Resource Assessment Service

Deep Creek Lake
Submerged Aquatic Vegetation Survey
2016

Report of Survey Activity and Results

Prepared For

Maryland Department of Natural Resources

Maryland Park Service

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EXECUTIVE SUMMARY

Submerged aquatic vegetation (SAV) can be found in a variety of aquatic habitats and forms the foundation of healthy lake ecosystems. Similar to their terrestrial counterparts, SAV are underwater grasses which provide a myriad of important ecological functions. Through the process of photosynthesis, SAV produces oxygen which is vital to the survival of all lake organisms. It provides food, habitat and nursery grounds for many species of fish and invertebrates, absorbs nutrients which decreases the likelihood of algal blooms, improves water clarity by reducing turbidity, diminishes shoreline erosion by reducing the effects of waves and currents, and is a major food source for waterfowl. Healthy native aquatic plant communities also help prevent the establishment of invasive plants like *Myriophyllum spicatum* (Eurasian watermilfoil), *Hydrilla verticillata* (Water thyme) and *Potamogeton crispus* (Curly pondweed).

During the summer 2016 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a 7th year of SAV monitoring in Deep Creek Lake (DCL). Despite its inherent ecological benefits, SAV can be an impediment to recreation and boat traffic in shallow areas, or in areas with fluctuating water levels. Due to concerns raised by some DCL residents regarding the density of SAV during the summer season, RAS biologists implemented an SAV monitoring program surveying representative transects in summer 2010 and has repeated the program each summer since. In 2012, SAV monitoring was expanded to include a shoreline survey designed to determine the spatial extent of *Myriophyllum* species (including Eurasian watermilfoil, an invasive species) throughout the lake. This shoreline survey has been conducted each year since 2012, but evolved to include documentation of all species of management concern, including native and invasive species. In 2016, the survey was further expanded to capture all SAV present along the shoreline, regardless of species.

Like many natural ecosystems, Deep Creek Lake has a fluctuating environment. Because of its role as a hydroelectric utility, the water level in the lake fluctuates often, which affects the distribution of SAV growing in the lake. There are also periods of heavy precipitation, drought conditions, and record high and low temperatures. Because of its fluctuating environment, it is necessary to maintain a long-term SAV monitoring program in DCL in order to track changes over time. As such, our SAV monitoring objectives were to define the distribution and relative abundance of SAV species present in the lake and to record their change over time via the study of representative transects, and to identify the location and extent of any species of management concern, such as non-native species like *Myriophyllum spicatum, Hydrilla verticillata* and *Potamogeton crispus,* and native species like *Potamogeton amplifolius*, or Large-leafed pondweed, via the shoreline survey. *Potamogeton amplifolius* was thought to be extirpated from the state until 2013, when it was documented in both Rocky Gap State Park's Lake Habeeb and Deep Creek Lake. Since its discovery, populations have expanded in both density and distribution throughout Deep Creek Lake. This program is continually adapting to answer evolving management questions, and is a component of the comprehensive water quality and habitat monitoring program in DCL which began in April 2009 and has continued to present.

Major findings from the 2016 SAV monitoring efforts in DCL are as follows:

- There is a diverse population of SAV growing throughout the lake with densities ranging from sparse to 100% cover where present.

Ten genera of vascular plants and two genera of macroalgae have been observed in Deep Creek Lake based on the transect surveys and during the shoreline surveys.

By increasing monitoring and plant identification efforts again in 2016, one additional, shallow water, native species was added to the list of plants present in DCL, *Procerpinaca palustris* (Marsh mermaidweed).

The high density and diversity of SAV in most areas of DCL are promoting water clarity throughout the lake and providing habitat for a healthy population of fish and invertebrates.

Sagittaria cristata (Crested arrowhead) and *Vallisneria americana* (Wild celery) were dominant vascular species observed at transect sites throughout the lake in 2016. Other commonly observed plants were *Elodea* spp., *Myriophyllum* spp., and *Potamogeton* spp. Macroalgae was also dominant at several transect sites.

Species zonation was apparent at most sites with *Sagittaria cristata* dominating the shallower portions and *Potamogeton spp., Vallisneria americana, Myriophyllum spp*., and macroalgae most commonly observed at deeper depths.

Of the 8 transects surveyed in 2016, Holy Cross Cove (HCC) and Meadow Mountain Run (MMR) were the most diverse sites with 8 species observed. The transect site showing the lowest diversity was Deep Creek Cove (DCC) with 2 species observed.

Potamogeton amplifolius continued to expand its distribution; its abundance was significantly higher in 2016 compared to previous years and has been increasing over time at transect sites. This species is considered legally endangered in Maryland and was thought to be extirpated from Maryland waters.

Though not identified to the species level during the transect surveys, *Myriophyllum spicatum*, or Eurasian Watermilfoil, is believed to be the dominant *Myriophyllum* species present in DCL. This plant is considered an Aquatic Invasive Species (AIS) and efforts have been underway since 2012 to monitor its distribution. No significant shifts in the *Myriophyllum* species were observed during the 2016 surveys.

Potamogeton crispus, another AIS plant, is a species of management concern in DCL. While the 2016 surveys did not find additional plants outside of the Pawn Run Cove area (where it was originally identified in 2015), the number of beds mapped in the area in 2016 increased three-fold. This species will continue to be monitored closely.

A third year of invasive plant management control was successfully implemented in the southern leg of Deep Creek Lake in 2016 to control for the AIS *Hydrilla verticillata*. Thirteen areas were identified for treatment based on the 17 locations where *Hydrilla* was found growing at varying densities from 2013-2015. The areas treated with herbicide continued to show positive signs of *Hydrilla* suppression with no viable above ground biomass observed at the end of 2016 growing season. No new beds of *Hydrilla* were found in 2016.

INTRODUCTION

During the summer 2016 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a seventh year of submerged aquatic vegetation (SAV) monitoring in Deep Creek Lake (DCL). Despite its inherent ecological benefits, SAV can be an impediment to recreation and boat traffic in shallow areas, or in areas with fluctuating water levels. Due to concerns raised by some DCL residents regarding the density of SAV during the summer season, RAS biologists implemented an SAV monitoring program surveying representative transects in summer 2010 and have repeated the program each summer since. In 2012, SAV monitoring was expanded to include a comprehensive shoreline survey designed to determine the spatial extent of *Myriophyllum* species (including *M. spicatum*, an invasive species) throughout the lake. This survey was repeated in 2013 and in 2014 to document the extent of both *Myriophyllum* and *Hydrilla verticillata,* another invasive SAV species found in the southern portion of the lake during transect surveys. In 2015, the survey was expanded again to document the distribution of other SAV visible from the surface, including species of management concern such as *Potamogeton amplifolius* (Broadleaved or Large-leaf pondweed). *Potamogeton amplifolius* is a native plant, previously thought to be extirpated from Maryland's waters but was found in 2013 in both Deep Creek Lake and Rocky Gap Lake and has been expanding in density and distribution within DCL waters since then. In 2016, the shoreline survey further evolved to capture SAV species visible from the surface as well as those not visible. The presence of SAV was determined using side-scanner sonar then species were identified from rake grab samples.

Our DCL monitoring objectives were to define the distribution and relative abundance of SAV species present in the lake and to record their change over time via the study of representative transects, and to determine the distribution of SAV lakewide via the shoreline survey. This SAV monitoring program is continually adapting to answer evolving management questions, and is a component of the comprehensive water quality and habitat monitoring program in DCL which began in April 2009 and has continued to present.

Background

Deep Creek Lake is located in Garrett County, western Maryland. The lake was formed in 1925 when Deep Creek was impounded for hydro-electric power generation. Following its creation, DCL was owned by multiple power companies until 2000, when the State of Maryland purchased the lake bottom and shoreline buffer zone. The State's acquisition of DCL has presented many unique and challenging management issues, particularly to DNR's Park and Resource Assessment Services.

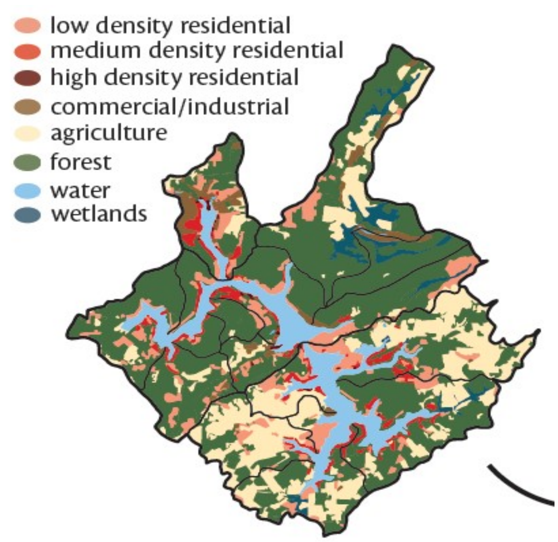


Figure 1. Land use in the Deep Creek Lake watershed.

With 68 miles of shoreline, DCL is Maryland's largest reservoir with an estimated surface area of 3,900 acres and a photic zone within the lake of 1480 acres. The lake is composed of a mainstem, branches, and multiple small, shallow coves fed by four major tributaries and more than 50 smaller streams. The lake's 180,000 acre watershed, which is in the Youghiogheny River watershed, is located west of the eastern continental divide, ultimately draining into the Gulf of Mexico. Because it is a reservoir, the water level fluctuates seasonally due to managed releases and hydrographic conditions, resulting at times in lower than average water levels. Since the lake was created, it has become a four-season travel destination with endless recreational opportunities, particularly in the last thirty years since the completion of Interstate 68. Towns have grown up around the lake, and much of the lake's shore is now lined with hotels, condominiums, and private homes. The northern portion of the lake watershed is primarily composed of towns, residential areas, and forested land. The southern portion of the lake watershed is dominated by agricultural land (Fig. 1) (Kelsey and Powell, 2011).

Beginning in late spring when temperatures increase, SAV begins growing throughout the lake's photic zone, particularly in the shallower coves, which are the first to receive nutrient-enriched runoff from the surrounding watershed, and are warmer due to shallower depths. Similar to their terrestrial counterparts, these underwater grasses provide a myriad of important ecological functions. Through the process of photosynthesis, SAV produces oxygen that is vital to the survival of other lake organisms. It provides food, habitat, and nursery grounds for many species of fish and invertebrates, as well as waterfowl. It absorbs nutrients, which in turn decreases the likelihood of algal blooms, and it improves water clarity by locking sediments in their root systems. SAV also diminishes the effects of shoreline erosion by reducing the impacts of currents and waves (generated by wind as well as heavy boat wakes), also improving water clarity. Additionally, healthy native aquatic plant communities help prevent the establishment and spread of aquatic invasive species (AIS) plants like Eurasian watermilfoil (*Myriophyllum spicatum*), Hydrilla (*Hydrilla verticillata)*, and Curly Pondweed *(Potamogeton crispus),* all of which are found in Deep Creek Lake.

Aquatic Invasive Species

Aquatic invasive species (AIS) have been shown to create significant economic and ecological harm, including the loss of biodiversity, altered aquatic food webs, reduced water quality, reduced public safety and health, a decline in fisheries, damage to infrastructure, reduced boating, fishing, and other recreational opportunities, and a loss of tourism revenue to local communities. In 2015, the General Assembly passed House Bill 860, entitled the State Lakes Invasive Species Act of 2015, which provides that after April 1, 2017, an owner of a vessel may not place the vessel or have the vessel placed in a lake at a public launch or public dock unless the owner has cleaned the vessel and removed all visible organic material. The Act also directed the Maryland Department of Natural Resources to convene a workgroup to evaluate actions that could reduce the risk of the introduction and spread of aquatic invasive species in Maryland state-owned-and-managed lakes. As of 2015, at least 3 species of AIS plants have been found in DCL. The most concerning is *Hydrilla verticillata,* which was found in DCL in 2013. The genus *Hydrilla* has a single species, *H. verticillata*, which is considered an exotic invasive species found throughout the United States. The strain found in Deep Creek Lake is the monoecious strain introduced to Delaware in 1976. This plant is a rooted aquatic plant that forms dense mats in still or slowly moving water. *Hydrilla* is very similar in appearance to the native waterweed *Elodea* species (*Elodea canadensis* and *Elodea nutallii*), which are found throughout Deep Creek Lake. Also of concern is *Myriophyllum spicatum*, or Eurasian watermilfoil. There are approximately 70 species of *Myriophyllum* (watermilfoil). They are submersed aquatic plants that are most commonly recognized for their long stems and whorled leaves that are finely, pinnately divided. The name *Myriophyllum* comes from Latin, "myrio" meaning "too many to count", and "phyllum" meaning "leaf". While *Myriophyllum* fruits and leaves are an important food source for waterfowl, which are thought to play an important role in seed and clonal dispersal (Jacobs and Margold, 2009), *Myriophyllum spicatum*, or Eurasian watermilfoil, can be invasive and out compete other native species for habitat. *Myriophyllum spicatum* is one of at least three species of *Myriophyllum* found in Deep Creek Lake, but *M. spicatum* is the only invasive variety present. *Potamogeton crispus* or Curly Pondweed, was only recently discovered in DCL in 2015 but has been shown to be a highly invasive aquatic plant in other freshwater lakes, such as the Finger Lakes in central New York state, and thus its appearance in 2015 is a concern to DCL lake management efforts. It is a plant that generally prefers waters high in nutrients and is an early and late season specialist that dominates in the spring and produces burr-like turions in mid July, senesces in late summer, then goes through another growth cycle in the late fall/winter. Initial observations of the plant population in DCL, suggest that the plant may follow a slightly different life cycle than described in the literature. Fluctuating lake levels and fall/winter draw down may in part be altering the timing of appearance, turion production and senescence of the plant at DCL. Its potential to spread in DCL is consequently currently unknown.

METHODS

In June 2010, RAS biologists, accompanied by local SAV experts from Frostburg State University, identified six representative areas to survey SAV in Deep Creek Lake. These areas were selected based on the presence of SAV as well as their spatial distribution within the lake. They include two north/western sites (Red Run Cove and McHenry), two central sites (Meadow Mountain Run and Honi Honi), and two south/ eastern sites (Deep Creek Cove and Green Glade Cove). Two additional survey sites were added in the summer of 2015 to provide better spatial representation, particularly in the southern end of the lake. The newly added locations were in Holy Cross Cove and Paradise Point Cove. See Figure 2 for a map of locations, and Table 1 for spatial coordinates and site abbreviations.

Figure 2. Aerial map of Deep Creek Lake with MD DNR SAV transect locations indicated by red dots.

Table 1. Transect names, abbreviations, and coordinates

Site	Abbreviation	Latitude (°N)	Longitude (°W)
Red Run Cove	RRC	39.49977	79.3711
McHenry	McH	39.55087	79.35787
Honi Honi	HHO	39.50485	79.32091
Meadow Mountain Run	MMR	39.51182	79.30334
Deep Creek Cove	DCC	39.45368	79.30904
Green Glade Cove	GGC	39.47844	79.26206
*Paradise Point Cove	PPC	39.50137	79.29363
*Holy Cross Cove	HCC	39.48447	79.30193

* New transects added in 2015

At the time each survey location was established in June 2010, the extent of the SAV bed was identified by dive certified SAV biologists using SCUBA. Along the shoreward edge of the bed, a spot was randomly selected to begin a transect. Rebar was used to mark each point and secure a transect tape. A biologist then swam the tape out, perpendicular to shore, to the deep edge of the SAV bed where a weighted buoy was placed to mark the point and secure the opposite end of the tape. If conditions were considered unsafe due to heavy boat traffic, transects were terminated prior to the edge of bed. If the SAV bed extended farther than 200 meters from shore, transects were terminated at 200 meters. Both ends of the transect were georeferenced using a handheld Garmin Global Positioning System (GPS) device so that all future surveys could be repeated in the same location. If the SAV beds expanded or contracted, a new point was recorded and the transect was terminated at the current edge of bed. One transect was completed at each site during the 2010-2014 surveys. In 2015 and 2016, an additional transect was added to each survey site for a total of 2 transects at each of 8 sites.

During each sampling event, SAV biologists sampled eleven $0.25m^2$ quadrats per transect. To establish the sampling positions, the transect lengths were divided by 10 for a total of 11 quadrats per transect. For example, if a transect was 100 meters long, quadrats were sampled at 0m, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, and 100m from the shoreward edge of bed. Within each quadrat, the percent cover of both underwater grasses and macroalgae (MA) were visually quantified for each species present. A total SAV percent cover was also estimated, as well as a total macroalgae percent cover. In this case, SAV is any vascular plant present, whereas macroalgae is any nonvascular plant present. The two groups are quantified and recorded separately because of their differing responses to water quality dynamics. [Note: SAV and MA were not originally separated, so results in this report regarding previous years may vary from results in past reports.] Additionally, MA was previously identified to the genus level. In 2013, MA was only identified as MA and previous year's data were clumped to reflect the lack of differentiation. Canopy height for each species present was recorded when possible, as well as water depth at each quadrat. Shoot counts for each species were completed within a smaller square in the bottom right corner of the quadrat when feasible. If the plant could not be identified to the species level, only the genus was recorded. Transects were surveyed twice in 2010 (early and late season) and three times in 2011 - 2014 (early, mid, and late season). An analysis of the dataset showed that, aside from a difference in SAV abundance over the course of the growing season, no differences in community composition were detected between sampling events. Therefore, to reduce expenditures and simplify the sampling design, the SAV in DCL was only surveyed once in subsequent years, during peak biomass (late August/early September), for both 2015 and 2016. Sampling for the 2016 SAV survey was conducted on September 7 and 8, 2016.

A comprehensive shoreline survey was conducted over the course of roughly one month from August 29-September 26, 2016. The goal of this survey was to document the distribution and relative abundance of SAV visible and not visible (using a throw rake) from the surface, including invasives such as *Hydrilla, Myriophyllum spicatum* and *Potamogeton crispus*. During the 2016 shoreline survey, 3 vessels surveyed the entire 68-mile shoreline of the lake. Each boat was equipped with a driver and one or two on-board "observers" that had hand-held Garmin GPS units to mark SAV bad locations. One of the boats was additionally equipped with Lowrance HDS echo-sounders (with side and downscan functionality). The Lowrance echo-sounders display unique signatures for different species of SAV; that functionality combined with the on-board observers provided the ability to locate and geographically mark and record patches of various SAV species either visually or with the help of echo sounders. Although there are between three and four species of *Myriophyllum* believed to be present in DCL, only one, *Myriophyllum spicatum*, is invasive. Because it is physically similar to and difficult to differentiate from other species of the genus, all *Myriophyllum* observations were recorded at the genus level. Another genus that is hard to differentiate to the species level with the naked eye are the waterweeds, *Elodea canadensis* and *Elodea nutallii.* When found on either the transects or shoreline survey, all *Elodea* observations were recorded at the genus level.

In response to the September 2013 discovery of invasive *Hydrilla verticillata* and the July 2015 finding of another AIS, *Potamogeton crispus,* DNR biologists and Deep Creek Lake Natural Resource Management Area (DCL NRMA) staff conducted additional, more intensive surveys in the southern end of the lake where those plants were found. The goal was early detection of new AIS species as well as documentation of additional species not previously recorded during the shoreline survey. These surveys were conducted from boats, kayaks, and paddleboards to document the presence and relative abundance of species observed. When visibility precluded identification, haphazard rake tosses were also conducted and species presence, location, and relative abundance were recorded. To determine the relative efficacy of the aforementioned methods at early detection of AIS, additional targeted surveys were completed by both SCUBA diving and snorkeling in specific "high risk" areas. Species and location data collected during these targeted surveys are not included in this report unless an unreported or additional AIS species were found, such as the case with *P. crispus.*

Approximately 30 small beds of *P. crispus* (<5m^2) were found in the Pawn Run area in July-August 2015, located in the southwestern portion of DCL. Beds were GPS marked with PVC and selectively identified for hand-removal in August by DNR RAS biologists and DCL NRMA staff. Beds were monitored again and mapped in August 2016 to determine if bed location or size had changed (See Appendix F). Over 90 beds were mapped in the Pawn Run Cove area suggesting a more than three fold increase in abundance. However no additional locations of *P. crispus* were found growing in DCL, outside of the Pawn Run area, although floating fragments were observed in the

North Glade area in 2016 and Hickory Cove area in 2016 and near the State Park in 2015. DNR Biologists will continue to monitor this small population and track any changes in bed density or distribution.

Data Analysis

Transects

Species richness was defined for each transect and sampling event as the number of species observed per transect. Shannon species diversity, which is a measure of both the number of species (richness) and the relative contribution of each of these species to the total number of individuals in a community, was also calculated and analyzed. Frequency of occurrence and density for each species or genera at each site were calculated using the following formulas:

Frequency of Occurrence = # of quadrats found/total # of quadrats

Density = sum of % cover values/total # of quadrats

Density and frequency of occurrence were used to determine which species were dominant at each site during each sampling event. Dominance was defined as density being equal to or greater than 10% <u>or</u> frequency of occurrence being equal to or greater than 50%. To determine dominance for sampling year 2010, a species/ genus had to be found dominant during both sampling events that took place that year. For sampling years 2011-2014, in which three sampling events took place, only the August and September events were considered and a species/genus had to be found dominant during both sampling events to be determined dominant for the site for the year. In 2015 and 2016, when only one sampling even took place (but two transects were surveyed at each site rather than just one), a species needed to be dominant on both transects to be considered dominant for the site for the year.

To graphically display observed changes in total SAV and total macroalgae over time, density bar charts were created in Excel. To identify any significant differences in SAV among sites and changes over time, statistical analyses were performed using SigmaPlot and SAS statistical software package (Enterprise Guide 5.1, SAS Institute Incorporated, Cary, NC). Changes in total SAV and macroalgae density were assessed using linear regression. Species richness and diversity, total SAV % cover, density and frequency, individual species % cover and frequency, transect length and total macroalgae density were compared over time and among sites using nested 2-Way ANOVAs with site and sampling year as treatments. Homogeneity of variances was assessed using Levene's test. Following a significant ANOVA ($p \leq 0.05$), pairwise comparisons were performed using Student Newman Keuls test.

Shoreline survey

Data collected during the comprehensive shoreline survey were transferred from hand-held Garmin GPS units into ArcGIS for mapping and analysis (ArcGIS Desktop 10.1. Redlands, CA: Environmental Systems Research Institute). From 2012 to 2016, the focus of the shoreline survey evolved. In 2012, the primary goal was to determine the spatial extent of *Myriophyllum* species. After the discovery of *Hydrilla verticillata* in September 2013, an additional focus of the shoreline survey was to document the location of any non-native species or native species of management concern, such as *Potamogeton amplifolius*, which can produce a canopy that may reach the surface in good conditions. An additional find of *Potamogeton crispus* in July 2015 prompted the 2015 survey to expand again. Coordinates were recorded for any non-native SAV species as well as native species that were visible from the surface, such as *V. americana* and *P. amplifolius*. For years 2012-2015, coordinates were taken at the center of each bed or patch of SAV visible at the surface and beds were assigned area values based on GPS points and field observations. This allowed for the creation of lakewide *Myriophyllum* maps from 2012-2015. In 2016, efforts were made to record coordinates for all species of SAV, both visible at the surface and those not visible, utilizing a throw rake to survey the bottom when visibility was limited. If a bed was visibly circular in nature, a GPS point was recorded in the center of the bed, and the diameter of the bed was estimated in meters. If the bed was not circular in nature, a collection of GPS points was taken around the outer perimeter of the bed to allow for polygons to be drawn in ArcGIS. SAV species composition and relative abundance (% cover by species) were estimated. When visibility was limited, a modified weighted rake, connected to a 30m rope, was deployed haphazardly off the boat in replicates of 3 tosses, each allowed to drag on the bottom of the lake for 5-10m, then retrieved and species collected on the rake identified and recorded. While the rake methodology does not work well for robust, basal species such as *Sagittaria cristata*, the addition of this approach allowed for the detection of shallower species, often not visible from the surface and thus a more complete representation of the total diversity of SAV found throughout Deep Creek Lake. The cumulative results of the 2016 SAV shoreline survey will be provided in a digital ArcGIS format separate from this report.

Due to the survey focus and methodology evolving over time, general observations made during the 2016 shoreline survey will be mentioned in this report as appropriate. However, quantitative comparison across years will be restricted to the transect data surveys and specific species of concern, such as *Hydrilla verticillata* and *Potamogeton crispus,* where methodology mapping these species remained constant across years.

RESULTS

Ten genera of vascular aquatic plants have been observed in Deep Creek Lake from 2010-2016 while conducting SAV surveys (Table 2). An additional native plant, *Procerpinaca palustris* (Marsh mermaidweed) was identified by DCL NRMA and DNR staff in 2016 This highlights the need for continued and expanded SAV monitoring, especially into the shallower regions of the lake, where diversity is often greater and visibility can be limiting.

In an effort to verify the identification of SAV to the species level, DNR biologists and DCL NRMA staff began collecting voucher specimens of the various species of SAV found at DCL in 2015. When possible, whole plant specimens (as much of the plant and reproductive parts that could be obtained) were collected, bagged in lake water, and sent to the DNR Wye Mills Laboratory. There, the Maryland State Botanist identified, pressed, mounted, labeled, and archived the specimens for future reference at the DNR Tawes Herbarium. If the State Botanist confirmed the species identification recorded in the field, then it was assumed that a positive identification to the species level for the plant in question had been made. Results denote positive identification with a "yes" in the final column of Table 2: List of Species. If either a voucher specimen was not obtained and/or a positive identification by the State Botanist or DNR field biologists could not be confirmed, a "no" is indicated in the final column of Table 2.

Two species of macroalgae (*Nitella flexilis* and *Chara vulgaris*) have also been observed throughout the lake during surveys. In 2013, it was determined that *Nitella* and *Chara* would no longer be differentiated due to physical similarity and difficulty in differentiation while SCUBA diving, so they are no longer separated in the analysis. Both species were simply recorded as "macroalgae" from 2014 to 2016. Common names and abbreviations for both SAV and macroalgae species can be found in Table 2. Pictures, line drawings, and a brief description of each species observed are given in Appendix A.

Table 3 includes a summary of sampling results, including transect length, total SAV density and frequency of occurrence, total macroalgae density and frequency of occurrence, species richness, and density and frequency of occurrence for each SAV species observed during each survey. Table 4 gives the dominant species observed during each sampling event and for the year. Figures 3 - 10 show total SAV and total macroalgae density graphed over time for each transect, with corresponding trendlines showing overall increasing, decreasing, or no-change trends. In many cases, there was an inverse relationship between SAV and macroalgae; where SAV was dense, macroalgae was sparse, and vice versa. Most species that were observed were seen throughout the lake, but each site was dominated by only a few species (Table 4).

Table 2. List of SAV species/genera observed in Deep Creek Lake during summers 2010-2016 SAV surveys. Also given are the abbreviations used in this report and the plant's common name.

SAV/MA	Species	Abbrev-iation	Common name	Voucher & Positive ID
SAV	*Sagittaria cristata*	Sc	Crested arrowhead	no
SAV	*Vallisneria americana*	Va	Wild celery	yes
SAV	*Elodea spp.*	E spp.	Waterweeds	na
SAV	*Elodea nutallii*	En	Western or Nutalls waterweed	yes
SAV	*Elodea canadensis*	Ec	Common waterweed	no
SAV	*Ceratophyllum echinatum*	Ce	Spineless hornwort	yes
SAV	*Ceratophyllum demersum*	Cd	Coontail	no
SAV	*Myriophyllum spp.*	Myr spp.	Watermilfoil	na
SAV	*Myriophyllum spicatum*	Ms	Eurasian watermilfoil	no
SAV	*Myriophyllum humile*	Mh	Low watermilfoil	yes
SAV	*Myriophyllum sibricum*	Msb	Northern watermilfoil	no
SAV	*Myriophyllum heterophyllum*	Mh	Two-leafed milfoil	no
SAV	*Hydrilla verticillata*	Hv	Hydrilla	yes
SAV	*Najas flexilis*	Nf	Slender/nodding naiad	yes
SAV	*Najas guadalupensis*	Ngp	Southern naiad	yes
SAV	*Najas gracillima**	Ng	Slender waternymph	no
SAV	*Najas minor**	Nm	Spiny naiad	no
SAV	*Utricularia vulgaris*	Uv	Common bladderwort	no
SAV	*Isoetes spp.*	Iso	Quillwort	yes
SAV	*Potamogeton pusillus*	Pp	Slender pondweed	yes
SAV	*Potamogeton crispus*	Pcr	Curly pondweed	yes
SAV	*Potamogeton epihydrus*	Pepi	Ribbon-leafed pondweed	yes
SAV	*Potamogeton vaseyi*	Pv	Vasey's pondweed	yes
SAV	*Potamogeton spirillus*	Ps	Spiral pondweed	no
SAV	*Potamogeton diversifolius*	Pd	Waterthread pondweed	yes
SAV	*Potamogeton amplifolius*	Pa	Broad-leaved pondweed	yes
SAV	*Potamogeton nodosus*	Pn	Longleaf pondweed	yes
SAV	*Potamogeton robbinsii*	Pr	Robins pondweed	no
SAV	*Procerpinaca palustris*	Ppa	Marsh mermaidweed	yes
MA	*Chara vulgaris*	Cv	Chara	yes
MA	*Nitella flexilis*	Nit	Nitella	yes

* Species was found that could not be positively identified; thought to be *N. minor* or *N. gracillima*

Species in red denote non-native aquatic invasive species (AIS)

Table 3. Summary of sampling results, including date, transect length (m), richness, total SAV density, total macroalgae density (MA) and density and frequency of occurrence (in parentheses) for each SAV species observed during each survey.

Date	ID	Length (m)	Rich-ness	Total SAV	MA	Sc	Va	Ec	Cd spp	Myr spp	Nf	Ng	Uv	Iso	Ppu	Pepi	Pv	Ps	Pd	Pa
8/4/10	RRC	127	9	35(82)	28(55)	6(18)	0(0)	5(55)	0(0)	3(9)	<1(18)	0(0)	<1(9)	<1(9)	10(18)	0(0)	9(45)	0(0)	0(0)	0(0)
9/15/10	RRC	125	7	33(91)	40(64)	9(18)	0(0)	10(55)	0(0)	<1(18)	0(0)	0(0)	<1(9)	0(0)	<1(9)	0(0)	11(27)	0(0)	0(0)	0(0)
6/14/11	RRC	100	5	48(82)	13(27)	2(18)	0(0)	9(55)	0(0)	5(36)	0(0)	0(0)	0(0)	0(0)	32(82)	0(0)	0(0)	0(0)	0(0)	0(0)
8/9/11	RRC	110	7	71(100)	2(18)	13(27)	0(0)	17(64)	0(0)	4(55)	<1(18)	0(0)	0(0)	0(0)	5(45)	0(0)	32(100)	0(0)	0(0)	0(0)
9/12/11	RRC	100	6	41(100)	0(0)	13(27)	0(0)	20(73)	0(0)	3(45)	2(9)	0(0)	0(0)	0(0)	3(45)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/27/12	RRC	100	7	58(100)	34(45)	13(27)	0(0)	23(64)	0(0)	6(55)	0(0)	0(0)	<1(9)	0(0)	14(55)	0(0)	0(0)	0(0)	2(27)	0(0)
8/22/12	RRC	110	7	42(91)	15(27)	9(18)	0(0)	27(55)	0(0)	5(64)	<1(9)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
9/19/12	RRC	100	7	39(100)	18(36)	7(18)	0(0)	22(64)	0(0)	4(55)	0(0)	<1(9)	0(0)	0(0)	4(9)	0(0)	2(18)	0(0)	0(0)	0(0)
6/20/13	RRC	100	6	71(100)	1(9)	15(27)	0(0)	44(73)	0(0)	3(27)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	9(55)	0(0)	0(0)	0(0)
8/15/13	RRC	100	9	29(100)	17(64)	13(36)	0(0)	2(73)	0(0)	5(64)	<1(18)	0(0)	<1(9)	<1(9)	4(45)	0(0)	4(27)	0(0)	0(0)	0(0)
9/27/13	RRC	90	7	31(100)	6(55)	12(36)	0(0)	1(27)	0(0)	12(100)	0(0)	0(0)	10(18)	<1(9)	0(0)	0(0)	<1(45)	0(0)	0(0)	0(0)
6/30/2014	RRC	100	9	22(100)	22(55)	9(27)	0(0)	<1(18)	0(0)	3(55)	<1(9)	0(0)	0(0)	1(18)	<1(27)	0(0)	6(55)	0(0)	0(0)	1(9)
8/12/2014	RRC	110	8	45(100)	6(27)	13(36)	0(0)	<1(18)	0(0)	7(55)	2(36)	0(0)	0(0)	<1(9)	19(36)	0(0)	8(45)	0(0)	0(0)	0(0)
9/17/2014	RRC	100	5	23(73)	10(18)	10(27)	0(0)	0(0)	0(0)	4(18)	<1(9)	0(0)	0(0)	0(0)	10(27)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	RRC	100	7	50(100)	5(18)	14(36)	0(0)	0(0)	0(0)	<1(18)	5(27)	6(27)	0(0)	0(0)	19(45)	0(0)	<1(9)	0(0)	0(0)	6(18)
9/1/2015	RRC	100	6	40(82)	12(55)	11(36)	0(0)	0(0)	0(0)	<1(18)	11(36)	0(0)	0(0)	<1(9)	15(36)	0(0)	3(7)	0(0)	0(0)	0(0)
9/8/2016	RRC	80	5	31(82)	31(73)	21(27)	0(0)	0(0)	0(0)	4(27)	0(0)	0(0)	0(0)	0(0)	4(36)	0(0)	<1(9)	0(0)	0(0)	2(36)
9/8/2016	RRC	90	6	37(100)	24(82)	30(55)	0(0)	0(0)	0(0)	1(36)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	2(45)	0(0)	0(0)	5(9)
8/4/10	McH	80	5	34(100)	4(27)	2(18)	10(18)	12(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	9(45)	0(0)	0(0)	0(0)	0(0)	0(0)
9/15/10	McH	90	7	14(82)	5(18)	<1(18)	10(18)	2(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	<1(9)	0(0)	0(0)
6/14/11	McH	76.5	4	4(27)	53(82)	<1(9)	3(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
8/9/11	McH	90	8	10(55)	32(82)	<1(18)	7(18)	<1(27)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	<1(36)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/12/11	McH	60	7	16(82)	8(64)	<1(9)	10(27)	<1(27)	0(0)	<1(27)	0(0)	0(0)	<1(18)	0(0)	3(45)	0(0)	0(0)	0(0)	0(0)	0(0)
6/27/12	McH	100	7	12(55)	55(73)	0(0)	8(18)	3(27)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	0(0)
8/22/12	McH	90	5	30(73)	26(64)	<1(9)	5(9)	13(73)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	3(36)	0(0)	0(0)	0(0)	0(0)	0(0)
9/19/12	McH	75	7	30(100)	18(64)	7(18)	14(18)	<1(36)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	<1(36)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/20/13	McH	50	6	19(100)	16(64)	0(0)	11(45)	4(73)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	3(91)	0(0)	0(0)	0(0)
8/15/13	McH	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0(0)
9/27/13	McH	30	3	35(91)	0(0)	<1(9)	34(82)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
6/30/2014	McH	60	5	8(91)	33(64)	<1(9)	7(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	<1(45)	0(0)	0(0)	0(0)
8/12/2014	McH	50	6	23(73)	8(45)	<1(9)	23(55)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/17/2014	McH	60	5	22(91)	2(45)	0(0)	15(45)	2(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	5(27)	0(0)	0(0)	0(0)
8/31/2015	McH	50	5	23(82)	10(45)	0	21(45)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	0(0)	<1(9)	0(0)
8/31/2015	McH	80	3	12(4)	0(0)	45(9)	14(27)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/8/2016	McH	50	5	22(100)	11(45)	2(9)	13(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(36)	0(0)	<1(18)	0(0)	0(0)	0(0)
9/8/2016	McH	57	5	40(100)	18(45)	<1(9)	34(45)	<1(27)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	3(45)	0(0)	0(0)	0(0)	0(0)	0(0)
8/5/10	HHO	195	6	38(91)	30(55)	15(36)	0(0)	1(27)	0(0)	21(64)	<1(18)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
9/15/10	HHO	200	5	46(90)	8(40)	6(27)	0(0)	2(18)	0(0)	31(55)	0(0)	0(0)	0(0)	0(0)	0(0)	8(9)	0(0)	0(0)	0(0)	0(0)
6/14/11	HHO	150	7	40(82)	20(64)	7(45)	0(0)	14(18)	<1(9)	16(36)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	<1(9)	0(0)	0(0)
8/9/11	HHO	180	9	44(82)	25(64)	15(45)	0(0)	3(18)	0(0)	5(18)	<1(27)	2(18)	15(45)	0(0)	<1(9)	0(0)	2(18)	0(0)	0(0)	0(0)
9/12/11	HHO	162	8	29(91)	15(18)	7(36)	0(0)	6(27)	0(0)	6(45)	3(18)	0(0)	3(9)	0(0)	11(27)	<1(9)	0(0)	0(0)	0(0)	0(0)
6/27/12	HHO	180	7	37(73)	41(45)	15(36)	0(0)	4(36)	0(0)	3(45)	0(0)	0(0)	6(27)	0(0)	5(36)	4(27)	0(0)	0(0)	0(0)	0(0)
8/22/12	HHO	180	6	36(73)	34(55)	15(36)	0(0)	6(27)	0(0)	12(45)	0(0)	0(0)	<1(27)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)	0(0)
9/19/12	HHO	190	6	72(100)	7(18)	17(36)	0(0)	27(64)	0(0)	27(73)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/20/13	HHO	150	8	39(100)	10(27)	19(45)	0(0)	10(55)	0(0)	4(36)	0(0)	<1(9)	4(27)	<1(9)	<1(27)	0(0)	0(0)	0(0)	0(0)	0(0)
8/15/13	HHO	150	6	22(91)	6(36)	5(27)	0(0)	<1(18)	0(0)	11(45)	0(0)	<1(18)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
9/27/13	HHO	140	5	23(91)	<1(9)	11(36)	0(0)	<1(9)	0(0)	11(64)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
6/30/2014	HHO	140	4	25(100)	<1(18)	7(36)	0(0)	0(0)	0(0)	18(55)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
8/12/2014	HHO	110	5	9(91)	1(18)	3(27)	0(0)	0(0)	0(0)	5(64)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	<1(9)
9/17/2014	HHO	150	4	22(100)	<1(18)	8(45)	<1(9)	0(0)	0(0)	14(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	HHO	130	6	31(100)	5(64)	15(45)	0(0)	<1(9)	0(0)	9(54)	0(0)	0(0)	10(36)	0(0)	3(45)	0(0)	0(0)	0(0)	0(0)	2(9)
9/1/2015	HHO	140	9	44(100)	24(64)	18(55)	4(9)	2(36)	0(0)	11(45)	0(0)	<1(9)	4(45)	<1(9)	10(55)	0(0)	0(0)	0(0)	<1(9)	0(0)
9/8/2016	HHO	120	6	23(100)	10(64)	12(27)	0(0)	<1(27)	0(0)	6(64)	0(0)	0(0)	0(0)	0(0)	3(45)	0(0)	0(0)	0(0)	0(0)	5(18)
9/8/2016	HHO	155	7	48(100)	5(45)	18(36)	0(0)	3(27)	0(0)	21(64)	<1(18)	0(0)	0(0)	0(0)	3(36)	0(0)	0(0)	0(0)	0(0)	5(9)

Date	ID	Length (m)	Rich-ness	Total SAV	MA	Sc	Va	Ec	Cd spp	Myr spp	Nf	Ng	Uv	Iso	Ppu	Pepi	Pv	Ps	Pd	Pa
8/5/10	MMR	63	6	51(100)	0(0)	30(82)	21(55)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/15/10	MMR	60	3	51(82)	0(0)	34(64)	17(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
6/14/11	MMR	55	4	35(100)	0(0)	29(82)	6(73)	0(0)	0(0)	0(0)	<1(36)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
8/9/11	MMR	55	8	46(100)	<1(9)	37(91)	5(18)	<1(9)	0(0)	0(0)	2(36)	0(0)	2(82)	0(0)	<1(18)	0(0)	<1(45)	0(0)	0(0)	0(0)
9/12/11	MMR	60	4	51(100)	0(0)	34(73)	17(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
6/27/12	MMR	55	7	46(100)	2(9)	34(82)	11(64)	1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(18)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
8/22/12	MMR	60	7	54(82)	5(27)	35(73)	16(45)	<1(9)	0(0)	0(0)	0(0)	0(0)	4(18)	1(9)	0(0)	0(0)	0(0)	2(18)	0(0)	0(0)
9/19/12	MMR	60	5	65(91)	3(18)	40(73)	23(64)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)
6/20/13	MMR	50	6	46(100)	0(0)	36(91)	7(55)	1(18)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	2(45)	0(0)	0(0)	0(0)
8/15/13	MMR	55	4	57(100)	0(0)	40(82)	15(64)	<1(27)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/27/13	MMR	45	3	67(100)	0(0)	53(82)	13(64)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
6/30/2014	MMR	50	4	58(100)	0(0)	49(91)	7(64)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)
8/12/2014	MMR	50	4	43(100)	0(0)	30(82)	12(64)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/17/2014	MMR	50	4	47(100)	0(0)	34(91)	15(73)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	MMR	55	4	53(100)	0(0)	35(82)	18(64)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	MMR	50	6	42(91)	<1(91)	22(64)	19(73)	<1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	<1(9)
9/7/2016	MMR	60	7	60(100)	3(37)	34(64)	22(73)	2(27)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(18)	0(0)	0(0)	<1(9)
9/7/2016	MMR	52.5	5	55(100)	1(55)	34(82)	20(73)	1(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)
8/5/10	DCC	200	7	87(100)	13(18)	<1(18)	0(0)	60(82)	<1(18	7(9)	0(0)	0(0)	0(0)	0(0)	11(27)	0(0)	9(36)	0(0)	0(0)	0(0)
9/16/10	DCC	200	7	68(100)	7(18)	2(27)	0(0)	44(73)	17(36	0(0)	0(0)	0(0)	0(0)	<1(9)	3(18)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/14/11	DCC	200	4	70(100)	0(0)	7(27)	0(0)	36(82)	14(45	0(0)	0(0)	0(0)	0(0)	0(0)	13(36)	0(0)	0(0)	0(0)	0(0)	0(0)
8/9/11	DCC	200	8	58(82)	0(0)	5(9)	0(0)	24(64)	3(27)	8(9)	0(0)	0(0)	0(0)	0(0)	1(9)	0(0)	1(9)	<1(9)	13(27)	0(0)
9/12/11	DCC	200	6	54(100)	2(9)	7(18)	0(0)	31(64)	14(45	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/27/12	DCC	200	6	29(100)	30(55)	4(27)	0(0)	18(73)	2(55)	<1(9)	0(0)	0(0)	0(0)	0(0)	4(36)	0(0)	0(0)	0(0)	0(0)	0(0)
8/22/12	DCC	200	4	52(91)	22(55)	6(18)	0(0)	43(73)	2(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/19/12	DCC	200	6	68(100)	7(27)	12(18)	0(0)	54(73)	<1(9)	<1(18)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
6/20/13	DCC	200	8	38(91)	21(55)	1(27)	0(0)	16(64)	3(45)	<1(9)	3(9)	0(0)	0(0)	0(0)	<1(18)	0(0)	15(45)	0(0)	0(0)	0(0)
8/15/13	DCC	200	10	55(91)	32(73)	6(18)	0(0)	20(55)	3(36)	9(36)	2(18)	0(0)	0(0)	1(9)	<1(9)	0(0)	5(27)	0(0)	7(9)	0(0)
9/27/13	DCC	200	8	41(82)	47(91)	5(9)	0(0)	23(55)	<1(9)	2(36)	<1(9)	0(0)	0(0)	0(0)	4(18)	0(0)	5(9)	0(0)	0(0)	0(0)
6/30/2014	DCC	200	7	16(73)	59(91)	0(0)	0(0)	<1(27)	<1(9)	1(18)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	5(45)	0(0)	9(9)	0(0)
8/12/2014	DCC	200	3	20(55)	41(82)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	19(55)	0(0)	0(0)	0(0)
9/17/2014	DCC	150	3	<1(9)	9(55)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	DDC	200	3	9(27)	85(91)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	3(9)	0(0)	6(18)	0(0)	0(0)	0(0)
9/1/2015	DDC	200	3	7(55)	74(91)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	6(45)	0(0)	0(0)	0(0)
9/8/2016	DDC	100	2	6(64)	54(100)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	3(64)	0(0)	0(0)	0(0)
9/8/2016	DDC	100	2	4(55)	65(91)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	4(55)	0(0)	0(0)	0(0)
8/5/10	GGC	70	5	49(100)	11(64)	20(55)	0(0)	27(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	<1(18)	0(0)	0(0)	0(0)
9/15/10	GGC	70	4	31(55)	30(45)	20(36)	0(0)	13(27)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
6/14/11	GGC	65	5	26(82)	4(27)	13(36)	0(0)	6(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	7(82)	0(0)	0(0)	0(0)
8/9/11	GGC	55	7	68(100)	2(18)	21(45)	0(0)	9(36)	0(0)	6(9)	0(0)	0(0)	11(73)	0(0)	15(55)	0(0)	6(36)	0(0)	0(0)	0(0)
9/12/11	GGC	54	5	36(73)	8(45)	20(36)	0(0)	4(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	8(18)	0(0)	5(18)	0(0)	0(0)	0(0)
6/27/12	GGC	65	4	48(91)	7(18)	14(45)	0(0)	23(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	11(27)	0(0)	0(0)	0(0)	0(0)	0(0)
8/22/12	GGC	66	6	31(82)	5(36)	20(45)	0(0)	11(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)
9/19/12	GGC	80	6	48(91)	7(9)	25(36)	0(0)	22(55)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/20/13	GGC	50	8	26(100)	<1(9)	18(55)	0(0)	1(45)	0(0)	<1(27)	<1(9)	0(0)	0(0)	<1(18)	<1(9)	0(0)	5(64)	0(0)	0(0)	0(0)
8/15/13	GGC	40	7	36(100)	2(73)	28(64)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	<1(36)	0(0)	7(36)	0(0)	0(0)	0(0)
9/27/13	GGC	40	7	26(100)	8(55)	23(55)	0(0)	2(45)	0(0)	<1(36)	0(0)	0(0)	0(0)	<1(9)	<1(18)	0(0)	<1(18)	0(0)	0(0)	0(0)
6/30/2014	GGC	50	7	14(100)	10(64)	11(45)	0(0)	<1(45)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(55)	0(0)	<1(9)	0(0)
8/12/2014	GGC	60	5	20(82)	5(82)	14(45)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	2(27)	0(0)	0(0)	0(0)
9/17/2014	GGC	45	5	12(91)	15(55)	8(45)	0(0)	1(36)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	2(36)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	GGC	60	4	25(91)	21(73)	20(54)	0(0)	0(0)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)	<1(27)	0(0)	2(2)	0(0)	0(0)	0(0)
9/1/2015	GGC	60	4	18(91)	9(73)	11(45)	0(0)	0(0)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	4(54)	0(0)	2(3)	0(0)	0(0)	0(0)
9/8/2016	GGC	65	6	37(100)	7(45)	16(45)	0(0)	5(18)	0(0)	9(27)	0(0)	0(0)	0(0)	0(0)	1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/8/2016	GGC	71	6	38(82)	7(64)	32(55)	0(0)	<1(18)	0(0)	4(18)	<1(9)	0(0)	0(0)	0(0)	<1(36)	0(0)	<1(9)	0(0)	<1(9)	0(0)

Date	ID	Length (m)	Rich-ness	Total SAV	MA	Sc	Va	Ec	Cd spp	Myr spp	Nf	Ng	Uv	Iso	Ppu	Pepi	Pv	Ps	Pd	Pa
8/5/10	GGC	70	5	49(100)	11(64)	20(55)	0(0)	27(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	<1(18)	0(0)	0(0)	0(0)
9/15/10	GGC	70	4	31(55)	30(45)	20(36)	0(0)	13(27)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
6/14/11	GGC	65	5	26(82)	4(27)	13(36)	0(0)	6(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	7(82)	0(0)	0(0)	0(0)
8/9/11	GGC	55	7	68(100)	2(18)	21(45)	0(0)	9(36)	0(0)	6(9)	0(0)	0(0)	11(73)	0(0)	15(55)	0(0)	6(36)	0(0)	0(0)	0(0)
9/12/11	GGC	54	5	36(73)	8(45)	20(36)	0(0)	4(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	8(18)	0(0)	5(18)	0(0)	0(0)	0(0)
6/27/12	GGC	65	4	48(91)	7(18)	14(45)	0(0)	23(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	11(27)	0(0)	0(0)	0(0)	0(0)	0(0)
8/22/12	GGC	66	6	31(82)	5(36)	20(45)	0(0)	11(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)
9/19/12	GGC	80	6	48(91)	7(9)	25(36)	0(0)	22(55)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	0(0)	0(0)	0(0)
6/20/13	GGC	50	8	26(100)	<1(9)	18(55)	0(0)	1(45)	0(0)	<1(27)	<1(9)	0(0)	0(0)	<1(18)	<1(9)	0(0)	5(64)	0(0)	0(0)	0(0)
8/15/13	GGC	40	7	36(100)	2(73)	28(64)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	<1(36)	0(0)	7(36)	0(0)	0(0)	0(0)
9/27/13	GGC	40	7	26(100)	8(55)	23(55)	0(0)	2(45)	0(0)	<1(36)	0(0)	0(0)	0(0)	<1(9)	<1(18)	0(0)	<1(18)	0(0)	0(0)	0(0)
6/30/2014	GGC	50	7	14(100)	10(64)	11(45)	0(0)	<1(45)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(55)	0(0)	<1(9)	0(0)
8/12/2014	GGC	60	5	20(82)	5(82)	14(45)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	2(27)	0(0)	0(0)	0(0)
9/17/2014	GGC	45	5	12(91)	15(55)	8(45)	0(0)	1(36)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	2(36)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	GGC	60	4	25(91)	21(73)	20(54)	0(0)	0(0)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)	<1(27)	0(0)	2(2)	0(0)	0(0)	0(0)
9/1/2015	GGC	60	4	18(91)	9(73)	11(45)	0(0)	0(0)	0(0)	<1(27)	0(0)	0(0)	0(0)	0(0)	4(54)	0(0)	2(3)	0(0)	0(0)	0(0)
9/8/2016	GGC	65	6	37(100)	7(45)	16(45)	0(0)	5(18)	0(0)	9(27)	0(0)	0(0)	0(0)	0(0)	1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/8/2016	GGC	71	6	38(82)	7(64)	32(55)	0(0)	<1(18)	0(0)	4(18)	<1(9)	0(0)	0(0)	0(0)	<1(36)	0(0)	<1(9)	0(0)	<1(9)	0(0)
9/1/2015	HCC	60	3	36(82)	7(36)	14(27)	20(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)	0(0)	0(0)
9/1/2015	HCC	50	3	31(82)	3(36)	26(54)	4(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	0(0)	0(0)	0(0)	0(0)
9/7/2016	HCC	50	7	41(64)	21(55)	2(9)	34(45)	0(0)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)	0(0)	6(9)
9/7/2016	HCC	50	5	43(100)	17(45)	9(18)	14(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	19(45)	0(0)	<1(9)	0(0)	0(0)	0(0)
9/1/2015	PPC	200	5	41(73)	18(27)	13(27)	28(54)	0(0)	0(0)	0(0)	<1(9)	0(0)	3(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(9)
9/2/2015	PPC	200	6	47(91)	26(55)	11(45)	29(45)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	2(18)	0(0)	0(0)	5(18)
9/7/2016	PPC	190	7	37(91)	15(55)	13(27)	16(38)	4(45)	0(0)	0(0)	<1(9)	0(0)	3(9)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	5(27)
9/7/2016	PPC	160	8	50(100)	9(45)	11(45)	12(36)	16(45)	0(0)	1(9)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	1(18)	0(0)	0(0)	11(73)

Density = sum of % cover values / total # of quadrats.
Frequency of Occurrence = # of quadrats where observed /total # of quadrats

Density(Frequency)

Richness = # of species present. MA counts as one species even if both Nitella and Chara were present.

RRC = Red Run Cove
McH = McHenry
HHO = Honi Honi
MMR = Meadow Mountain Run (State Park)
DCC = Deep Creek Cove (where Hv treatment is happening)
GGC = Green Glade Cove
PPC = Paradise Point Cove
HCC = Holy Cross

Table 4. Dominant Genera and/or Species for each transect according to year (2010-2016).

	2010	2011	2012	2013	2014	2015	2016
RRC	*Elodea spp.*, Macroalgae	*Sagittaria cristata, Elodea spp.*	*Elodea spp., Myriophyllum spp.*, Macroalgae	*Sagittaria cristata, Myriophyllum spp.*, Macroalgae	*Sagittaria cristata Potamogeton pusillus*	*Sagittaria cristata Potamogeton pusillus*	*Sagittaria crista* and Macroalgae
McH	*Vallisneria americana*	Macroalgae	Macroalgae	*Vallisneria americana* (only 1 sampling event available)	*Vallisneria americana*	*Vallisneria americana*	*Vallisneria americana*
HHO	*Myriophyllum spp.*	Macroalgae	*Sagittaria cristata, Myriophyllum spp.*	*Myriophyllum spp.*	*Myriophyllum*	*Sagittaria cristata Myriophyllum spp. Macroalgae*	*Sagittaria cristata Myriophyllum spp. Macroalgae*
MMR	*Sagittaria cristata, Vallisneria americana*	*Sagittaria cristata*	*Sagittaria cristata, Vallisneria americana*	*Sagittaria cristata, Vallisneria americana*	*Sagittaria cristata, Vallisneria americana*	*Sagittaria cristata, Vallisneria americana*	*Sagittaria cristata, Vallisneria americana*
DCC	*Elodea spp.*	*Elodea spp.*	*Elodea spp.*	*Elodea spp.*, Macroalgae	Macroalgae	Macroalgae	Macroalgae
GGC	*Sagittaria cristata, Elodea spp.*, Macroalgae	*Sagittaria cristata*	*Sagittaria cristata, Elodea spp.*	*Sagittaria cristata*, Macroalgae	Macroalgae	*Sagittaria cristata*, Macroalgae	*Sagittaria cristata*, Macroalgae
PPC	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	*Sagittaria cristata Vallisneria americana*	*Sagittaria cristata Vallisneria americana*
HCC	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	not sampled; added in 2015	*Sagittaria cristata*	*Vallisneria americana Macroalgae*

Dominance was defined as density being equal to or greater than 10% or frequency of occurrence being equal to or greater than 50%. To determine dominance for sampling years 2010-14, a species/genus had to be found dominant during both the August and September sampling events that took place that year. For sampling years 2015-2016, in which only one sampling event took place but 2 transects were sampled at each location, a species/genus had to be dominant at both transects to be dominant for the year.

The following are site specific results as analyzed across year (2010-2016) based on August and September transect data. Sites found in the northern section of the lake are discussed first (Red Run Cove and McHenry), followed by sites in the middle portion or central region (Meadow Mountain/State Park and Honi Honi as well as the newly added central to southern sites Paradise Point Cove and Holy Cross), and finally the southern sites (Green Glade Cove and Deep Creek Cove) are discussed last.

Red Run Cove (RRC): In the northwestern arm of the lake near the dam, Red Run Cove (RRC) is a site with a transect length from 80-127m and max depth of 4.1m. SAV Survey results indicate that macroalgae and *Elodea* dominated this bed in 2010 (Table 4). In 2011, *Elodea* maintained dominance, but *S. cristata* replaced macroalgae. *Elodea* co-dominated with *Myriophyllum* and macroalgae in 2012. In 2013, *Elodea* was no longer dominant plant at the site and instead *Sagittaria cristata, Myriophyllum spp.* and macroalgae dominated at this site. By 2014, *Potamogeton pusillus* began to dominate the site along with *S. cristata.* This pattern continued into 2015 with both *Potamogeton pusillus* and *S. cristata* co-dominating. In 2016, the site was dominated by *S. cristata* and macroalgae. Total SAV density (% cover) in RRC showed a slightly decreasing, though statistically insignificant trend, from 2010-2016, despite early season spikes in density. Macroalgae trends at the site between 2010 and 2016 were relatively static over the time period (Figure 3a). Species richness was relatively level over the time period (2010-2016) at Red Run with a maximum species richness of 9 species observed in 2015 and a low of 6 species in 2011 and 7 species were observed in 2016 (Figure 3b). *Myriophyllum* was observed at low densities in RRC during every sampling event, although it had a short- lived spike in frequency of occurrence in September 2013.

Figure 3a: SAV and Macroalgae Abundance at Red Run Cove

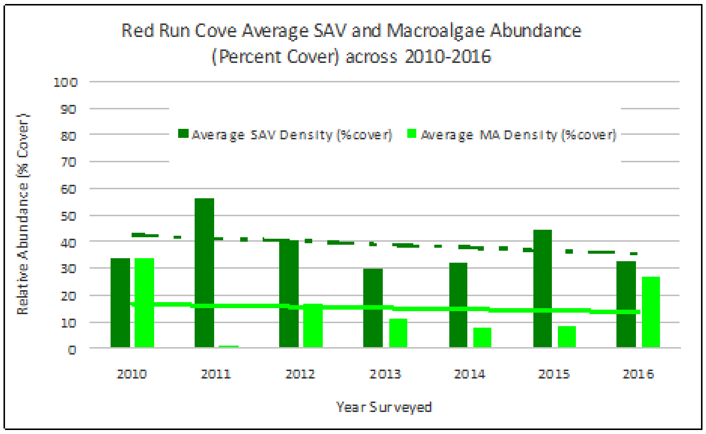
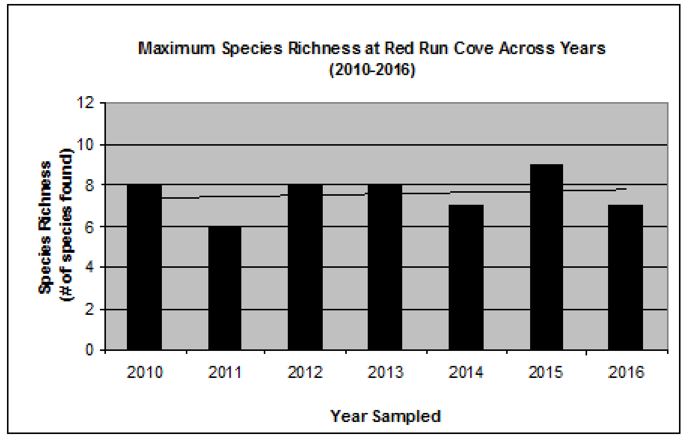


Figure 3b:Species Richness at Red Run Cove



<u>McHenry Cove (McH)</u>: In the northeastern arm of the lake, near Wisp Resort, McHenry (McH) is a site with a transect length from 30-100m and max depth of 5.4m. SAV survey results showed *Vallisneria americana* as the dominant in 2010 (Table 4). Macroalgae dominated the bed in 2011 and again in 2012, but was outcompeted by *V. americana* as the only dominant in 2013, following a sewage spill in the vicinity in August. It appears that the raw sewage may have acted to smother the macroalgae growing near the bottom while the *V. americana* was unaffected because its leaves extended high into the water column. *Vallisneria americana* was the only dominant plant from 2014 through 2016. Average SAV density showed a slight increasing trend and average macroalgae density a slight decreasing trend over the time period (2010-2016) at this location, though neither was statistically significant (Figure 4a). Maximum species richness, while experiencing a slight decline in 2013-14, remained relatively unchanged over the period (Figure 4b). Six species were observed at the site in 2010 and again at 2016. *Myriophyllum* was only observed in trace amounts and low frequencies from 2010-2016, with a slight spike in 2011-2012 returning to trace amounts in 2013 and an overall no change over time.

Figure 4a: SAV and Macroalgae Abundance at McHenry Cove

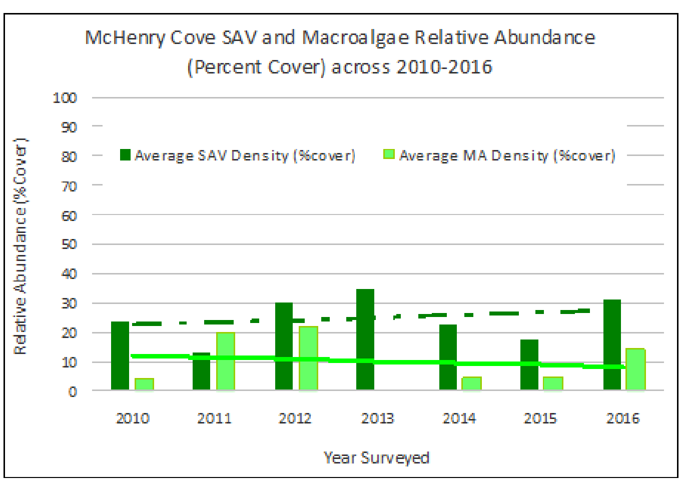
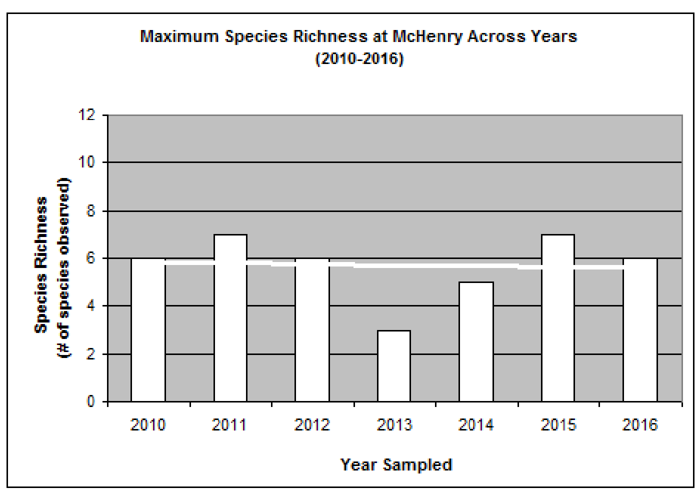


Figure 4b:Species Richness at McHenry Cove



Honi Honi (HHO): In the middle portion of Deep Creek Lake, the SAV bed surveyed near the Honi Honi (HHO), on the western shore of the central portion of the lake area, was a long transect ranging from 110-200m with the greatest maximum depth of any transect (6.3m). This SAV bed was dominated by *Myriophyllum* in 2010, by macroalgae in 2011, and by *S. cristata* and *Myriophyllum* in 2012. In 2013 and 2014 *Myriophyllum* was the lone dominant species and remained dominant in 2015 and 2016 along with *Sagittaria cristata* and macroalgae (Table 4). Total SAV and total macroalgae densities showed relatively static, but slightly decreasing trends at this location between 2010 and 2016 (Figure 5a). *Myriophyllum spp.* was commonly observed at this transect, and showed statistically higher relative abundance (based on % cover) than all other sites. Average SAV abundance (% cover) showed a decline over time (Figure 5a). Maximum species richness increased at this site in 2015 to a high of 11 species but dropped back down to 7 species in 2016 which is more consistent with species richness trends at this site (Figure 5b).

Figure 5a: SAV and Macroalgae Abundance at Honi Honi Cove

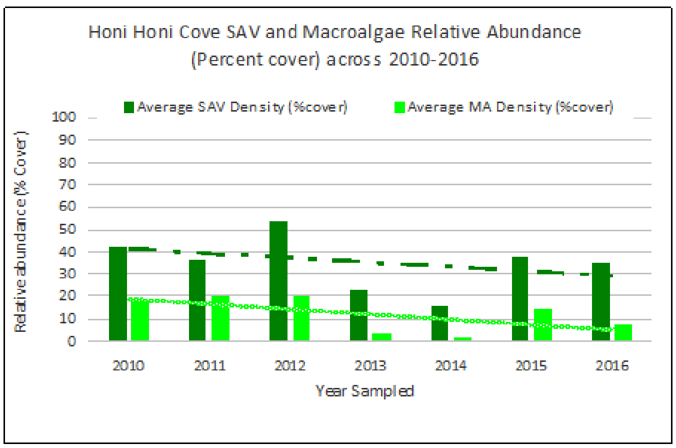
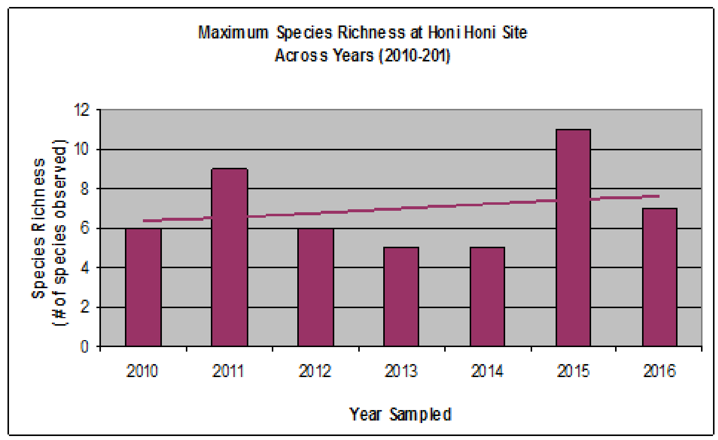


Figure 5b:Species Richness at Honi Honi Cove



Meadow Mountain Run (MMR): Across the lake from Honi Honi, the SAV bed surveyed offshore of the State Park in Meadow Mountain Run Cove (MMR) was dominated by *S. cristata* and *V. americana* from 2010-2016 except in 2011 when only *S. cristata* was dominant during the Aug-September time frame (Table 4). This transect ranged from 45-63m with a max depth of 4.2m. Total SAV and macroalgae abundance remained relatively unchanged from 2010-2016 (Figure 6a) and *Myriophyllum* was never observed at this transect. Species richness trends also remained relatively unchanged, but showed a slight increasing trend over the 2010-2016 time period with a maximum species richness of 8 species observed in 2011, a slight decrease during 2013-14 to a low of 4 species, and rebounding to the observed high richness (8 species) again in 2015 and 2016 (Figure 6b). Two species that had previously been observed at the site, but not on a transect until 2016 included *Elodea spp.* and *P. amplifolius.* Both species showed signs of lake-wide expansion during the shoreline survey in 2016.

Figure 6a: SAV and Macroalgae Abundance at Meadow Mtn Run

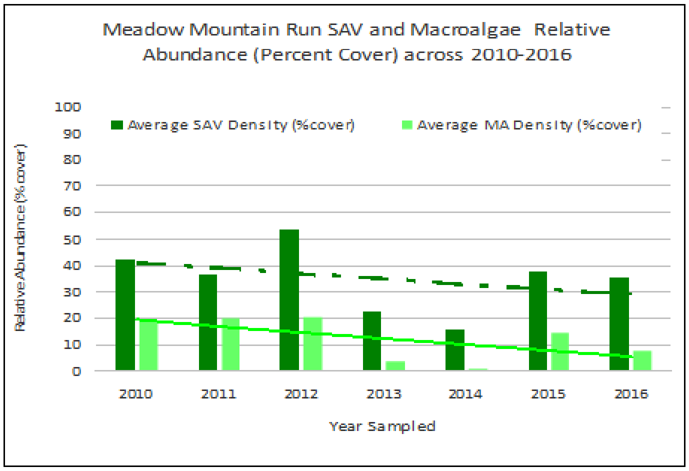
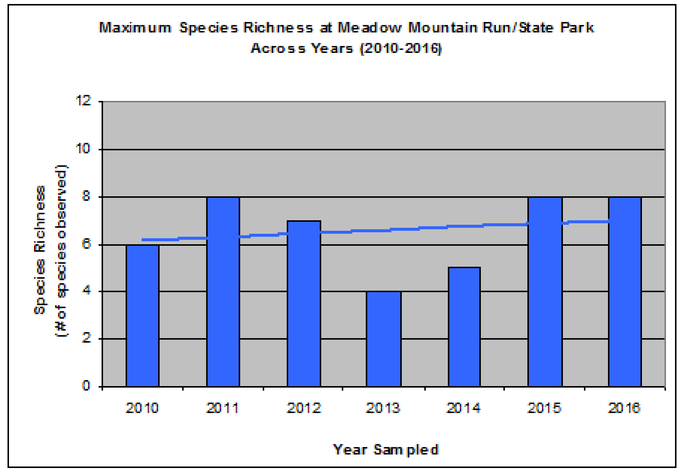


Figure 6b:Species Richness at Meadow Mtn Run



Paradise Point Cove (PPC): On the other side of the Glendale Bridge in the central mainstem of the southeastern section of the lake, Paradise Point Cove (PPC) is a newly surveyed transect site. Surveying began in 2015 and continued to 2016. The site was selected to provide better representation in the southern section of the lake. The site is thought to be representative of the central to southern portion of the lake, with "southern" portion deemed to begin on the south side of the Glendale Bridge. Transect lengths were the maximum 200m and averaged 175m in 2016 with maximum depths reaching approximately 3 meters. The dominant plants were *Sagittaria cristata* and *Vallisneria americana* across both years however. Species richness was found to be 9 in 2015 and 8 in 2016 with average SAV abundance relatively unchanged across years. Besides the dominant plants, other noteworthy species observed on this transect were *P. amplifolius* and *N. flexilis*, *Elodea* species and *P. vaseyii*, *P. pusillus*, *U. vulgaris* and macroalgae. Average SAV abundance showed no change across years (2015-2016) and a slight decrease in macroalgae abundance during the same time period (Figure 7).

Holy Cross Cove (HCC): Along the southwestern mainstem of the lake, just north of the southern extent of the *Hydrilla* found in DCL, Holy Cross Cove (HCC) is a new site surveyed in 2015 to provide better representation in the southern section of the lake. This transect ranged between 50-60m with a maximum depth up to 3m making this one of the shorter transects surveyed in 2015 and 2016. In 2015, *Sagittaria cristata* was the only plant found to be dominant along both transects. However, *Vallisneria americana* was found to be dominant along one transect with *P. pusillus* and macroalgae found along both transects. In 2016, *S. cristata* was not observed to be dominant, only *V. americana* and macroalgae were dominant. Species richness was only 4 in 2015 but increased to 8 species in 2016. Anecdotal observations indicate this is a newly colonized site by SAV (within the last three years). Both average SAV abundance and average macroalgae abundance increased from 2015 to 2016 (Figure 8).

Figure 7: SAV and Macroalgae Abundance at Paradise Point Cove

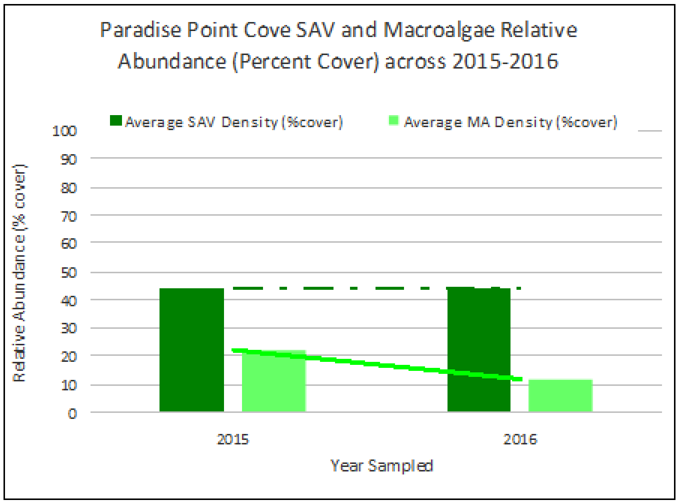
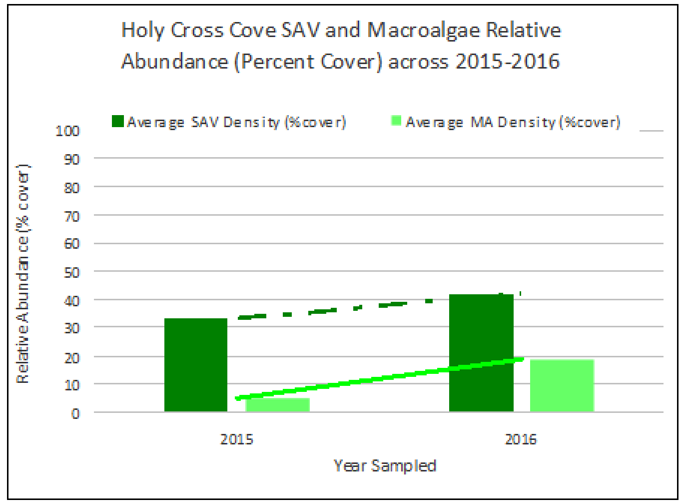


Figure 8: SAV and Macroalgae abundance at Holy Cross



<u>Deep Creek Cove (DCC):</u> In the southern portion of the lake, Deep Creek Cove (DCC) had one of the longest transects (constant length of 200m until September 2014 when it decreased temporarily to 150m, and max depth of 3.7m, returning to 200m in 2015). In 2016, the transect length decreased to 100m. This transect was dominated by *Elodea spp.* in 2010-2013, and then co-dominated with macroalgae in 2013 and shifted to only macroalgae dominated during 2014-2015. In 2016, the site was dominated by both macroalgae and *P. vaseyii*. *Ceratophyllum demersum* was also very common (although not dominant) in 2011. As *Elodea spp.* abundance began to decline, macroalgae and *P. vaseyii* became more common, although *P. vaseyii* was never dominant at the site. *Hydrilla verticillata* was discovered floating near the transect at this site during the September 2013 survey. A search led to the source of the floating plants in a nearby cove and later to an extensive eradication program at affected areas (See Appendix D). These results are discussed later in this report but it should be noted that beginning in 2014, Deep Creek Cove was treated with the herbicide, Flouridone, which is targeted for *Hydrilla* control, but can negatively impact other species of SAV as well. The herbicide treatment continued at the site in 2015-2016 and the decrease in species richness, abundance and frequency also continued.

Species richness reached a maximum in 2013 of 9 and a minimum of 2 in 2016 (Figure 9b). Deep Creek Cove had significantly higher macroalgae relative abundance, significantly lower SAV relative abundance and significantly lower richness than other sites in 2016. Additionally, similar trends were seen over time at DCC as total SAV decreased significantly between 2010 and 2016 while total macroalgae increased significantly over that time period (see Figure 9a). *Myriophyllum* was present in low densities (<10% cover) and oscillating frequencies during most sampling events through 2013, but did not change significantly over time.

Figure 9a: SAV and Macroalgae Abundance at Deep Creek Cove

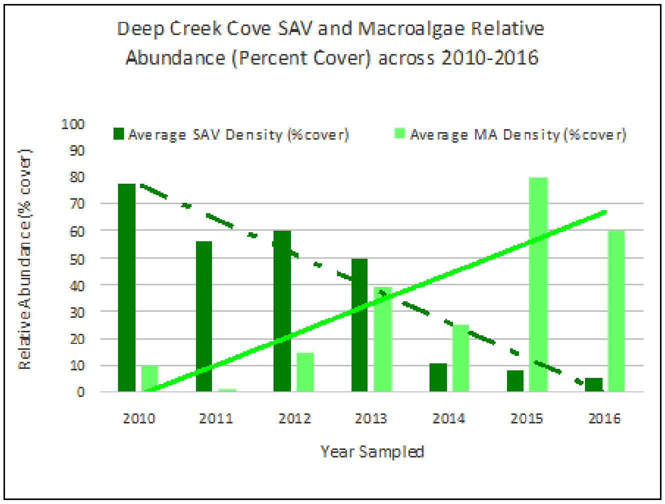
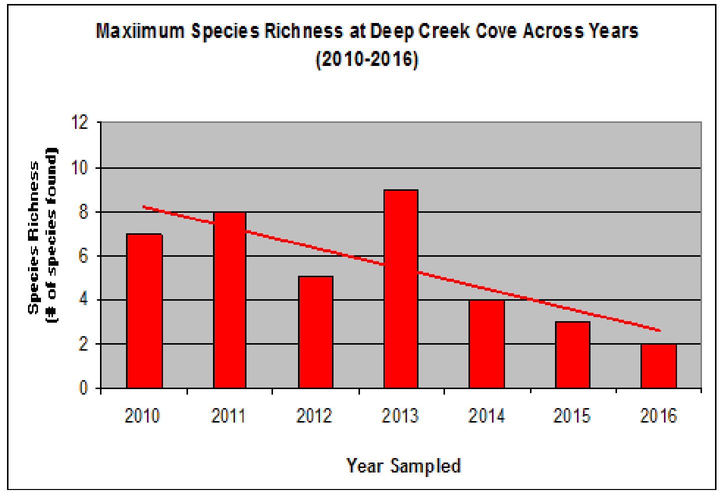


Figure 9b: Species Richness at Deep Creek Cove



Green Glade Cove (GGC): East of DCC in the southeastern portion of the lake, GGC had transect lengths ranging from 40-80m and a max depth of 4m. This SAV bed was dominated by *S. cristata*, *Elodea spp.*, and macroalgae in 2010. In 2011, the dominant plant observed was solely *S. cristata* and in 2012, *S. cristata* and E*lodea spp.* co-dominated. In 2013 and 2015, macroalgae and *S. cristata* co-dominated and only macroalgae was dominant in 2014 (Table 4). *Sagittaria cristata* co-dominated with macroalgae from 2015-2016. Average SAV abundance showed a slight decreasing trend between 2010 and 2016 while macroalgae abundance was relatively constant from 2010-2016 (Figure 10a). Species richness was relatively constant across years, increasing slightly by 2016 to 6 species (Figure 10b). Macroalgae abundance was relatively low across years (2010-2016) and *Myriophyllum* was present in low densities during most sampling events, and did not change significantly over time.

Figure 10a: SAV and Macroalgae Abundance at Green Glade Cove

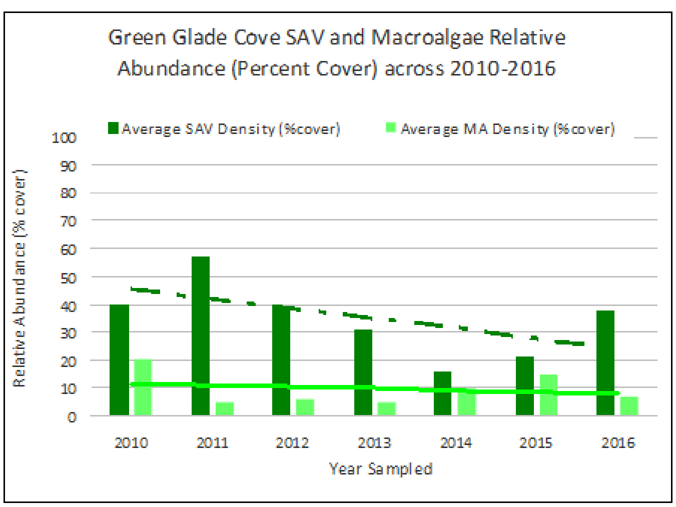
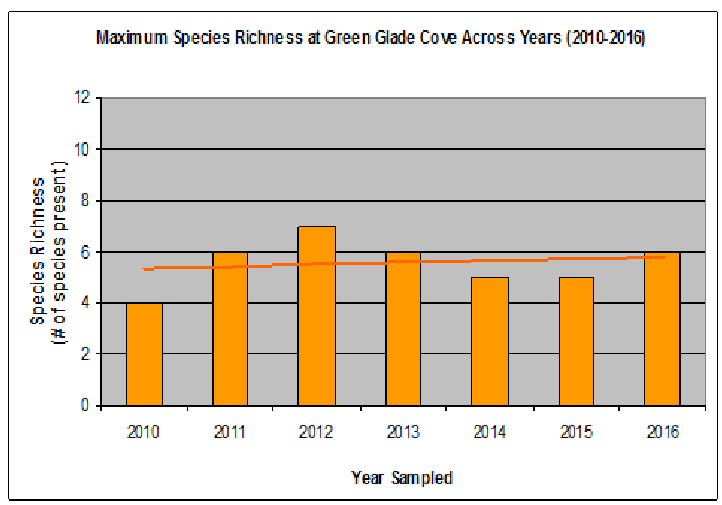


Figure 10b: Species Richness at Green Glade Cove



In 2016, total average SAV density was greatest at Meadow Mountain Cove/State Park (57.5%), Paradise Point Cove (44%) and Holy Cross Cove (42%) and lowest in Deep Creek Cove (5%) (Figure 11). Total macroalgae cover was highest in Deep Creek Cove (Table 3) during 2016 and species richness was coincidentally lowest there as well. Green Glade Cove (GCC), McHenry (McH) and Holy Cross Cove (HCC) showed increasing trends in SAV % cover from 2015-2016. The Honi Honi and Meadow Mountain Run sites showed slight declines in SAV and macroalgae abundance over the time period (2010-2016), although not statistically significant. The Holy Cross Cove (HCC), Meadow Mountain Run (MMR) and Paradise Point Cove (PPC) sites showed the greatest species richness in 2016 with 8 species found, followed by Red Run Cove (RRC) and Honi Honi (HHO) site, each with 7 species found in 2016 (Figure 12). *Sagittaria cristata, V. americana* and macroalgae were the dominant plants observed across all transects in 2016 (see Table 4). *Potamogeton vaseyii, P. pusillus, Elodea spp.* and *Myriophyllum spp.* were also fairly common throughout, followed by *P. amplifolious, Najas flexilis, Najas guadalupensis, Utricalaria vulgaris, Isoetes spp.* and *P. diversifolius.* No *C. demersum, P. robbinsii* or *P. spirillus* was found in 2016 during the transect survey (Table 3).

In general, species zonation was apparent at all sites. *Sagittaria cristata*, a plant with low canopy height, was observed at all sites during every sampling event, with occasional exceptions. In all cases, it was observed at its highest densities along the shallow edge of the SAV beds. Along transects with little slope and minimal depth, *S. cristata* maintained high densities father from shore. As transects moved offshore and got deeper, *S. cristata* was generally replaced by *Potamogeton spp.,* and *V. americana* or a combination thereof. All of these species can form canopies from 0.5-2 meters or more. *Potamogeton spp.* were seen reaching the surface at shallow to mid-depths during the August and September sampling events due to their reproductive strategy. During late summer/early fall, the *Potamogetons* send their reproductive structures to the surface to take advantage of its two dimensional aspect. Along the deeper edges of the SAV beds, we observed more *Myriophyllum,* and *P. pusillus*, *P. amplifolius* and the two species of macroalgae (which have lower light requirements), *Chara* and *Nitella. Elodea spp.* shows great annual variability in abundance and depth. It has been found in the shallows (<1m water) as well as along the deeper edges (2-3m water).

Figure 11. SAV and Macroalgae Density at each Transect in 2016

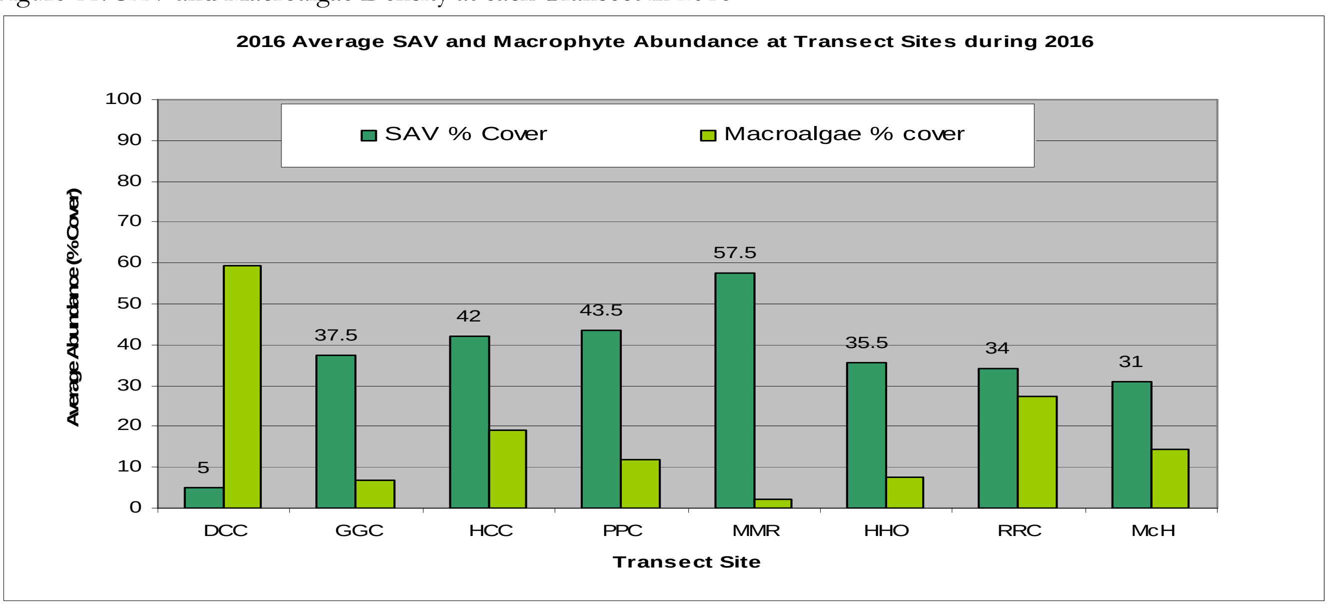
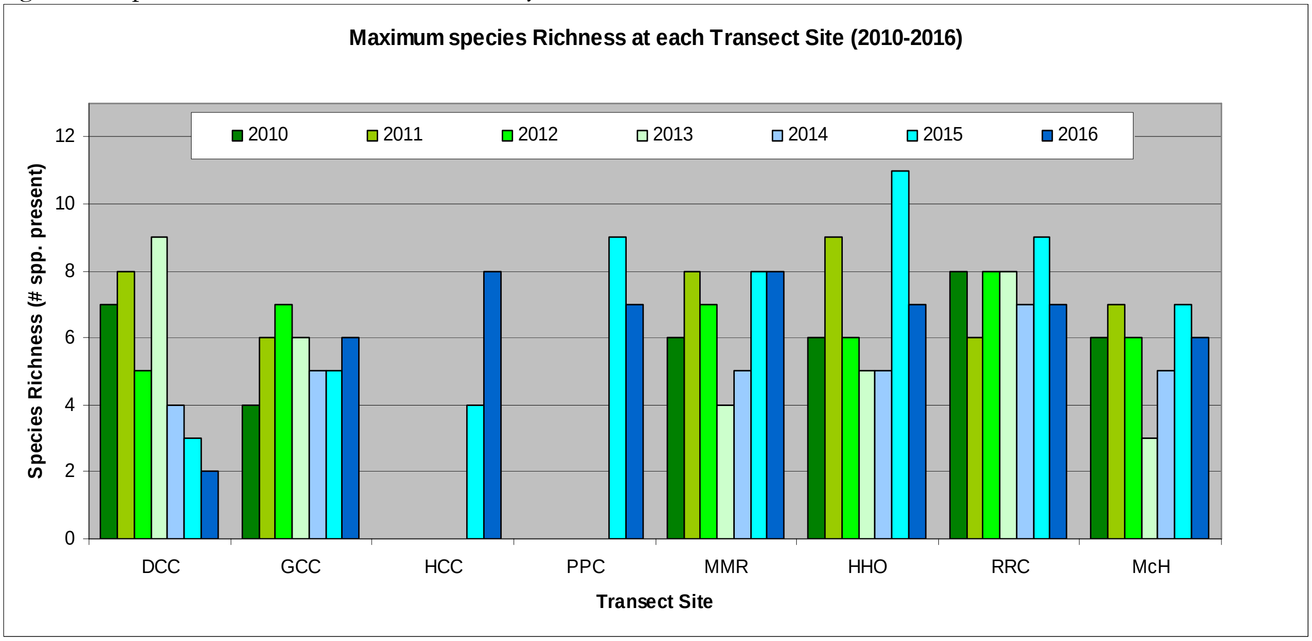


Figure 12: Species Richness at each site across years 2010-2016

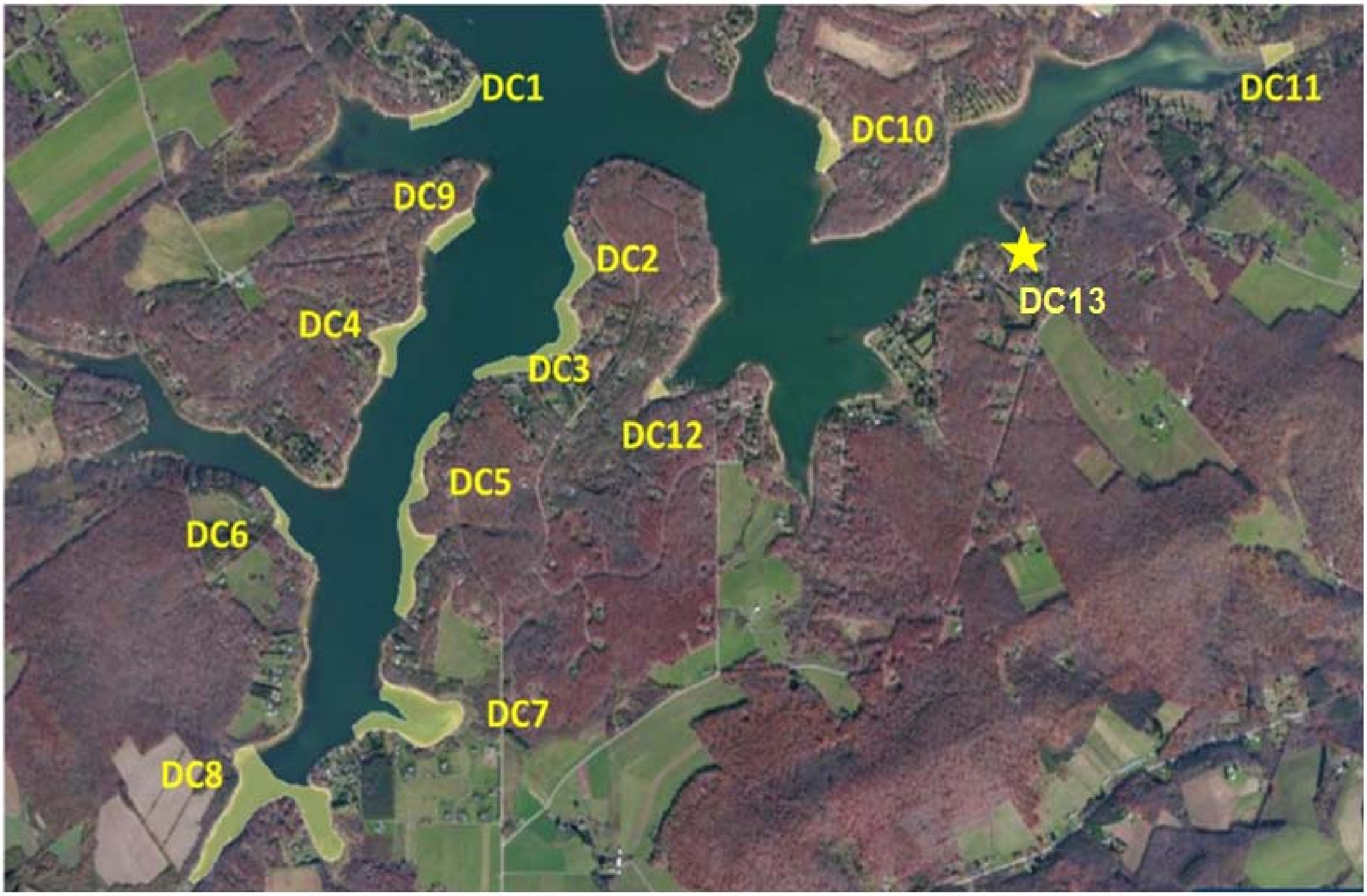


Currently, three aquatic invasive species (AIS) have been documented in DCL These include *M. spicatum, H. verticillata* and *P. crispus.* The latter *(P. crispus)* was first documented in July 2015, while *H. verticillata* was first found in September 2013. *Myriophyllum spicatum* was identified before the survey began in 2009. Beds of *Myriophyllum* spp. are found throughout the lake's coves, fringing the shorelines and in deeper water. One additional non-native species (*Najas minor*) was found but not positively confirmed. *N. minor* often resembles *N. gracillima* and without seed being found, it is difficult to differentiate between species.

Approximately 30 small beds of *P. crispus* ($<5m^2$) were found in the Pawn Run area in July-August 2015, located in the southwestern portion of DCL. Beds were GPS marked with PVC and selectively identified for hand-removal in August by DNR RAS biologists and DCL NRMA staff. Beds were monitored again and mapped in August 2016 to determine if bed location or size had changed (See Appendix C). Over 90 beds were mapped in the Pawn Run Cove area suggesting a more than three fold increase in abundance. However no additional locations of *P. crispus* were found growing in DCL, outside of the Pawn Run area, although floating fragments were observed in the North Glade area in 2016 and Hickory Cove area in 2016 and near the State Park in 2015. DNR Biologists will continue to monitor this small population and track any changes in bed density or distribution.

Since 2013, *Hydrilla verticillata* has only been found in the southern portion of the lake (Figure 13). Because of the aggressive nature of the invasive plant, an active control/eradication program began whereby beds and nearby areas where *Hydrilla* was documented were treated with the herbicide Flourodone. For additional information on that treatment process and the monitoring to document its efficacy, please see Appendix D. In an effort to provide early detection for any new *Hydrilla* beds, DNR personnel survey the entire shoreline looking for new beds of *Hydrilla.* No new beds of Hydrilla were found during the 2016 shoreline survey.

Figure 13. *Hydrilla* treatment zones for 2016. * *Hydrilla* was observed at DC13 Location in 2015 and is a new treatment zone in 2016



DISCUSSION and CONCLUSION

Deep Creek Lake, as a whole, continues to support a healthy population of SAV and the SAV in turn promotes a healthy lake. There are ten genera of vascular plants commonly observed in DCL, including one species of *Potamogeton (P. amplifolius)* that is legally classified as endangered in Maryland and was thought to be completely extirpated from the state. There are also at least three species of non-native SAV *(Hydrilla verticillata, Potamogeton crispus*, and *M. spicatum)* that are considered aquatic invasive species. A fourth non-native plant, *Najas minor,* was found in small amounts by DNR RAS and DCL NRMA staff independent of the shoreline and transect surveys, but was not positively confirmed by the state botanist.

The number of species documented within DCL waters increased in recent years with at least 5 new species found in 2015 and no new species confirmed in 2016. This is, in part, thought to be a function of the increased effort and staff that have been actively surveying more areas of Deep Creek Lake throughout the growing season (independently of the transect and shoreline surveys). This increase in effort to survey more of the lake's waters also led to the identification of non-native *P. crispus* beds found in the Pawn Run area of DCL and has aided in early detection of invasive species. This will hopefully allow the success of the *Hydrilla* eradication/control effort initiated in 2014 to be more effective. With the increased level of effort, scientists have also observed morphological and possibly phenotypic differences in the species found in DCL compared to the same species found in the

Chesapeake Bay. This suggests the possibility of genetic differences and the need for additional methods to positively identify plants to the species level. It is necessary to determine if the physical differences in the appearance of the plants are due to environmental cues (water quality, temperature, clarity) or an artifact of genetic diversity, hybridization and/or if they are a different species or sub species altogether. In support of this effort, a collection of voucher specimens for each species of SAV found in DCL, which began in 2015, will continue as new species are discovered and/or changes in morphological characteristics are identified. This will assist with more accurate identification of plant species observed and will allow comparisons to previous year's findings.

In general, the native SAV population in DCL is doing well throughout much of the lake. Aside from some shallow water areas, the water in Deep Creek Lake is clear and allows light to penetrate to impressive depths, encouraging SAV and macroalgae to grow as deep as five meters on some transects. Because of the varying light requirements of different species and other physical factors, species zonation was apparent at every site. Zonation is an inherent characteristic of any SAV bed in which a depth or sediment gradient is present, but could be particularly exaggerated in Deep Creek Lake as a direct result of the winter water level draw-down, which limits the shoreward expansion of canopy forming species. *Sagittaria cristata* was observed at each site during most sampling events and was the dominant plant found throughout the lake during the transect survey (based on frequency of occurrence and abundance). It is short in stature and can withstand extensive periods of exposure during lake level draw down, and was most prevalent along the shallow edges of the SAV beds.

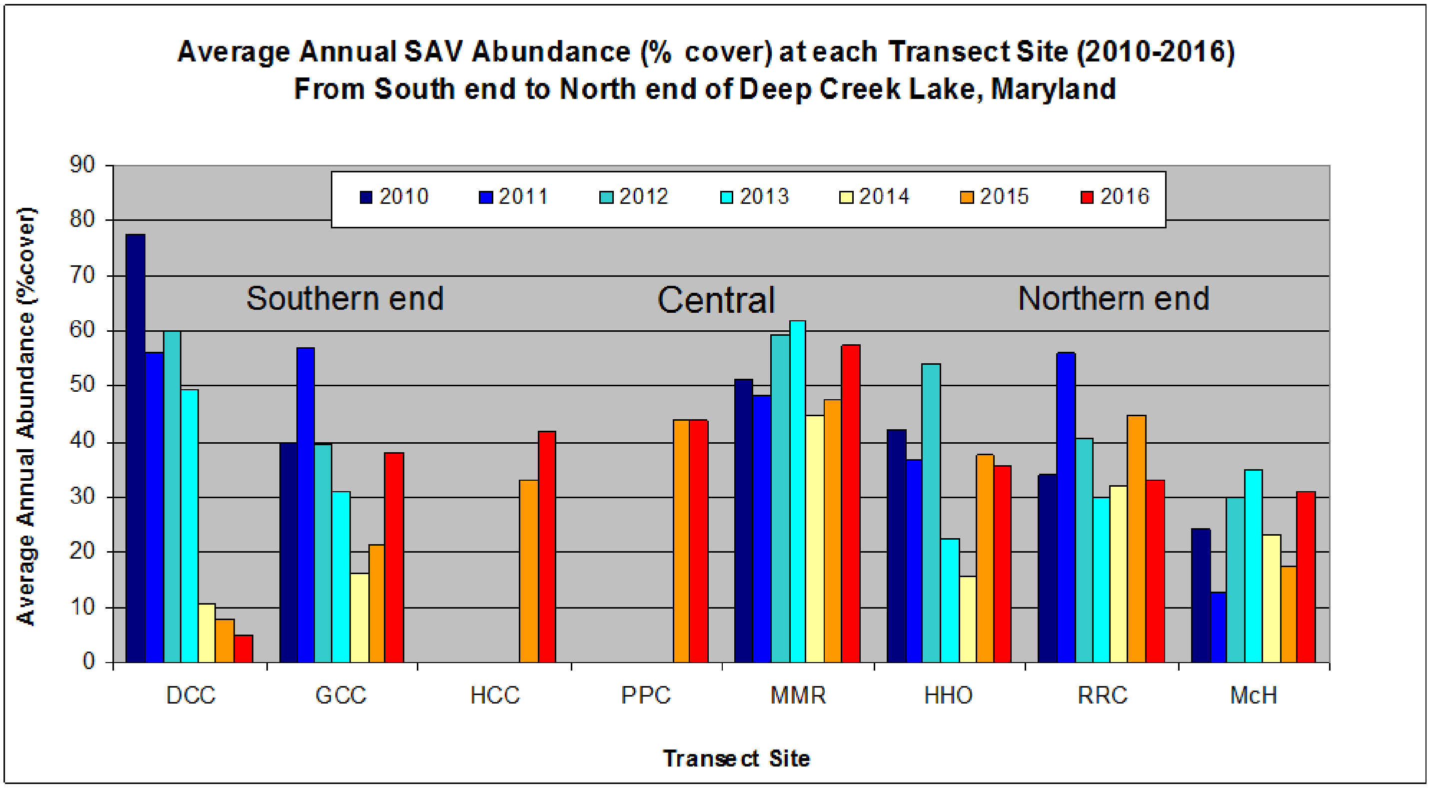
Vallisneria americana was the second most dominant plant (based on frequency of occurrence) found lakewide during the 2016 transect survey. The increase in the distribution and abundance of *V. americana* as documented in the shoreline survey is likely a function of the plant expanding its distribution and abundance as well as a function of improvements made to the survey itself. Greater effort was made to document the presence and relative abundance of all canopy forming species, not just *Myriophyllum* species, as was the case when the survey began in 2012. *Vallisneria americana* is both a canopy and meadow forming species of SAV, meaning that it tends to grow laterally via rhizomes forming grass like meadows but also sends energy to its leaves to elongate towards the surface. As water levels drop in the late summer/early fall, beds of *V. americana* are more visible from the surface and thus beds are more easily detected and identified during the September shoreline survey. *Vallisneria americana* is great habitat for juvenile fish species as well as food for waterfowl. It also slows wave energy and stabilizes sediments.

Other frequently observed plants during the transect survey include those from the genus *Potamogeton,* including *P. pusillus, P. vaseyii* and *P. amplifolius*. *Potamogeton pusillus,* or slender pondweed tends to inhabit the deeper waters of Deep Creek Lake (3-6m range depending on water levels. The fact that it inhabits deeper water in DCL, combined with the fact that *P. pusillus* is a relatively thin and spindly plant compared to other plants in the genus like *P. amplifolius*, or broadleafed pondweed, suggests that it is likely under-reported in its distribution and density lake-wide in the shoreline survey. Detections using side scan sonar are more difficult and the morphology of the plant doesn't allow robust, dense beds to be easily visible from the surface. However, other plants in the genus to include *P. amplifolius, P. epihydrus*, and *P. nodosus* are much more easily visible in the shoreline survey and were all documented to be expanding in density and distribution throughout the lake in 2015 and continued in 2016. *Potamogeton vaseyii*, showed a reduction in distribution and abundance in the transect survey. *Potamogeton vaseyii* tends to be a plant that prefers shallower waters (0-1.5m deep) while the other pondweeds referenced previously (*P. amplifolius, P. nodosus* and *P. epihydrus*) are generally found in the deeper waters of DCL. The reason for the observed decline in shallow water species like *P. vaseyii* and increase in deeper water plants like other *Potamogetons* and *V. americana* cannot be fully explained without additional water quality and habitat data, but could suggest that wave energy or changes in water levels could be a factor with conditions proving more stable in the deeper waters of the lake. Competition with other natives in the shallows may also be a factor.

Other noticeable changes in species distribution and/or abundance during the 2016 surveys include observed increases in the native plants, *Elodea spp*.and *Potamogeton amplifolius*, and a decline in the *Myriophyllum spp.* (presumed to be the non-native *M. spicatum*). All three changes were observed in the shoreline survey and to a lesser extent the transect survey. This suggests positive changes in the lake's water and habitat quality. *Elodea spp.* had been one of the more common plants observed throughout the lake from 2010-2012 but declined in 2013-2014. The increase in Elodea density and distribution during the 2015-2016 surveys suggests a possible "recovery" of the plant population and may be indicative of better water quality and/or habitat conditions in the lake during 2015-2016. In addition to the changes in *Elodea spp.* abundance and distribution, a noticeable decline in distribution and abundance of *Myriophyllum* species were observed lake-wide both in the shoreline survey and transect survey. Because the decline in *Myriophyllum* species was observed throughout the lake in 2015-2016, the decline could be due to natural variability within the species population. It could also suggest it is being out-competed for habitat by other species, such *Potamogeton amplifolius,* which is a large stature plant that often grows to the water surface and is commonly found in the deeper regions of the lake's waters where *Myriophyllum* generally dominates. *Potamogeton amplifolius* was documented in the lake for the first time during the 2013 shoreline survey. In 2013, it was observed at several locations, showed an increase in distribution and density during the 2014 survey, and continued expanding its distribution and bed size in the 2015 and 2016. Field observations made during the 2014-2016 surveys indicate that it is spreading and increasing in frequency of occurrence throughout the lake. The increases in distribution of *Elodea spp.* and *P. amplifolius*, and subsequent decline in *Myriophyllum* species are all viewed as positive changes for the lake habitat and water quality. Dense *Elodea* beds can effectively improve water clarity by anchoring the sediments and reducing the impacts of boat wakes on the resuspension of sediments. *Potamogeton amplifolius* was previously believed to be extirpated from Maryland waters. Its expanding presence in the lake is welcome and suggests that it may be a strong large-bodied competitor for *Myriophyllum spp. Potamogeton amplifolius* provides excellent habitat for fish and food for waterfowl and like other SAV species, can improve water clarity by removing nutrients and reducing wave energy and resuspension of sediments.

Although our survey results from 2010-2016 indicate that DCL continues to support a healthy and relatively diverse population of SAV, there have been noticeable, and at times, statistically significant changes observed. *Elodea*, once a common and dominant species that grew along the deeper and intermediate edges of SAV beds in the lake, was observed at only four of the six original transect sites and at only one of the new sites in 2016. This is an increase from the 2015 transect survey where it was only found at 3 of 6 sites, but it was observed in dramatically reduced densities and frequencies compared to the initial 2010 survey (Table 3). While the 2015 and 2016 shoreline survey showed a partial recovery lake-wide in *Elodea* species since 2014, the overall decline may be indicative of a larger habitat quality issue. Reductions in *P. vaseyii* (a plant which largely filled the niche of *Elodea spp.* when it declined) distribution and abundance were also observed in 2014 and continued that declining trend in 2015 and 2016. *Potamogeton vaseyii* had inhabited some of the same regions in the southern portions of the lake as *Elodea spp.*, particularly at DCC and GGC, suggesting that there may be a regional issue as to habitat quality in the southern portion of the lake as overall SAV density decreased significantly at DCC. Decreasing trends over time were also observed at GGC from 2010-2014 but appear to be on the increase in 2015-2016, which is encouraging (Figures 9a and 9b). Given that lake-wide data suggest that average SAV abundance continued to increase from 2015-2016, the declining trend in SAV (abundance and frequency) in the southern portion of the lake, particularly at DCC, warrants concern (Figure 14).

Figure 14: Average SAV Abundance (% cover) at each transect over time (2010-2016) Transects sites are listed fromrom south to north end of Deep Creek Lake.



A comparison of 2010-2016 data also indicates that the dominant plant communities shifted slightly again in 2015 and 2016, with slight changes in species dominance at the various transect sites over time (see Table 4). The collective changes observed over the last 7 years suggest a spatial pattern developing that may be indicative of changing water quality and habitat conditions, particularly in the southern end of the lake. The far southern sites (DCC and GGC) have been largely dominated by macroalgae, whereas the middle portion of the lake sites (MMR, HHO and newly added PPC) are more diverse and dominated by *V. americana*, *S. cristata*, and co-dominated with either *Myriophyllum* species or macroalgae. The northern sites (RRC and McH) have shown a positive shift away from being dominated by macroalgae and more commonly and recently (2013-2016) dominated by SAV species such as *V. americana* and *S. cristata*. It should be noted that the geomorphology and land use varies throughout the watershed. The northern section of the lake is generally deeper and narrower with steeper sloping shorelines compared to the southern end of the lake which is generally shallower and wider. The middle portion of the lake is somewhat intermediate and variable with regard to depth. With regards to land use, the northern portion of the lake's watershed and shoreline is more residential and the southern portion of the lake's watershed is dominated by agriculture. The western shore is heavily developed (Figure 1) and the eastern shore, alternatively, has a greater proportion of forested land, particularly around Deep Creek Lake State Park. It is not uncommon for watershed land use to positively or negatively affect an adjacent body of water (Landry and Golden, in review) and thus could be responsible for the observed shifts in plant communities.

Other possible explanations for the observed changes in species richness and dominance (both frequency and abundance) could be due to annual changes in temperature, precipitation, and/or natural population variability. Additional hypotheses for the observed changes could include changes in early season (May-July) water levels throughout the growing season compared to previous years, changes in wave energy (larger, heavier ballast boats using shallower regions of the lake), increased boat use in the southern end of the lake, or changes in water quality or watershed land use as previously mentioned (more development or agricultural input) in the southern end of the lake. All are possible explanations for the observed changes. Additional monitoring and observations may help determine the more likely cause for the changes. When available, current long-term State of Maryland Deep Creek Lake water quality monitoring data will be analyzed to identify possible causes for changes observed in SAV distribution and abundance. It should be noted that SAV populations are dynamic with multiple stressors and as such it is quite possible that more than one explanation may be responsible for the observed changes.

Aquatic Invasive Species

The number of species documented within DCL waters increased in recent years with at least 5 new species found in 2015 and no new species confirmed in 2016. This is in part thought to be a function of the increased effort and staff that have been actively surveying all areas (both shallow and deep) of Deep Creek Lake throughout the growing season (independently of the transect and shoreline surveys). This increase in effort to survey more of the lake's waters also led to the identification of non-native *P. crispus* beds found in the Pawn Run area of DCL and has aided in early detection of invasive species. This will hopefully allow the success of the *Hydrilla* eradication/control effort initiated in 2014 to be more effective. With the increased level of effort, scientists have also observed morphological and possibly phenotypic differences in the species found in DCL compared to the same species found in the Chesapeake Bay. This suggests the possibility of genetic differences and the need for additional methods to positively identify plants to the species level. It is also necessary to determine if the physical differences in the appearance of the plants are due to environmental cues (water quality, temperature, clarity) or an artifact of genetic diversity, hybridization and/or if they are a different species or sub species altogether. In support of this effort, a collection of voucher specimens for each species of SAV found in DCL, which began in 2015, will continue as new species are discovered and/or changes in morphological characteristics are identified. This will assist with a more accurate identification of plant species observed and will allow comparisons to previous year's findings.

Hydrilla verticillata does pose a threat to the health and biodiversity of Deep Creek Lake. *Hydrilla* has a greater competitive capacity than *Myriophyllum* over most native species for a number of reasons. It has the ability to grow under low-light conditions, much like macroalgae. It needs only 1% of sunlight to grow, allowing it to thrive under the canopy of other plants as well as deeper than other plants. Its low light requirements allow it to start photosynthesizing earlier in the morning, capturing and diminishing CO_2 that would otherwise be available for its competitors (Langeland, 1996). In addition to CO_2, *Hydrilla* can use bicarbonate as a carbon source when water column CO_2 is unavailable (Salvucci and Bowes, 1983), increasing the alkalinity of the water as it does, making conditions inhospitable to most native species. *Hydrilla* also employs dispersal strategies that allow it start new beds far from parent beds. Like many SAV, *Hydrilla* uses vegetative fragmentation as a means of reproduction (Akers, 2010). When the plant is disturbed, in a manner which breaks it into multiple pieces, those pieces float away and are capable of rooting where they land and forming new plants. In addition to vegetative fragmentation, *Hydrilla* reproduces by seed, turions, and tubers. Turions are growth structures which break from the main stem of the plant at the end of the growing season to drift, and much like vegetative fragmentation, eventually sink and start a new plant. Tubers are reproductive structures that store nutrients and are used by plants to survive winter and drought conditions, to provide energy and nutrients for re-growth during the next growing season or when environmental conditions are more suitable. Tubers are what make *Hydrilla* so successful and difficult to fully eradicate. The monoecious strain, which is most likely the strain present in DCL, can form tubers quickly during short photoperiods (Spencer and Anderson, 1986). One tuber can lead to the production of several hundred others in the course of one growing season, and they can survive for four to seven years in the sediment before sprouting, even if no water is present for much of that time (Akers, 2010). With that said, *Hydrilla* is between 93 to 95 percent water, so it can create huge volumes of biomass with very few resources. As a result, it can grow very rapidly, doubling its biomass every two weeks in summer conditions.

Fortunately, RAS biologists discovered *Hydrilla* very early in its infestation of DCL, a fact that underscores the importance of routine monitoring in any aquatic environment. Given that the invasion was relatively recent and populations of *Hydrilla* were small, control options where more viable than for *Myriophyllum.* The management program (see Appendix D) that was rapidly designed and implemented first during the summer 2014 season and again in 2015-2016 was highly successful with no living *Hydrilla* observed in the treatment areas at the end each of the growing seasons. 2016 marks the first year that no additional beds of *Hydrilla* were found outside of the treatment areas. Previously, one small bed (< $2m^2$) of *Hydrilla* was discovered in September 2015 outside the treatment area, and 2 additional beds were found in the fall of 2014. With no new beds of *Hydrilla* found in 2016, the *Hydrilla* control/eradication program showed continued success. Frequent scouting of the affected area and nearby areas, combined with comprehensive shoreline surveys will continue to make it possible to quickly identify and treat new patches. Because the prevailing science suggests that a multi-year effort is required to achieve control in a water body, management will continue for several years pending funding and need.

Potamogeton crispus, another invasive aquatic plant, first found in DCL during the 2015 SAV growing season was again documented to be slightly expanding its density and distribution in 2016. DNR RAS biologists first saw a floating fragment of *P. crispus* near the State Park (MMR) site in June 2015 but a survey of the cove and surrounding areas in June-July could not confirm the fragment was from a plant growing in the vicinity. Deep Creek Lake NRMA staff later discovered several beds of *P. crispus* growing in the Pawn Run area of the lake in July 2015. Shortly thereafter, DNR RAS biologists confirmed the find and together DNR RAS and DCL NRMA staff identified and recorded the location of all *P. crispus* beds in the Pawn Run area. It was determined that a selective hand-removal would be conducted on the majority of *P. crispus* beds. Several small beds were allowed to persist into September to track the plant's life cycle and timing of turion production (as that is the primary method of expansion for the plant) (Xie et. al, 2015). The plants observed in DCL from July-September 2015 did not follow the life cycle suggested by published literature, which suggests plants senesce in June after turion production and reappear in November, persisting through ice cover. In DCL, plants remained green and vibrant through August, not taking on the reddish brown coloration often observed before turion production and subsequent senescence. Plants were checked weekly for turion production. They did not produce turions until late August (Aug 21st), at which point plants were still green and vibrant. As lake water depths dropped quickly over the next month, the plants quickly disappeared with no remaining plants visible at the end of September through December. Ice conditions in the cove did not allow for a safe survey of the affected area from January-March but when the ice melted, the affected area was checked at the end of March 2016. No visible *P. crispus* beds were observed, nor were any other SAV species.

In 2016, the *P. crispus* beds in Pawn Run Cove appeared in late April 2016 and followed a more typical life cycle, producing turions by late June-early July and had begun to decline by mid-July 2016. DNR staff again mapped the P. crispus beds in early August 2016 (August 7-8, 2016) and found 90+ beds which is a three-fold increase in number of beds from 2015 (See Appendix C). It should be noted that the distribution and abundance at the time of mapping had visibly been reduced to close to half the original distribution and size observed earlier that season. So it is thought that there were at least 150 or more beds of *P. crispus* in the Pawn Run Cove during the 2016 growing season. So despite the effort to remove by hand these plants, the population appears to have increased between 3 and 5 times from the previous year. Observations of the plants health and reproductive status suggests that the plants may be following a more typical life cycle and should be mapped possibly earlier during the growing season, possibly June-July time frame. Despite suggestions in the literature that *P. crispus* can be found growing under ice, plants were again not visible after ice off in early March-April 2017. This is likely due to the winter draw down of the lake and the area typically inhabited by *P. crispus* being exposed and dry over winter. A continued monitoring of the plant's life cycle is planned for the 2017 SAV growing season.

RECOMMENDATIONS

Survey results from 2010-2016 indicate that DCL, as a whole, continues to support a healthy and relatively diverse population of SAV. It is essential that efforts continue to promote the healthy growth of native SAV and protect water quality and nearshore habitat for these communities. Based on the results and conclusions of this study, several recommendations are offered in an effort to improve the accuracy and efficacy of the transect and shoreline survey and provide necessary information to the DCL NRMA Lake Manager and staff to allow for proper and sustainable management of Deep Creek Lake.

The first recommendation began in 2015 and concerns efforts to more accurately document and identify species of SAV found in DCL. Due in part to the diversity of SAV found in Deep Creek Lake and the difficulty identifying and differentiating some species from other morphologically similar species in the genus, it is strongly recommended that multiple voucher specimens be collected, dried, identified, pressed, and mounted for future reference. This would allow for more precise future identification of species with morphological and seasonal variations.

Secondly, it is recommended that as genetic analysis becomes more cost effective, this level of precise identification should be considered for the AIS present in the lake, as well as for other plants of special management interest, such as *P. amplifolius* and *Myriophyllum* species. Given the difficulty in differentiating the *Myriophyllum* species, especially between the native *M. sibricum* and the invasive *M. spicatum*, and the fact that these species often co-occur in a water body (Moody and Les, 2007; Tavalire et al., 2012), it is recommended that a genetic analysis be conducted of a subset of the *Myriophylllum* species found in DCL. This would allow an accurate species identification, an estimate of relative abundance of each species within the lake, and if there is any hybridization occurring among the *Myriophyllum* species present. Genetic analysis of DCL AIS may also be useful to differentiate among other morphologically similar species such as *E. canadensis* and *E. nutallii*. As neither species of *Elodea* is a plant of special management interest, however, this is not a priority.

The third recommendation is to increase the nearshore water quality and habitat quality monitoring that is done throughout the lake with a particular emphasis on the southern arm of the lake (specifically the areas near DCC and GGC and possibly as far north as the newly added HCC transect area). Efforts were initiated in support of this recommendation in August 2016 and are planned to continue through 2017 and beyond. Based on 2010-2016 transect and shoreline survey data, SAV species in the DCC area were shown to have significantly declined in diversity, frequency of occurrence, and abundance over the observed time period. The southern legs of the lake are also within the total area that is affected by the *Hydrilla* herbicide treatment. While the declining trends in SAV were observed prior to the initiation of the herbicide treatment in 2014, a more spatially intensive monitoring plan (both SAV and water/habitat quality) should be explored in an effort to better understand possible causes of the decline. An increase in the spatial and temporal resolution of water quality data within the lake will also improve the ability to compare SAV data to water quality data each year and better understand observed changes. It is recommended that when resources and data allow, it would be beneficial to compare the species specific and total changes in SAV distribution and abundance at DCL to other nearby lakes to determine if species and community changes are a function of local conditions in Deep Creek Lake changing or a more regional shift due to weather/ climate variability.

The final recommendation concerns the status of aquatic invasive plants in the lake. Tracking of the newly found *P. crispus* community in Pawn Run Cove should continue with an increased effort to determine if those plants are spreading throughout the lake. While the hand-removal method that was used in 2015 was not a feasible method of control, other options for control may need to be considered if the current population continues to expand or if the plant is found growing in other portions of the lake. It is recommended that extra emphasis be placed on developing and implementing a more detailed water and habitat quality monitoring plan in the Pawn Run area. Documenting changes in the *P. crispus* morphology and life cycle so as to better determine and predict how this plant functions and responds to changing conditions in DCL would also be beneficial. *Potamogeton crispus* management should be included in future AIS management plans drafted for DCL.

Pending no further introductions of *Hydrilla* to DCL, it is expected that the management plan will continue to be successful at controlling and potentially eradicating *Hydrilla*. Intensive monitoring for early detection and spread of *Hydrilla* should continue similar to what was done in 2014-2016 with more intensive monitoring in and around the areas already affected. One of the best ways to prevent further expansion of non-native AIS in DCL is to prevent any further introductions, monitor current populations, and boat responsibly in areas where they are growing. In an effort to better communicate the importance of preventing new introductions of all AIS to the lake and minimizing the spread of currently found AIS within the lake, it is recommended that the AIS educational effort initiated in 2013 continue and expand as funding and resources allow,

In summary, the current and recommended SAV and water quality monitoring discussed in this report should continue and evolve in accordance with new findings and improvements to the current science related to these efforts. Cumulatively, this will serve as a management tool for DCL NRMA staff and provide a scientific foundation upon which management decisions can effectively be made and implemented.

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APPENDIX A

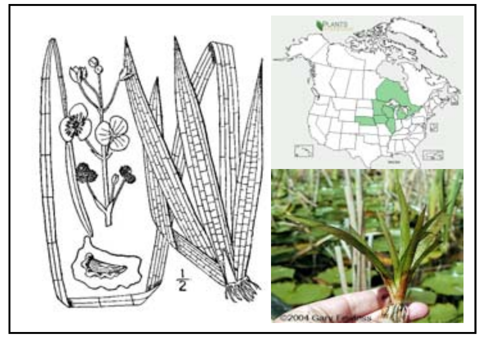
Deep Creek Lake

Submerged Aquatic Vegetation and Macroalgae

Plant Guide

This appendix provides drawings, pictures, distribution maps, and a brief description of each species of submerged aquatic vegetation observed in Deep Creek Lake during the summers 2010 - 2014 SAV surveys.

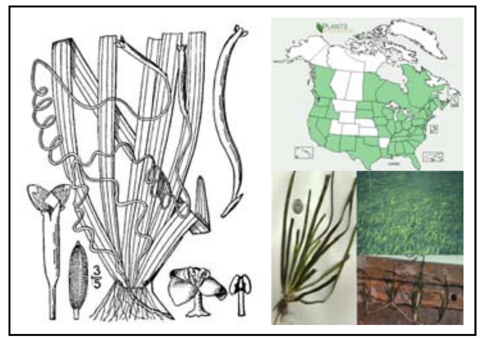
Sagittaria cristata (Crested arrowhead)



Monocot, Perennial, Native to the continental US and Canada. Distribution includes IA, IL, MI, MN, NE, and WI. It has not been previously documented in MD according to the USDA Plant Database (http://plants.usda.gov/java).

Crested arrowhead grows along the margins and bottoms of shallow lakes, ponds, and swamps. It may grow up to 75 cm tall, though in DCL it hasn't been observed more than 10 cm high. Flowering occurs July through August.

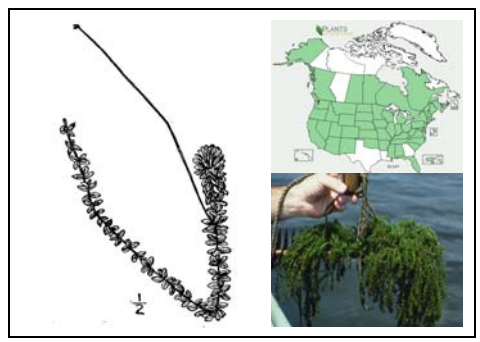
Vallisneria americana (Wild celery)



Monocot, Perennial, Native to continental US and Canada. Distribution in all but seven states and most of Canada.

Wild celery is primarily a freshwater species, although it is occasionally found in brackish waters (up to 12-15 ppt). Wild celery seems to prefer coarse silty to sandy soil, and is fairly tolerant of murky waters and high nutrient loading. It can tolerate wave action better than some other grass species.

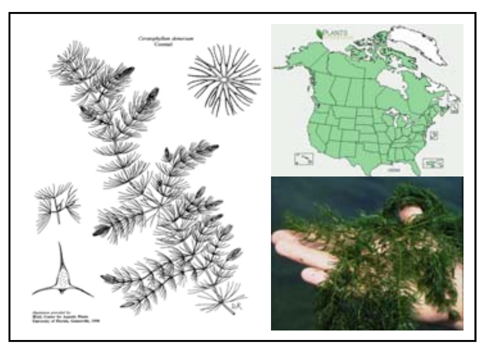
Elodea canadensis (Canadian waterweed)



Monocot. Perennial. Native to the continental US and Canada, but considered Invasive in Puerto Rico. Distributed in all but three continental US states: TX, LA, and GA.

This waterweed is primarily a freshwater species. It prefers loamy soil and slow-moving water with high nitrogen and phosphorous concentrations. It will grow in a wide range of conditions, from very shallow to deep water, and in many sediment types. It can even continue to grow unrooted, as floating fragments.

Ceratophyllum demersum (Coontail)



Dicot. Perennial. Native to the continental US and Alaska, Canada, Puerto Rico, and the US Virgin Islands. Invasive in Hawaii. Distribution is ubiquitous throughout the US.

Coontail's leaves grow in crowded whorls which make it resemble a raccoon's tail underwater. Each leaf is forked into segments with fine teeth on one side of the leaf margin. Leaves are brittle and keep their shape out of water. Coontail may float in dense mats beneath the surface and its base is only occasionally attached to the sediment. It may also be found near the bottom in deep water – in creek channels, for example.

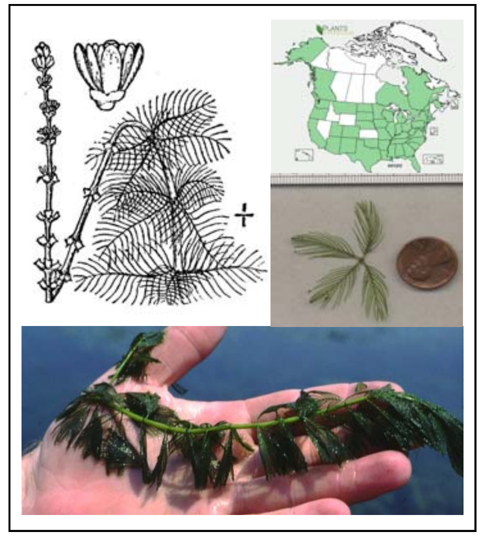
***Myriophyllum spicatum* (Eurasian water milfoil)**

Dicot, Perennial. Invasive to the continental US, Alaska, and Canada. Native to Europe, Asia, and northern Africa. Invasive distribution throughout the US.

This plant has a long stem that branches profusely when it reaches the surface of the water. Leaves are finely divided and feather-like in appearance. There are usually 12 to 21 pairs of leaflets.

Eurasian watermilfoil can grow in ponds, lakes, reservoirs, and slow flowing rivers and streams. It will grow in shallow or deep water, fresh or brackish water, and within a wide temperature range. It tends to do well in waters that have had some sort of disturbance like intense plant management, overabundance of nutrients, or extensive motorboat use.

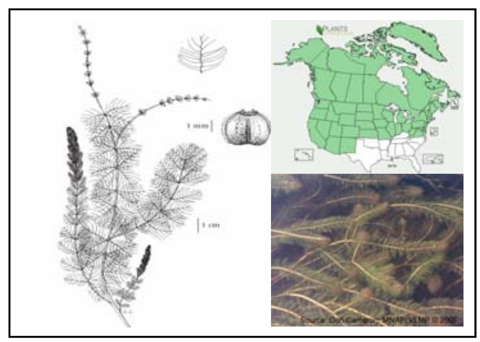
Dispersal through vegetative means is Eurasian watermilfoil's main reproductive strategy. The plant goes through autofragmentation during the growing season, where roots develop at the nodes, then fragments float away and establish elsewhere.



***Myriophyllum sibiricum* (Northern water milfoil)**

Dicot, Perennial. Native to the continental US, Alaska, Canada, and elsewhere. Distribution throughout Canada and the US with the exception of southeastern states from TX east to FL.

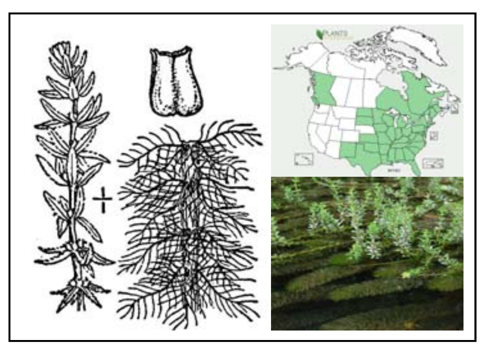
This plant is distinguished from the Eurasian water milfoil by its less finely divided leaves and larger floral bracts. It typically has 5-10 thread-like segments on each side of the midrib whereas Eurasian water milfoil has 12-24 segments. It is found in shallow to deep water of lakes, ponds, marshes, where its presence significantly increases the abundance of macroinvertebrates, although the value of milfoil is likely due more to its value as habitat than as food.



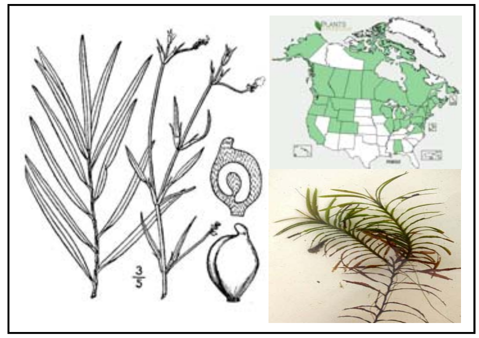
***Myriophyllum heterophyllum* (Two-leafed water milfoil)**

Dicot, Perennial. Native to the continental US and Canada with distribution throughout the eastern US and Canada.

Two-leafed water milfoil has fine densely packed, featherlike leaves whorled around a main stem. It can grow up to 15 feet and may exhibit a three to six inch green spike-like flower above the waterline in late June or in July. A cross-section of the stem will reveal "pie-shaped" air chambers.



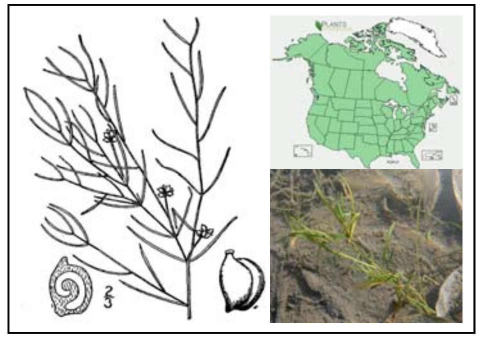
***Potamogeton robbinsii* (Robbin's pondweed)**



Monocot. Perennial. Native to the continental US, Alaska, and Canada. Distribution limited to ~ half US states and most of Canada.

This pondweed is found in deep to shallow, often muddy waters of lakes, ponds, and rivers. It is the only *Potamogeton* that has branching inflorescences, though it rarely flowers. This plant is believed extirpated from Maryland and is threatened or endangered in several of its native states.

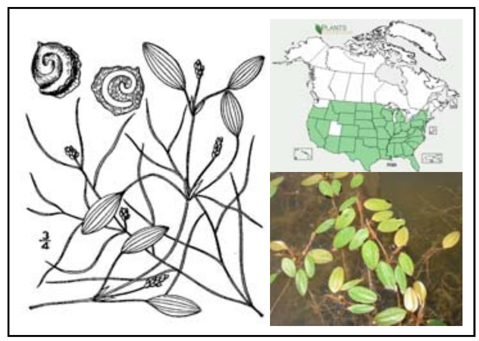
***Potamogeton pusillus* (Slender pondweed)**



Monocot. Perennial. Native to the continental US, Alaska, and Canada. Distributed throughout native range.

Slender pondweed grows in soft, fertile mud substrates and quiet to gently flowing water. Leaf blades of slender pondweed are entire and have pointed tips and can have a purplish tint. Like all other pondweeds, slender pondweed is considered an important food for waterfowl.

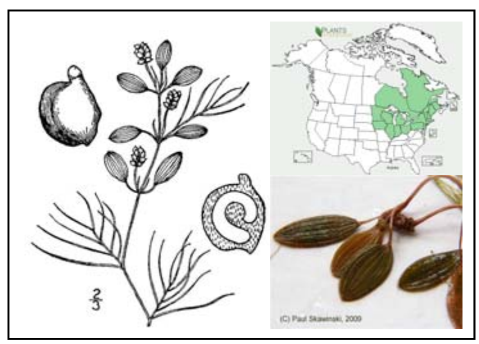
***Potamogeton diversifolius* (Waterthread pondweed**)



Monocot. Perennial. Native to the continental US and distributed throughout with the exception of far northeast.

This pondweed produces a very narrow, compressed stem branching to around 35 cm. It has thin, pointed linear leaves a few cm long spirally arranged about the thin stem. Flowers emerge from the water surface.

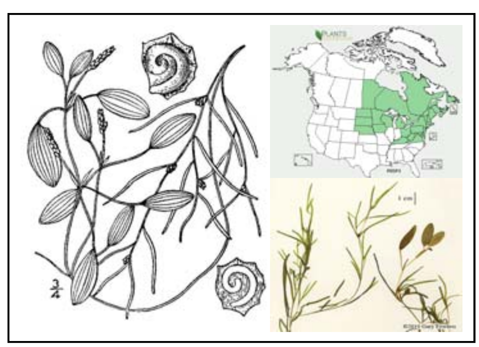
Pota*mogeton vaseyi* (Vasey's pondweed)



Monocot. Perennial. Native to the continental US and Canada. Distribution limited to the northeastern US and eastern Canada.

Not previously documented in Maryland, Vasey's pondweed is considered threatened, endangered, or of special concern where found in northeastern US states. It grows in quiet waters and has dimorphic leaves: very narrow, flaccid, submersed leaves and wider, thicker floating leaves.

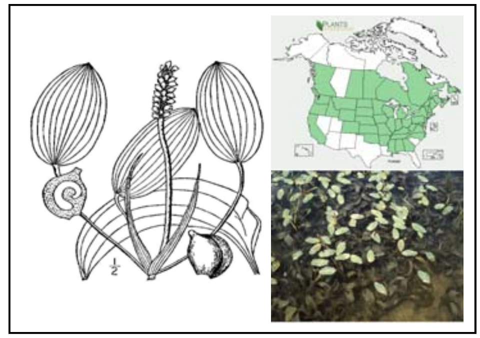
***Potamogeton spirillus* (Spiral pondweed)**



Monocot. Perennial. Native to the continental US and Canada, but distributed only throughout the northeast US and northern mid-west, and eastern Canada.

Spiral pondweed usually grows in shallow water: lakes, ponds, wet swales, and rarely quiet river borders. The submersed leaves are often curved, giving the whole bushy plant the aspect of a broad-leaved *Najas*.

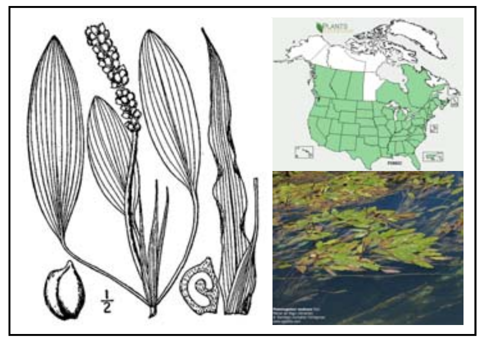
Potamogeton amplifolius (Largeleaf pondweed)



Monocot. Perennial. Native to the continental US and Canada.

Potamogeton amplifolius grows in lakes, ponds, and rivers, often in clear deep water. Grows from rhizomes, seed, or fragmentation and produces a very slender, cylindrical, sometimes spotted stem up to a meter + long. Alternate leaves take two forms: Submersed leaves are up to 20 centimeters long by 7 wide folded along midrib with a curling appearance. Floating leaves are up to 10 centimeters long by 5 wide, leathery in texture, and grow on long petioles. The inflorescence is a spike of many flowers rising above the water surface on a thick peduncle.

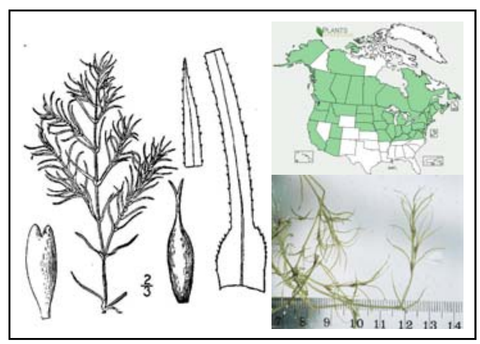
Potamogeton nodosus (Longleaf pondweed)



Monocot. Perennial. Native to the continental US and Canada, Puerto Rico, and Hawaii.

Longleaf pondweed can be found in ponds, lakes, ditches, and streams. It produces a thin, branching stem easily exceeding a meter in maximum length. Leaves are linear to widely lance-shaped and up to 15 centimeters long by 4 wide. Both floating leaves and submerged leaves are borne on long petioles. The inflorescence is a spike of many small flowers arising from the water on a peduncle.

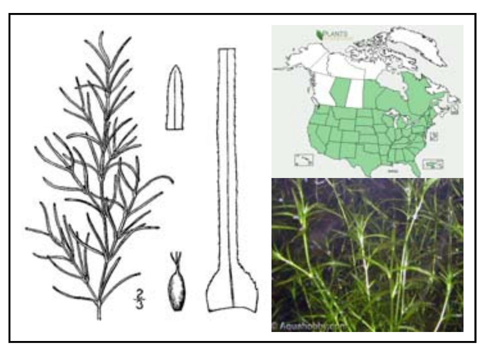
Najas flexilis (Slender or nodding naiad)



Monocot. Annual. Native to the continental US, Alaska, and Canada. Found in most northern states and Canada.

Naiads grow in small freshwater streams. They prefer sandy substrates and tolerate relatively low light. Naiads vary in size from inch-high tufts on sandy bottoms to highly branched plants two or three feet high. *Najas flexilis* is considered to be excellent food sources for waterfowl.

Najas guadalupensis (Southern naiad)



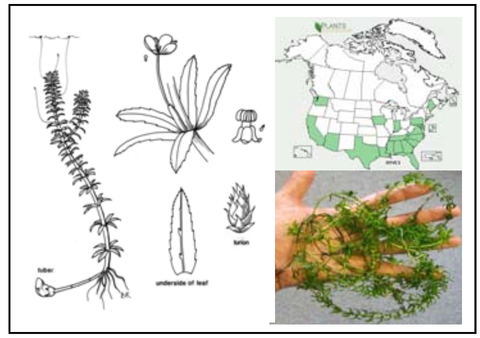
Monocot. Annual. Native to the continental US, Puerto Rico, and Canada. Invasive to Hawaii. Distributed throughout US.

This plant grows in ponds, ditches, and streams. It produces a slender, branching stem up to 60 to 90 centimeters in maximum length. The thin, somewhat transparent, flexible leaves are up to 3 cm long and just 1-2 mm wide. They are edged with minute, unicellular teeth. Tiny flowers occur in the leaf axils; staminate flowers grow toward the end of the plant and pistillate closer to the base

Hydrilla verticillata **(Waterthyme)**

Monocot. Perennial. Invasive in the continental US.

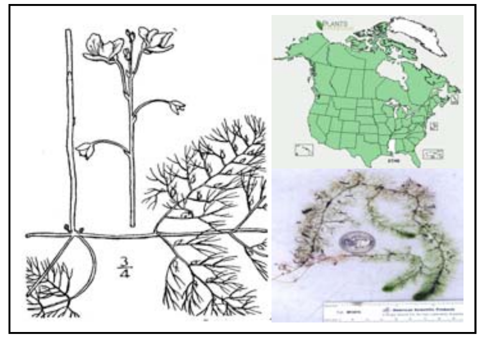
Hydrilla may be found in all types of water bodies. Its stems are slender, branched and up to 25 feet long. *Hydrilla's* small leaves are strap-like and pointed and grow in whorls of four to eight around the stem. Leaf margins are distinctly saw-toothed. *Hydrilla* produces tiny white flowers on long stalks, as well as 1/4 inch turions at the leaf axils and tubers attached to the roots. Reproduction is mainly fragmentation but also by growth of turions and tubers; which remain viable for several years.



Utricularia vulgaris **(Common bladderwort)**

Dicot. Perennial. Native to the continental US, Alaska, and Canada.

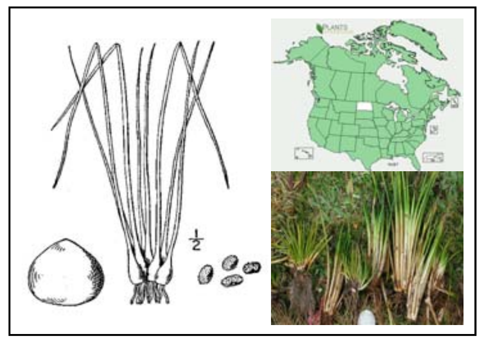
Several species of bladderwort occur in the Chesapeake Bay region, primarily in the quiet freshwater of ponds and ditches. They can also be found on moist soils associated with wetlands. Bladderworts are considered carnivorous because minute animals can be trapped and digested in the bladders that occur on the underwater leaves.



Isoetes spp. **(Quillwort)**

Lycopod. Perennial. Native to the continental US, Alaska, and Canada. Distributed throughout.

Quillwort leaves are hollow. Each leaf is narrow (2–20 cm long and 0.5–3 mm wide). They broaden to a swollen base up to 5 mm wide where they attach in clusters to a bulb-like, underground rhizome. This base also contains male and female sporangia, protected by a thin velum. Quillwort species are very difficult to distinguish by general appearance.

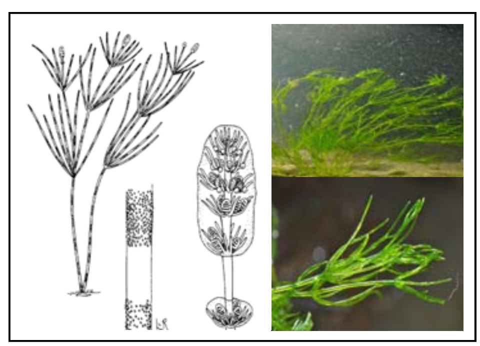


Chara vulgaris **(*Chara*, Common stonewort) Macroalgae**

Chara is a green alga belonging to the Charales, a lineage that may have given rise to all land plants. The stoneworts are a very distinctive group of green algae that are sometimes treated as a separate division (the Charophyta). These algae can occur in fresh or brackish waters, and they have cell walls that contain large concentrations of calcium carbonate. Charophytes have relatively complex growth forms, with whorls of "branches" developing at their tissue nodes. Charophytes are also the only algae that develop multicellular sex organs.

Nitella flexilis **(*Nitella*, Smooth stonewort) Macroalgae**

Nitella flexilis is closely related to *Chara vulgaris* in the Stonewort family, a group of complex algae that superficially resemble vascular plants more than they do other groups of algae. *Nitella* is a green, freshwater algae; a robust species growing up to a meter long with axes up to 1mm wide. Branches in whorls once or twice divided.



Vascular plant drawings, except *Hydrilla*, were obtained from Britton and Brown (1913) via the USDA Plant Database. USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *An illustrated flora of the northern United States, Canada and the British Possessions. 3 vols. Charles Scribner's Sons, New York.*

Drawings of *Hydrilla verticillata, Chara vulgaris,* and *Nitella flexilis* are credited to IFAS Center for Aquatic Plants, University of Florida, Gainesville, 1990.

Distribution maps were obtained from the USDA Plant Database.
USDA, NRCS. 2011. The PLANTS Database (http://plants.usda.gov, 10 November 2011). National Plant Data Team, Greensboro, NC 27401-4901 USA.

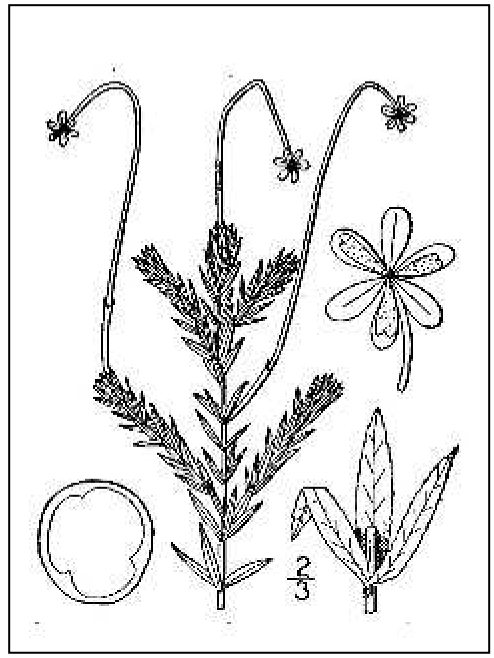
Images were obtained from the following:

Sagittaria cristata: www.uwgb.edu
Vallisneria Americana: www.dnr.state.md.us
Elodea Canadensis: www.dnr.state.md.us
Ceratophyllum demersum: www.dnr.state.md.us
Myriophyllum spicatum: www.dnr.state.md.us
Myriophyllum sibiricum: www.mainevolunteerlakemonitors.org
Myriophyllum heterophyllum: www.missouriplants.com
Potamogeton robbinsii: www.yankee-lake.org
Potamogeton pusillus: http://flora.nhm-wien.ac.at
Potamogeton diversifolius: www.dcnr.state.al.us
Potamogeton vaseyi: www.botany.wisc.edu
Potamogeton spirillus: www.uwgb.edu/
Potamogeton amplifolius: www.plants.usda.gov
Potamogeton nodosus: www.apatita.com
Hydrilla verticillata: www.dnr.state.md.us
Najas flexilis: www.vilaslandandwater.org
Najas guadalupensis: www.aquahobby.com
Utricularia vulgaris: www.dnr.state.md.us/bay/sav/key
Isoetes spp.: www.nybg.org
Chara vulgaris: www.biolib.cz
Nitella flexilis: www.diszhal.info

2015 Additions to Deep Creek Lake plant list

***Elodea nutallii* (Western waterweed or Nuttall's waterweed)**

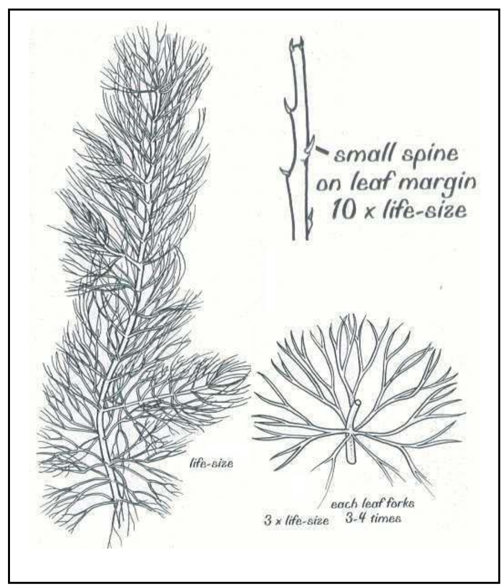
Monocot. Perennial. Native to North America; this plant is commonly found growing submersed in lakes, rivers, and other shallow water bodies and can easily be confused with common waterweed or *Elodea canadensis* however *E. nutallii* has thinner leaves which come to an acute point. It is not native to Europe but commonly found there; most likely introduced there as an aquarium plant



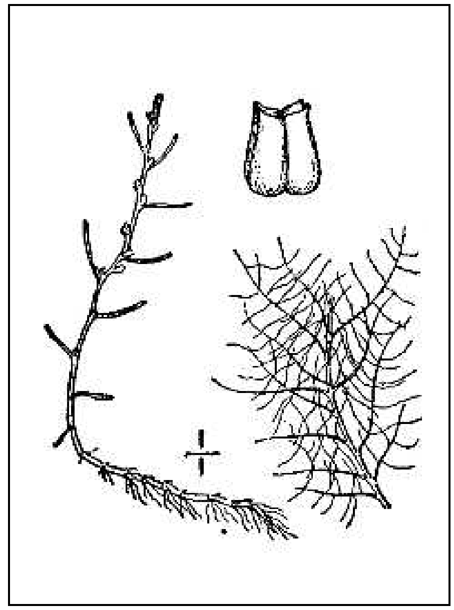
***Ceratophyllum echinatum* (Spineless hornwort)**

Dicot. Perennial. Found in ponds and lakes generally in eastern North America. The only species of its genus endemic to North America. Listed as endangered in Maryland and commonly called prickley hornwort.

Like coontail, the spineless hornwort usually does not have any roots with stems that are freely branching (0.3-4.0 m long). The leaves are submerged and they are usually in whorls of 5 to 12. The flower is tiny, could be male or female, and blooms from February to July. The fruits have dry seeds with a lot of spines and a rough surface.

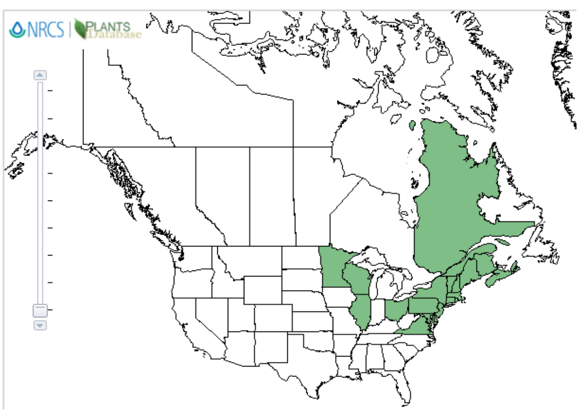


***Myriophyllum humile* (low water milfoil)**



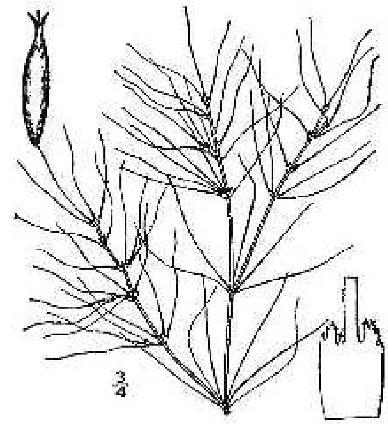
Dicot, Perennial. Native to the continental US and Canada. Often found in still or slow-moving, waters of lakes, rivers, pools, and pond shorelines. Commonly found on shorelines of receding waters. *Myriophyllum humile* is extremely variable and shows different morphologies depending on water level. Stems generally become longer and branches bear more and finer segments as water depth increases, with terrestrial forms appearing strikingly different from aquatic forms. Can be confused with the invasive *M. spicatum*.

In Maryland, this plant was recently documented in Deep Creek Lake and has also been found in some of the western Maryland lakes; typically in the shallow portions of the lake's shorelines. It has also been documented on the eastern shore of Maryland.



Najas gracillima **(slender waternymph or thread leafed naiad)**

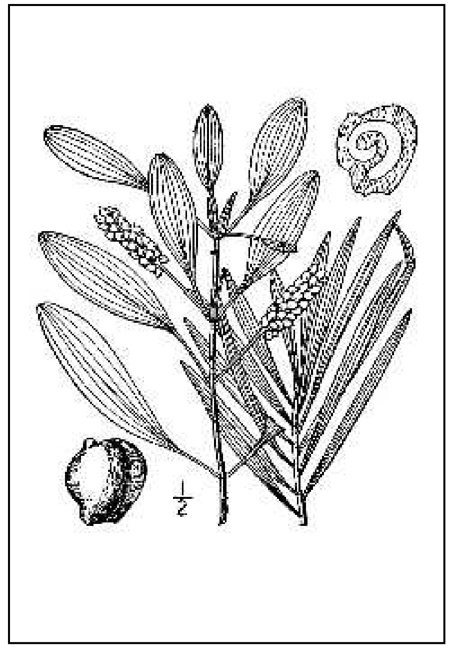
Monocot. Annual. Native to the US, but listed as endangered or extirpated in Maryland. This plant is found often growing in sandy or gravelly soils in lakes and rivers more common to the Northeastern states and eastern mid-western states. In Minnesota it is found in less than 15% of lakes statewide and it is thought to be less common perhaps due to declining water quality and generally prefers shallow (less than 1m water) depths and low wave energy. Shoreline development or agriculture are thought to impact it's distribution. It is thought to be rare in Maryland but may be found in the shallow portions of the western Maryland lakes to include Deep Creek.



USDA-NRCS PLANTS Database
Britton, N.L., and A. Brown. 1913.
Illustrated flora of the northern states
and Canada. Vol. 1: 190.

It is a submerged aquatic plant with leaves between 6mm-28mm long and leaf margins are minutely serrulate with 13-17 teeth per side with a midvein. There are both male and female flowers on the same plant and light brown seeds in fusiform shape. The see is not recurved and the surface is dull and pitted.

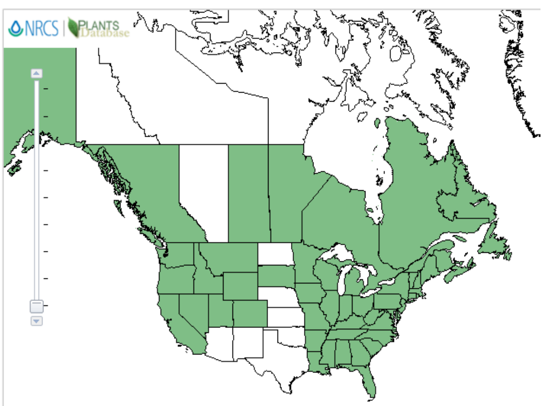
Potamogeton epihydrus **(Ribbonleaf pondweed)**



Monocot. Perennial. Native to the continental US and Canada.

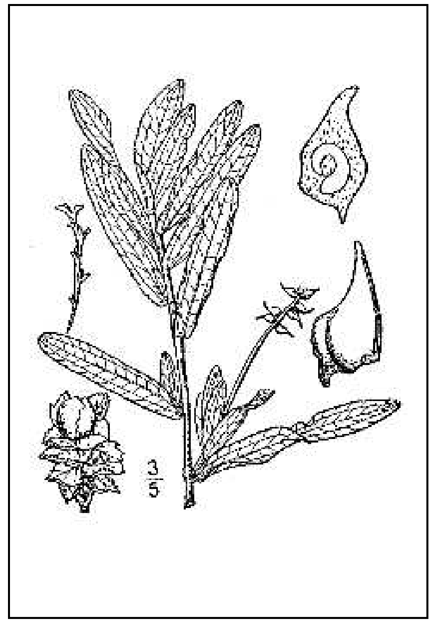
Ribbonleaf pondweed has stems that rarely grow more than 1m in length with two types of leaves, both submerged and floating. The submerged leaves are 5-25cm long and up to 1cm wide, can be translucent, linear in shape and ribbon-like, red-brown to light green in color with a blunt to acute tip. The floating leaves are similar to other Potamogeton leaves, opaque and up to 8cm long and 3cm wide. The inflorescence is a small spike of flowers that emerged from the water. This species can hybridize with other Potamogetons, notably *P. nodosus* and *P. gramineus.*

Ribbonleaf pondweed is a temperate to boreal species plant, more common in the northern part of the US and southern Canada. It grows well in lakes and shallow, slow flowing waters and may be negatively impacted by acidic waters.



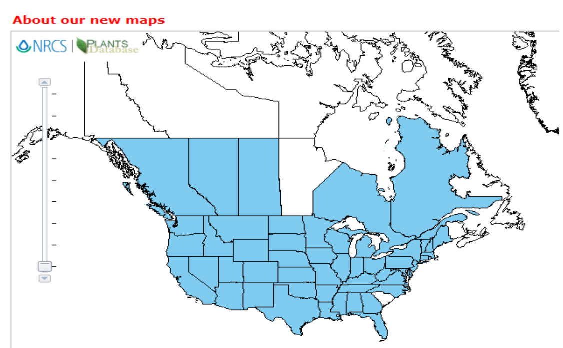
Potamogeton crispus **(Curly pondweed)**

Monocot. Perennial. Non-Native/Invasive to the continental US and Canada.



Curly pondweed is a non-native invasive plant that can grow up to 5m in length. There are no floating leaves, only submerged leaves and they are wavy, arranged alternately along the stem and have minuet teeth along the leaf margin. The leaves are 4-10cm long and up to 5-10mm wide and olive green to reddish brown in color with a slightly visible mid-vein.

In the Chesapeake Bay, *P. crispus* has two distinct growth periods, it generally is one of the first species that comes up in the spring, usually dies back in the summer and shows another regrowth in the fall. It's unknown if the variety of *P. crispus* in DCL is that of the Bay or elsewhere. In the colder regions of its range, *P. crispus* produces turions, its primary means of reproduction, in July after the plant flowers and fruits in June. After turion production, usually in mid-July throughout most areas of its range, the plant undergos dormancy in the fall, as waters cool again, the turions sprout and *P. crispus* survives the winter as whole, intact leafy plants (even under thick ice and snow cover). The plant then grows rapidly in early spring when water temperatures are still quite cool (10-15°C).



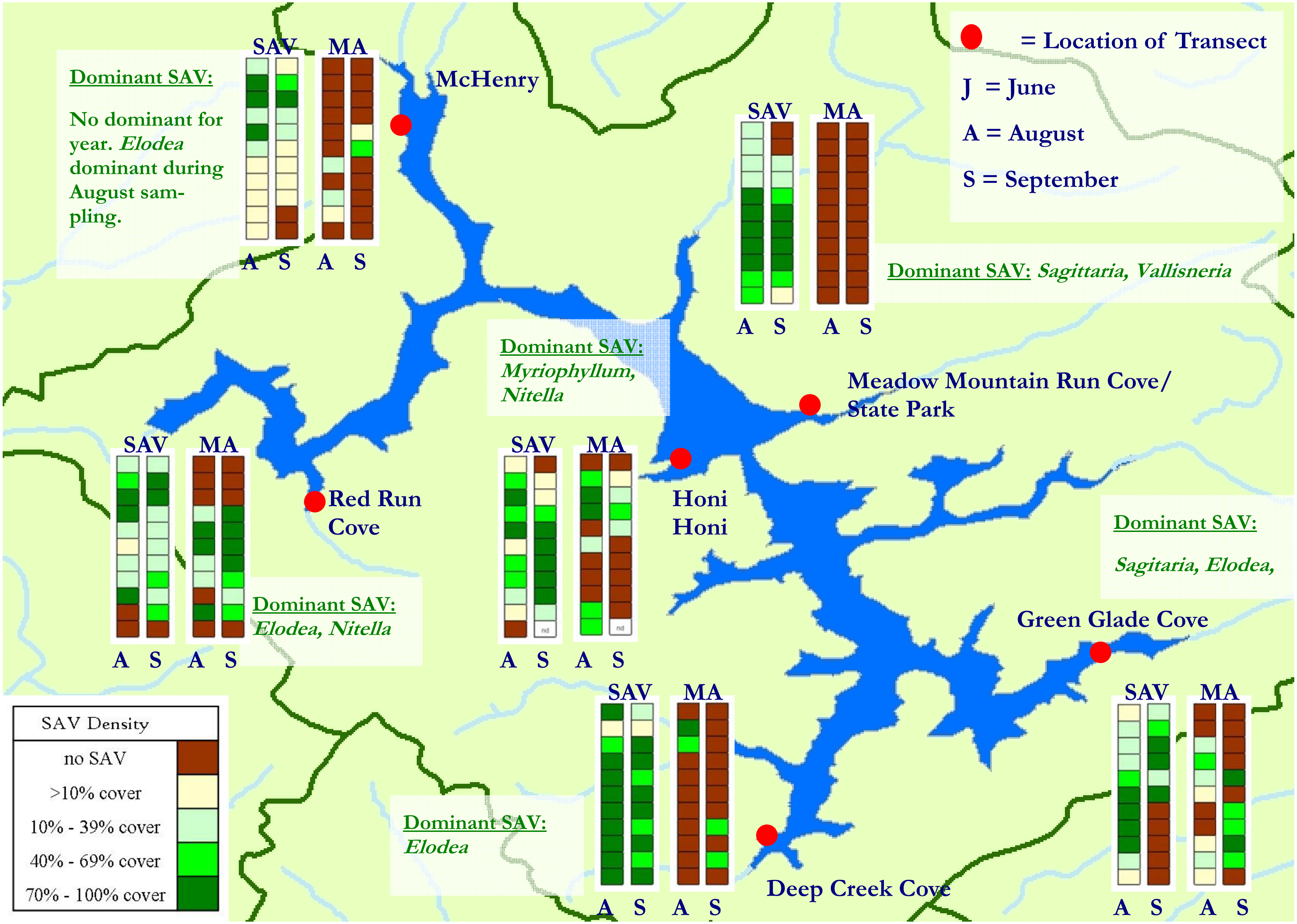
Based on limited observations of the newly found population at DCL, plants don't seem to adhere to either of the above descriptions of life cycle. Plants were found in July 2015 and tracked throughout the year. Plants looked green and vibrant throughout the summer months and turion production happened in late August. The plants did not senesce until late September when water level dropped and were not found overwinter, nor in March after ice off.

APPENDIX B

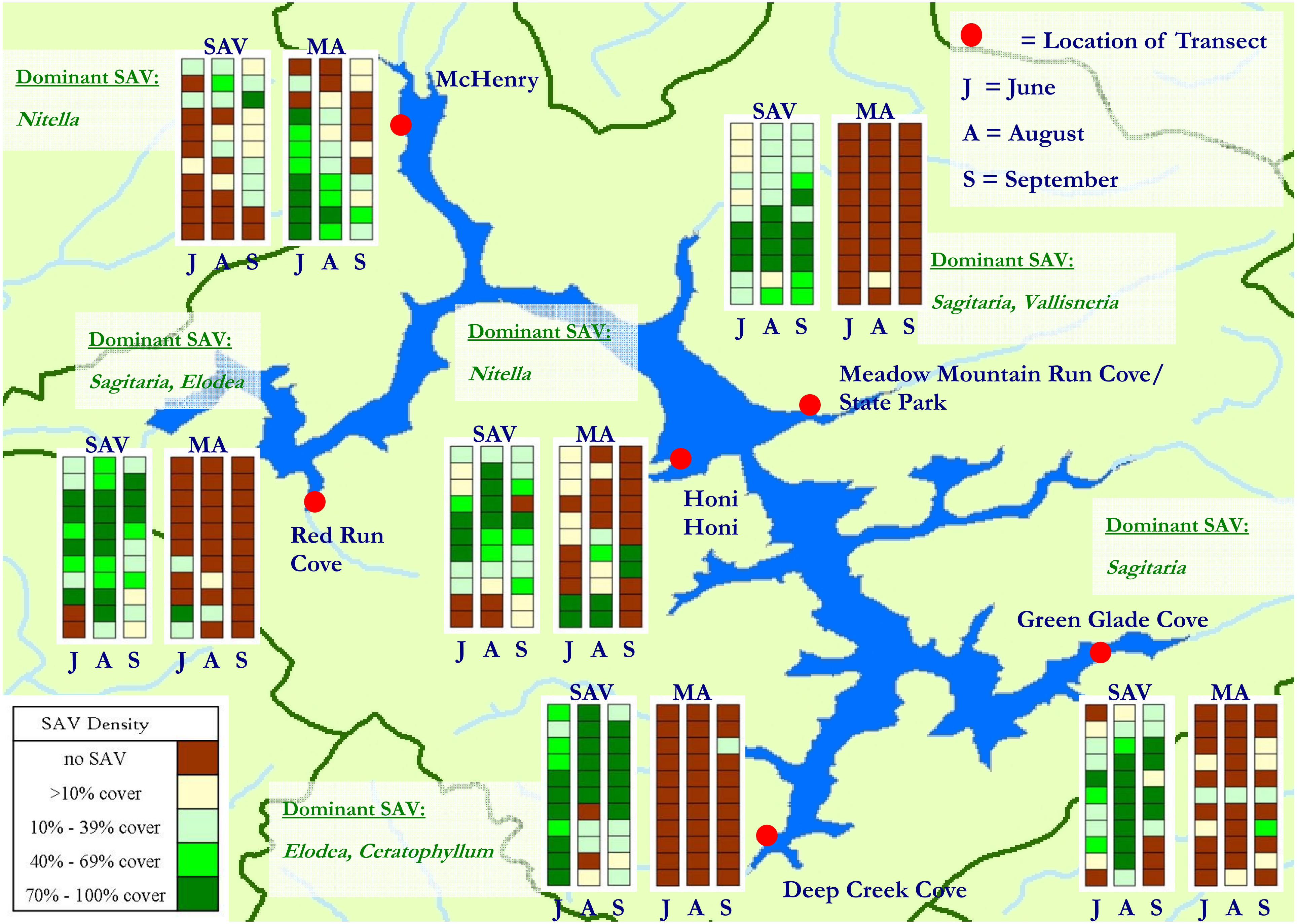
Deep Creek Lake

Color Coded Transects

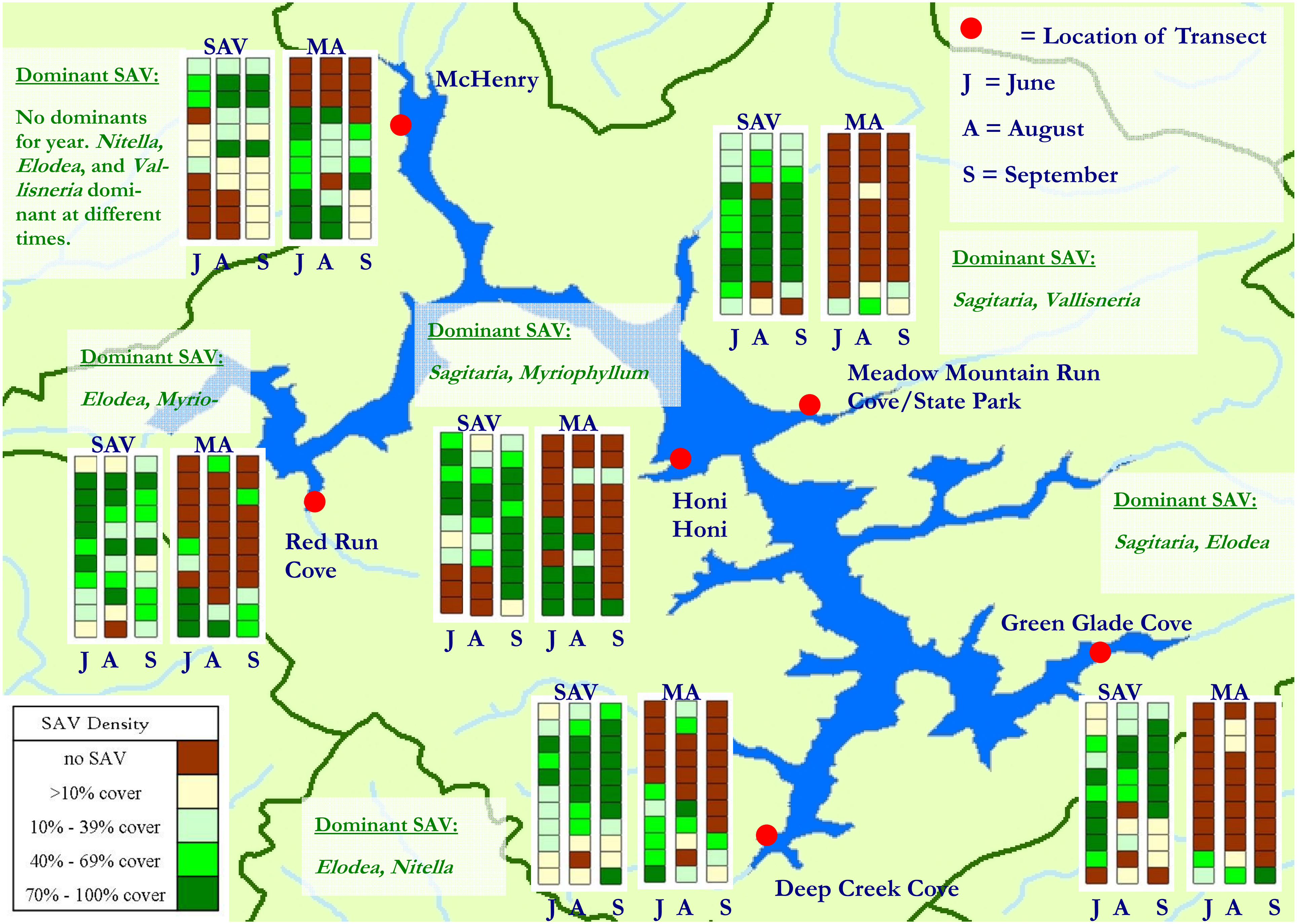
Deep Creek Lake, MD 2010



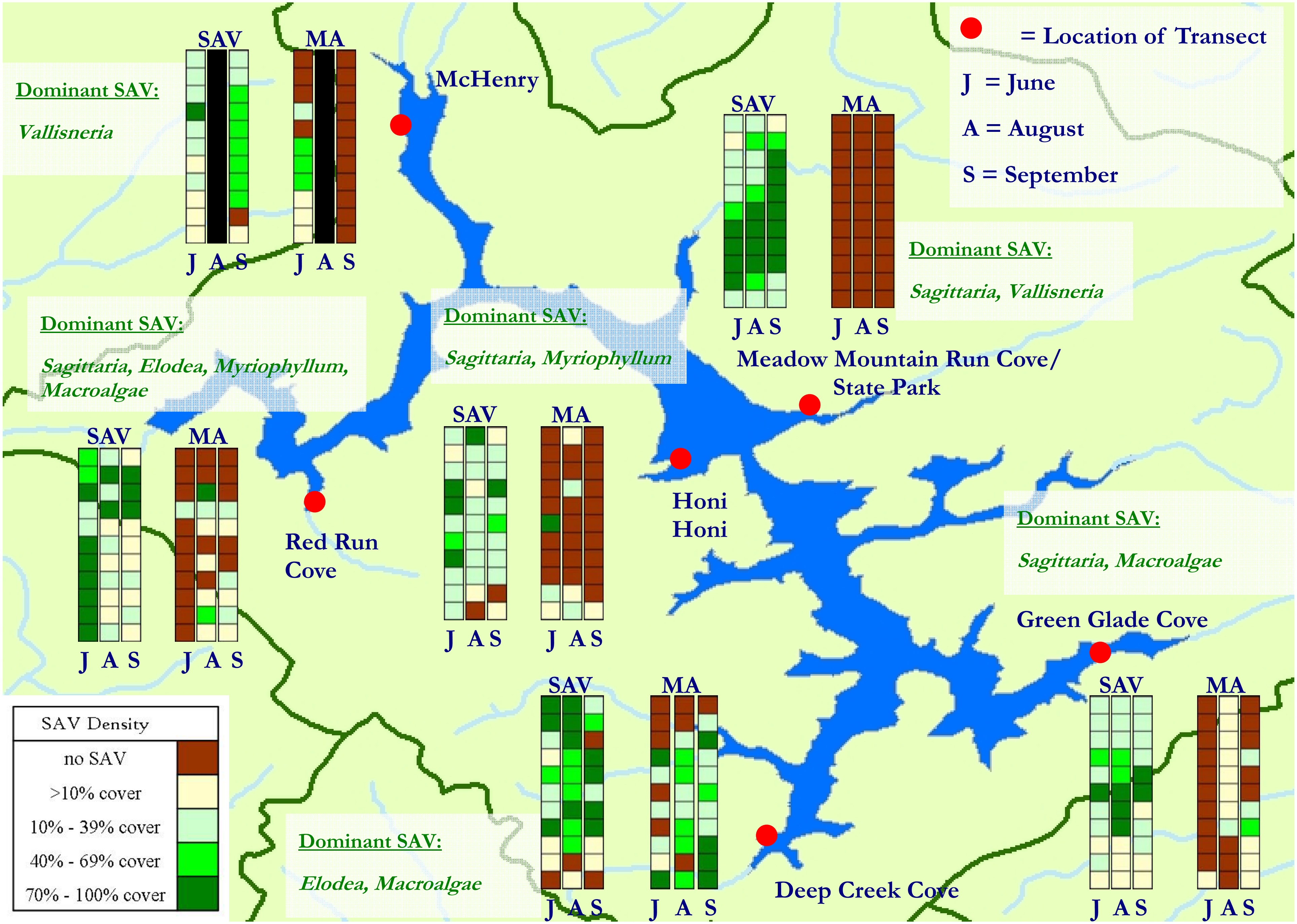
Deep Creek Lake, MD 2011



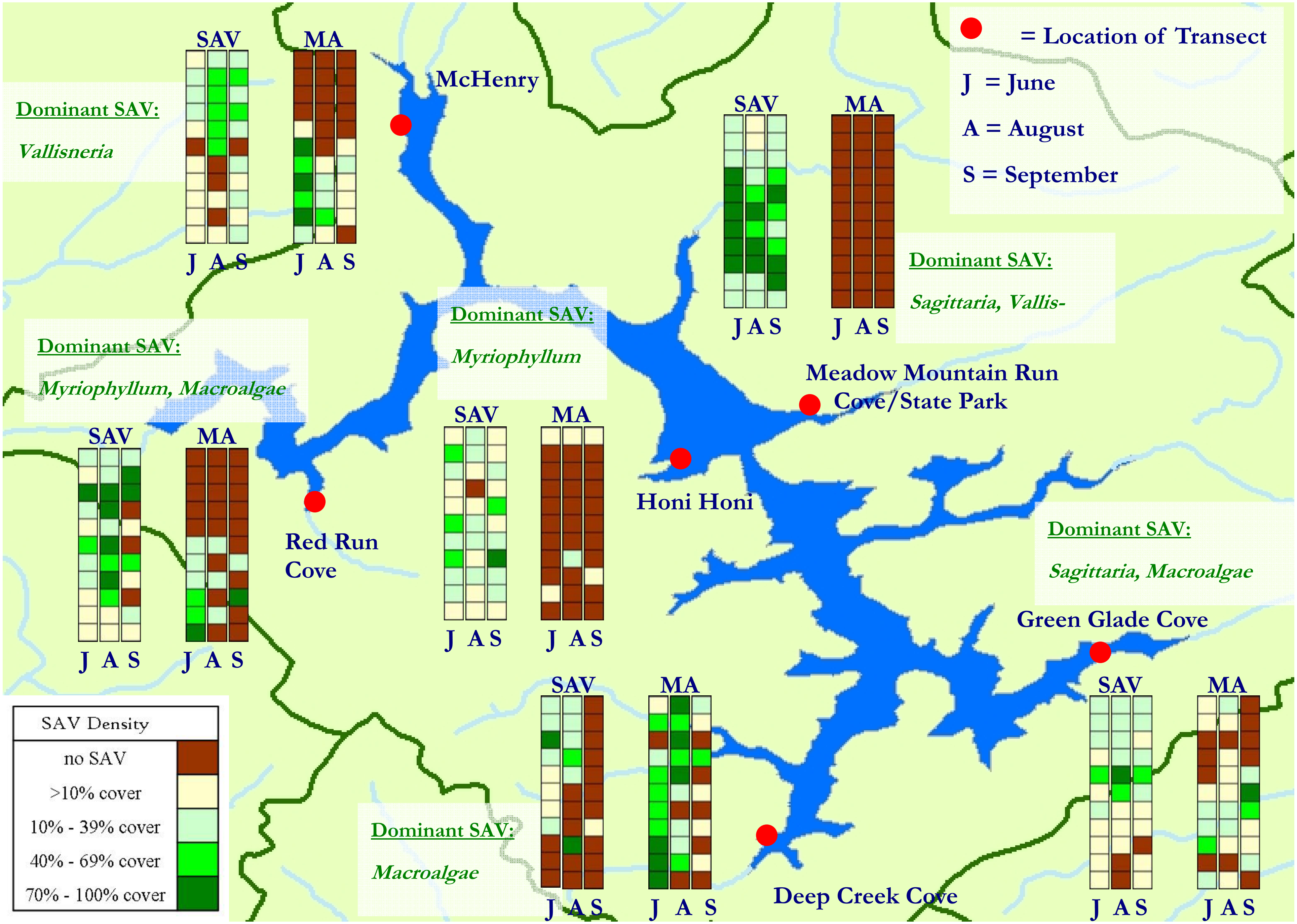
Deep Creek Lake, MD 2012



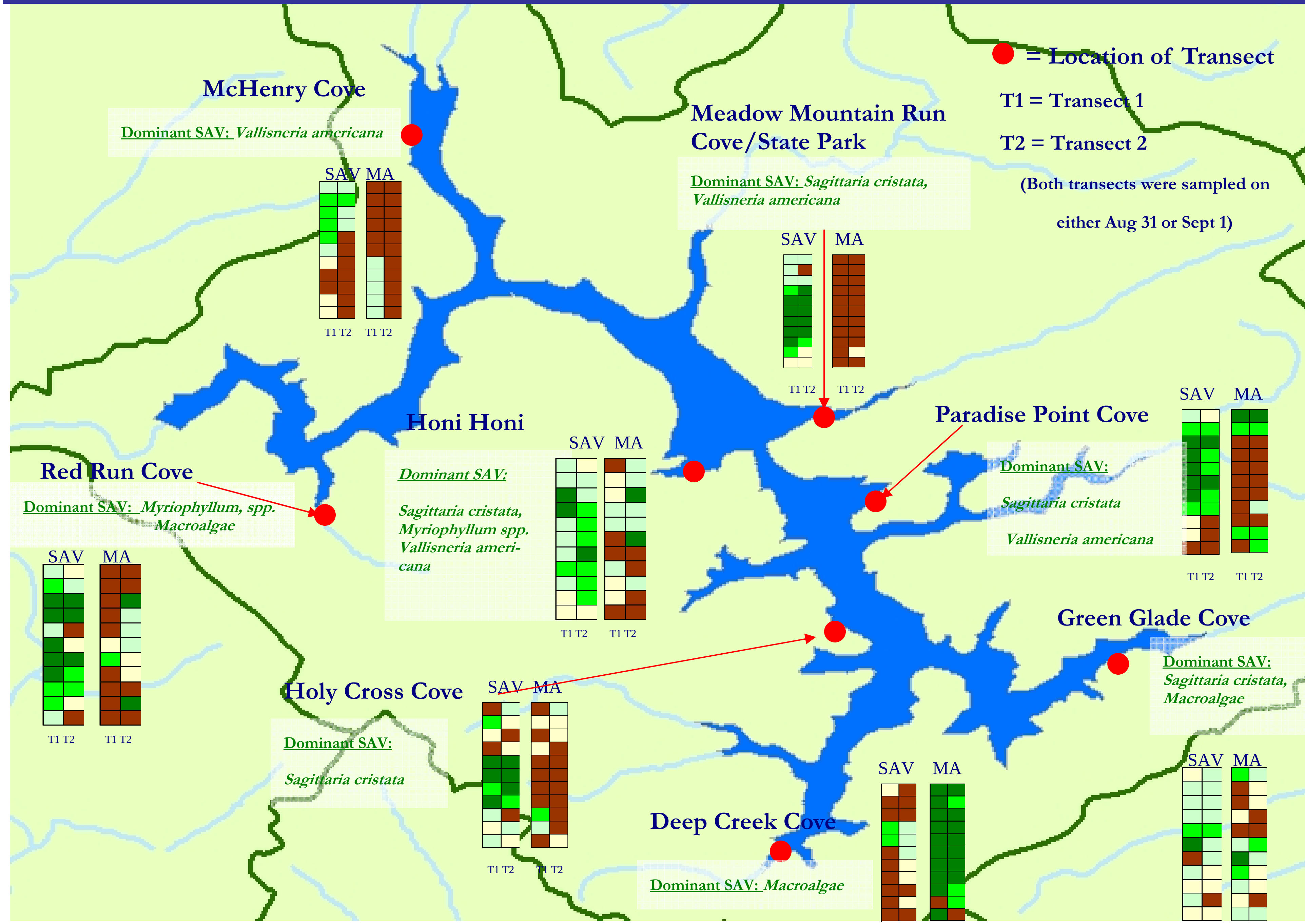
Deep Creek Lake, MD 2013



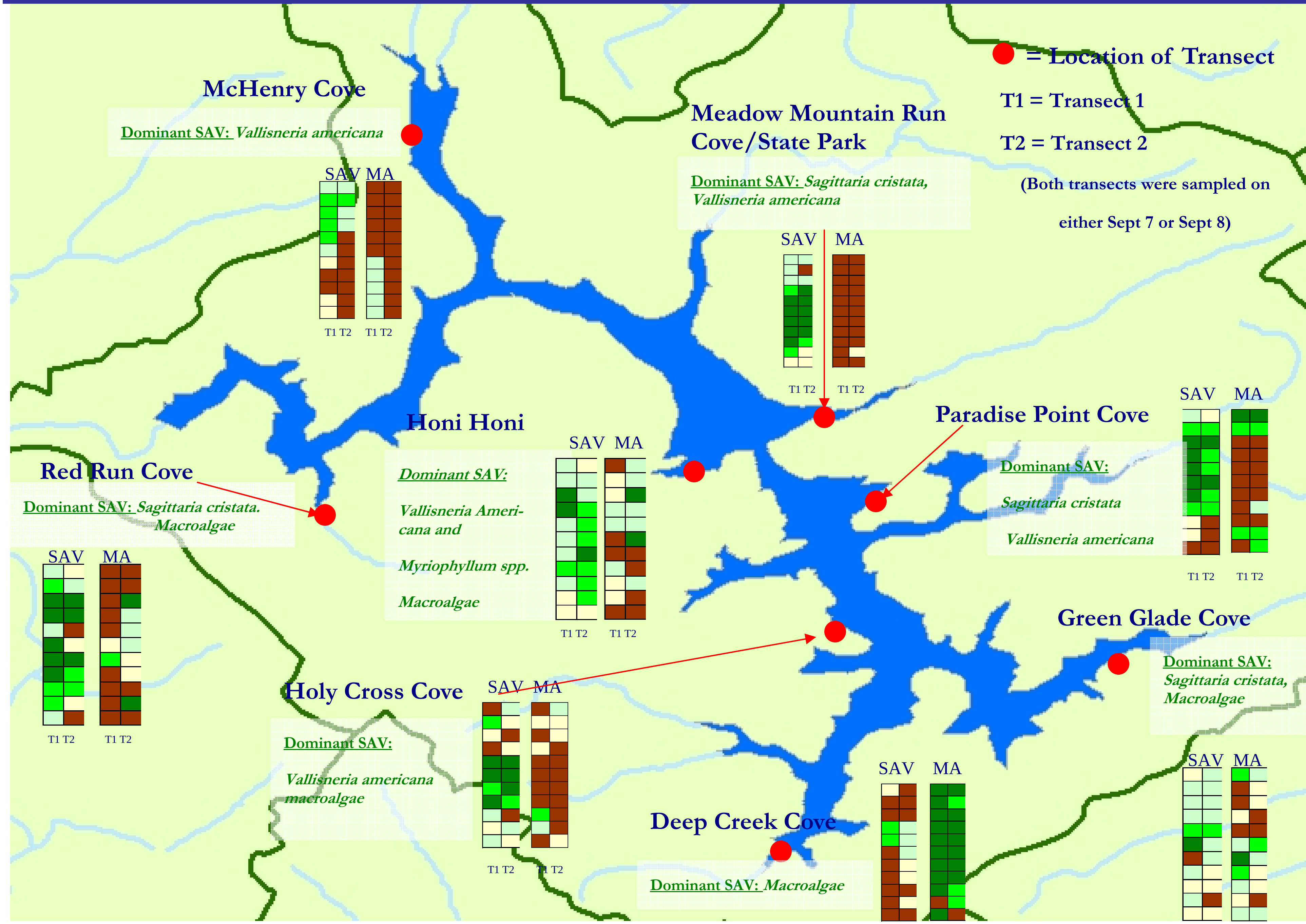
Deep Creek Lake, MD 2014



Deep Creek Lake, MD 2015



Deep Creek Lake, MD 2016



Appendix F: Potamogeton crispus

# of beds	GPS #	# of plants or bed size	water depth	GPS North Coordinate	GPS West Coordinate	date documented
1	8	2	0.75	39.28.09.0	79.19.09.7	8/14/2015
2	19	8	0.75	39.28.08.7	79.19.10.0	8/14/2015
3	21	9	0.85	39.28.09.3	79.19.09.8	8/14/2015
4	22	12	0.37	39.28.09.5	79.19.13.4	8/14/2015
5	23	4	0.97	39.28.09.3	79.19.13.6	8/14/2015
6	24	4	0.88	39.28.09.8	79.19.09.0	8/14/2015
7	25	3	0.8	39.28.09.3	79.19.14.0	8/14/2015
8	26	3	0.61	39.28.09.2	79.19.13.6	8/14/2015
9	27	7	0.91	39.28.09.1	79.19.14.8	8/14/2015
10	309	2	0.87	39.28.08.7	79.19.12.9	8/7/2015
11	310	10+	1.05	39.28.09.4	79.19.11.9	8/7/2015
12	311	50+	0.6	39.28.09.3	79.19.13.4	8/7/2015
13	312	8	1	39.28.09.1	79.19.13.4	8/7/2015
14	313	15	1.05	39.28.08.7	79.19.06.3	8/7/2015
15	314	3	1.02	39.28.08.6	79.19.06.4	8/7/2015
16	315	10	0.96	39.28.08.8	79.19.07.0	8/7/2015
17	316	10	1	39.28.08.5	79.19.07.0	8/7/2015
18	317	21	0.98	39.28.09.0	79.19.07.6	8/7/2015
19	318	19	1.02	39.28.09.2	79.19.08.4	8/7/2015
20	319	8	0.98	39.28.09.3	79.19.08.9	8/7/2015
21	320	11	0.82	39.28.09.1	79.19.09.4	8/7/2015
22	321	15	0.85	39.28.08.9	79.19.09.2	8/7/2015
23	322	17	0.8	39.28.09.0	79.19.09.4	8/7/2015
24	323	6	0.8	39.28.08.8	79.19.09.6	8/7/2015
25	324	34	1.02	39.28.09.5	79.19.10.7	8/7/2015
26	325	6	0.93	39.28.09.4	79.19.10.6	8/7/2015
27	327	36	0.91	39.28.09.5	79.19.11.1	8/7/2015
28	328	2m^2	0.97	39.28.09.5	79.19.10.9	8/7/2015
29	329	13	0.94	39.28.09.4	79.19.14.1	8/7/2015
30	330	56	0.67	39.28.09.7	79.19.14.1	8/7/2015
31	331	9	0.93	39.28.09.4	79.19.14.2	8/7/2015
32	332	5	0.82	39.28.09.8	79.19.14.6	8/7/2015
33	333	0.75m^2	0.8	39.28.09.5	79.19.14.5	8/7/2015
34	334	0.5m^2	0.9	39.28.09.2	79.19.13.6	8/7/2015
35	335	4.0m^2	0.96	39.28.09.4	79.19.14.2	8/7/2015
36	336	0.25m^2	0.95	39.28.09.3	79.19.14.1	8/7/2015
unknown	326	data lost	data lost	39.28.09.5	79.19.10.6	8/7/2015

**GPS #326 is believed to be a P. crispus bed but data was lost so it is not included

Results of the 2016 (August 8th and 9th mapping effort) of *P. crispus* in Pawn Run Cove

# of beds	GPS #	Estimated bed size (meters)	water depth	GPS N	GPS W	date mapped
1	931	0.50	na	39.469197	-79.3202363	8/8/2016
2	932	0.25	na	39.46918116	-79.3202461	8/8/2016
3	933	0.50	na	39.46918468	-79.3202461	8/8/2016
4	934	0.25	na	39.46893021	-79.31941998	8/8/2016
5	935	0.25	na	39.46896742	-79.31924488	8/8/2016
6	936	0.25	na	39.46896977	-79.31922477	8/8/2016
7	937	0.25	na	39.46892635	-79.31895328	8/8/2016
8	938	0.25	na	39.4689256	-79.31893392	8/8/2016
9	939	0.50	na	39.46892157	-79.31886317	8/8/2016
10	940	0.25	na	39.46919558	-79.31844852	8/8/2016
11	941	0.25	na	39.469297	-79.31920272	8/8/2016
12	942	0.25	na	39.46929767	-79.3193199	8/8/2016
13	943	0.25	na	39.46930328	-79.31933097	8/8/2016
14	944	1m2	na	39.46930664	-79.31933491	8/8/2016
15	945	4m2	na	39.4693094	-79.31937154	8/8/2016
16	946	1m2	na	39.46931745	-79.31938076	8/8/2016
17	947	0.50	na	39.46930789	-79.31942719	8/8/2016
18	948	3m2	na	39.46930957	-79.31944312	8/8/2016
19	949	0.50	na	39.4689924	-79.31912754	8/8/2016
20	950	0.25	na	39.46913238	-79.31929995	8/8/2016
21	951	2m2	na	39.46918988	-79.31932367	8/8/2016
22	952	2m2	na	39.46919507	-79.31928093	8/8/2016
23	953	2m2	na	39.46925324	-79.31936785	8/8/2016
24	954	0.50	na	39.46929214	-79.3195732	8/8/2016
25	955	?	na	39.46929021	-79.31956885	8/8/2016
26	956	1.5m2	na	39.46928686	-79.31957287	8/8/2016
27	957	1m2	na	39.46925869	-79.31958552	8/8/2016
28	958	2.25m2	na	39.46926464	-79.31958636	8/8/2016
29	959	3m2	na	39.4692949	-79.31958268	8/8/2016
30	960	0.50	na	39.46931418	-79.31961478	8/8/2016
31	774	1.5m2	na	39.48566199	-79.27723613	8/8/2016
32	775	5m2	na	39.48566199	-79.27723613	8/8/2016
33	776	1m2	na	39.46922885	-79.31974621	8/8/2016
34	777	1.5m2	na	39.4692032	-79.31970136	8/8/2016
35	778	3m2	na	39.46919072	-79.31969189	8/8/2016
36	779	3m2	na	39.46924855	-79.31973011	8/8/2016
37	780	1m2	na	39.46929893	-79.31975962	8/8/2016
38	781	0.50	na	39.46931795	-79.31986749	8/8/2016
39	782	1.5m2	na	39.46919574	-79.31984939	8/8/2016

# of beds	GPS #	Estimated bed size (meters)	water depth	GPS N	GPS W	date mapped
40	783	2m2	na	39.46924201	-79.31979918	8/8/2016
41	784	1m2	na	39.46924193	-79.31972936	8/8/2016
42	785	1m2	na	39.46923154	-79.31974445	8/8/2016
43	786	1m2	na	39.46921771	-79.31960246	8/8/2016
44	787	1.5m2	na	39.46926003	-79.31982961	8/8/2016
45	788	1.5m2	na	39.46929859	-79.31981142	8/8/2016
46	789	1m2	na	39.46922793	-79.31992306	8/8/2016
47	790	1m2	na	39.4693058	-79.31990739	8/8/2016
48	791	1.5m2	na	39.46928241	-79.31995885	8/8/2016
49	792	1m2	na	39.46932768	-79.32006438	8/8/2016
50	793	1m2	na	39.46932885	-79.32021174	8/8/2016
51	794	0.50	na	39.46931753	-79.32018617	8/8/2016
52	795	1.5m2	na	39.46933053	-79.32018718	8/8/2016
53	796	0.50	na	39.4693498	-79.32012691	8/8/2016
54	797	1m2	na	39.46924461	-79.32005365	8/8/2016
55	798	0.25	na	39.46919541	-79.32019925	8/8/2016
56	799	0.50	na	39.46920631	-79.32016882	8/8/2016
57	800	1.0m	na	39.46915216	-79.32039714	8/9/2016
58	801	1m2	na	39.46917362	-79.32043067	8/9/2016
59	802	2m2	na	39.46923304	-79.32041391	8/9/2016
60	803	0.5m	na	39.46923573	-79.32048733	8/9/2016
61	804	0.25m	na	39.46918585	-79.32053067	8/9/2016
62	805	3m2	na	39.46918594	-79.32052631	8/9/2016
63	806	20m2	na	39.46920446	-79.32053033	8/9/2016
63	807	20m2	na	39.46922097	-79.32053452	8/9/2016
63	808	20m2	na	39.4692426	-79.32055187	8/9/2016
63	809	20m2	na	39.46928317	-79.32056713	8/9/2016
63	810	20m2	na	39.46927453	-79.32054617	8/9/2016
64	811	5m2	na	39.46924235	-79.32060745	8/9/2016
65	812	3m2	na	39.46925785	-79.32056788	8/9/2016
66	813	2m2	na	39.46931175	-79.32064625	8/9/2016
67	814	0.5m	na	39.4692996	-79.32062832	8/9/2016
68	815	0.5m	na	39.46930965	-79.32064525	8/9/2016
69	816	0.5m	na	39.4692939	-79.32066402	8/9/2016
70	817	1m2	na	39.46928795	-79.32063192	8/9/2016
71	818	0.5m	na	39.46931904	-79.32063854	8/9/2016
72	819	0.5m	na	39.46933086	-79.32067869	8/9/2016
73	820	0.5m	na	39.469326	-79.32073326	8/9/2016
74	821	0.25m	na	39.46928443	-79.32071574	8/9/2016

# of beds	GPS #	Estimated bed size (meters)	water depth	GPS N	GPS W	date mapped
75	822	0.5m	na	39.46928225	-79.32069244	8/9/2016
76	823	0.5m	na	39.46929297	-79.3206403	8/9/2016
77	824	0.5m	na	39.46930228	-79.3206419	8/9/2016
78	825	5m2	na	39.46932877	-79.32071247	8/9/2016
79	826	5m2	na	39.46939825	-79.32069889	8/9/2016
80	827	5m2	na	39.46944142	-79.32069034	8/9/2016
81	828	5m2	na	39.46939666	-79.32071306	8/9/2016
82	829	2m2	na	39.46939029	-79.32070023	8/9/2016
83	830	0.75m	na	39.46941133	-79.32070484	8/9/2016
84	831	1.5m2	na	39.46932801	-79.32025147	8/9/2016
85	832	0.50	na	39.46934603	-79.3202254	8/9/2016
86	833	0.25	na	39.46930152	-79.32020964	8/9/2016
87	834	1m2	na	39.46930337	-79.3202259	8/9/2016
88	835	0.5m	na	39.46930781	-79.32023051	8/9/2016
89	836	0.50	na	39.4692576	-79.32019338	8/9/2016
90	837	0.25	na	39.46931267	-79.32016991	8/9/2016
91	838	0.25	na	39.46946682	-79.32044467	8/9/2016
92	839	0.25	na	39.4693835	-79.32019145	8/9/2016
93	840	0.25	na	39.46925693	-79.32018165	8/9/2016
94	841	0.50	na	39.46926942	-79.32016689	8/9/2016
95	842	0.25	na	39.46925006	-79.32019891	8/9/2016
96	843	0.25	na	39.46922994	-79.32029539	8/9/2016
97	844	0.25	na	39.46924176	-79.32029598	8/9/2016

At time of mapping (Aug 8 and 9, 2016; less than 1/2 the beds seen earlier in the year were still present

APPENDIX D

Deep Creek Lake

Hydrilla Management Plan and Report of Control Activity

2015

Prepared by Mark Lewandowski

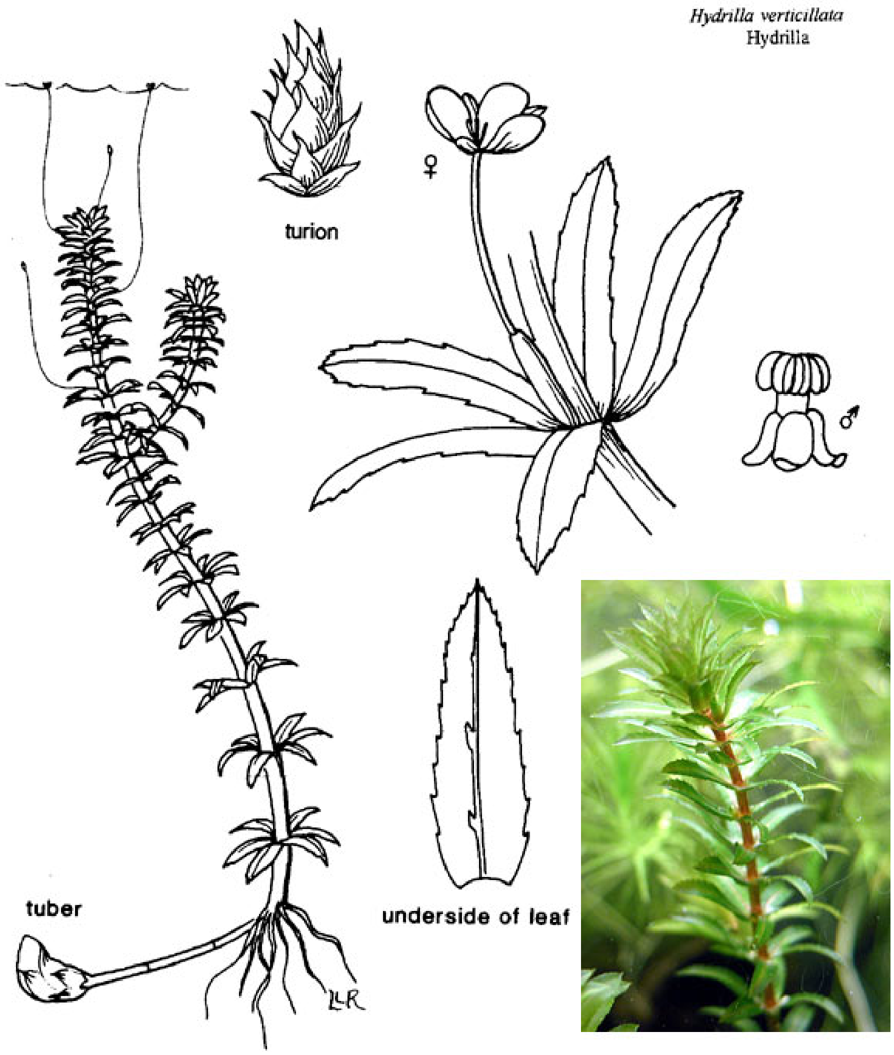


illustration provided by:
IFAS, Center for Aquatic Plants
University of Florida, Gainesville, 1990

Background

Hydrilla verticillata is a listed noxious weed (Federal Noxious Weed Act -- Public Law 93-629 (7 U.S.C. 2801 et seq.; 88 Stat. 2148). A noxious weed is defined as any plant designated by a Federal, State, or county government as injurious to public health, agriculture, recreation, wildlife or property. *Hydrilla* is a rooted submersed perennial monocot, native to Asia (Haller, 2009). There is only one species of *Hydrilla* identified, but two biotypes have invaded the United States. The dioecious biotype (separate male and female plants) is found south of Virginia and was introduced in the 1950s. The monoecious biotype (male and female reproductive structures on the same plant), found in North Carolina and above, was introduced in the 1970s. North Carolina is the only known state where the two biotypes overlap in range.

Hydrilla is infamous for its rapid growth (up to 1" per day) and ability to "top out" and form dense mats of vegetation at the water surface. *Hydrilla* thrives in lower light and deeper conditions than native plants, and the dense mats it forms can shade out native species of submerged aquatic vegetation (SAV). *Hydrilla* can spread rapidly via fragmentation and it has a very effective overwintering strategy (prolific tuber production). Due to how densely it grows, *Hydrilla* can not only alter ecosystem functions in a body of water, but also make navigation and recreation difficult. There are economic concerns as well. Aside from the cost of management and control (for example, Florida spends approximately $15 million per year on *Hydrilla* control (Haller, 2009)), there is also the potential for lowered waterfront property values due to the reduced recreational opportunities and unsightly nature of a "topped out" *Hydrilla* bed. Water-dependent industries, such as tourism, hydroelectric power, and businesses dependent on water withdrawal, are also affected.

During routine SAV transect monitoring on September 27th, 2013, a Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologist observed floating fragments of *Hydrilla verticillata* in Deep Creek Lake (DCL), Garrett County, Maryland. While *Hydrilla* is common in other waters in Maryland, this was the first reported sighting in DCL by DNR staff. The State of Maryland *Rapid Response Planning for Aquatic Invasive Species* plan (Figure 1) was immediately initiated. A survey of the entire lake shoreline was undertaken over the course of several days and finished on October 22nd, 2013. During the survey, *Hydrilla* was found and mapped in 14 locations; all contained in the southwestern leg of the lake, known locally as Deep Creek Cove (Figure 2). Patches ranged in size from 1m^2 to roughly 5 acres, totaling an estimated 6.5 acres. Specimen samples were collected and taken to an outside expert (Nancy Rybicki, USGS) for positive identification and determination of the biotype (monoecious).

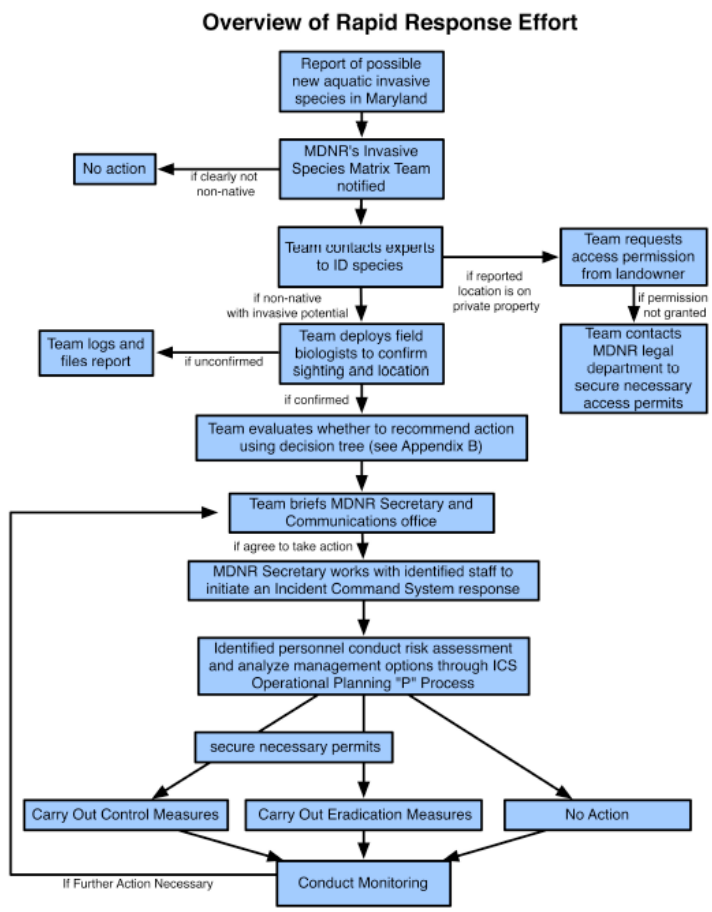


Figure 1. Diagram of the *Rapid Response Planning for Aquatic Invasive Species*

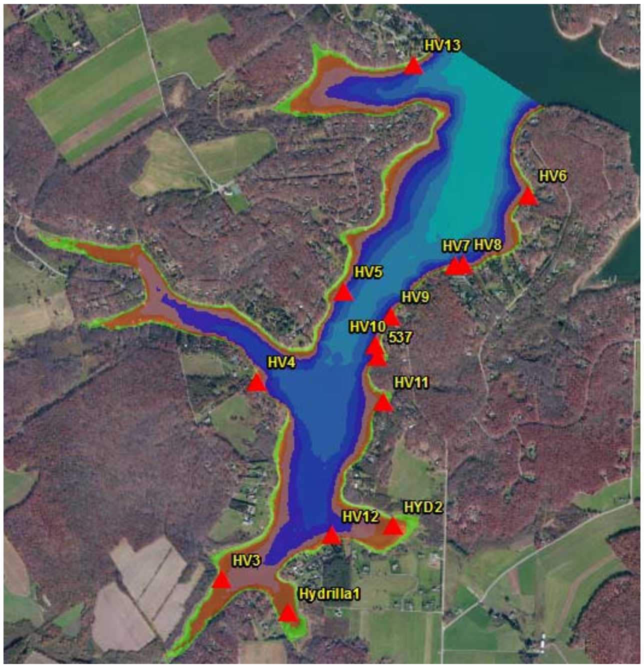


Figure 2. *Hydrilla* patches identified by DNR biologists, October 2013.

In response to this discovery, RAS biologists commenced a thorough literature review of *Hydrilla* biology and management/control options and convened an expert panel (Table 1) to aid in development of the Deep Creek Lake *Hydrilla* Management Plan. In consultation with lake management, the defined goal of the management plan was to contain *Hydrilla* populations, reduce the standing biomass as low as is technically and financially feasible, and prevent *Hydrilla* from becoming a nuisance in the lake. Several management techniques were considered, including several forms of mechanical/physical control, biological control, and chemical control. Ultimately it was determined that chemical control using selective herbicides that have minimal impact to other SAV and/or aquatic resources offered the greatest chance of success.

Table 1. List of expert panel members and affiliations

Name	Affiliation
Dr. Mike Netherland	University of Florida/US Army Corps of Engineers
Dr. Lynn Gettys	University of Florida
Dr. John Madsen	Mississippi State University
Mr. James Balyszak	Cornell University Extension
Dr. Nancy Rybicki	United States Geological Survey
Mr. Mark Lewandowski	Maryland Department of Natural Resources
Dr. Robert Richardson	North Carolina State University

Herbicidae control is the most common form of nuisance aquatic plant management to reduce or eliminate populations. Herbicides approved for aquatic use are some of the most intensively studied production chemicals and have undergone extensive review before being registered by the United States Environmental Protection Agency as an aquatic herbicide. Additionally, the use of herbicides in aquatic systems has a long history of research and proven results.

For the purposes of managing *Hydrilla* in Deep Creek Lake, it was determined that a two-pronged herbicide application approach would be used. The first step, a "block treatment," was designed to treat large volumes of the infested cove with a systemic herbicide as soon as *Hydrilla* emerged from its overwintering tubers in the spring. Systemic herbicides are compounds that are taken up by the plant and then move throughout the plant's tissues, killing it and preventing spring establishment (Netherland, 2009). Several months following the block treatment, the second step, a "spot treatment," would then be implemented. Spot treatments address any *Hydrilla* patches that survive the systemic herbicides. Surviving patches would be dosed with contact herbicides which only affect plant tissues in direct contact with the compound (Netherland, 2009).

The consensus of the expert panel was to use a formulation of fluridone for the systemic block treatments (http://ccetompkins.org/environment/invasive-species/fluridone-herbide-treatment-faq), and diquat and flumioxazin for the spot treatments. *Hydrilla* is very susceptible to fluridone at low concentrations (5-10 ppb), while native plants are less so. The disadvantage is that a long contact time (45 days) is necessary for adequate control; consequently "bump" applications are needed to keep concentrations at the required level. With that, however, the plants die and decompose slowly, reducing the risk of dissolved oxygen sags that might cause fish kills.

Diquat (trade name Reward™) is a non-volatile contact herbicide that rapidly controls aquatic weeds by interfering with photosynthesis (Reward™ Herbicide label, 2010). Flumioxazin (Trade name Clipper™) is a broad spectrum herbicide that also controls aquatic weeds by interfering with photosynthesis by inhibiting protoporphyrinogen oxidase, an essential enzyme required by plants for chlorophyll biosynthesis. Clipper™ is fast acting, can be applied subsurface and is most effective when applied to young, emergent plants (Clipper™ label, 2011).

<ins>Education and Outreach Prior to Treatment</ins>

While controlling the existing biomass and preventing the in-lake spread of *Hydrilla* was of primary concern, it was equally important to prevent further invasion. The expert panel together with RAS biologists and managers came to the consensus that investment of resources was best spent on simple vessel cleaning stations, outreach staff ("Launch Stewards"), and educational materials. An extensive campaign to educate stakeholders on the risks associated with invasive species introductions and what they could do to minimize spread of these species was consequently implemented. Prior to the spring 2014 treatment, DNR provided all of the affected residents with information about the *Hydrilla* infestation in Deep Creek Cove, instructions for closures and water use, and literature regarding the herbicides. Signs were posted at all lake launches to educate boaters on the proper way to clean their vessels to avoid invasive species introductions. The Maryland Park Service (MPS) hired seasonal Launch Stewards to conduct voluntary vessel inspections at the State Park boat launch and provide educational materials to boaters. The DNR Communications Office developed an instructional video on how to properly clean your vessel and avoid aquatic introductions, which was posted on DNR's website and linked to The Friends of DCL website.

While conducting vessel inspections, the Launch Stewards recorded any SAV found as well as data regarding the type of boat entering the lake, the state where it was registered, where the vessel had last been launched and where it was most commonly used. In 2014, two launch stewards inspected 1,066 vessels between June 3rd and September 23rd. Of the boats inspected, only 23 vessels (2.2%) were carrying potential AIS. The vegetation was mostly found on the hull, trailer bunks, and propellers. There was no correlation between the presence of vegetation and the type of vessel and the most common SAV species found were wild celery (*Vallisneria americana*) and several types of pondweeds (*Potamogeton*). In 2015, five stewards worked the launch between 6:00 AM to 7:00 PM, working seven days a week between Memorial Day and Labor Day. With an increase in coverage, the 2015 steward program inspected 2,256 vessels, with 41(1.8%) found to have vegetation on them. Again, there was no correlation between presence of vegetation and vessel type and all of the species found were native to MD. Most of these vessels use Deep Creek Lake and other local lakes and rivers in Maryland, Pennsylvania, and West Virginia, but some were from as far away as Utah, Florida, and Connecticut. This highlights how simple it is to transport invasive species over state lines and introduce them to new ecosystems if precautions aren't taken.

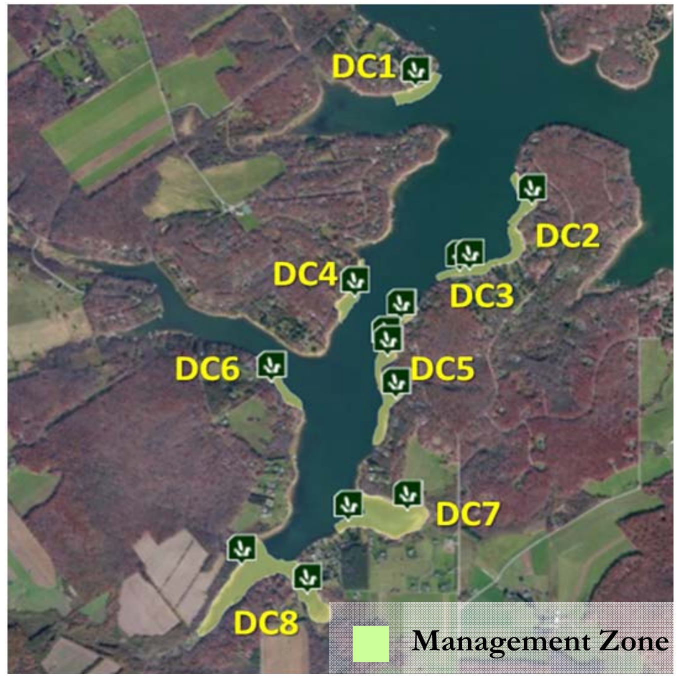


Figure 3. 2014 *Hydrilla* management zones.

Preliminary Study

To determine lake energy and water flow characteristics in DCL prior to treatment, a hydrological tracer study was conducted between April 28th and May 3rd, 2014. Rhodamine WT dye pellets were used to most closely mimic the pelletized Sonar® that would be used during *Hydrilla* control. Rhodamine pellets were placed in two coves in the southwestern leg of the lake and monitored for dissolution over the course of four days. It was determined that DCL is a very low energy environment with predominantly wind-driven water flow and particularly long residence times in the coves.

2014 Results

The fourteen *Hydrilla* patches observed in 2013 were divided into eight management zones that ranged in size from five to 29 acres (total of 93.5 acres) (Figure 3). Because of the long residence time in the coves where *Hydrilla* was observed, it was determined that five low-dose Sonar® applications would be necessary to maintain adequate concentrations throughout the SAV growing season. Herbicide application took place within each management zone every three weeks between June and September (June 11th, July 1st, July 21st, August 13th and September 3rd). This approach controlled for any late-germinating tubers and prevented any additional tuber development during the 2014 season. FasTEST® samples for herbicide monitoring were collected on a weekly or biweekly basis to document and adjust dosage if necessary.

Routine surveys of each management zone were conducted on a monthly basis to confirm Sonar® efficacy and monitor conditions. Starting in July, when SAV in DCL is nearing its peak biomass, broader scouting was conducted to detect possible new areas of infestation. Four new patches were detected: two in early August while scouting and two in mid-September during the comprehensive shoreline survey. One of these patches was in the previously infested Deep Creek Cove. The other three patches were found in Green Glade Cove, the southeastern leg of the lake (Figure 4). Licensed applicators from DNR Fisheries Service treated these patches with the contact herbicides Reward® and Clipper®.

At the conclusion of the 2014 summer season, no *Hydrilla* was observed in any of the management zones. Some *Hydrilla* plant material was still observed, however, in the four newer infestation areas due to the short window for successful treatment. These areas were included in the management plan for 2015, with positive control of these areas expected.

2015 Results

The DNR Resource Assessment Service built on the success of the 2014 Management Plan and continue with the herbicidal treatment of *Hydrilla* in DCL in 2015. RAS implemented a similar strategy using multiple Sonar® pellet applications. Four new management zones were delineated to include the four new *Hydrilla* patches, and modifications were made to the current zones, for a total of 12 management zones covering 104 acres. Treatment began as soon as DNR divers observed *Hydrilla* emerging in most of the treatment areas. Treatments took place on June 10th, July 1st, July 27th, August 31st. Adjusting the formulations of Sonar® kept the dosage rate in the necessary range for the treatment period and allowed for one fewer treatment. No *Hydrilla* was observed in any of the treatment areas throughout the summer. One patch was observed outside the treatment zone, in an arm of Green Glade Cove.

Outreach and education efforts previously outlined continued in 2015. Additionally, local boat rental businesses will be more involved in outreach and education efforts in the future. DNR will continue with voluntary vessel inspections at the State Park boat launch and collect data from boaters regarding lake use and point of origin. The DNR Park Service's partnership with Garrett Community College for the 2015 provided 5 students to act as launch stewards. They collected valuable data to build on the 2014 effort, and will likely continue to act as DNR's primary means of AIS outreach at Deep Creek Lake.

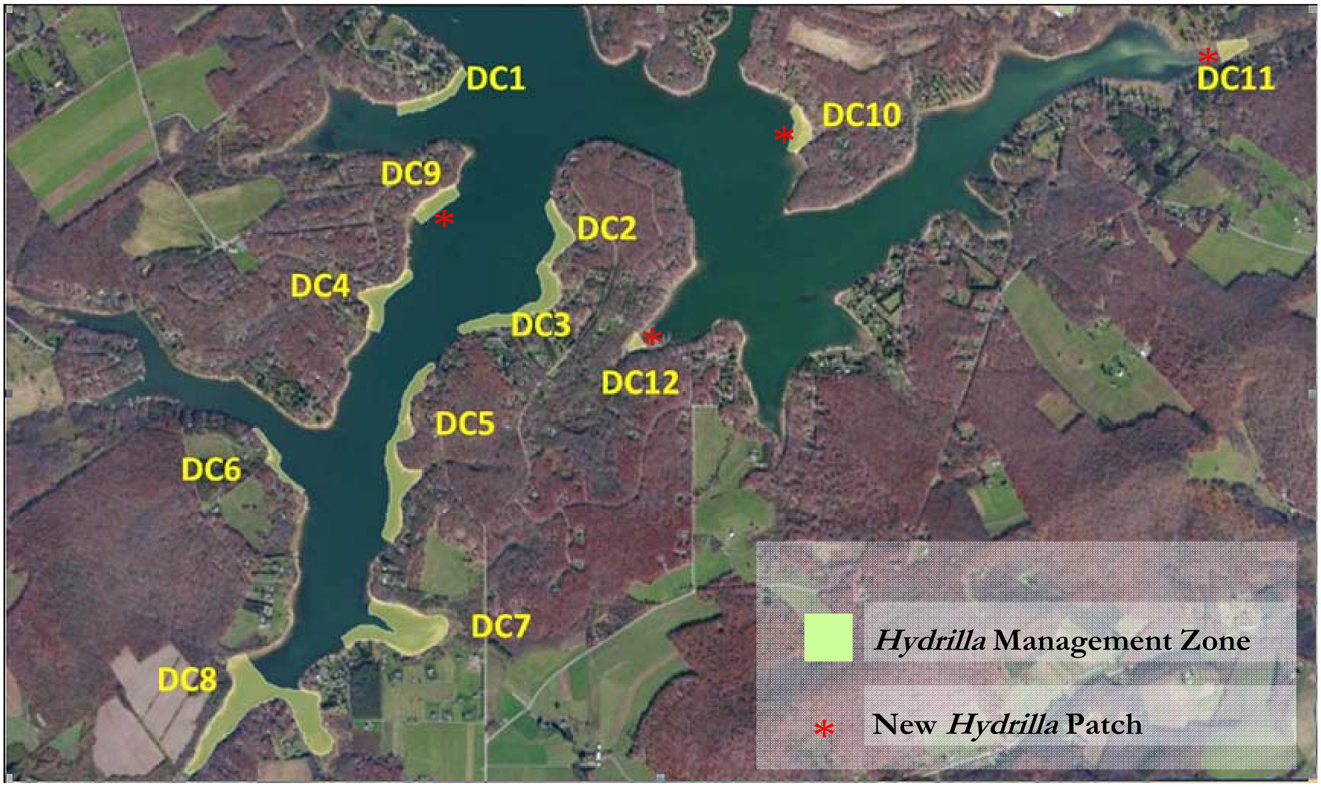


Figure 4. 2015 *Hydrilla* management zones and *Hydrilla* patches discovered in August and September, 2014.

<u>2016 Projections</u>

DNR has a contract in place for the 2016 treatment and will continue its *Hydrilla* control strategy in the future. The new infestation will be added to the current treatment areas, and will be monitored throughout the summer.

The management of *Hydrilla* in Deep Creek Lake will require a prolonged multi-faceted approach, and will require a significant investment in time, money and effort to be successful. It is a reasonable expectation that control efforts will be underway for many years. However, the *Hydrilla* invasion is still fairly recent. Now is an excellent opportunity to manage this potential threat to the Lake's ecosystem and the region's economy.

References

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Netherland, M.D. 2009. Chapter 11, "Chemical Control of Aquatic Weeds." Pp. 65-77 in Biology and Control of Aquatic Plants: A Best Management Handbook, L.A. Gettys, W.T. Haller, & M. Bellaud (eds.) Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pp