	7.3	9.9	81		
10/25/2018	DPR0103 S	1.00	11.4	7.31	9.9	81	1.9	1.8
5/1/2018	DPR0021	18.3	6.40	7	10.6	89		
5/23/2018	DPR0021	18.1	7.2	7.39	8.53	89	2.09	2.4
6/6/2018	DPR0021	18.0	7.60	5.6	7.4	91		
7/10/2018	DPR0021	18.8	8.00	6.4	2.8	97		
7/31/2018	DPR0021	20.0	8.5	6.7	1.04	99	3	1.7
8/7/2018	DPR0021	18.0	9.10	5.9	0.5	97		
10/1/2018	DPR0021	15.0	14.40	6.3	0.5	113		
10/25/2018	DPR0021	17.0	11.2	6.7	0.6	123	15.8*	na
10/25/2018	DPR0021	17.0	11.20	6.7	0.6	123		

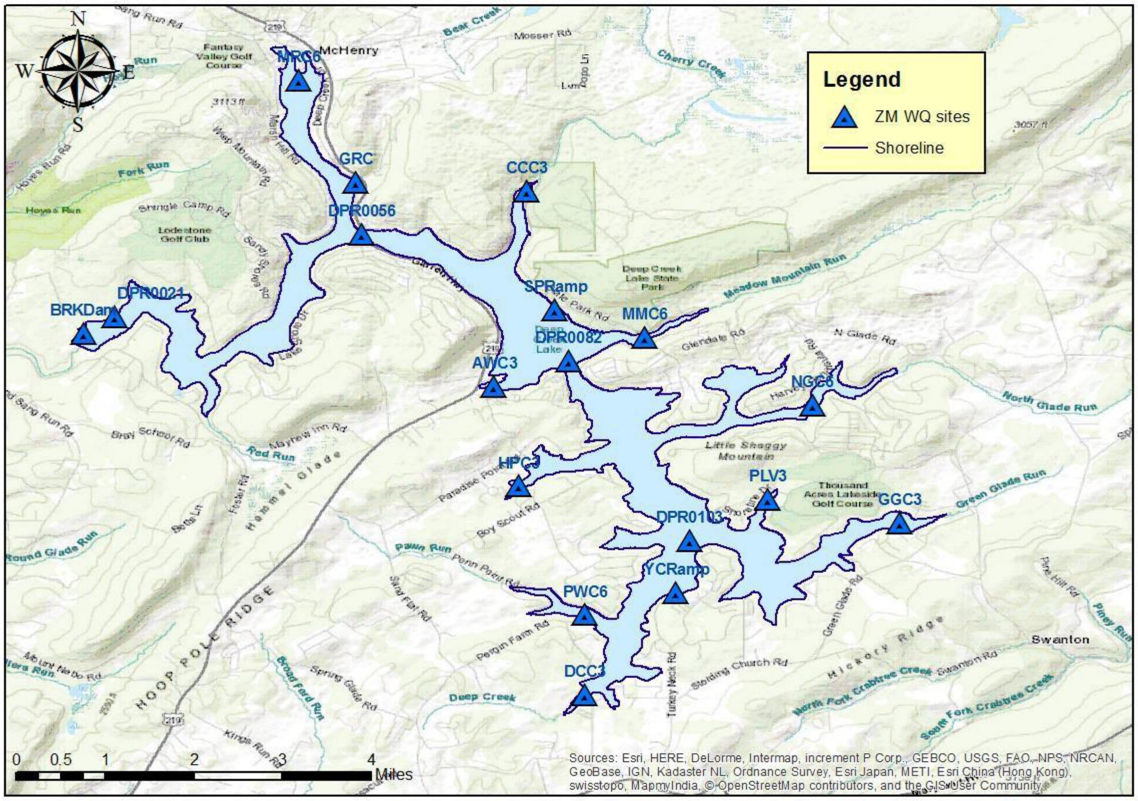
DATE	SITE	Depth (m)	Temp (°C)	pH	ODO (mg/L)	Sp Cond (µS/cm)	Turbidty (FNU)	SECCHI (M)
5/1/2018	DPR0056	12.0	8.40	7	10.7	87		
5/23/2018	DPR0056	13.1	9.9	7.47	8.44	87.4	0.61	2.0
6/6/2018	DPR0056	14.0	13.70	6.2	6.8	90		
7/10/2018	DPR0056	13.0	12.00	6.2	1.1	95		
7/31/2018	DPR0056	13.5	11.8	6.8	0.3	100.2	9.3	2.2
8/7/2018	DPR0056	13.0	12.60	6.3	0.4	105		
10/1/2018	DPR0056	14.3	15.20	5.9	1.1	95		
10/25/2018	DPR0056	12.8	12.8	7	8.4	84	2.8	na
10/25/2018	DPR0056	12.8	12.80	7	8.4	84		
5/1/2018	DPR0082	11.9	8.40	6.9	10.7	84		
5/23/2018	DPR0082 B	12.7	10.3	7.57	7.65	84.3	0.42	2.4
6/6/2018	DPR0082	12.4	10.80	6	4.6	87		
7/10/2018	DPR0082	13.0	12.40	6.2	0.3	95		
7/31/2018	DPR0082 B	12.0	13.3	6.94	0.24	102	0.6	1.8
8/7/2018	DPR0082	12.1	13.90	6.4	0.4	107		
10/1/2018	DPR0082	11.7	17.00	5.9	5.6	80		
10/25/2018	DPR0082	11.4	11.90	7.1	9.2	81		
10/25/2018	DPR0082 B	11.4	11.9	7.1	9.2	81	5.3	na
5/1/2018	DPR0103	9.9	9.10	6.9	10.7	79		
5/23/2018	DPR0103 B	9.8	12.8	7.56	7.39	80.5	0.9	1.9
6/6/2018	DPR0103	9.5	15.80	6.3	4.9	84		
7/10/2018	DPR0103	9.4	16.80	6.1	0.2	92		
7/31/2018	DPR0103 B	9.4	16.1	7.01	0.27	105.3	1.4	1.8
8/7/2018	DPR0103	8.8	20.00	6.2	0.4	93		
10/1/2018	DPR0103	7.5	18.50	6.3	7.3	81		
10/25/2018	DPR0103	9.2	10.90	7.2	9.6	81		
10/25/2018	DPR0103 B	9.2	10.9	7.2	9.6	81	4	na

Appendix D. Water quality data (Calcium, magnesium and hardness) from the 2018 water quality monitoring effort to assess zebra mussel habitat suitability in Deep Creek Lake. Data were provided by the University of Maryland's Appalachian Laboratory for the Maryland Department of Natural Resources, in partnership with the Deep Creek Watershed Foundation, Inc. and Brookfield Renewable.

Sample I.D.	Date Collected	Magnesium (mg/L)	Calcium (mg/L)	Hardness (mg equivalent $CaCO_3$/L)
AWC3	5/23/18	1.434	7.279	24.08
AWC3	7/31/18	1.523	7.561	25.15
AWC3	10/23/2018	1.593	7.766	25.95
BRKDam	5/23/18	1.414	7.566	24.72
BRKDam	7/31/18	1.423	6.975	23.28
BRKDam	10/23/2018	1.538	7.789	25.78
CCC3	5/23/18	1.445	6.807	22.95
CCC3	7/31/18	1.474	7.249	24.17
CCC3	10/23/2018	1.615	7.699	25.87
DCC3	5/23/18	1.459	6.995	23.47
DCC3	7/31/18	1.400	6.343	21.60
DCC3	10/24/2018	1.619	6.912	23.93
GGC3	5/23/18	1.446	6.903	23.19
GGC3	7/31/18	1.500	6.445	22.27
GGC3	10/24/2018	1.545	6.822	23.4
GRC	5/23/18	1.423	7.830	25.41
GRC	7/31/18	1.498	7.370	24.57
GRC	10/23/2018	1.556	7.845	26
HPC3	5/23/18	1.458	7.388	24.45
HPC3	7/31/18	1.388	6.314	21.48
HPC3	10/23/2018	1.494	7.059	23.78
MMC6	5/23/18	1.412	7.447	24.41
MMC6	7/31/18	1.404	6.654	22.40
MMC6	10/23/2018	1.585	7.54	25.35
MRC6	5/23/18	1.423	8.520	27.13
MRC6	7/31/18	1.437	7.011	23.42
MRC6	10/23/2018	1.577	8.27	27.14
NGC6	5/23/18	1.456	7.267	24.14
NGC6	7/31/18	1.472	6.316	21.83
NGC6	10/23/2018	1.679	7.403	25.4
PLV3	5/23/18	1.423	7.204	23.85
PLV3	7/31/18	1.532	7.282	24.49
PLV3	10/24/2018	1.606	7.342	24.95
PWC6	5/23/18	1.439	7.198	23.90
PWC6	7/31/18	1.554	7.478	25.07
PWC6	10/24/2018	1.636	7.544	25.57

Sample I.D.	Date Collected	Magnesium (mg/L)	Calcium (mg/L)	Hardness (mg equivalent $CaCO_3$/L)
DPR0021S	5/23/18	1.366	7.347	23.97
DPR0021S	7/31/18	1.367	6.633	22.19
DPR0021S	10/25/2018	1.589	8.01	26.54
DPR0056S	5/23/18	1.426	7.561	24.75
DPR0056S	7/31/18	1.504	7.242	24.28
DPR0056S	10/25/2018	1.477	7.156	23.95
DPR0082S	5/23/18	1.412	7.347	24.16
DPR0082S	7/31/18	1.466	6.702	22.77
DPR0082S	10/25/2018	1.463	6.864	23.16
DPR0103S	5/23/18	1.433	7.170	23.80
DPR0103S	7/31/18	1.471	6.784	23.00
DPR0103S	10/25/2018	1.516	7.033	23.8
SPRamp	5/23/18	1.440	7.607	24.92
SPRamp	7/31/18	1.553	7.761	25.77
SPRamp	10/23/2018	1.545	7.806	25.85
YCRamp	5/23/18	1.423	7.127	23.66
YCRamp	7/31/18	1.542	7.513	25.11
YCRamp	10/24/2018	1.566	7.334	24.76

2018 Zebra Mussel Water Monitoring Locations at Deep Creek Lake, Maryland



Appendix E: Results of the 2009 Zebra Mussel Habitat Suitability water sampling/analysis. Data was provided by the University of Maryland' Appalachian Laboratory in Frostburg, Maryland and is the property of the Maryland Department of Natural Resources.

2009 Zebra Mussel Habitat Suitability Data

Deep Creek Lake, Maryland

Site Code	Date sampled	Magnesium (mg/L)	Calcium (mg/L)	Hardness (mg equivalent $CaCO_3$/L)
UDC0004-D13	8/27/2009	1.621	7.360	25.053
UDC0004-D13B	10/28/2009	1.840	8.338	28.395
UDC0004-D13-B	7/30/2009	1.533	6.847	23.409
UDC0004-D13S	10/28/2009	1.509	8.356	27.077
UDC0004-D13-S	7/30/2009	1.474	6.650	22.673
CCC0008-D10B	10/28/2009	1.796	8.917	29.662
CCC0008-D10-B	7/30/2009	1.625	7.493	25.400
CCC0008-D10S	10/28/2009	1.765	8.060	27.392
CCC0008-D10-S	7/30/2009	1.610	7.458	25.253
CCC008-D10	8/27/2009	1.727	8.054	27.222
DPR0021-D1S	10/28/2009	1.610	8.762	28.508
DPR0021-D1-S	7/30/2009	1.555	7.314	24.668
DPR0021-D2B	10/28/2009	1.691	9.044	29.546
DPR0021-D2-B	7/30/2009	1.709	8.569	28.434
DPR0056-D3S	10/28/2009	1.557	8.492	27.617
DPR0056-D3-S	7/30/2009	1.587	7.806	26.024
DPR0056-D4B	10/28/2009	1.700	8.510	28.248
DPR0056-D4-B	7/30/2009	1.584	7.358	24.898
DPR0082-D5S	10/28/2009	1.682	8.636	28.491
DPR0082-D5-S	7/30/2009	1.600	7.431	25.144
DPR0082-D6B	10/28/2009	1.720	8.194	27.545
DPR0082-D6-B	7/30/2009	1.662	7.896	26.560
DPR0103-D7S	10/28/2009	1.652	7.621	25.834
DPR0103-D7-S	7/30/2009	1.576	6.965	23.881
DPR0103-D8B	10/28/2009	1.466	8.215	26.548
DPR0103-D8-B	7/30/2009	1.526	6.997	23.755
DPR0119-D17	8/27/2009	1.692	7.639	26.043
DPR0119-D17B	10/28/2009	1.599	7.877	26.253
DPR0119-D17S	10/28/2009	1.647	7.905	26.522
DPR0119-D17-S	7/30/2009	1.545	6.836	23.434
GGC0015-D15	8/27/2009	4.644	7.344	37.460
GGC0015-D15B	10/28/2009	1.664	7.875	26.518
GGC0015-D15-B	7/30/2009	1.504	6.633	22.756
GGC0015-D15S	10/28/2009	1.683	7.897	26.652
GGC0015-D15-S	7/30/2009	1.577	6.936	23.812
MMR0004-D11B	10/28/2009	1.429	8.054	25.995
MMR0004-D11-B	7/30/2009	1.561	7.233	24.488
MMR0004-D11S	10/28/2009	1.597	8.481	27.754
MMR0004-D11-S	7/30/2009	1.612	7.584	25.575
MMR0004-D11	8/27/2009	1.553	7.368	24.792

Site Code	Date sampled	Magnesium (mg/L)	Calcium (mg/L)	Hardness (mg equivalent $CaCO_3$/L)
MRC0011-D9	8/27/2009	1.710	8.269	27.690
MRC0011-D9B	10/28/2009	1.689	9.025	29.491
MRC0011-D9-B	7/30/2009	1.504	7.558	25.067
MRC0011-D9S	10/28/2009	1.707	9.001	29.504
MRC0011-D9-S	7/30/2009	1.581	7.582	25.440
NGC0010-D12	8/27/2009	1.701	7.599	25.980
NGC0010-D12B	10/28/2009	1.693	8.109	27.221
NGC0010-D12-B	7/30/2009	1.581	6.929	23.810
NGC0010-D12S	10/28/2009	1.707	7.980	26.955
NGC0010-D12-S	7/30/2009	1.608	7.125	24.410
PLV0004-D14	8/27/2009	1.611	7.256	24.753
PLV0004-D14B	10/28/2009	1.600	8.213	27.095
PLV0004-D14S	10/28/2009	1.639	8.201	27.228
PLV0004-D14-S	7/30/2009	1.569	6.951	23.815
Power Plant	6/17/2009	1.616	7.645	25.746
Power Plant	7/20/2009	1.667	7.823	26.397
Power Plant	8/19/2009	1.674	7.832	26.448
Power Plant	9/18/2009	1.703	8.240	27.587
PWC0004-D16	8/27/2009	1.684	7.620	25.963
PWC0004-D16B	10/28/2009	1.619	8.282	27.347
PWC0004-D16S	10/28/2009	1.666	8.254	27.470
PWC0004-D16-S	7/30/2009	1.506	7.012	23.710

2009-2016 Deep Creek Lake
Water Quality Monitoring Locations