Resource Assessment Service

Deep Creek Lake

Submerged Aquatic Vegetation Survey

2014

Report of Survey Activity and Results

Prepared For

Maryland Department of Natural Resources

Maryland Park Service

Prepared by

J. Brooke Landry, Lee Karrh, Rebecca Golden, and Mark Lewandowski

Maryland Department of Natural Resources

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EXECUTIVE SUMMARY

Submerged aquatic vegetation 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 produce 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) and *Hydrilla verticillata* (Water thyme).

During the summer 2014 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a fifth 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 transect monitoring plan in summer 2010 and has 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 Eurasian watermilfoil, 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*. *Hydrilla* is an invasive plant that was discovered in the southern portion of the lake in September 2013. Following the discovery of *Hydrilla*, a management and control plan was designed and successfully implemented during the 2014 summer season.

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 *Myriophyllum* and *Hydrilla* via the shoreline survey. This work is a component of the comprehensive water quality and habitat monitoring program in DCL which began in April 2009. Major findings are as follows:

The majority of observed species showed no significant change in density or distribution from 2010 to 2014, but total SAV decreased significantly at three of the six transect sites, all of which were in the middle and southern portion of the lake.

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 (nineteen species) and two genera of macroalgae have been observed on the transects and during the shoreline surveys.

Sagittaria cristata, (Crested arrowhead), *Vallisneria americana,* (Wild celery), and *Myriophyllum spp.,* (Watermilfoil) were dominant vascular species observed throughout the lake in 2014. Macroalgae was also dominant in several areas.

Species zonation is apparent at every site with *Sagittaria cristata* dominating the shallows; *Potamogeton spp.,* and *Vallisneria americana* most common in the mid depths; and *Myriophyllum spp*., and macroalgae most commonly observed at greater depths.

The distribution and abundance of all SAV species differ primarily by site, with significant annual changes occurring rarely.

Potamogeton amplifolius and *Potamogeton robinssii* have been documented in DCL. Both of these species are considered legally endangered in Maryland and were thought to be extirpated from Maryland waters.

Based on the six study areas under this assessment, there is no evidence that *Myriophyllum* density increased significantly from 2010 to 2014, but frequency of occurrence did increase significantly in Green Glade Cove.

Though not identified to the species level during the transect surveys, *Myriophyllum spicatum*, or Eurasian Watermilfoil, is present in DCL. This plant is considered an Aquatic Invasive Species. Invasive species are non-native plants or animals that adversely affect the habitats they invade economically and/or ecologically. They disrupt by dominating a region and oftentimes displacing native populations. Over the past 300 years, approximately 50,000 non-native species have become established in the United States; 200 introduced species have viable, wild populations in the Chesapeake Bay watershed.

DNR biologists conducted a third *Myriophyllum* survey in September 2014 during the plant's peak biomass. Results of the survey indicate that *Myriophyllum* was more frequently occurring in September 2014 than in June 2013. *Myriophyllum* was present at 214 locations throughout the Lake at the time of the 2014 survey, and occupied approximately 4% (60 acres) of available benthic habitat, compared to 2% (29 acres) in 2013. This is most likely due to the time of season the survey was conducted and not to an actual expansion of *Myriophyllum* in the lake.

During the September 2013 transect survey, the invasive aquatic plant *Hydrilla verticillata* was discovered in Deep Creek Cove. In response, an additional comprehensive shoreline survey was completed on October 21, 2013. The results of the survey indicated that *Hydrilla* was growing in 14 locations at varying densities, but those 14 sites were contained within the southwest leg of the lake. A panel of experts from around the country was assembled to advise MD DNR in the creation of a Deep Creek Lake specific *Hydrilla* Management Plan. The resulting plan was successfully implemented during the summer 2014 season with no living *Hydrilla* observed in any of the management zones at the end of the growing season. Additional patches of *Hydrilla* identified throughout the summer were independently treated and will be included in 2015 *Hydrilla* control activity.

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

Like most any ecosystem, 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.

INTRODUCTION

During the summer 2014 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a fifth 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 transect monitoring plan in summer 2010 and has 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 Eurasian Watermilfoil, 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*. *Hydrilla* is an invasive plant that was discovered in September 2013 during routine transect monitoring. Following the discovery of *Hydrilla*, a management and control plan was designed and successfully implemented during the 2014 summer season. Appendix D describes the management plan and results.

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 identify the location and extent of *Myriophyllum* and *Hydrilla* via the shoreline survey. This work is a component of the comprehensive water quality and habitat monitoring program in DCL which began in April 2009.

<u>Background</u>

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.

With a surface area of 3,900 acres and 68 miles of shoreline, DCL is Maryland's largest reservoir. 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 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).

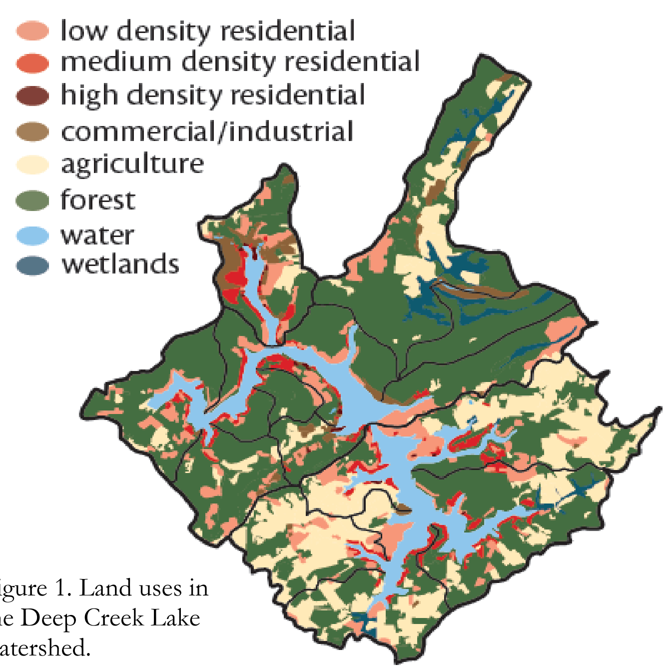

Figure 1. Land uses in the Deep Creek Lake watershed.

Beginning in late spring when temperatures increase, SAV begin 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, SAV are underwater grasses which provide a myriad of important ecological functions. Through the process of photosynthesis, SAV produce oxygen that is vital to the survival of other lake organisms. They provide food, habitat, and nursery grounds for many species of fish and invertebrates, as well as waterfowl. They absorb nutrients, which in turn decreases the likelihood of algal blooms, and they improve water clarity by locking sediments in their root systems. SAV also diminish 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 invasive plants like Eurasian watermilfoil (*Myriophyllum spicatum*) and *Hydrilla verticillata*, both of which are found in Deep Creek Lake.

There are approximately 70 species of *Myriophyllum* (watermilfoil): 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". *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, is one of three species of *Myriophyllum* found in Deep Creek Lake, but it is the only invasive variety.

The genus *Hydrilla*, on the other hand, has a single species, *H. verticillata*, which is considered an exotic invasive 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 canadensis*, which is found throughout Deep Creek Lake.

METHODS

In June 2010, RAS biologists, accompanied by local SAV experts from Frostburg State University, identified six representative areas to survey in Deep Creek Lake. These areas were selected based on spatial distribution (two north/western, two central, and two south/eastern) and the presence of SAV. These locations are as follows: Red Run Cove (-79.3711, 39.49977), an area near the town of McHenry (-79.35787, 39.55087), an area near the Honi Honi Bar and Restaurant (-79.32091, 39.50485), Meadow Mountain Run Cove (-79.30334, 39.51182), Deep Creek Cove (-79.30904, 39.45368), and Green Glade Cove (-79.26206, 39.47844). See Figure 2 for a map of locations and Table 1 for a list of site abbreviations.

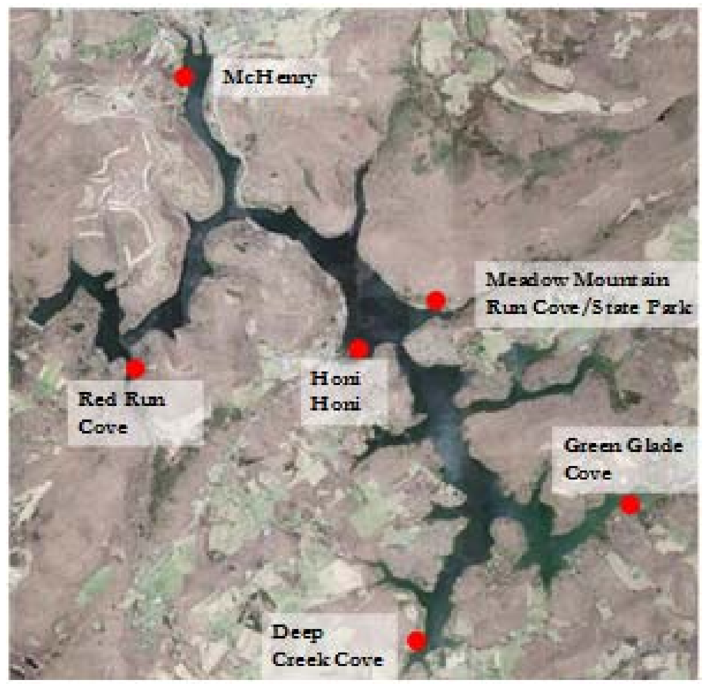

Figure 2. Aerial map of Deep Creek Lake with MD DNR SAV transect locations indicated by red dots.

Table 1. Transect names and abbreviations.

Site	Abbreviation
Red Run Cove	RRC
McHenry	McH
Honi Honi	HHO
Meadow Mountain Run	MMR
Deep Creek Cove	DCC
Green Glade Cove	GGC

At the time each transect 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 recorded 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.

During each sampling event, SAV biologists sampled eleven 0.25m² 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 non-vascular 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 on August 5th and September 16th, 2010, on June 14th, August 9th and September 12th, 2011, on June 27th, August 22nd, and September 19th, 2012, on June 20th, August 15th, and September 27th, 2013, and on June 30th, August 12th, and September 17th, 2014.

Following the discovery of *Hydrilla* in the south western leg of the lake in September 2013, an expert panel was assembled and determined that herbicide application would be the most prudent means of control possible. The experts agreed that the most effective control method was to seek eradication of *Hydrilla*. The 14 infested areas were divided into eight management zones ranging from 5 to 29 acres in size, for a total of 93.5 acres. RAS biologists confirmed initial *Hydrilla* emergence in late May and began herbicide treatment in June. Treatment efficacy and water quality monitoring continued through September.

A comprehensive shoreline survey was conducted on September 15th and 16th, 2014, in order to observe *Myriophyllum's* spatial extent during its peak biomass and to locate any possible new *Hydrilla* infestations. The survey was conducted of the entire 68-mile shoreline over a two-day period using three boats. Each boat was equipped with a driver and one to two on-board "observers", as well as Lowrance HDS echo-sounders (with side and down-scan functionality) and hand-held Garmin GPS units. 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 *Myriophyllum* and *Hydrilla* patches. Although there are three species of *Myriophyllum* 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.

<u>Data Analysis</u>

Raw transect data were entered into a Microsoft Excel spreadsheet. Using color-blocking, total SAV and total macroalgae data were used to create color-coded representations of the transects which were geographically overlaid onto a map of Deep Creek Lake.

Species richness was defined for each transect and sampling event as the number of species observed per transect. 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 where observed /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% or 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, a species/genus had to be found dominant during two of the three sampling events.

To graphically display observed changes in total SAV and total macroalgae over time, density data bar charts were created in Sigma Plot 12.0 (Systat, Inc., San Jose, CA) To show observed changes in *Myriophyllum* specifically, frequency of occurrence and density data graphs were also created in Sigma Plot graphing software. Bar graphs were created to show change in *Myriophyllum* density while point/line graphs were created and overlaid on density graphs to simultaneously show changes in frequency of occurrence over time.

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 and Species richness and diversity, total SAV density and total macroalgae density were compared over time and among sites using 3-Way ANOVAs with site, sampling year and quadrat (nested in site) as treatments. Individual species density and frequency of occurrence were also assessed in order to determine differences over space and time using 3-Way ANOVAs. Homogeneity of variances was assessed using Levene's test. Following a significant ANOVA ($p \leq .05$), pairwise comparisons were performed using Bonferroni's test.

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). To determine the spatial extent of *Myriophyllum*, coordinates taken at the center of each bed or patch were assigned area values based on GPS points and field observations and were merged to create a lakewide map of *Myriophyllum*. Coordinates were also recorded for each *Hydrilla* patch observed and then transferred into ArcGIS for mapping and analysis.

RESULTS

We observed ten genera of vascular aquatic plants and two species of macroalgae during our 2010 - 2014 SAV surveys. These plants include *Vallisneria americana, Sagittaria cristata, Elodea canadensis*, *Myriophyllum spp.* (including the native *M. sibiricum,* the native *M. heterophyllum,* and *M. spicatum,* or Eurasian watermilfoil, an Aquatic Invasive Species in North America), *Ceratophyllum demersum*, *Najas flexilis*, *Najas guadalupensis*, *Utricularia vulgaris*, *Isoetes spp*., and five species of *Potamogeton*, including *Potamogeton robbinsii* and *P. amplifolius*, both species legally classified as endangered and thought to be extirpated from Maryland waters, *P. pusillus, P. vaseyii, P. spirillus,* and *P. diversifolius*. *Potamogeton nodosus* was also observed in DCL, as was *Hydrilla verticillata*, but because they were not on any of the transects, they were not included in the transect data analyses. The two macroalgae observed include *Nitella flexilis* and *Chara vulgaris*. In 2013 sampling, it was determined that *Nitella* and *Chara* would no longer be differentiated during sampling due to physical similarity and difficulty in differentiation while SCUBA diving. Common names and abbreviations for these species can be found in Table 2. Pictures, line drawings, and a brief description of each species are given in Appendix A.

Due to the difficulty in accurately identifying *Myriophyllum* to the species level, particularly while

Table 2. List of SAV species/genera observed in Deep Creek Lake during summers 2010-2014 SAV surveys. Also given are the abbreviations used in this report and the plant's common name. Note: * indicates that the plant was observed in the Lake, but not on a transect, so was not included in any analyses.

Species	Abbreviation	Common name
Sagittaria cristata	Sc	Crested arrowhead
Vallisneria americana	Va	Wild celery
Elodea canadensis	Ec	Canadian waterweed
Ceratophyllum demersum	Cd	Coontail
Myriophyllum spp.	Myr	Watermilfoil
*Hydrilla verticillata**	Hv	*Hydrilla*
Najas flexilis	Nf	Slender/nodding naiad
Najas guadalupensis	Ng	Southern naiad
Utricularia vulgaris	Uv	Common bladderwort
Isoetes spp.	Iso	Quillwort
Potamogeton pusillus	Pp	Slender pondweed
Potamogeton robbinsii	Pr	Robbin's pondweed
Potamogeton vaseyi	Pv	Vasey's pondweed
Potamogeton spirillus	Ps	Spiral pondweed
Potamogeton diversifolius	Pd	Waterthread pondweed
Potamogeton amplifolius	Pa	Broad-leaved pondweed
*Potamogeton nodosus**	Pn	Longleaf pondweed
Chara vulgaris	Cv	*Chara*
Nitella flexilis	Nit	*Nitella*

diving, *Myriophyllum spp.* were only identified and recorded at the genus level for the SAV transect and shoreline surveys. Samples collected throughout the lake, stored, and examined for species level identification in the lab confirmed that *M. spicatum*, *M. sibiricum*, and *M. heterophyllum* were all present in DCL.

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. Figure 3 shows total SAV and total macroalgae density graphed over time for each transect, with corresponding trendlines showing overall increasing, decreasing, or no-change trends. Maps of Deep Creek Lake with color-coded total SAV and total macroalgae survey data, found in Appendix B, compliment the bar charts in Figure 3 but more clearly display the quadrat by quadrat relationship between SAV and macroalgae. In many cases, there was an inverse relationship between SAV and macroalgae; where SAV was dense, macroalgae was sparse, and vice versa. Figure 4 shows *Myriophyllum* density and frequency of occurrence graphed over time for each transect.

Most species that were observed were seen throughout the lake, but each site was dominated by only a few species. The survey results for the SAV bed in Red Run Cove (RRC) (transect length from 90-127m and max depth of 4.1m), in the northwestern portion of the lake near the dam, indicate that macroalgae and *E. canadensis* dominated this bed in 2010 (Table 4). In 2011, *E. canadensis* maintained dominance, but *S. cristata* replaced macroalgae. *Elodea canadensis* co-dominated with *Myriophyllum* and macroalgae in 2012 and in 2013, *Sagittaria cristata* also co-dominated at this site. By 2014, *S. cristata* and *E. canadensis* decreased in density and frequency, leaving macroalgae and *Myriophyllum* to dominate alone. Total SAV in RRC showed a decreasing though statistically insignificant trend from 2010-2014, despite early season spikes in density. There was also a statistically insignificant overall decrease in macroalgae

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)	Richness	Total SAV	MA	Sc	Va	Ec	Cd	Myr	Nf	Ng	Uv	Iso	Pp	Pr	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)
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	77	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)
8/5/10	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)
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)

Table 3. cont.

Date	ID	Length (m)	Richness	Total SAV	MA	Sc	Va	Ec	Cd	Myr	Nf	Ng	Uv	Iso	Pp	Pr	Pv	Ps	Pd	Pa
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)
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)

at this site between 2010 and 2014 (Figure 3). *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, as seen in Figure 4.

The SAV bed surveyed near McHenry (McH) (transect length from 30-100m and max depth of 5.4m), also in the northern portion of the lake but in the eastern arm, showed no true dominant in 2010, although *E. canadensis* dominated in August (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 again in 2014. Total SAV and total macroalgae showed opposite trends at this location, though neither was statistically significant (Figure 3). SAV increased between 2010 and 2014, while macroalgae decreased. *Myriophyllum* was only observed in trace amounts and low frequencies during five of the fourteen sampling events (Figure 4), and it did not change over time.

The SAV bed surveyed near the Honi Honi (HHO), on the western shore of the central 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, Myriophyllum,* and macroalgae in 2012. In 2013, there were two dominants*: S. cristata* and *Myriophyllum,* but by 2014, *Myriophyllum* was again the lone dominant species (Table 4). Total SAV and total macroalgae densities decreased significantly (P = 0.038 and 0.024, respectively) at this location between 2010 and 2014 (Figure 3). *Myriophyllum* was commonly observed at this transect, but it did not change significantly over time either in density or frequency of occurrence (Figure 4).

Across the lake from Honi Honi, the SAV bed surveyed

Table 4. Dominance by site and year, where dominance is 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 2010, a species/genus had to be found dominant during both sampling events that took place that year. For years 2011- 2014, in which three sampling events took place, a species/genus had to be found dominant during two of the three sampling events.

2010

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	8/5/10	Ec, Pp, Cv, MA	*Elodea canadensis*, Macroalgae
	9/16/10	Ec, Pv, MA	
McH	8/5/10	Ec	no dominant for year
	9/16/10	none	
HHO	8/5/10	Sc, Myr, MA	*Myriophyllum*
	9/16/10	Myr	
MMR	8/5/10	Sc, Va	*Sagittaria cristata*, *Vallisneria americana*
	9/16/10	Sc, Va	
DCC	8/5/10	Ec, Pp, MA	*Elodea canadensis*
	9/16/10	Ec, Cd	
GGC	8/5/10	Sc, Ec, MA	*Sagittaria cristata*, *Elodea canadensis*, Macroalgae
	9/16/10	Sc, Ec, Cv, MA	

2011

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/14/11	Ec, Pp, MA	*Sagittaria cristata*, *Elodea canadensis*
	8/9/11	Sc, Ec, Myr, Pv	
	9/12/11	Sc, Ec	
McH	6/14/11	MA	Macroalgae
	8/9/11	MA	
	9/12/11	Va, MA	
HHO	6/14/11	Ec, Myr, MA	Macroalgae
	8/9/11	Sc, Uv, MA	
	9/12/11	Pp, MA	
MMR	6/14/11	Sc, Va	*Sagittaria cristata*, *Vallisneria americana*
	8/9/11	Sc, Uv	
	9/12/11	Sc, Va	
DCC	6/14/11	Ec, Cd, Pp	*Elodea canadensis*, *Ceratophyllum demersum*
	8/9/11	Ec, Pd	
	9/12/11	Ec, Cd	
GGC	6/14/11	Sc, Pv	*Sagittaria cristata*
	8/9/11	Sc, Uv, Pp	
	9/12/11	Sc	

2012

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/27/12	Sc, Ec, Myr, Pp, MA	*Elodea canadensis*, *Myriophyllum*, Macroalgae
	8/22/12	Ec, Myr, MA	
	9/19/12	Ec, Myr, MA	
McH	6/27/12	MA	Macroalgae
	8/22/12	Ec, MA	
	9/19/12	Va, MA	
HHO	6/27/12	Sc, MA	*Sagittaria cristata*, *Myriophyllum*, Macroalgae
	8/22/12	Sc, Myr, MA	
	9/19/12	Sc, Ec, Myr	
MMR	6/27/12	Sc, Va	*Sagittaria cristata*, *Vallisneria americana*
	8/22/12	Sc, Va	
	9/19/12	Sc, Va	
DCC	6/27/12	Ec, Cd, MA	*Elodea canadensis*, Macroalgae
	8/22/12	Ec, MA	
	9/19/12	Sc, Ec	
GGC	6/27/12	Sc, Ec, Pp	*Sagittaria cristata*, *Elodea canadensis*
	8/22/12	Sc, Ec	
	9/19/12	Sc, Ec	

2013

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/20/13	Sc, Ec, Pv	*Sagittaria cristata*, *Elodea canadensis*, *Myriophyllum*, Macroalgae
	8/15/13	Sc, Ec, Myr, MA	
	9/27/13	Sc, Myr, Utr, MA	
McH	6/20/13	Va, Ec, Pv, MA	*Vallisneria americana*
	8/15/13	no data	
	9/27/13	Va	
HHO	6/20/13	Sc, Ec, MA	*Sagittaria cristata*, *Myriophyllum*
	8/15/13	Myr	
	9/27/13	Sc, Myr	
MMR	6/20/13	Sc, Va	*Sagittaria cristata*, *Vallisneria americana*
	8/15/13	Sc, Va	
	9/27/13	Sc, Va	
DCC	6/20/13	Ec, MA	*Elodea canadensis*, Macroalgae
	8/15/13	Ec, MA	
	9/27/13	Ec, MA	
GGC	6/20/13	Sc, Pv	*Sagittaria cristata*, Macroalgae
	8/15/13	Sc, MA	
	9/27/13	Sc, MA	

2014

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/30/14	Myr, Pv, MA	*Myriophyllum*, Macroalgae
	8/12/14	Sc, Myr, Pp	
	9/17/14	MA	
McH	6/30/14	MA	*Vallisneria americana*
	8/12/14	Va	
	9/17/14	Va	
HHO	6/30/14	Myr	*Myriophyllum*
	8/12/14	Myr	
	9/17/14	Myr	
MMR	6/30/14	Sc, Va	*Sagittaria cristata*, *Vallisneria americana*
	8/12/14	Sc, Va	
	9/17/14	Sc, Va	
DCC	6/30/14	MA	Macroalgae
	8/12/14	MA, Pv	
	9/17/14	MA	
GGC	6/30/14	Sc, Pv, MA	*Sagittaria cristata*, Macroalgae
	8/12/14	Sc, MA	
	9/17/14	MA	

offshore of the State Park in Meadow Mountain Run Cove (MMR) was dominated by *S. cristata* and *V. americana* during all five summers (Table 4). This transect ranged from 45-63m with a max depth of 4.2m. Total SAV increased between 2010 and 2014 while macroalgae was only present in very low densities in 2012 (Figure 3). *Myriophyllum* was never observed at this transect.

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 to 150m, and max depth of 3.7m). This expansive bed was dominated by *E. canadensis* in 2010, but in 2011, *C. demersum* was found to be co-dominant with *E. canadensis* (Table 4*).* In 2012 and 2013, *E. canadensis* co-dominated with macroalgae, and by 2014, macroalgae was the lone dominant plant. Total SAV in DCC decreased significantly between 2010 and 2014 ($P < 0.001$), while total macroalgae increased significantly ($P = 0.009$) (Figure 3). *Myriophyllum* was present in low densities and oscillating frequencies during most sampling events, but did not change significantly over time (Figure 4). *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. These results are discussed later in this report.

Green Glade Cove (GGC), east of DCC in the southeastern portion of the lake, had transect lengths ranging from 40-80m and a max depth of 4m. This SAV bed was dominated by *S. cristata*, *E. canadensis*, and macroalgae in 2010. In 2011, the dominant plant observed was *S. cristata* and in 2012, *S. cristata* and *E. canadensis* co-dominated. In 2013 and 2014, macroalgae and *S. cristata* co-dominated (Table 4). Both total SAV and total macroalgae showed a decreasing trend between 2010 and 2014, but only SAV decreased significantly ($P = 0.015$) (Figure 3). *Myriophyllum* was present in low densities during most sampling events, but it did not change significantly over time. *Myriophyllum* frequency of occurrence increased significantly between 2010 and 2014 ($P = 0.020$) (Figure 4).

Overall, total SAV density was lowest in 2014 in DCC, GGC, and HHO and total macroalgae cover was highest in 2014 in DCC (Table 3). Species richness was also lowest in 2014 at DCC and HHO. *Sagittaria cristata, E. canadensis, V. americana, C. demersum, Myriophyllum* and macroalgae were the dominant plants observed at our sites during the five year monitoring period (Table 4). The greatest densities and highest frequencies of occurrence of *S. cristata* and *V. americana* were observed at MMR. *Elodea canadensis* and *C. demersum* densities and frequencies of occurrence were higher at DCC than at the other sites, but both had all but disappeared there by 2014. Between 2010 and 2014, the only significant change in *Myriophyllum* was at GGC, where frequency, but not density, increased over time. Although both density and frequency of occurrence were higher at HHO than other sites, neither metric changed significantly over time at that site or in any of the other surveyed coves. *Potamogeton pusillus* and *P. vaseyii* were observed at least once at all six sites, but at low densities. While *P. amplifolius* was observed in Deep Creek Lake during the shoreline surveys in 2013, it was not observed at any of the transect sites until 2014, when it appeared in very low frequencies and densities at RRC and HHO.

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 at the McH and DCC transects. 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.*, *V. americana*, *C. demersum,* or a combination thereof. Along the deeper edges of the SAV beds, we observed more *C. demersum* and *Myriophyllum,* and the two species of macroalgae (which have lower light requirements), *Chara* and *Nitella.*

While the SAV transects surveyed represent the lake as a whole, the comprehensive shoreline survey allowed us to map the lake-wide spatial extent of *Myriophyllum* specifically. With this sampling design, in 2012 we identified 130 locations with *Myriophyllum*, totaling approximately 86 acres where *Myriophyllum* was present at varying densities (Table 5). Using bathymetry data collected by the Maryland Geological Survey, 86 acres represents approximately 2.3% of the lake surface and 5.8% of the waters less than six meters deep, the photic

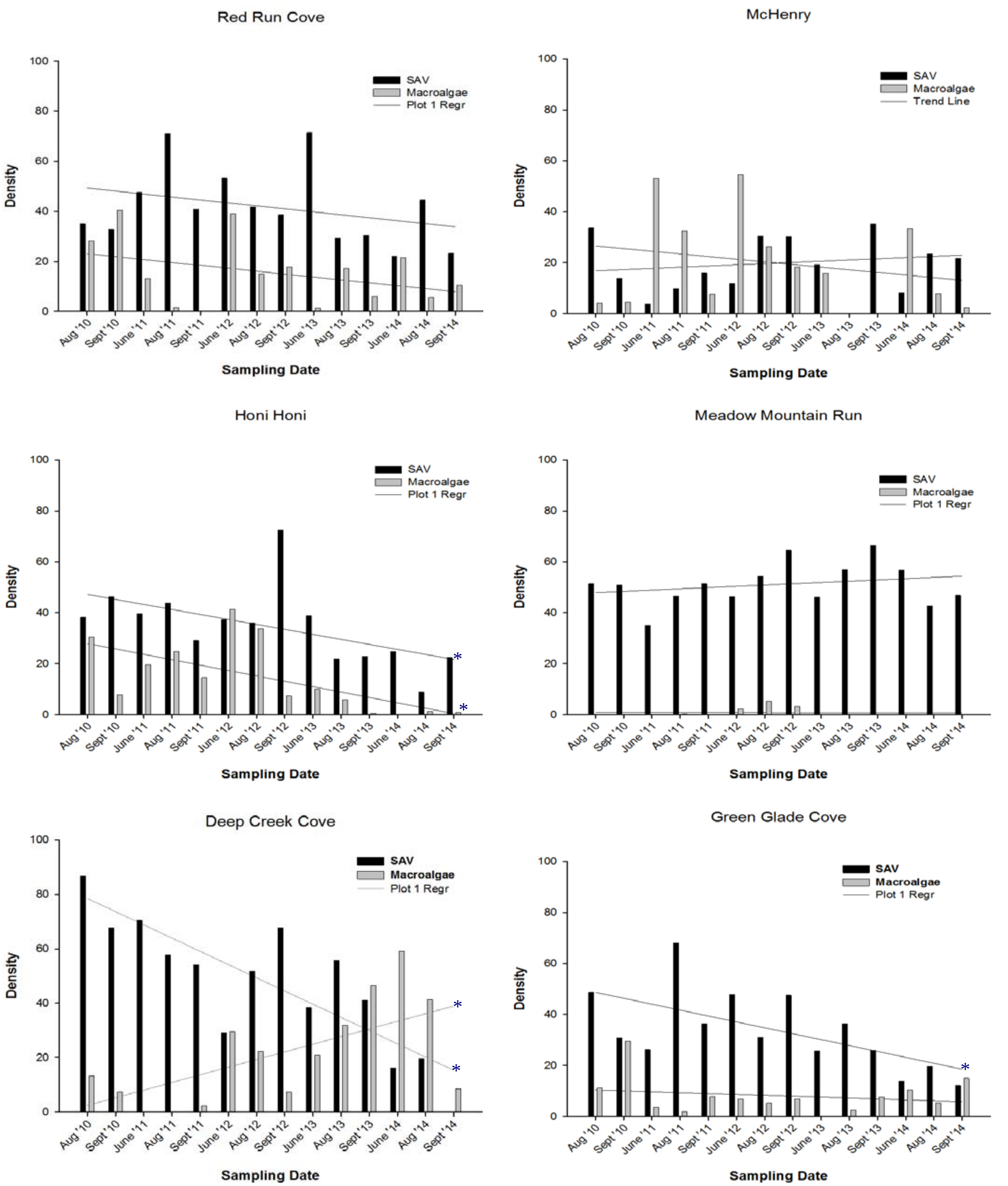

Figure 3. Total SAV and total macroalgae density (where density = sum of % cover values/total # of quadrats) graphed over time for each transect, with corresponding trend-lines showing overall increasing, decreasing, or no-change trends. Asterisks (*) indicate significant ($p \leq 0.05$) change from 2010 to 2014.

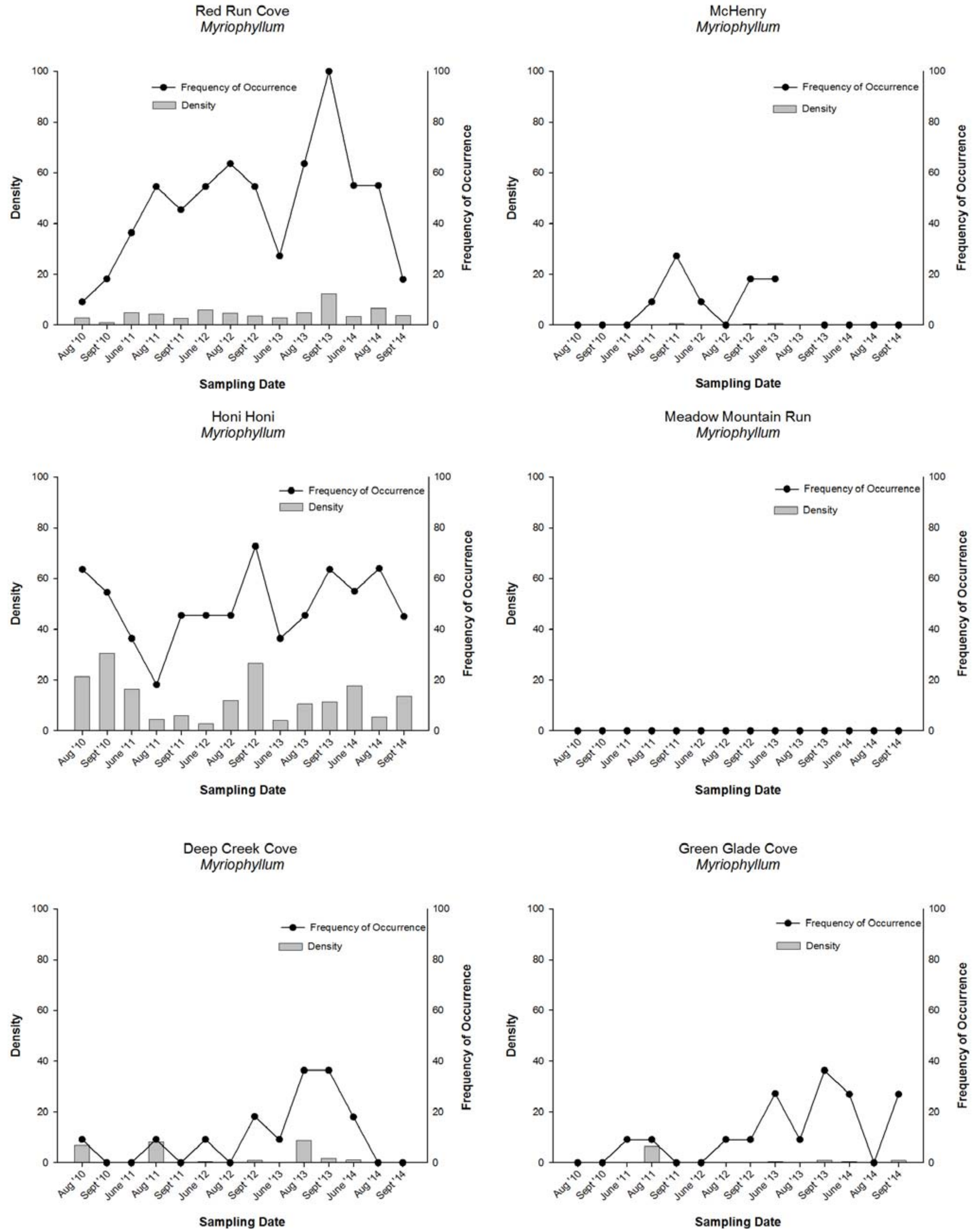

Figure 4. *Myriophyllum* density (bars, where density = sum of % cover values/total # of quadrats) and frequency of occurrence (point and line, where Frequency = # of quadrats where observed/total # quadrats) graphed over time, 2010-2014, for each transect.

zone in which plants may grow in Deep Creek Lake. The remaining 94.2% of habitat within the photic zone was free of *Myriophyllum*. During the June 2013 shoreline survey, *Myriophyllum* was only identified at 69 locations throughout the lake, totaling approximately 29 acres where *Myriophyllum* was present at varying densities. Twenty-nine acres represents 0.74% of the lake surface, and 1.96% of bottom available within the photic zone. In 2014, the shoreline survey was conducted later in the growing season (September) when *Myriophyllum* was at its peak biomass and spatial extent. During the survey, *Myriophyllum* was identified at 214 locations in patches of varying size and density, totaling approximately 60 acres. Sixty acres represents 1.54% of the lake's surface of 3,900 acres, and 4.05% of its 1,480 acre photic zone.

Table 5. Results of 2012-2014 Shoreline Survey

Date	# *Myr* Patches	Area (acres)	% Lake Surface	% Photic Zone
Jun-12	130	86	2.2	5.8
Jun-13	69	29	0.74	1.96
Sep-14	214	60	1.54	4.05

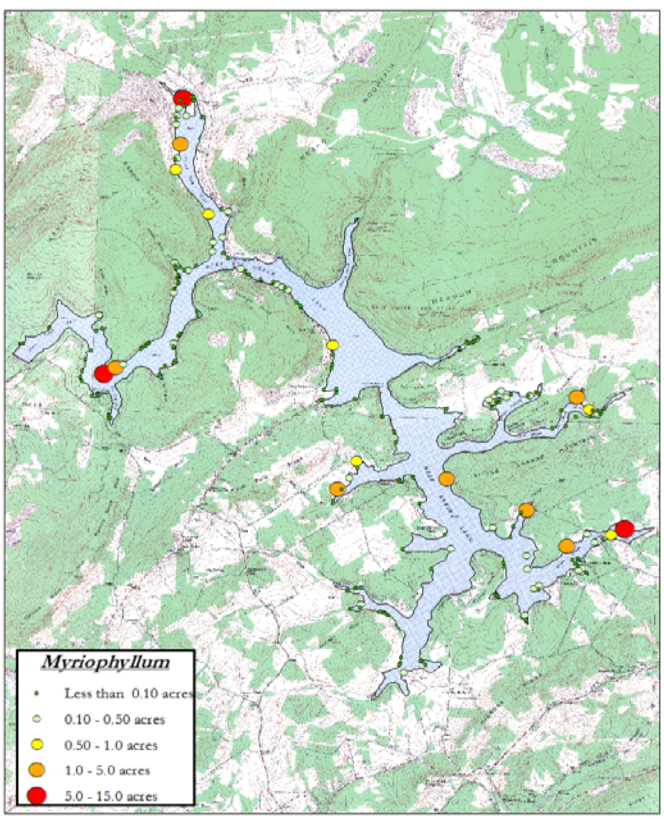

Figure 5. Results of 2014 Shoreline Survey. *Myriophyllum* observations are shown in acres, with symbol size proportional to patch size.

The largest *Myriophyllum* bed observed occupied approximately 10.9 acres in Marsh Run Cove (Fig. 5). The second largest, at 8.5 acres, was observed at the other end of the lake in Green Glade Cove. The third largest occupied 5.9 acres in the north-west arm of the lake just opposite the mouth of Red Run Cove. Every other bed was less than four acres and there were only ten patches larger than one acre. The average size of the 204 patches under one acre equaled 0.0957 acres. Appendix C includes more detailed maps of both the 2013 and 2014 *Myriophyllum* observations throughout the lake.

Hydrilla management was successfully implemented during the summer 2014 season, with no *Hydrilla* observed in any of the treated patches by the end of the season. Careful monitoring and scouting of the infested area, however, revealed two new patches in early August. Two additional patches were discovered during the comprehensive shoreline survey in September. One of the new patches was located just outside of south-

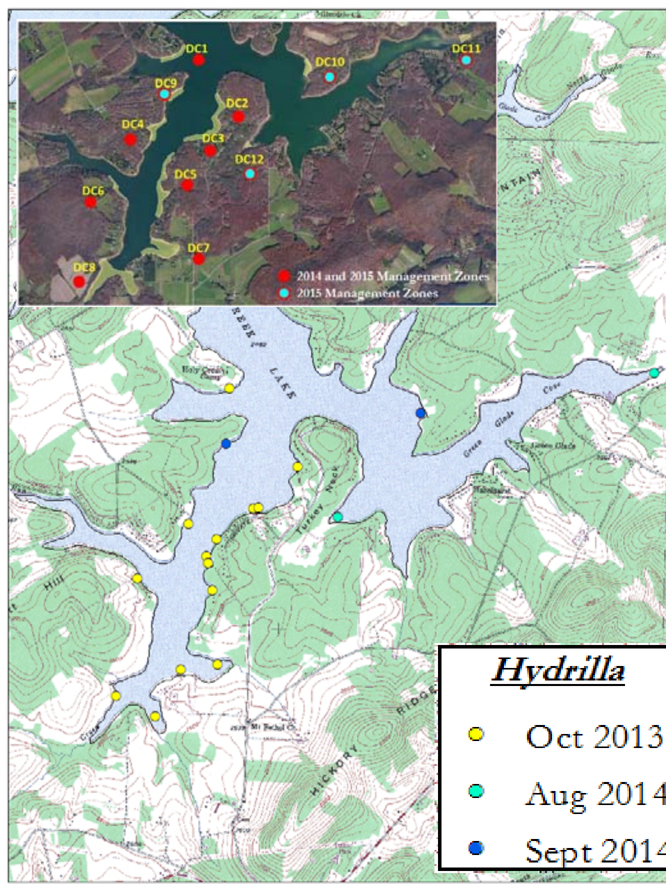

Figure 6. Map of *Hydrilla* observations in DCL with inset of 2014 and 2015 management zones.

western leg of the lake and the other three in the southeastern leg (GGC). *Hydrilla* control activity in 2015 will include four new management zones to incorporate these new patches (Fig. 6).

DISCUSSION and CONCLUSION

Deep Creek Lake, as a whole, continues to support a healthy population of SAV and the SAV in turn promote a healthy lake. There are ten genera of plants commonly observed in DCL and these include two species of *Potamogetons* that are legally classified as endangered in Maryland and were thought to be completely extirpated from the state. *Potamogeton robbinsii* is a relatively small stature plant that was first documented at one of our transect sites in 2010. *Potamogeton amplifolius*, however, was only recently observed. It was documented for the first time during the 2013 shoreline survey and was observed at several locations again during the 2014 shoreline survey. Field observations made during both surveys indicate that it is spreading and increasing in frequency of occurrence throughout the lake. *Potamogeton amplifolius* is a large-stature plant that may grow to the water surface. It provides excellent habitat for fish and food for waterfowl. Because it was previously believed to be extirpated from Maryland waters, its expanding presence in the lake is welcome. *Potamogeton amplifolius* may also prove to be particularly beneficial as a large-bodied competitor for *Myriophyllum*.

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 5 meters on some transects. Because of varying light requirements and other physical factors, species zonation was apparent at every site. Zonation is an inherent characteristic of any SAV bed, 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*, commonly known as Crested arrowhead, was observed at each site during most sampling events. This plant, which is short in stature and can withstand extensive periods of exposure during lake level draw down, was most prevalent along the shallow edges of the SAV beds. *Potamogeton spp.* (also present to some extent in the shallows), *Vallisneria americana,* and/or *Ceratophyllum demersum* replaced *S. cristata* as the beds extended into deeper water. 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 edge of the SAV beds, we were more likely to observe *E. canadensis*, *Myriophyllum* and macroalgae.

Although our survey results indicate that DCL, as a whole, continues to support a healthy and relatively diverse population of SAV, there were noticeable and at times statistically significant changes observed in 2014. *Elodea canadensis*, once a common and dominant species that grew along the deeper edges of SAV beds in the lake, was observed at four of the six transect sites but in dramatically reduced densities and frequencies (Table 3). While *E. canadensis* was the only individual plant to become so sparse, overall SAV density decreased significantly at the transect sites in the southern portion of the lake (DCC and CCG) and at HHO (Figure 3). Data also indicate that the dominant plant communities shifted (Table 4). Since 2010, macroalgae has frequently been a dominant plant at the transect sites, but in 2014 it was more often the only dominant or one of two co-dominants with *Myriophyllum* and *S. cristata*. This shift shows a spatial pattern in that the western shore sites are dominated by *Myriophyllum* and macroalgae, whereas the eastern shore sites are dominated by *V. americana*, *S. cristata*, and macroalgae. The sites at which total SAV is decreasing are dominated by macroalgae (DCC), *S. cristata* and macroalgae (GGC), and *Myriophyllum* (HHO). These results suggest that the SAV habitat conditions along the western shore and the southern portion of the lake may be changing. The southern portion of the lake is dominated by agriculture and the western shore is heavily developed (Figure 1). The eastern shore, alternatively, has a greater proportion of forested land, particularly around Deep Creek Lake State Park. Our transect site adjacent to the State Park, MMR, is dominated by *V. americana* and *S. cristata*. It is not uncommon for watershed land use to positively or negatively affect an adjacent body of water (Landry, in prep). When available, current long-term State of

Maryland Deep Creek Lake water quality monitoring data will be analyzed to identify possible causes for the SAV declines.

While the transect surveys were able to indicate some changes in *Myriophyllum*, the shoreline surveys gave a more comprehensive look at its growth habits throughout the lake. In 2013, this nuisance plant was present at varying densities in 29 acres of the lake and occupied less than 2% of available benthic space for vegetative growth. This number was down from 2012 when 130 patches were observed covering 86 acres. The reduction in *Myriophyllum* observations was most likely due to abnormally high lake levels, higher turbidity, and a very cool spring. In June, 2013, there was consequently less SAV, and because of the conditions, it was more difficult to locate. To control for a winter season affect in 2014, the shoreline survey was conducted in September. This allowed RAS biologists to observe *Myriophyllum* during its peak biomass and greatest spatial extent throughout the lake. At that time, total area equaled approximately 60 acres; this was less than the 86 acres observed in 2012, but the total number of observed patches increased to 214. Of these 214 patches, only ten made up beds over one acre in area. These numbers indicate that as the growing season progresses, *Myriophyllum* spreads to more locations throughout the lake, but it does necessarily occupy more space by growing into large beds or meadows. Based on these observations, Myriophyllum is present throughout DCL and the populations seem to be stable or declining. While it may be a cove-specific nuisance, RAS biologists do not advocate establishing a control program at this time. *Myriophyllum* populations will be continually monitored and recommendations for management will be updated as situations change.

Hydrilla verticillata, on the other hand, 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 (Appendix D) that was rapidly designed and implemented during the summer 2014 season was highly successful with no living *Hydrilla* observed in the treatment areas at the end of the growing season. Frequent scouting of the affected area combined with the comprehensive shoreline surveys also made 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 in 2015. While we expect the management plan to be successful in controlling, if not eradicating, *Hydrilla* from DCL, the best possible way to prevent further expansion of *Hydrilla*, *Myriophyllum,* or any other invasive plant species is to prevent any further introductions, to promote the growth of native SAV, and to boat responsibly in areas where they are growing.

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APPENDIX A

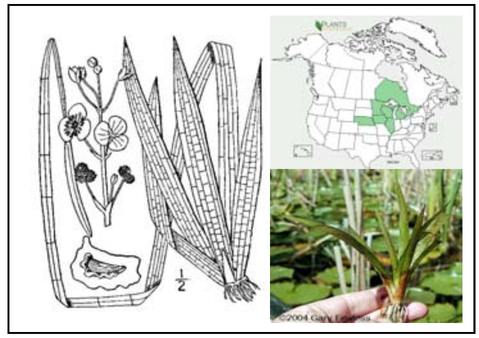
Deep Creek Lake

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.

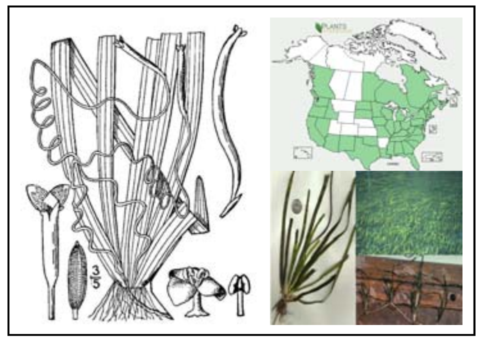
***Sagittaria cristata* (Crested arrowhead)**



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.

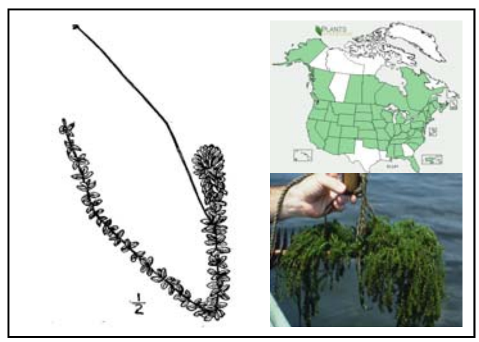
***Vallisneria americana* (Wild celery)**



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.

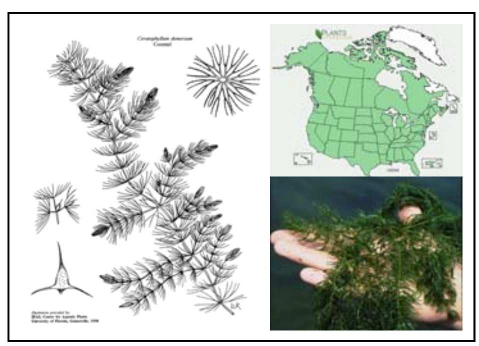
***Elodea canadensis* (Canadian waterweed)**



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.

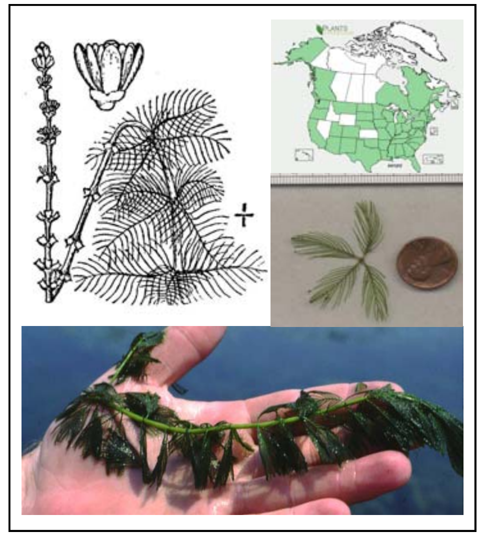
***Ceratophyllum demersum* (Coontail)**



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)



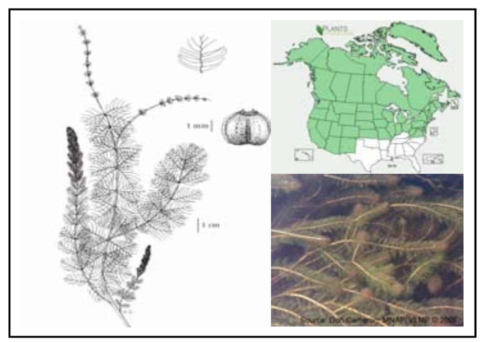
Dicot, Perennial. Invasive to the continental US, Alaska, and Canada. Native to Europe, Asia, and northern Africa. Invasive distribution throughout the US.

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.

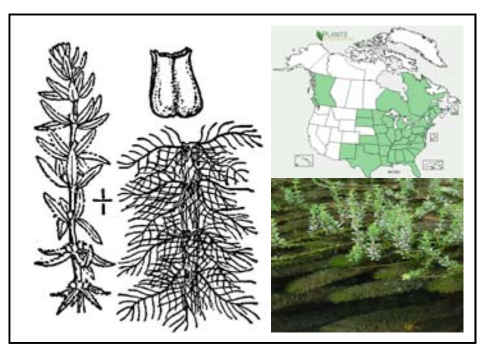
Myriophyllum sibiricum (Northern water milfoil)



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)



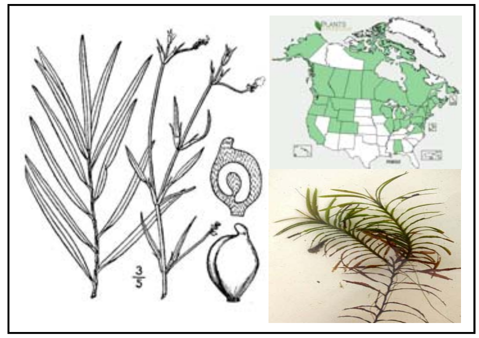
Dicot, Perennial. Native to the continental US and Canada with distribution throughout the eastern US and Canada.

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.

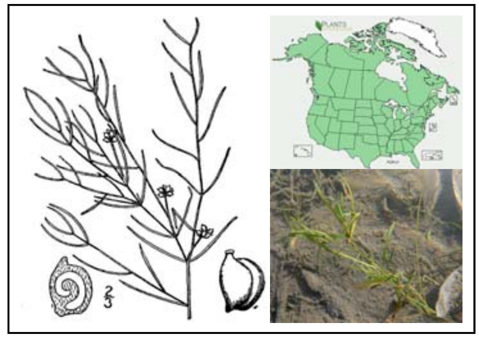
This pondweed is found in deep to shallow, often muddy waters of lakes, ponds, and rivers. It is the only *Potamogeton* that has branching inflorescences, though it rarely flowers. This plant is believed extirpated from Maryland and is threatened or endangered in several of its native states.



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

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

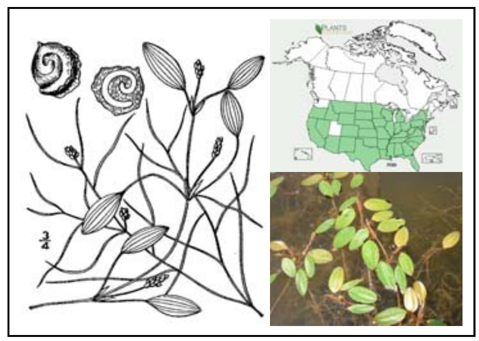
Slender pondweed grows in soft, fertile mud substrates and quiet to gently flowing water. Leaf blades of slender pondweed are entire and have pointed tips and can have a purplish tint. Like all other pondweeds, slender pondweed is considered an important food for waterfowl.



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

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

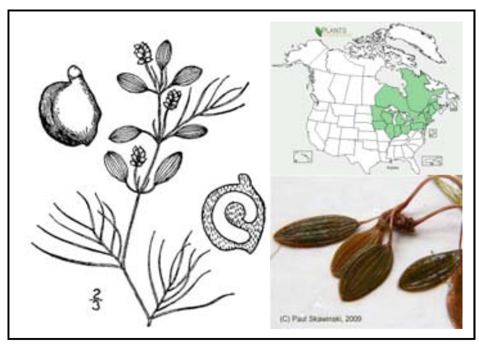
This pondweed produces a very narrow, compressed stem branching to around 35 cm. It has thin, pointed linear leaves a few cm long spirally arranged about the thin stem. Flowers emerge from the water surface.



Pota*mogeton vaseyi* (Vasey’s pondweed)

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

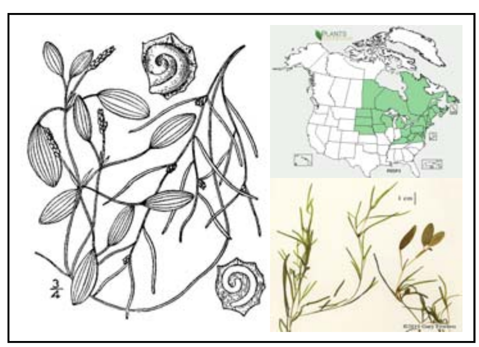
Not previously documented in Maryland, Vasey’s pondweed is considered threatened, endangered, or of special concern where found in northeastern US states. It grows in quiet waters and has dimorphic leaves: very narrow, flaccid, submersed leaves and wider, thicker floating leaves.



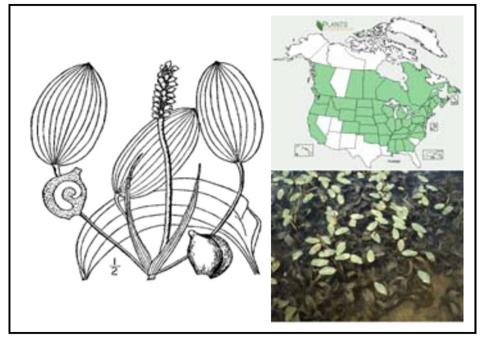
***Potamogeton spirillus* (Spiral pondweed)**

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*.



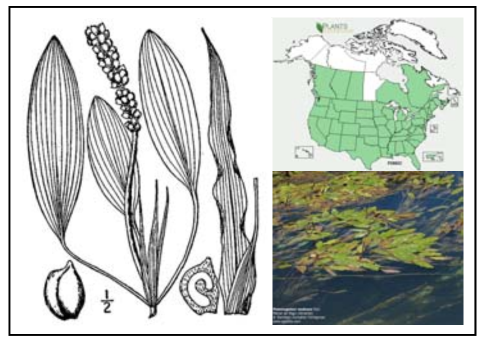
Potamogeton amplifolius **(Largeleaf pondweed)**



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.

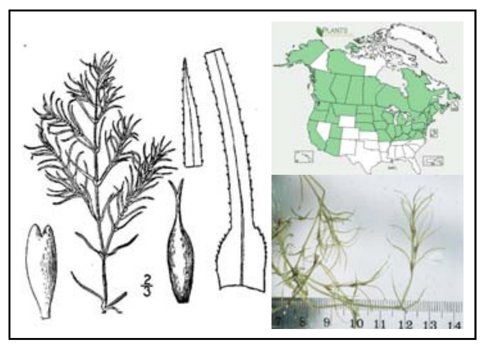
Potamogeton nodosus **(Longleaf pondweed)**



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.

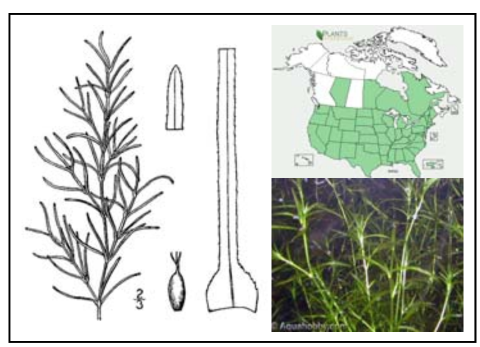
Najas flexilis **(Slender or nodding naiad)**



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)**



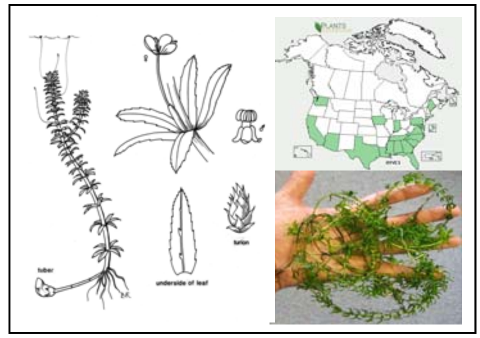
Monocot. Annual. Native to the continental US, Puerto Rico, and Canada. Invasive to Hawaii. Distributed throughout US.

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.

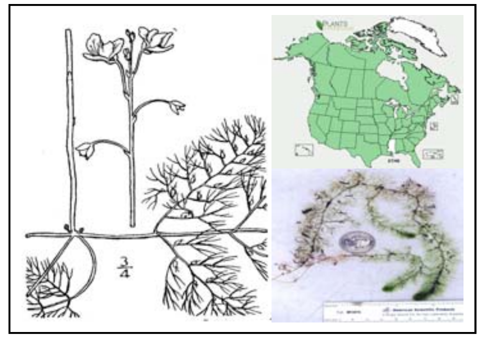
Hydrilla may be found in all types of water bodies. Its stems are slender, branched and up to 25 feet long. *Hydrilla's* small leaves are strap-like and pointed and grow in whorls of four to eight around the stem. Leaf margins are distinctly saw-toothed. *Hydrilla* produces tiny white flowers on long 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.

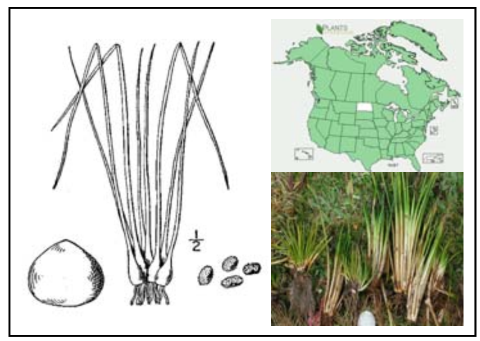
Several species of bladderwort occur in the Chesapeake Bay region, primarily in the quiet freshwater of ponds and ditches. They can also be found on moist soils associated with wetlands. Bladderworts are considered carnivorous because minute animals can be trapped and digested in the bladders that occur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

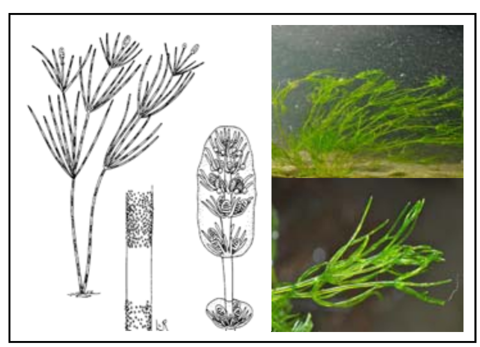


***Chara vulgaris* (*Chara*, Common stonewort) Macroalgae**

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:

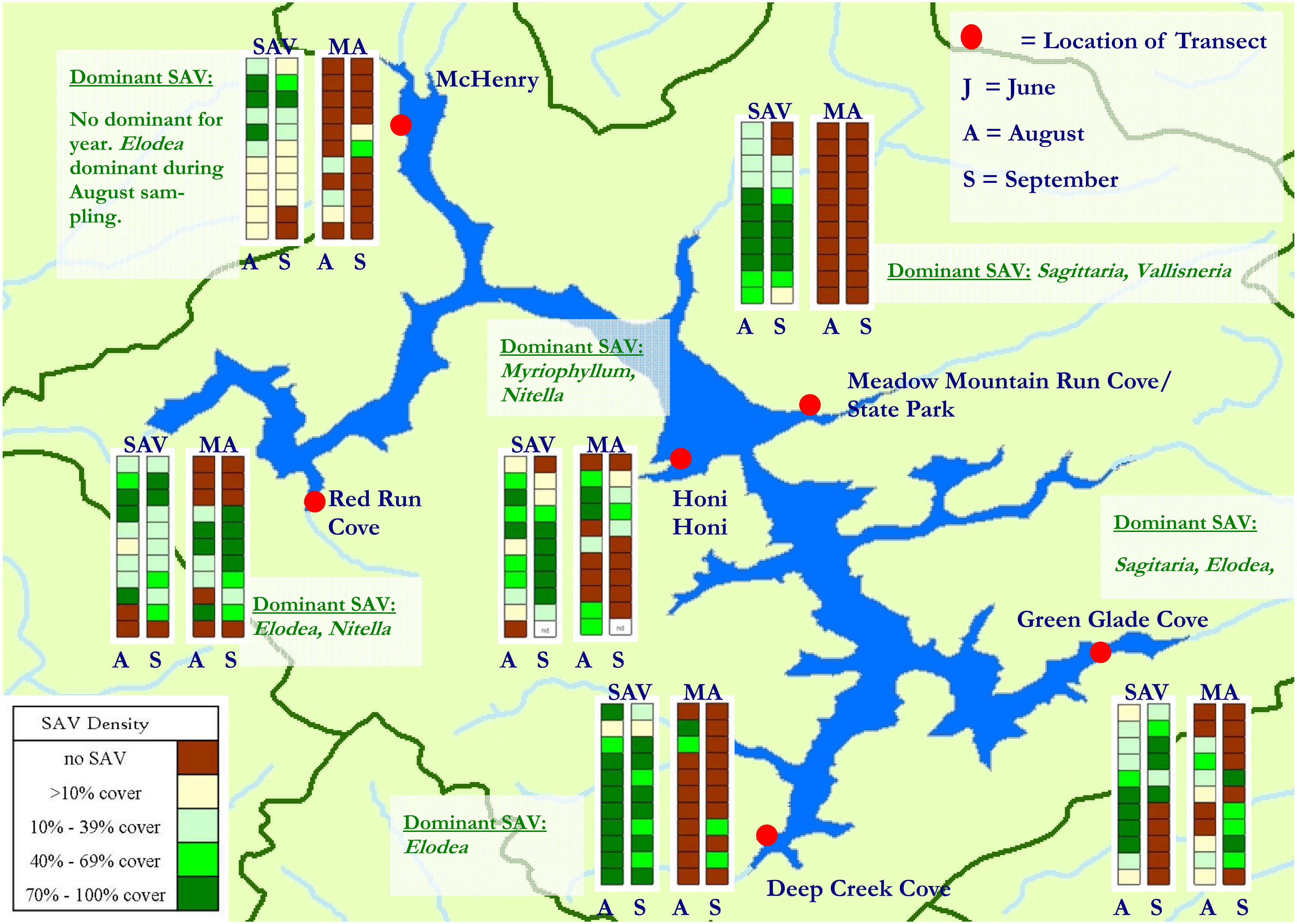
Sagittaria cristata: www.uwgb.edu
Vallisneria Americana: www.dnr.state.md.us
Elodea Canadensis: www.dnr.state.md.us
Ceratophyllum demersum: www.dnr.state.md.us
Myriophyllum spicatum: www.dnr.state.md.us
Myriophyllum sibiricum: www.mainevolunteerlakemonitors.org
Myriophyllum heterophyllum: www.missouriplants.com
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

APPENDIX B

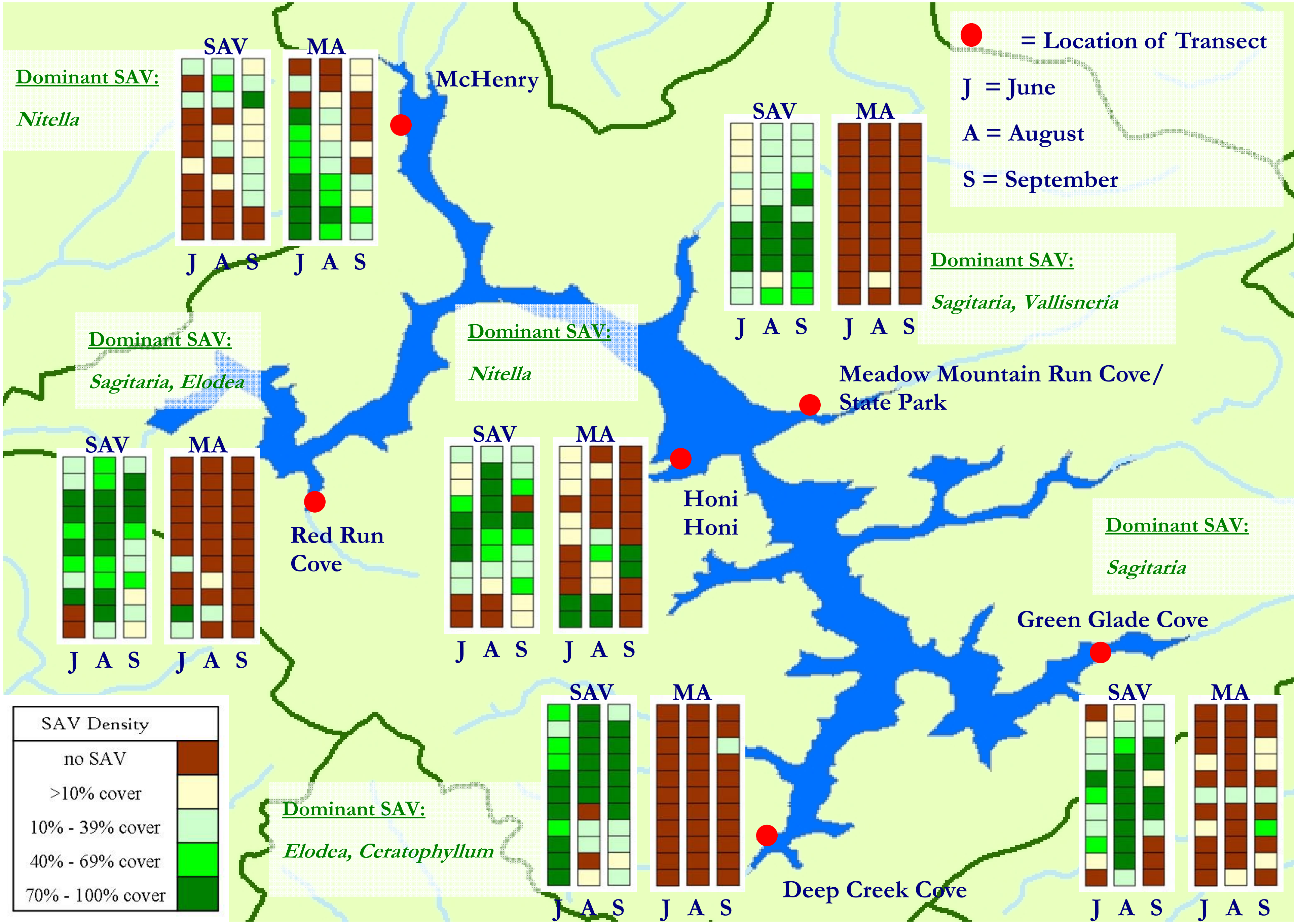
Deep Creek Lake

Color Coded Transects

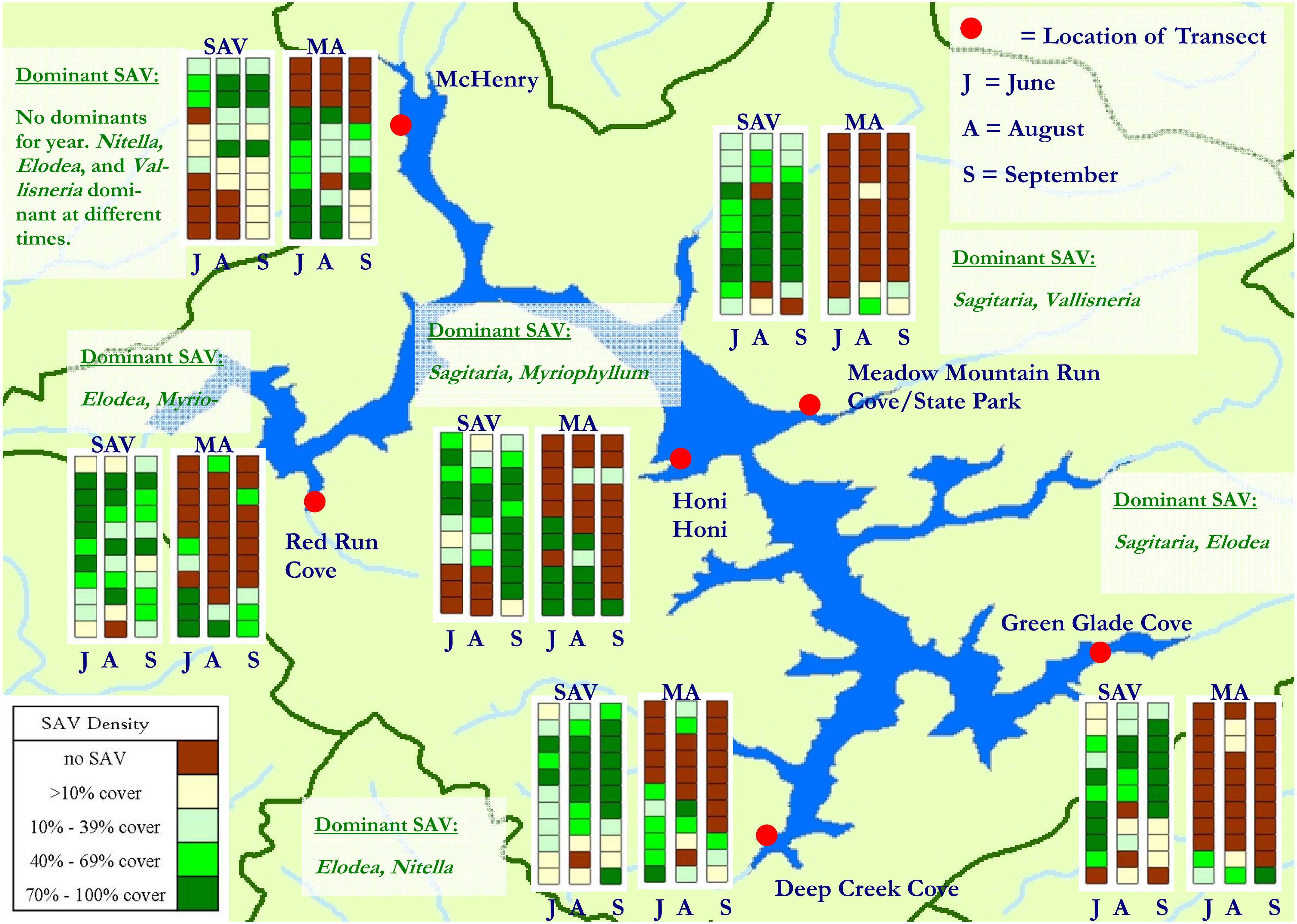
Deep Creek Lake, MD 2010



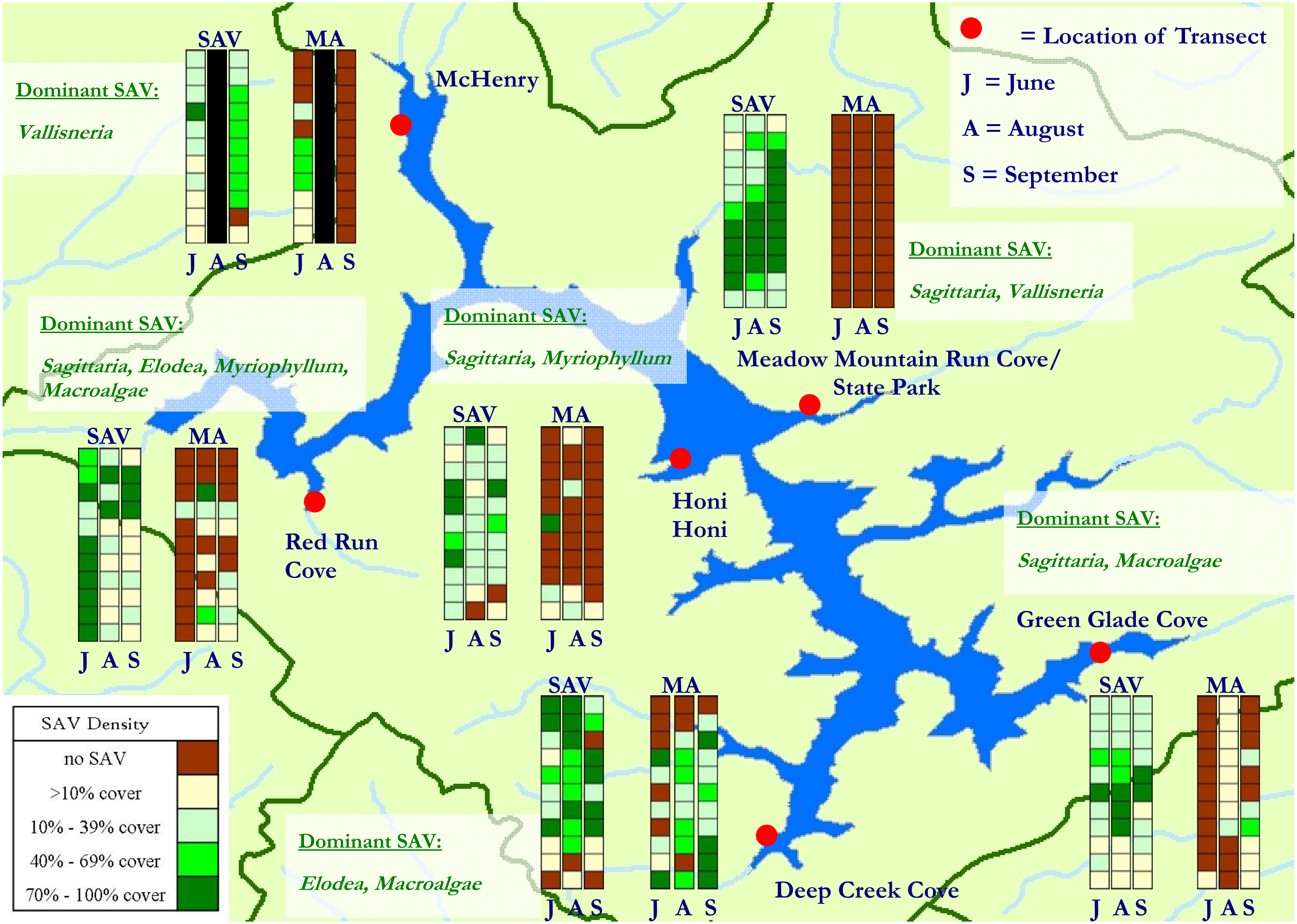
Deep Creek Lake, MD 2011



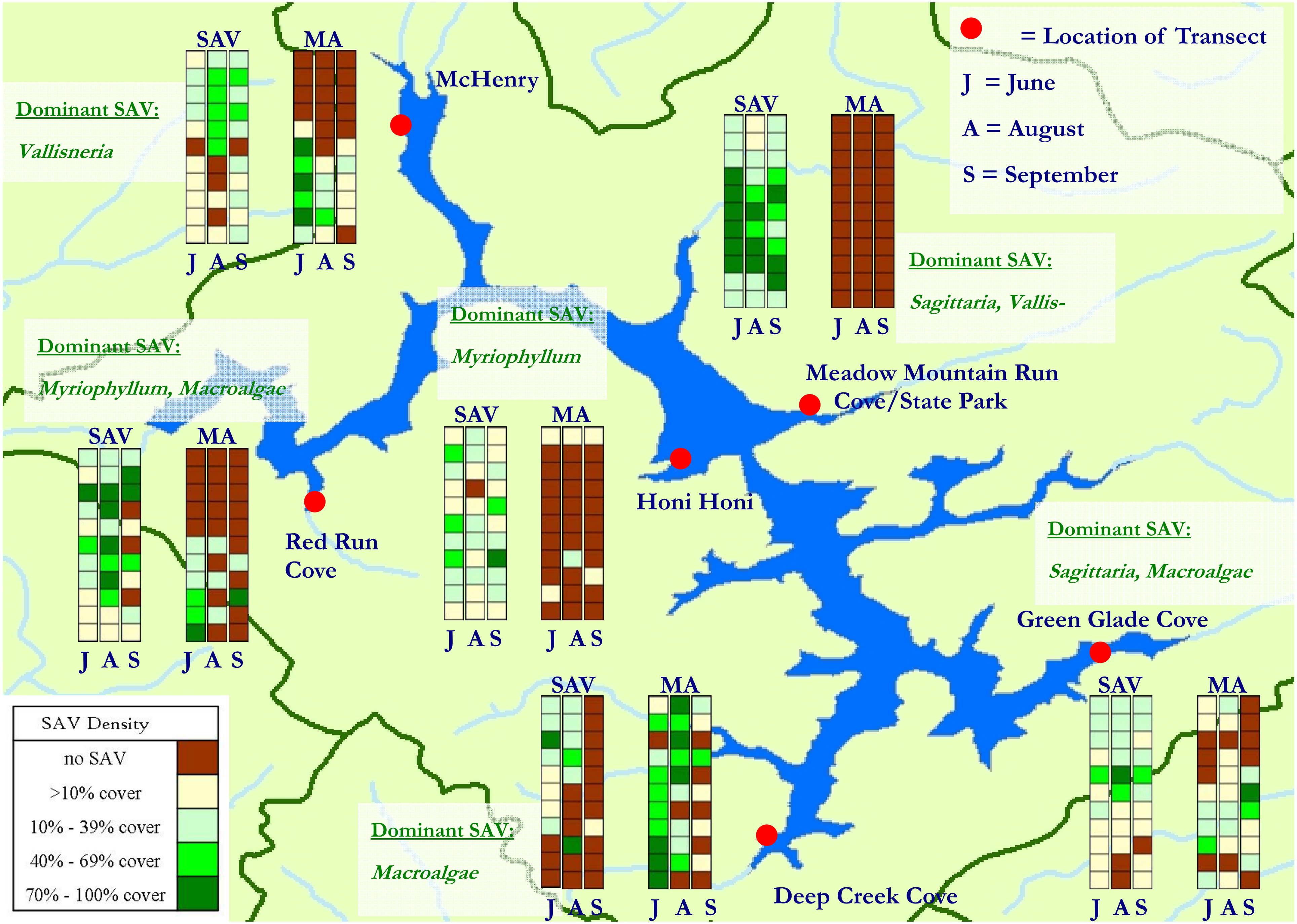
Deep Creek Lake, MD 2012



Deep Creek Lake, MD 2013



Deep Creek Lake, MD 2014



APPENDIX C

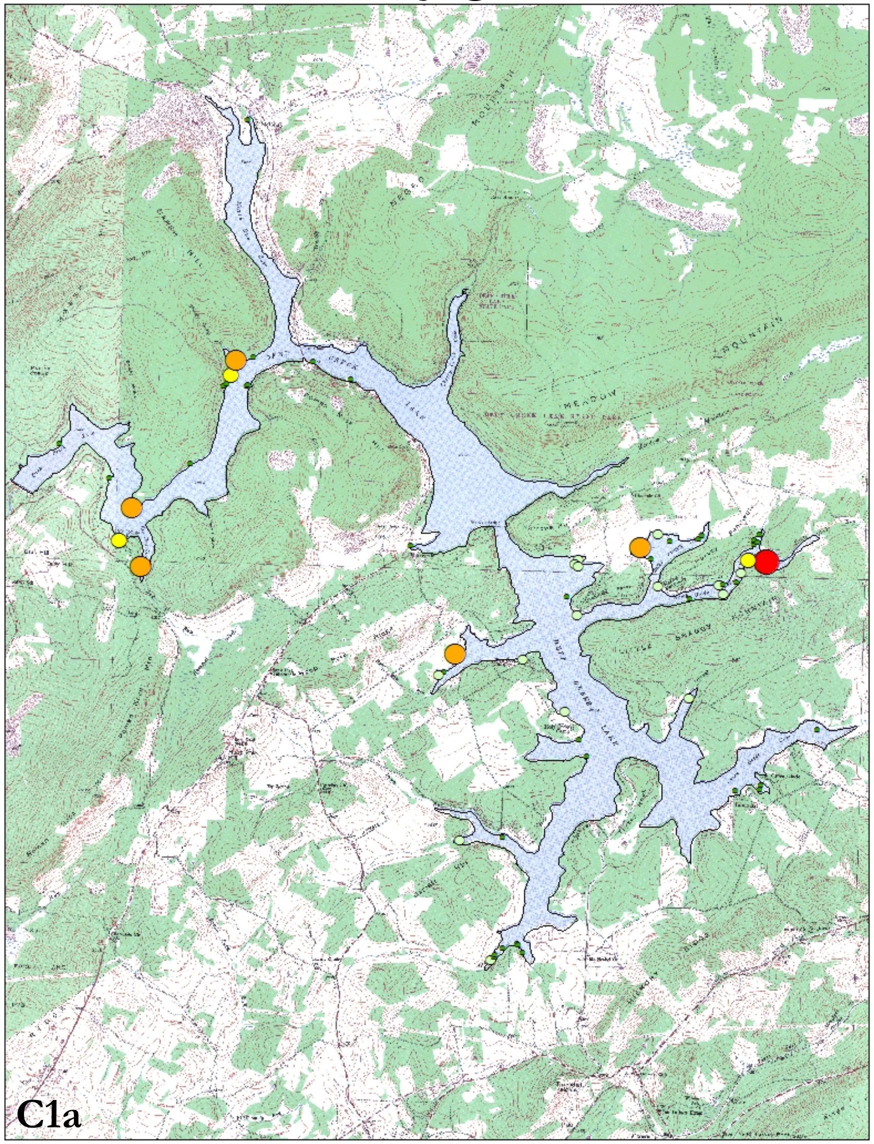
Deep Creek Lake

Comprehensive Shoreline Survey

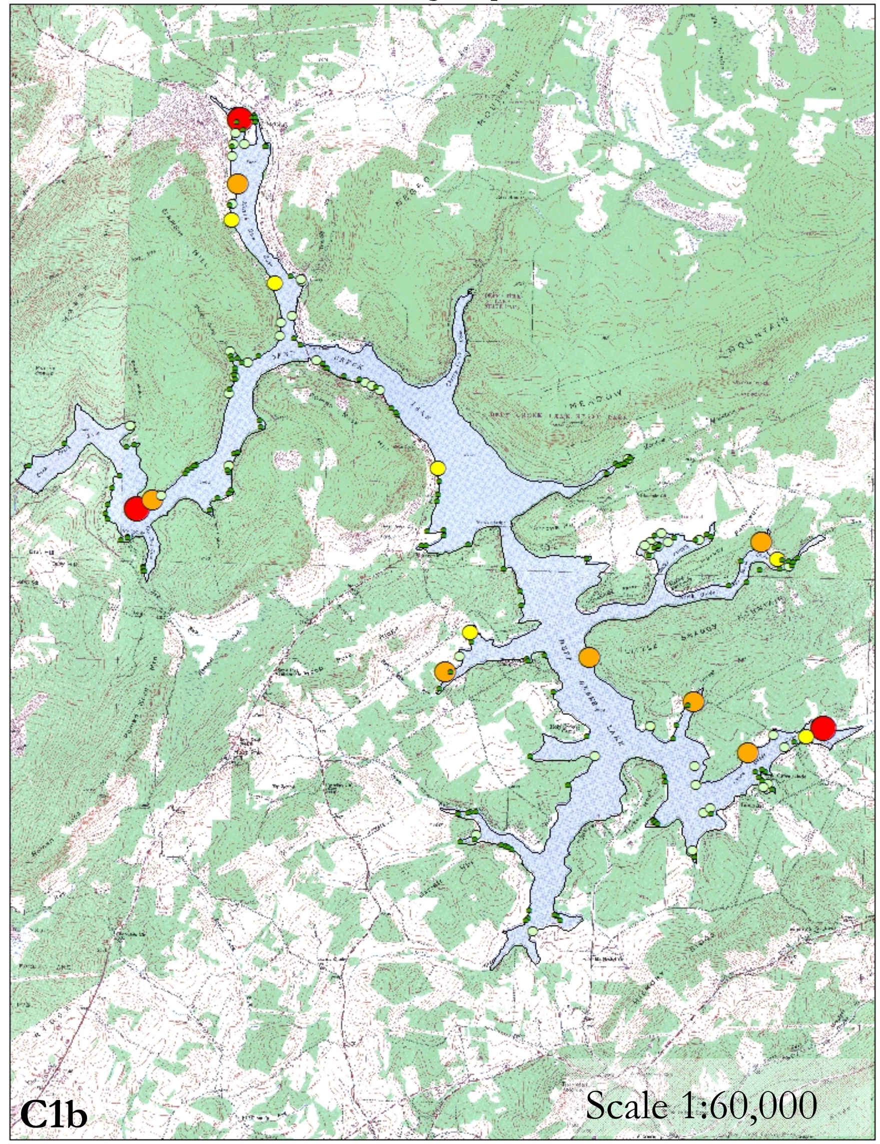
Myriophyllum Distribution

2013-2014

2013



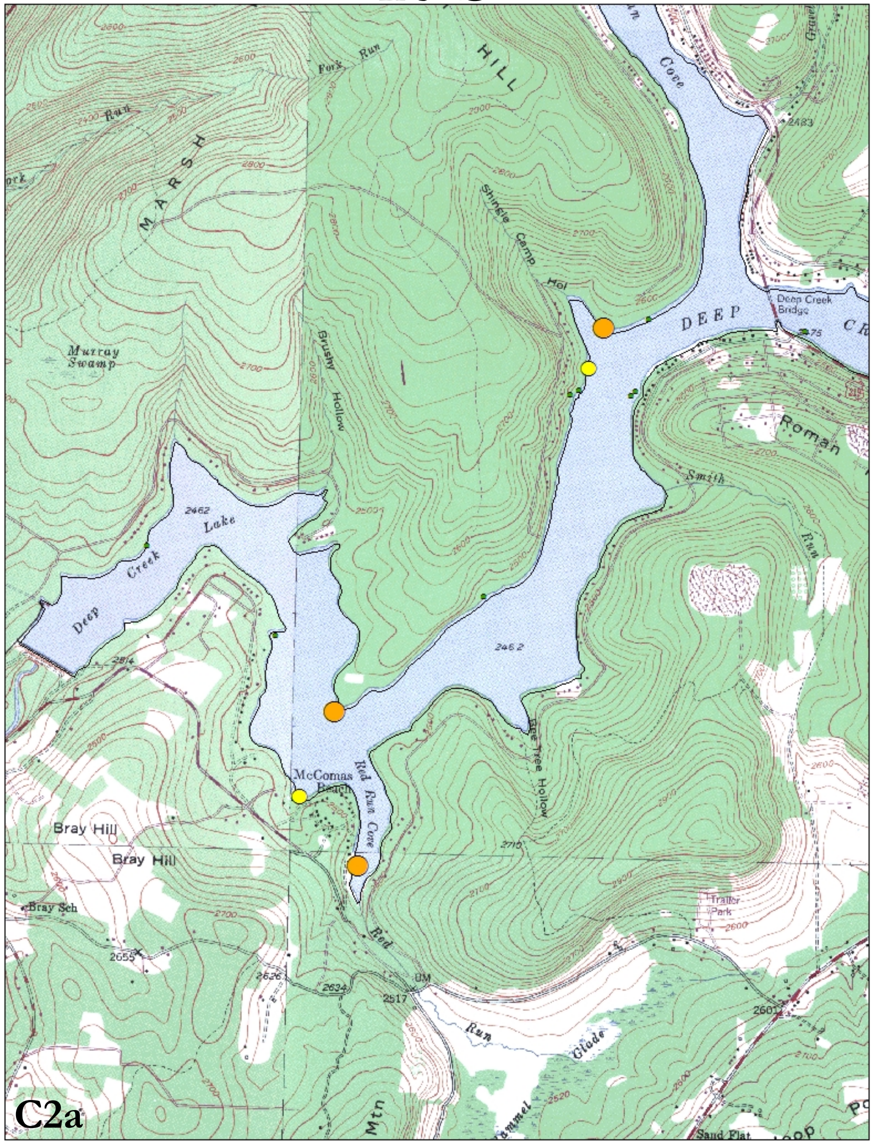
2014



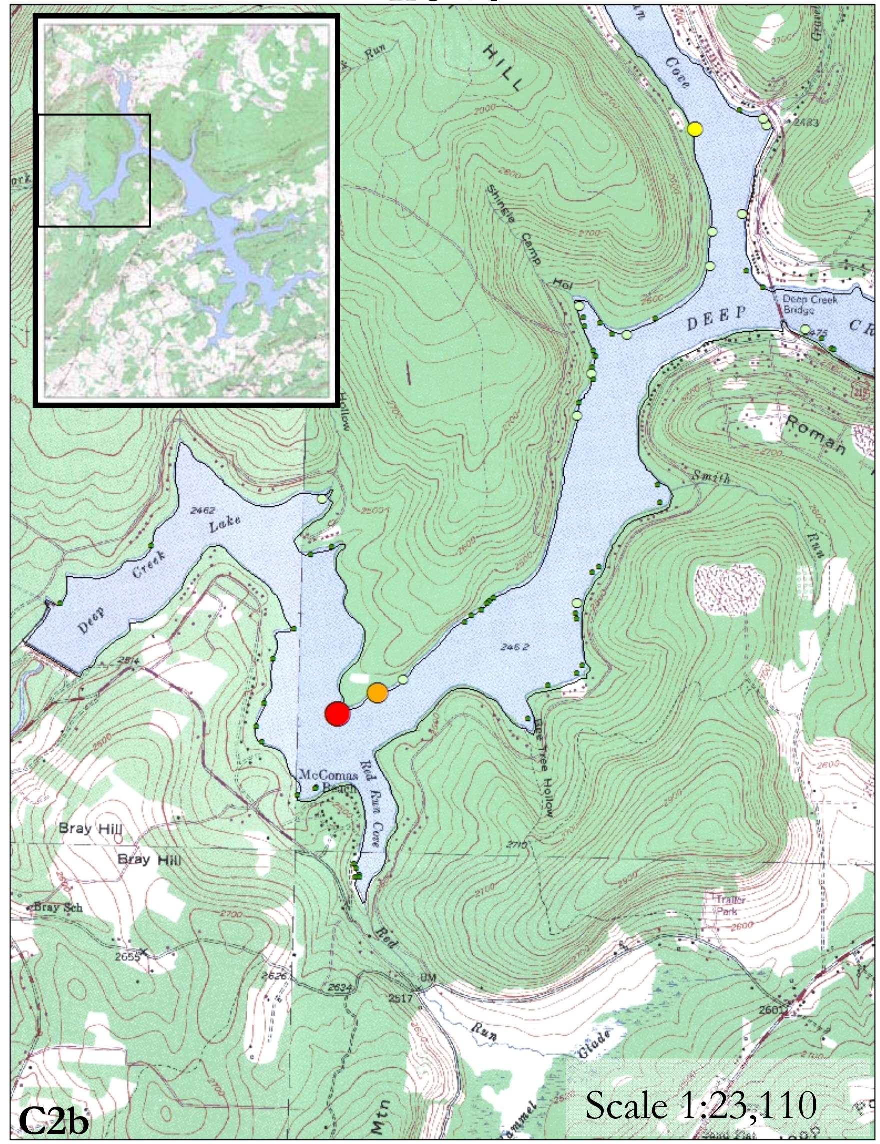
***Myriophyllum* observations**

Less than 0.1 acre | 0.1 – 0.5 acres | 0.5 – 1.0 acres | 1.0 – 5.0 acres | 5.0 – 15 acres

2013



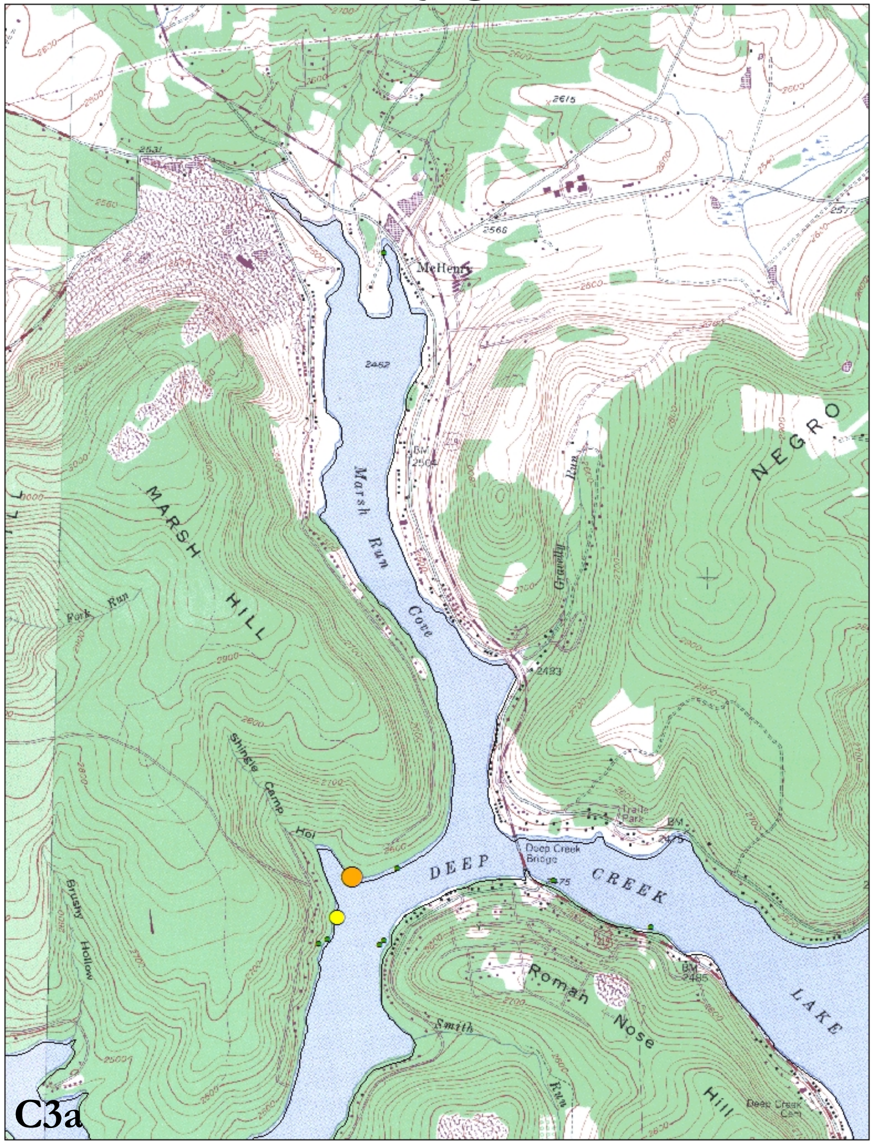
2014



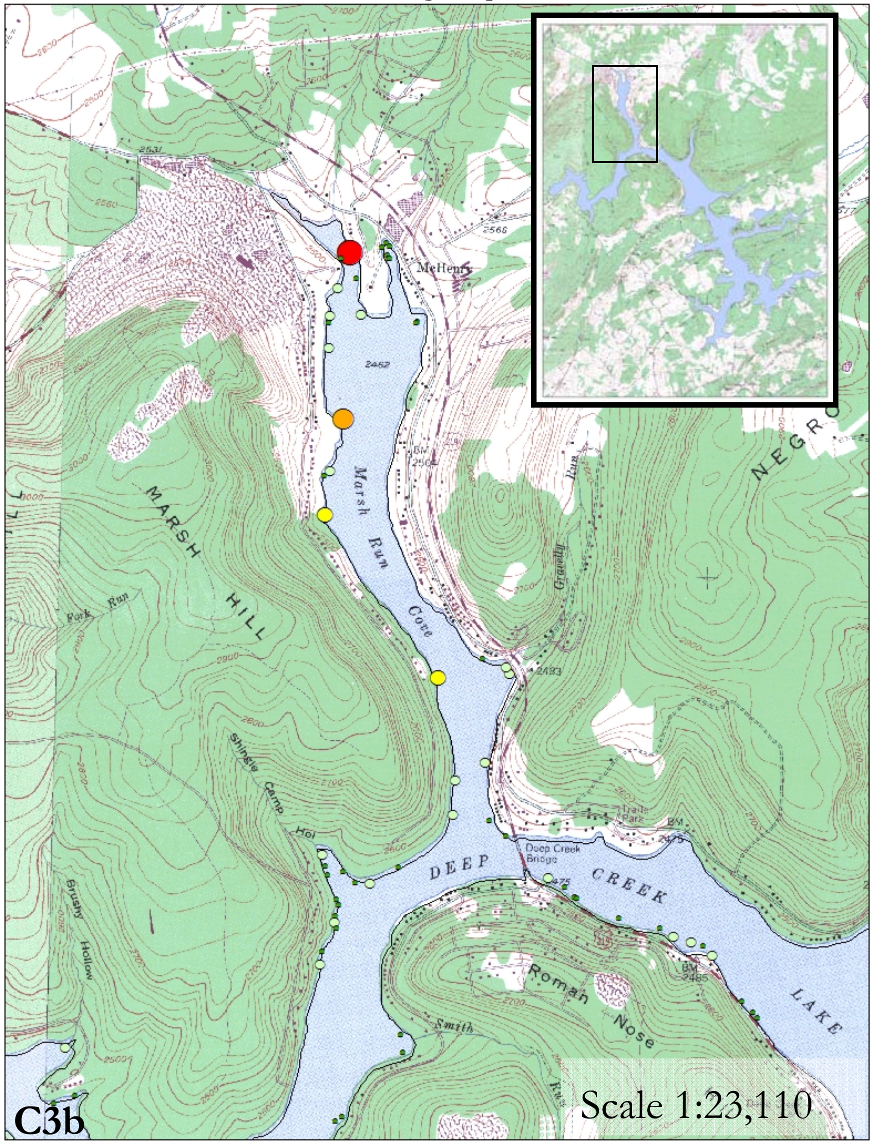
***Myriophyllum* observations**

Less than 0.1 acre | 0.1 – 0.5 acres | 0.5 – 1.0 acres | 1.0 – 5.0 acres | 5.0 – 15 acres

2013



2014

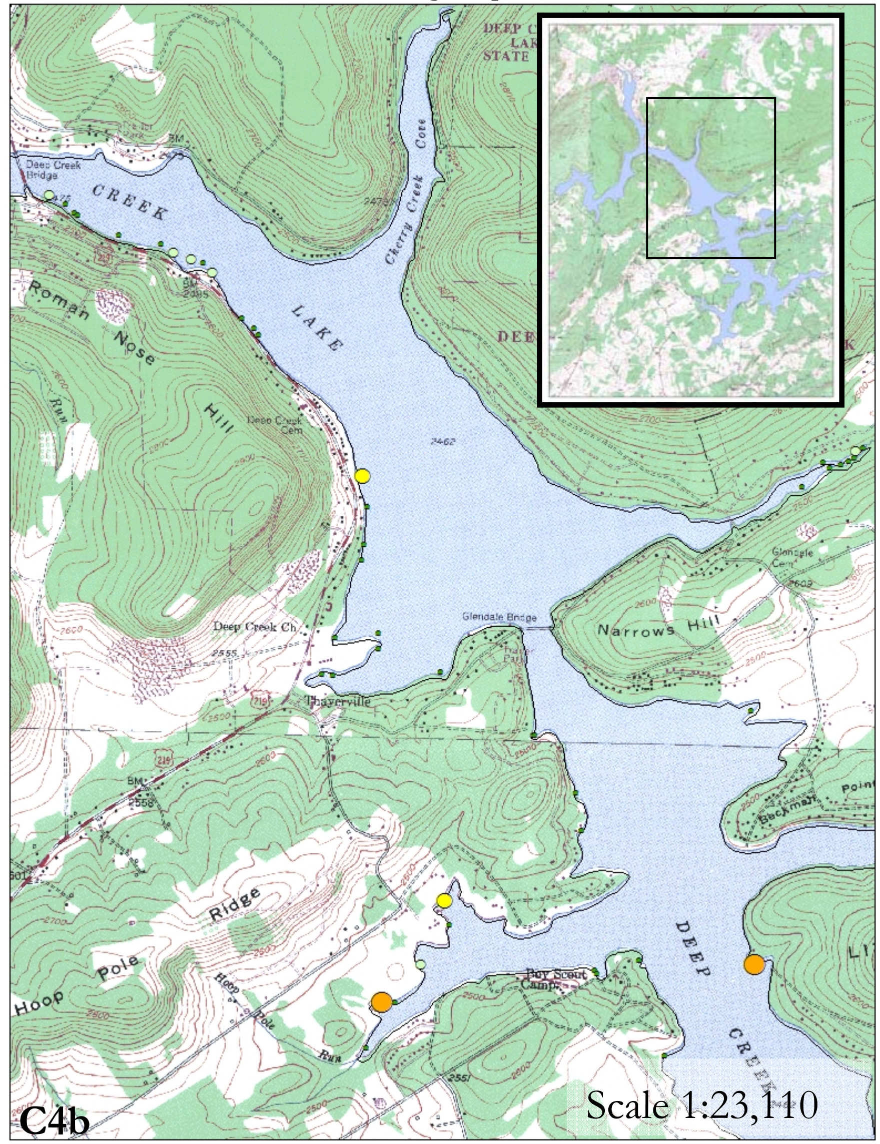


***Myriophyllum* observations**

Less than 0.1 acre	0.1 – 0.5 acres	0.5 – 1.0 acres	1.0 – 5.0 acres	5.0 – 15 acres

2013

2014



***Myriophyllum* observations**

Less than 0.1 acre

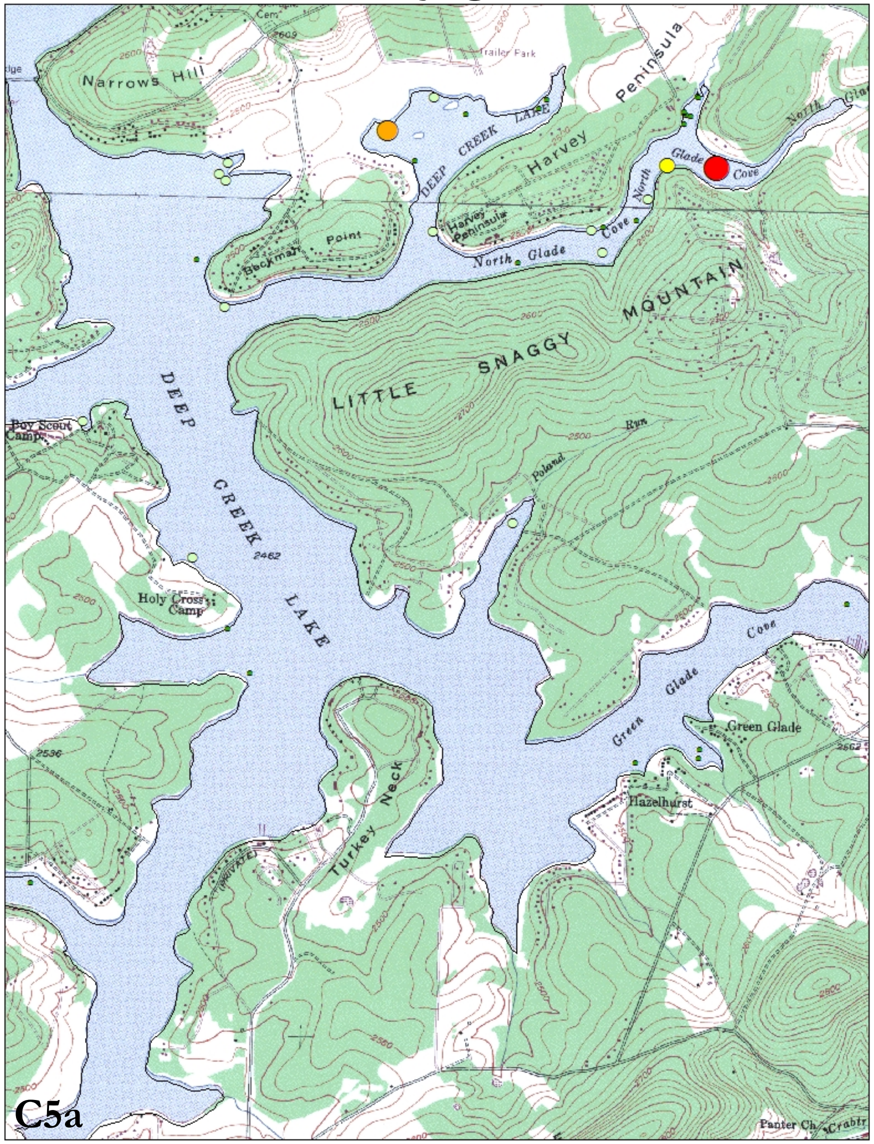
0.1 – 0.5 acres

0.5 – 1.0 acres

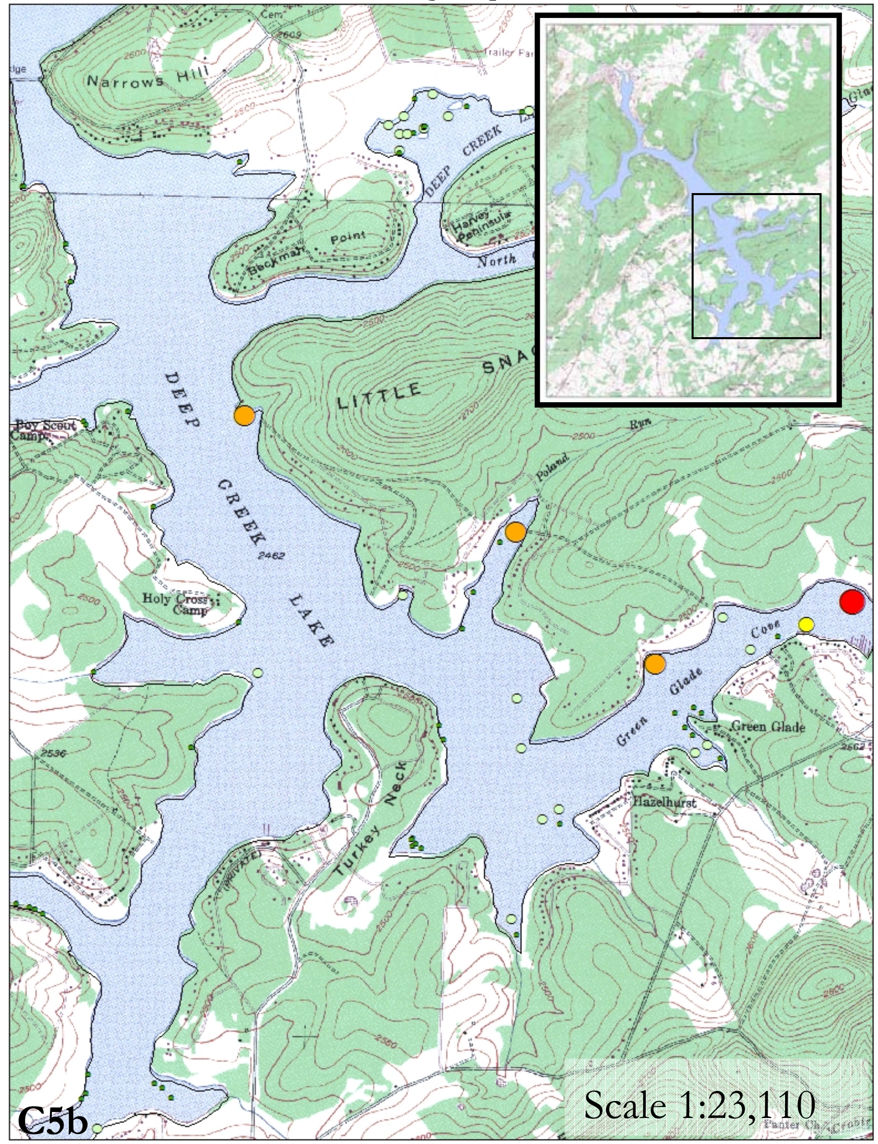
1.0 – 5.0 acres

5.0 – 15 acres

2013

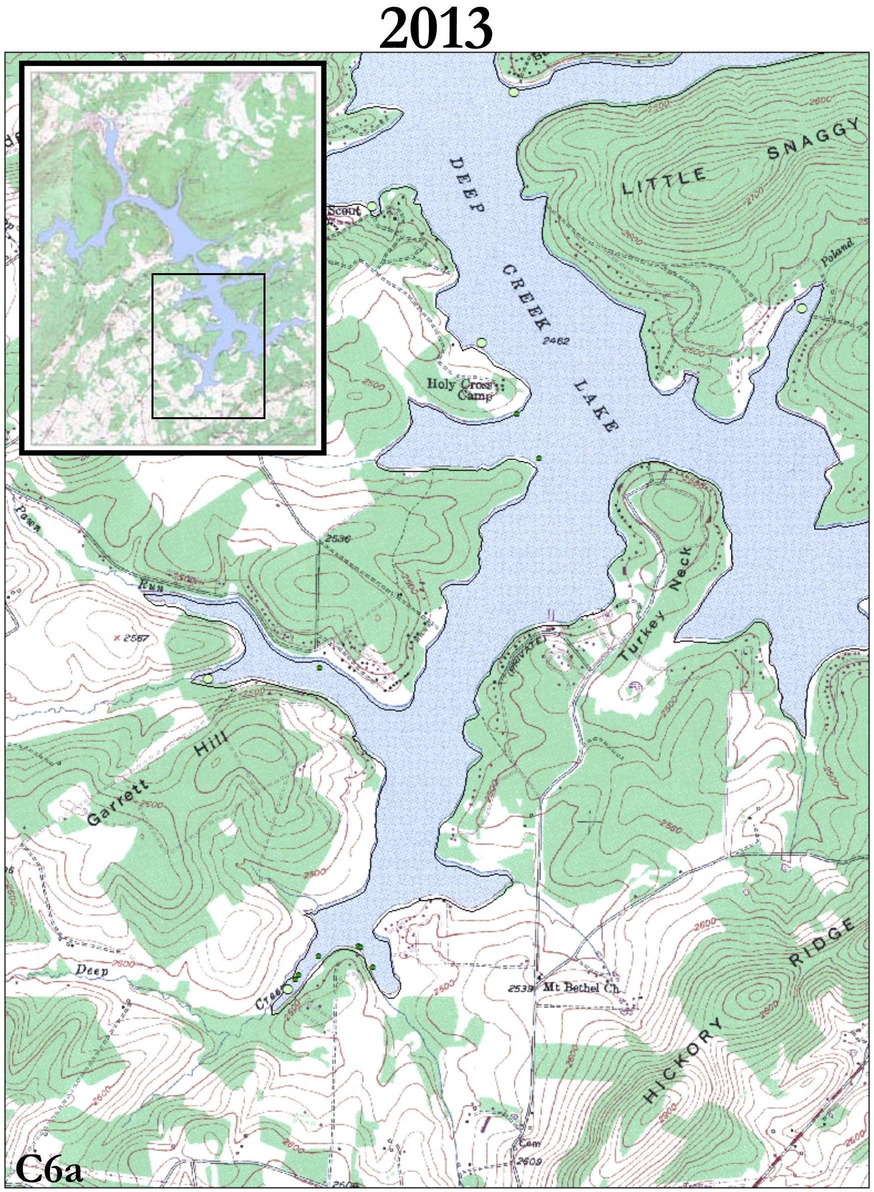


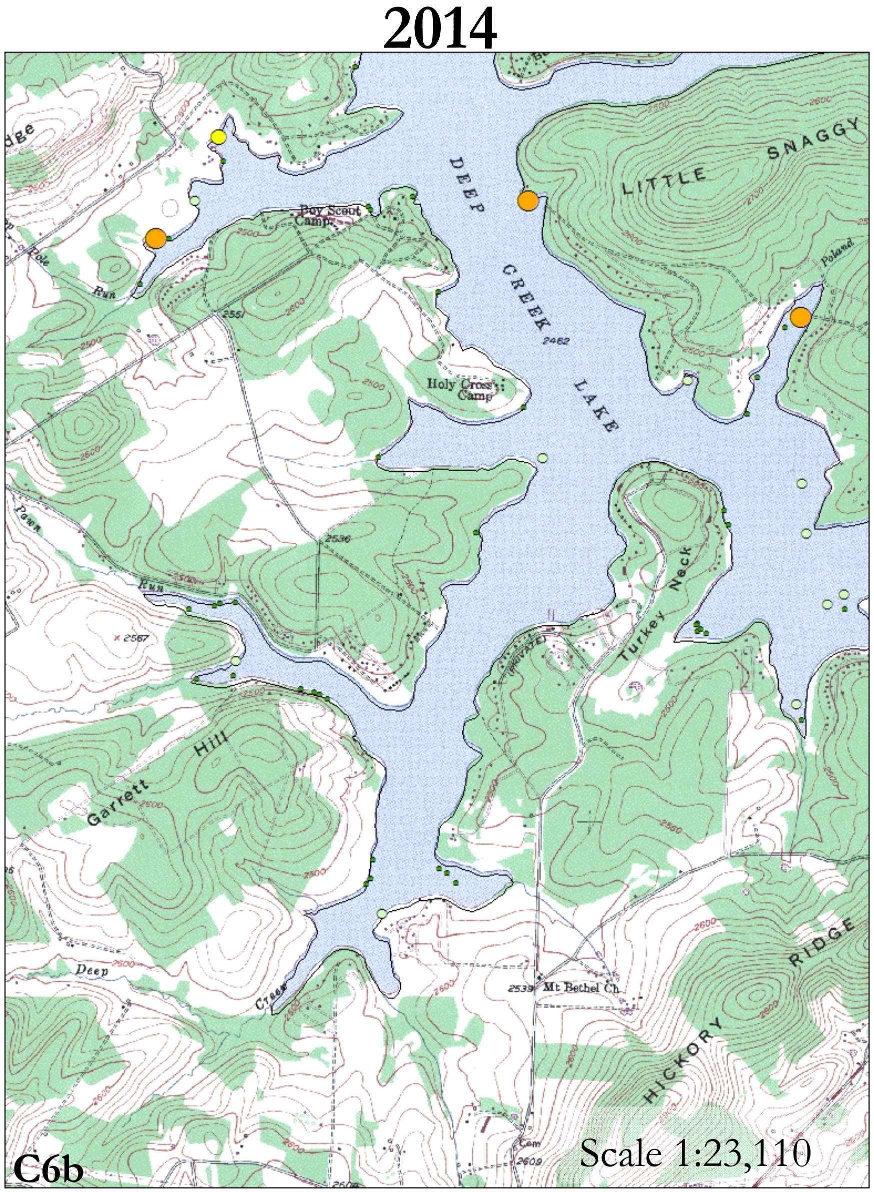
2014



***Myriophyllum* observations**

Less than 0.1 acre | 0.1 – 0.5 acres | 0.5 – 1.0 acres | 1.0 – 5.0 acres | 5.0 – 15 acres



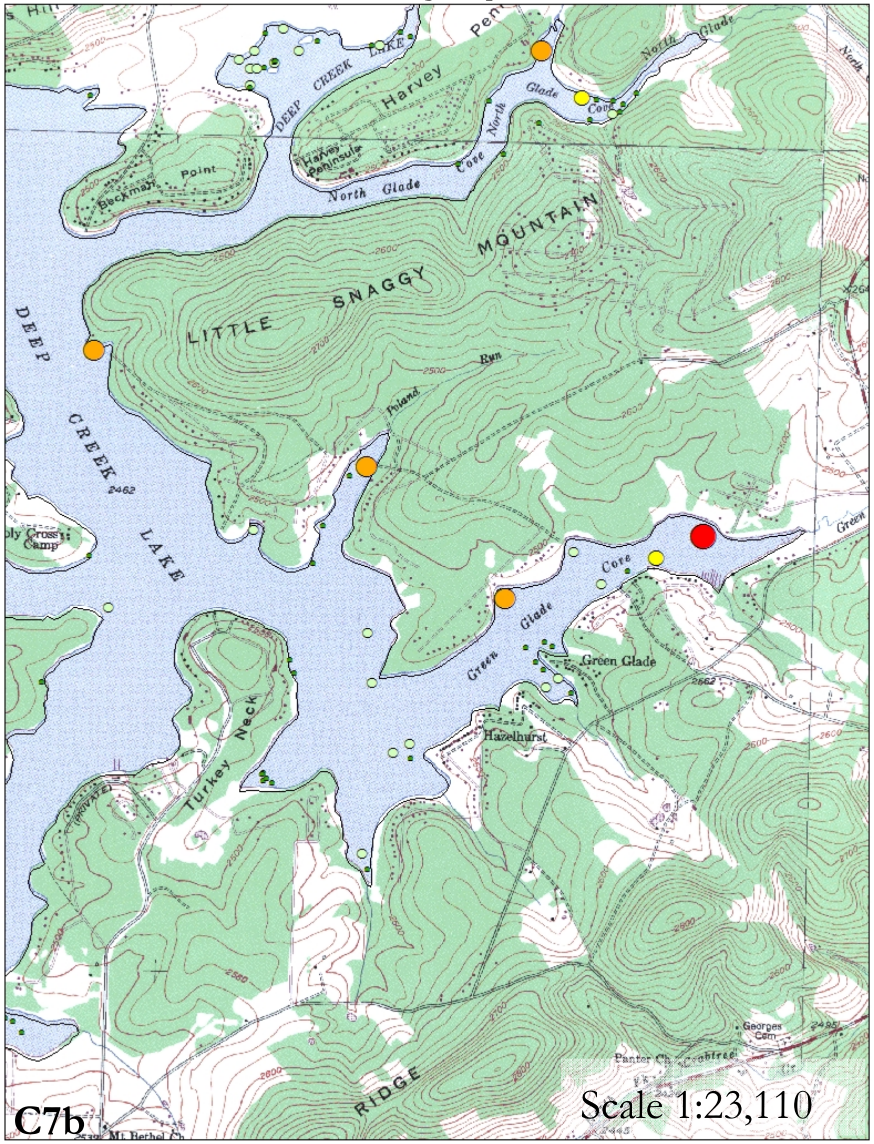


***Myriophyllum* observations**

Less than 0.1 acre	0.1 – 0.5 acres	0.5 – 1.0 acres	1.0 – 5.0 acres	5.0 – 15 acres

2013

2014



***Myriophyllum* observations**

Less than 0.1 acre

0.1 – 0.5 acres

0.5 – 1.0 acres

1.0 – 5.0 acres

5.0 – 15 acres

APPENDIX D

Deep Creek Lake

Hydrilla Management Plan and Report of Control Activity

2014

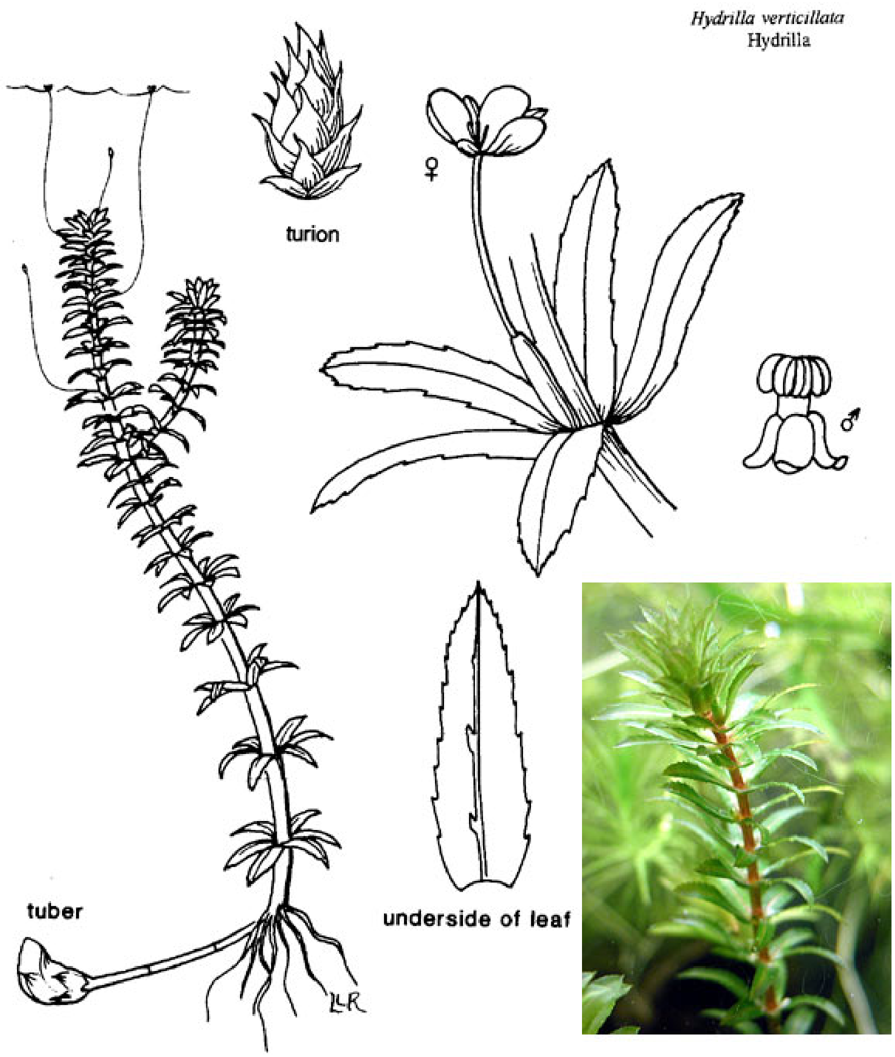


illustration provided by:
IFAS, Center for Aquatic Plants
University of Florida, Gainesville, 1990

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 1m² 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).

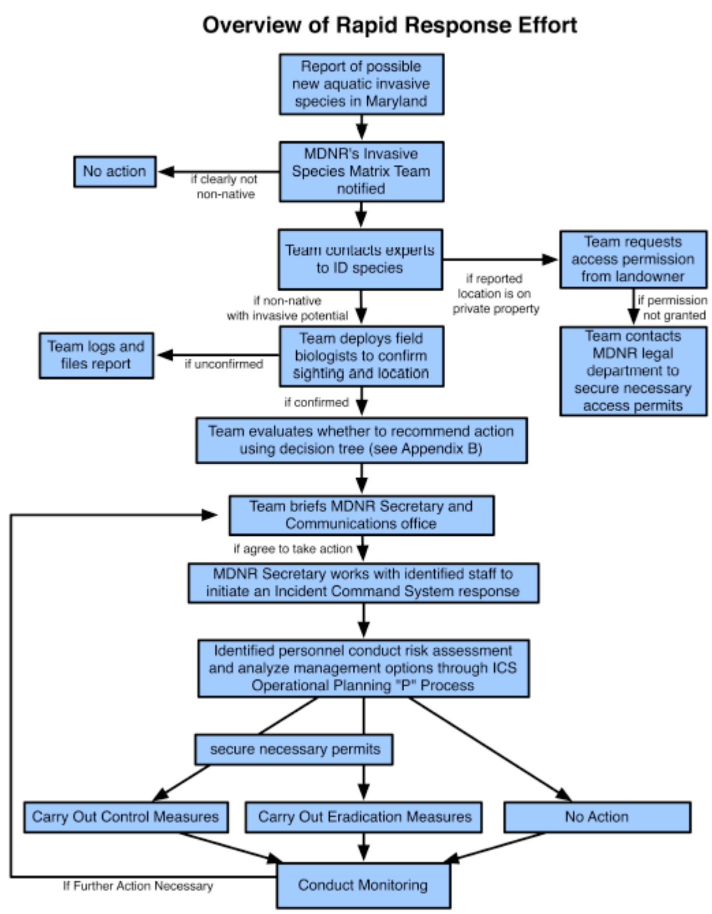


Figure 1. Diagram of the *Rapid Response Planning for Aquatic Invasive Species*

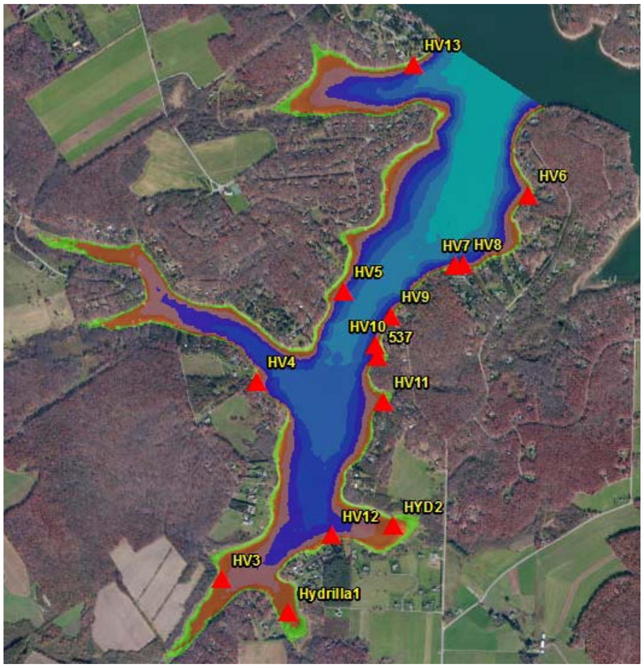


Figure 2. *Hydrilla* patches identified by DNR biologists, October 2013.

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

Herbicidal 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).

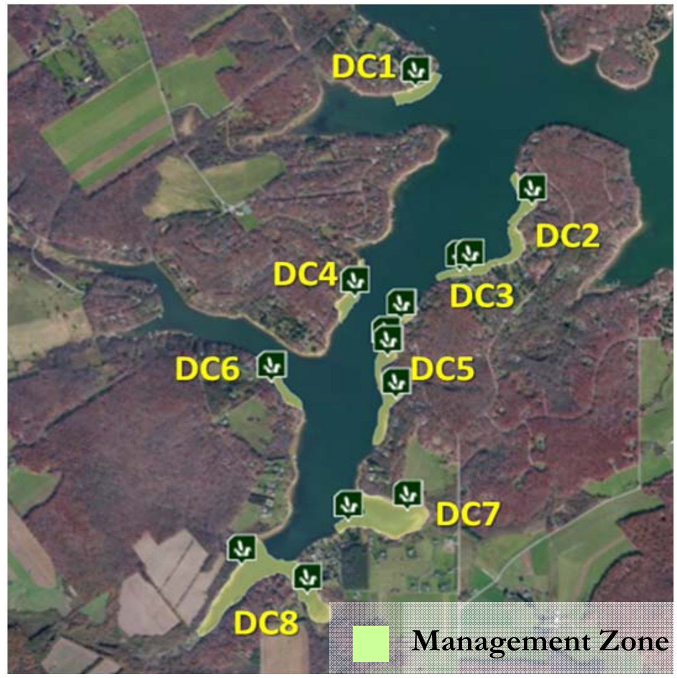


Figure 3. 2014 *Hydrilla* management zones.

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

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, and where it was most commonly used (Table 2). The two launch stewards, working simultaneously 40 hours per week, inspected 1,066 vessels between June 3rd and September 23rd. Of the boats inspected, only 23 vessels (2.2%) were carrying SAV. 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*). One boat was carrying the invasive Eurasian watermilfoil (*Myriophyllum spicatum*). The most common type of vessel inspected were ski boats (539) from Maryland that predominantly use Deep Creek Lake. Fishing boats (276) and pontoons (111) were also common, as well as skiffs (44), outboards (35), jet skis (33), and john boats (23). 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.

Management Plan and Results 2014

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. With this information, 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 only five low-dose Sonar® applications would be necessary to maintain adequate concentrations throughout the SAV growing season. Herbicide application ultimately 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.

Table 2. 2014 Launch Steward survey results.

Most Common Body of water		Most Recent Body of water		Type of vessel		State of origin	
Deep Creek Lake	479	Deep Creek Lake	454	Ski Boats	539	MD	528
Deep Creek Lake + others	30	Deep Creek Lake + others	4	Fishing Boats	276	PA	341
Other (Lakes, rivers)	201	Other (Lakes, rivers)	206	Pontoons	111	WV	66
Chesapeake Bay	39	Chesapeake Bay	28	Skiffs	44	VA	47
Youghiogheny	25	Youghiogheny	31	Outboards	35	OH	38
Monongahela	19	Monongahela	16	Jet skis (PWC)	33	NY	10
Cheat Lake	15	Cheat Lake	12	John Boats	23	DE	10
Potomac	18	Potomac	18	Sailboat	2	NJ	8
Susquehanna	14	Susquehanna	14	Dinghy	1	FL	5
Gulf of Mexico	0	Gulf of Mexico	1	Trailers	2	NC	6
Unknown	226	Unknown	283			CT	1
						IA	1
						IL	1
						IN	1
						KY	1
						TN	1
						UT	1

These areas will be included in the management plan for 2015, with positive control of these areas expected.

Management Plan 2015

The DNR Resource Assessment Service will build on the success of the 2014 Management Plan and continue with the herbicidal treatment of *Hydrilla* in DCL in 2015. The prevailing science suggests that a multi-year effort is required to achieve control in a water body (up to seven years may be necessary after the last plant is observed for total tuber control) and RAS worked again with the expert panel to develop a successful management plan for 2015.

RAS will implement a similar strategy in 2015 using multiple Sonar® pellet applications. Four new management zones will be delineated to include the four new *Hydrilla* patches, and modifications will be made to the current zones, for a total of 12 management zones (Figure 4).

DNR is working with the herbicide supply company, SePRO, to reduce application rates and possibly limit the number of applications to four in 2015. Adjusting the formulations of Sonar® may keep the dosage rate in the necessary range for the treatment period and allow for fewer treatments. The modifications in the herbicide formulations will be dependent on the morphology of the substrate, water exchange and presence/abundance of native vegetation. Isolated coves with little water flow will be treated with a different formulation than coves with more water movement or those bordering deeper, untreated waters. DNR will also add two new contact herbicides this year: Komeen® or Komeen® Crystal granular and Stingray®. These herbicides offer a different weed control spectrum and allow for more flexibility in treating new infestations.

Outreach and education efforts previously outlined will continue. Additionally, local boat rental businesses will be more involved in outreach and education efforts. 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 has entered into

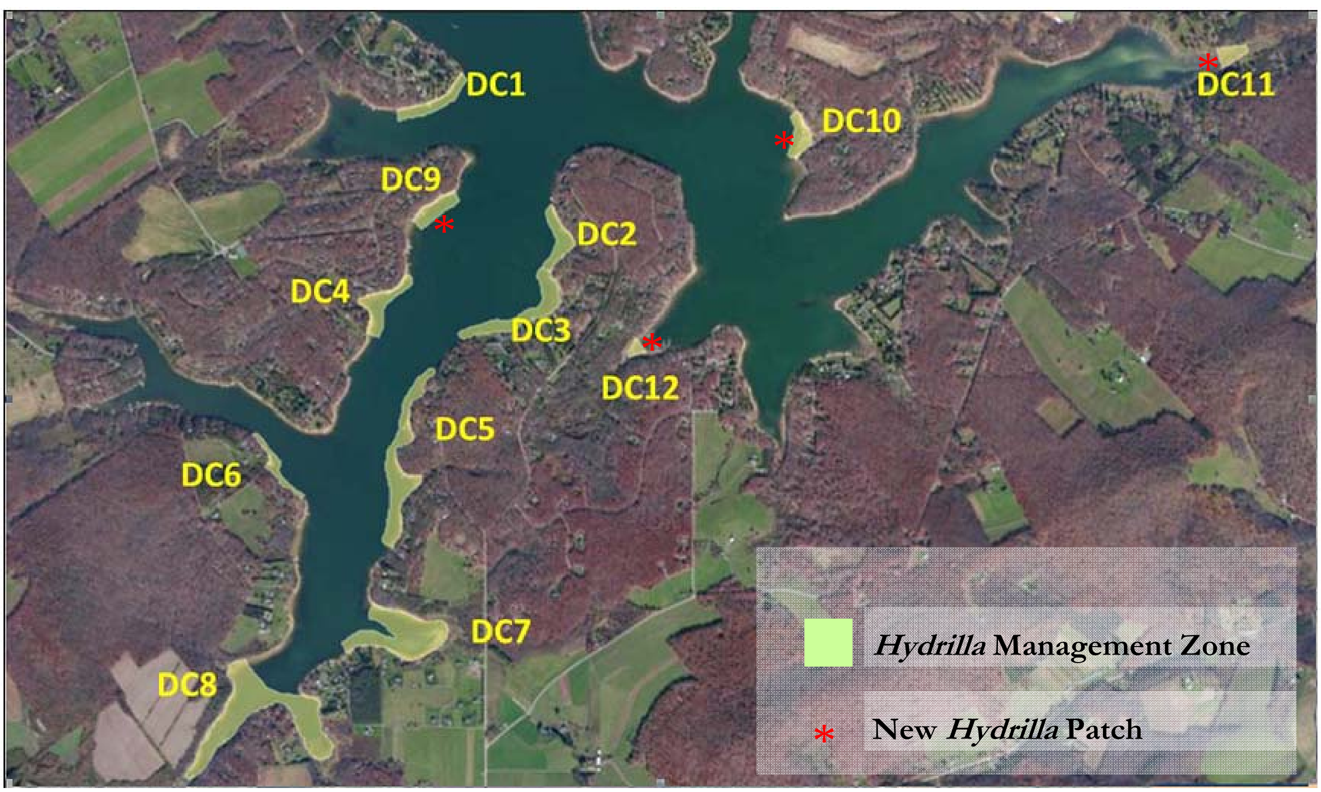


Figure 4. 2015 *Hydrilla* management zones and *Hydrilla* patches discovered in August and September, 2014.

partnership with Garrett Community College (GCC) for the 2015 season to assist with this effort. Students from the GCC Environmental Program will act as Launch Stewards, increasing the number of boats that will be inspected and expanding the hours of inspection.

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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