2017 Aquatic Plant Survey Report

Lake Redstone Bays

Cardinal, South Chickadee, Eagle, Hummingbird, Killdeer Martin-Meadowlark, Mockingbird, Mourning Dove, Oriole, Quail, Swallow, Warbler, & Woodpecker
Sauk County, Wisconsin

Project initiated by:
Lake Redstone Protection District

Survey and report completed by:
Aquatic Plant & Habitat Services, LLC
Sara Hatleli
N4888 Beck Rd. Taylor, WI 54659
715-299-4604, Sarahatleli97@gmail.com

ABSTRACT

An aquatic plant survey of Cardinal, South Chickadee, Eagle, Hummingbird, Killdeer, Martin-Meadowlark, Mockingbird, Mourning Dove, Oriole, Quail, Swallow, Warbler, and Woodpecker Bays was conducted on Lake Redstone in Sauk County, Wisconsin on September 8th and 9th, 2017. The surveys employed methods from Hauxwell (2010), but with a higher resolution survey grid to serve as pre- and post- treatment assessments in the management of Eurasian watermilfoil (*Myriophyllum spicatum*, EWM). Each bay has its own management history with varying stages of pre-and post-treatment monitoring for EWM. Oriole Bay was treated with herbicides in 2013; Martin-Meadowlark and Swallow Bays were treated with herbicides in May 2015; Cardinal, South Chickadee, and Oriole Bays were treated with herbicides in spring of 2016; Hummingbird and a northern portion of Woodpecker Bay were treated in 2017. EWM was found in all bays in 2017 and was the most or second-most common plant in nine of the bays. A statistically significant increase in EWM was found in Swallow and South Chickadee Bays when compared to 2016 data. Chi-square results also revealed a statistically significant decrease of 10 native species across five bays, but this could be a function of a September survey in 2017 compared to an August survey in 2016. Coontail (*Ceratophyllum demersum)* was the most or second-most common native species in twelve bays.

Management Recommendations are as follows; 1) Protect native aquatic plants. 2) Control nuisance native vegetation with hand-pulling or raking, where permitted 3) Continue water quality monitoring. 4) If chemical treatment using 2,4-D is pursued, aim for sheltered areas to prevent rapid dispersion and dilution of herbicide. 5) Consider using a “trigger” littoral frequency of EWM to help determine whether herbicide treatment should be used the following year. The average pre-treatment littoral frequency of EWM for bays treated in the past is 40%. 6) Include Secchi depth measurements of each bay in future aquatic plant surveys. 7) Explore Diver Assisted Suction Harvesting (DASH) as an option for EWM control.

TABLE OF CONTENTS

Abstract 3

Table of Contents 4

Introduction 7

Study Site 7

Water Chemistry & Clarity 7

Goals and Objectives 7

Methods 8

Field Methods 9

Data Analysis Methods 10

Summary Statistics 10

Individual Species Statistics 10

Chi-square Tests 10

Results 11

Cardinal Bay 15

South Chickadee Bay 18

Eagle Bay 19

Hummingbird Bay 20

Killdeer Bay 20

Martin-Meadowlark Bay 21

Mockingbird Bay 23

Mourning Dove Bay 23

Oriole Bay 24

Quail Bay 25

Swallow Bay 26

Warbler Bay 27

Woodpecker Bay 28

Eurasian Watermilfoil & Management History 30

Cardinal Bay EWM 30

South Chickadee Bay EWM 31

Eagle Bay EWM 31

Hummingbird Bay EWM 32

Killdeer Bay EWM 32
Martin-Meadowlark Bay EWM 32
Mockingbird Bay EWM 33
Mourning Dove Bay EWM 34
Oriole Bay EWM 35
Quail Bay EWM 35
Swallow Bay EWM 36
Warbler Bay EWM 36
Woodpecker Bay EWM 37
Discussion 37
Aquatic Plants are Necessary for Healthy Lakes 38
Survey Timing and Chi-Square Results 38
Sample Size and Chi-Square Results 39
Identifying Trigger Frequencies for Herbicide Treatment 39
General Management Recommendations 39
Cardinal Bay 40
Chickadee Bay 40
Eagle Bay 41
Hummingbird Bay 41
Killdeer Bay 41
Martin-Meadowlark Bay 41
Mockingbird Bay 42
Mourning Dove Bay 42
Oriole Bay 42
Quail Bay 42
Swallow Bay 42
Warbler Bay 43
Woodpecker Bay 43
References 46
Appendix A – Cardinal Bay Maps 47
Appendix B – South Chickadee Bay Maps 49
Appendix C - Eagle Bay Maps 50
Appendix D – Hummingbird Bay Maps 51

Appendix E – Killdeer Bay Maps 55
Appendix F – Martin-Meadowlark Bay Maps 55
Appendix G – Mockingbird Bay Maps 58
Appendix H – Mourning Dove Bay Maps 59
Appendix I – Oriole Bay Maps 64
Appendix J –Quail Bay Maps 65
Appendix K – Swallow Bay Maps 66
Appendix L – Warbler Bay Maps 69
Appendix M – Woodpecker Bay Maps 72
Appendix N – Chi-Square Test Graphs 74

INTRODUCTION

The Lake Redstone Protection District (LRPD) partnered with Aquatic Plant and Habitat Services to complete an aquatic plant survey of Cardinal, South Chickadee, Eagle, Hummingbird, Killdeer, Oriole, Martin-Meadowlark, Mockingbird, Mourning Dove, Quail, Swallow, Warbler, and Woodpecker Bays in 2017. These particular bays were selected because of the abundance of vegetation and the presence of Eurasian watermilfoil (EWM). To be eligible for possible chemical treatment of EWM, the Wisconsin Department of Natural Resources requested a point intercept macrophyte survey of the bays at a higher sampling intensity than would be done on a whole-lake scale.

Study Site

Lake Redstone is a drainage lake in Sauk County, Wisconsin with a surface area of 605 acres (245 hectares). The lake is an impoundment of Big Creek, which is a tributary of the Baraboo River, in Sauk County. The lake was created in 1965 with the construction of the dam on Big Creek initiated by a real estate developer with the intention of establishing 1,600 residential lots (Leverance & Panuska, 1997). The lake reached full pool in 1966 and water quality issues emerged including algae blooms, low dissolved oxygen, and sedimentation. The lake is considered an Area of Special Natural Resource Interest due to the presence of certain plant or animal species or unique ecological communities identified in the WDNR Natural Heritage Inventory. The thirteen bays surveyed in 2017 are illustrated in Figure 1.

Water Chemistry & Clarity

Lake Redstone is one of 65 Long Term Trend Lakes in Wisconsin. Such lakes are monitored from May through September annually to provide reference conditions for regional trophic classification and to track changes within and among lakes in Wisconsin. Volunteers also contribute to the relatively large body of data that is available for Lake Redstone. The lake has a flushing rate of about 1.8 times during the growing season (May-September), meaning an entire lake volume worth of water flows through the system nearly twice during that five-month monitoring period (Leverance & Panuska, 1997). Lake Redstone is classified as a eutrophic system based on data collected by volunteers and professionals since 1979. Volunteers collect water samples for chlorophyll and phosphorus analysis while water clarity is measured in the field using a Secchi disk. Based on chlorophyll data from the past 5 years the trophic state index is 66, which is considered poor for reservoirs (WDNR, 2017).

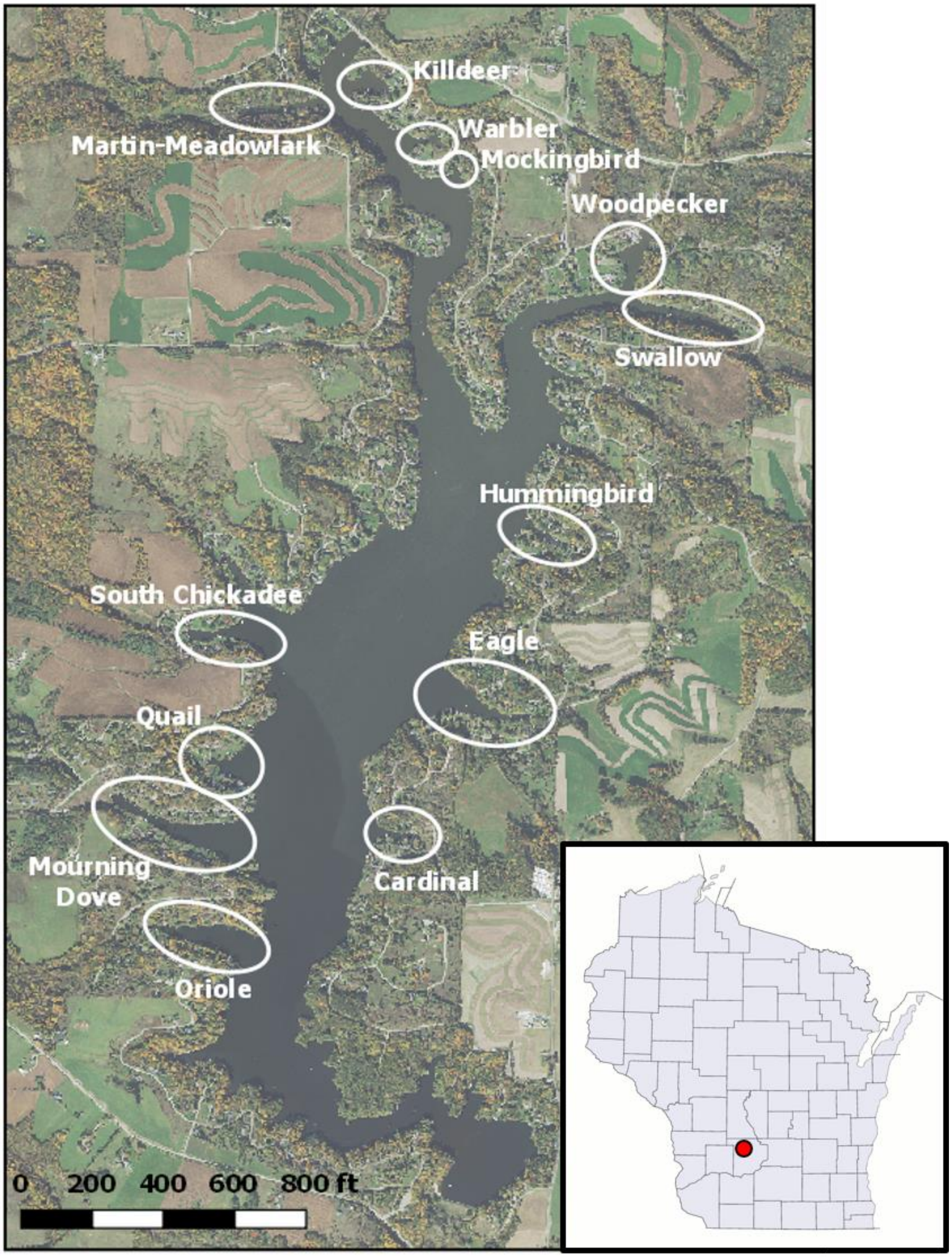
GOALS AND OBJECTIVES

GOAL: The main goal was to survey aquatic plants in select bays at a higher resolution (compared to whole-lake survey) for making management decisions, specifically related to EWM management.

OBJECTIVES:

1. Complete a survey of all aquatic plants in thirteen selected bays at pre-determined survey points.
2. Analyze data and create maps of plant distribution, sediment type, and depth.
3. Provide a final report that includes management recommendations.
4. Compare results of the previous surveys using Chi-square tests to identify statistically significant changes in native and invasive plant species since 2014.

Figure 1 – Lake Redstone Map and Bay Locations



METHODS

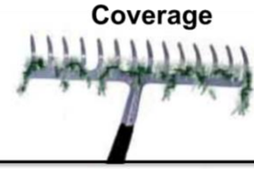
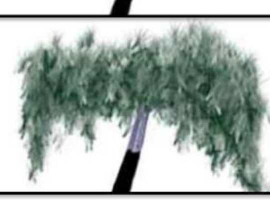
Field Methods

Field methods followed the standardized protocol developed by the Wisconsin Department of Natural Resources (WDNR) in Hauxwell et. al (2010) and the surveys were completed on September 8th and 9th, 2017. Previous plant survey dates are in List 1. Point-intercept maps were generated for Cardinal (71 points), South Chickadee (56 points), Eagle (115 points), Hummingbird (65 points), Killdeer (62 points), Martin-Meadowlark (56 points), Mockingbird (40 points), Mourning Dove (123 points), Oriole (104 points), Quail (77 points), Swallow (72 points), Warbler (65 points), and Woodpecker (86 points) resulting in 992 sample points. The sample points were uploaded to an iPhone and Avenza Maps application was used to navigate to each point in the bays. Points that were deeper than 12 feet were not surveyed based on previous findings that the maximum rooting depth in Lake Redstone was 12 feet in 2005 and 10 feet in 2012 (Berg, 2012). Furthermore, maximum rooting depth of previous bay-wide surveys was 9.5 feet (Table 3). Sonar was used to record depth at sites deeper than 12 feet. A double-sided rake head on a telescopic pole was used to sample each point for aquatic plants, depth, and dominant sediment type (muck, rock, or sand). The rake fullness rating for total coverage of plants on the rake and a separate rake fullness rating for each species present were recorded (Figure 2). Any survey points that were inaccessible were recorded as such and no sample was taken. Aquatic plants found within 6 feet of the sample point but not found on the rake were counted as visual observations. Plant identification was verified using Skawinski (2014).

List 1 – Aquatic Plant Survey Dates 2014-2017

- August 11, 2014
- July 17-18, 2015
- August 17-18, 2016
- September 8-9, 2017

Figure 2 - Rake Fullness Rating Illustration

Rating	Coverage	Description
1		Few plants
2		Plants cover length of the rake but not tines
3		Rake completely covered, tines not visible

Data Analysis Methods

Survey data were used to calculate statistics including Simpson Diversity Index, species richness, Nichols (1999) Floristic Quality Index, frequencies, rake fullness and number of visual sightings among other summary statistics. Following guidelines in Hauxwell (2010), species that were recorded as visuals (i.e., within 6 feet of a survey point but not sampled with the rake) were not included in Simpson Diversity Index and FQI calculations. Also, filamentous algae data were not used in some statistical calculations but were collected to gauge its frequency throughout the thirteen bays.

Summary Statistics

Summary statistics provide a general overview of the plant community in each bay and can be used to make comparisons among the bays and within the same bay over time. However, ***these statistics should not be used to compare to other lakes where a whole-lake survey has been done***. Explanations of summary statistics are in Table 2. Floristic Quality Index (FQI, Nichols 1999) is listed in Table 1 but is worth providing more explanation. The FQI incorporates aquatic plant species associated with lake communities and native to Wisconsin by using the Coefficient of Conservatism (C) ranging from 0 to 10. The C value estimates the likelihood of a plant species occurring in an environment that is relatively unaltered from pre-settlement conditions. As human disturbance increases, species with a lower C value occur more frequently while more sensitive species with a higher C value occur less frequently. To calculate floristic quality, the mean C value of all species found in the lake is multiplied by the square root of the total number of plant species in the lake. Only plants found on the rake are included in the calculations. In other words, the FQI metric helps us understand how close the aquatic plant community is to one of undisturbed conditions. A higher FQI value assumes a healthier aquatic plant community. Floristic quality values can be compared on a statewide value, but Nichols (1999) recommends comparing values within one of the four ecoregional-lake types. Lake Redstone falls within the "Driftless" ecoregional-lake type. However, the ***FQI values for each bay or even all bays combined cannot be compared to other lakes in the driftless region because the bays are not representative of a whole-lake survey***.

Individual Species Statistics

Individual species statistics assess the plant species composition in the thirteen bays of Lake Redstone and allow for comparisons of the plant community within the bays (Table 1).

Chi-square Tests

A chi-squared test of plant occurrence was done for bays that were surveyed in previous years. The statistical test helps determine whether there is a significant difference between the two years by comparing the number of sites a particular plant species was found the two years. The alpha, or Type I error rate was set at 0.05, meaning there is a 5% chance of claiming there is a significant change when no real change has occurred.

Table 1 – Individual Statistic Explanation

Individual Statistic	Explanation
Average Rake Fullness	Mean rake fullness rating ranging from 1 to 3. See Rake Fullness Illustration.
Number of sites where a species was found	The total number of survey points where a particular species was found on the rake.
Number of visual sightings	The total number of times a particular species was visually observed within 6 feet of a sampling point, but not collected on the rake.
Frequency of Occurrence (split into two subcategories)	a) Among vegetated sites only – The number of sites at which a particular species is found on the rake divided by the total number of vegetated sites (Table 2, #2).
	b) Among sites shallower than the maximum depth of plants – The number of sites at which a particular species is found on the rake divided by the total number of sites less than or equal to the maximum depth of plants (Table 2, #4). Also know as littoral frequency.
Relative frequency (%)	This value represents the degree to which a particular species contributes to the total of all observations. The sum of all relative frequencies is 100%.

Table 2 – Summary Statistic Explanations

	Statistic	Explanation
1	Total number of sites visited	The total number of sites sampled, which is not necessarily equal to the number of survey points because some sites may not be accessible.
2	Total number of sites with vegetation	Number of sites where at least one plant was found on the rake (does not include moss, sponges, filamentous algae, or liverworts).
3	Maximum depth of plants	Depth of deepest site where at least one plant was found on the rake (does not include moss, sponges, filamentous algae, or liverworts).
4	Total number of sites shallower than maximum depth of plants	Number of sites where depth was less than or equal to the maximum depth where at least one plant was found on the rake. Also known as littoral sites.
5	Frequency of occurrence at sites shallower than maximum depth of plants	Total number of sites with vegetation (2) / Total number of sites shallower than maximum depth of plants (4). Also known as littoral frequency.
6	Average number of species per site (split into four subcategories)	a) Shallower than maximum depth – the average number of species found per site at sites less than or equal to the maximum depth where at least one plant was found on the rake (4).
		b) Vegetated sites only – the average number of species found per site at sites where at least one plant was found on the rake (2).
		c) Native species shallower than maximum depth – Same explanation as 6(a), non-native species excluded from average.
		d) Native species at vegetated sites only – Same explanation as 6(b), non-native species excluded from average.
7	Species Richness (split into two subcategories)	a) Total number of species found on the rake at all sites (does not include moss, sponges, filamentous algae, or liverworts
		b) Including visuals – Same explanation as 7(a) and including visual observations within 6 feet of the sample sight
8	Simpson Diversity Index	Estimates the heterogeneity of a community by calculating the probability that two individuals randomly selected from the data set will be different species. The index ranges from 0-1, and the closer the value is to one, the more diverse the community. Visual observations (within 6 feet of sample point) are not included in calculation of index.
9	Coefficient of Conservatism (C)	This is not a statistical calculation, but rather a value assigned to each plant species based on how sensitive that species is to disturbance. C values range from 1 to 10 with higher values assigned to species that are more sensitive to disturbance (Nichols, 1999).
10	Floristic Quality Index	How similar the aquatic plant community is to one that is undisturbed (Nichols, 1999). This index only factors species raked at survey points and does not include non-native species. The FQI is calculated using coefficient of conservatism values (9).

RESULTS

The results for all thirteen bays are summarized in Tables 3, 4, 5, 6, and 7. Table 3 includes the summary statistics for 2017 as well as previous years where applicable. Table 4 covers floristic quality results for 2017 and previous years in bays where surveys were completed. Tables 5, 6, and 7 list individual species found in each bay in 2017 and corresponding statistics for each species. Results are further described later in this section for each bay.

Table 3 - Summary Statistics for All Bays, 2014-2017

Bay & Year		1	2	3	4	5	6 Average # of species per site				7 Species Richness		8	
		Total # sites visited	Total # sites w/ vegetation	Max. depth of plants	Total # sites shallower than max. depth of plants	Littoral frequency**	a) Shallower than max. depth	b) Vegetated sites only	c) Native shallower than max. depth	d) Native at veg. sites only	a) Total # species on rake at all sites	b) Including visuals	Simpson's Diversity Index	Littoral frequency of EWM
Martin-Meadowlark	**2014**	52	45	4	52	86.54	2.25	2.6	1.81	2.41	7	9	0.8	42
	2015	54	30	3	50	60.00	1.12	1.87	1.12	1.87	7	8	0.75	0
	2016	54	50	4	54	92.59	2.63	2.84	2.41	2.83	8	9	0.83	22
	2017	55	37	3	48	77.08	1.54	2.00	1.31	1.80	6	6	0.79	23
Swallow	**2014**	70	43	4	64	67.19	1.36	2.02	0.83	1.56	7	7	0.69	52
	2015	71	37	5	71	52.10	0.72	1.38	0.69	1.32	8	10	0.66	1
	2016	72	44	4	65	67.69	1.23	1.82	1.09	1.65	7	7	0.70	9
	2017	72	40	4	66	60.61	1.30	2.15	0.98	1.76	8	8	0.78	29
Cardinal	**2015**	67	33	7	46	71.74	1.15	1.61	0.85	1.39	7	8	0.74	30
	2016	65	39	6	45	86.67	1.73	2.00	1.42	1.83	9	11	0.83	31
	2017	66	35	7	46	76.09	1.61	2.11	1.11	1.65	8	9	0.76	50
Chickadee* (South Arm)	**2015**	55	7	3	11	63.64	1.00	1.57	0.45	1.25	4	5	0.61	55
	2016	56	7	5	28	25.00	0.46	1.86	0.36	1.43	6	7	0.71	11
	2017	56	11	5.5	36	30.56	0.53	1.73	0.25	1.13	3	4	0.54	28
Oriole	**2015**	68	26	9	48	54.17	0.90	1.65	0.63	1.36	5	5	0.70	27
	2016	62	28	7	44	63.64	0.91	1.43	0.77	1.26	6	6	0.69	14
	2017	56	22	9.5	46	47.83	0.76	1.59	0.52	1.09	5	6	0.57	24
Eagle	**2014**	105	16	6.5	55	29.09	0.56	1.94	0.38	1.40	7	7	0.76	15
	2017	100	14	5	40	35.00	0.58	1.64	0.28	1.10	4	7	0.57	30
Hummingbird	**2016**	59	34	6	59	57.63	0.93	1.62	0.58	1.21	7	9	0.66	36
	2017	63	32	6	63	50.79	0.81	1.59	0.52	1.27	7	8	0.65	29
Mourning Dove	**2016**	122	59	7.5	89	66.29	1.04	1.58	0.88	1.39	9	10	0.68	17
	2017	122	56	6.5	78	71.79	1.19	1.66	0.88	1.28	8	9	0.62	31
Woodpecker	**2016**	83	22	4.5	77	28.57	0.77	2.68	0.68	2.36	7	8	0.82	9
	2017	85	15	4	70	21.43	0.39	1.80	0.29	1.43	4	4	0.68	10
Warbler	**2017**	62	9	3	18	50.00	0.78	1.56	0.33	1.50	4	7	0.58	44
Killdeer	**2017**	62	5	3	10	50.00	1.00	2.00	0.60	2.00	4	4	0.72	40
Mockingbird	**2017**	35	15	5	35	42.86	0.71	1.67	0.63	1.47	7	8	0.74	6
Quail	**2017**	75	23	8.5	67	34.33	0.64	1.87	0.42	1.27	5	6	0.67	22

**All data are for South Arm of Chickadee Bay only.*

***Also known as the "frequency of occurrence at sites shallower than the maximum rooting depth of plants"*

Herbicide treatment occurred during years when littoral frequency of EWM is red.

Table 4 – Floristic Quality Results 2014-2017

Bay & Year		Coontail, *Ceratophyllum demersum*	Slender waterweed, *Elodea nuttallii*	Water stargrass, *Heteranthera dubia*	Small duckweed, *Lemna minor*	Slender naiad, *Najas flexilis*	White water lily, *Nymphaea odorata*	Long-leaf pondweed, *Potamogeton nodosus*	Small pondweed, *Potamogeton pusillus*	Large duckweed, *Spirodela polyrhiza*	Sago pondweed, *Stuckenia pectinata*	Broad-leaved cattail, *Typha latifolia*	Wild celery, *Vallisneria americana*	N (native species only)	Mean C	FQI
Martin-Meadowlark	**2014**	X	X	-	X	-	X	-	-	X	-	-	-	**5**	**5.0**	**11.5**
	2015	X	X	-	X	-	X	X	-	X	X	-	-	**7**	**5.0**	**13.2**
	2016	X	X	-	X	-	X	X	X	X	-	-	-	**7**	**5.6**	**14.7**
	2017	X	X	-	X	-	X	-	X	-	-	-	-	**5**	**5.4**	**12.1**
Swallow	**2014**	X	-	-	X	-	X	-	-	X	X	-	-	**5**	**4.2**	**9.4**
	2015	X	X	-	X	-	X	-	X	X	-	-	-	**6**	**5.3**	**13.1**
	2016	X	X	-	X	-	X	-	-	X	-	-	-	**5**	**5.0**	**11.2**
	2017	X	X	-	X	-	X	-	X	X	-	-	-	**6**	**5.3**	**13.1**
Cardinal	**2015**	X	X	-	X	-	-	-	X	-	X	-	X	**6**	**5.0**	**12.2**
	2016	X	X	X	X	-	-	-	X	X	X	-	X	**8**	**5.1**	**14.5**
	2017	X	X	X	-	X	X	-	X	-	-	-	X	**7**	**5.4**	**14.4**
Chickadee (South Arm)	**2015**	X	X		-	-	-	-	X	-	-	-	-	**3**	**5.7**	**9.8**
	2016	X	X	-	-	-	X	-	X	-	X	-	-	**5**	**5.2**	**11.6**
	2017	X	-	-	-	-	-	-	-	-	X	-	-	**2**	**3**	**4.2**
Oriole	**2015**	X	X	-	-	-	-	-	X	-	X	-	-	**4**	**5.0**	**10.0**
	2016	X	X	-	-	-	X	-	X	-	X	-	-	**5**	**5.2**	**11.6**
	2017	X	X	-	-	-	X	-	X	-	-	-	-	**4**	**5.8**	**11.5**
Eagle	**2014**	X	X	-	-	-	X	-	X	-	X	-	-	**5**	**5.2**	**11.6**
	2017	X	-	-	X	-	-	-	X	-	-	-	-	**3**	**4.7**	**8.1**
Humming-bird	**2016**	X	X	-	-	-	X	-	X	-	X	-	X	**6**	**5.3**	**13.1**
	2017	X	X			-	X		X		X	-	X	**6**	**5.3**	**13.1**
Mourning Dove	**2016**	X	X	-	X	-	X	-	X	-	X	-	X	**7**	**5.1**	**13.6**
	2017	X	X	-	-	X	X	-	X	-	X	-	X	**7**	**5.4**	**14.4**
Woodpecker	**2016**	X	X	-	X	-	X	X	-	X	-	-	-	**6**	**5.3**	**13.1**
	2017	X	-	-	X	-	X	-	-	-	-	-	-	**3**	**4.3**	**7.5**
Warbler	**2017**	X	-	-	-	-	-	X	X	-	-	-	-	**3**	**5.7**	**9.8**
Killdeer	**2017**	X	-	-	X	-	X	-	-	-	-	-	-	**3**	**4.3**	**7.5**
Mockingbird	**2017**	X	X	-	X	-	X	-	-	-	-	X	-	**5**	**4.2**	**9.4**
Quail	**2017**	X	-	-	-	-	-	-	X	-	X	-	X	**4**	**4.8**	**9.5**

This table includes only those species that were found on the rake at survey points and those that are listed in Nichols (1999). X=present.

Table 5 – Individual Species Results for Cardinal, South Chickadee, Eagle, and Hummingbird Bays, 2017

Bay Name	Common Name	Scientific Name	Relative Frequency (%)	Number of Sites	Number of Visual Sites	Frequency of Occurrence at Vegetated Sites	Frequency of Occurrence at Sites ≤max Depth	Average Rake Fullness
Cardinal	Coontail	*Ceratophyllum demersum*	33.78	25	0	71.43	54.35	1.96
	Eurasian water milfoil	*Myriophyllum spicatum*	31.08	23	14	65.71	50.00	1.22
	Small pondweed	*Potamogeton pusillus*	10.81	8	1	22.86	17.39	1.00
	Wild celery	*Vallisneria americana*	9.46	7	2	20.00	15.22	1.00
	Slender waterweed	*Elodea nuttallii*	6.76	5	0	14.29	10.87	1.00
	Filamentous algae		-	5	2	14.29	10.87	1.00
	Sago pondweed	*Stuckenia pectinata*	5.41	4	2	11.43	8.70	1.00
	Water star-grass	*Heteranthera dubia*	1.35	1	2	2.86	2.17	1.00
	Slender naiad	*Najas flexilis*	1.35	1	1	2.86	2.17	1.00
	White water lily	*Nymphaea odorata*	*	*	2	*	*	*
Chickadee	Eurasian water milfoil	*Myriophyllum spicatum*	52.63	10	2	90.91	27.78	1.40
	Coontail	*Ceratophyllum demersum*	42.11	8	0	72.73	22.22	2.00
	Sago pondweed	*Stuckenia pectinata*	5.26	1	0	9.09	2.78	1.00
	Filamentous algae		*	*	3	*	*	*
	White water lily	*Nymphaea odorata*	*	*	2	*	*	*
Eagle	Eurasian water milfoil	*Myriophyllum spicatum*	52.17	12	15	85.71	30.00	1.00
	Coontail	*Ceratophyllum demersum*	39.13	9	0	64.29	22.50	1.44
	Small duckweed	*Lemna minor*	4.35	1	0	7.14	2.50	1.00
	Small pondweed	*Potamogeton pusillus*	4.35	1	1	7.14	2.50	1.00
	Curly-leaf pondweed	*Potamogeton crispus*	*	*	1	*	*	*
	White water lily	*Nymphaea odorata*	*	*	7	*	*	*
	Sago pondweed	*Stuckenia pectinata*	*	*	2	*	*	*
	Filamentous algae		*	*	2	*	*	*
Hummingbird	Coontail	*Ceratophyllum demersum*	47.06	24	1	75.00	38.10	1.54
	Eurasian water milfoil	*Myriophyllum spicatum*	35.29	18	17	56.25	28.57	1.06
	Sago pondweed	*Stuckenia pectinata*	7.84	4	1	12.50	6.35	1.00
	Filamentous algae			4	9	12.50	6.35	1.00
	White water lily	*Nymphaea odorata*	3.92	2	3	6.25	3.17	1.00
	Slender waterweed	*Elodea nuttallii*	1.96	1	0	3.13	1.59	1.00
	Small pondweed	*Potamogeton pusillus*	1.96	1	0	3.13	1.59	1.00
	Wild celery	*Vallisneria americana*	1.96	1	1	3.13	1.59	1.00
	Long-leaf pondweed	*Potamogeton nodosus*	*	*	1	*	*	*

Table 6– Individual Species Results for Killdeer, Martin-Meadowlark, Mockingbird, Mourning Dove, and Oriole Bays, 2017

Bay Name	Common Name	Scientific Name	Relative Frequency (%)	Number of Sites	Number of Visual Sites	Frequency of Occurence at Vegetated Sites	Frequency of Occurrence at Sites ≤max Depth	Average Rake Fullness
Killdeer	Eurasian watermilfoil	*Myriophyllum spicatum*	44.44	4	5	80.00	40.00	1.00
	Coontail	*Ceratophyllum demersum*	22.22	2	1	40.00	20.00	1.00
	White water lily	*Nymphaea odorata*	22.22	2	10	40.00	20.00	1.00
	Small duckweed	*Lemna minor*	11.11	1	1	20.00	10.00	1.00
Mart-Mead	Small duckweed	*Lemna minor*	31.08	23	10	62.16	47.92	1.00
	Coontail	*Ceratophyllum demersum*	17.57	13	7	35.14	27.08	1.00
	White water lily	*Nymphaea odorata*	17.57	13	20	35.14	27.08	1.00
	Slender waterweed	*Elodea nuttallii*	16.22	12	0	32.43	25.00	1.00
	Filamentous algae		-	12	1	32.43	25.00	1.00
	Eurasian water milfoil	*Myriophyllum spicatum*	14.86	11	19	29.73	22.92	1.09
	Small pondweed	*Potamogeton pusillus*	2.70	2	0	5.41	4.17	1.00
Mockingbird	Small duckweed	*Lemna minor*	36.00	9	8	60.00	25.71	1.00
	Coontail	*Ceratophyllum demersum*	32.00	8	1	53.33	22.86	1.13
	White water lily	*Nymphaea odorata*	12.00	3	4	20.00	8.57	1.00
	Eurasian water milfoil	*Myriophyllum spicatum*	8.00	2	8	13.33	5.71	1.00
	Curly-leaf pondweed	*Potamogeton crispus*	4.00	1	0	6.67	2.86	1.00
	Slender waterweed	*Elodea nuttallii*	4.00	1	0	6.67	2.86	1.00
	Broad-leaved cattail	*Typha latifolia*	4.00	1	1	6.67	2.86	1.00
	Filamentous algae		-	1	5	6.67	2.86	1.00
	Sago pondweed	*Stuckenia pectinata*	*	*	1	*	*	*
Mourning Dove	Coontail	*Ceratophyllum demersum*	54.84	51	0	91.07	65.38	1.71
	Eurasian water milfoil	*Myriophyllum spicatum*	25.81	24	13	42.86	30.77	1.33
	Filamentous algae		-	8	0	14.29	10.26	1.25
	White water lily	*Nymphaea odorata*	5.38	5	14	8.93	6.41	1.40
	Small pondweed	*Potamogeton pusillus*	5.38	5	1	8.93	6.41	1.00
	Wild celery	*Vallisneria americana*	3.23	3	1	5.36	3.85	1.00
	Slender waterweed	*Elodea nuttallii*	2.15	2	0	3.57	2.56	1.00
	Sago pondweed	*Stuckenia pectinata*	2.15	2	2	3.57	2.56	1.00
	Slender naiad	*Najas flexilis*	1.08	1	0	1.79	1.28	3.00
	Curly-leaf pondweed	*Potamogeton crispus*	*	*	3	*	*	*
Oriole	Coontail	*Ceratophyllum demersum*	57.14	20	2	90.91	43.48	1.70
	Eurasian water milfoil	*Myriophyllum spicatum*	31.43	11	5	50.00	23.91	1.27
	Slender waterweed	*Elodea nuttallii*	5.71	2	0	9.09	4.35	1.00
	White water lily	*Nymphaea odorata*	2.86	1	0	4.55	2.17	1.00
	Small pondweed	*Potamogeton pusillus*	2.86	1	0	4.55	2.17	1.00
	Sago pondweed	*Stuckenia pectinata*	*	*	1	*	*	*

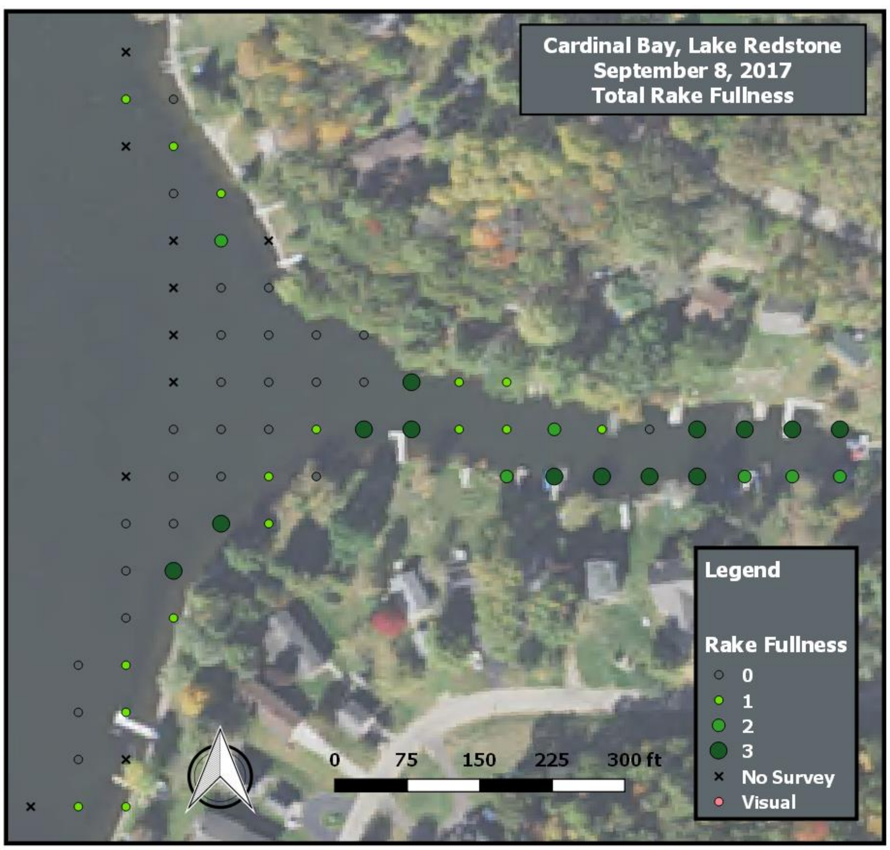
Table 7 – Individual Species Results for Quail, Swallow, Warbler, and Woodpecker Bays, 2017

Bay Name	Common Name	Scientific Name	Relative Frequency (%)	Number of Sites	Number of Visual Sites	Frequency of Occurence at Vegetated Sites	Frequency of Occurrence at Sites ≤max Depth	Average Rake Fullness
Quail	Coontail	*Ceratophyllum demersum*	41.86	18	00	78.26	26.87	1.11
	Eurasian water milfoil	*Myriophyllum spicatum*	34.88	15	12	65.22	22.39	1.20
	Wild celery	*Vallisneria americana*	16.28	7	00	30.43	10.45	1.00
	Sago pondweed	*Stuckenia pectinata*	4.65	2	00	8.70	2.99	1.00
	Small pondweed	*Potamogeton pusillus*	2.33	1	00	4.35	1.49	1.00
	White water lily	*Nymphaea odorata*	*	*	6	*	*	*
Swallow	White water lily	*Nymphaea odorata*	27.91	24	17	60.00	36.36	1.00
	Coontail	*Ceratophyllum demersum*	25.58	22	0	55.00	33.33	1.05
	Eurasian water milfoil	*Myriophyllum spicatum*	22.09	19	27	47.50	28.79	1.00
	Small duckweed	*Lemna minor*	17.44	15	12	37.50	22.73	1.00
	Curly-leaf pondweed	*Potamogeton crispus*	2.33	2	2	5.00	3.03	1.00
	Large duckweed	*Spirodela polyrhiza*	2.33	2	7	5.00	3.03	1.00
	Slender waterweed	*Elodea nuttallii*	1.16	1	0	2.50	1.52	1.00
	Small pondweed	*Potamogeton pusillus*	1.16	1	1	2.50	1.52	1.00
	Filamentous algae		*	*	1	*	*	*
Warbler	Eurasian water milfoil	*Myriophyllum spicatum*	57.14	8	5	88.89	44.44	1.00
	Coontail	*Ceratophyllum demersum*	28.57	4	0	44.44	22.22	1.00
	Long-leaf pondweed	*Potamogeton nodosus*	7.14	1	1	11.11	5.56	1.00
	Small pondweed	*Potamogeton pusillus*	7.14	1	0	11.11	5.56	1.00
	Curly-leaf pondweed	*Potamogeton crispus*	*	*	1	*	*	*
	Small duckweed	*Lemna minor*	*	*	1	*	*	*
	White water lily	*Nymphaea odorata*	*	*	2	*	*	*
Woodpecker	White water lily	*Nymphaea odorata*	37.04	10	10	66.67	14.29	1.00
	Small duckweed	*Lemna minor*	33.33	9	2	60.00	12.86	1.00
	Eurasian water milfoil	*Myriophyllum spicatum*	25.93	7	9	46.67	10.00	1.14
	Filamentous algae		-	2	0	13.33	2.86	1.00
	Coontail	*Ceratophyllum demersum*	3.70	1	0	6.67	1.43	1.00

Cardinal Bay

A total of 71 survey waypoints were attempted in Cardinal Bay, 66 of which were surveyed because 3 points were too deep (>12 feet), 1 point was obstructed by piers, and one point was on land. The maximum rooting depth was 7 feet. Forty-six survey points were ≤7 feet and 35 of those sites had vegetation. The average number of species found at the 35 vegetated sites was 2.11 and the average rake fullness was 1.91 (Table 3). A total of 9 species of aquatic plants were found, one of which was "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 9 species. Coontail and Eurasian watermilfoil were the most common species found at 54% and 50% of littoral survey points respectively (51% and 31% in 2016). Together they accounted for 65% of the total relative frequency, indicating the plant community is more homogeneous than it was in 2016 when those species accounted for 47% of the total relative frequency (Table 5). Slender naiad (*Najas flexilis*, a native aquatic plant*)* was found at 1 site and visually observed at another site but was not documented in previous whole-lake aquatic plant surveys in 2005 and 2012 (Berg, 2012) nor had it been documented in any previous bay-wide surveys. Maps of plant species can be found in Appendix A. The Simpson Diversity Index for Cardinal Bay was 0.76 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include invasive species. Therefore, 7 species were counted yielding a relatively high floristic quality of 14.4 with an average C value of 5.4 (Table 4). Chi-square tests revealed a statistically significant decrease in small duckweed and filamentous algae between 2016 and 2017 and a statistically significant decrease in filamentous algae when comparing data from 2015 and 2017 (Appendix N).

Figure 3 – Cardinal Bay Total Rake Fullness Map



South Chickadee Bay

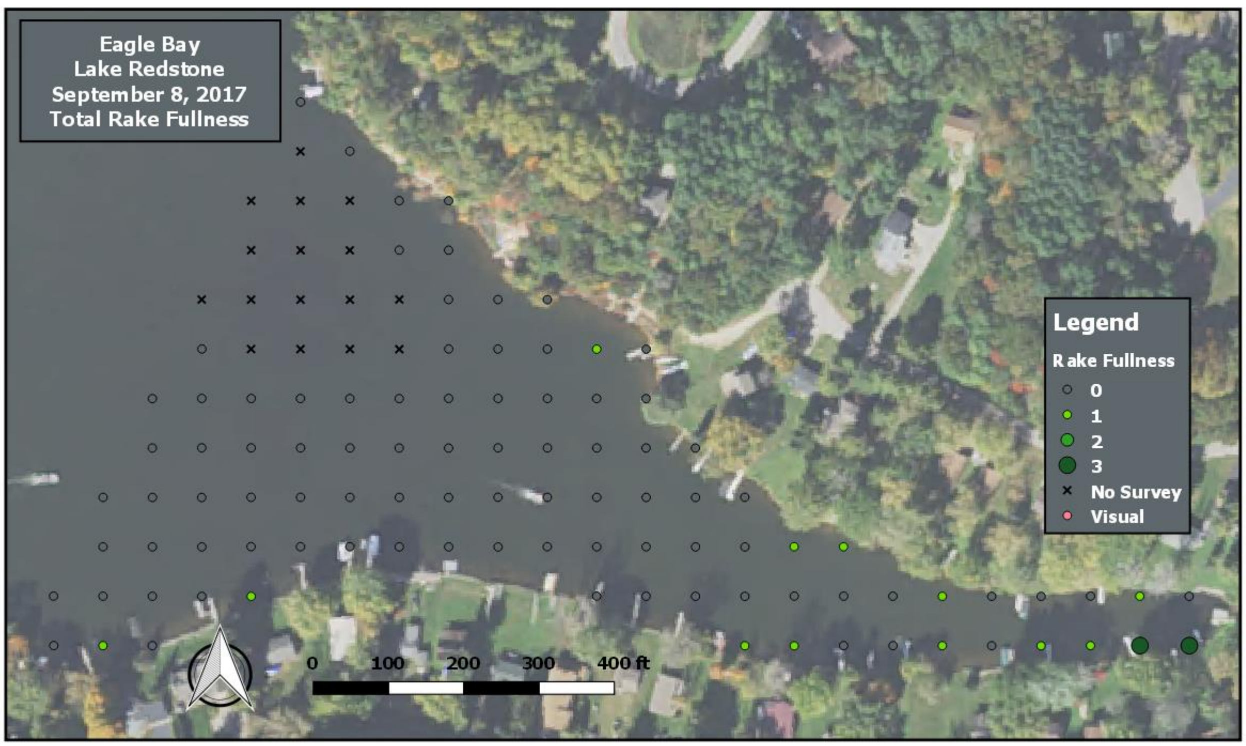
There were 56 points surveyed in South Chickadee Bay in 2017, 36 of which were the same depth or shallower than the maximum rooting depth of 5.5 feet. Only 11 sites had vegetation with an average number of 1.73 species found per site and the average rake fullness of 1.91 (Table 3). A total of 4 species of aquatic plants were found, one of which was "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 4 species. Eurasian watermilfoil and coontail were the most common species found at 28% and 22% of littoral survey points respectively (11% and 21% in 2016). Together they accounted for 95% of the total relative frequency (69% in 2016), indicating a highly homogeneous plant community in the bay (Table 5). Chi-square tests of all plant species revealed a statistically significant increase in Eurasian watermilfoil when compared to 2016. There were not statistically significant changes between the 2015 and 2017 data. Maps of plant species can be found in Appendix B. The Simpson Diversity Index for South Chickadee Bay was the much lower at 0.54 compared to 0.71 in 2016. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 2 species were included in the calculation, yielding a low floristic quality of 4.2 and low average C value of 3 (Table 4).

Figure 4 – South Chickadee Bay Total Rake Fullness Map

Eagle Bay

In Eagle Bay, 100 points were surveyed out of a possible 115 because 15 points were deeper than 12 feet. Forty survey points were the same depth or shallower than the maximum rooting depth of 5 feet and 14 of those sites had vegetation. The average number of species found at vegetated points was 1.64 and the average rake fullness was 1.27 (Table 3). A total of 7 species of aquatic plants were found, three of which were "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 7 species. Eurasian watermilfoil and coontail were the most common species found at 30% and 23% of littoral survey points respectively (15% and 22% in 2014). Together they accounted for 91% of the total relative frequency (65% in 2014), suggesting a highly homogeneous plant community (Table 5). Maps of plant species can be found in Appendix C. The Simpson Diversity Index was low at 0.57 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 3 species were included in the calculation, yielding a floristic quality of 8.1 with an average C value of 4.7 (Table 4). Chi-square tests revealed no statistically significant differences between data from 2014 and 2017.

Figure 5 – Eagle Bay Total Rake Fullness Map



Hummingbird Bay

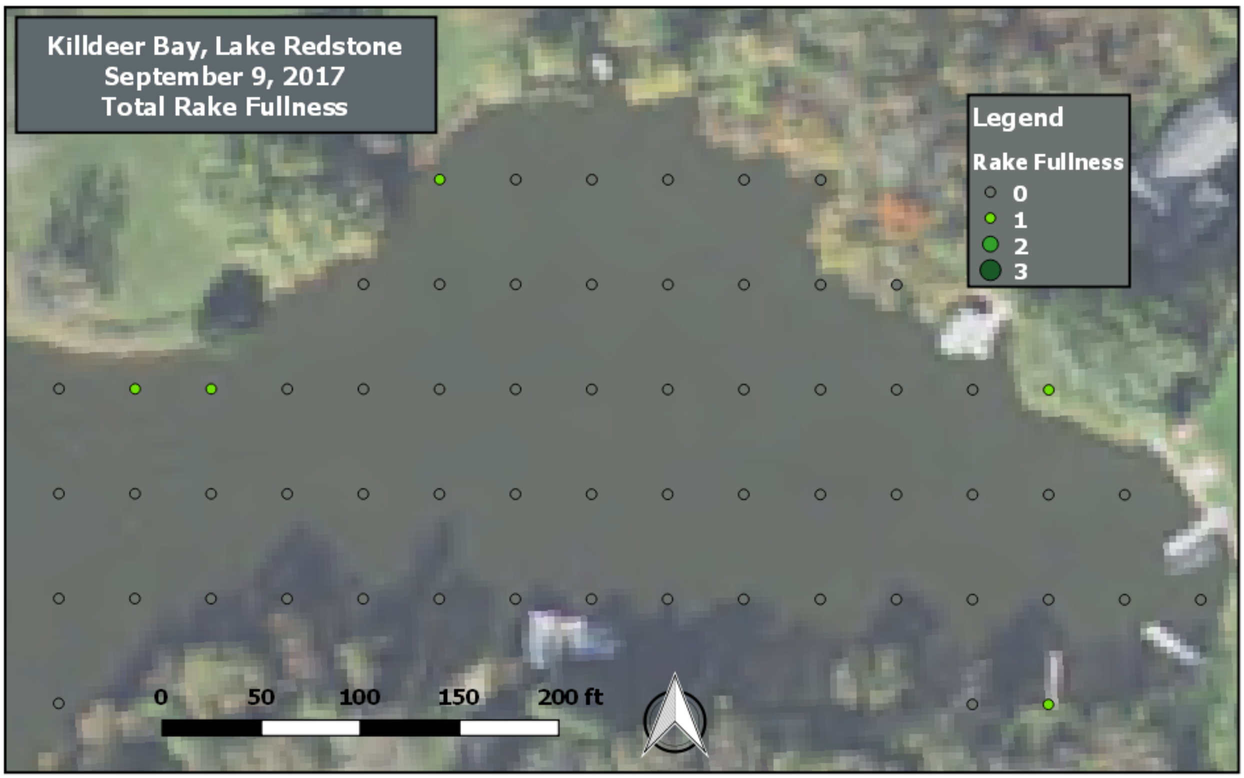
Sixty-three points were surveyed out of a possible 65 because two points were obstructed by piers. All survey points were the same depth or shallower than the maximum rooting depth of 6 feet and 32 of those sites surveyed had vegetation. The average number of species found at vegetated points was 1.59 and the average rake fullness was 1.50 (Table 3). A total of 8 species of aquatic plants were found, one of which was "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 8 species. Coontail and Eurasian watermilfoil were the most common species found at 38% and 29% of littoral survey points respectively (41% and 36% in 2016). Together they accounted for 82% of the total relative frequency (same in 2016), indicating a very homogeneous plant community (Table 5). Maps of plant species can be found in Appendix D. The Simpson Diversity Index was 0.65 (0.66 in 2016) on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 6 species were included in the calculation, yielding a floristic quality of 13.1 with an average C value of 5.3 (Table 4). Chi-square tests revealed no statistically significant differences between data from 2016 and 2017.

Figure 6 – Hummingbird Bay Total Rake Fullness Map

Killdeer Bay

Sixty-two points were surveyed and 10 survey points were the same depth or shallower than the maximum rooting depth of 3 feet. Only 5 sites had vegetation present with an average number of species of 1.8 at those sites and the average rake fullness of 1.00 (Table 3). A total of 4 species of aquatic plants were found. Eurasian watermilfoil and coontail were the most common species found at 40% and 20% of littoral survey points respectively. Together they accounted for 67% of the total relative frequency indicating a homogeneous plant community (Table 6). Maps of plant species can be found in Appendix E. The Simpson Diversity Index was 0.69 on a scale from 0 to 1. The FQI does not include aquatic invasive species so only 3 species were included in the calculation, yielding a floristic quality of 7.5 with an average C value of 4.3 (Table 4).

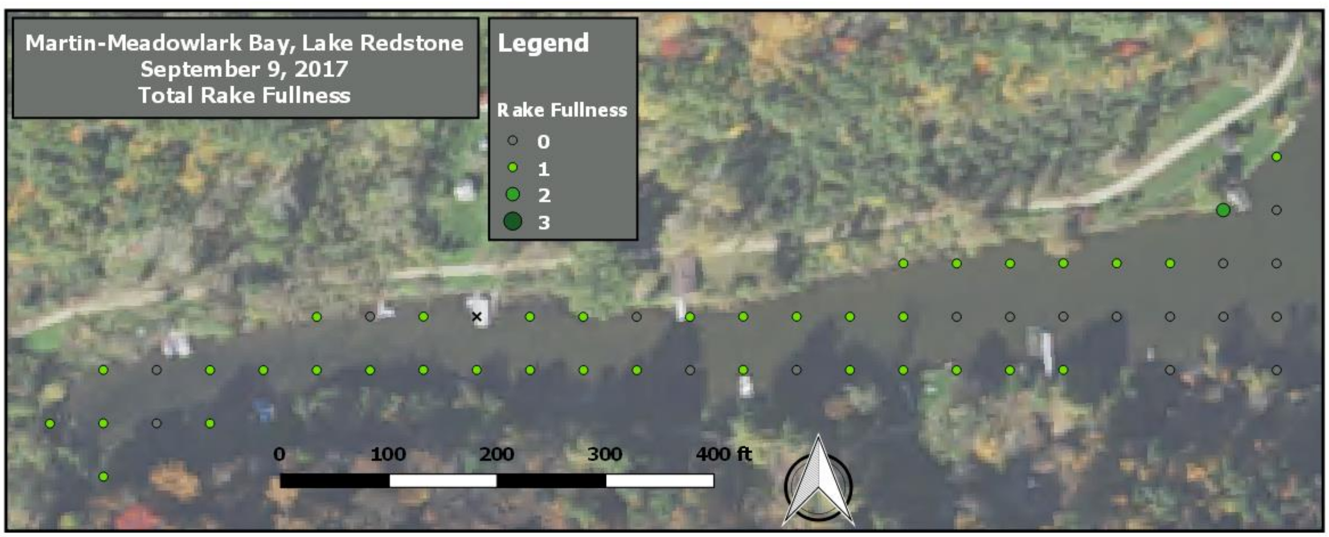
Figure 7 – Killdeer Bay Total Rake Fullness Map



Martin-Meadowlark Bay

In Martin-Meadowlark Bay 55 points were actually surveyed out of a possible 56 because one point was obstructed by piers. Forty-eight survey points were the same depth or shallower than the maximum rooting depth of 3 feet and 37 of those sites surveyed had vegetation. The average number of species found at vegetated points was 2.00 and the average rake fullness was 1.03 (Table 3). A total of 6 species of aquatic plants were found, not counting filamentous algae. Small duckweed and coontail were the most common species found at 48% and 27% of littoral survey points respectively (37% and 65% in 2016). Together they accounted for 49% of the total relative frequency (39% in 2016), indicating a more heterogeneous plant community than other bays (Table 6). Chi-square tests of all plant species revealed a statistically significant decrease in presence of coontail, slender waterweed, large duckweed, long-leaf pondweed and white-water lily when compared to 2016 data (Appendix N). Maps of plant species can be found in Appendix F. The Simpson Diversity Index for Martin-Meadowlark Bay was 0.79 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 5 species were included in the calculation, yielding a floristic quality of 12.1 with an average C value of 5.4 (Table 4).

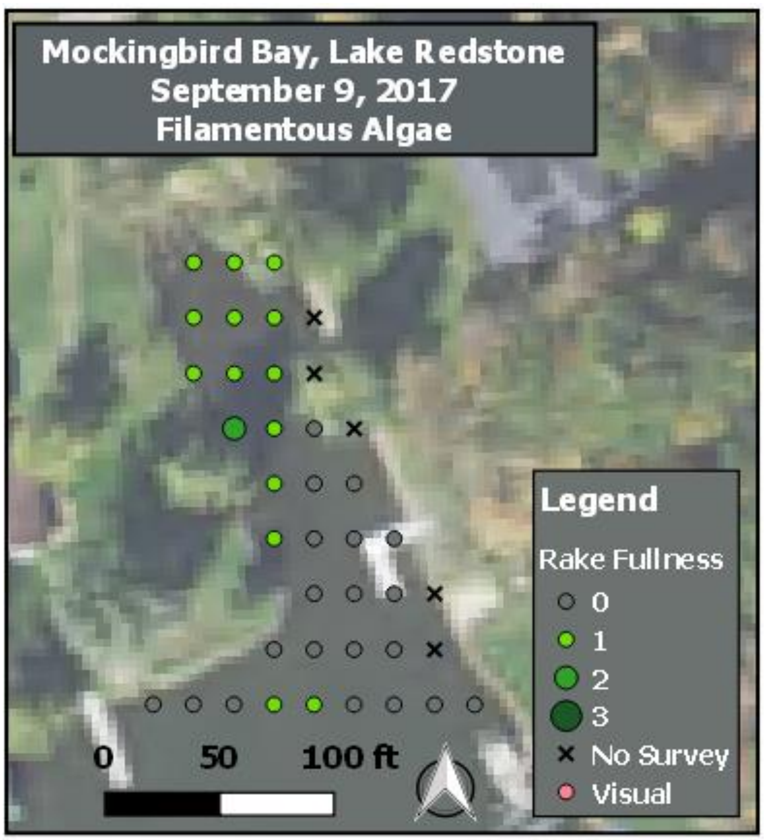
Figure 8 – Martin-Meadowlark Bay Total Rake Fullness Map



Mockingbird Bay

There were 40 survey points and 35 were actually visited because four were on land and one was obstructed by piers. All survey points were the same depth or shallower than the maximum rooting depth of 5 feet and vegetation was found at 15 sites with an average number of species of 1.67 per site and an average rake fullness of 1.08 (Table 3). A total of 8 species of aquatic plants were found, one of which was "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 8 species. Small duckweed and coontail were the most common species found at 26% and 23% of survey points (≤maximum rooting depth) respectively. Together they accounted for 68% of the total relative frequency, indicating a homogeneous plant community (Table 6). Maps of plant species can be found in Appendix G. The Simpson Diversity Index was 0.74 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 5 species were included in the calculation, yielding a floristic quality of 9.4 with an average C value of 4.8 (Table 4).

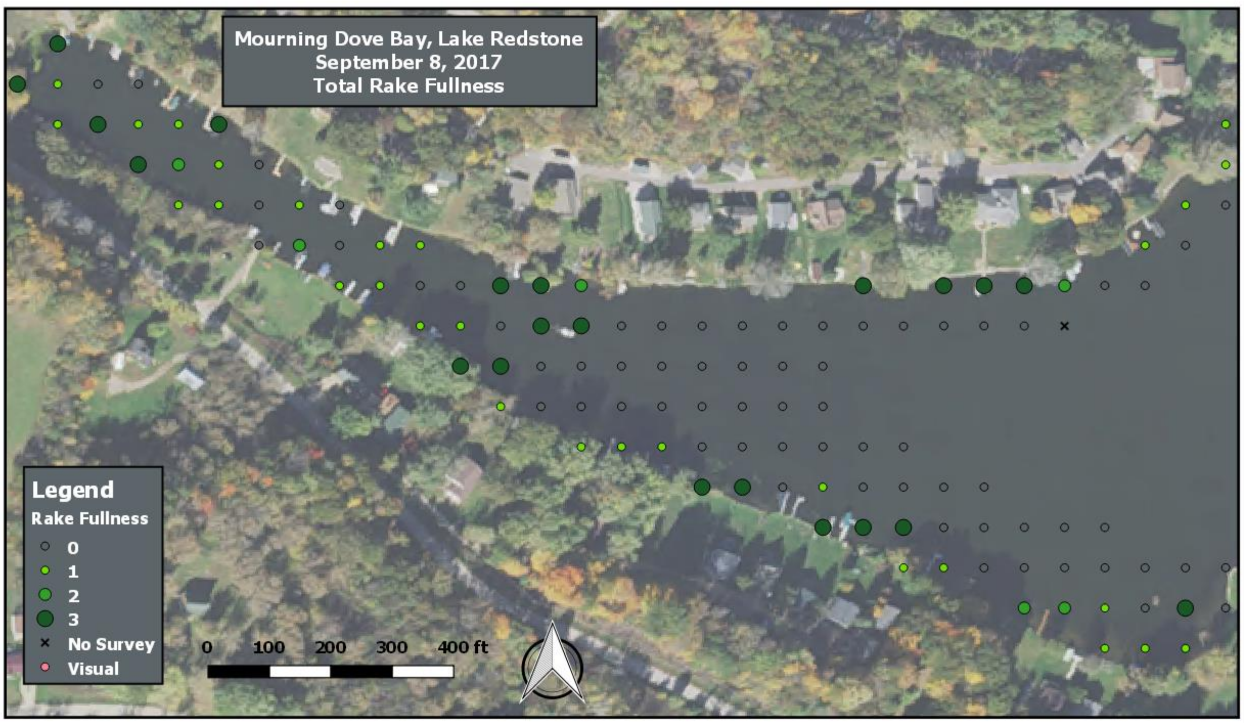
Figure 9 – Mockingbird Bay Total Rake Fullness Map



Mourning Dove Bay

There were 123 survey points and all but one were surveyed with 78 survey points at the same depth or shallower than the maximum rooting depth of 6.5 feet. Vegetation was found at 56 sites with an average number of species of 1.66 per site and an average rake fullness of 1.08 (Table 3). A total of 9 species of aquatic plants were found, one of which was "visual only" (i.e., within 6 feet of the survey point but not found on the rake). Filamentous algae is not counted as one of the 9 species. Coontail and Eurasian watermilfoil were the most common species found at 65% and 31% of littoral survey points respectively. Together they accounted for 69% of the total relative frequency, indicating a homogeneous plant community (Table 6). Maps of plant species can be found in Appendix H. The Simpson Diversity Index was 0.62 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include visuals or aquatic invasive species. Therefore, 7 species were included in the calculation, yielding a high floristic quality of 14.4 with an average C value of 5.4 (Table 4).

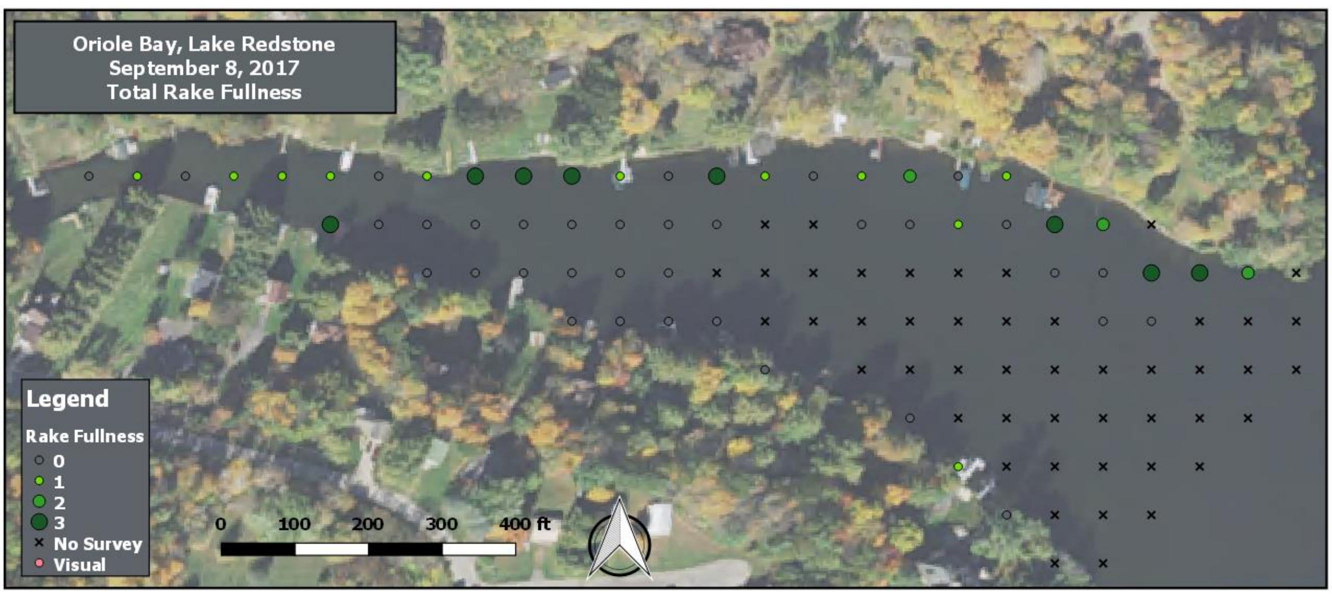
Figure 10 – Mourning Dove Bay Total Rake Fullness Map



Oriole Bay

A total of 104 predetermined survey waypoints were attempted in Oriole Bay, 56 of which were actually surveyed because 48 points were deeper than 12 feet. The maximum rooting depth was 9.5 feet in Oriole Bay. There were 46 survey points ≤9.5 feet deep and 22 sites had vegetation. The average number of species found at the 28 sites with vegetation was 1.59 and the average rake fullness was 1.86 (Table 3). A total of 6 species of aquatic plants were found, one of which was "visual only" and not including filamentous algae. Coontail and Eurasian watermilfoil were the most common species found at 43% (45% in 2016) and 24% (14% in 2016) of littoral survey point, respectively. Together they accounted for 89% of the total relative frequency (65% in 2016), indicating the plant community in Oriole Bay is highly homogeneous (Table 6). Chi-square tests of all plant species revealed a statistically significant decrease in sago pondweed when compared to 2016 data. There were no statistically significant changes between the 2015 and 0217 data sets. All chi-square test results are in Appendix N. Maps of plant species can be found in Appendix I. The Simpson Diversity Index for Oriole Bay was 0.57 on a scale from 0 to 1. The FQI does not include aquatic invasive species. Therefore, 4 species were included in the calculation, yielding a floristic quality of 11.5 with an average C value of 5.8 (Table 4).

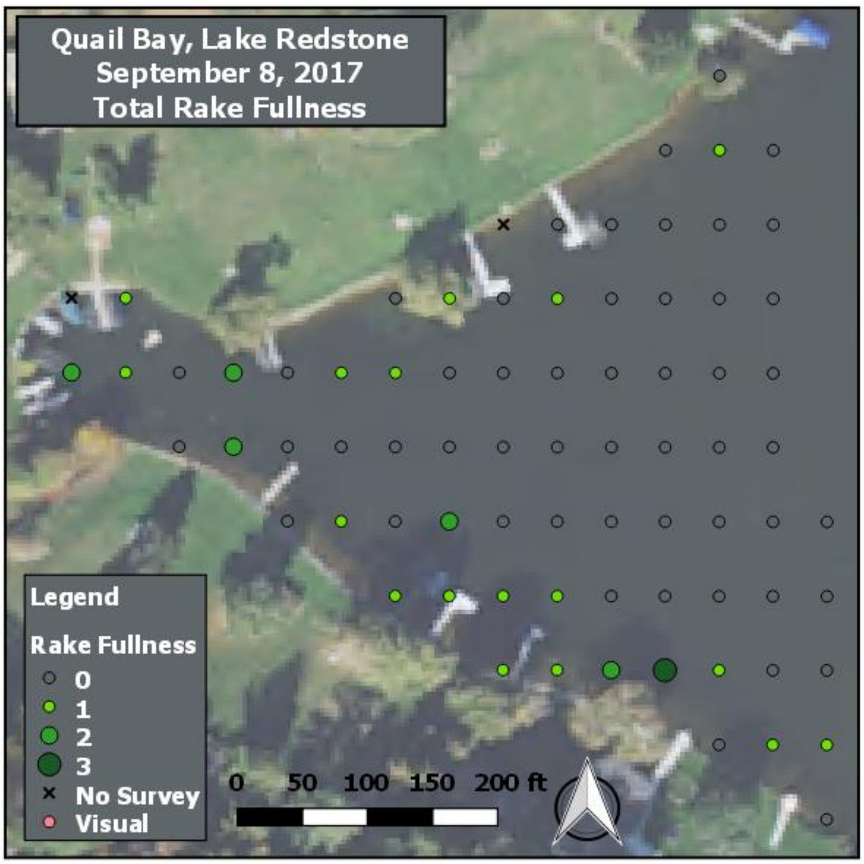
Figure 11 – Oriole Bay Total Rake Fullness Map



Quail Bay

A total of 77 predetermined survey waypoints were attempted in Quail Bay, 75 of which were actually surveyed because one site was on land and one was obstructed by piers. The maximum rooting depth was 8.5 feet and there were 67 survey points ≤8.5 feet deep, 23 of which had vegetation. The average number of species found at the 28 sites with vegetation was 1.87 and the average rake fullness was 1.30 (Table 3). A total of 6 species of aquatic plants were found, one of which was "visual only" and not including filamentous algae. Coontail and Eurasian watermilfoil were the most common species found at 27% and 22% of littoral survey points, respectively. Together they accounted for 77% of the total relative frequency, indicating the plant community in Quail Bay is homogeneous (Table 7). Maps of plant species can be found in Appendix J. The Simpson Diversity Index for Quail Bay was 0.67 on a scale from 0 to 1. The FQI does not include aquatic invasive species. Therefore, 4 species were included in the calculation, yielding a floristic quality of 9.5 with an average C value of 4.8 (Table 4).

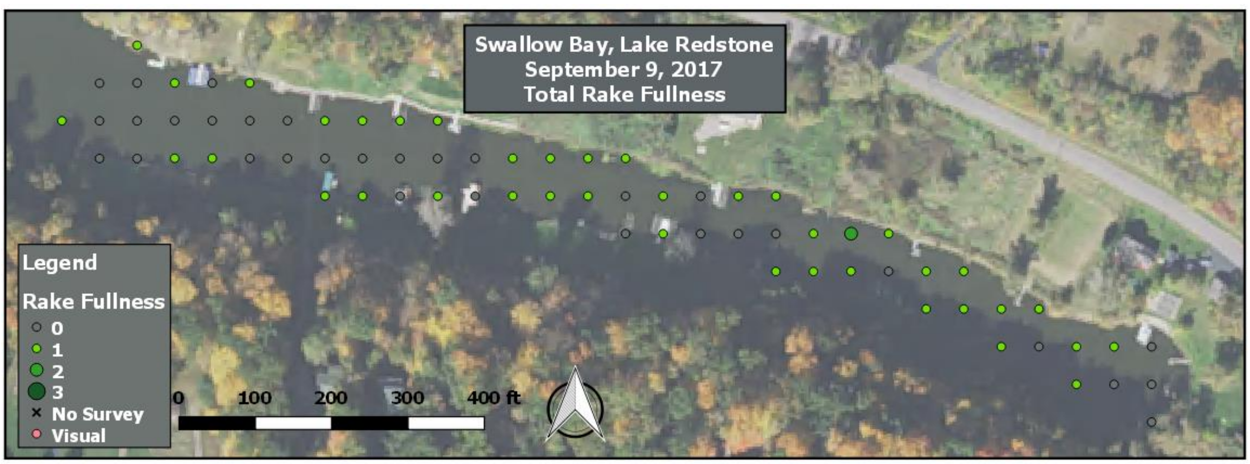
Figure 12 – Quail Bay Total Rake Fullness Map



Swallow Bay

In Swallow Bay all 72 points were surveyed, 66 were shallower than the maximum rooting depth of 4 feet and 40 sites had vegetation. The average number of species found at vegetated sites was 2.15 and the average rake fullness was 1.03 (Table 3). A total of 8 species of aquatic plants were found in Swallow Bay, not including filamentous algae. White water lily and coontail were the most common species found at 36% and 33% of littoral survey points respectively (29% and 58% in 2016). Together they accounted for 53% of the total relative frequency indicating the plant community of Swallow Bay is somewhat heterogeneous (Table 7). Chi-square tests of all plant species revealed a statistically significant increase in small duckweed and Eurasian watermilfoil and a decrease in coontail when compared to 2016 data. Chi-square test of the 2014 data compared to 2017 revealed a statistically significant increase in small duckweed and decrease in coontail and filamentous algae (Appendix N). Maps of plant species can be found in Appendix K. The Simpson Diversity Index for Swallow Bay was 0.78 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include aquatic invasive species. Therefore, 6 species were included in the calculation, yielding a floristic quality of 13.1 with an average C value of 5.3 (Table 4).

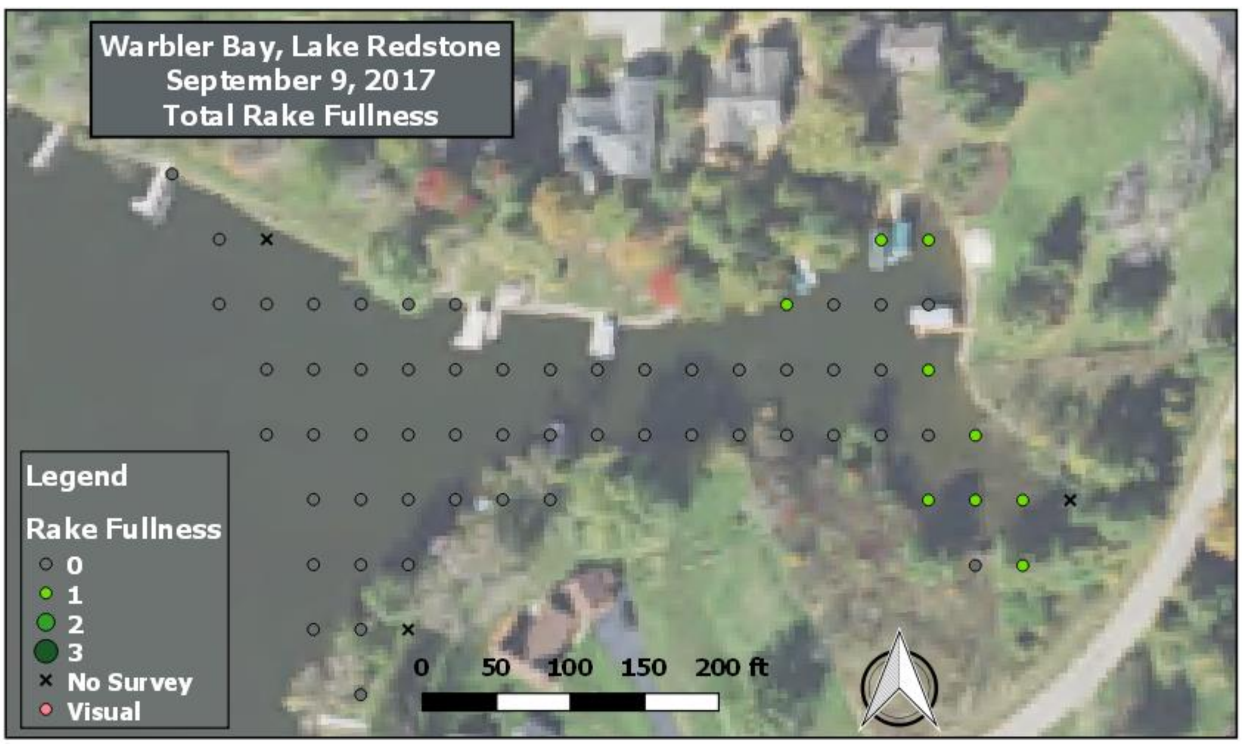
Figure 13 – Swallow Bay Total Rake Fullness Map



Warbler Bay

In Warbler Bay there were 65 survey points and 62 were actually surveyed because 3 sites were on land. The maximum rooting depth of plants was 3 feet and there were 18 sites ≤3 feet while only 9 of those sites had vegetation present. The average number of species found at vegetated sites was 1.56 and the average rake fullness was 1.00 (Table 3). A total of 7 species of aquatic plants were found in Warbler Bay, 3 of which were "visual only" and not including filamentous algae. Eurasian watermilfoil and coontail were the most common species found at 44% and 22% of littoral survey points respectively. Together they accounted for 86% of the total relative frequency indicating the plant community of Warbler Bay is highly heterogeneous (Table 7). Maps of plant species can be found in Appendix L. The Simpson Diversity Index was 0.58 on a scale from 0 to 1. The FQI only factors species raked at survey points and does not include aquatic invasive species. Therefore, 3 species were included in the calculation, yielding a floristic quality of 9.8 with an average C value of 5.7 (Table 4).

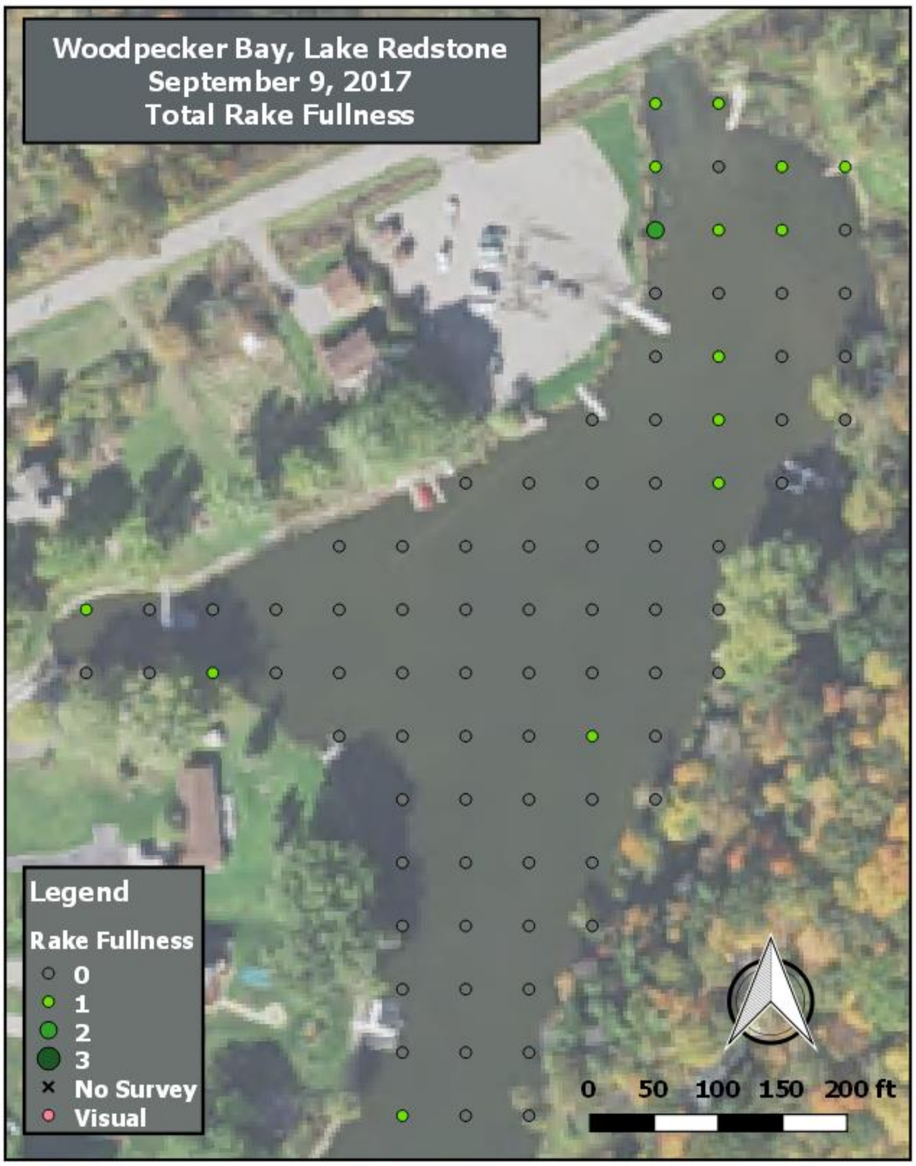
Figure 14 – Warbler Bay Total Rake Fullness Map



Woodpecker Bay

A total of 86 survey waypoints were attempted, 85 of which were surveyed. The maximum rooting depth was 4 feet and 70 of the survey points were ≤4 feet. Vegetation was present at 15 survey points. An average of 1.80 species was found at vegetated sites and the average rake fullness was 1.07 (Table 3). A total of 4 species of aquatic plants were found. White water lily and small duckweed were the most common species, found at 14% and 13% of littoral survey points, respectively. Together they accounted for 70% of the total relative frequency, indicating the plant community is homogeneous (Table 6). Maps of plant species can be found in Appendix N. A chi-square test comparing data from 2016 and 2017 revealed a statistically significant decrease in large duckweed, filamentous algae, and coontail (Appendix N). The Simpson Diversity Index was 0.68 on a scale from 0 to 1. The FQI does not include aquatic invasive species or visual observations. Therefore, 3 species were included in the calculation, yielding a floristic quality of 7.5 with an average C value of 4.3 (Table 4).

Figure 15 – Woodpecker Bay Total Rake Fullness Map



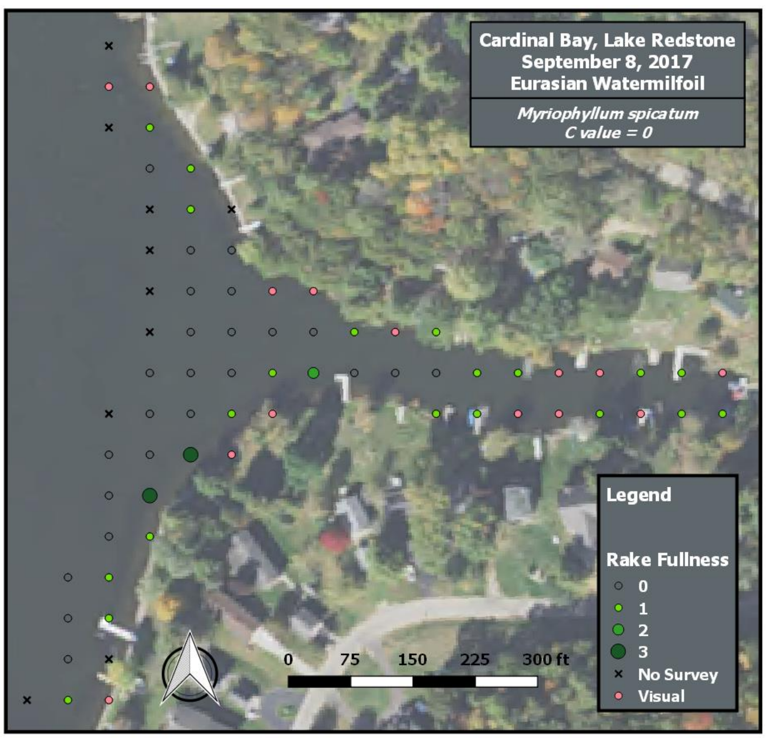
Eurasian Watermilfoil & Management History

Eurasian watermilfoil (EWM) was found in all bays and was the most common plant in 4 bays and second-most common plant in 5 bays. A more detailed assessment of EWM in each bay is included in this section since each bay has its own management history. The timing of annual surveys should be taken into consideration when interpreting these results because they occurred in July, August, and September (see List 1).

Cardinal Bay EWM

EWM was the second-most common plant with scattered distribution at 23 sites and visual observation at another 14 points. Total rake fullness was "3" at two of the sites and "2" at one site. EWM littoral frequency was 50% in 2017 and 31% in 2016 (Table 3). It was also the second-most common plant in 2016 with occurrence at 14 sites and visual observation at another 5 sites. Herbicide was applied in Cardinal Bay in spring of 2016. A chi-square test of EWM in 2016 compared to 2017 reveals no significant difference between the years. There was also no statistically significant difference between 2015 and 2016 nor when the 2015 data was compared to the 2017 data.

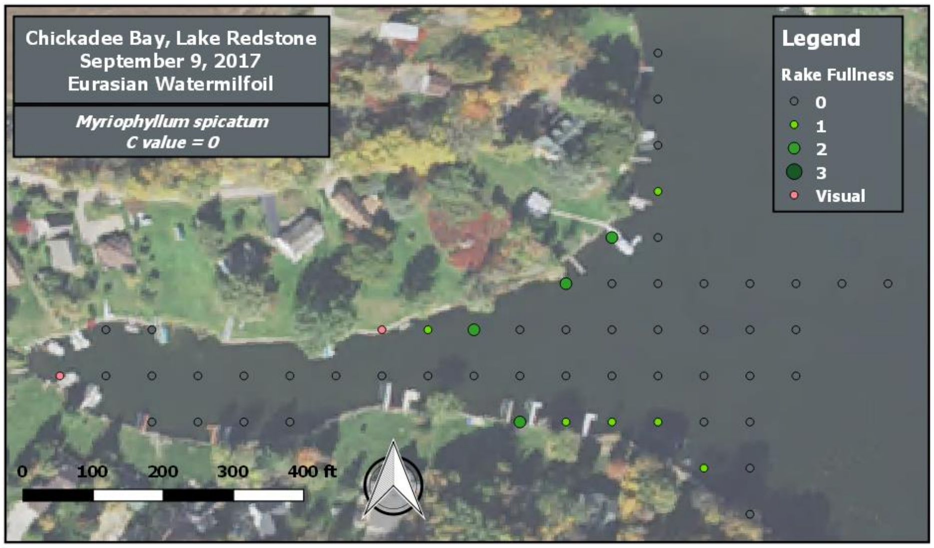
Figure 16 - Cardinal Bay EWM



South Chickadee Bay EWM

EWM was the most common aquatic plant in 2017 and was found at 10 sites with rake fullness values of "2" at 4 of those sites. There were another two visual observations in the bay. There were only 3 sites total in 2016. EWM littoral frequency was 28% in 2017 and 11% in 2016 (Table 3). Herbicides were applied to the southern arm of Chickadee Bay in spring of 2016 to combat EWM. A chi-square test of EWM presence in 2016 compared to 2017 revealed a statistically significant increase between the years. No statistically significant difference was detected between 2015 and 2016 nor was there a statistically significant difference between 2015 and 2017.

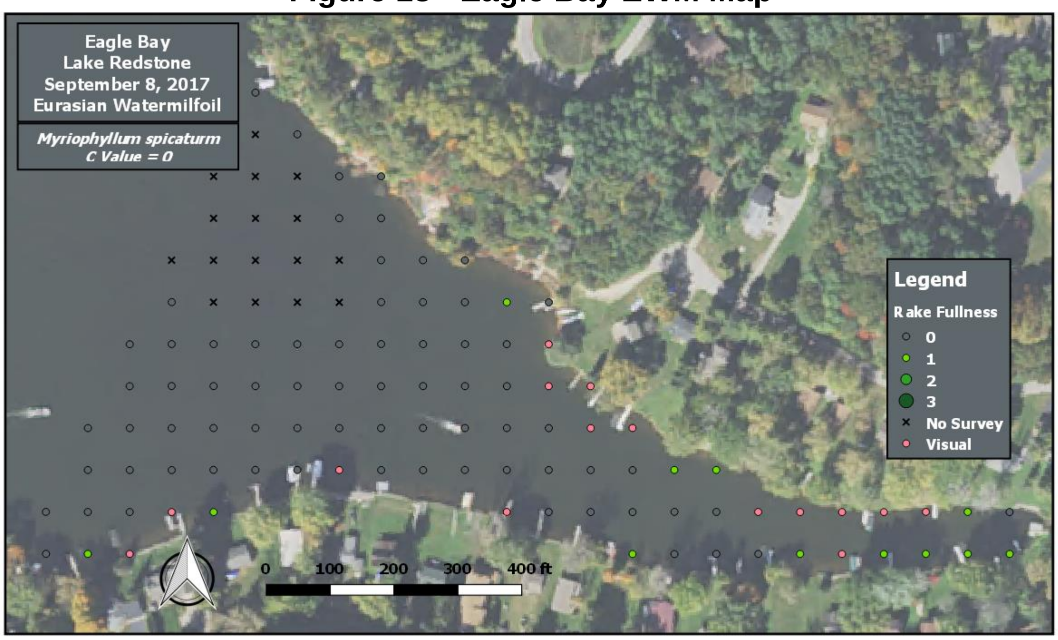
Figure 17– South Chickadee Bay EWM Map



Eagle Bay EWM

EWM was found at 12 survey points and another 15 visual observations, making it the most common plant species in Eagle Bay (8 sites and 8 visual in 2014). Littoral frequency of EWM was 30% in 2017 and 15% in 2016. EWM was distributed throughout the narrowest section of the bay and along the shore toward the mouth of the bay. No herbicide treatment has been conducted in Eagle Bay. Comparisons between 2014 and 2017 using chi-square tests reveal no statistically significant difference in any plant species.

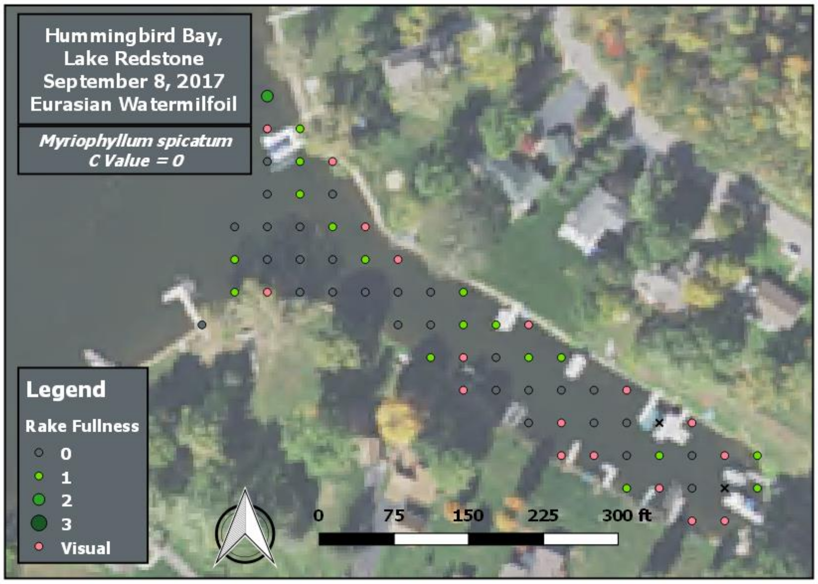
Figure 18 - Eagle Bay EWM Map



Hummingbird Bay EWM

EWM was found at 18 survey points and another 17 visual observations (21 sites and 3 visual in 2016), making it the second most common plant species distributed throughout Hummingbird Bay. One site had a total rake fullness of "2." EWM littoral frequency was 29% in 2017 and 36% in 2016. Herbicide treatment was conducted in Hummingbird Bay in spring 2017. There was no statistically significant difference in EWM between 2016 and 2017.

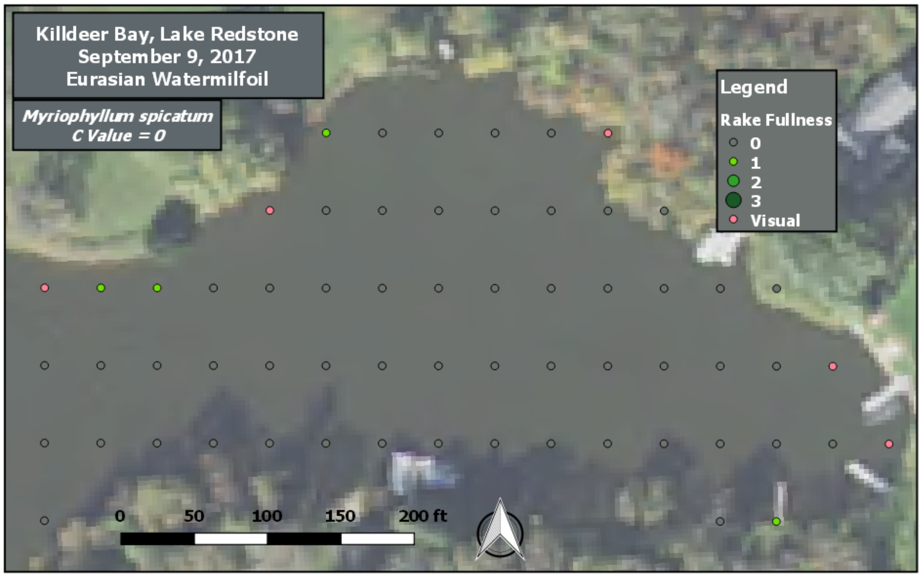
Figure 19 - Hummingbird Bay EWM Map



Killdeer Bay EWM

EWM was found at 4 survey points and another 5 visual observations, making it the most common plant species in Killdeer Bay. EWM littoral frequency was 40% and no herbicide treatment has been used in Killdeer Bay.

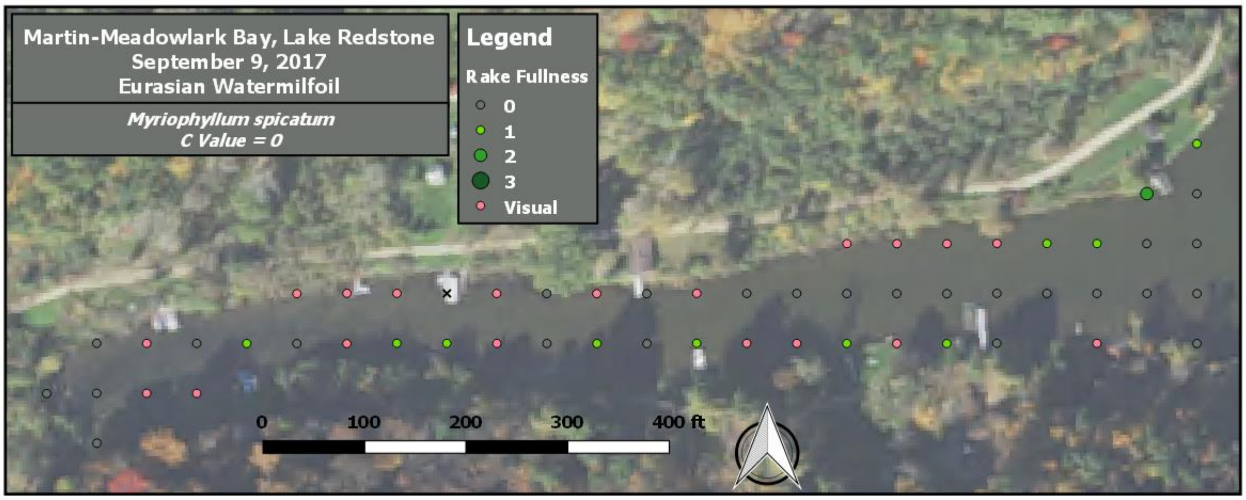
Figure 20 – Killdeer Bay EWM Map



Martin-Meadowlark Bay EWM

The first survey in 2014 revealed EWM at 22 sites. Herbicide treatment was conducted in spring of 2015 and a survey that same summer yielded promising results with no EWM found in the bay. The 2016 survey revealed EWM at 12 sites, which is a statistically significant increase from 2015 according to the chi square test (7 visual observations in 2016 also). In 2017, EWM was found at 11 sites (one of which had a total rake fullness of "2") and another 19 visual observations distributed throughout the bay, which is not a statistically significant change compared to 2016. EWM was not among the most common plant species found in the bay with a low relative frequency of 15%. Littoral frequency of EWM was 22% in 2016 and 23% in 2017 (Table 3).

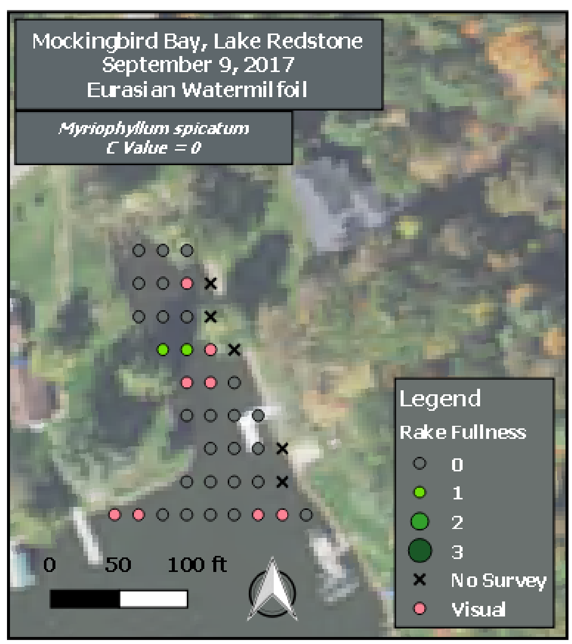
Figure 21 – Martin-Meadowlark EWM Map



Mockingbird Bay EWM

EWM was found at 2 survey points and another 8 visual observations resulting in low relative frequency of 8%. Littoral frequency was 6%. No herbicide treatment has been carried out in Mockingbird Bay and the 2017 survey was intended to gauge EWM and help determine the need for possible herbicide treatment in 2018.

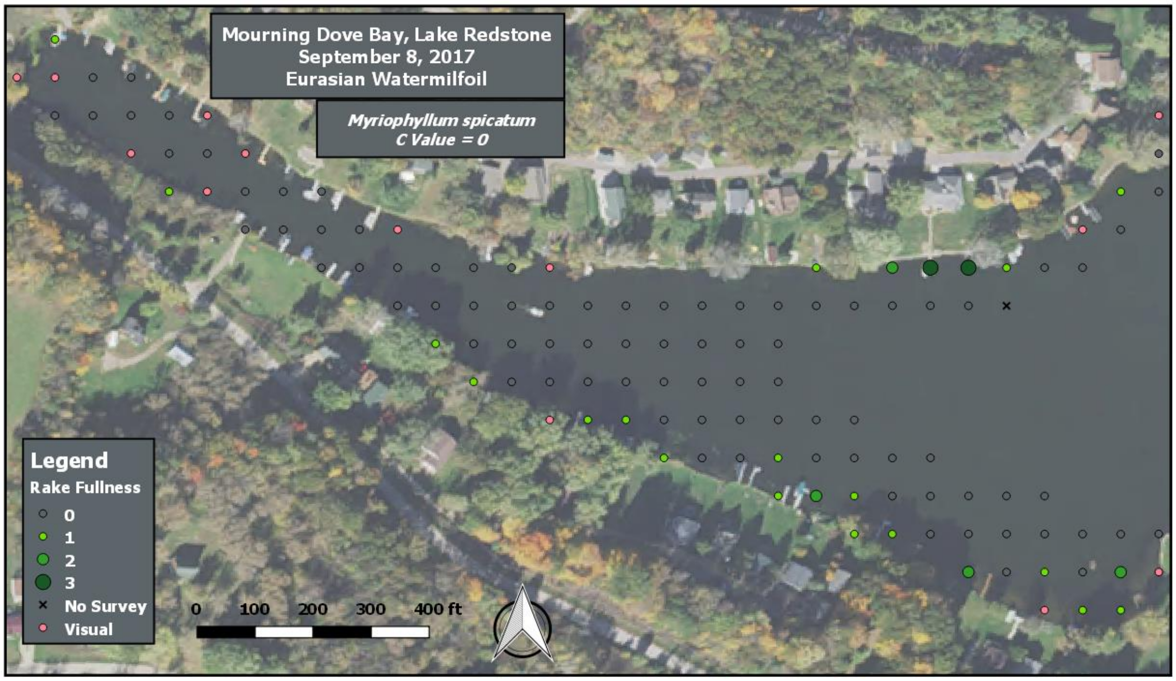
Figure 22 - Mockingbird Bay EWM Map



Mourning Dove Bay EWM

EWM was found at 24 survey points and another 13 visual observations, making it the second most common plant species in Mourning Dove Bay. Total rake fullness was "3" at two sites and "2" at four sites. Littoral frequency of EWM was 31% in 2017 and 17% in 2016. There was no statistically significant difference in EWM occurrence between 2016 and 2017. Herbicide treatment was conducted in 2013 with pre- and post-treatment surveys completed by WDNR.

Figure 23 - Mourning Dove Bay EWM Map



Oriole Bay EWM

EWM was the second-most common plant with occurrence at 11 sites, mainly along the northern shore, and visual observation at another 5 points (6 sites and 7 visual in 2016). Total rake fullness was "2" at three of the sites. Herbicide was applied in spring of 2016 to control EWM. Littoral frequency was 24% in 2017 and 14% in 2016. A chi-square test of EWM 2017 compared to 2016 reveals no statistically significant difference between the years.

Figure 24 – Oriole Bay EWM Map

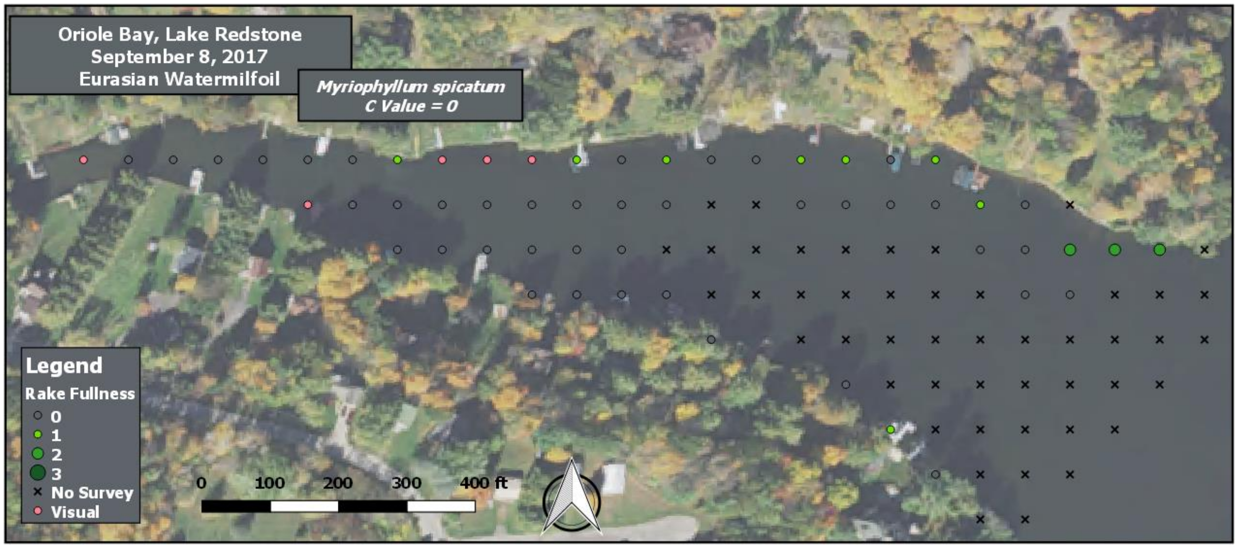
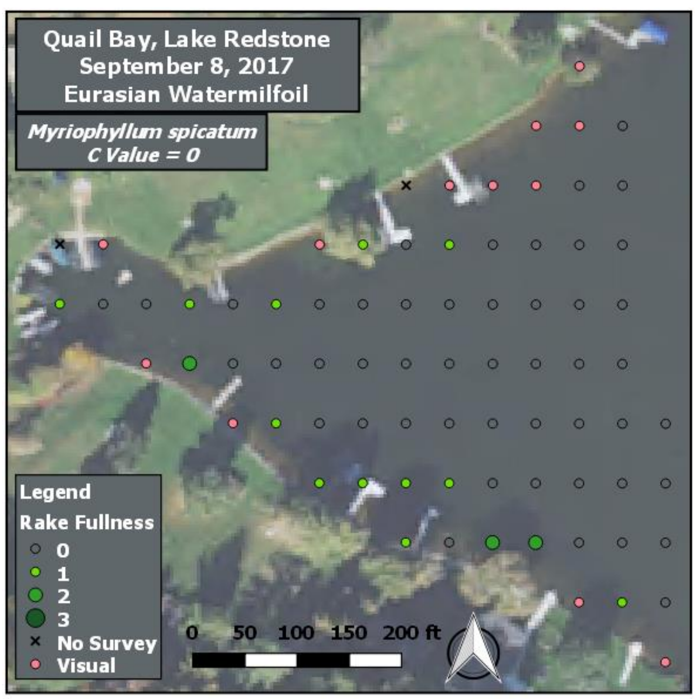


Figure 25 - Quail Bay EWM Map

Quail Bay EWM

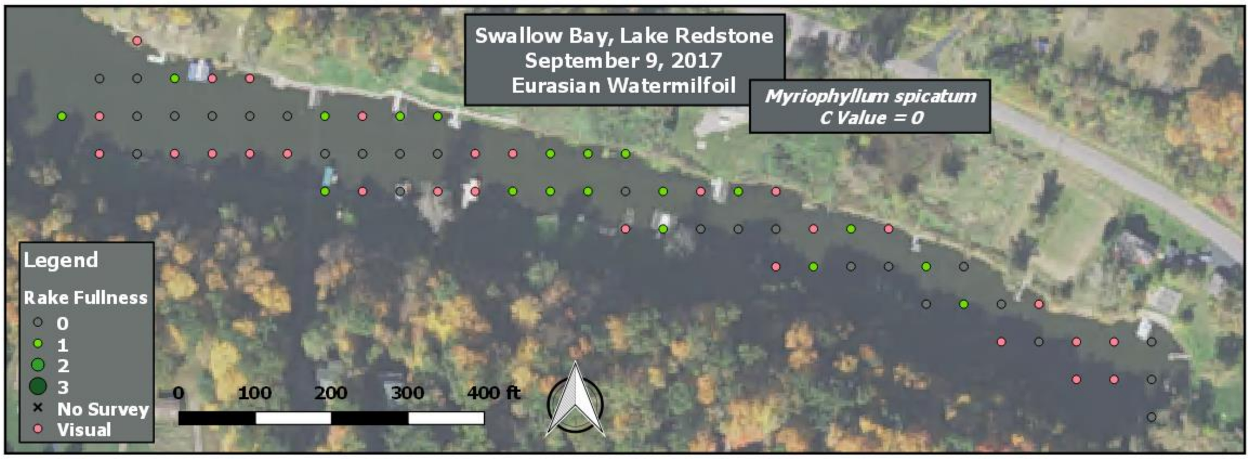
EWM was the second-most common plant with occurrence at 15 sites and visual observation at another 12 points. Total rake fullness was "2" at three sites. No herbicide treatment has occurred in Quail Bay. Relative frequency was high at 35% and littoral frequency was 22%.



Swallow Bay EWM

The first survey in 2014 revealed EWM at 33 sites. Herbicide treatment was conducted in spring of 2015 and a survey that same summer yielded promising results with EWM at only 1 site with another 4 visual observations. EWM was found at 6 sites in 2016, which was ***not*** a statistically significant increase from 2015 according to the chi-square test. EWM was found at 19 sites and another 27 visual observations in 2017, which was a statistically significant increase compared to 2016. A chi-square test of the 2014 EWM data compared to 2017 reveals a statistically significant decrease in EWM. The EWM was found scattered throughout the bay and not concentrated in any particular area. EWM was the third-most common species with a relative frequency of 22%. The littoral frequency of EWM was 29% in 2017 and 9% in 2016.

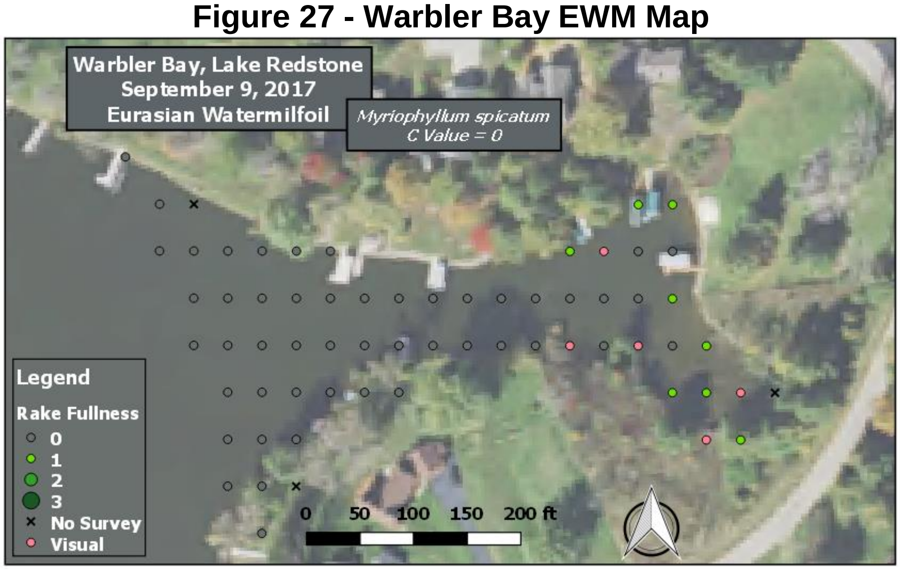
Figure 26 - Swallow Bay EWM Map



Warbler Bay EWM

EWM was the most common plant with occurrence at 8 sites and visual observation at another 5 points. Plant occurrence was low overall with vegetation at only 9 sites. No herbicide treatment has occurred in Warbler Bay. Relative frequency of EWM was high at 57% and littoral frequency was 44%.

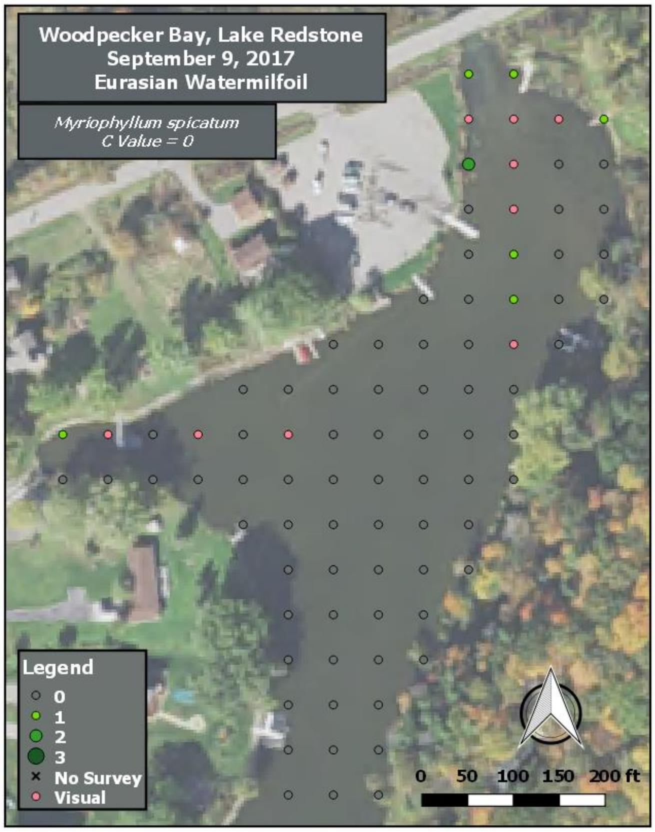
Figure 27 - Warbler Bay EWM Map



Woodpecker Bay EWM

EWM was found at 7 survey points and 9 visual observations (7 points and 1 visual in 2016) with a littoral frequency of 10%. One site had a total rake fullness of "2." Only four species of plants were found in Woodpecker Bay with EWM ranking third and a relative frequency of 26%. Herbicide treatment was conducted in the northern section of the bay in spring of 2017. There was no statistically significant difference in EWM in 2017 compared to 2016.

Figure 28 - Woodpecker Bay EWM Map



DISCUSSION

Aquatic Plants are Necessary for Healthy Lakes

Aquatic plants serve important functions in lake systems. They provide structural habitat for small invertebrates that are an important food source for juvenile game fish and adult panfish. Plants also provide structural habitat for juvenile and small fish to hide from predators and vice versa as larger predators may lurk in the shadows of plants in wait of forage. Aquatic plants also provide foraging and/or hiding structure for reptiles, amphibians, and waterfowl. The shorelines of lakes are buffered from wave action when aquatic plants absorb some of the wave energy. Aquatic plants are important consumers of nutrients that would otherwise be available for nuisance algal growth. For these reasons, native aquatic plants should be protected in lakes and a healthy aquatic plant community should be promoted.

There are times when native aquatic plants grow to nuisance levels that hinder the aforementioned functions and also negatively impact recreation. An overabundance of vegetation can cause oxygen depletion in the water as plants decompose, thereby reducing the oxygen available to fish and other aquatic organisms. Although the natural growth and senescence of aquatic plants is an important part of the cycling of nutrients in lakes, too many plants may cause a release of excess nutrients as they die. The excess nutrients could then serve to increase vegetation and also feed algae blooms.

Survey Timing and Chi-Square Results

The aquatic plant survey was scheduled for September in 2017 because observations in previous years suggested EWM occurrence increased after the plant surveys were already complete, thereby possibly under-reporting EWM when surveyed in July and August. If this were the case, one might hypothesize a statistically significant increase of EWM in several bays where previous year's data exists ***and*** no herbicide treatment occurred that year[1]. However, this was not the case. Chi-square tests showed a statistically significant increase in EWM in only two bays (Swallow and South Chickadee), suggesting a later survey is not critical ***or*** EWM was not as prevalent in 2017 compared to previous years.

The later survey in 2017 might explain some of the significant declines in native aquatic plants. Standard methodology for Wisconsin aquatic plant surveys recommends they occur between early July and mid-August (Hauxwell, 2010). With the September 2017 survey results, there was a statistically significant decline in 5 species in Martin-Meadowlark, two species in Woodpecker one species in Swallow, Cardinal, and Oriole when compared to the August 2016 results. There was a statistically significant increase in only one native species in Swallow Bay from 2016 to 2017. Furthermore, if we compare the August 2014 data from Swallow and Martin-Meadowlark Bay to September 2017, there is a statistically significant decrease in three species total and increase in two species total. Based on these results, native species differences between 2016 and 2017 may be due to timing of the survey and not actual changes in plant occurrence. For this reason, native species differences are not elaborated upon for each bay later in this section.

---

[1] Previous years' data exists for Cardinal, South Chickadee, Eagle, Hummingbird, Martin-Meadowlark, Mourning Dove, Oriole, Swallow, and Woodpecker Bays. Hummingbird and northern Woodpecker Bays were treated in spring 2017 so we would expect a decrease in EWM, not an increase.

Deciding on future timing of EWM surveys should take the items in List 2 under consideration. The decision should also depend on whether obtaining accurate native species data is a priority.

List 2 – Items for Consideration in Timing of Future Plant Surveys

- The point-intercept aquatic plant survey protocol measures presence and absence, not biomass.
- Biomass of EWM should be higher during a September survey and is expected to yield higher visual detection of the plant at sites within 6 feet of the survey point. Visual observations, however, do not infer greater occurrence because the EWM would be at the same locations in August but may have not been detectable as visual observations. Furthermore, only plants found on the rake (not visual observations) are included in statistical analyses and chi-square tests.
- A September survey is not expected to yield different EWM results from a mid-August survey. Another September survey will help support or refute this expectation.
- A September survey will alleviate the concern of under-reporting EWM. It is probable, however, that the observed increase of EWM in September is due to increased biomass (recall that the point-intercept survey measures present/absence, not biomass).
- A September survey may yield lower native species occurrence than a mid-August survey (inferred from Hauxwell et al. (2010)).

Sample Size and Chi-Square Results

In order for the chi-square distribution to be valid, the calculated expected values must not be too small. Small expected values occurred occasionally, but only when no significant difference was found. In other words, sample size was not an issue for any species found to have statistically significant differences as illustrated in Appendix N.

Identifying Trigger Frequencies for Herbicide Treatment

One possible management strategy is to identify a littoral frequency of EWM that triggers consideration for herbicide treatment the following spring. Littoral frequency is calculated by dividing the number of sites with EWM by the number of total sites shallower than maximum rooting depth of plants. For example, Martin-Meadowlark and Swallow Bays had high EWM littoral frequencies of 42% and 52%, respectively, before herbicide treatment occurred in 2015 (Table 8). Cardinal, south Chickadee, and Oriole had moderate-to-high EWM littoral frequencies of 30%, 55%, and 27%, respectively, before herbicide treatment in 2016. Hummingbird Bay had 36% littoral frequency of EWM before herbicide treatment in 2017. Woodpecker Bay had low EWM littoral frequency of only 9% in 2016 but only the northern section of the bay was treated in 2017 thereby focusing on the area where the most EWM was found. If we take an average pre-treatment littoral frequency of EWM for all bays that had herbicide treatment (not including Woodpecker), the result is approximately 40%. Details of each bays in this discussion section will refer to this 40% average as the "trigger" for herbicide consideration.

General Management Recommendations

Similar to previous years' recommendations, aquatic plants with low frequency of occurrence and/or higher conservatism value should be protected. These species include sago pondweed, small pondweed, slender waterweed, slender naiad, white water lily, long-leaf pondweed, and water celery. Coontail was the most or second-most commonly occurring plant in 12 bays and may pose hindrance to navigation in some of the bays. Hand removal of nuisance aquatic plants, such as coontail in some instances, is permitted by Chapter NR 109 but the removal cannot occur in a designated sensitive area (identified in Sefton & Graham 2009) without a permit, is limited to a single area no more than 30 feet wide measured along shore, and must not harm the aquatic plant community.

Volunteer water monitoring and early detection of aquatic invasive species is an important component of lake management. Continued water monitoring and AIS surveying is recommended.

Eurasian watermilfoil (EWM) was found in all 13 bays and can be controlled to some degree, but complete eradication is not a realistic management goal. Research suggests that small-scale chemical treatments using 2,4-D results in the rapid dissipation of herbicide off the treatment area, thereby decreasing efficacy. In other words, 2,4-D does not stay where it is applied in high enough concentrations and for a long enough period to cause mortality of EWM (Nault, et al. 2012). Narrow, sheltered bays present the best environment for keeping 2,4-D "sheltered" from mixing with the untreated water. Any chemical treatment should be monitored with a pre-and post-survey to determine effectiveness of treatment. Hand-pulling EWM is a possible control technique, especially where workers can wade and reach the EWM without snorkel or SCUBA gear due to low water clarity and limited visibility. Diver assisted suction harvesting (DASH) is another alternative for consideration. Although water clarity is relatively low in most areas of Lake Redstone, exploring this option with DASH consultants is recommended.

Curly-leaf pondweed (CLP) was found in Eagle, Mockingbird, Mourning Dove, Swallow, and Warbler Bays and in low enough occurrence that it was not cause for concern at this time. CLP can be controlled to some degree, but complete eradication is not a realistic management goal. Monitoring and hand-pulling CLP is recommended for control at this time.

Cardinal Bay

Herbicide treatment in spring of 2016 did not result in a statistically significant reduction of EWM when compared to survey results of 2015. Although there was higher occurrence of EWM in 2017 (23 sites + 14 visual) compared to 2016 (14 sites + 5 visual), the increase was not statistically significant. Given the increase in littoral frequency in 2017 to 50% (above the 40% trigger, see above) and very small change after herbicide treatment in 2016, the bay should be considered for different herbicide other than the type used in 2016. Other alternatives to control EWM such as manual/mechanical are also recommended. Cardinal Bay is not a designated sensitive area.

Chickadee Bay

Only the south arm of Chickadee Bay was treated with herbicide for EWM control in spring 2016, so the post-treatment survey in 2016 and 2017 focused on this area only. The decrease of EWM from 6 sites (+1 visual) in 2015 to 3 sites (+0 visual) in 2016 was not statistically significant. The increase of EWM from 2016 to 2017 ***was*** statistically significant. However, much of the EWM was found concentrated near shore in relatively small patches that could be addressed using manual/mechanical means. Furthermore, the littoral frequency of EWM was 28% (below the 40% trigger, see above). Hand pulling

EWM in areas of higher abundance and close monitoring are recommended for 2018. South Chickadee is a designated sensitive area.

Eagle Bay

EWM increased in Eagle Bay between 2014 (8 sites + 8 visual) and 2017 (12 sites + 15 visual), but this increase was not statistically significant. EWM was concentrated along the northern shore and in the eastern section of the bay with a maximum rooting depth of 5 feet. Herbicide treatment has not been attempted in Eagle Bay and the lack of significant increase over the last 3 years suggests herbicides may not be the best approach at this time. Also, the littoral frequency of EWM was 30% (below the 40% trigger, see above). For these reasons, no active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. The eastern half of Eagle Bay is a designated sensitive area.

Hummingbird Bay

Herbicide treatment using 2,4-D occurred in Hummingbird Bay in early spring 2017 resulting in a decrease of EWM at survey sites in 2017 (18 sites + 17 visual) compared to 2016 (21 sites + 3 visual) but the decrease was not statistically significant. In addition, the littoral frequency of EWM was 29% in 2017 (below the 40% trigger, see above). No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Hummingbird Bay is not a designated sensitive area.

Killdeer Bay

This was the first year of surveying for Killdeer Bay and no herbicide treatment has been done. The bay had very little vegetation with aquatic plants at only 5 sites and only 10 sites were shallower than the maximum rooting depth of 3 feet (62 sites total visited). Observation on the date of survey suggests the water clarity was lower in Killdeer Bay compared to some of the more southern bays. Lower water clarity will limit aquatic plant growth to the more shallow regions of the bay where adequate sunlight reaches the sediment allowing photosynthesis to occur. Water clarity assessment were not part of the surveying protocol in 2017 but should be added for future survey to better understand the situation in Killdeer Bay. EWM was found 5 sites + 4 visual observations. The littoral frequency of EWM was 40%, but that value should be considered artificially high because there were so few littoral sites in the bay (10) and a shallow maximum rooting depth of only 3 feet compared to other bays. Due to the low EWM occurrence overall, herbicide treatment is not recommended for 2018. No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Killdeer Bay is not a designated sensitive area but is designated for other public rights features.

Martin-Meadowlark Bay

The herbicide treatment of EWM in May 2015 appeared to be effective since no EWM was found that year but there was a statistically significant increase of EWM in 2016 (12 sites + 7 visual). EWM was found at 11 sites + 19 visual in 2017, a change that was not statistically significant. Overall, the comparison of 2014 data (pre-herbicide) to 2017 data reveals a statistically significant decrease in EWM overall. Furthermore, the littoral frequency of EWM was 23% in 2017 (below the 40% trigger, see above). For these reasons, no active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Along the northern shore in the eastern half of the bay is a designated sensitive area so raking or hand-pulling nuisance native vegetation is not allowed in that area without a permit.

Mockingbird Bay

No herbicide treatment has been done in Mockingbird Bay. The area of the bay is only 0.4 acres with 40 points 17 feet apart (5.3 m). Thirty-five point were actually visited because 4 points were on land and 1 was obstructed by piers. The boat used for surveying was 16 feet long, resulting in difficulty navigating to each survey point. A lower survey point resolution would have yielded fewer points in the small area and less rigor in statistical calculations. EWM was present at only 2 sites + 8 visual. Littoral frequency of EWM was very low at 6% (below the 40% trigger, see above). No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Mockingbird Bay is not a designated sensitive area.

Mourning Dove Bay

Herbicide treatment was conducted in 2013 in Mourning Dove Bay. EWM was found at 15 sites + 6 visual in 2016 and 24 sites + 13 visual in 2017 but the increase was not statistically significant. The littoral frequency of EWM was 31% in 2017 (below the 40% trigger, see above). However, the increase in EWM was more pronounced compared to the increase in other bays. Manual, mechanical, and/or herbicide treatment are recommended for consideration in 2018. Mourning Dove Bay is a designated sensitive area.

Oriole Bay

EWM was found at 6 sites + 7 visual in 2016 and 11 sites + 5 visual in 2017 but the increase is not statistically significant. Herbicide treatment was used in the bay in spring of 2016 to control EWM, resulting in a decrease in EWM when compared to 2015 data, but the change was not statistically significant. The littoral frequency of EWM was 24% in 2017 (below the 40% trigger, see above). Since herbicides did not result in effective EWM control, manual and/or mechanical control is recommended for 2018. Oriole Bay is a designated sensitive area.

Quail Bay

No herbicide treatment has been done in Quail Bay and 2017 was the first year of survey. EWM was the second-most common plant and was found at 15 sites + 12 visual. The littoral frequency of EWM was 22% (below the 40% trigger, see above). No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Quail Bay is not a designated sensitive area.

Swallow Bay

An herbicide treatment was done in Swallow Bay in spring 2015 yielding a statically significant decrease in EWM compared to 2014. EWM was not much higher in 2016 (6 sites + 10 visual) but in 2017 there was a statistically significant increase (19 sites + 27 visual). In other words, herbicide treatment appeared to effectively control EWM for two growing seasons (2015-2016) before a statistically significant increase occurred. Whether herbicide is considered for control in 2018 depends on whether two growing seasons of effective control is acceptable when weighing against the cost (financial and environmental). Furthermore, the littoral frequency of EWM was 29% in 2017 (below the 40% trigger, see above). Also, EWM occurrence in 2017 was still statistically lower than 2014. Based on the increase of EWM in 2017 alone, herbicide treatment is a reasonable alternative for 2018. Managers should also note the previous length of effective treatment (2 years) and the fact that EMW is still lower than 2014 levels. Manual and mechanical removal should also be considered. Swallow Bay is a designated sensitive area.

Warbler Bay

This was the first year of surveying for Warbler Bay and no herbicide treatment has been done. The bay had very little vegetation with aquatic plants at only 9 sites and only 18 sites were shallower than the maximum rooting depth of 3 feet (62 sites total visited). EWM was found 8 sites + 5 visual observations. The littoral frequency of EWM was 44%, but that value should be considered artificially high because there were so few littoral sites in the bay (18) and a shallow maximum rooting depth of only 3 feet compared to other bays. Due to the low EWM occurrence overall, herbicide treatment is not recommended for 2018. No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Warbler Bay is not a designated sensitive area.

Woodpecker Bay

EWM was found at 7 sites + 1 visual concentrated in the northeast area in 2016. Herbicide treatment was conducted in spring 2017 in the northernmost areas of the bay. EWM was found at 7 sites + 9 visual in 2017, again concentrated in the northern section of the bay. Littoral frequency of EWM was 10% (below the 40% trigger, see above). No active management (continue to monitor), manual or mechanical removal of EWM is recommended for 2018. Much of Woodpecker Bay is a designated sensitive area.

Table 8 – Management Recommendation Summary Table for All Bays

Bay & Year		Littoral frequency of EWM	Statistically Significant increase (+) decrease (-) or no change in EWM	Recommended EWM Management Options for 2018	Sensitive Areas Designation	Max Rooting Depth EWM 2017 (ft)
Martin-Meadowlark	**2014**	42	na	No Active Mgmt Manual Mechanical	Yes	3
	2015	**0**	-			
	2016	22	+			
	2017	23	none			
Swallow	**2014**	52	na	Herbicide Manual/Mechanical	Yes	4
	2015	**1**	-			
	2016	9	none			
	2017	29	+			
Cardinal	**2015**	30	na	Manual/Mechanical Different herbicide than 2016	No	7
	2016	**31**	none			
	2017	50	none			
Chickadee* (South Arm)	**2015**	55	na	Manual/Mechanical	Yes	5.5
	2016	**11**	none			
	2017	28	+			
Oriole	**2015**	27	na	Manual/Mechanical	Yes	5
	2016	**14**	none			
	2017	24	none			
Eagle	**2014**	15	na	No Active Mgmt Manual/Mechanical	Yes	5
	2017	30	none			
Hummingbird	**2016**	36	na	No Active Mgmt Manual/Mechanical	No	5.5
	2017	**29**	none			
Mourning Dove	**2016**	17	na	Manual/Mechanical Herbicide	Yes	6.5
	2017	31	none			
Woodpecker	**2016**	9	na	No Active Mgmt Manual/Mechanical	Yes	2
	2017	**10**	none			
Quail	**2017**	22	na	No Active Mgmt Manual/Mechanical Herbicide	No	5.5
Killdeer	**2017**	40	na	No Active Mgmt Manual/Mechanical	Other Public Rights Features	3
Warbler	**2017**	44	na	No Active Mgmt Manual/Mechanical	No	3
Mockingbird	**2017**	6	na	No Active Mgmt Manual/Mechanical	No	2

**All data are for South Arm of Chickadee Bay only. **Also known as the "frequency of occurrence at sites shallower than the maximum rooting depth of plants. Herbicide treatment occurred during years when littoral frequency of EWM is red. "na" = not applicable.*

Table 9 - Management Recommendations Summary

1. Protect native aquatic plants as they provide important structural habitat and contribute to a healthy lake system.
2. If necessary, shore land owners can hand pull or rake nuisance vegetation in a <30-foot-wide area that is contiguous and parallel to shore in areas that are not designated sensitive areas.
3. Continue volunteer water quality monitoring.
4. If chemical treatment using 2,4-D is pursued, consider treating only the areas most sheltered from wind and wave action to prevent rapid dilution of the herbicide. Any chemical treatment should be monitored with pre-and post-surveys to determine effectiveness of treatment.
5. Consider using “trigger” littoral frequencies of EWM (40% average) to help determine whether herbicide treatment is reasonable.
6. Include water clarity (Secchi depth) measurements in each bay during future aquatic plant surveys.
7. Explore Diver Assisted Suction Harvesting (DASH) as an option for EWM control.

REFERENCES

Berg, M.S. 2012. July Warm Water Point Intercept Aquatic Macrophyte Survey, Lake Redstone, Sauk County, Wisconsin. Endangered Resource Services LLC. 71pp.

Hauxwell, J., S. Knight, K. Wagner, A. Mikulyuk, M. Nault, M. Porzky and S. Chase. 2010. Recommended baseline monitoring of aquatic plants in Wisconsin: sampling design, field and laboratory procedures, data entry and analysis, and applications. Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010. Madison, Wisconsin. 46pp.

Leverance, J. and J. Panuska. 1997. Water Quality Model Study for Lake Redstone, Sauk County. Prepared for the Lake Redstone Protection District by the Wisconsin Department of Natural Resources. 14 pp.

Nault, M., A. Mikulyuk, J. Hauxwell, J. Skogerboe, T. Asplund, M. Barton, K. Wagner, T. Hoyman, and E. Heath. 2012. Herbicide Treatments in Wisconsin Lakes. Lakeline, Spring 2012.

Nichols, S.A. 1999. Floristic Quality Assessment of Wisconsin Lake Plant Communities with Example Applications. Journal of Lake and Reservoir Management. 15(2):133-141.

Sefton, D. and S. Graham. 2009. Designation of Critical Habitat, Lake Redstone, Sauk County, Wisconsin. Wisconsin Department of Natural Resources. 29 Oct. 2016 http://dnr.wi.gov/lakes/criticalhabitat/Project.aspx?project=22761946.

Skawinski, P.M. 2014. Aquatic Plants of the Upper Midwest: A photographic field guide to our underwater forests. Second Edition.

WDNR. 2017. Wisconsin Department of Natural Resources. 23 Nov. 2017 http://dnr.wi.gov/lakes/lakepages/.

APPENDIX A – CARDINAL BAY MAPS

Figure 29 - Cardinal Bay Maps of Depth, Sediment, Filamentous Algae, & Coontail

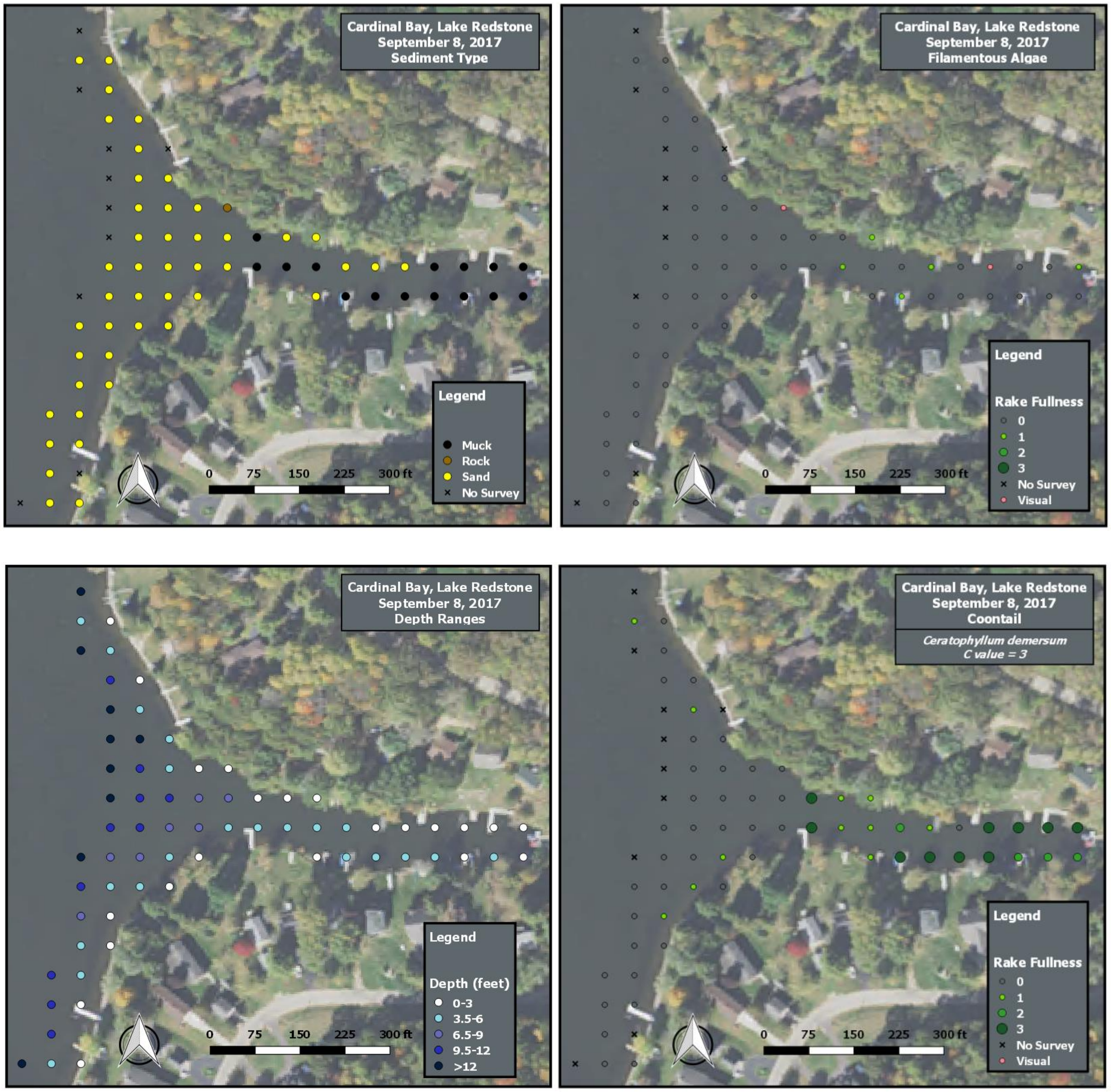
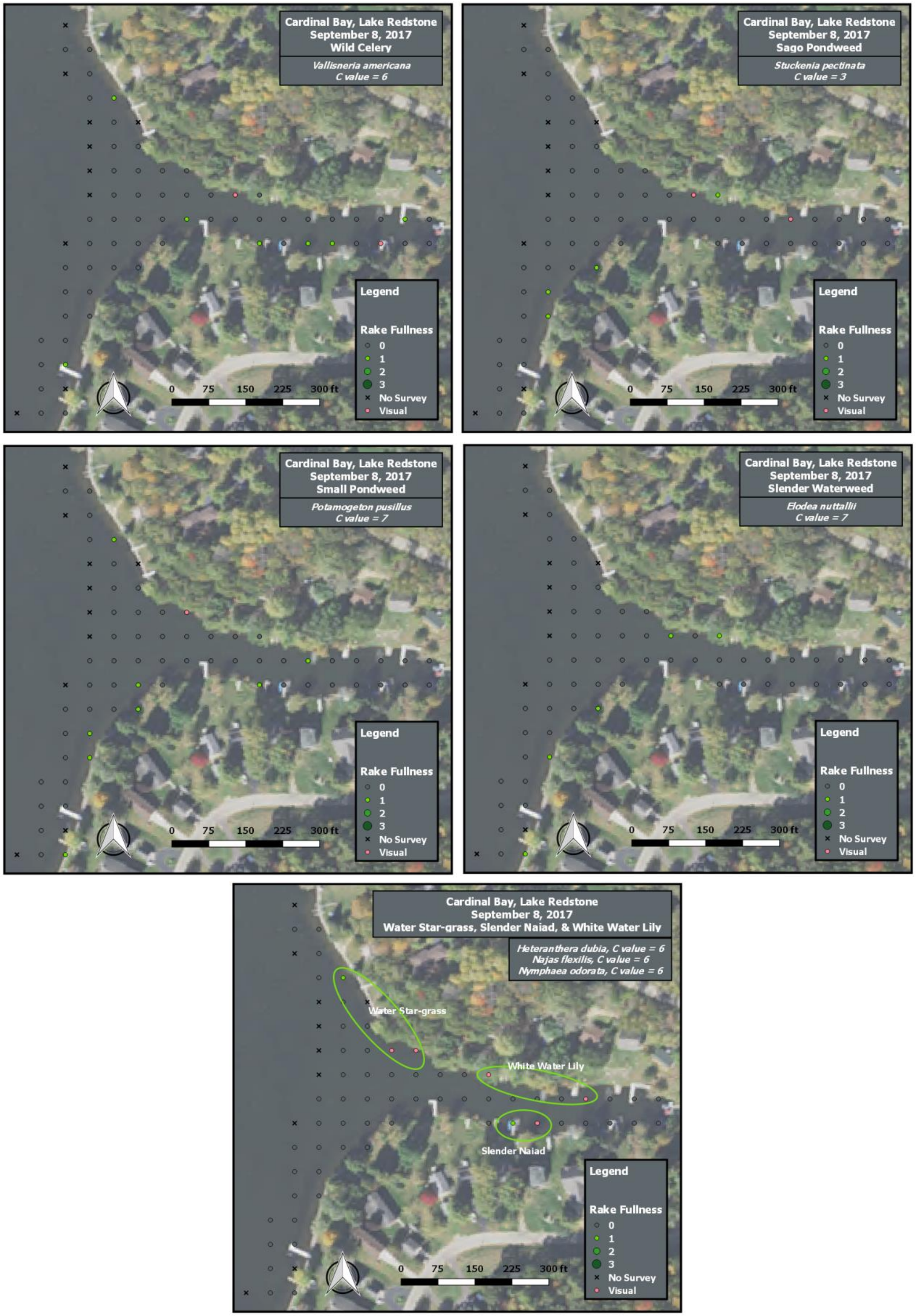
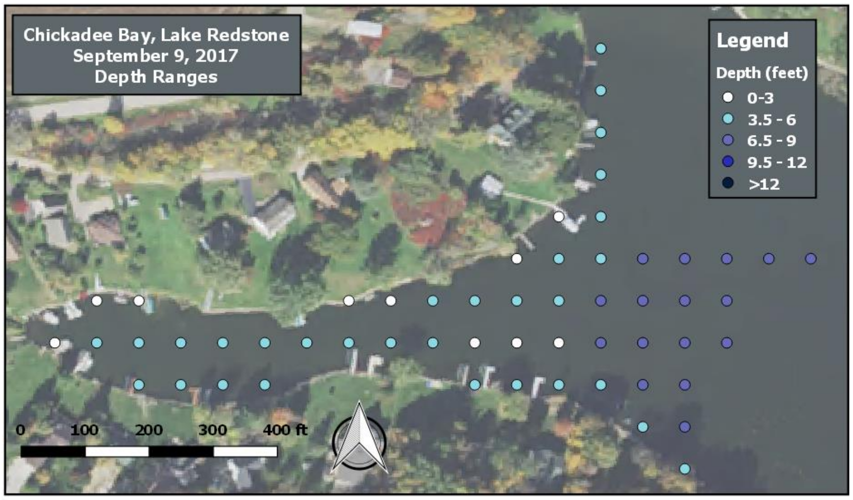


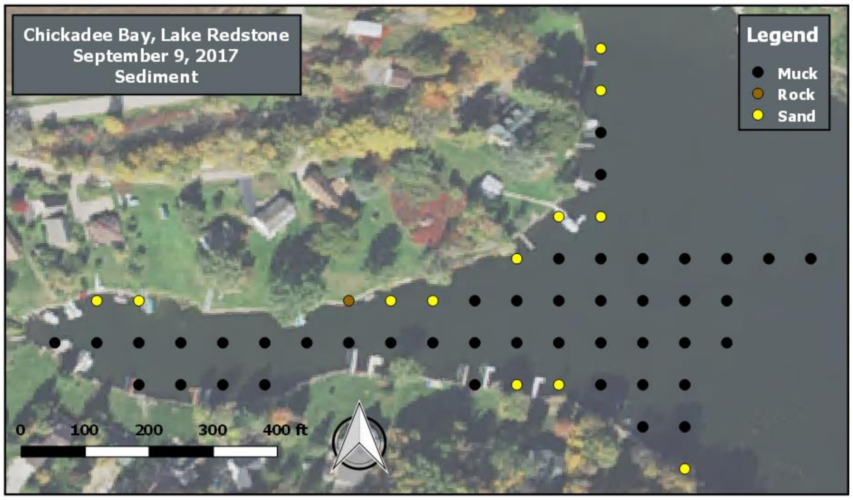
Figure 30 – Cardinal Bay Maps of Wild Celery, Sago Pondweed, Small Pondweed, Slender Waterweed, Slender Naiad, Water Star-grass, & White Water Lily



APPENDIX B – SOUTH CHICKADEE BAY MAPS

Figure 31 – South Chickadee Maps of Depth, Sediment, & Filamentous Algae





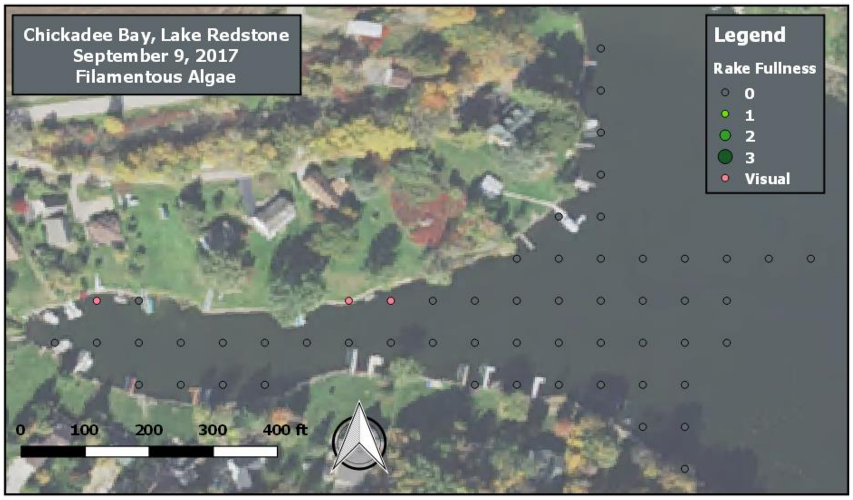
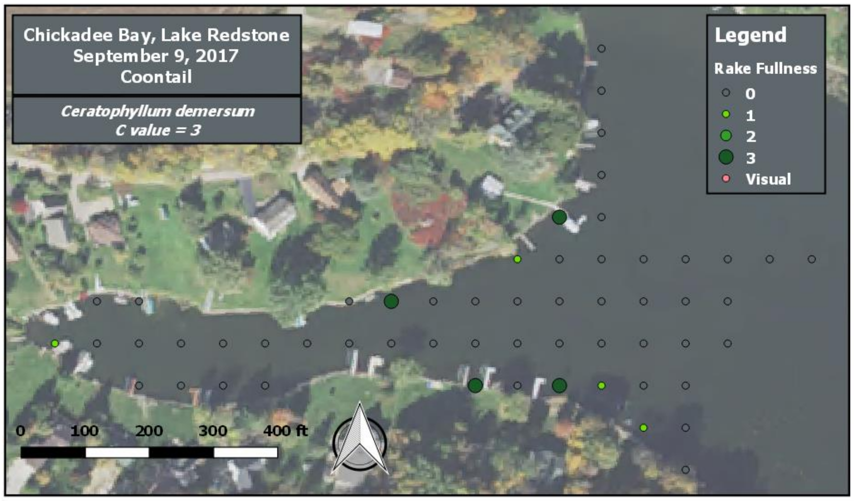
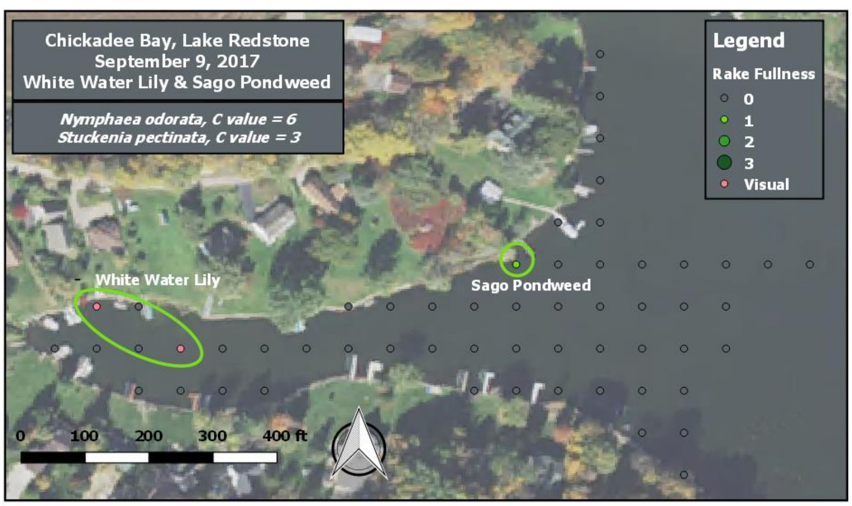


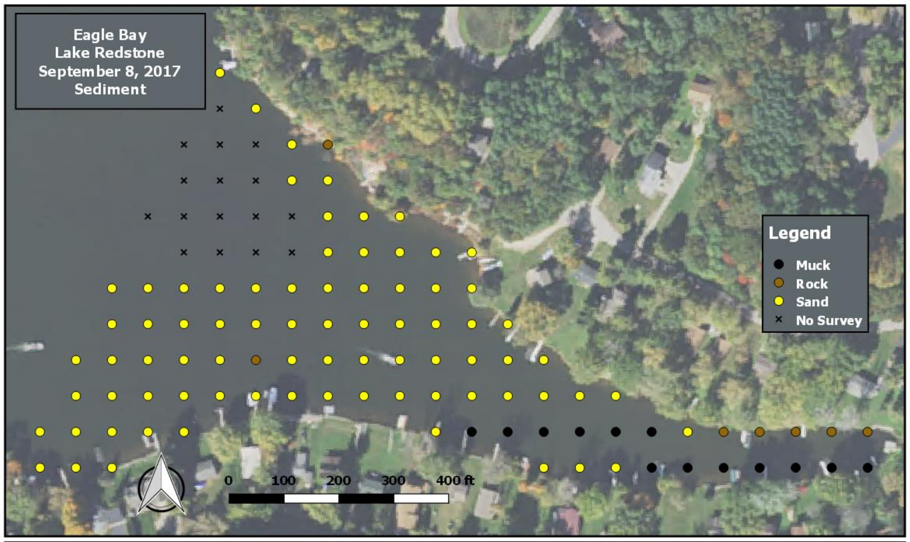
Figure 32 – South Chickadee Maps of Coontail, White Water Lily, & Sago Pondweed

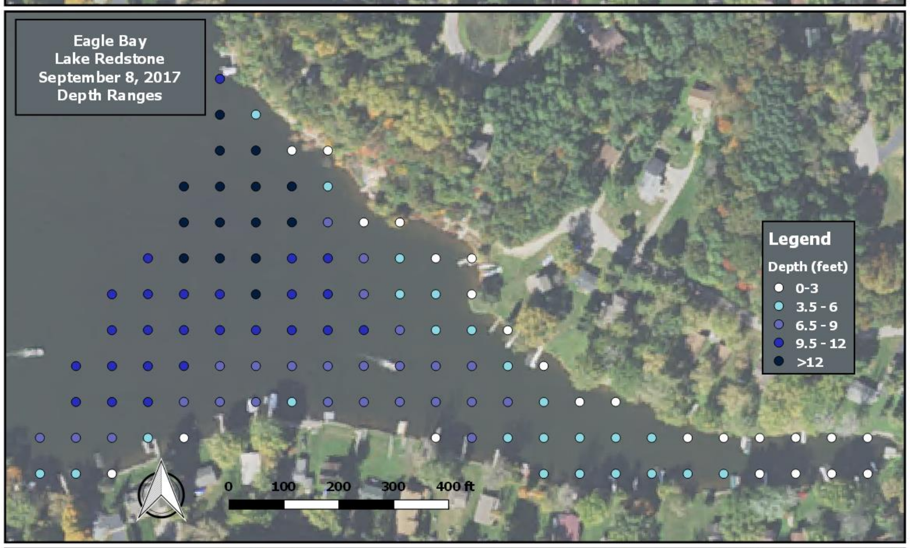




APPENDIX C - EAGLE BAY MAPS

Figure 33 – Eagle Bay Maps of Sediment, Depth, & White Water Lily





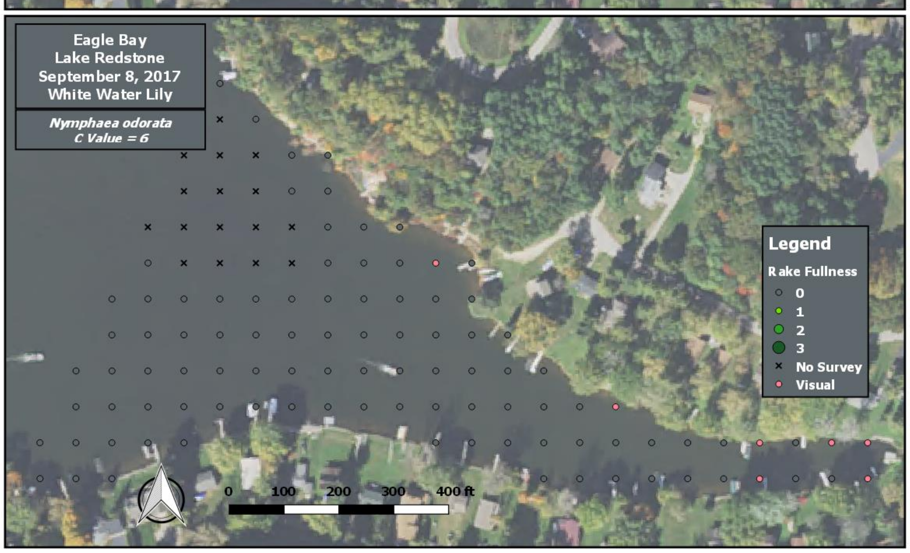
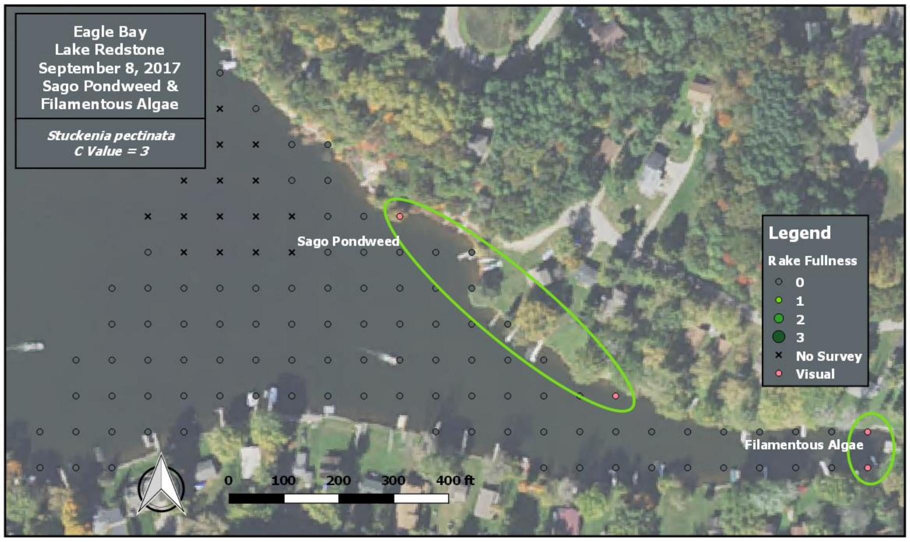
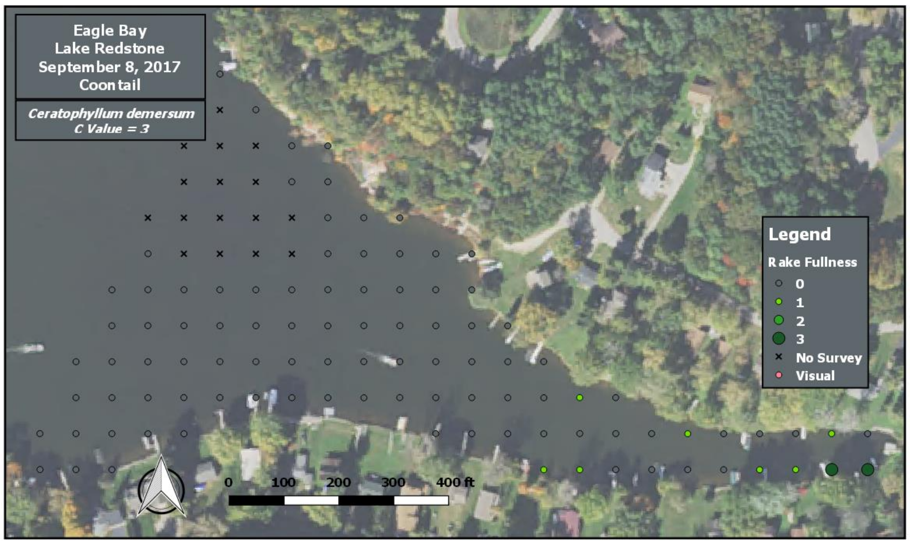
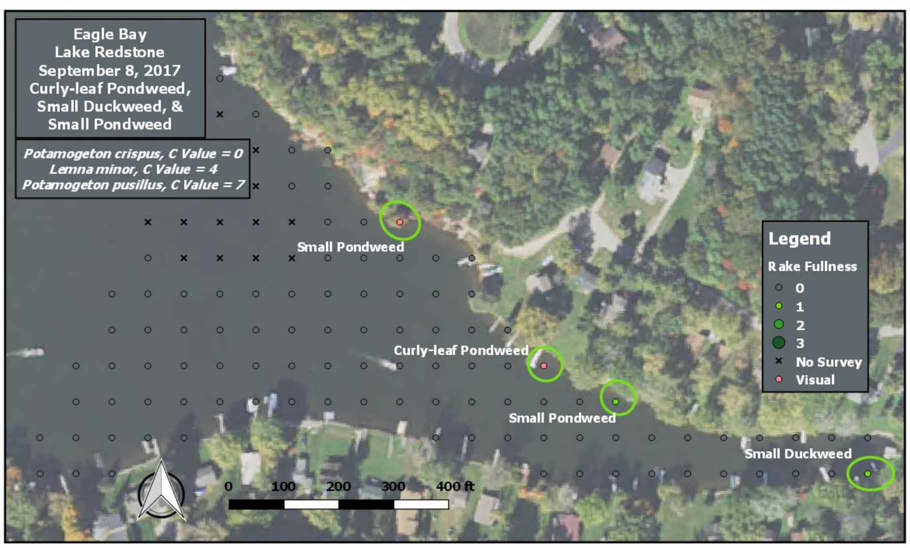


Figure 34 – Eagle Bay Maps of Sago Pondweed, Filamentous Algae, Coontail, Curly-leaf Pondweed, Small Duckweed, and Small Pondweed







APPENDIX D – HUMMINGBIRD BAY MAPS

Figure 35 – Hummingbird Bay Maps of Sediment, Depth, & Filamentous Algae

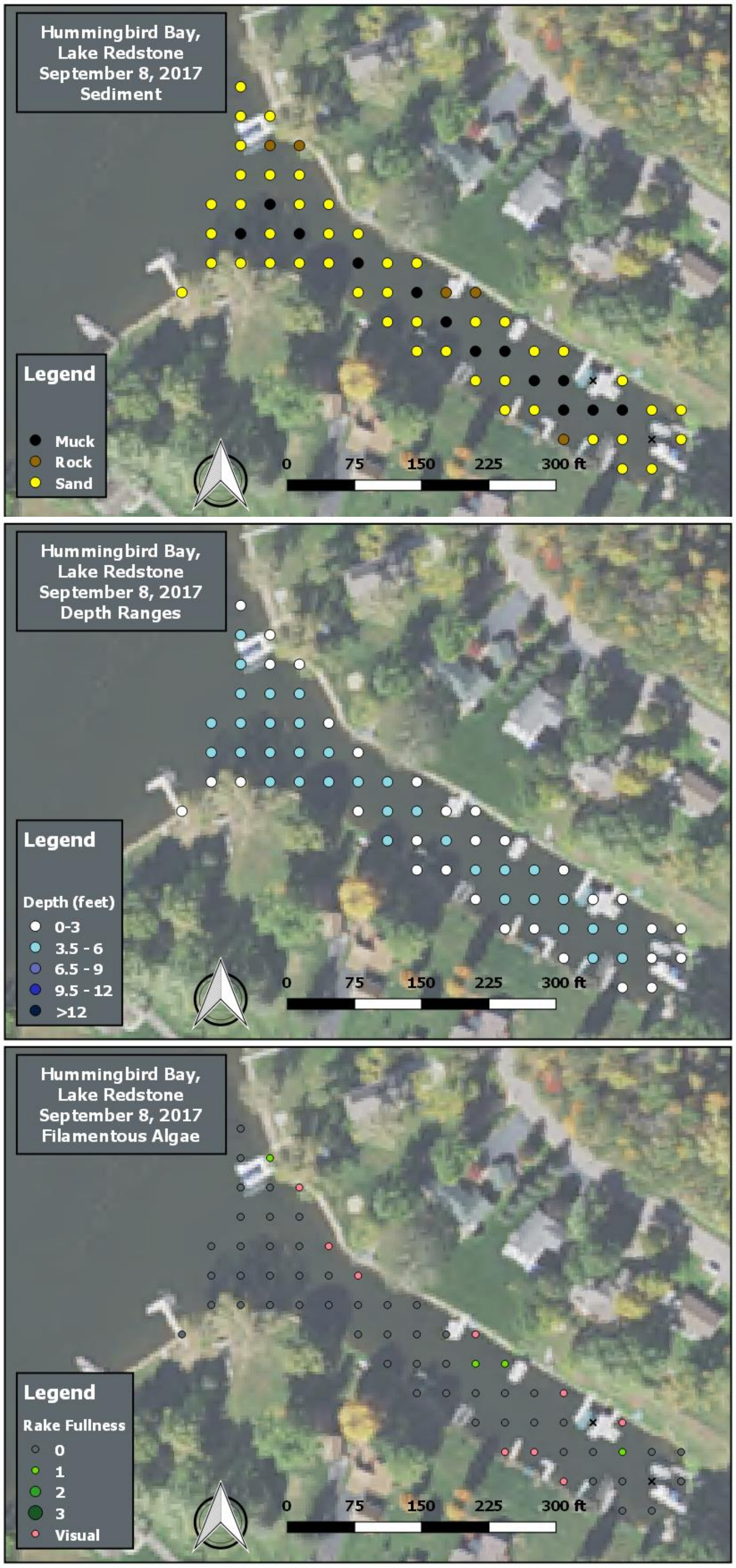
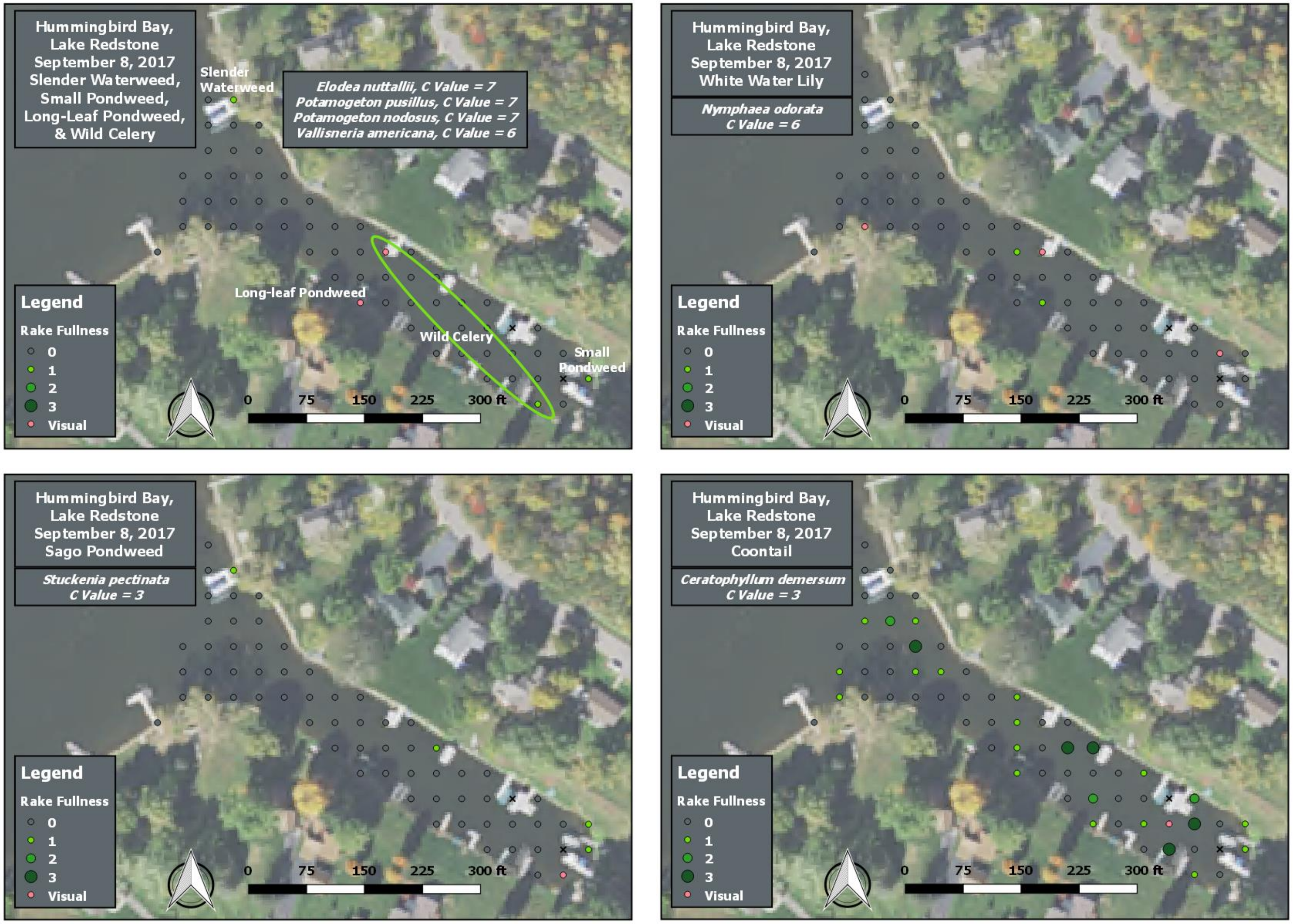
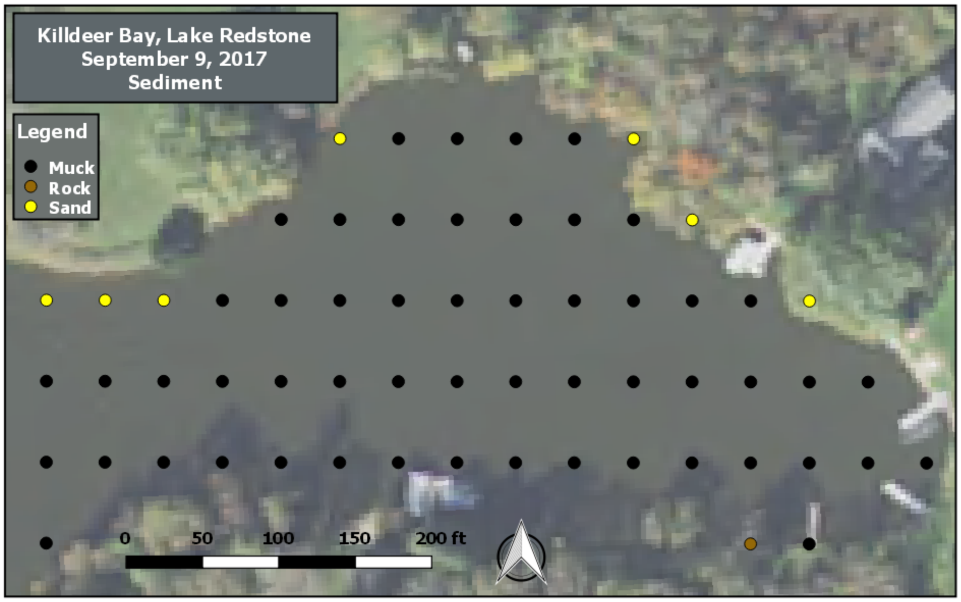


Figure 36 – Hummingbird Bay Maps of All Native Species



APPENDIX E – KILLDEER BAY MAPS

Figure 37 – Killdeer Maps of Sediment & Depth Ranges



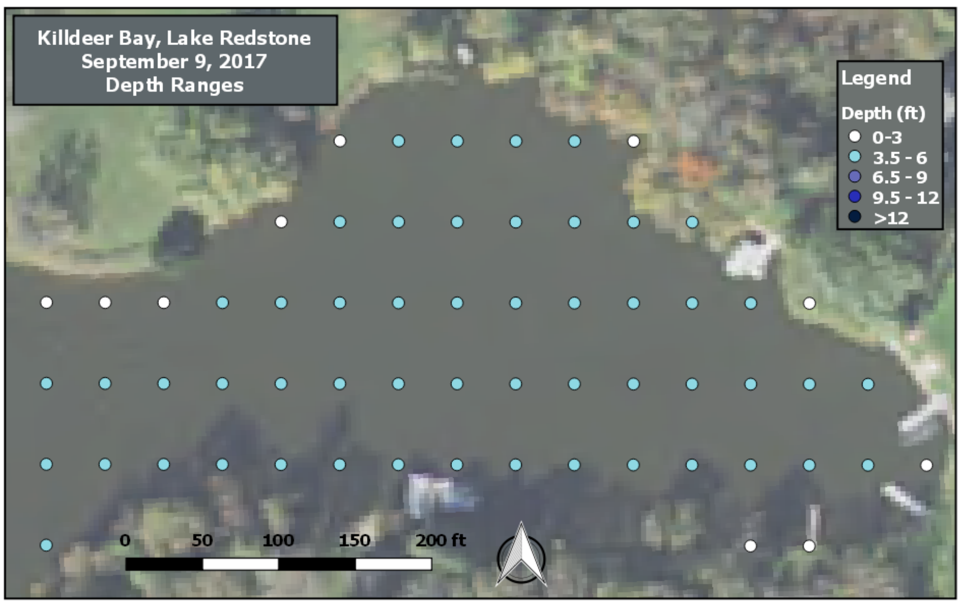
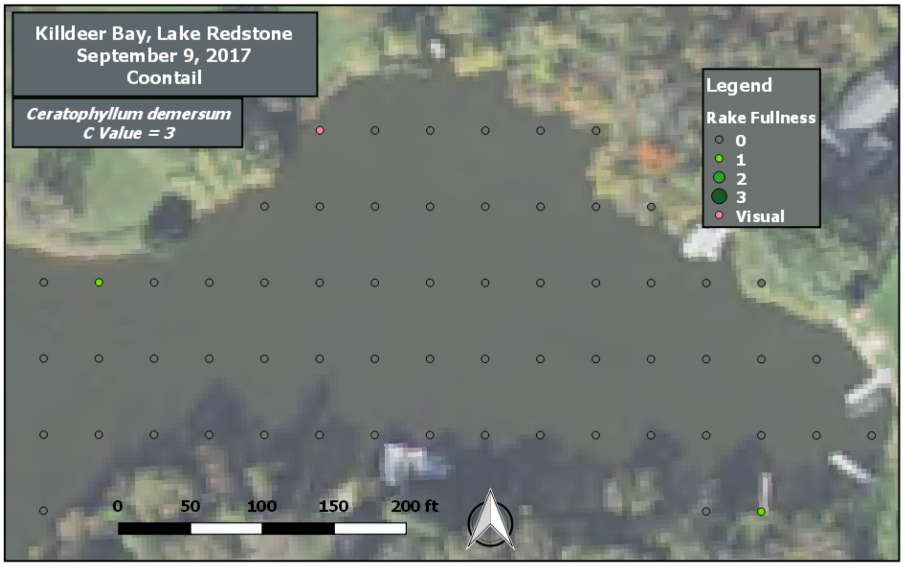
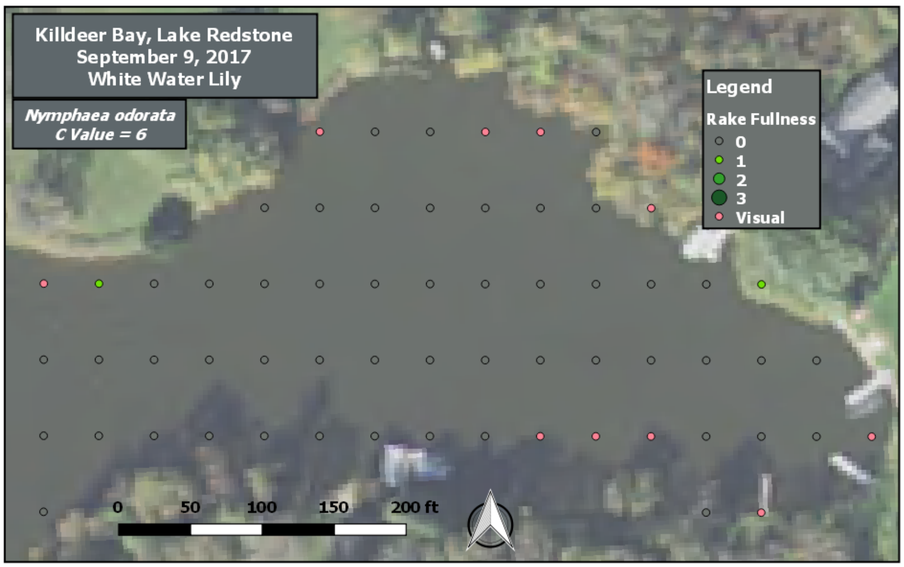
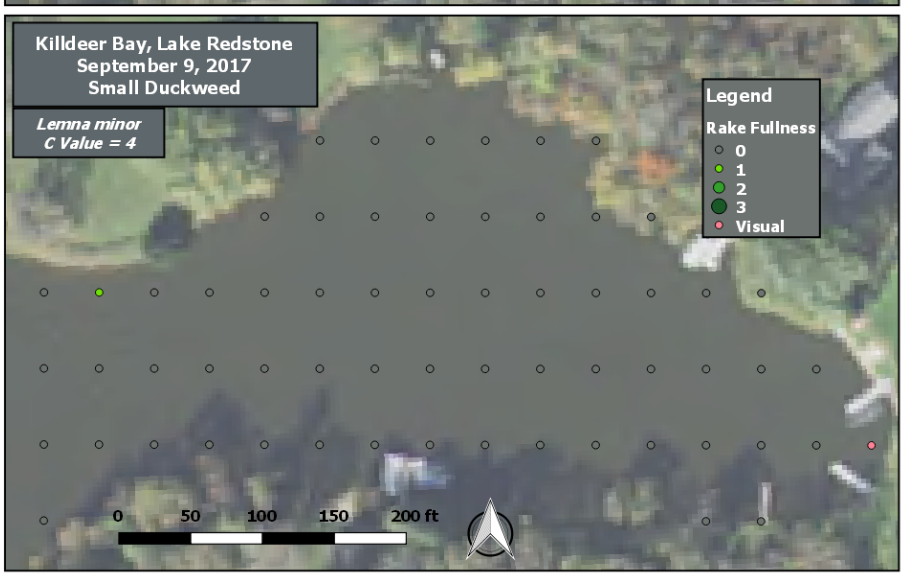


Figure 38 – Killdeer Maps of Coontail, White Water Lily, & Small Duckweed







APPENDIX F – MARTIN-MEADOWLARK BAY MAPS

Figure 39 – Martin-Meadowlark Maps of Depth, Sediment, Filamentous Algae, & Small Duckweed

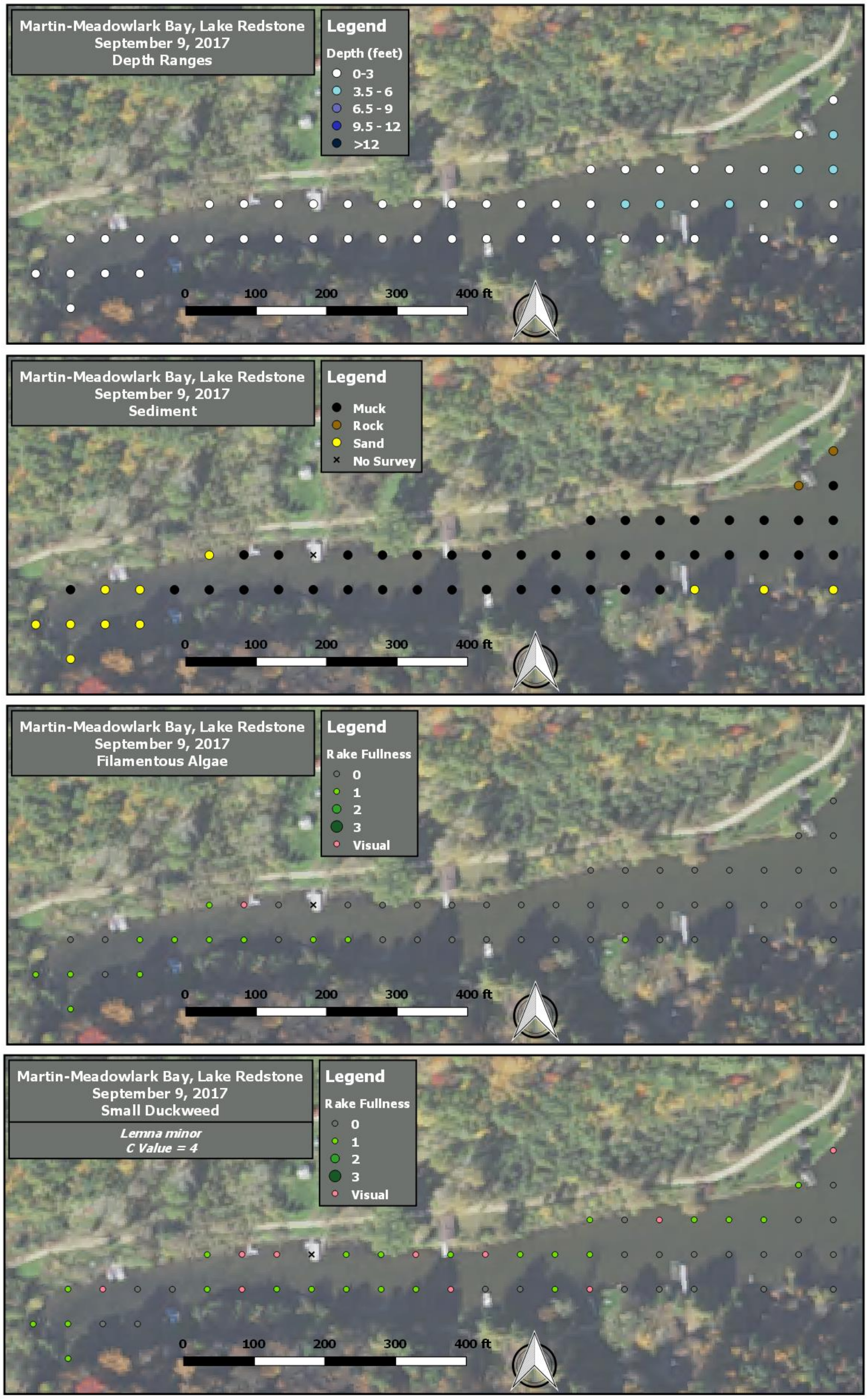
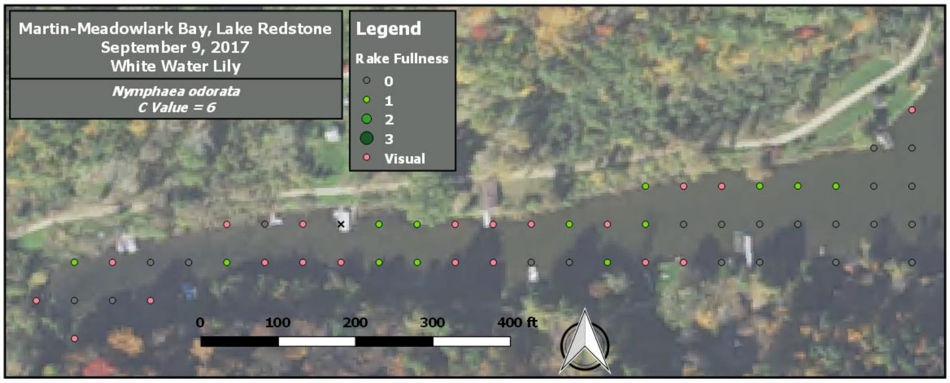
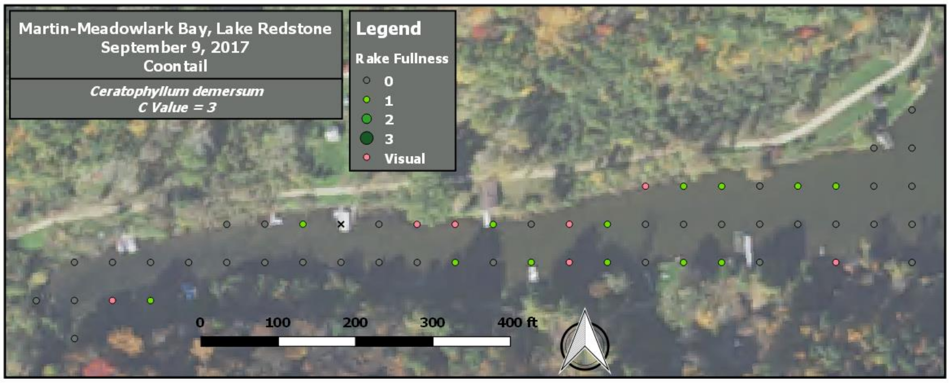
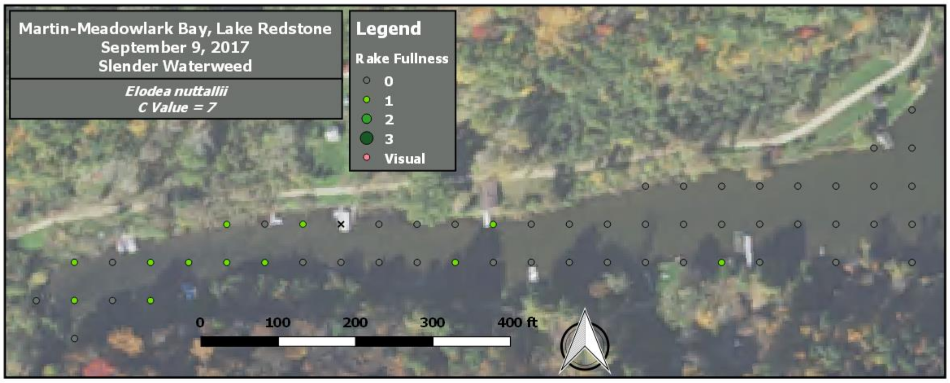
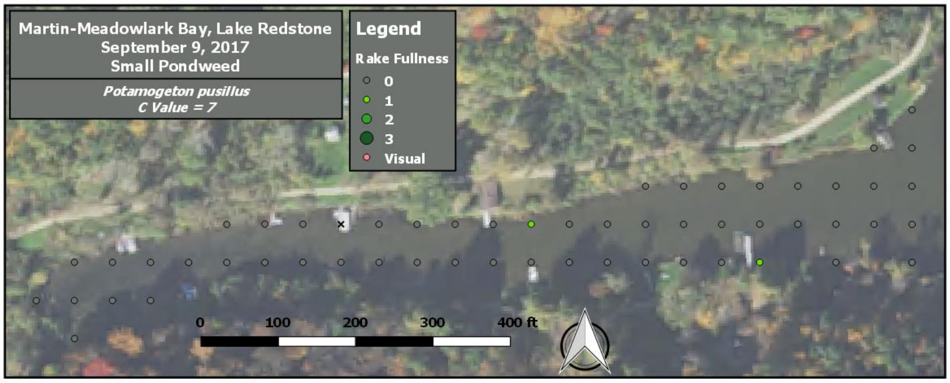


Figure 40 – Martin-Meadowlark Maps of White Water Lily, Coontail, Slender Waterweed, & Small Pondweed









APPENDIX G – MOCKINGBIRD BAY MAPS

Figure 41 – Mockingbird Bay Maps of Sediment, Depth Ranges, Filamentous Algae, & Coontail

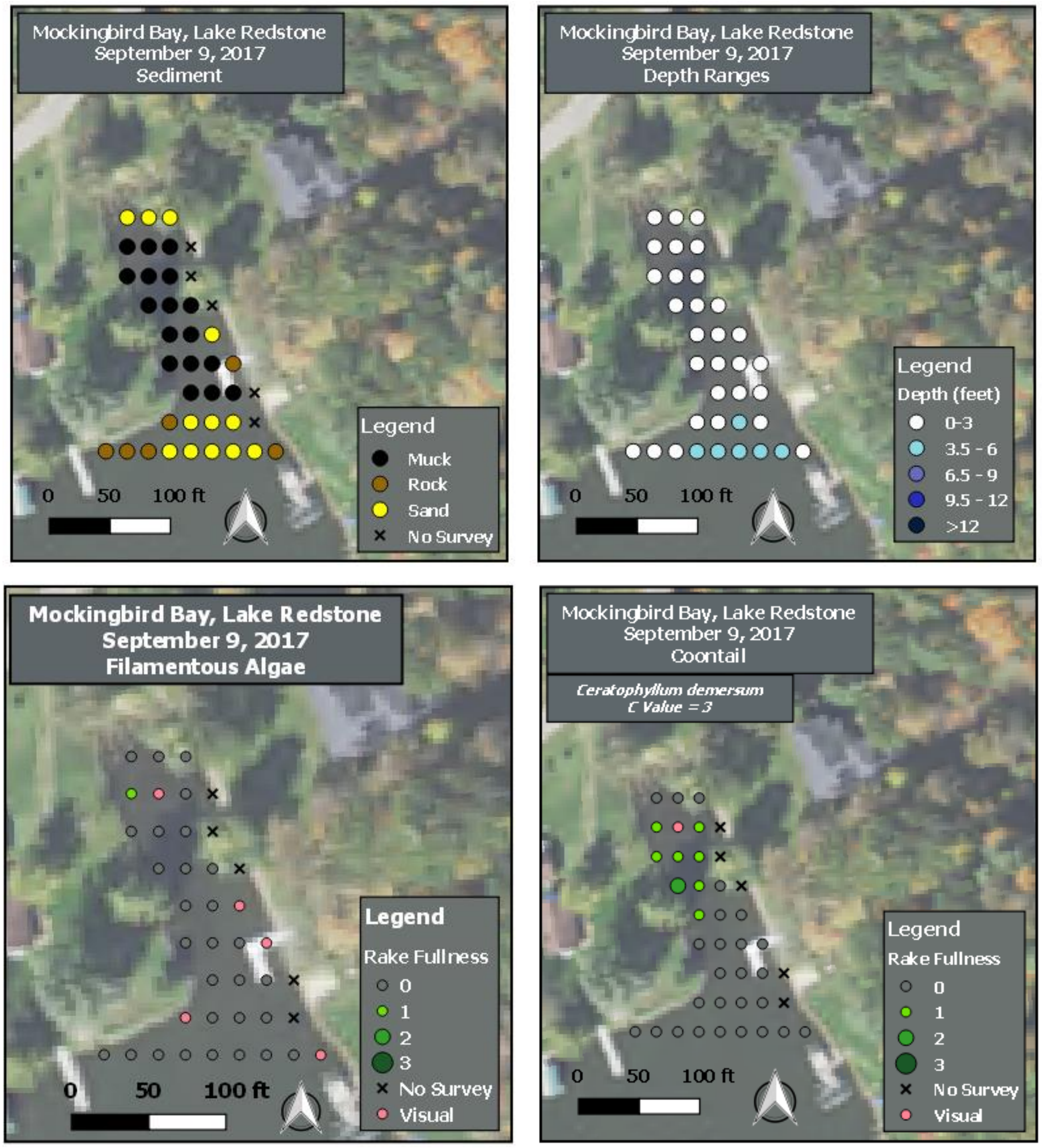
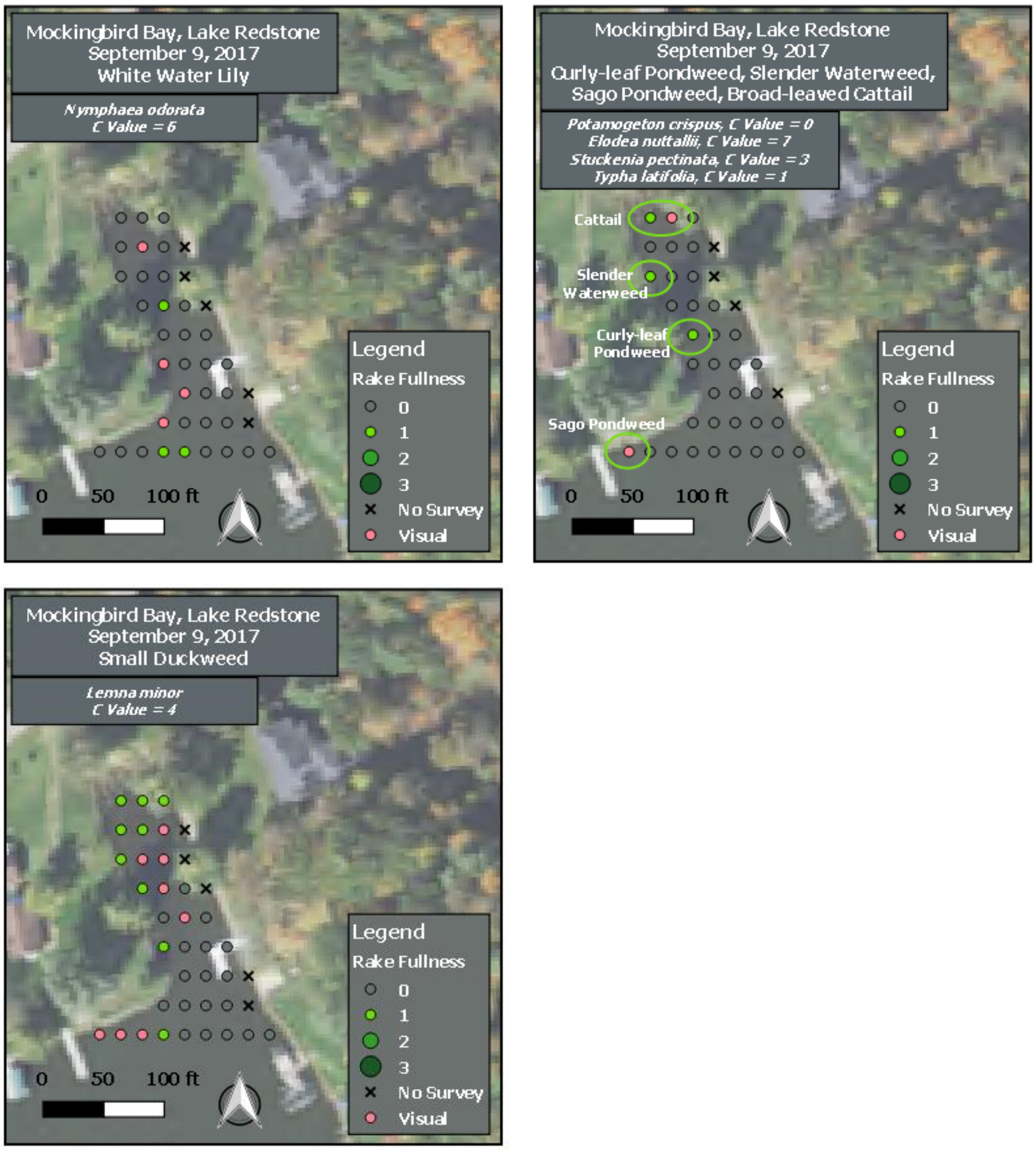
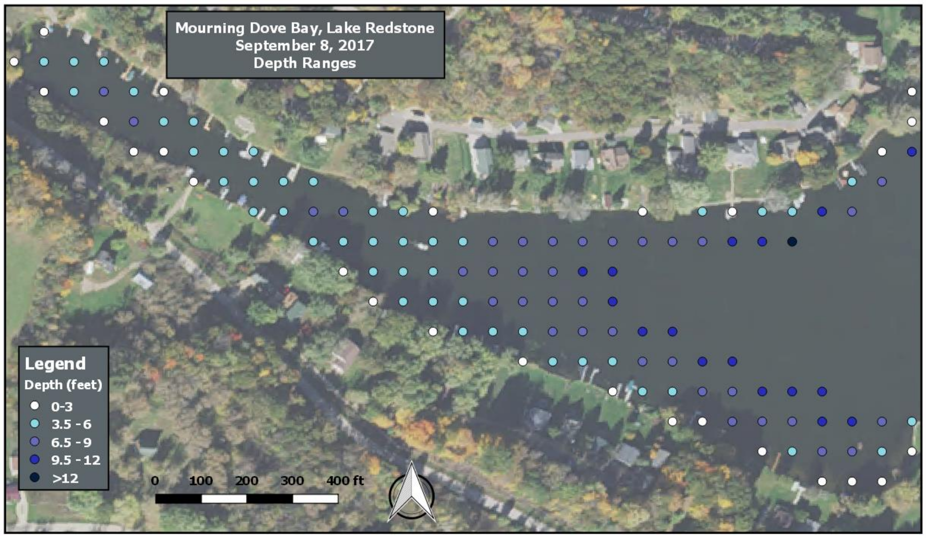


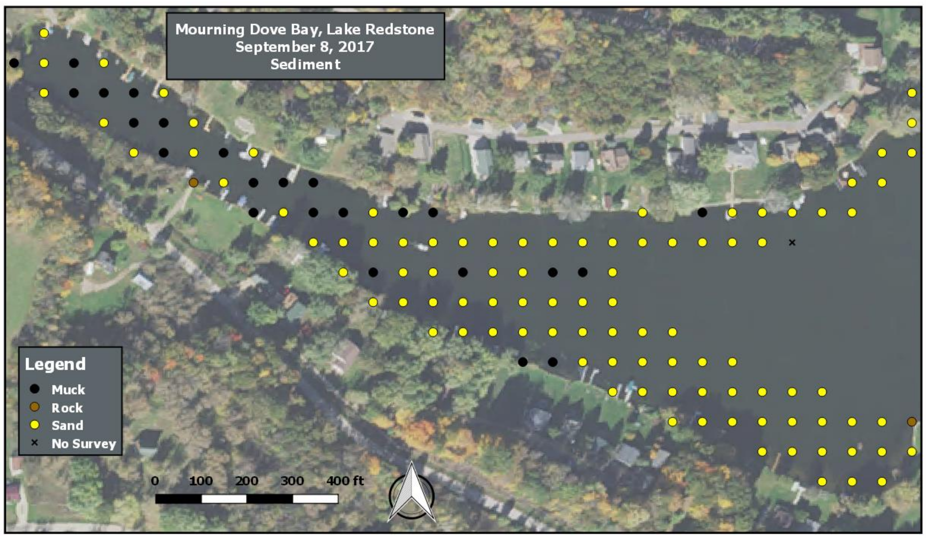
Figure 42 – Mockingbird Bay Maps of White Water Lily, Curly-leaf Pondweed, Slender Waterweed, Sago Pondweed, Broad-leaved Cattail, & Small Duckweed



APPENDIX H – MOURNING DOVE BAY MAPS

Figure 43 - Mourning Dove Bay Maps of Depth, Sediment, and Coontail





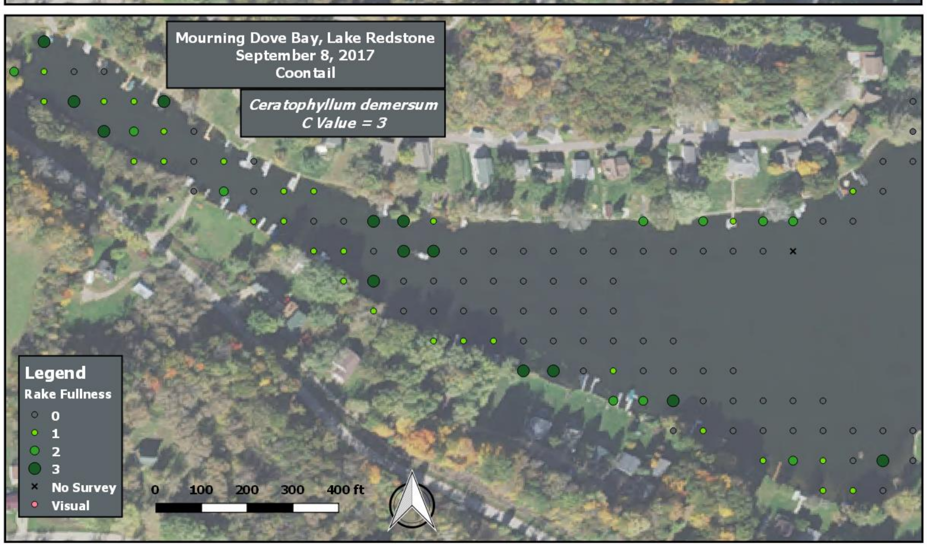
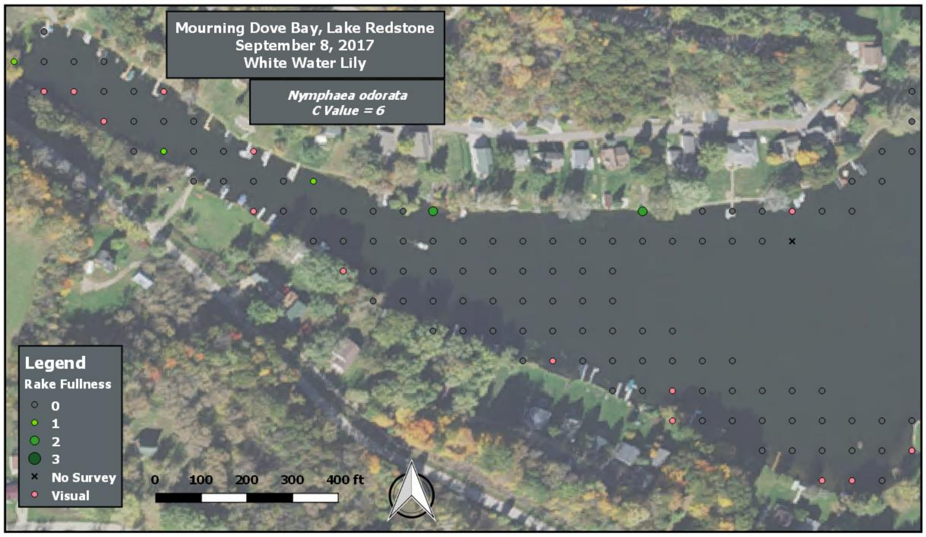
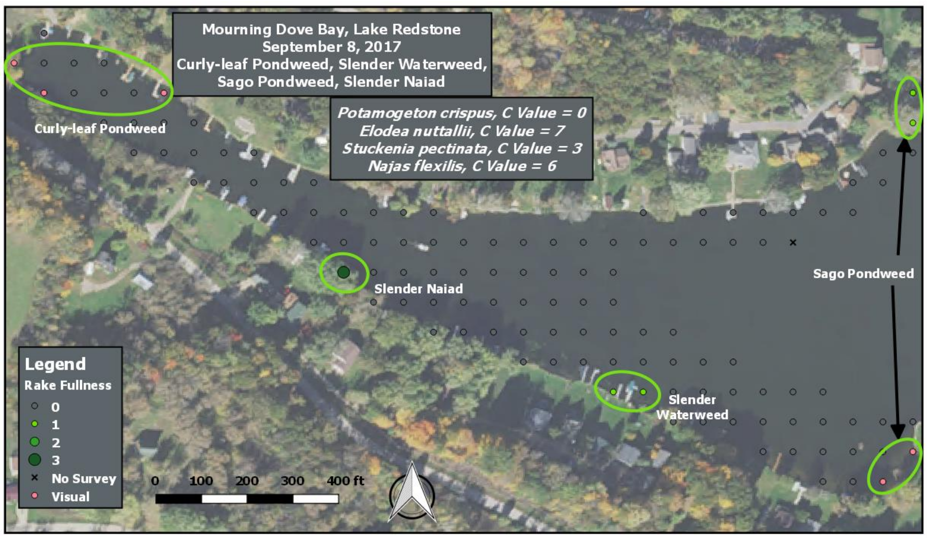


Figure 44 – Mourning Dove Bay Maps of White Water Lily, Curly-leaf Pondweed, Slender Waterweed, Sago Pondweed, Slender Naiad, & Filamentous Algae





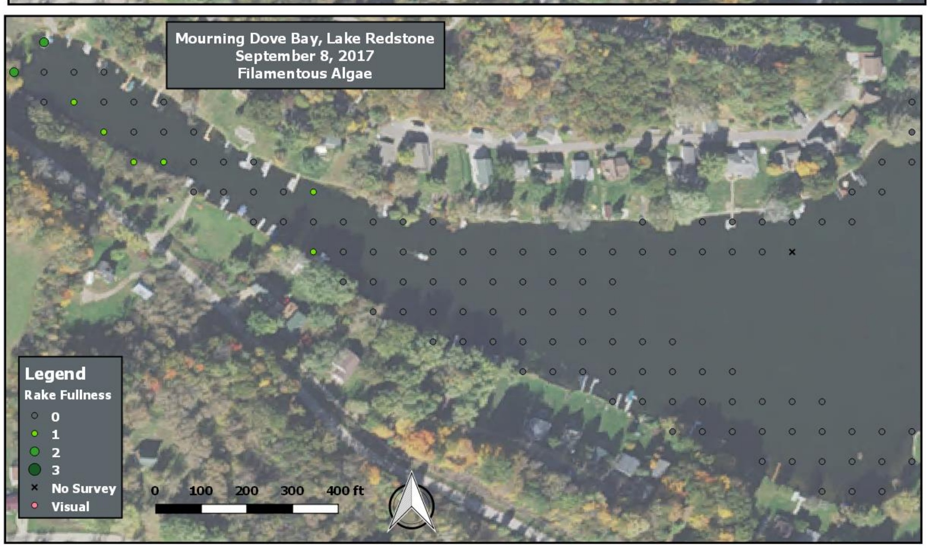
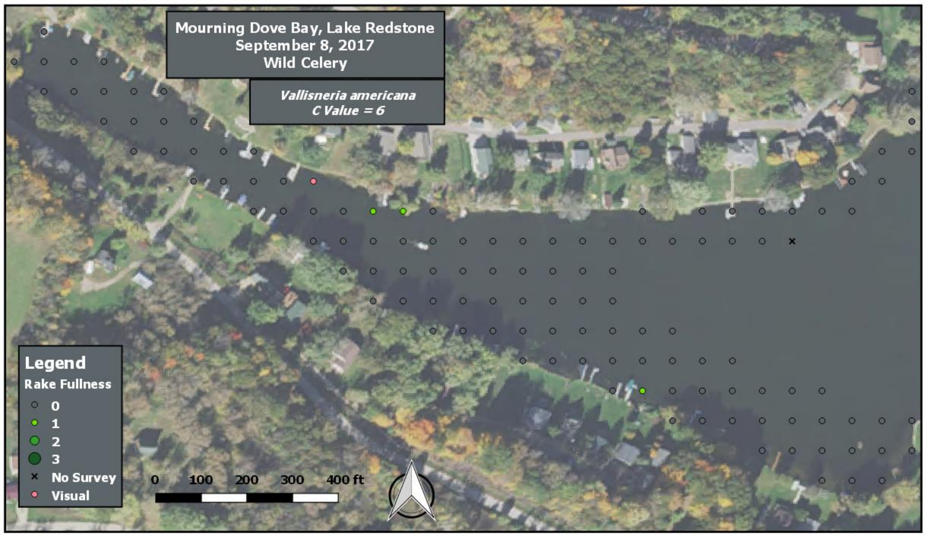
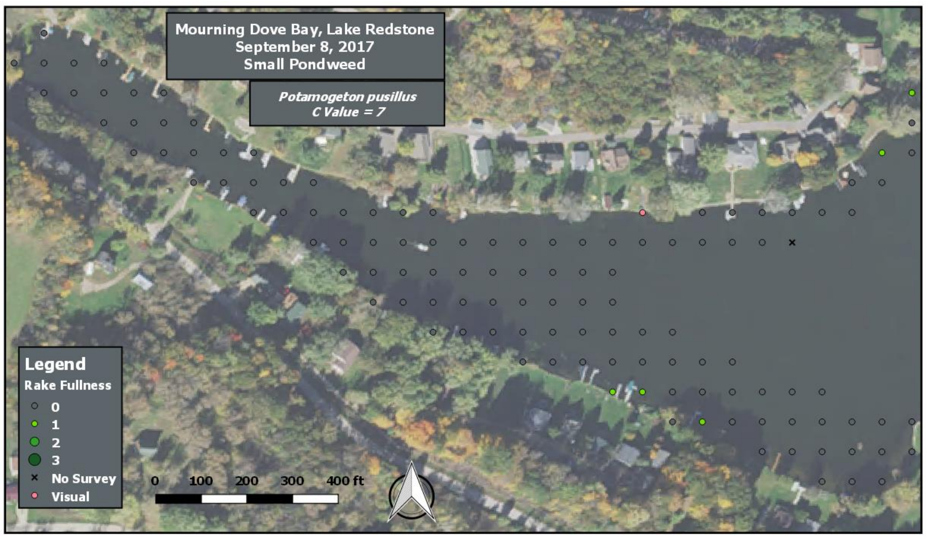


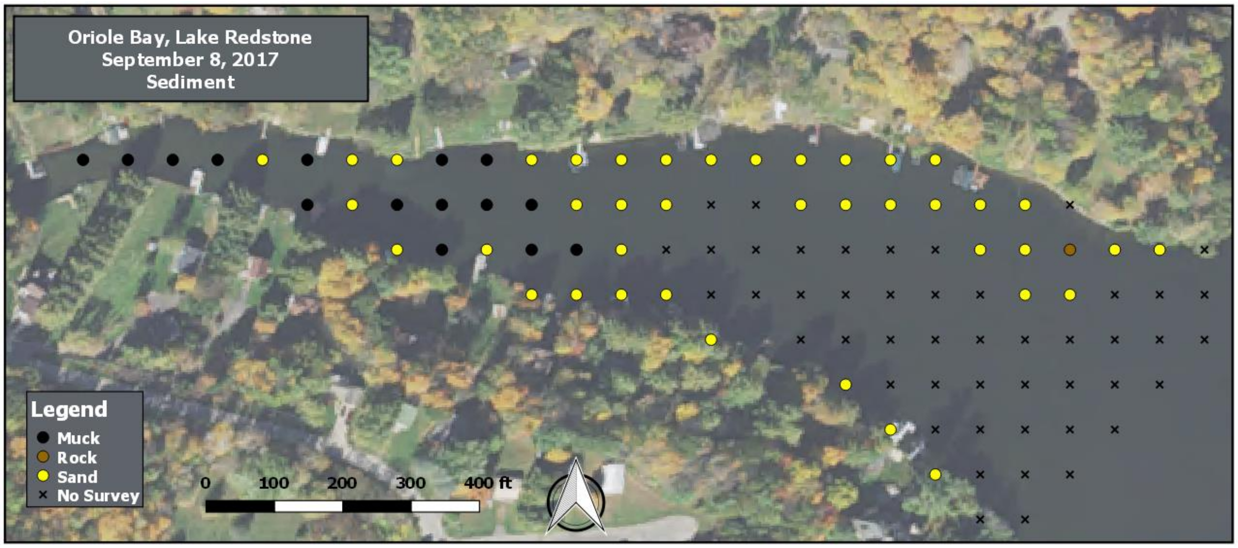
Figure 45 – Mourning Dove Bay Maps of Wild Celery & Small Pondweed





APPENDIX I – ORIOLE BAY MAPS

Figure 46 – Oriole Bay Maps of Sediment & Depth



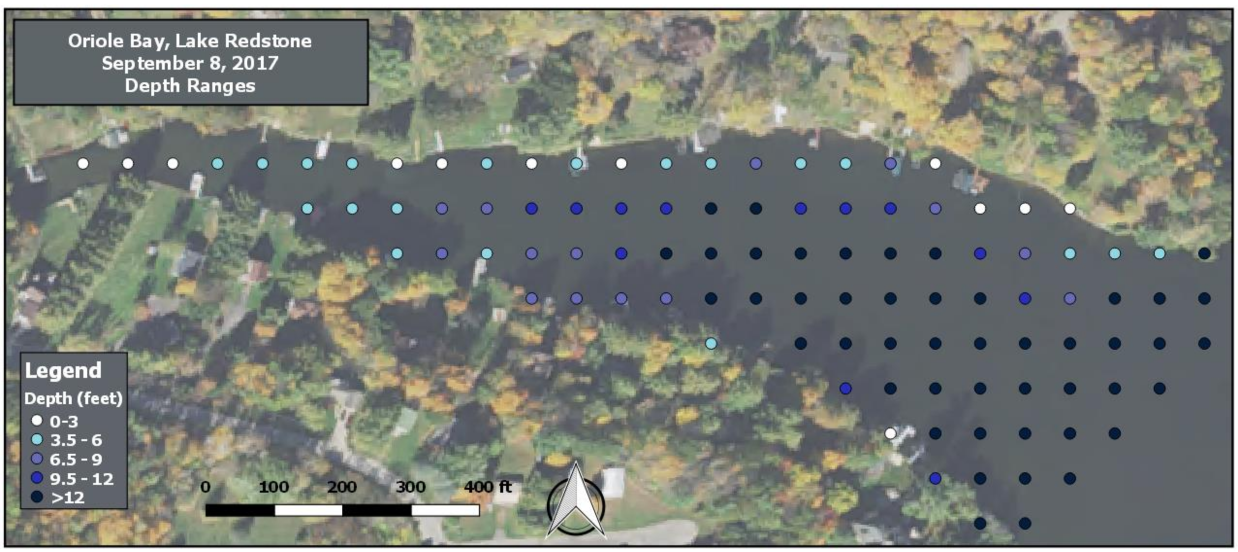
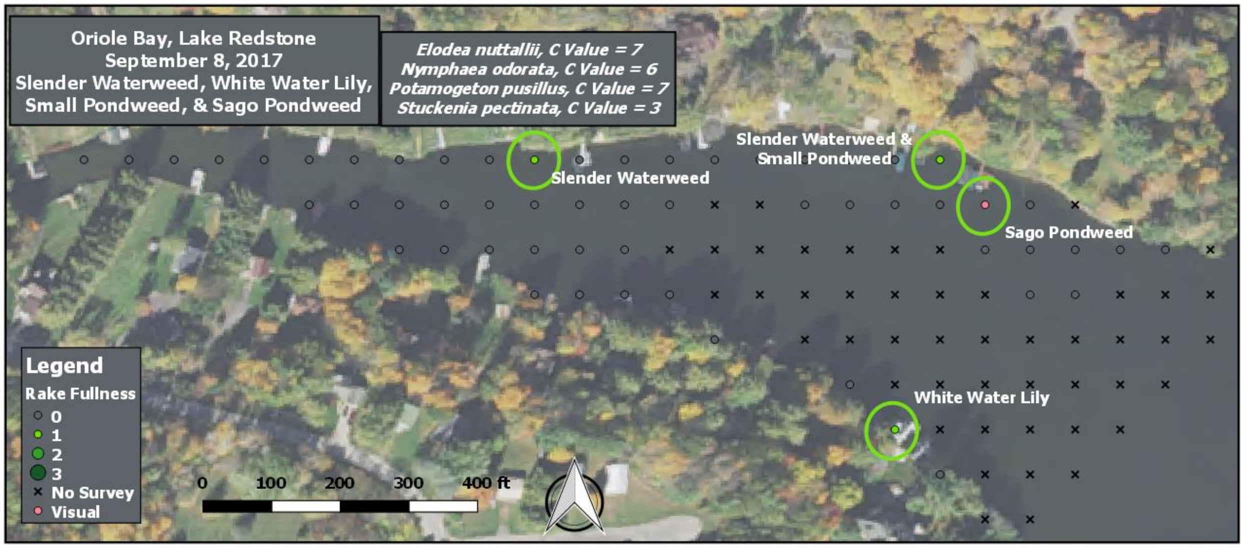
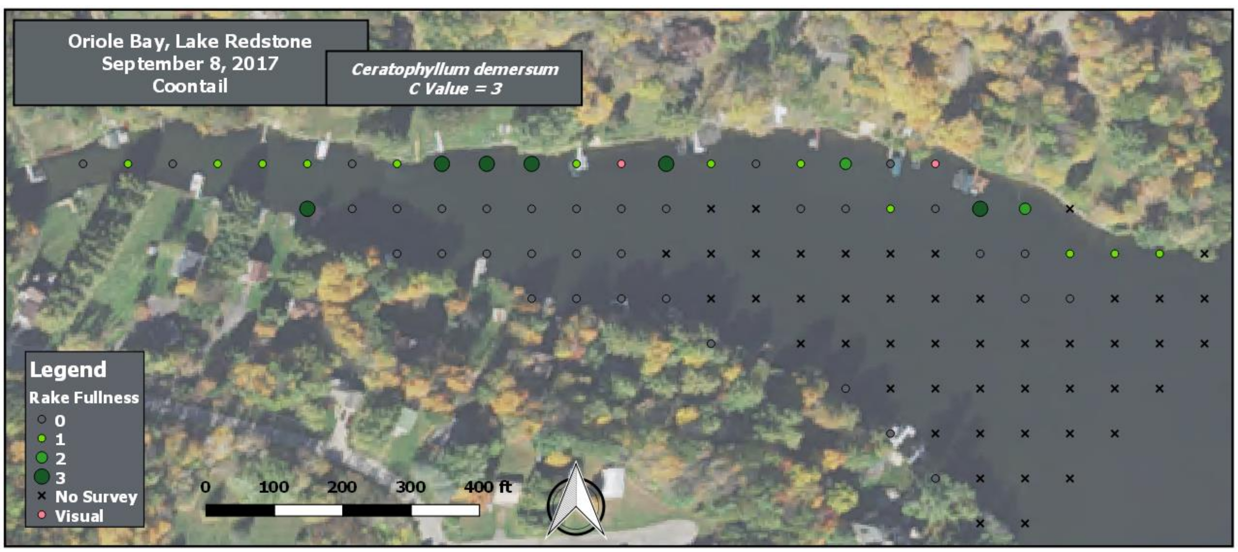


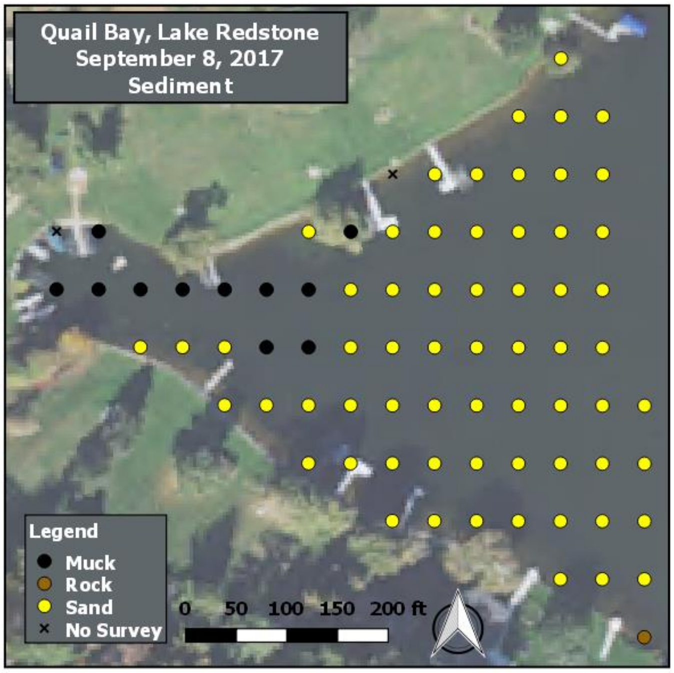
Figure 47 – Maps of Oriole Bay Slender Waterweed, White Water Lily, Small Pondweed, Sago Pondweed, & Coontail,

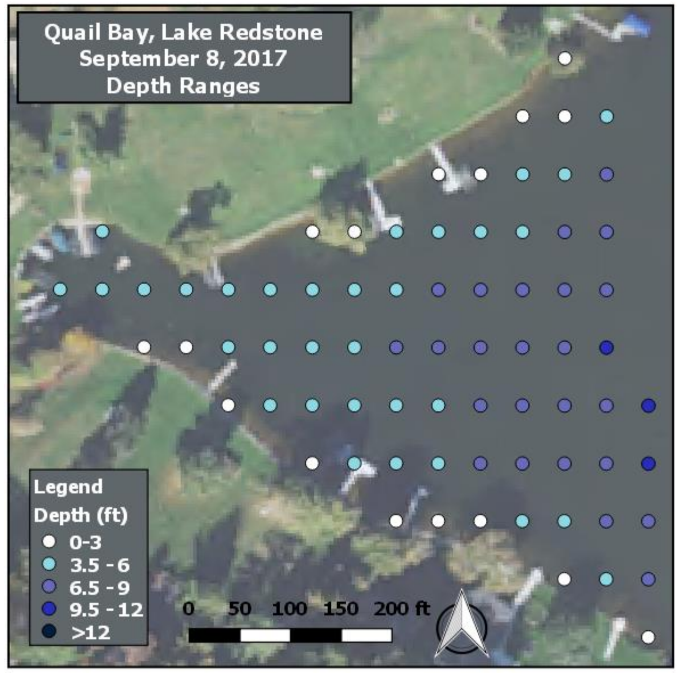




APPENDIX J –QUAIL BAY MAPS

Figure 48 – Quail Bay Maps of Sediment, Depth, & Wild Celery





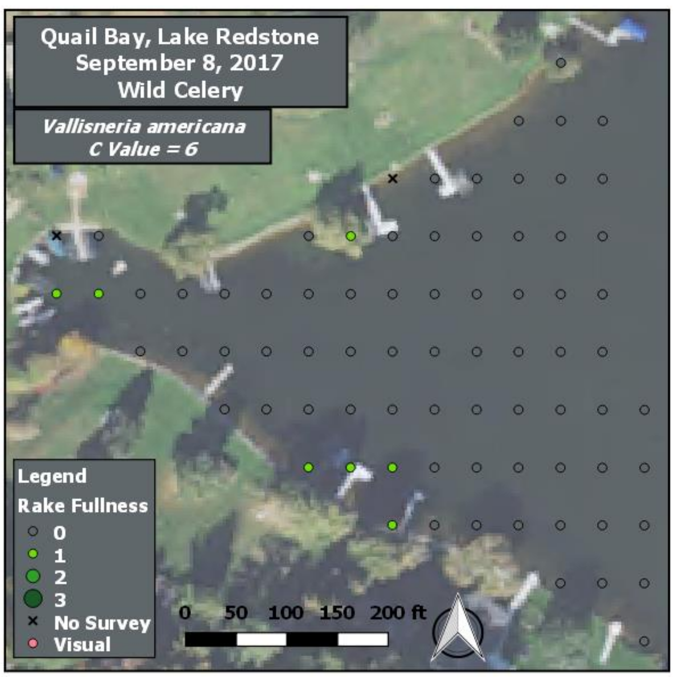
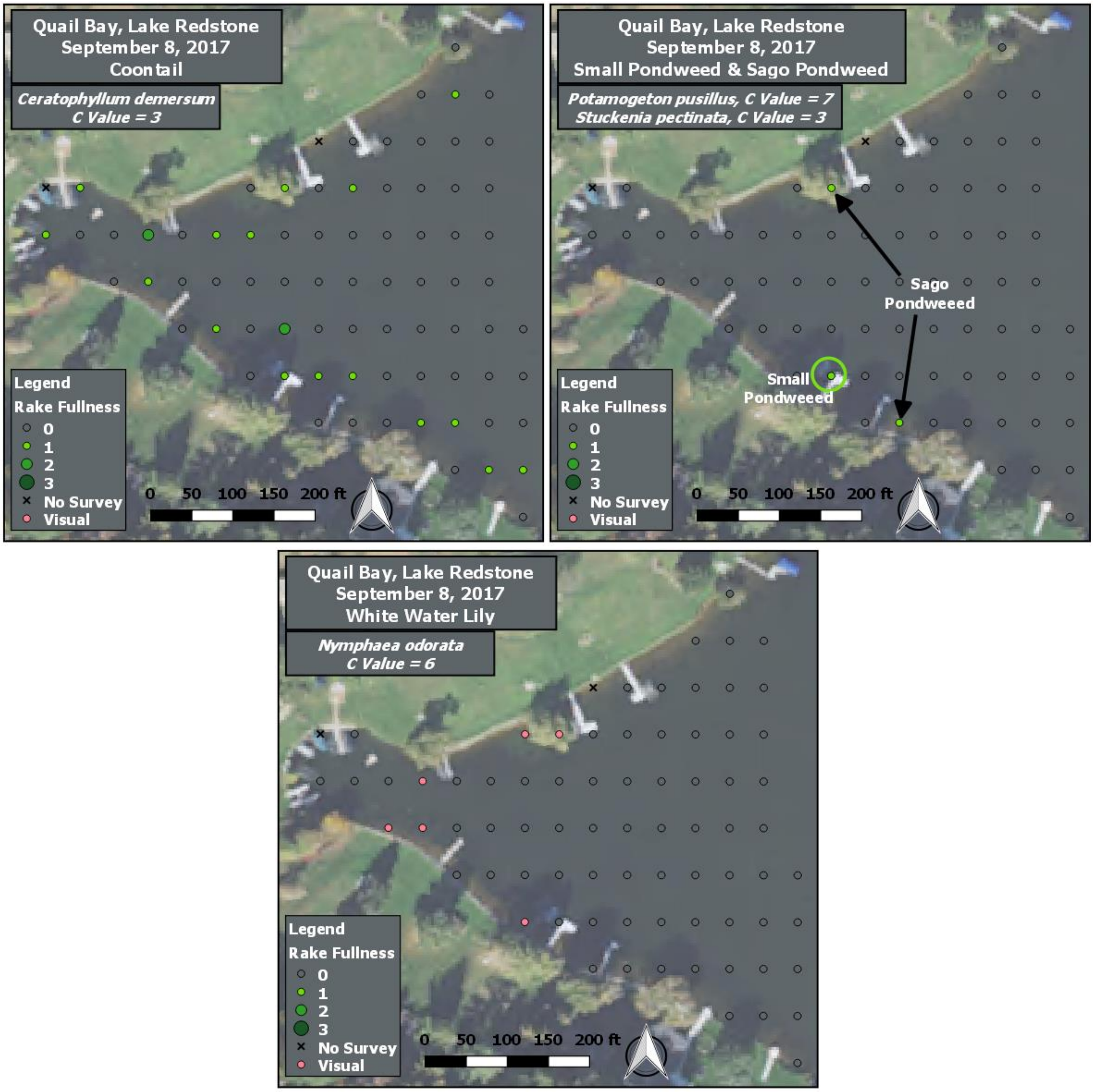


Figure 49 – Quail Bay Maps of Coontail, Small Pondweed, Sago Pondweed, & White Water Lily



APPENDIX K – SWALLOW BAY MAPS

Figure 50 – Swallow Bay Maps of Depth, Sediment, Small Duckweed, & Curly-leaf Pondweed

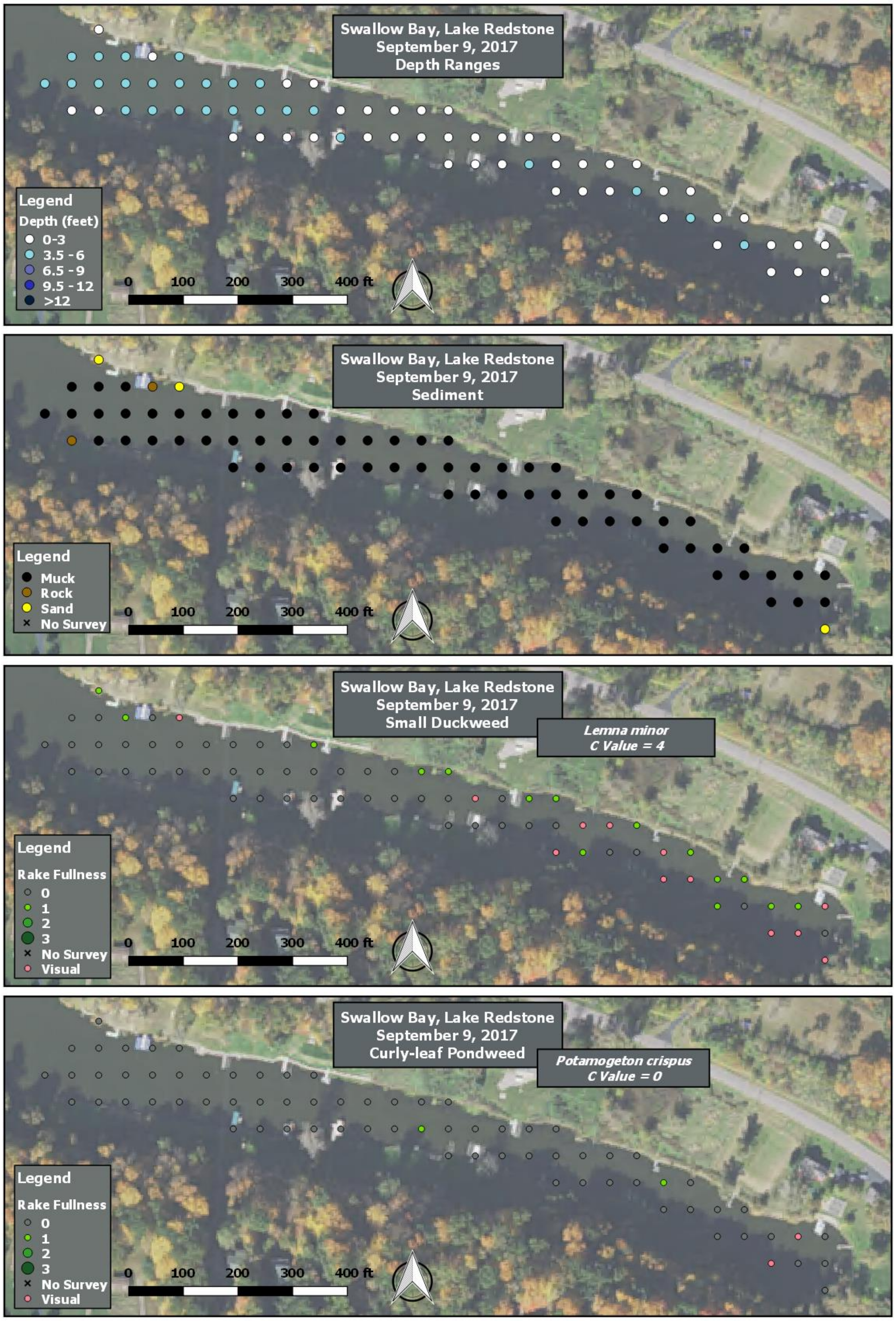
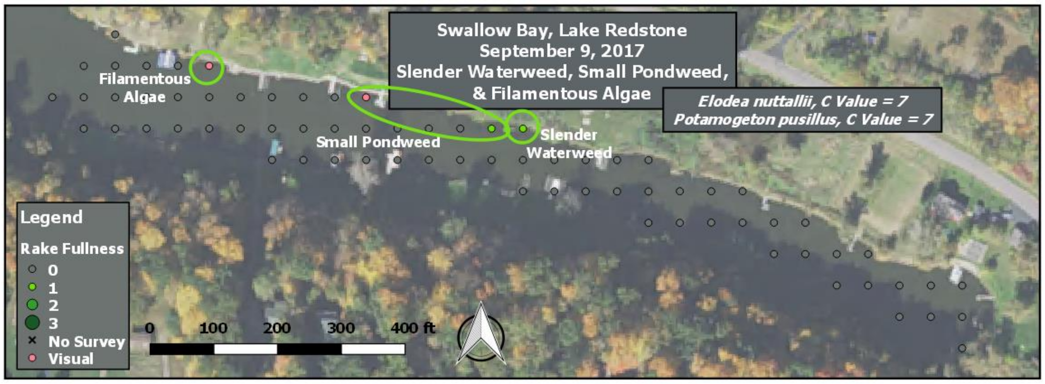
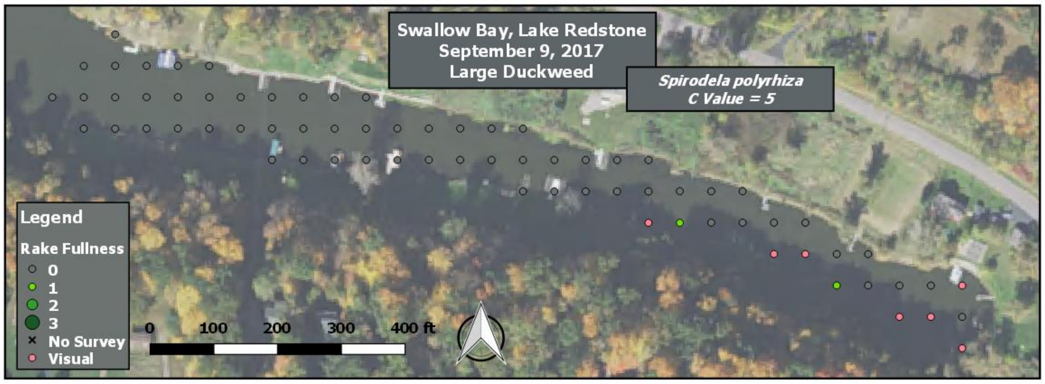
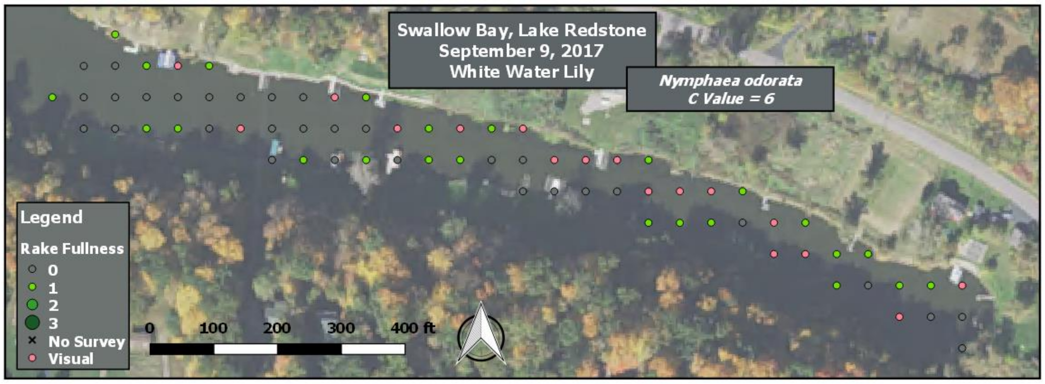
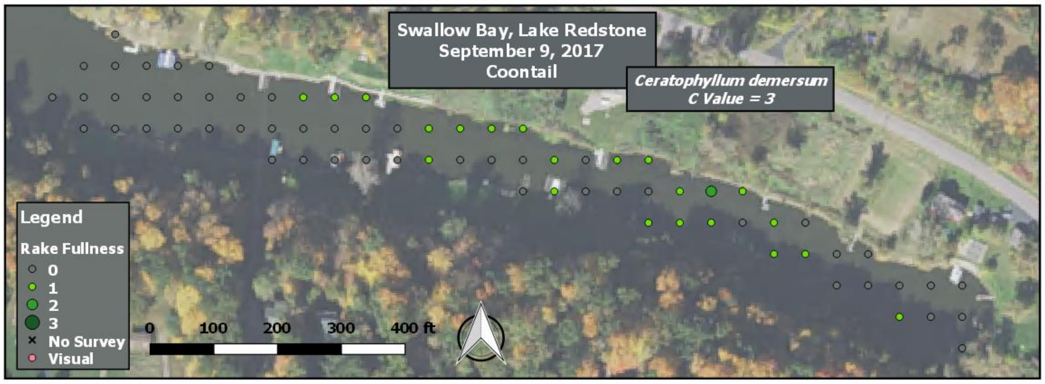


Figure 51 – Swallow Bay Maps of Slender Waterweed, Small Pondweed, Filamentous Algae, Large Duckweed, White Water Lily, & Coontail



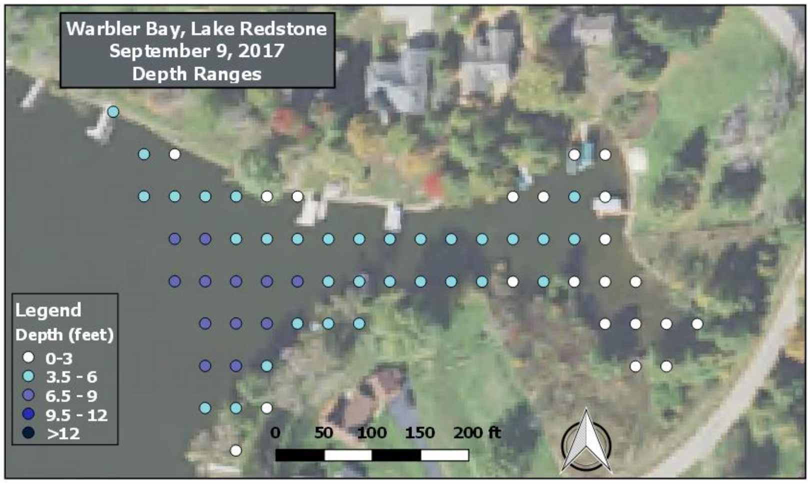


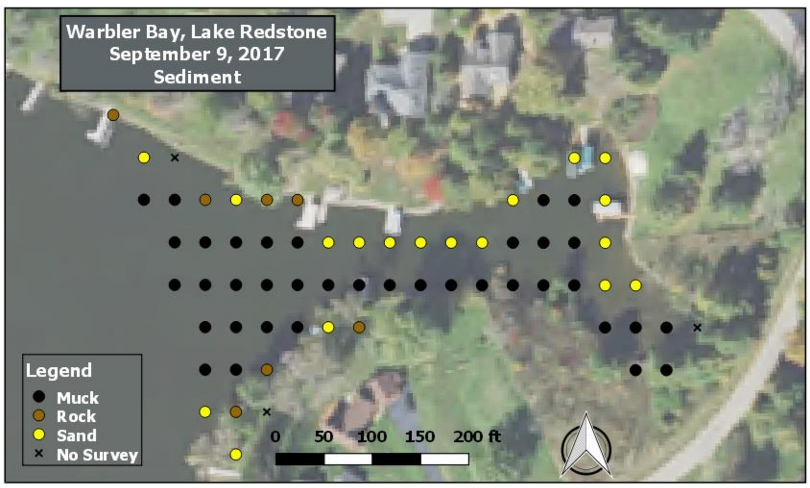




APPENDIX L – WARBLER BAY MAPS

Figure 52 – Warbler Bay Maps of Depth, Sediment, & Coontail





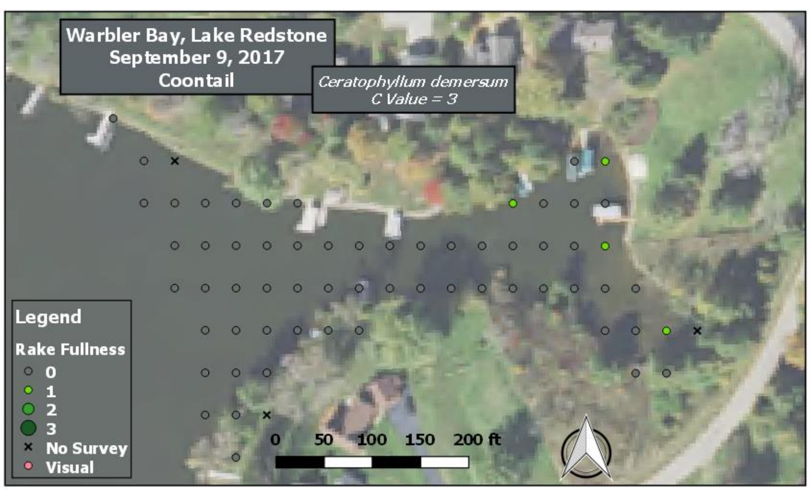
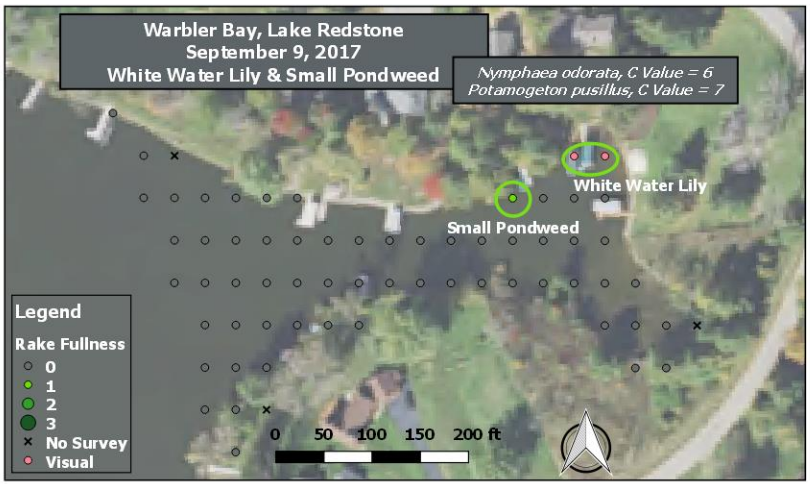
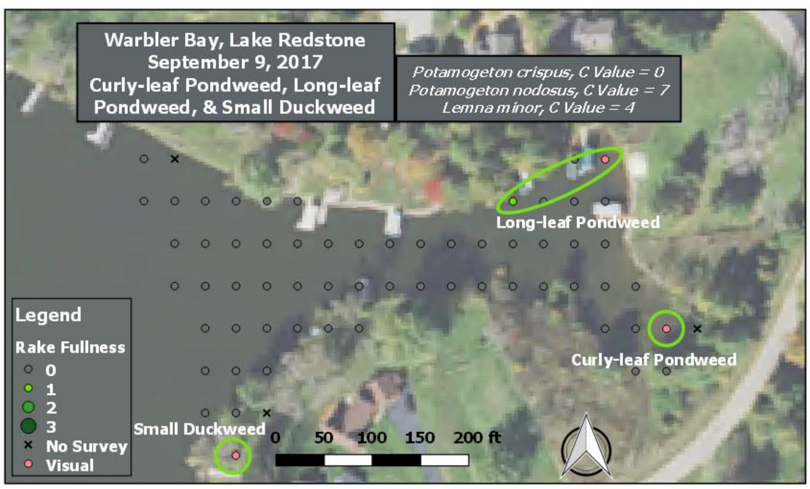


Figure 53 - Warbler Bay Maps of White Water Lily, Small Pondweed, Curly-leaf Pondweed, Long-leaf Pondweed, & Small Duckweed





APPENDIX M – WOODPECKER BAY MAPS

Figure 54 – Woodpecker Bay Maps of Depth, Sediment, Coontail, & Filamentous Algae

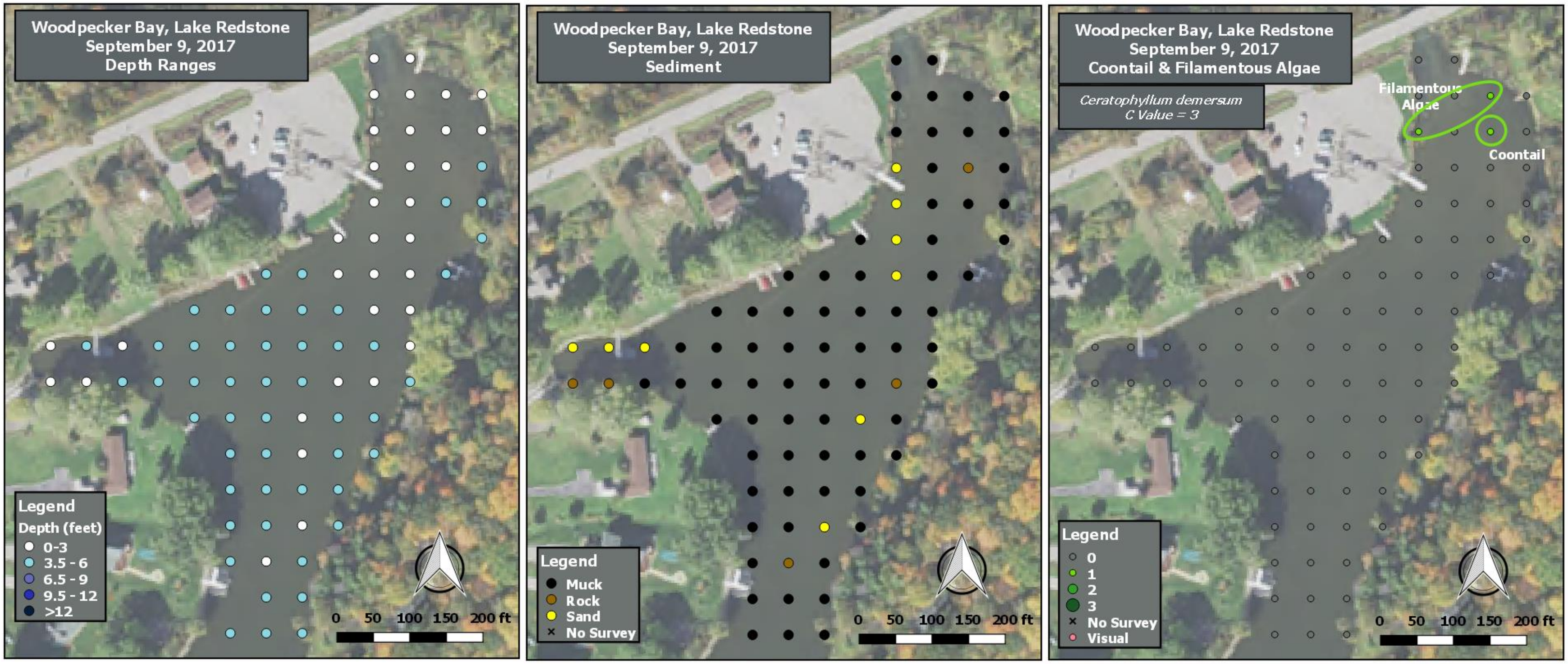
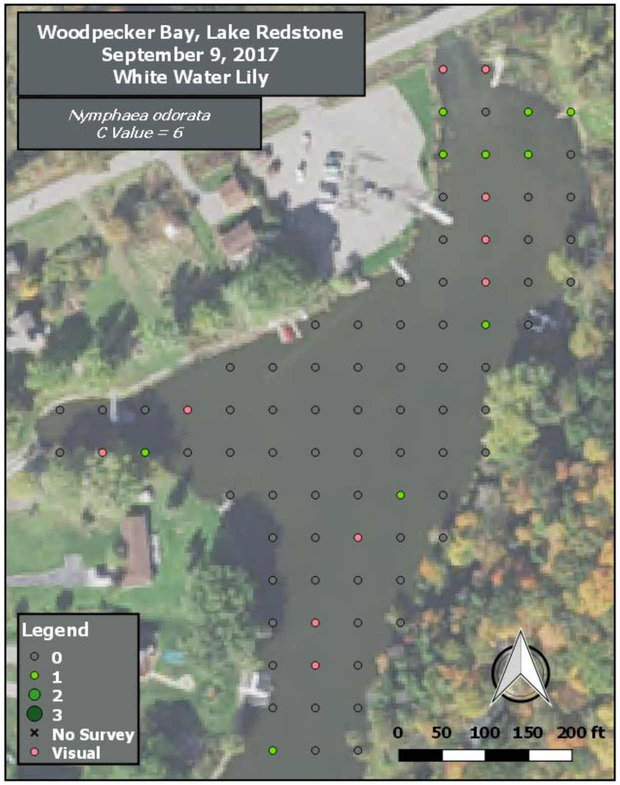
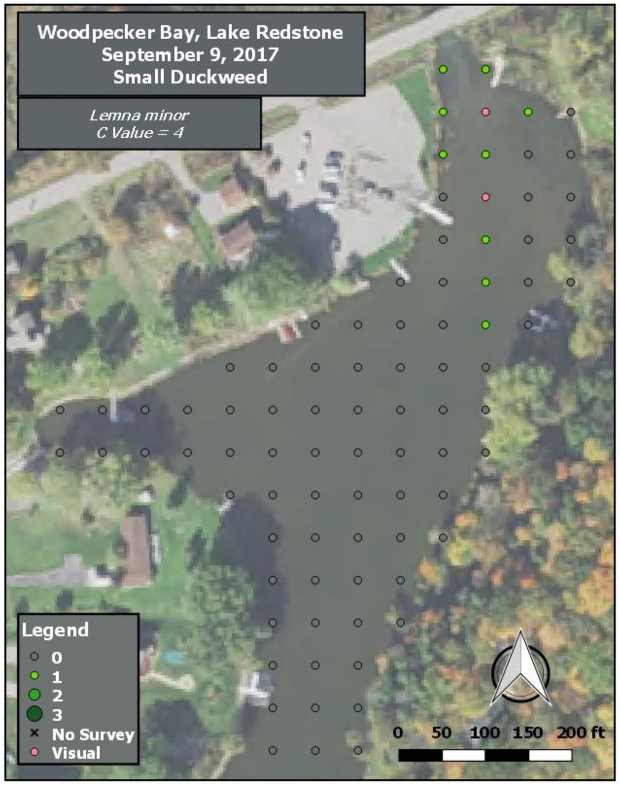


Figure 55 – Woodpecker Bay Maps of White Water Lily & Small Duckweed

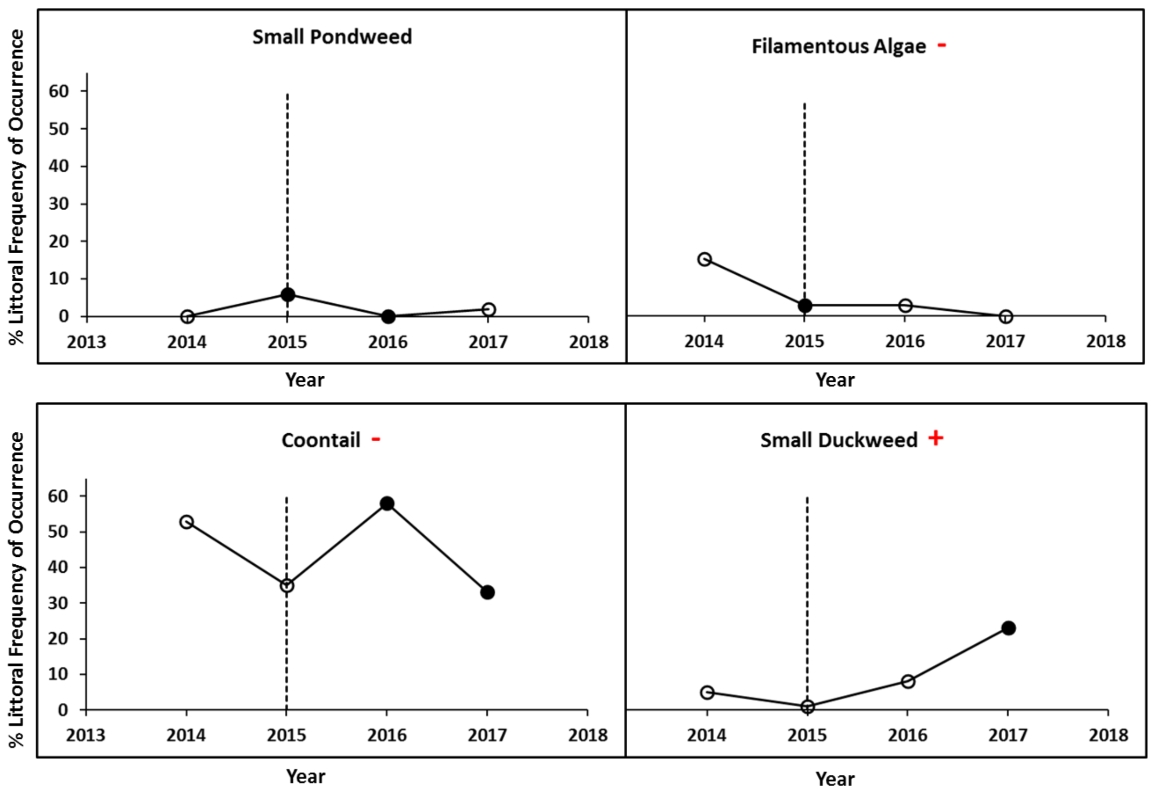




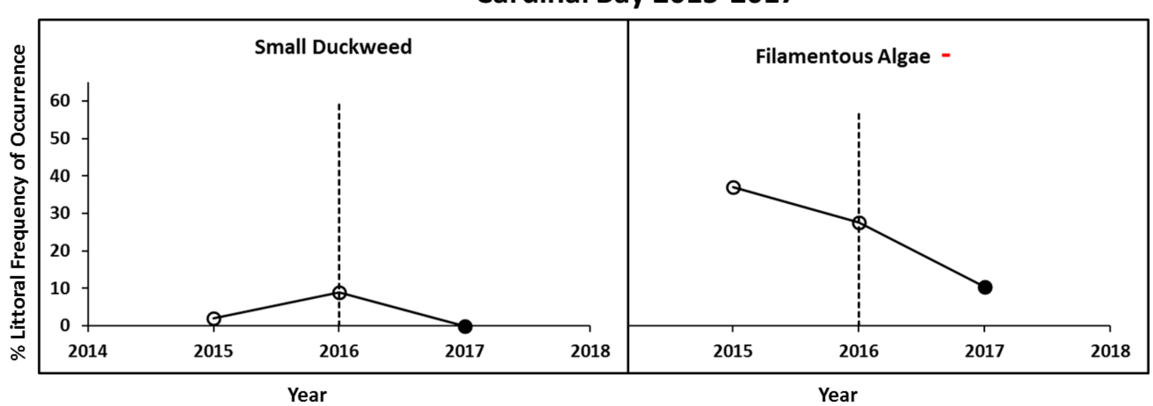
APPENDIX N – CHI-SQUARE TEST GRAPHS

Percent littoral frequency (# sites plants found at points shallower than maximum rooting depth) is on the y-axis and each year a plant survey was completed is on the x-axis. Only species with a statically significant change (using Chi-square tests) for at least one of the years are displayed. The dashed vertical lines represent years when herbicide treatments were done. Open circles represent no statistically significant change, solid circles represent a statistically significant change. Statistically significant changes between the first year of surveying and 2017 data are represented by + or – adjacent to plant names.

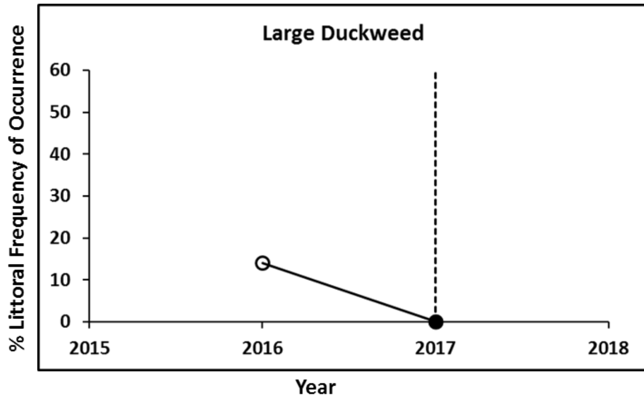
Swallow Bay 2014-2017

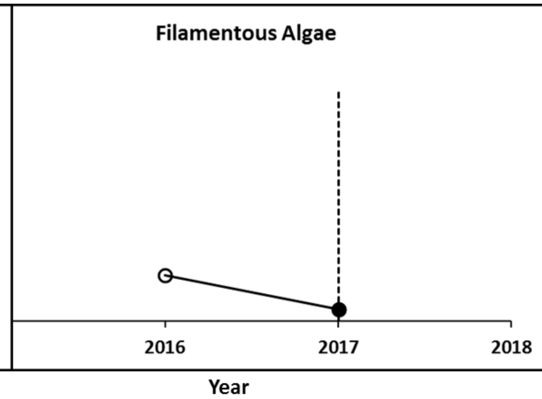


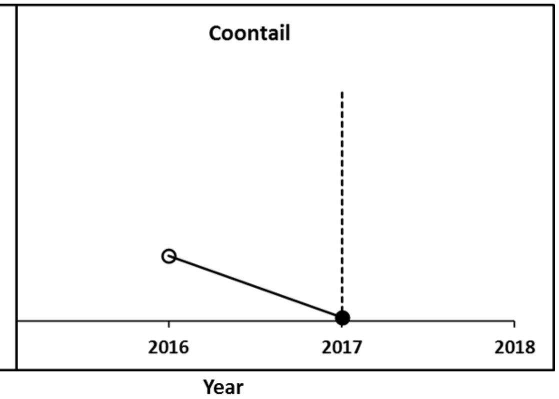
Cardinal Bay 2015-2017



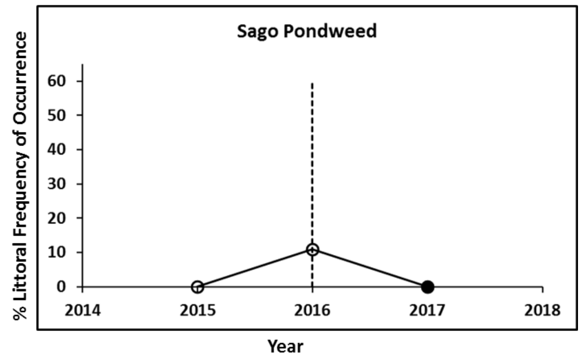
Woodpecker Bay 2016-2017



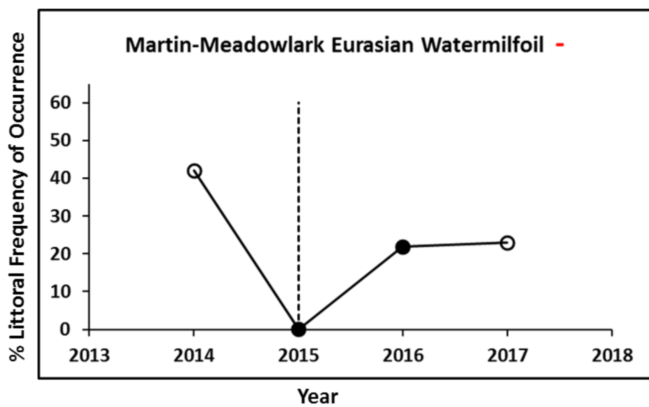


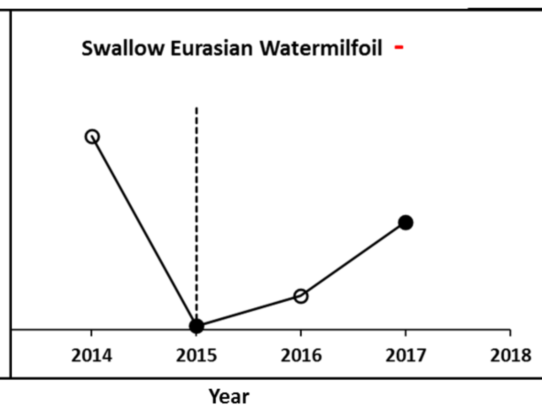


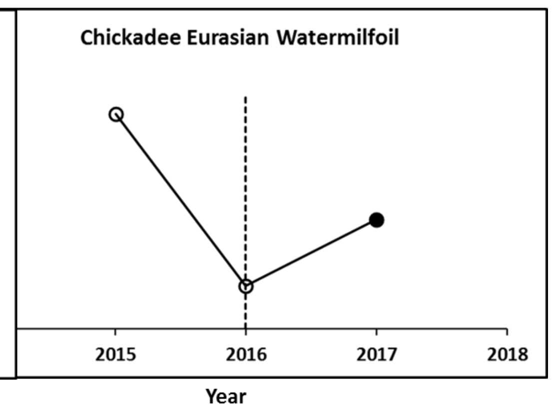
Oriole Bay 2015-2017

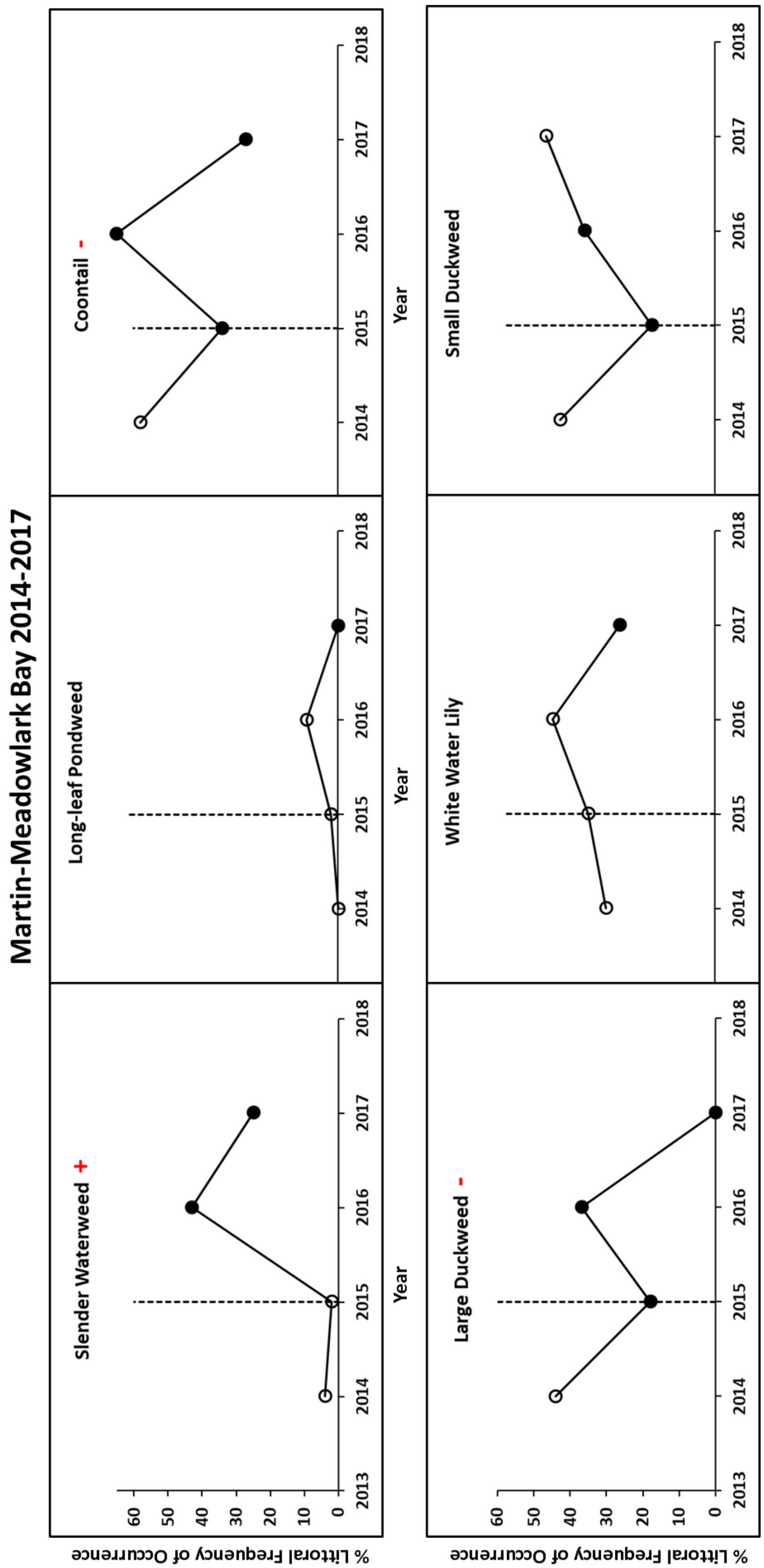


Chi-squre Results for Eurasian Watermilfoil








Martin-Meadowlark Bay 2014-2017
Slender Waterweed +
Long-leaf Pondweed
Coontail -
Large Duckweed -
White Water Lily
Small Duckweed
Year
% Littoral Frequency of Occurrence
2013
2014
2015
2016
2017
2018
0
10
20
30
40
50
60