Maryland Department of Natural Resources

Tidewater Ecosystem Assessment

Deep Creek Lake
Submerged Aquatic Vegetation Survey
Year 4

Report of Survey Activity and Results

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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).

Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a fourth season of Submerged Aquatic Vegetation (SAV) monitoring in Deep Creek Lake (DCL), Garrett County, MD, during summer 2013 as part of the lake's expanding water quality and aquatic habitat monitoring program. The project's goal was to define the distribution and relative abundance of SAV species present by surveying transects in six representative areas throughout the lake using globally accepted methodology. In June 2012, the transect survey was expanded to include a comprehensive shoreline survey of *Myriophyllum spp*. This shoreline survey was repeated in June 2013. Following the discovery of *Hydrilla verticillata* in Deep Creek Cove in September 2013, an additional shoreline survey was completed. Monitoring objectives were to define the distribution and relative abundance of all SAV species present in the lake and to record their change over time via the study of representative transects, and to determine the location and extent of *Myriophyllum spp.* and *Hydrilla verticillata* via the shoreline surveys. Survey results are as follows:

- **The majority of observed species, as well as the physical characteristics of each survey site, showed no significant change in density or distribution from 2010 to 2013.**

- 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 were observed on the transects and during the shoreline surveys.

- *Sagittaria cristata,* (Crested arrowhead), *Vallisneria americana,* (Wild celery), *Elodea canadensis,* (Canadian waterweed), *Ceratophyllum demersum,* (Coontail), and *Myriophyllum spp.,* (Watermilfoil) were dominant vascular species observed throughout the lake. Macroalgae was also dominant in some areas.

- Species zonation is apparent at every site with *Sagittaria cristata* dominating the shallows; *Potamogeton spp., Vallisneria americana,* and *Ceratophyllum demersum* dominating the mid depths; and *Elodea canadensis, Myriophyllum spp.*, and Macroalgae most commonly observed at greater depths.

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

- *Potamogeton amplifolius* and *P. robinssii* were observed during the surveys. Both of these species are rare and 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 2013, but frequency of occurrence is trending upwards.

- 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 second *Myriophyllum* survey in 2013. Results of the survey indicate that there was both less *Myriophyllum* in June 2013 than in July 2012, and that it was more difficult to locate. These results are likely due to lower than normal spring temperatures, increased turbidity, and abnormally high water levels. *Myriophyllum* was present at 69 locations throughout the Lake at the time of the 2013 survey, and occupied less than 2% (~29 acres) of available benthic habitat.

- During the September 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 indicate that *Hydrilla* is growing in 14 locations at varying densities in the Lake, but those 14 sites are contained within the southwest leg. A panel of experts from around the country has been assembled to advice MD DNR of control options in the implementation of a Deep Creek Lake specific *Hydrilla* Management Plan.

- The high density and diversity of SAV in 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.

TABLE OF CONTENTS

INTRODUCTION

During the summer 2013 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a fourth 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 repeated the survey in summers 2011, 2012, and 2013. The 2012 summer survey was expanded to include a comprehensive shoreline survey of *Myriophyllum* species (including Eurasian Watermilfoil, an invasive species). This survey was repeated in 2013. An additional shoreline survey was initiated in October 2013 to document the spatial extent of the newly observed *Hydrilla verticillata* (also an invasive species) in the lake. Our 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 surveys. 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 RAS and Park Service.

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 very shallow coves.

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).

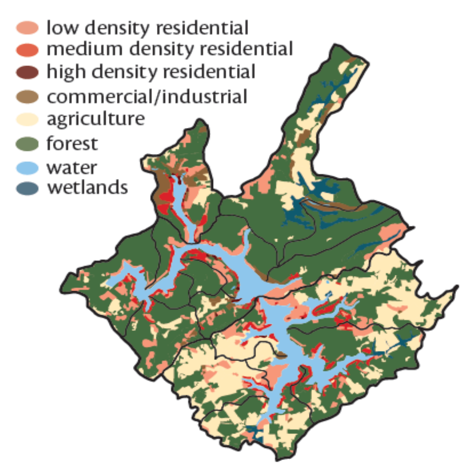

Figure 1. Land uses in the Deep Creek Lake watershed.

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 all 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 thought to be 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 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 in Oakland (-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.

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

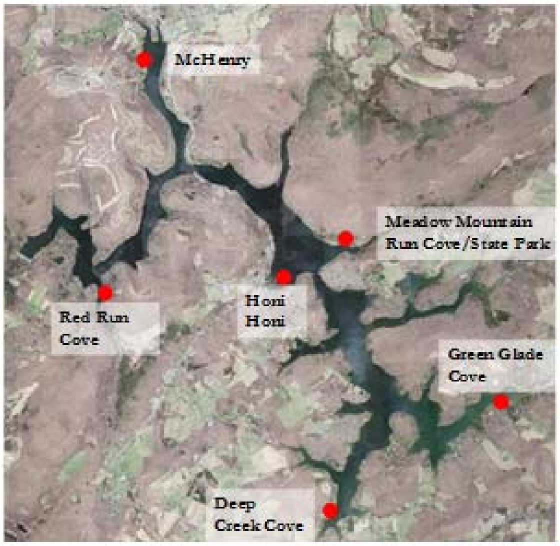

Figure 2. Aerial map of Deep Creek Lake with MD DNR SAV transect locations indicated by red dots.

Table 1. Transect names and abbreviations.

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

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 0.25m^2 quadrats per transect. To establish the sampling positions, the transect lengths were divided by 10 for a total of 11 quadrats per transect. For example, if a transect was 100 meters long, quadrats were sampled at 0m, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90, 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 years 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, and on June 20th, August 15th, and September 27th, 2013. In August, 2013, the transect at McHenry was not surveyed due to a sewage spill in the vicinity.

On June 16th, 2013, the *Myriophyllum* survey was conducted of the entire 68-mile shoreline to determine the location and extent of the plant, and to determine change in extent from 2012. The survey was conducted 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 *Myriophyllum* using the hand-held GPS. 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.

On October 21st, 2013, after the discovery of the invasive species *Hydrilla verticillata* near the Deep Creek Cove transect on September 27, 2013, an additional survey was conducted of the entire 68-mile shoreline to determine the location and extent of *Hydrilla verticillata*. The survey was conducted over a two-day period using two boats and the same methodology as the *Myriophyllum* survey.

<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% <u>or</u> frequency of occurrence being equal to or greater than 50%. To determine dominance for sampling year 2010, a species/genus had to be found dominant during both sampling events that took place that year. For sampling years 2011-2013, 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 were entered into Sigma Plot graphing software and bar charts were created. To show observed changes in *Myriophyllum* specifically, frequency of occurrence and density data for this genus were also entered into 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 the SAS statistical software package (Enterprise Guide 5.1, SAS Institute Incorporated, Cary, NC). Species richness and diversity, Total SAV density and Total Macroalgae density were compared over time and among sites using 3-Way ANOVAs. Individual species density and frequency of occurrence were also assessed in order to determine differences over space and time using 1-Way ANOVAs. Homogeneity of variances was assessed using Levene's test. Following a significant ANOVA ($p \leq 0.05$), pairwise comparisons were performed using Bonferroni's test.

Data collected during the *Myriophyllum* and *Hydrilla* shoreline surveys were transferred from hand-held Garmin GPS units into ArcGIS for mapping and analysis (ArcGIS Desktop 9.3. Redlands, CA: Environmental Systems Research Institute). To determine the area affected by these invasive species, polygons were drawn based on GPS points and notes from the field and were merged to create maps of *Myriophyllum* and *Hydrilla* distribution.

RESULTS

We observed ten genera of vascular aquatic plants and two species of macroalgae during our 2010, 2011, 2012, and 2013 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*, a species thought to be extirpated from Maryland waters, *P. pusillus, P. vaseyii, P. spirillus,* and *P. diversifolius. Potamogeton amplifolius* (also believed to be extirpated from Maryland waters) and *P. nodosus* were 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 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 diving, *Myriophyllum spp*. were only identified and recorded at the genus level for the SAV transect survey. 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, maximum water depth, Total SAV density, Total Macroalgae density, species richness, and density and frequency of occurrence for Total Macroalgae and 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

Table 2. List of SAV species/genera observed in Deep Creek Lake during summers 2010-2013 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	**Water thyme**
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

Appendix B, compliment the bar charts in Figure 3 but more clearly display the quadrat by quadrat relationship between SAV and macroalgae. In most 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, Table 3), 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. Total SAV in RRC showed a slightly decreasing though statistically insignificant trend from 2010-2013, despite a spike in SAV density in June 2013. There was, however, a significant overall decrease in Macroalgae at this site between 2010 and 2013, although data indicate that Macroalgae density oscillates over time (Figure 3). *Myriophyllum* was observed at low densities in RRC during every sampling event, but its frequency of occurrence spiked dramatically in 2013, as seen in Figure 4.

Table 3. Summary of sampling results, including date, transect length, maximum water depth, Total SAV density, Total Macroalgae density, species richness, and density and frequency of occurrence (in parentheses) for each SAV and macroalgae species observed during each survey.

Date	ID	Length (m)	Max Depth (m)	Richness	SAV Density	MA Density	Sc	Va	Ec	Cd	Myr	Nf	Ng	Uv	Iso	Pp	Pr	Pv	Ps	Pd
8/4/10	RRC	127	3.3	9	35	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)
9/15/10	RRC	125	3.7	7	33	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)
6/14/11	RRC	100	4.1	5	48	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)
8/9/11	RRC	110	3.7	7	71	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)
9/12/11	RRC	100	3.3	6	41	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)
6/27/12	RRC	100	3.6	7	58	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)
8/22/12	RRC	110		7	42	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)
9/19/12	RRC	100		7	39	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)
6/20/13	RRC	100		6	71	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)
8/15/13	RRC	100		9	29	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)
9/27/13	RRC	90		7	31	6(55)	12(36)	0(0)	1(27)	0(0)	I2(100	0(0)	0(0)	10(18)	<1(9)	0(0)	0(0)	<1(45)	0(0)	0(0)
8/4/10	McH	80	4.0	5	34	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)
9/15/10	McH	90	4.0	7	14	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)
6/14/11	McH	77	5.3	4	4	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)
8/9/11	McH	90	4.8	8	10	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)
9/12/11	McH	60	4.0	7	16	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)
6/27/12	McH	100	5.4	7	12	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)
8/22/12	McH	90		5	30	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)
9/19/12	McH	75		7	30	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)
6/20/13	McH	50		6	19	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)
8/15/13	McH	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
9/27/13	McH	30		3	35	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)
8/5/10	HHO	195	5.8	6	38	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)
9/15/10	HHO	200	3.0	5	46	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)
6/14/11	HHO	150	5.6	7	40	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)
8/9/11	HHO	180	5.0	9	44	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)
9/12/11	HHO	162	4.1	8	29	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)
6/27/12	HHO	180	6.3	7	37	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)
8/22/12	HHO	180		6	36	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)
9/19/12	HHO	190		6	72	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)
6/20/13	HHO	150		8	39	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)
8/15/13	HHO	150		6	22	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)
9/27/13	HHO	140		5	23	<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)
8/5/10	MMR	63	3.0	6	51	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)
9/15/10	MMR	60	3.9	3	51	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)
6/14/11	MMR	55	4.1	4	35	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)
8/9/11	MMR	55	2.9	8	46	<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)
9/12/11	MMR	60	4.0	4	51	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)
6/27/12	MMR	55	4.2	7	46	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)
8/22/12	MMR	60		7	54	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)
9/19/12	MMR	60		5	65	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)
6/20/13	MMR	50		6	46	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)
8/15/13	MMR	55		4	57	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)
9/27/13	MMR	45		3	67	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)
8/5/10	DCC	200	2.5	7	87	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)
9/16/10	DCC	200	2.3	7	68	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)
6/14/11	DCC	200	3.0	4	70	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)
8/9/11	DCC	200	2.7	8	58	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)
9/12/11	DCC	200	3.7	6	54	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)
6/27/12	DCC	200	3.0	6	29	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)
8/22/12	DCC	200		4	52	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)
9/19/12	DCC	200		6	68	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)
6/20/13	DCC	200		8	38	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)
8/15/13	DCC	200		10	55	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)
9/27/13	DCC	200		8	41	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)
8/5/10	GGC	70	3.0	5	49	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)
9/15/10	GGC	70	3.5	4	31	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)
6/14/11	GGC	65	3.4	5	26	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)
8/9/11	GGC	55	3.6	7	68	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)
9/12/11	GGC	54	4.0	5	36	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)
6/27/12	GGC	65	3.4	4	48	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)
8/22/12	GGC	66		6	31	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)
9/19/12	GGC	80		6	48	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)
6/20/13	GGC	50		8	26	<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)
8/15/13	GGC	40		7	36	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)
9/27/13	GGC	40		7	26	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)

The SAV bed surveyed near McHenry (McH) (transect length from 30-100m and max depth of 5.4m, Table 3), 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. We did not survey this transect in August, 2013 due to a sewage spill in the vicinity. Interestingly, Macroalgae density was relatively high at this site in June, 2013. By September, post sewage spill, Macroalgae was completely absent on the transect. 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. Regardless of missing data from August 2013, Total SAV and Total Macroalgae showed opposite trends at this location (Figure 3). SAV increased between 2010 and 2013, while Macroalgae decreased. *Myriophyllum* was only observed in trace amounts and low frequencies during five of the eight sampling events (Figure 4), and it did not change significantly over time.

The SAV bed surveyed near the Honi Honi in Oakland (HHO), on the western shore of the central lake area, was a long transect (ranging from 140-200m) with the greatest maximum depth (6.3m) (Table 3). 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* (Table 4). Both Total SAV and Total Macroalgae density graphs show decreasing trendlines at this location, but statistical analyses indicate that the change was not significant (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).

Table 4. Dominance by site and year, where dominance is defined as density being equal to or greater than 10% <u>or</u> frequency of occurrence being equal to or greater than 50%. To determine dominance for 2010, a species/genus had to be found dominant during both sampling events that took place that year. For years 2011, 2012, and 2013, in which three sampling events took place, a species/genus had to be found dominant during two of the three sampling events.

2010

	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

	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

	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

	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	

Across the lake from Honi Honi, the SAV bed surveyed offshore of the State Park in Meadow Mountain Run Cove (MMR) was dominated by *S. cristata* and *V. americana* during all four summers (Table 4). This transect ranged from 45-63m with a max depth of 4.2m (Table 3). Both Total SAV and Total Macroalgae showed increasing trends at this location, but neither increased significantly between 2010 and 2013. 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 and max depth of 3.7m, Table 3). 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. Total SAV in DCC decreased between 2010 and 2013, while Total Macroalgae increased significantly (Figure 3). *Myriophyllum* was present in low densities during most sampling events, and did not change over time. Frequency of occurrence increased between 2010 and 2013, but not significantly (Figure 4). At this site during the September 2013 survey, *Hydrilla verticillata* was discovered floating near the transect. A search led to the source of the floating plants in a nearby cove and later to an entire shoreline survey to determine the extent of the invasion. 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 (Table 3). 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, Macroalgae joined *S. cristata* as a co-dominant (Table 4). Both Total SAV and Total Macroalgae showed a decreasing trend between 2010 and 2013, but only macroalgae decreased significantly (Figure 3). *Myriophyllum* was present in low densities during most sampling events, but it did not change significantly over time. Frequency of occurrence increased significantly in 2013 (Figure 4).

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 the exception of the transect at McH during the June 2012 and June 2013 sampling. 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, E. canadensis, Myriophyllum,* and the two species of macroalgae (which have lower light requirements), *C. vulgaris* and *Nitella flexilis*.

Sagittaria cristata, E. canadensis and Macroalgae were the dominant species observed at our sites during the four year monitoring period (2010-2013). *Potamogeton pusillus* and *P. vaseyii* were observed at least once at all six sites, but at very low densities. 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 significantly higher at DCC than at the other sites. *Myriophyllum* density was significantly higher at HHO (13) than other sites (0-4.5), and *Myriophyllum* was also observed more frequently at HHO (48% of quadrats) and RRC (48%) than at other sites (0-12%).

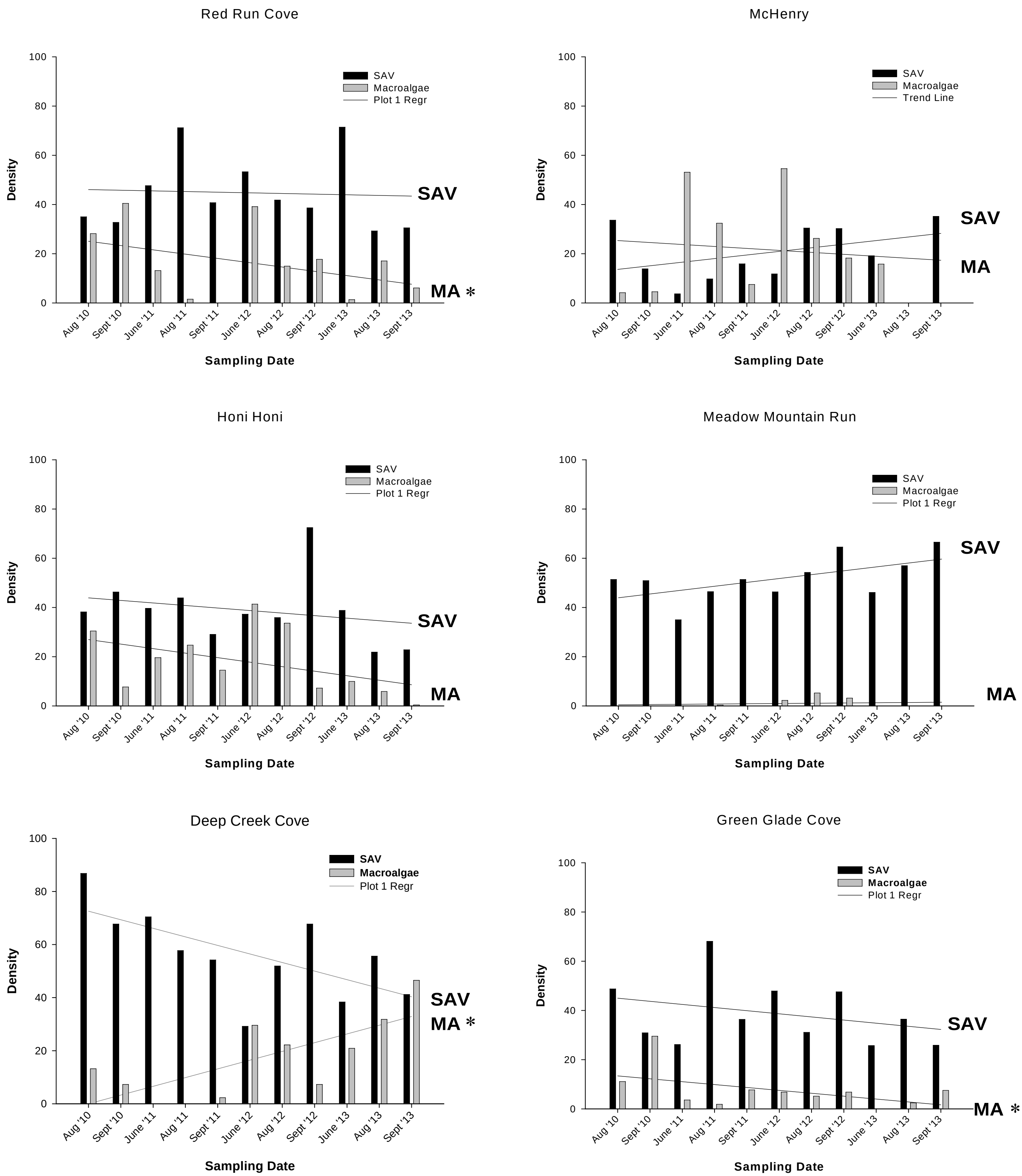

Figure 3. Total SAV and Total Macroalgae Density (where Density = sum of % cover values/total # of quadrats) graphed over time for each transect, with corresponding trend-lines showing overall increasing, decreasing, or no-change trends. Asterisks (*) indicate significant ($p \leq 0.05$) change from 2010 to 2013.

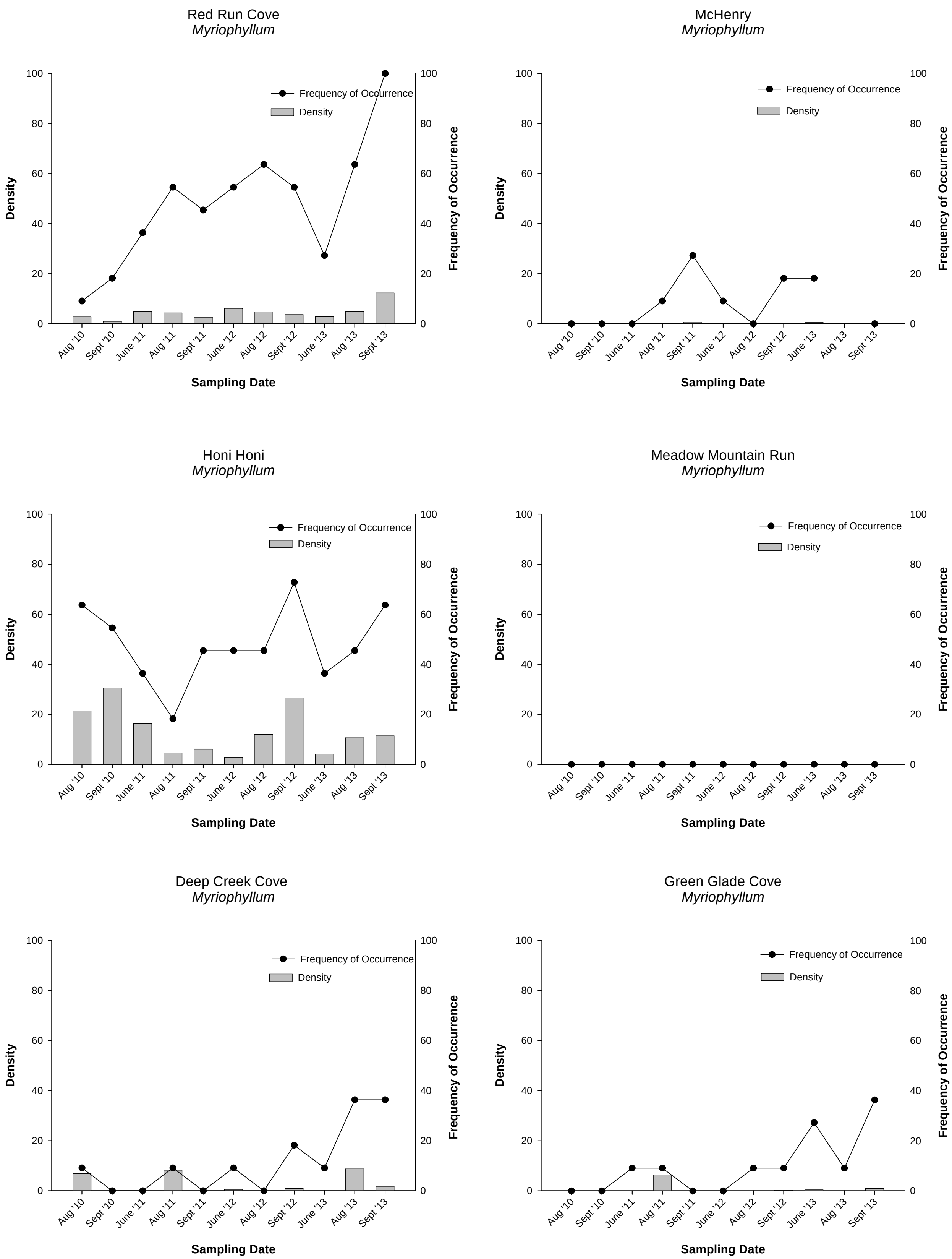

Figure 4. *Myriophyllum* Density (bars, where Density = sum of % cover values/total # of quadrats) and Frequency of Occurrence (point and line, where Frequency = # of quadrats where observed/total # quadrats) graphed over time for each transect.

Total SAV density, Total Macroalgae density, species richness and species diversity were all significantly different among sites. DCC contained the highest SAV coverage. MMR also had significantly higher SAV coverage and the lowest percent cover of Macroalgae. Observed macroalgae cover was significantly higher at McH, HHO, DCC, and RRC compared to the other sites. RRC also had the highest species richness and diversity, while McH had the fewest species observed. SAV cover and species diversity were significantly lower at McH than any other site.

While the SAV transects surveyed represent the lake as a whole, the comprehensive shoreline survey for *Myriophyllum* allowed us to map the lake-wide spatial extent of that genus specifically. With this sampling design, in 2012 we identified 130 locations with *Myriophyllum*, totaling approximately 86 acres where *Myriophyllum* was present at varying densities. 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 zone in which plants may grow in Deep Creek Lake. The remaining 94.2% of habitat within the photic zone was free of *Myriophyllum*.

This survey was repeated in June 2013. During this survey, *Myriophyllum* was only identified at 69 locations throughout the lake (Figure 5), 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.

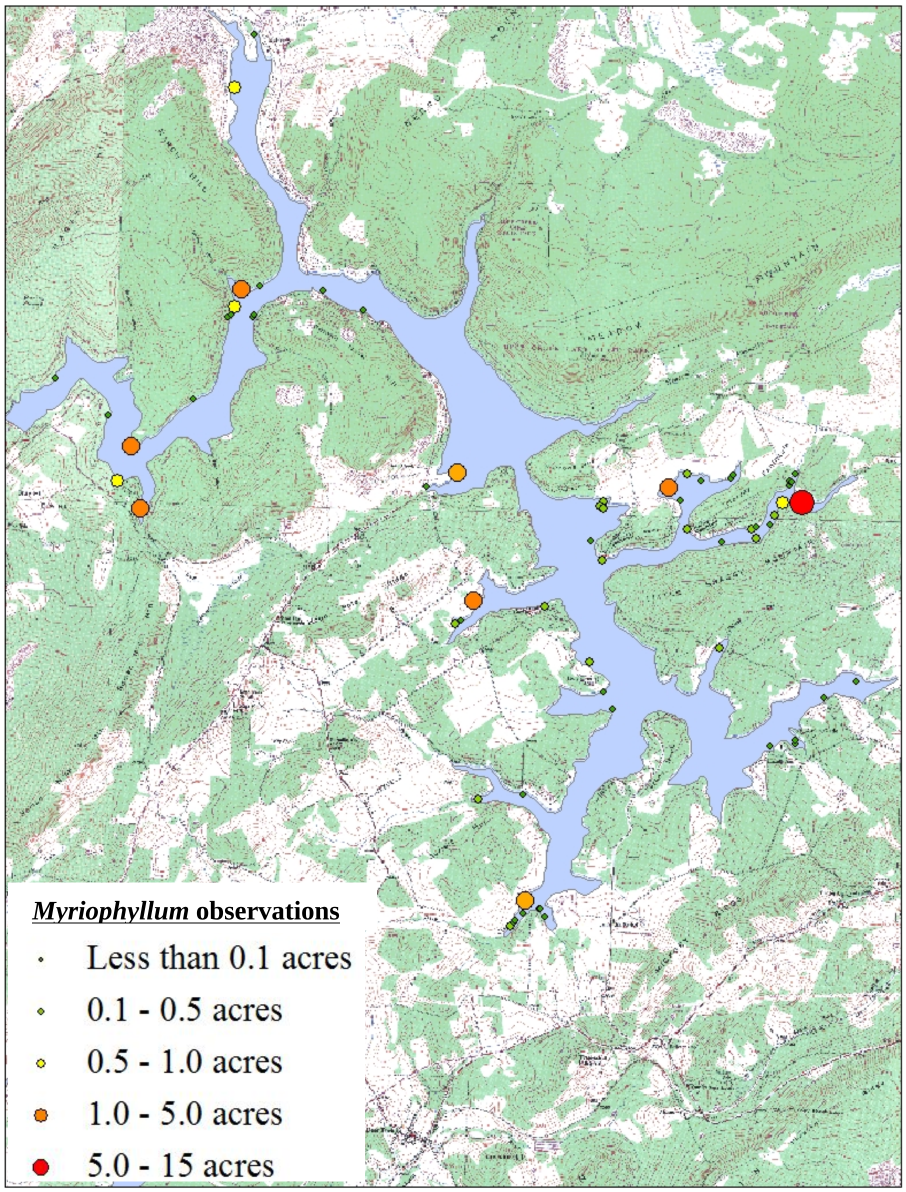

Figure 5. Results of 2013 *Myriophyllum* shoreline survey. *Myriophyllum* observations are shown in acres, with symbol size proportional to patch size.

Appendix C includes more detailed maps of both the 2012 and 2013 *Myriophyllum* observations throughout the lake with symbol size proportional to patch size. In 2012, during the survey, the majority of *Myriophyllum* was observed in the southern portion of the lake (Figure C1, C5-C7). In 2013, larger patches are not concentrated in the southern lake.

The *Hydrilla* survey was conducted in an identical manner to the *Myriophyllum* survey. The entire lake shoreline was surveyed, but *Hydrilla* was only observed at 14 locations, all in the southwest leg of the lake (Figure 6). The patches at the 14 sites range in size from 1 square foot to 5 acres. In most instances, *Hydrilla* was observed as small patches throughout SAV beds composed of several other species.

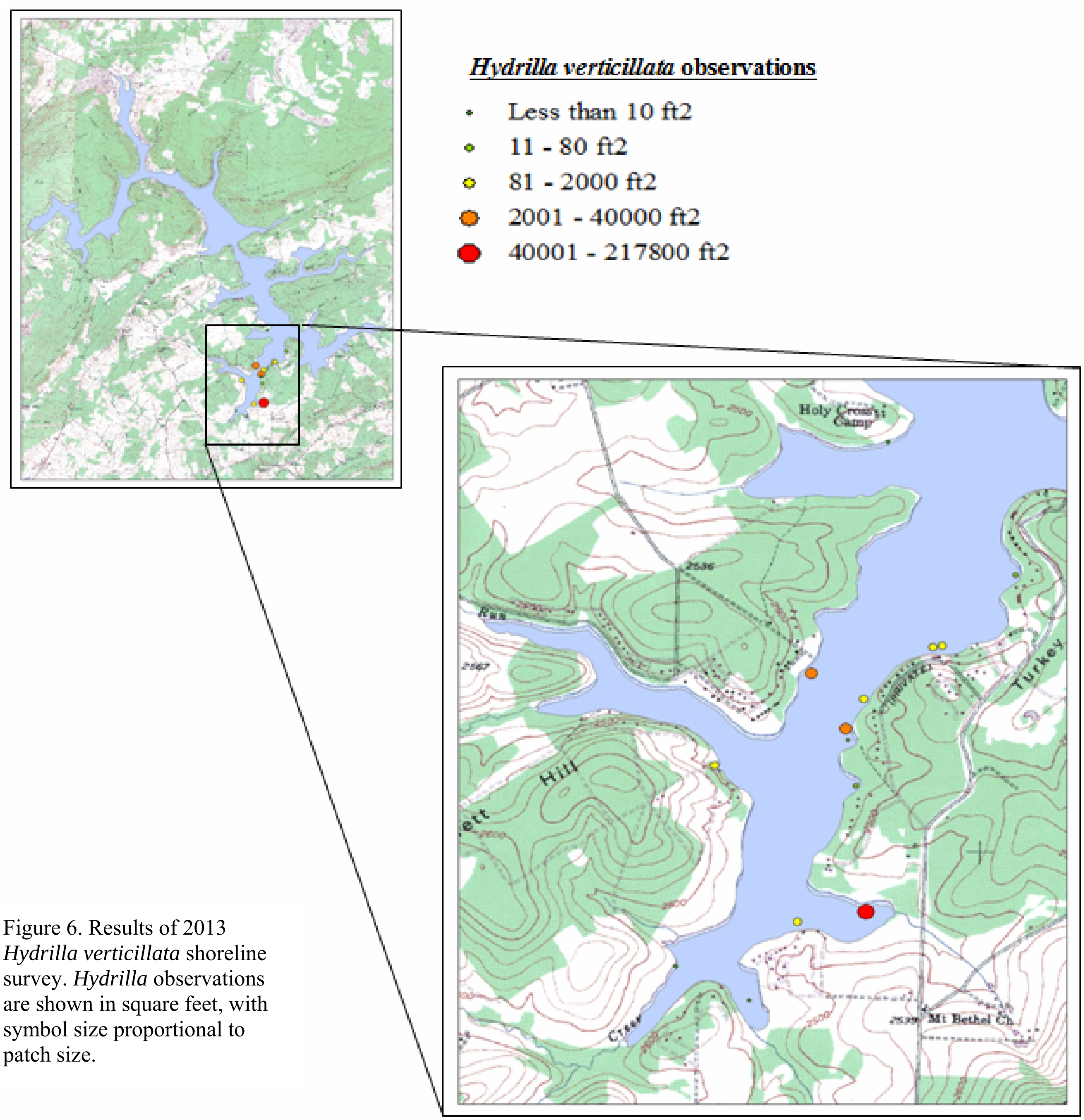

Figure 6. Results of 2013 *Hydrilla verticillata* shoreline survey. *Hydrilla* observations are shown in square feet, with symbol size proportional to patch size.

DISCUSSION and CONCLUSION

The goal of the SAV transect survey was to define the distribution and density of the SAV community at several representative sites throughout Deep Creek Lake. As such, the results of the survey provide a comprehensive analysis of the Lake's SAV community as a whole and how this community changes in space and time. The transect survey methodology is a globally accepted method to identify changes in an SAV community; it does not focus on any one species over another, as did our *Myriophyllum* and *Hydrilla* shoreline surveys. Our results indicate that DCL supports a healthy and diverse population of SAV, including 10 genera of vascular plants and 2 species of macroalgae. These SAV observations include two rare species of *Potamogetons* thought to be extirpated from Maryland waters. The distribution and density of these species differ primarily by site, with annual variations occurring occasionally. The majority of observed species, as well as the physical characteristics of each survey site, showed no significant change in density or distribution from 2010 to 2013.

Aside from some shallow water areas, the water in Deep Creek Lake is clear and allows light to penetrate to impressive depths. SAV and macroalgae were observed growing as deep as 5-6 m on some transects with species zonation 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 almost every sampling event. 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 transects extended into deeper water. All of these species can form canopies from 0.5-2m 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 transects and SAV beds, we were more likely to observe *Elodea canadensis, Myriophyllum*, and Macroalgae. *Elodea canadensis* and *Myriophyllum* can form canopies greater than 2m in clear water. One of the most notable observations made was an SAV bed extending into greater than 5m of water at the transect site near the Honi Honi in Oakland. Submerged aquatic vegetation observed here included *Myriophyllum* that grew nearly to the surface, and Macroalgae

Myriophyllum density and frequency of occurrence was higher at HHO than at the other sites. Although we observed a dramatic increase in frequency of occurrence of *Myriophyllum* at RRC from 2010 to 2013, density did not change over time in that cove. Neither *Myriophyllum* density nor frequency of occurrence changed significantly over time in any of the other surveyed coves except GGC, where frequency of occurrence increased significantly by 2013. The 2013 *Myriophyllum*-specific shoreline survey indicated that this nuisance plant was present at varying densities in 29 acres of the lake and occupies less than 2% of available benthic space for vegetative growth. This number is down from 2012 when 130 patches were observed covering 86 acres. The reduction in *Myriophyllum* observations is most likely due to abnormally high lake levels, higher turbidity, and a very cool spring. In June, 2013, there was consequently less grass, and because of the conditions, it was more difficult to locate. By September, 2013, it was clear that *Myriophyllum* had not, in fact, decreased in abundance, although it was likewise observed that *Myriophyllum* was still not forming monoculture stands to the exclusion of native species. It remains the opinion of DNR SAV biologists that *Myriophyllum* is currently not a problem in Deep Creek Lake, but that it should be monitored carefully.

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

As a final competitive edge, when *Hydrilla* was introduced into the United States, it came without the various natural controls that evolved with it, such as insects and diseases specialized for attacking it.

At this time, MD DNR has solicited the input of *Hydrilla* experts around the country, and has formed an advisory panel. The panel is currently formulating a *Hydrilla* Management Plan specific to the needs of Deep Creek Lake. Fortunately, *Hydrilla* has not been observed growing outside of the south-western leg of the lake. Having it isolated to one area will make management and control significantly more straightforward. Regardless, even carefully designed efforts to control aquatic plants may have unanticipated and adverse impacts on the lake ecosystem, so while management action will be forthcoming, it will not be implemented without extensive care and research.

The best possible way to prevent further expansion of either *Myriophyllum* or *Hydrilla* is to promote the growth of native species, to boat responsibly in areas where they are growing, and to develop ways to prevent further introduction or spread of any invasive species.

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APPENDIX A

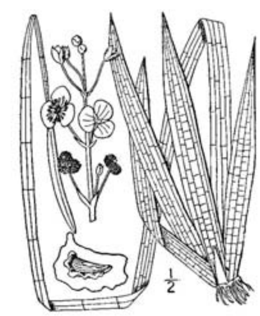
Deep Creek Lake Plant Guide

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 - 2013 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).

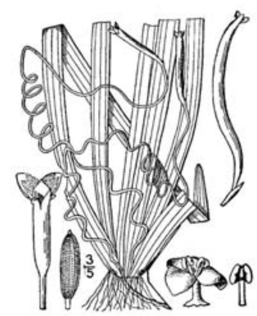
Crested arrowhead grows along the margins and bottoms of shallow lakes, ponds, and swamps. It may grow up to 75 cm tall, though in DCL it hasn't been observed more than 10 cm high. Flowering occurs July through August.



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)**

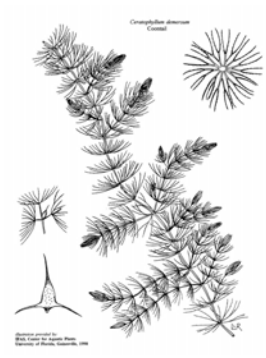
Monocot. Perennial. Native to the continental US and Canada, but considered Invasive in Puerto Rico. Distributed in all but three continental US states: TX, LA, and GA.

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.

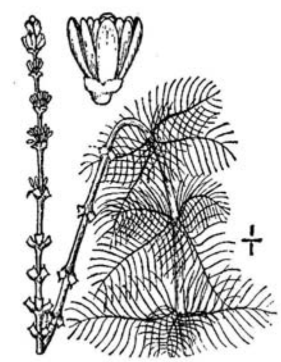
Coontail's leaves grow in crowded whorls which make it resemble a raccoon's tail underwater. Each leaf is forked into segments with fine teeth on one side of the leaf margin. Leaves are brittle and keep their shape out of water. Coontail may float in dense mats beneath the surface and its base is only 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.



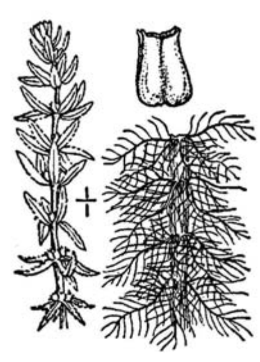
Dispersal through vegetative means is Eurasian watermilfoil's main reproductive strategy. The plant goes through autofragmentation during the growing season, where roots will develop at the nodes and the plant will break off at these nodes on its own. Fragments can also be produced by wind, waves, and human activity. These fragments will set root and grow into a new plant. New shoots begin to grow from the overwintering root crowns when water temperature reaches about 60^{o} F in the spring. Flowering generally occurs in July. Autofragmentation usually occurs after flowering. Plants die back to the roots in the fall. These roots store carbohydrates in order to initiate the rapid growth in the spring.

***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.

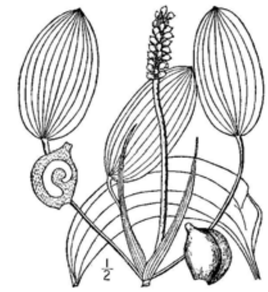
Not previously documented in Maryland, Vasey's pondweed is considered threatened, endangered, or of special concern where found in northeastern US states. It grows in quiet waters and has dimorphic leaves: very narrow, flaccid, submersed leaves and wider, thicker floating leaves.

***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.

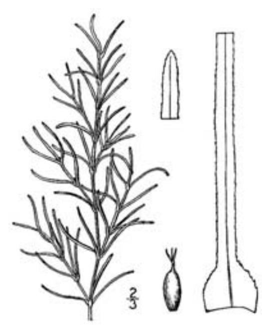
Longleaf pondweed can be found in ponds, lakes, ditches, and streams. It produces a thin, branching stem easily exceeding a meter in maximum length. Leaves are linear to widely lance-shaped and up to 15 centimeters long by 4 wide. Both floating leaves and submerged leaves are borne on long petioles. 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.

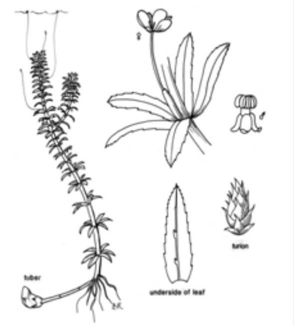
Najas guadalupensis (Southern naiad)
Monocot. Annual. Native to the continental US, Puerto Rico, and Canada. Invasive to Hawaii. Distributed throughout US.

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



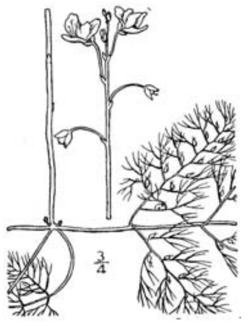
***Hydrilla verticillata* (Waterthyme)**
Monocot. Perennial. Invasive in the continental US.

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.



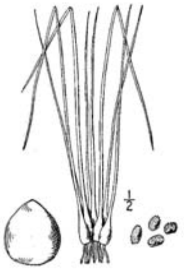
***Utricularia vulgaris* (Common bladderwort)**
Dicot. Perennial. Native to the continental US, Alaska, and Canada.

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.

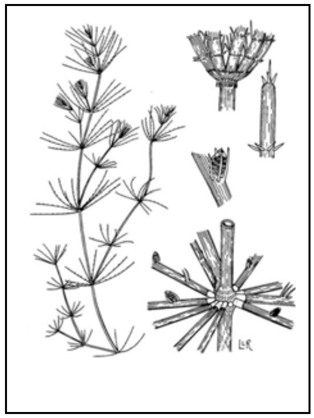
Quillwort leaves are hollow. Each leaf is narrow (2–20 cm long and 0.5–3 mm wide). They broaden to a swollen base up to 5 mm wide where they attach in clusters to a bulb-like, underground rhizome. This base also contains male and female sporangia, protected by a thin velum. Quillwort species are very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



Macroalgae

Chara vulgaris (Chara, Common stonewort)

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)

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.

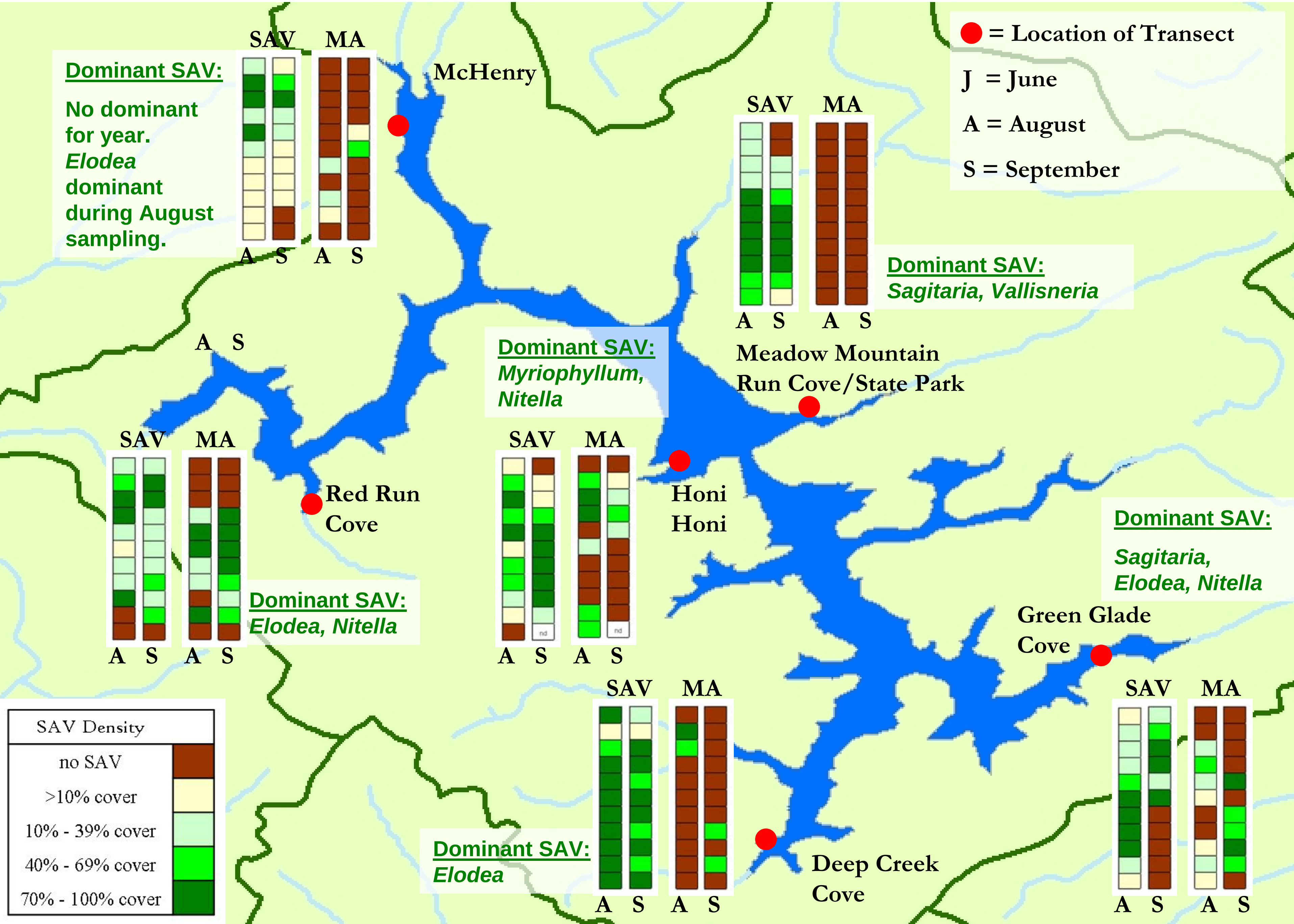
Images were obtained from the following:
Sagittaria cristata: www.uwgb.edu
Vallisneria Americana: www.dnr.state.md.us
Elodea Canadensis: www.dnr.state.md.us
Ceratophyllum demersum: www.dnr.state.md.us
Myriophyllum spicatum: www.dnr.state.md.us
Myriophyllum sibiricum: www.mainevolunteerlakemonitors.org
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

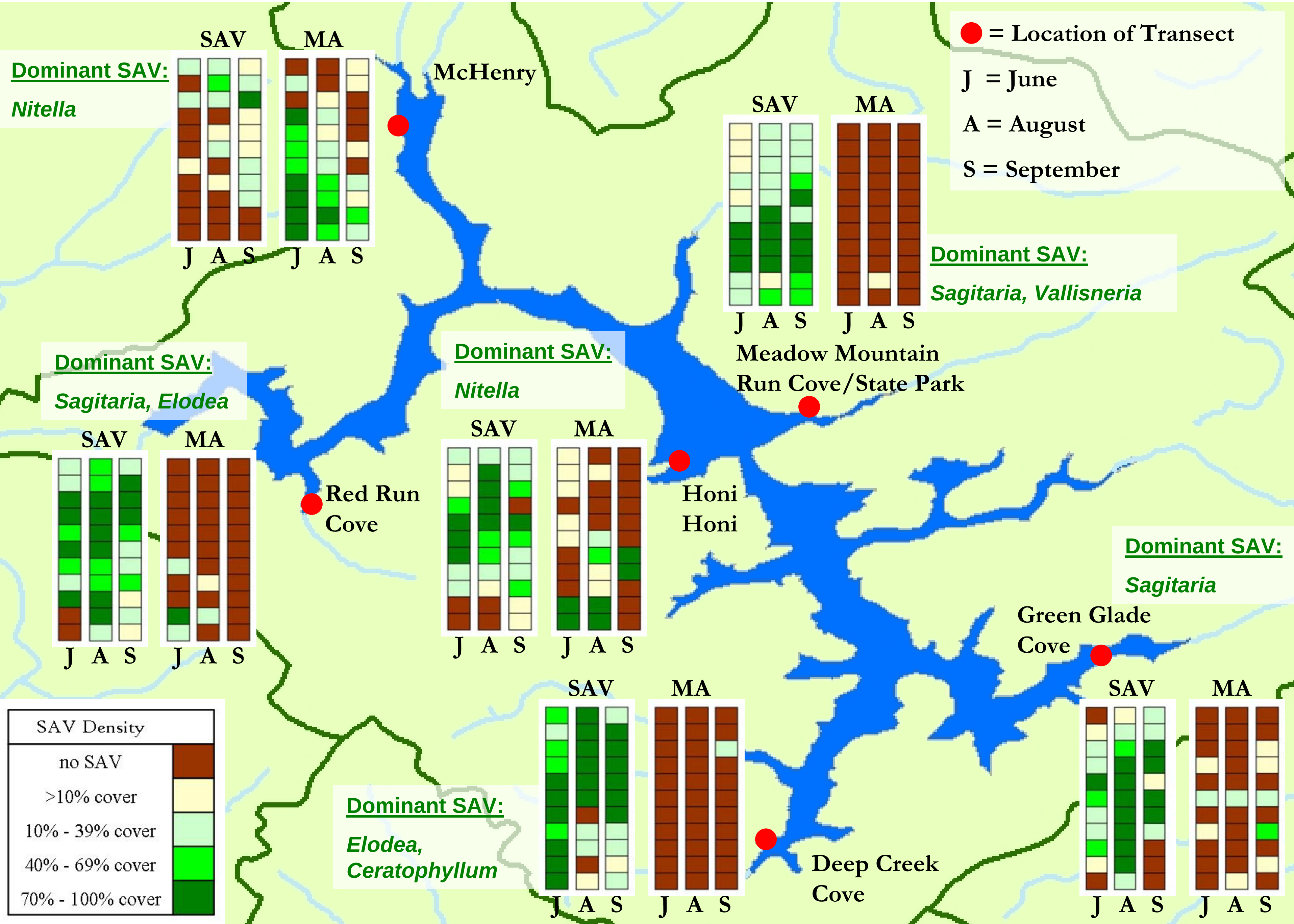
Deep Creek Lake
Submerged Aquatic Vegetation and Macroalgae Transect Results

2010-2013

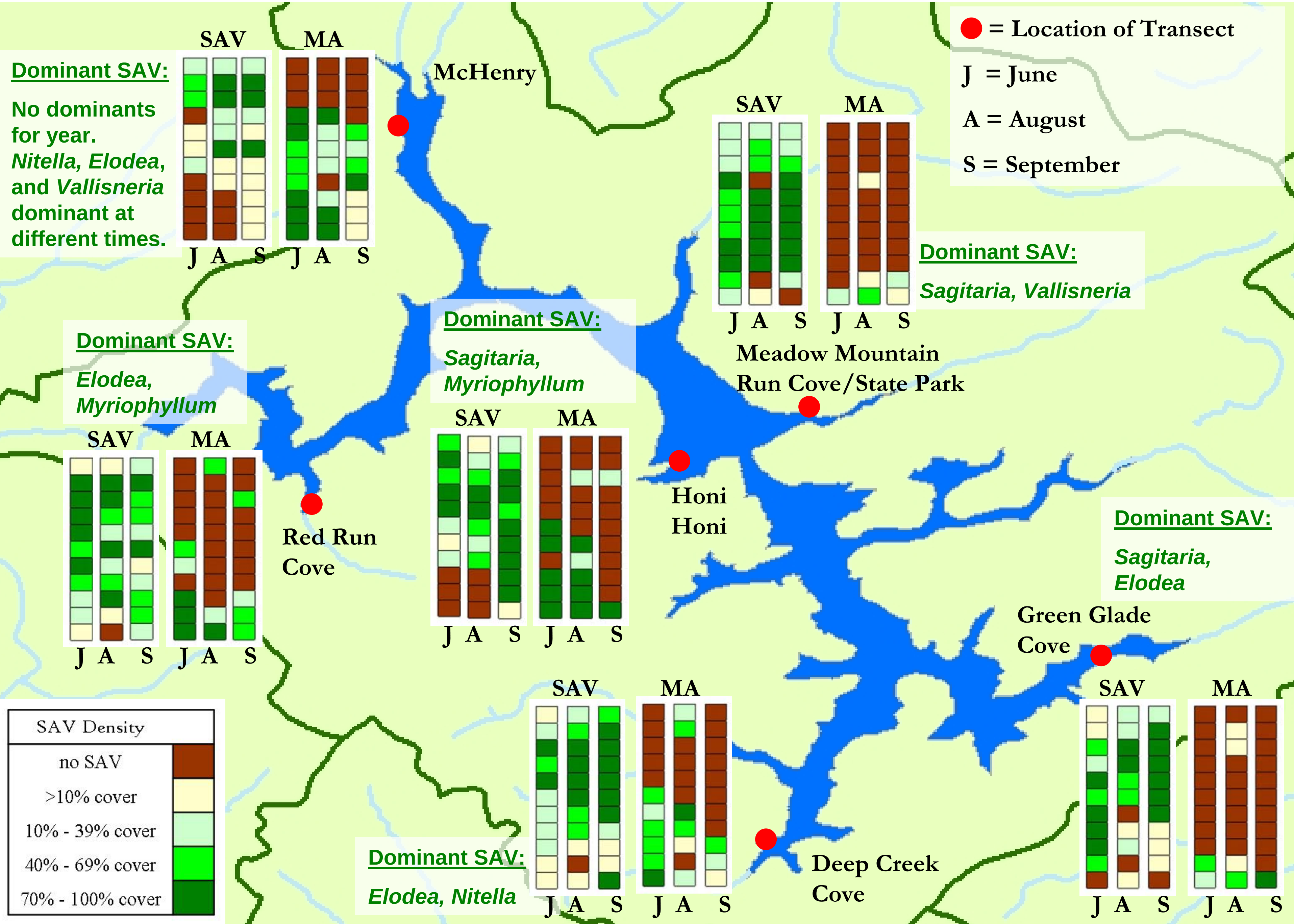
Deep Creek Lake, MD 2010



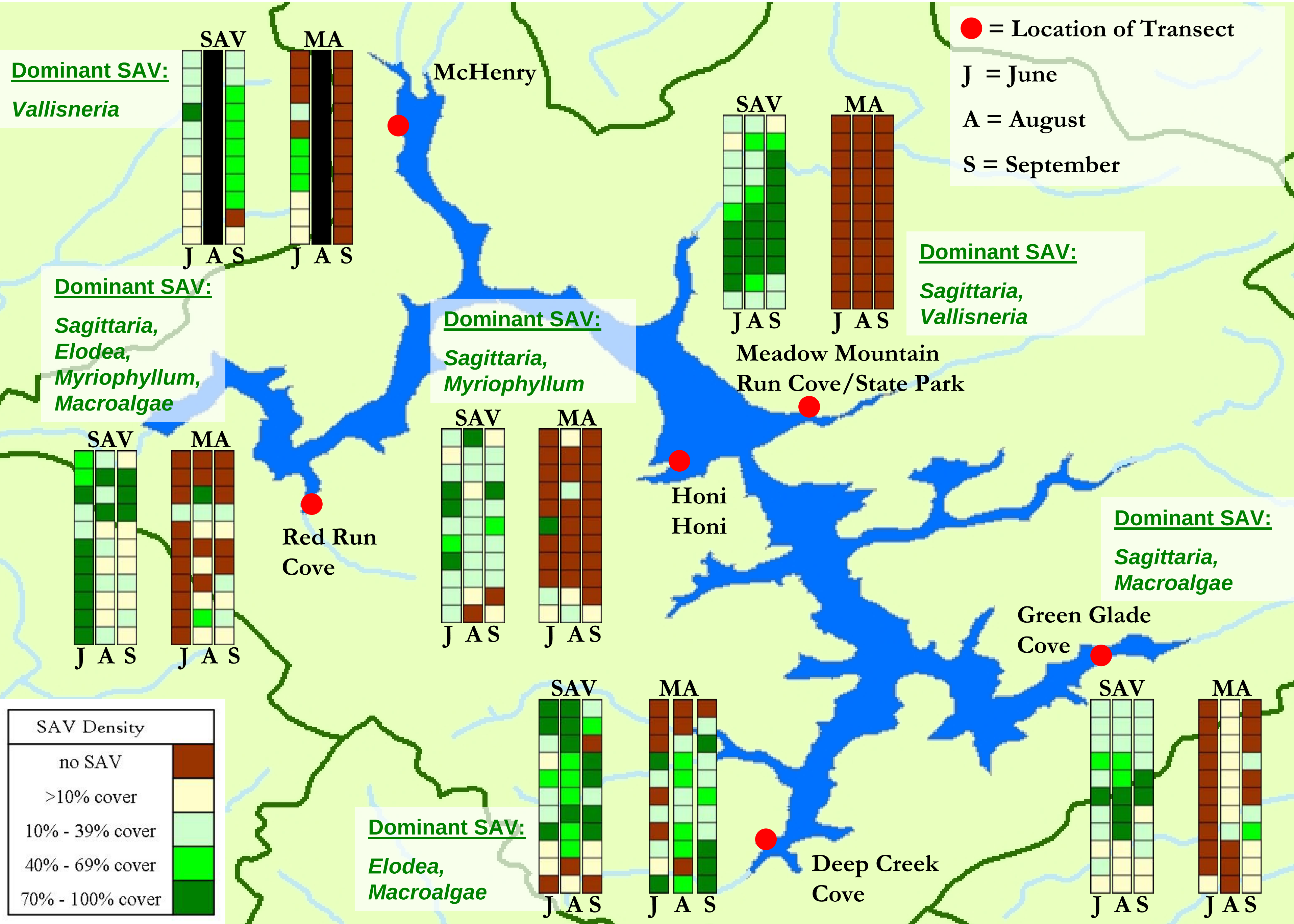
Deep Creek Lake, MD 2011



Deep Creek Lake, MD 2012



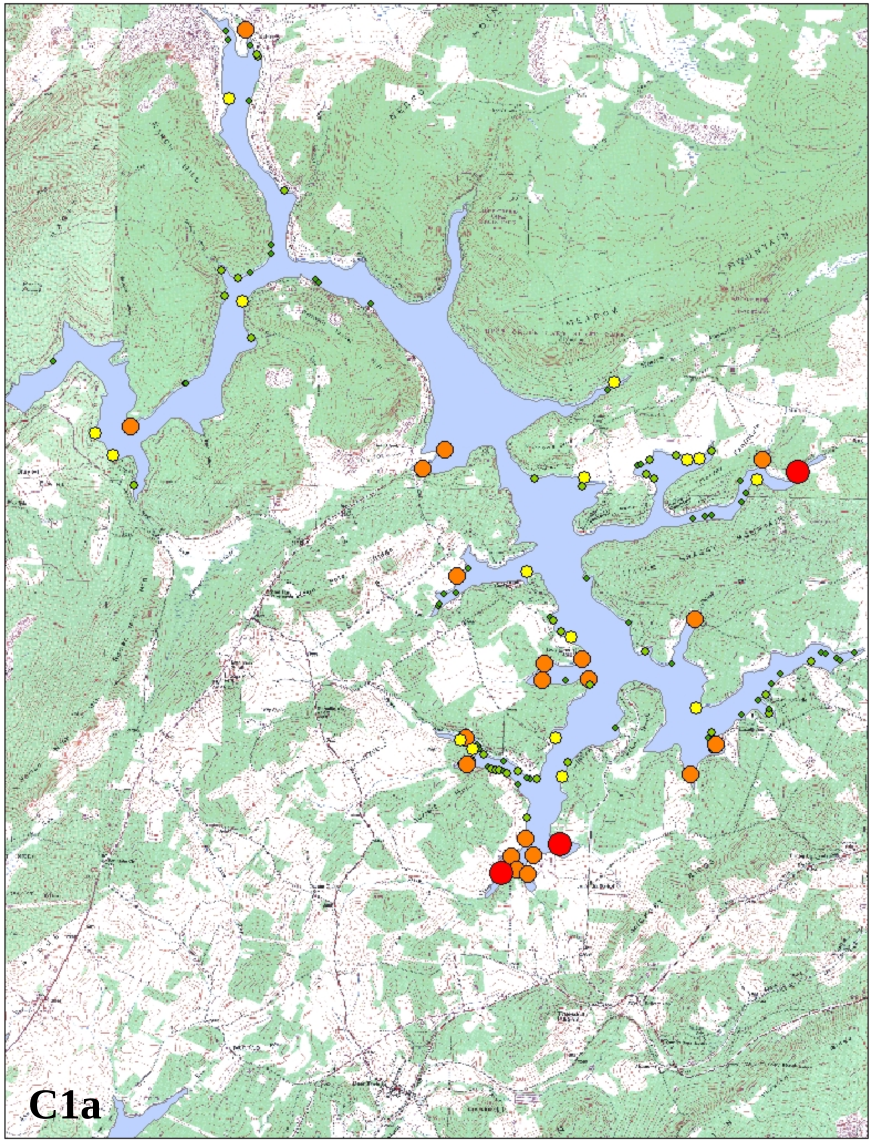
Deep Creek Lake, MD 2013



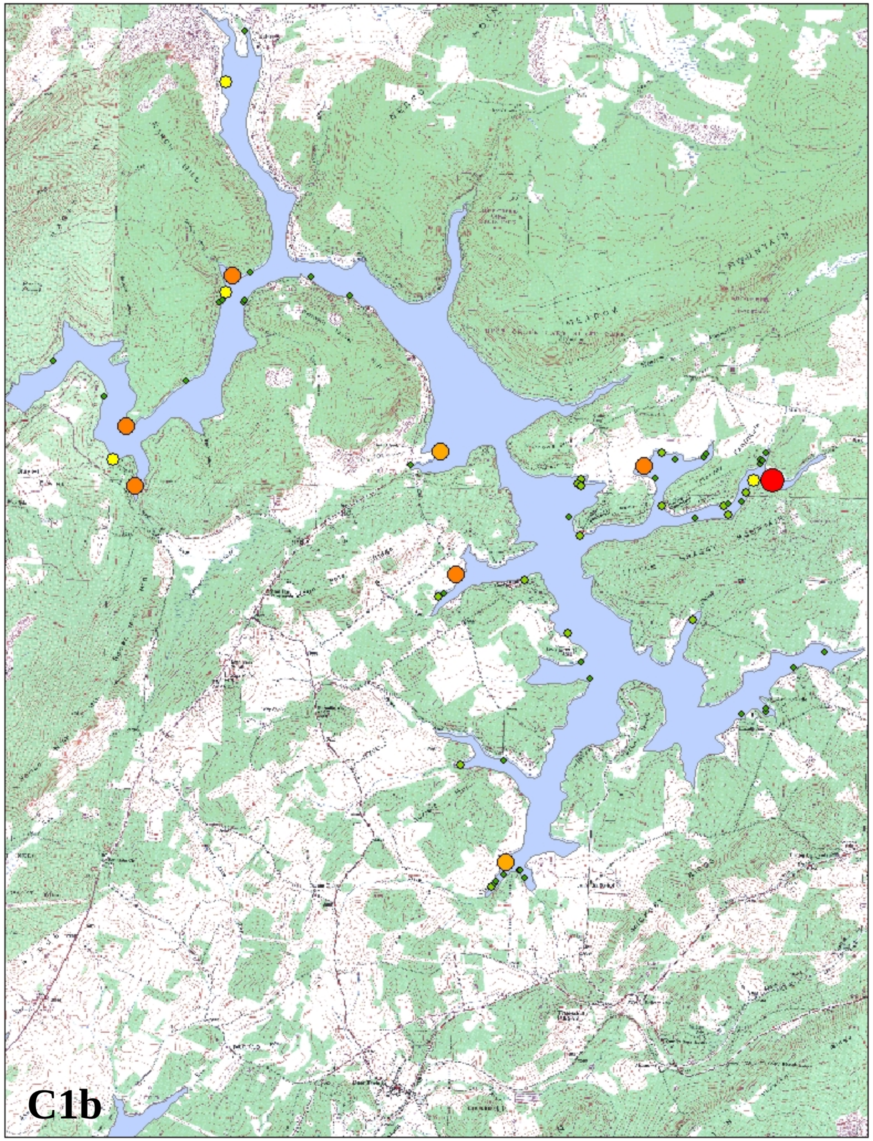
<u>APPENDIX C</u>

Deep Creek Lake *Myriophyllum* Survey Results
2012 and 2013

2012



2013

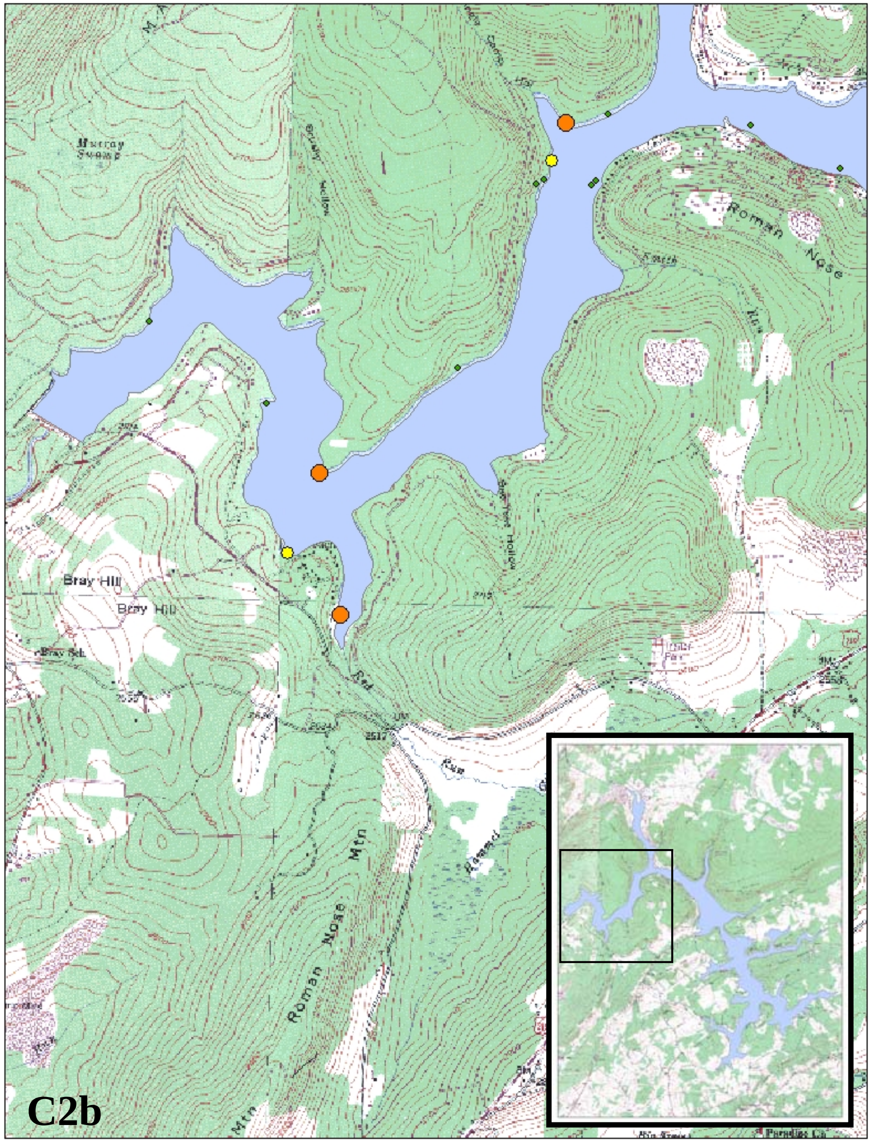


***Myriophyllum* observations**

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

2012

2013



***Myriophyllum* observations**

Less than 0.1 acre

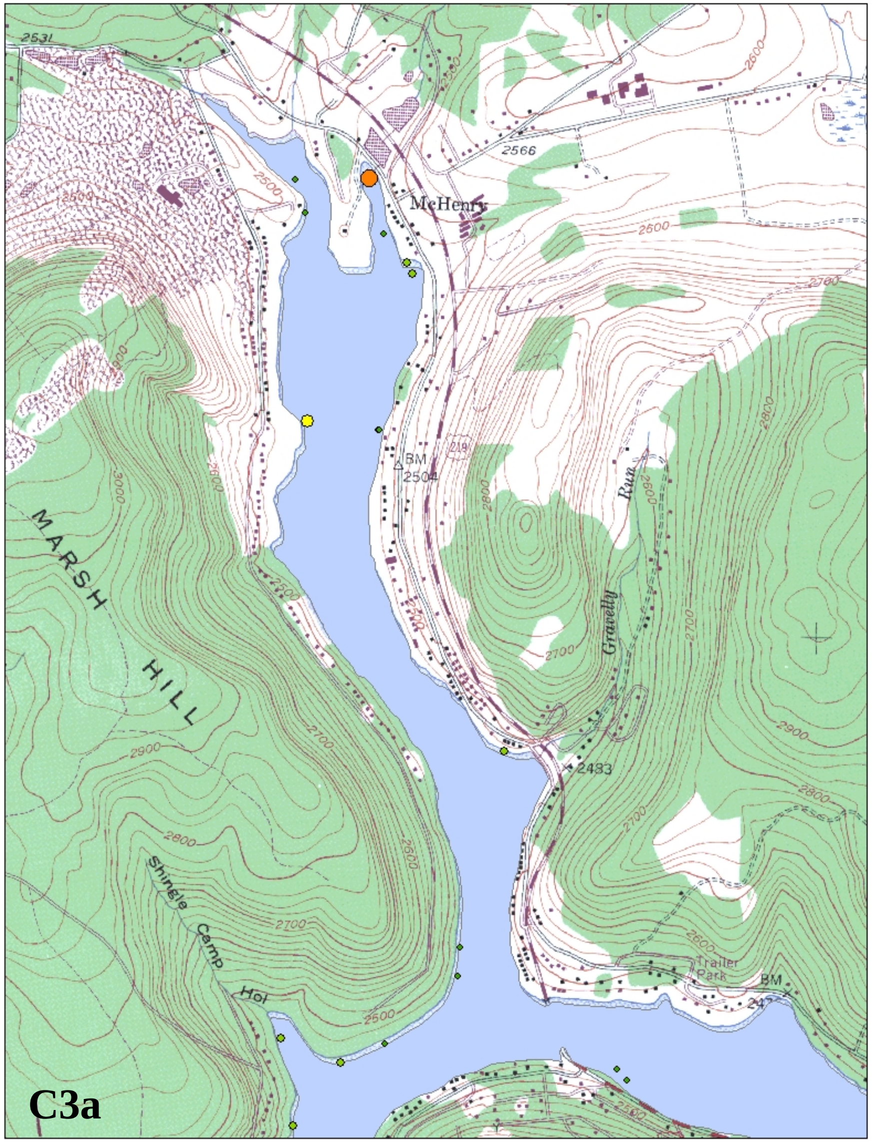
0.1 – 0.5 acres

0.5 – 1.0 acres

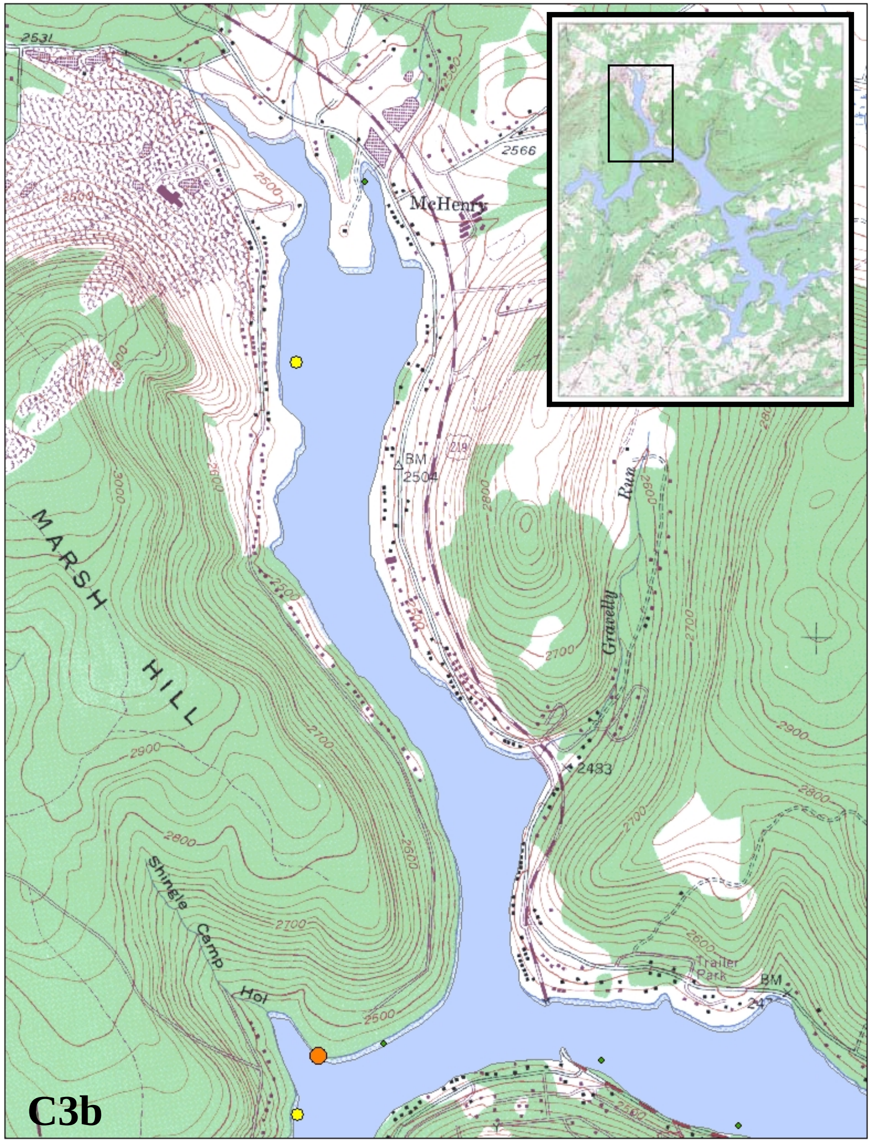
1.0 – 5.0 acres

5.0 – 15 acres

2012



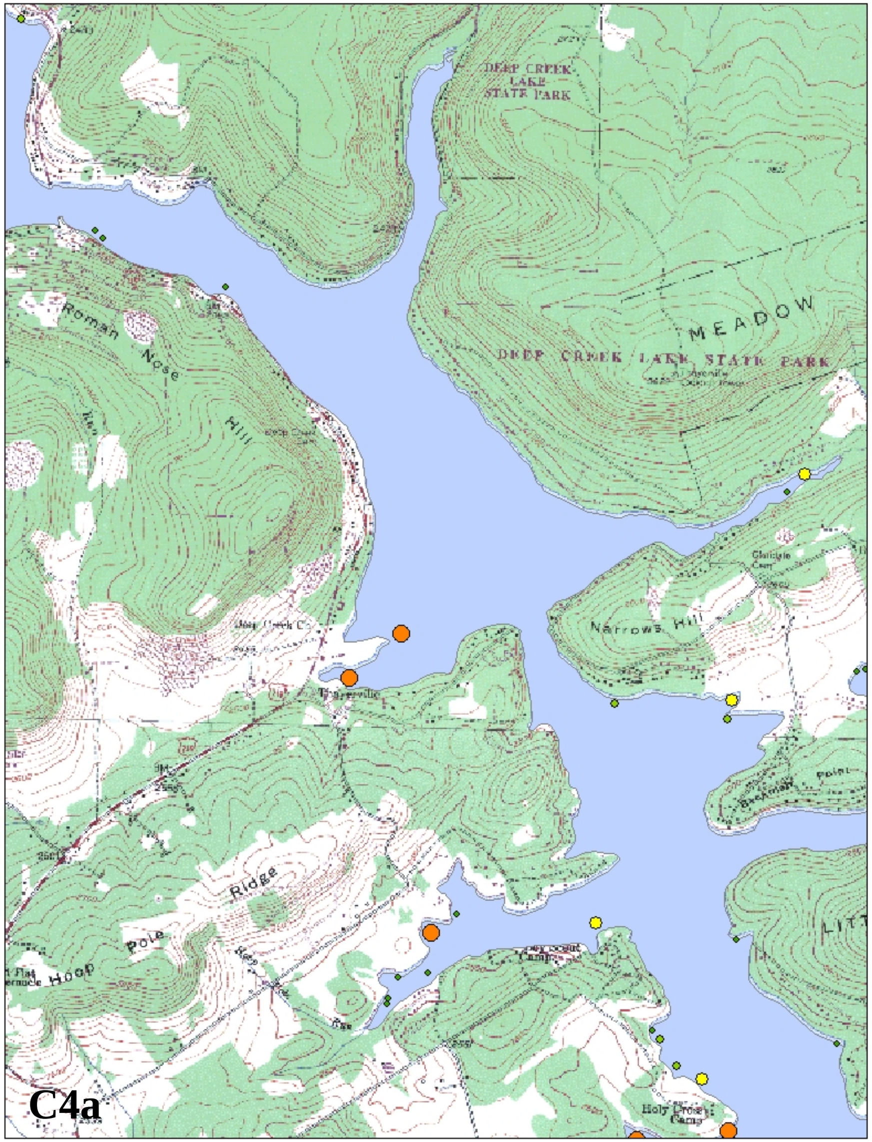
2013



***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

2012



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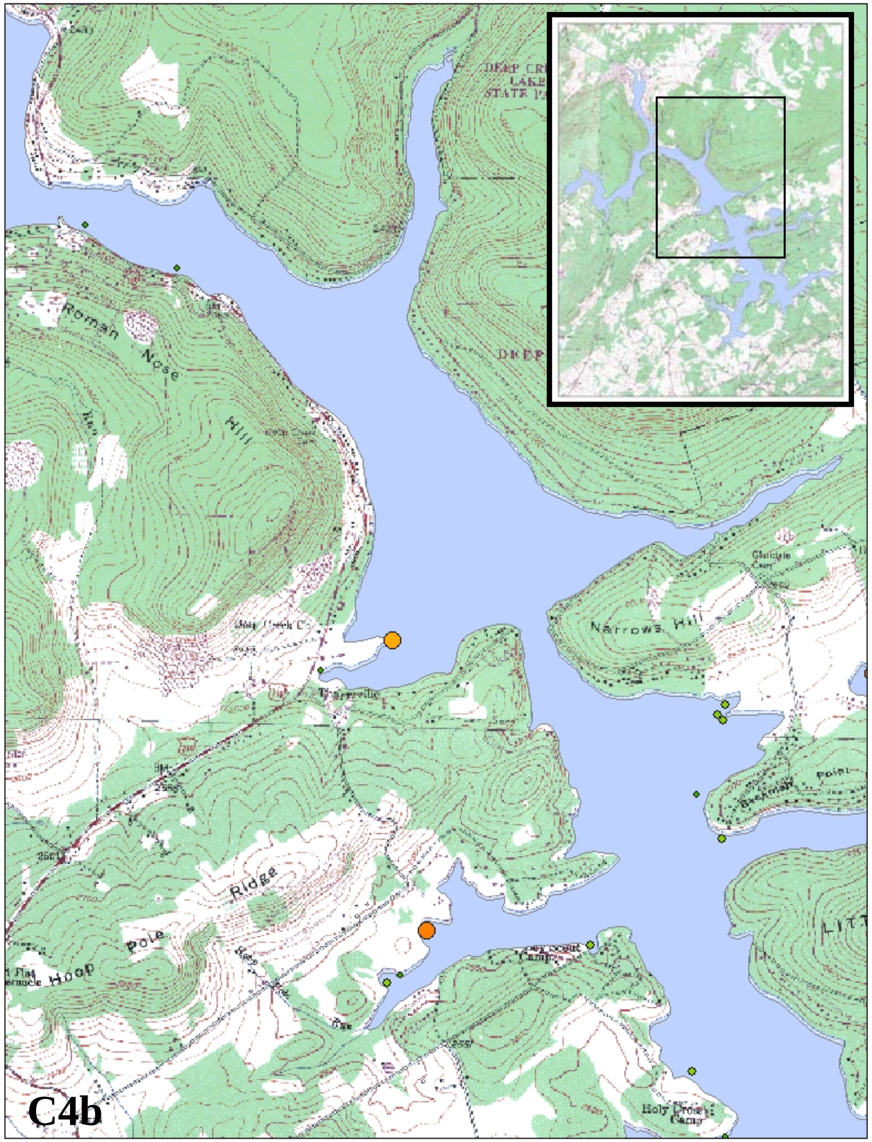

***Myriophyllum* observations**

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

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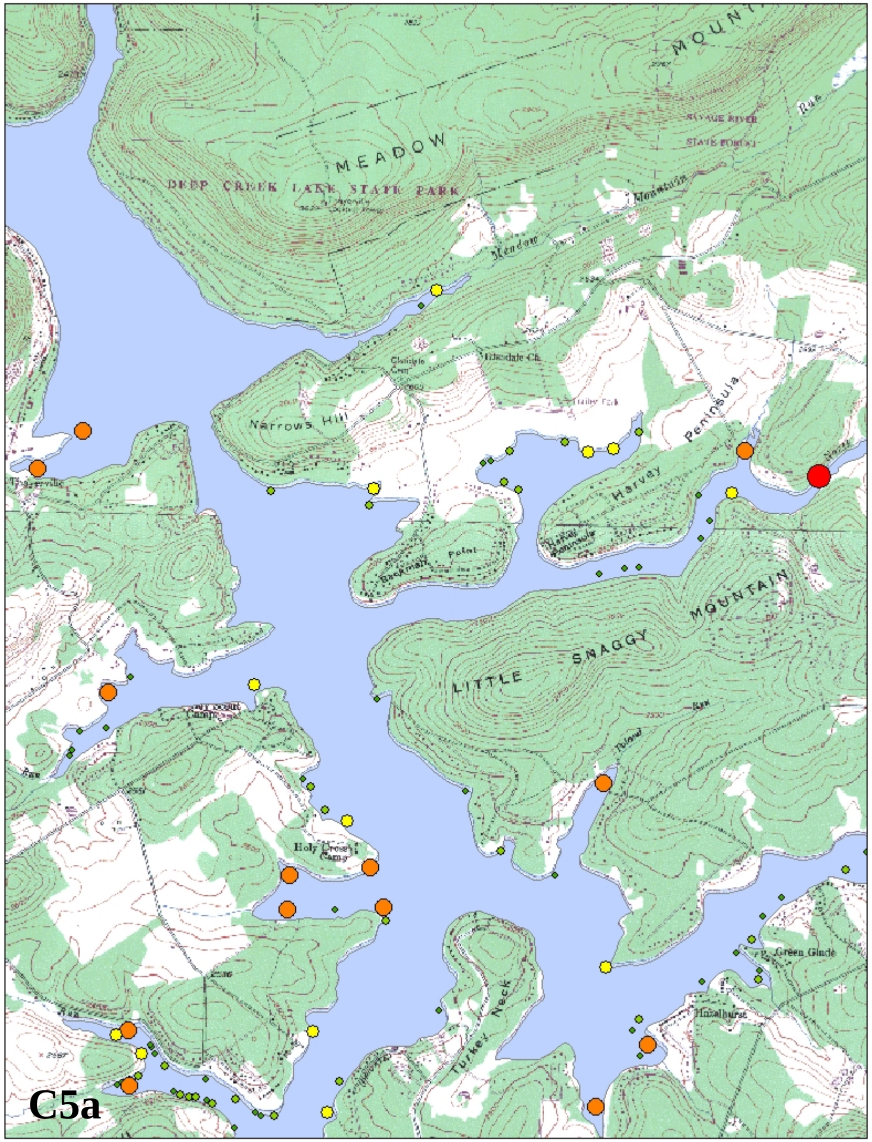
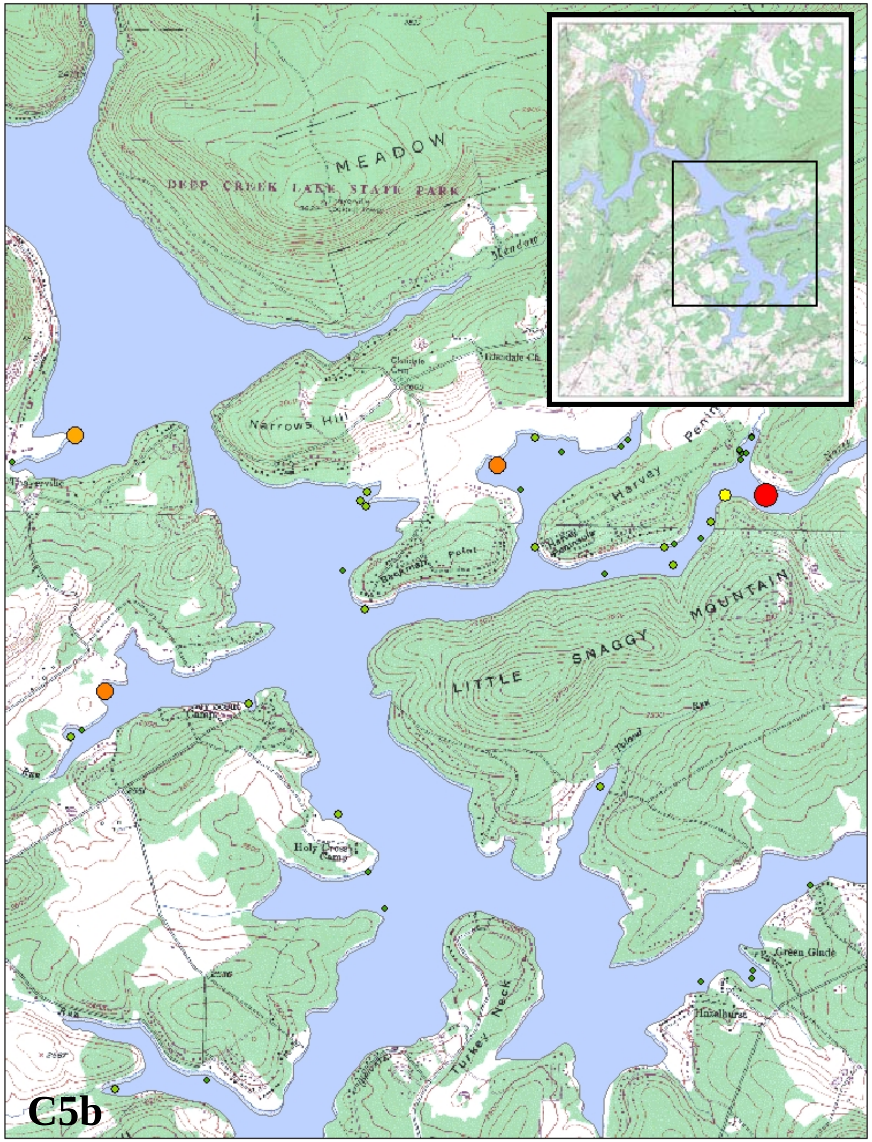


2013



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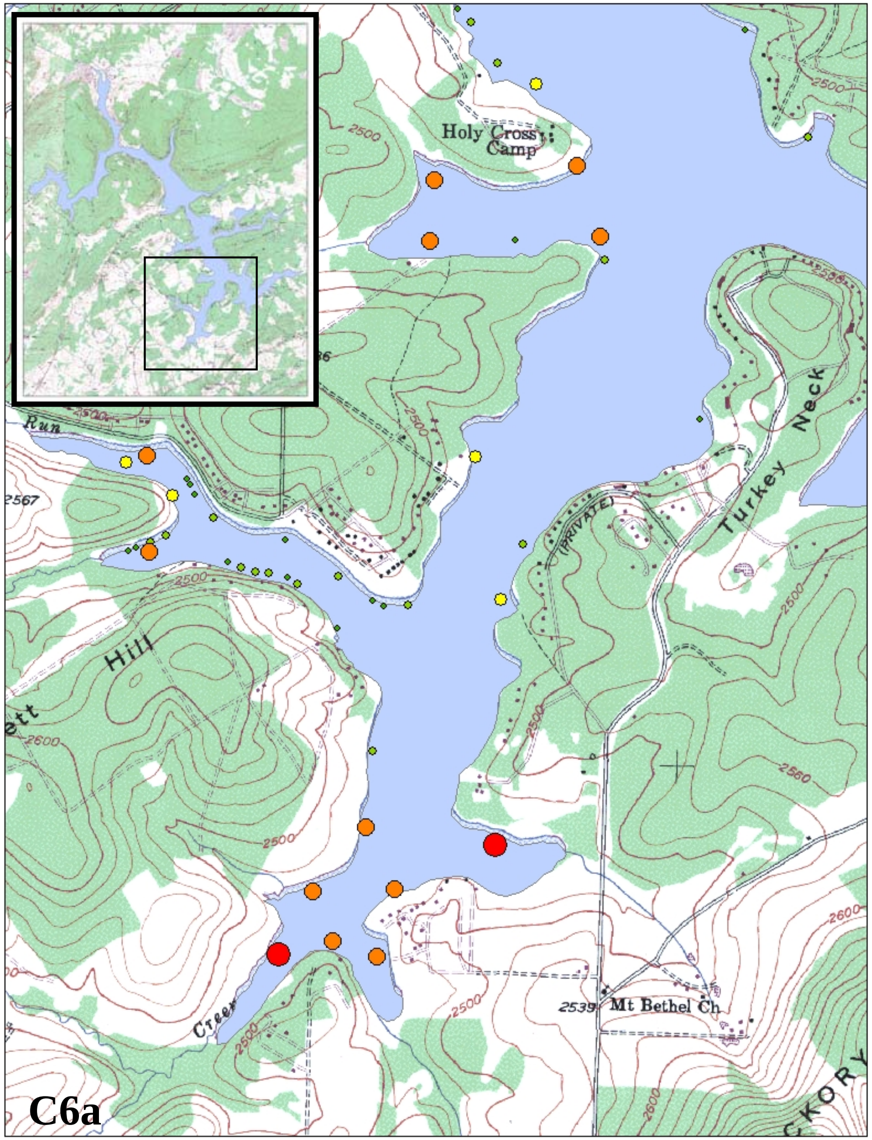

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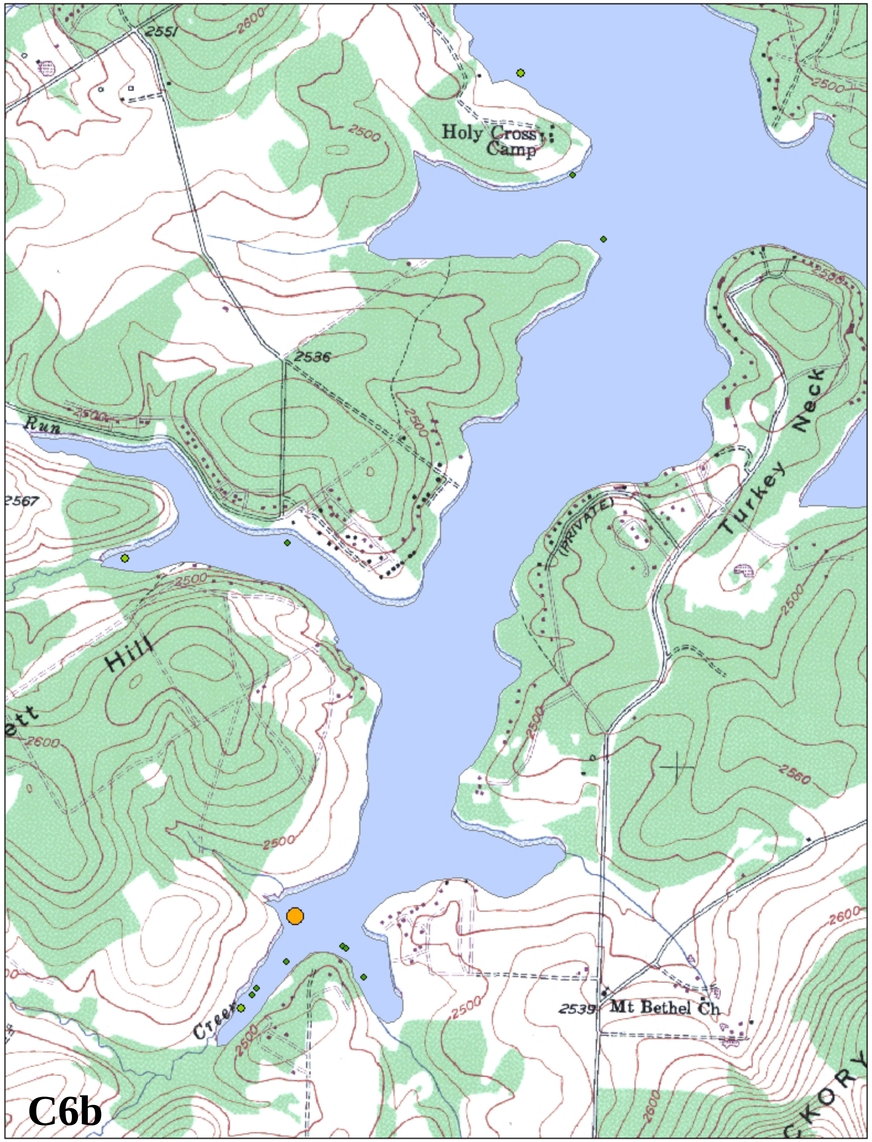

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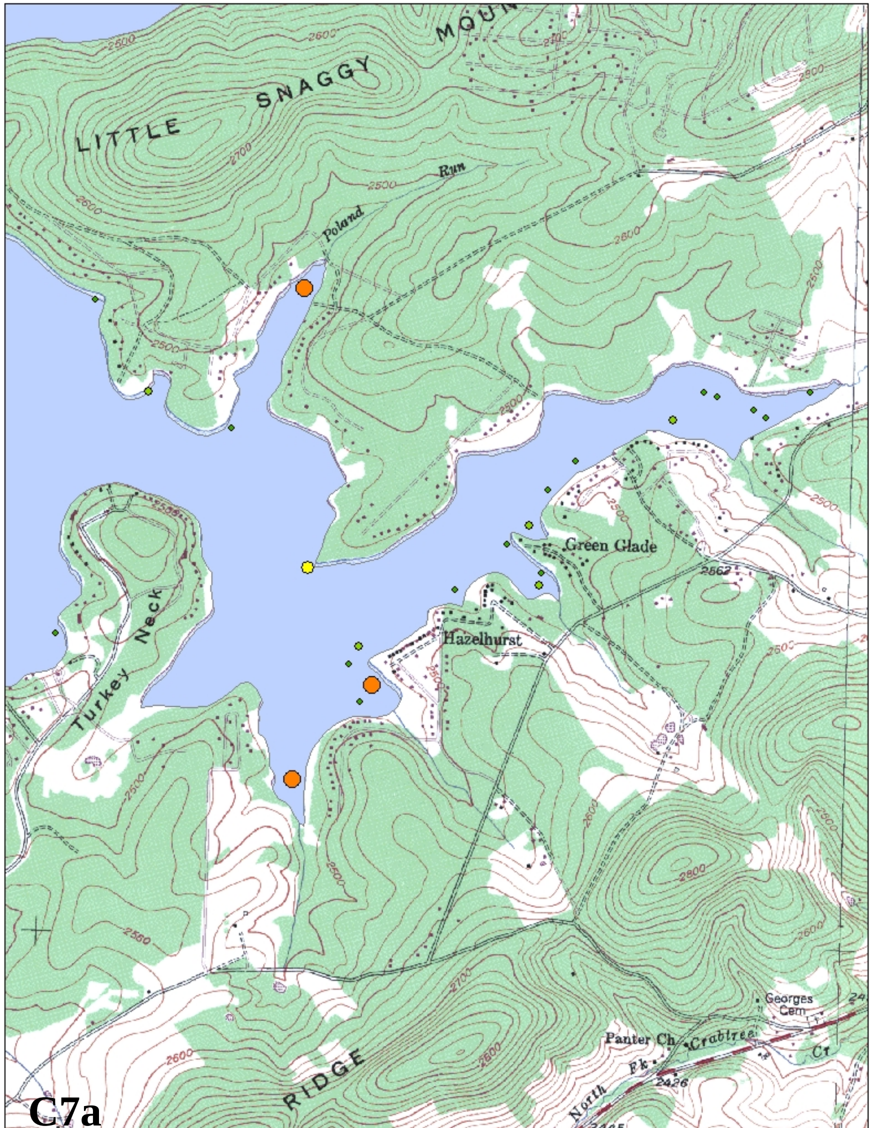
2012



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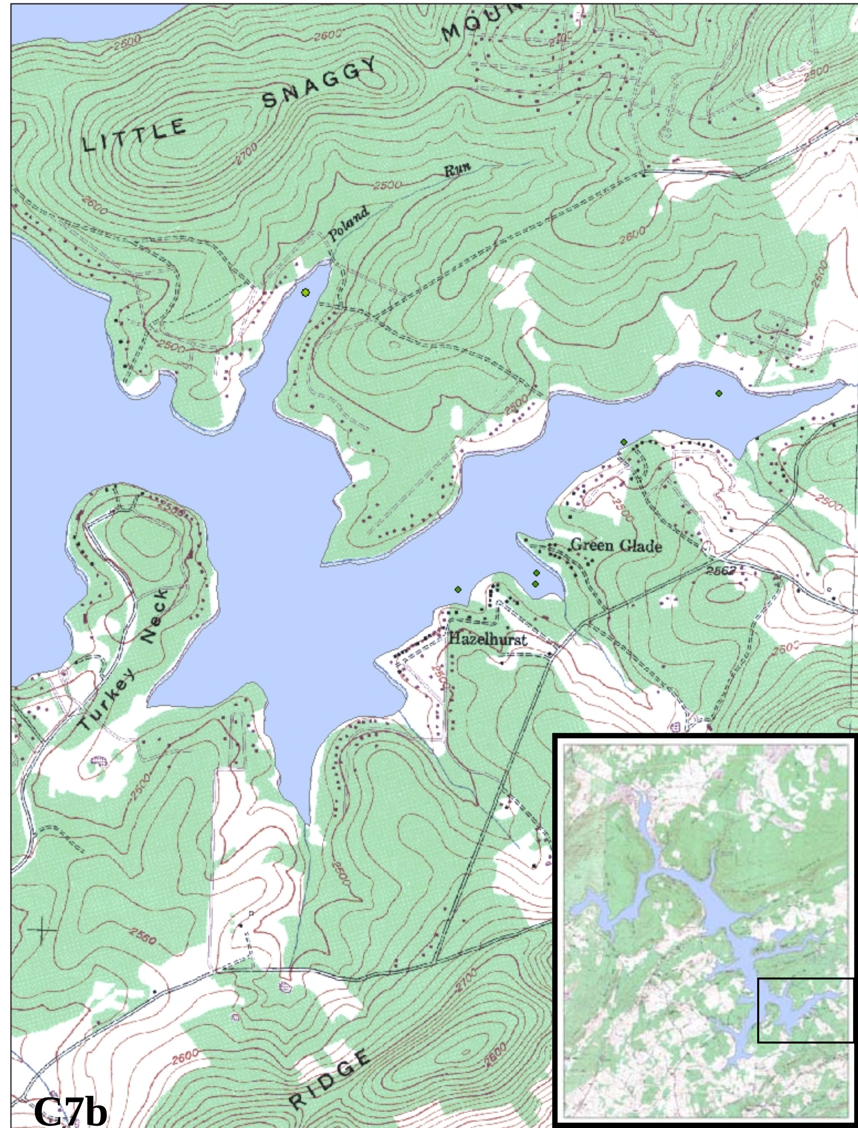

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Less than 0.1 acre	0.1 – 0.5 acres	0.5 – 1.0 acres	1.0 – 5.0 acres	5.0 – 15 acres