Ecology and Management of Flowering Rush (*Butomus umbellatus*) in the Detroit Lakes, Minnesota

A Report to the Pelican River Watershed District and Minnesota Department of Natural Resources

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Executive Summary

- Flowering rush and hardstem bulrush distribution in the Detroit Lakes system has not changed between 2010 and 2011.
- Flowering rush is invading hardstem bulrush populations and habitat.
- Flowering rush is establishing in existing native plant areas, rather than establishing in uninhabited areas.
- Flowering rush growth as height and biomass, as well as density, increases to a depth of 4 feet, and declines in deeper water. This corresponds to depths at which significant biomass is emergent.
- Bud density is negatively correlated with depth. With an average of 300 N/m^2, at least three times the number of buds is produced relative to the density of ramets (100 N/m^2). These buds are capable of dispersing with any sediment disturbance.
- Use of contact herbicides such as diquat will, at a minimum, reduce the nuisance created by flowering rush with minimal impact on native plant diversity. In the short term, while other herbicide use patterns are investigated, diquat treatments may also reduce the accumulation and spread of flowering rush propagules.

Introduction

Flowering rush (*Butomus umbellatus* L. [Butomaceae]) is an emergent invasive plant that has plagued the Detroit Lakes area, in particular, Detroit Lake, Lake Sallie, Lake Melissa and Mill Pond (Becker County) since the 1960s. It is native to Europe and Asia and first entered the United States in 1928. It has likely had several introductions into the U.S. as an ornamental plant for water gardens. There are currently two varieties that plague Minnesota, an asexually reproducing polyploidy variety and a sexually reproducing diploid variety. The asexually reproducing variety is currently plaguing the Detroit Lakes area (Eckert et al. 2000).

Flowering rush was introduced to North America at Laprairie, Quebec along the St. Lawrence River around the turn of the 20th century (Countryman 1970). It was then transported to the New York shore of Lake Champlain. Other locations in North America include Connecticut, the Great Lakes region of the Midwest, Idaho, Montana, and Washington (Core 1941, Countryman 1970, Stuckey 1968).

Flowering rush has been dispersed in North America predominantly through the ornamental water garden trade (Les and Mehrhoff 1999). Waterfowl and wildlife consume the foliage, rhizomes, and bulbils, which may disperse the plants through their digestive tracts, or dislodge the plant from the sediment and allow for water transport (Martin and Uhler 1939, Hewitt 1942, Hroudova et al. 1996).

While much has been learned on the cytogenetics and reproduction of this species (Thompson and Eckert 2004, Brown and Eckert 2005, Krahulcova and Jarolimova 1993); little is known of its ecology and impacts on native plant and animal communities. The purpose of this study was to 1) examine the habitat range of flowering rush and native plants, 2) analyze the depth distribution of biomass in flowering rush, and 3) assess submersed applications of aquatic herbicides to control flowering rush in the Detroit Lakes, Minnesota. An additional study of the phenology and carbohydrate storage, led by Michelle Marko, will be reported separately.

Materials and Methods

Habitat Range of Flowering Rush and Native Plants

A grid of sampling points 150 m apart throughout the Detroit Lakes system (Figure 1) was generated using GIS from the shoreline to a depth of 25' (7.7m), and GPS used to navigate to each point (Madsen 1999). The points were surveyed in both 2010 and 2011. At each point, the presence or absence of all plant species were recorded, depth measured, and recorded on a GPS device.

For each basin, the frequency of occurrence was compared for 2010 and 2011 using a Cochran-Mantel-Haenzel test (Wersal et al. 2010, Stokes et al. 2000).

An association analysis on flowering rush and native plant species will indicate which species may either occur with each other, or if the growth of one species excludes another (Madsen et al. 1994).

Analysis of Allocation with Depth

In mid-summer of each year, we sampled ten transects around the lake with a gradual slope from 1' to 10' water depth (or maximum extent of flowering rush), with three samples at each 1' depth interval (Figure 2). Samples at each depth interval were collected using a 6" core sampling device (Madsen et al. 1997), and sorted into roots or rhizomes, submersed leaves, emergent leaves, and inflorescences. The number of rhizomes, ramets, rhizome buds, inflorescences, and bulbils will also be recorded. Nondestructive observations will also be taken at each point to note plant height, water depth, height of leaf emergence, presence of inflorescences, and presence of buds. Plants will be washed, sorted into component parts noted above, and dried in a force-air oven until constant weight (usually 48 hours). Plants will be weighed, and results converted to grams dry weight per square meter.

Field Trial of Herbicides to Control Submersed Flowering Rush

While imazapyr has been relatively effective for within-year control of emergent flowering rush, no herbicide use patterns have been effective in controlling submersed populations of flowering rush. Therefore, we attempted two use herbicide use patterns to control submersed flowering rush

2010. In 2010, we attempted three treatments to control submersed flowering rush: endothall (as Aquathol K) at 3 ppm treated once, twice, and three times during the growing season; and a set of plots that were untreated references. Each plot was 1.25 acre in size, and the treatments were replicated three times, for a total of 9 treated and three reference plots (Figure 3, Table 1).

Assessment of management techniques in this system was done by sampling biomass collected with a biomass coring device to collect both shoots and rhizomes (Madsen et al. 2007, Madsen 1993). Ten cores per plot were collected before each proposed treatment, and at the end of the growing season in September. Cores were separated into emergent leaves, submersed leaves, rhizomes, rhizome buds, and inflorescences. Rhizomes and rhizome buds were counted. Plants were dried for 48 hours at 50C or greater, and weighed for biomass. In addition, approximately twenty points per plot were sampled using a point intercept method, using a 25 m grid interval (Madsen 1999) to evaluate the impact of treatments on native plant communities. Successful applications will reduce rhizome weight and rhizome bud number.

2011. Two treatments (and a set of untreated reference plots) were used for the submersed leaves of flowering rush, to occur in early June. We selected two ten-acre plots on the Flats area of Big Detroit, and two one-acre plots, one in the overlook region on the northern shore of Big Detroit Lake, and the other on the flats near the two endothall plots (Figure 4). The phenology plots in Big Detroit and Little Detroit served as reference plots, and were sampled on the same schedule as for the treatment plots (see below). The two ten acre plots were treated with endothall (Aquathol-K) at a rate of 3 ppm or 1.9 gallons per acre-foot. Water depths were determined from pretreatment data to more accurately estimate the amount of herbicide needed. The two one-acre plots were treated with Reward (diquat) at a rate of 2 gallons per surface-acre, the maximum rate allowed. Along with each treatment, the plots were treated with 10 ppb of Rhodamine WT dye to evaluate dissipation rates. Monitoring of dye is discussed in the assessment section. The diquat plots were treated twice, the first time in early June and the second time approximately four weeks later in early July; but due to environmental conditions and a lack of efficacy with the first treatment, the endothall plots were only treated once.

Dye dissipation. Sample locations were pre-determined and located inside each treatment area and at arbitrarily located positions outside of the treatment areas to a distance of 1600 m. Sample locations outside of the treatment area were placed to follow the dye as it moved with water flow. Measurements of dye concentration were made by sampling water in an integrated water sampler, and measuring the dye with a handheld Turner Designs fluorometer. Dye was measured at pretreatment, 1, 3, 6, 9, 12, and 24 hours after treatment. In addition, one datasonde was deployed to continuously record dye concentrations in the water from a fixed location in the plot. While the half-life will be referenced in this report, a full report on dye and herbicide dissipation will be presented separately.

Plant Assessment. Assessment of management techniques in this system was done sampling biomass collected with a 6” diameter biomass coring device to collect both shoots and rhizomes. Ten cores per plot were collected before each proposed treatment, and at the end of the growing season in September. Cores were separated into emergent leaves, submersed leaves, rhizomes, rhizome buds, and inflorescences. Rhizomes and rhizome buds were counted. Plants were dried for 48 hours at 50C or greater, and weighed for biomass. Successful applications should reduce both aboveground and belowground biomass.

All plots were also assessed for species composition using a point intercept method, before the first treatment and in September after the final treatment. Approximately twenty points per plot were sampled.

Results and Discussion

Habitat Range of Flowering Rush and Native Plants

A total of 31 plant species were observed in the Detroit Lake system (Tables 2 through 6). The occurrence of some species was fairly static for both years within a given basin, while other species varied significantly between the two years. While a number of species are of interest for habitat and conservation, the focus of these discussions will be flowering rush and hardstem bulrush. Inter-annual differences can be due to a number of factors, but no lakewide management activity was pursued that could cause these particular changes in distribution.

Flowering rush did not change in distribution in Big Detroit Lake (Table 2), Little Detroit Lake (Table 3), Curfman Lake (Table 4), Sallie Lake (Table 5), or Melissa Lake (Table 6). Proportion of littoral covered was highest in Curfman Lake followed by Big Detroit Lake, though this was not tested statistically (Figure 5, Tables 2-6).

Hardstem bulrush likewise did not change in distribution in Big Detroit Lake (Table 2), Little Detroit Lake (Table 3), Curfman Lake (Table 4), Sallie Lake (Table 5), or Melissa Lake (Table 6). Proportion of littoral zone covered by hardstem bulrush was greatest in Curfman Lake, followed by Sallie Lake (Figure 6, Tables 2-6).

Flowering rush was found from the shore out to a depth of 16 feet, with most plants found in 3 to 4 feet of depth (Figure 7). This represents a significant overlap with hardstem bulrush, which was found from shore to 14 feet, with most plants found in 2 to 4 feet water depth (Figure 8). Flowering rush and hardstem bulrush co-occur more often than a statistically-neutral model would predict, with a correlation coefficient of 0.36 (Table 7). Management of flowering rush will involve interaction in habitats occupied by hardstem bulrush. In fact, most hardstem bulrush habitats in the Detroit Lake system have been invaded by flowering rush.

An analysis of the occurrence of flowering rush and the presence of any native plant species indicates that the vast majority of flowering rush occurs in the company of native plants (Table 8). Flowering rush is utilizing the habitats of native plants, and not colonizing uninhabited areas; which supports the concept of “the rich get richer” first expounded by Stohlgren and others (2003).

Analysis of Allocation with Depth

Only 2011 data will be utilized in the analysis, as the 2010 data was incomplete. All data across transects were analyzed together; we did not analyze individual transects since biomass is notoriously high in variability.

Total plant height, from the bottom to tip of the leaf, increased fairly linearly from 1 to 4 feet water depth, then declined to an average of approximately 1.5 feet tall from 6 to 10 feet water depth (Figure 9). While the nonlinear regression indicates a maximum at 3 feet water depth, the peak was at 4 feet water depth, where plants averaged 5 feet tall. From 1 to 3 feet water depth, plants averaged almost 2 feet above the water surface. Total plant height follows more of a broken stick model, with plant height a constant function at depths greater than 6 ft.

Emergent plant height averaged around 1.5ft above water level, and then declined to almost zero above 5 feet deep (Figure 10). This result has great significance for treating flowering rush with foliar applications of aquatic herbicides. Plants in water deeper than 4 feet typically do not have leaf material extending above the water surface, yet plants can be found out to 9 feet water depth or more. Further studies examining the ratio of leaf material above and below water are needed to provide an effective recommendation for the depth to which foliar applications should be made.

Peak aboveground biomass of flowering rush (Figure 11) was observed at a depth of 3 feet, averaging almost 450 gDW / m^2. Aboveground biomass was strongly, but negatively, related to water depth. Aboveground biomass falls to below 100 gDW / m^2 at water depths of 6 feet or greater. This would support the observation that nuisance problems are most common at water depths of 4 feet and less.

Interestingly, belowground biomass almost linearly declined with depth from 1 to 10 feet (Figure 12). Water depth strongly affects the amount of carbohydrates that can be made, and the construction of more rhizomes. This relationship will reappear with other factors associated with rhizomes.

A flowering rush ramet is a single clump of leaves that grow from a bud. While they look like distinct clumps above the sediment, they may or may not be connects by rhizomes below the sediment surface. Ramet density was strongly inversely related to water depth (Figure 13), but this may also follow more of a broken stick model or sigmoid model, with relatively constant density in water depths from 1 to 4 feet, and a lower plateau of density at water depths of 5 to 6 feet and greater. Through time, flowering rush can grow to very high densities that form a turf or mat of plants (Figure 14). This mat may actually break off and float on the surface or, more commonly, sediments may accumulate and the plants grow above, causing a rapid filling of the littoral zone. In some areas, the ramet bases were several feet above the original lake bottom, which we determined using a sounding rod. Flowering rush may be an ecosystem engineer, causing the filling in of the margins of a lake.

Rhizome density was greatest in waters less than 6 feet deep, with the mathematical model projecting a maximum at 3 feet (Figure 15). Rhizomes easily break, creating a large number of pieces. These rhizome segments can initiate new growth, and may act as propagules when dislodged by feeding waterfowl or wave action.

Unlike rhizome segments, flowering rush buds on the rhizome are not affected by breakage and represent a potential new ramet. Bud densities were negatively related to water depth, through bud densities were not significantly difference in water depths between 1 and 6 feet deep (Figure 16). The mean number of buds was, in one depth range, over 300 buds per square meter. Each bud can form a new ramet. Given that the maximum ramet density was only 100 ramets per square meter, this indicates that a lot of new ramets are either awaiting dispersal, or the death of the existing ramets. No studies have been done on the population biology, dormancy, or dispersal and spread of flowering rush, yet this has significant potential impact to developing early detection and rapid response strategies or other management approaches. In developing a coherent ecological strategy for managing invasive plants, the chief overwintering and dispersal propagule(s) are the key (Madsen 2007). For waterchestnut, this is the seed; for curlyleaf pondweed, it is the turion; for hydrilla, it is the subterranean and axillary turions (Madsen 2007, Madsen 1990, Madsen 1993, Woolf and Madsen 2003, Netherland 1997).

The study of biomass allocation successfully demonstrated the effect of water depth on biomass growth and allocation in Detroit Lake flowering rush, and illustrates why flowering rush is so successful in depths 4 feet or less.

Field Trial of Herbicides to Control Submersed Flowering Rush

2010. The 2010 demonstration treatments did not result in any control with any treatment of endothall. Dye half-lives ranged from 3 to 6 hours (John Skogerboe, unpubl. data). After consultation, we decided that the plots were too small for endothall treatments to be effective, resulting in the recommendation for 2011 that endothall plots be 10 acres in size.

2011. The two diquat plots had a half-life of around 2 hours, and the two endothall plots had half-lives ranging from 3 to 12 hours. John Skogerboe will release the dye study data in a separate report. Diquat was treated twice, endothall just once. Biomass was collected through ten cores per plot before treatment, and in July and August. In addition, 25 points were sampled for presence/absence in each plot before treatment and in August. For the analysis, the two reference plots, the two diquat plots, and the two endothall plots were combined by treatment for analysis. Pretreatment data (Figure 17) demonstrates that the six plots were not statistically different with respect to the density of rhizomes, density of buds, and above or belowground biomass.

Four weeks after the first treatment in June, there was no difference in rhizome density (Figure 18). Treated plots had significantly more buds than untreated plots, which may be related to a compensation response from the treatment. Aboveground biomass in the diquat treatment was significantly less than the reference, but not the endothall treatment. Belowground biomass was greater in the diquat treatment than the reference.

In August, after the second diquat treatment, no difference was observed in rhizome or bud density (Figure 19). Aboveground biomass was significantly less in the diquat plot than the reference, and no difference in belowground biomass between reference and any treatment. Treating twice with diquat was effective in reducing aboveground biomass, but not sufficient to reduce rhizome biomass or density.

Mean species richness of all species (Figure 20) increased significantly between pretreatment point intercept data (collected in early June) and posttreatment data (collected in September). Total species richness would include invasive plant species, primarily flowering rush. As these data were collected four weeks after the last of two diquat treatments, some species may have been initially damaged but apparently recovered.

If only native plant species are included, the diversity of native plants increased in the diquat, endothall, and reference plots between pretreatment and posttreatment sampling (Figure 21). The diquat plots likely have a lower number of species (though not tested statistically) because the plots are smaller and positioned in less favorable sites, particularly the site on the rocky northern shore.

While diquat can control aboveground biomass, the long-term ability to control flowering rush is uncertain. However, it appears that the nuisance caused by flowering rush can be controlled with limited impact on native plant diversity. Further research is warranted on the use of diquat to control submersed flowering rush, including impact on native plant communities.

Conclusions and Recommendations

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- Flowering rush and hardstem bulrush distribution in the Detroit Lakes system has not changed between 2010 and 2011.
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- Flowering rush is establishing in existing native plant areas, rather than establishing in uninhabited areas.
- Flowering rush growth as height and biomass, as well as density, increases to a depth of 4 feet, and declines in deeper water. This corresponds to depths at which significant biomass is emergent.
- Bud density is negatively correlated with depth. With an average of 300 N/m^2, at least three times the number of buds is produced relative to the density of ramets (100 N/m^2). These buds are capable of dispersing with any sediment disturbance.

Recommendations

Management

- Use of contact herbicides such as diquat will, at a minimum, reduce the nuisance created by flowering rush with minimal impact on native plant diversity. In the short term, while other herbicide use patterns are investigated, diquat treatments may also reduce the accumulation and spread of flowering rush propagules.

Future Research

- No research has been performed examining the population biology and demography of flowering rush, yet these studies will be significantly in understanding the modes of localized and distance dispersal. Long term management is managing the demography of the critical overwintering and dispersing propagules.

- Determining the relationship between the amount of leaf material above and below the water and effective control with foliar herbicides will be critical in effectively utilizing foliar herbicides such as imazapyr for control of flowering rush
- Further research on developing systemic herbicide management of flowering rush may yield more rapid control of flowering rush populations than reliance on contact herbicides.
- Other contact herbicides, specifically flumioxazin, might be investigated for use in controlling submersed flowering rush.

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Table 1. Treatments for the 2010 in-lake management demonstration project. Plots were 1.25 acre in size, and were replicated three times per treatment. Phenology study plots were used as reference plots, but samples were taken at the same time and methods as the treatment plots. Samples were taken before each treatment and four weeks after the last treatment.

Herbicide (Water Column Concentration, ppm)	Timing of Treatment (and pretreatment samples)
Untreated reference	
Endothall (3 ppm) treated once	June
Endothall (3 ppm) treated twice	June and July
Endothall (3 ppm) treated three times	June, July, August

Table 2. Average depth (feet) and plant species percent frequency of occurrence in Big Detroit Lake littoral zone for 2010 and 2011 based on point intercept surveys. P-value given for comparison between years by a Cochran-Mantel-Haenzel statistic. P-values indicated with NA were not computable. P-values smaller than p=0.05 are highlighted.

Scientific Name	Common Name	2010	2011	p-value
DEPTH	In feet	11.0	10.9	NA
Bidens beckii	Water marigold	1.8	0	0.025
Butomus umbellatus	Flowering rush	10.7	14.0	0.24
Ceratophyllum demersum	Coontail	20.3	16.2	0.22
Chara	Chara	51.7	52.0	0.93
Drepanocladus	Drepanocladus moss	0	10.0	<0.0001
Elodea canadensis	Elodea	7.4	5.2	0.29
Heteranthera dubia	Yellow water stargrass	1.8	1.1	0.48
Hippuris vulgaris	Mare’s tail	0	0	NA
Lemna trisulca	Star duckweed	6.3	7.7	0.50
Myriophyllum sibiricum	Northern watermilfoil	13.7	17.0	0.28
Najas flexilis	Bushy pondweed	29.5	32.1	0.52
Nitella	Nitella	2.2	2.2	0.99
Nuphar luteum	Yellow pondlily	0.7	1.1	0.65
Nymphaea odorata	White waterlily	0	0	NA
Potamogeton amplifolius	Largeleaf pondweed	8.9	1.8	0.0003
Potamogeton crispus	Curlyleaf pondweed	0.4	1.1	0.32
Potamogeton foliosus	Leafy pondweed	4.1	6.3	0.24
Potamogeton gramineus	Variable-leaf pondweed	3.0	5.9	0.10
Potamogeton illinoensis	Illinois pondweed	8.5	7.0	0.52
Potamogeton natans	Floating-leaf pondweed	0	0	NA
Potamogeton praelongus	Whitestem pondweed	0.4	3.0	0.02
Potamogeton pusillus	Small pondweed	0	0	NA
Potamogeton richardsonii	Richardson’s pondweed	7.0	9.6	0.28
Potamogeton zosteriformis	Flatstem pondweed	10.7	10.0	0.78
Ruppia cirrhosa	Spiral ditchgrass	1.5	2.2	0.52
Ranunculus longirostris	White watercrowfoot	1.8	1.5	0.74
Schoenoplectus acutus	Hardstem bulrush	0	0.4	0.32
Stuckenia pectinata	Sago pondweed	18.5	15.1	0.30
Typha latifolia	Broadleaf cattail	0	0	NA
Utricularia vulgaris	Common bladderwort	33.6	35.1	0.72
Vallisneria americana	Water celery	17.3	16.6	0.82
	Number of observations	271	271	

Table 3. Depth (in feet) and plant species percent frequency of occurrence in Little Detroit Lake littoral zone for 2010 and 2011 based on point intercept surveys. P-value given for comparison between years by a Cochran-Mantel-Haenzel statistic. P-values indicated with NA were not computable. P-values smaller than p=0.05 are highlighted.

Scientific Name	Common Name	2010	2011	P-value
DEPTH	In feet	9.1	9.1	NA
Bidens beckii	Water marigold	2.9	0	0.025
Butomus umbellatus	Flowering rush	4.7	2.9	0.40
Ceratophyllum demersum	Coontail	26.9	17.0	0.027
Chara	Chara	91.2	81.9	0.011
Drepanocladus	Drepanocladus moss	0	0.6	0.32
Elodea canadensis	Elodea	7.0	2.9	0.082
Heteranthera dubia	Yellow water stargrass	0	1.8	0.082
Hippuris vulgaris	Mare's tail	0	0	NA
Lemna trisulca	Star duckweed	1.8	0	0.082
Myriophyllum sibiricum	Northern watermilfoil	39.8	22.2	0.0005
Najas flexilis	Bushy pondweed	20.5	16.4	0.33
Nitella	Nitella	6.4	0	0.0008
Nuphar luteum	Yellow pondlily	2.3	1.2	0.41
Nymphaea odorata	White waterlily	0	0	NA
Potamogeton amplifolius	Largeleaf pondweed	3.5	5.3	0.43
Potamogeton crispus	Curlyleaf pondweed	0	0	NA
Potamogeton foliosus	Leafy pondweed	1.2	0.6	0.56
Potamogeton gramineus	Variable-leaf pondweed	3.5	1.2	0.15
Potamogeton illinoensis	Illinois pondweed	17.0	2.3	0.0001
Potamogeton natans	Floating-leaf pondweed	2.3	0.6	0.18
Potamogeton praelongus	Whitestem pondweed	7.0	18.1	0.002
Potamogeton pusillus	Small pondweed	0	0.6	0.32
Potamogeton richardsonii	Richardson's pondweed	14.0	20.5	0.12
Potamogeton zosteriformis	Flatstem pondweed	8.2	7.6	0.84
Ruppia cirrhosa	Spiral ditchgrass	2.3	2.3	0.99
Ranunculus longirostris	White watercrowfoot	1.2	0	0.16
Schoenoplectus acutus	Hardstem bulrush	2.3	2.9	0.74
Stuckenia pectinata	Sago pondweed	23.4	19.9	0.43
Typha latifolia	Broadleaf cattail	0	0.6	0.32
Utricularia vulgaris	Common bladderwort	8.2	29.8	0.0001
Vallisneria americana	Water celery	5.8	5.3	0.81
	Number of observations	171	171	

Table 4. Depth (in feet) and plant species percent frequency of occurrence in Curfman Lake littoral zone for 2010 and 2011 based on point intercept surveys. P-value given for comparison between years by a Cochran-Mantel-Haenzel statistic. P-values indicated with NA were not computable. P-values smaller than p=0.05 are highlighted.

Scientific Name	Common Name	2010	2011	P-value
DEPTH	In feet	9.5	11.2	NA
Bidens beckii	Water marigold	0	0	NA
Butomus umbellatus	Flowering rush	64.0	43.5	0.16
Ceratophyllum demersum	Coontail	52.0	69.6	0.22
Chara	Chara	44.0	43.5	0.97
Drepanocladus	Drepanocladus moss	0	4.3	0.30
Elodea canadensis	Elodea	16.0	8.7	0.45
Heteranthera dubia	Yellow water stargrass	0	0	NA
Hippuris vulgaris	Mare’s tail	0	0	NA
Lemna trisulca	Star duckweed	0	26.1	0.007
Myriophyllum sibiricum	Northern watermilfoil	40.0	17.4	0.089
Najas flexilis	Bushy pondweed	0	0	NA
Nitella	Nitella	0	0	NA
Nuphar luteum	Yellow pondlily	16.0	17.4	0.90
Nymphaea odorata	White waterlily	0	0	NA
Potamogeton amplifolius	Largeleaf pondweed	4.0	17.4	0.13
Potamogeton crispus	Curlyleaf pondweed	0	0	NA
Potamogeton foliosus	Leafy pondweed	0	0	NA
Potamogeton gramineus	Variable-leaf pondweed	0	0	NA
Potamogeton illinoensis	Illinois pondweed	24.0	0	0.013
Potamogeton natans	Floating-leaf pondweed	8.0	0	0.17
Potamogeton praelongus	Whitestem pondweed	8.0	4.3	0.61
Potamogeton pusillus	Small pondweed	0	0	NA
Potamogeton richardsonii	Richardson’s pondweed	8.0	21.7	0.18
Potamogeton zosteriformis	Flatstem pondweed	12.0	0	0.090
Ruppia cirrhosa	Spiral ditchgrass	0	0	NA
Ranunculus longirostris	White watercrowfoot	0	0	NA
Schoenoplectus acutus	Hardstem bulrush	36.0	21.7	0.28
Stuckenia pectinata	Sago pondweed	16.0	43.5	0.038
Typha latifolia	Broadleaf cattail	12.0	0	0.090
Utricularia vulgaris	Common bladderwort	32.0	34.8	0.84
Vallisneria americana	Water celery	16.0	8.7	0.45
	Number of observations	25	25	

Table 5. Depth (in feet) and plant species percent frequency of occurrence in Sallie Lake littoral zone for 2010 and 2011 based on point intercept surveys. P-value given for comparison between years by a Cochran-Mantel-Haenzel statistic. P-values indicated with NA were not computable. P-values smaller than p=0.05 are highlighted.

Scientific Name	Common Name	2010	2011	P-value
DEPTH	In feet	11.8	11.4	NA
Bidens beckii	Water marigold	0	0	NA
Butomus umbellatus	Flowering rush	8.7	8.9	0.96
Ceratophyllum demersum	Coontail	0	17.1	0.0001
Chara	Chara	39.6	37.7	0.73
Drepanocladus	Drepanocladus moss	0	1.4	0.15
Elodea canadensis	Elodea	2.0	1.4	0.67
Heteranthera dubia	Yellow water stargrass	0	1.4	0.15
Hippuris vulgaris	Mare’s tail	0	0	NA
Lemna trisulca	Star duckweed	5.4	6.8	0.60
Myriophyllum sibiricum	Northern watermilfoil	19.5	17.8	0.72
Najas flexilis	Bushy pondweed	14.1	14.4	0.94
Nitella	Nitella	0	0	NA
Nuphar luteum	Yellow pondlily	1.3	0	0.16
Nymphaea odorata	White waterlily	0	2.1	0.079
Potamogeton amplifolius	Largeleaf pondweed	0	0.7	0.31
Potamogeton crispus	Curlyleaf pondweed	2.7	8.9	0.022
Potamogeton foliosus	Leafy pondweed	0.7	10.3	0.0003
Potamogeton gramineus	Variable-leaf pondweed	0	0	NA
Potamogeton illinoensis	Illinois pondweed	0.7	0.7	0.99
Potamogeton natans	Floating-leaf pondweed	0	0	NA
Potamogeton praelongus	Whitestem pondweed	4.7	2.1	0.21
Potamogeton pusillus	Small pondweed	0	0	NA
Potamogeton richardsonii	Richardson’s pondweed	10.1	10.3	0.95
Potamogeton zosteriformis	Flatstem pondweed	14.1	19.2	0.24
Ruppia cirrhosa	Spiral ditchgrass	0	2.7	0.042
Ranunculus longirostris	White watercrowfoot	3.4	4.8	0.53
Schoenoplectus acutus	Hardstem bulrush	6.7	5.5	0.66
Stuckenia pectinata	Sago pondweed	8.1	8.2	0.96
Typha latifolia	Broadleaf cattail	0	0	NA
Utricularia vulgaris	Common bladderwort	5.4	6.8	0.60
Vallisneria americana	Water celery	14.1	8.2	0.11
	Number of observations	149	146	

Table 6. Depth (in feet) and plant species percent frequency of occurrence in Melissa Lake littoral zone for 2010 and 2011 based on point intercept surveys. P-value given for comparison between years by a Cochran-Mantel-Haenzel statistic. P-values indicated with NA were not computable. P-values smaller than p=0.05 are highlighted.

Scientific Name	Common Name	2010	2011	P-value
DEPTH	In feet	10.2	10.2	NA
Bidens beckii	Water marigold	0	1.0	0.15
Butomus umbellatus	Flowering rush	1.9	1.0	0.43
Ceratophyllum demersum	Coontail	22.2	16.2	0.11
Chara	Chara	53.7	54.3	0.90
Drepanocladus	Drepanocladus moss	8.8	9.0	0.93
Elodea canadensis	Elodea	1.9	0.5	0.19
Heteranthera dubia	Yellow water stargrass	0	0	NA
Hippuris vulgaris	Mare's tail	0	0.5	0.31
Lemna trisulca	Star duckweed	1.9	1.0	0.43
Myriophyllum sibiricum	Northern watermilfoil	13.9	15.7	0.60
Najas flexilis	Bushy pondweed	16.2	22.9	0.083
Nitella	Nitella	0	0	NA
Nuphar luteum	Yellow pondlily	0.5	1.0	0.55
Nymphaea odorata	White waterlily	0	0	NA
Potamogeton amplifolius	Largeleaf pondweed	0	2.9	0.013
Potamogeton crispus	Curlyleaf pondweed	0	0	NA
Potamogeton foliosus	Leafy pondweed	0	1.0	0.15
Potamogeton gramineus	Variable-leaf pondweed	0	11.0	0.0001
Potamogeton illinoensis	Illinois pondweed	8.8	14.8	0.056
Potamogeton natans	Floating-leaf pondweed	0.9	0.5	0.58
Potamogeton praelongus	Whitestem pondweed	4.2	0	0.0028
Potamogeton pusillus	Small pondweed	0	0	NA
Potamogeton richardsonii	Richardson's pondweed	6.5	3.8	0.21
Potamogeton zosteriformis	Flatstem pondweed	11.1	15.7	0.16
Ruppia cirrhosa	Spiral ditchgrass	0.5	0.5	0.98
Ranunculus longirostris	White watercrowfoot	1.4	1.9	0.68
Schoenoplectus acutus	Hardstem bulrush	0.9	1.0	0.98
Stuckenia pectinata	Sago pondweed	13.4	7.6	0.052
Typha latifolia	Broadleaf cattail	0.5	0	0.32
Utricularia vulgaris	Common bladderwort	26.4	23.8	0.54
Vallisneria americana	Water celery	1.9	2.9	0.49
	Number of observations	216	210	

Table 7. Two-by-two table cross-tabulating the occurrence of flowering rush (*Butomus umbellatus*) with hardstem bulrush (*Schoenoplectus acutus*) from a 2011 survey of the Detroit Lake system. Number indicates the frequency of occurrence and column or row totals on the edges indicate total presence or absence of the species. Chi-square test is significant at the $p<0.0001$ level, and a correlation coefficient of 0.36.

	Hardstem bulrush absent	Hardstem bulrush present	
Flowering rush absent	754	8	762
Flowering rush present	53	16	69
Totals	807	24	831

Table 8. Two-by-two table cross-tabulating the occurrence of flowering rush (*Butomus umbellatus*) with the occurrence of any native plant (Native Cover) from a 2011 survey of the Detroit Lake system. Number indicates the frequency of occurrence and column or row totals on the edges indicate total presence or absence of the species. Chi-square test is significant at the $p<0.0001$ level, and a correlation coefficient of 0.15.

	Native Cover Absent	Native Cover Present	Total	
Flowering rush absent	202	560	762	
Flowering rush present	2	67	69	
Total	204	627	831	

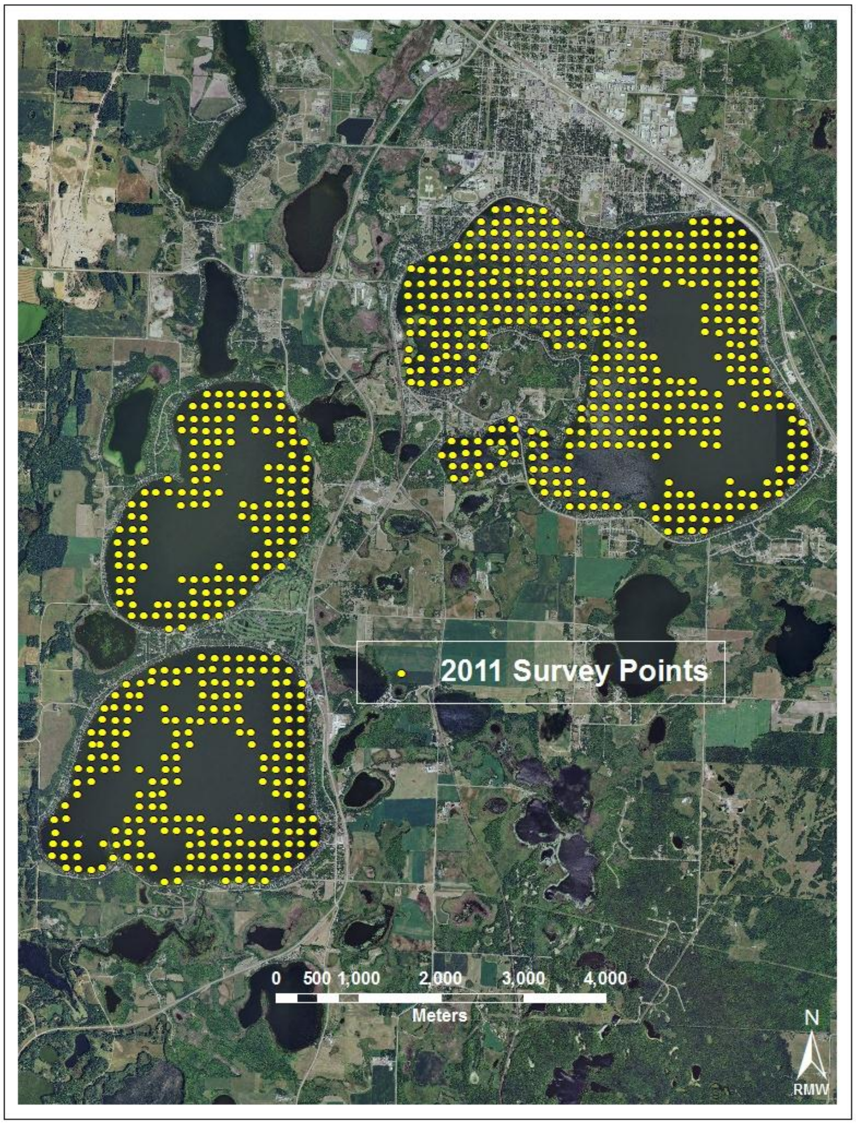

Figure 1. Point interval survey points in the Detroit Lake system used for point intercept surveys in 2010 and 2011. In 2010, the grid was continuous since no bathymetry data was available. The points shown are for depths at 25’ or less.

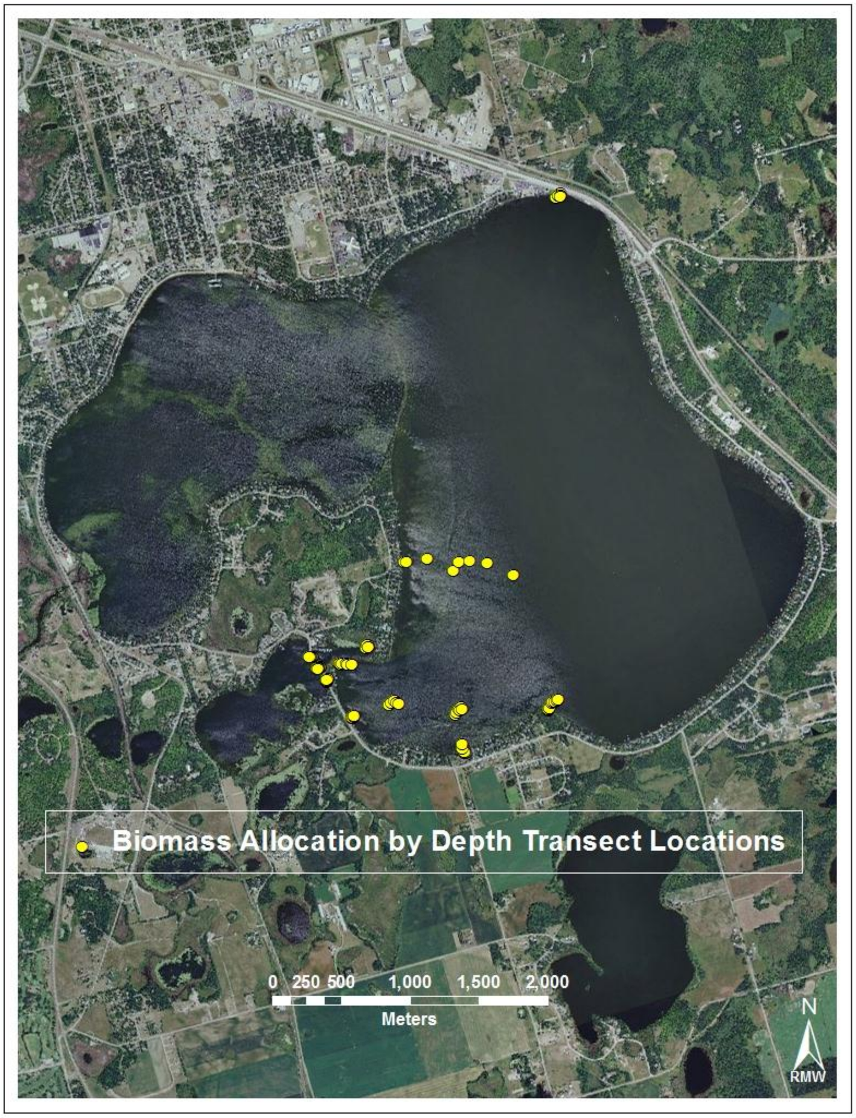

Figure 2. Locations of biomass by depth transect sample sites for 2011 in Big Detroit and Curfman Lakes.

Figure 3. Herbicide treatment plots for 2010 demonstration project. Plots were 1.25 acres in size. Plots were treated once, twice, or three times during the season, depending on treatment frequency, and each treatment type was replicated three times (in three plots) for a total of nine treatment plots. The phenology plots in Big Detroit, Little Detroit, and Curfman were used as untreated reference plots.

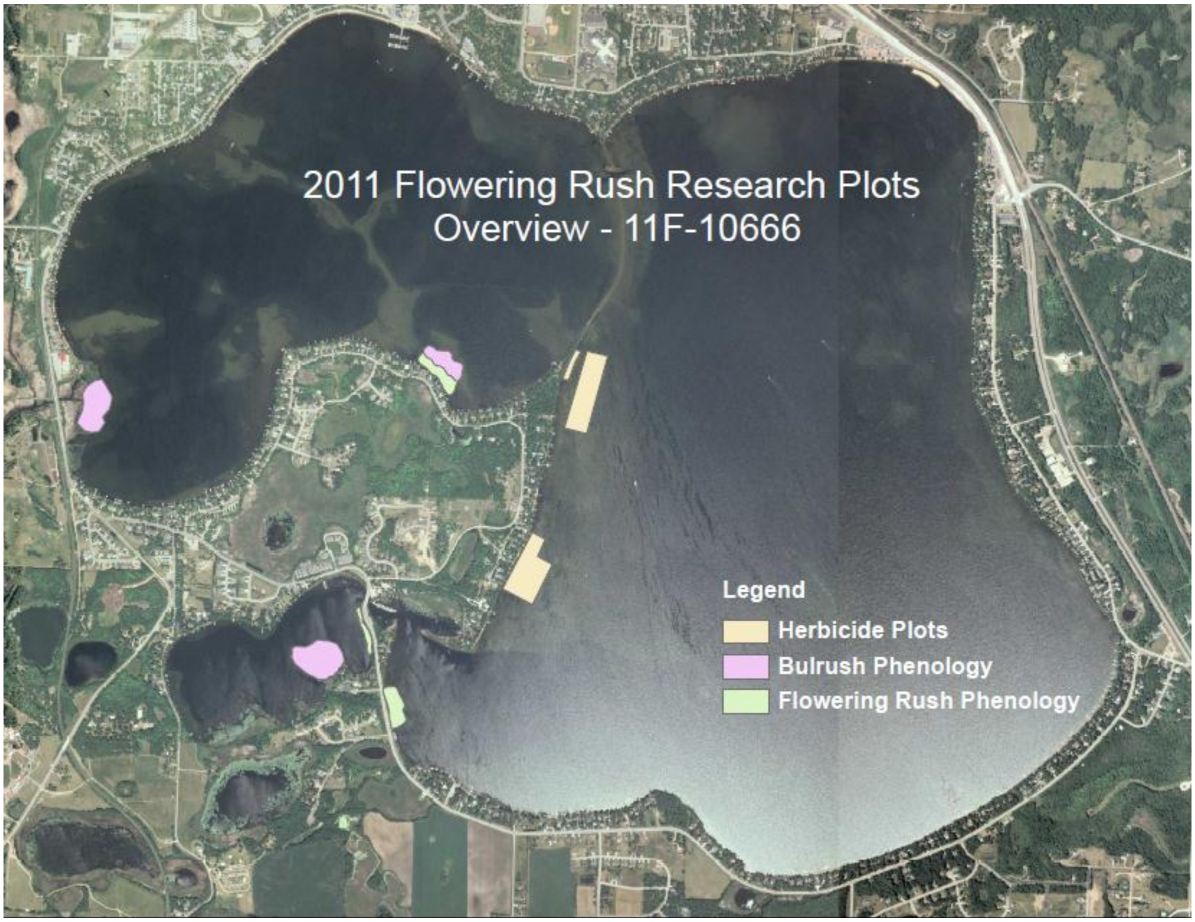

Figure 4. Herbicide treatment plots (tan) on Big Detroit Lake for 2011. The two large plots (10 acres) on the flats were treated with endothall, the two small plots (1 acre), one on the flats and one at the north end of Big Detroit Lake, were treated with diquat. The flowering rush phenology plots (lime green) on Big Detroit and Little Detroit Lakes were used as reference plots.

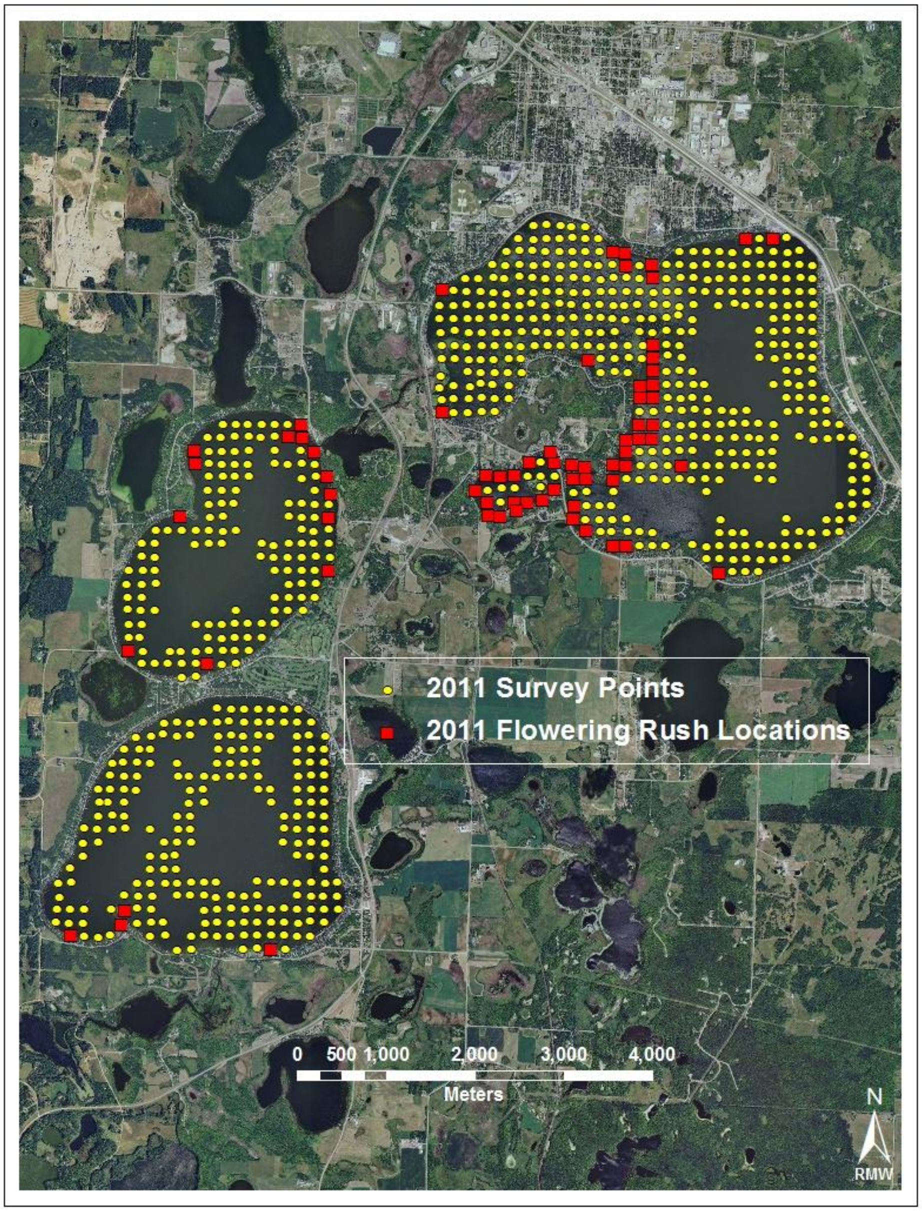

Figure 5. Flowering rush (*Butomus umbellatus*) locations in the Detroit Lakes from surveys in 2011.

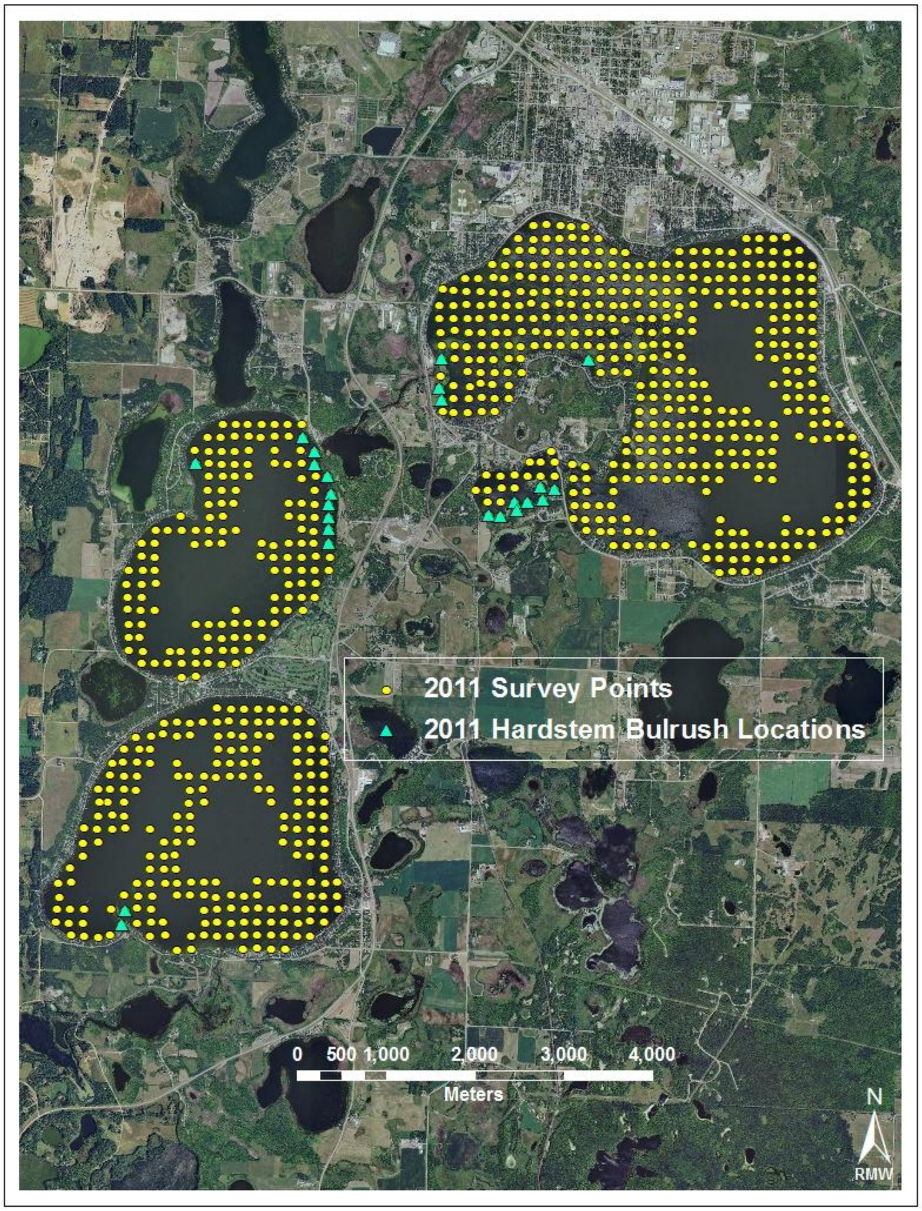

Figure 6. Hardstem bulrush (*Schoenoplectus acutus*) locations in Detroit Lakes system from a survey in 2011.

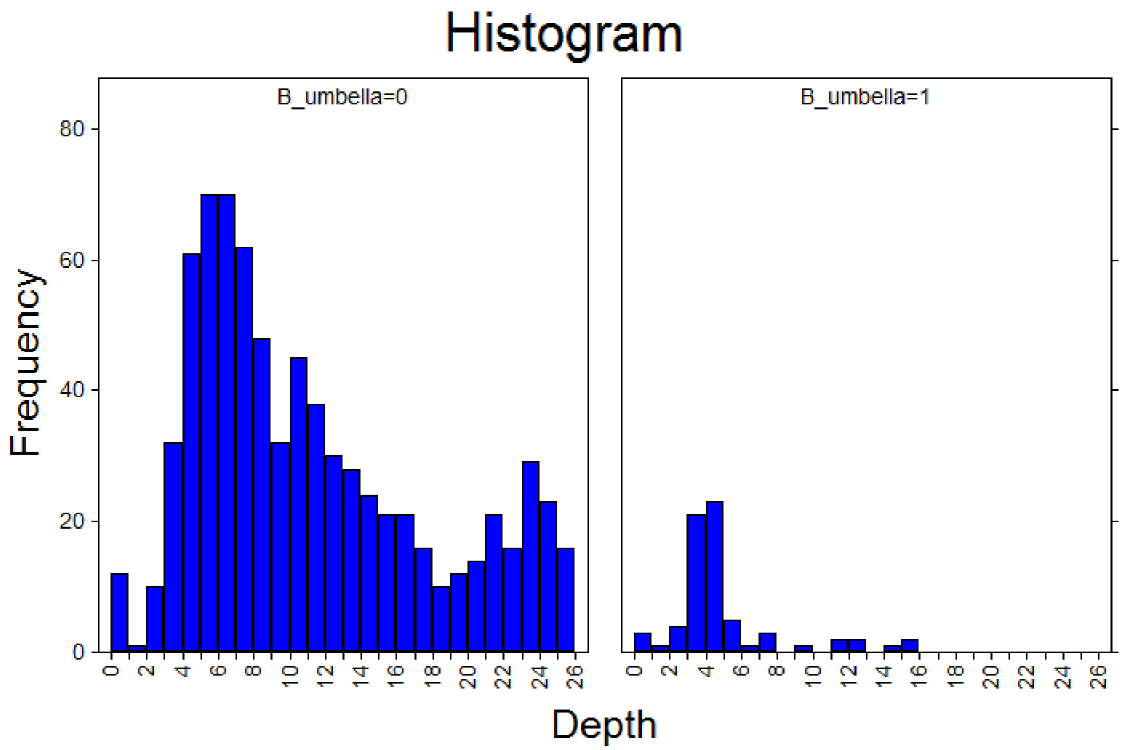

Figure 7. Frequency of points at which flowering rush (*Butomus umbellatus*) was absent (B_umbella=0) and for which flowering rush was present (B_umbella=1) for all five basins in the Detroit Lake system in 2011, by depth in feet.

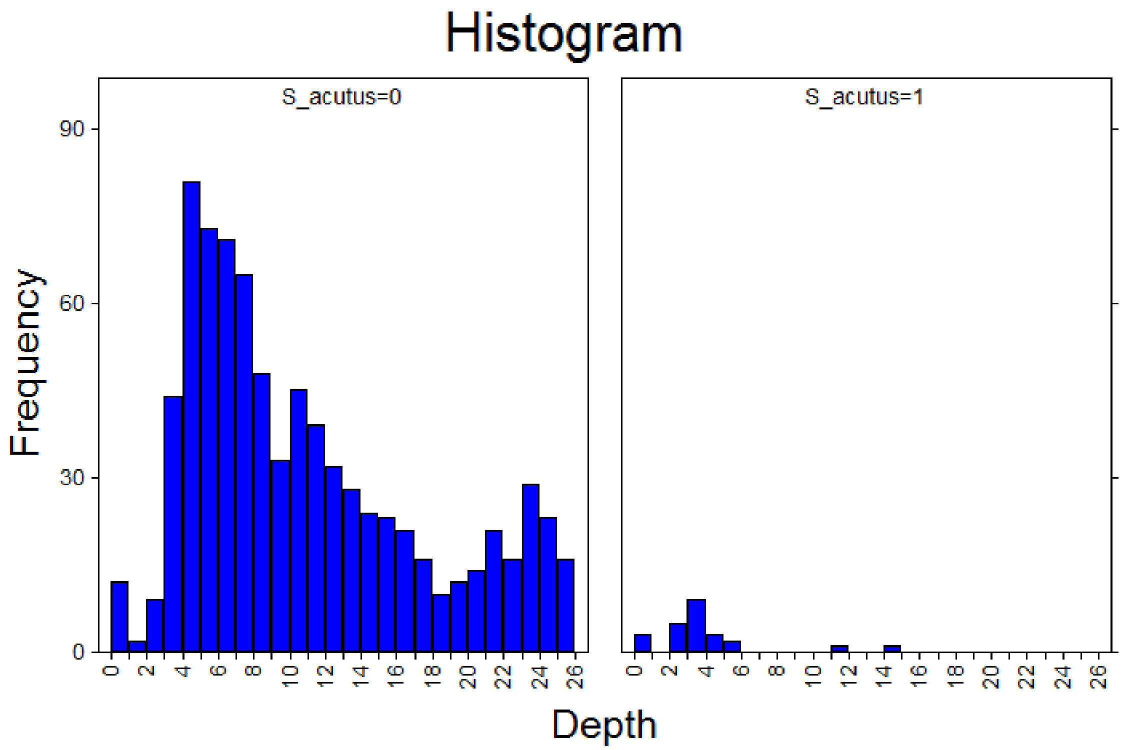

Figure 8. Frequency of points at which hardstem bulrush (*Schoenoplectus acutus*) was absent (S_acutus=0) and for which flowering rush was present (S_acutus=1) for all five basins in the Detroit Lake system in 2011, by depth in feet.

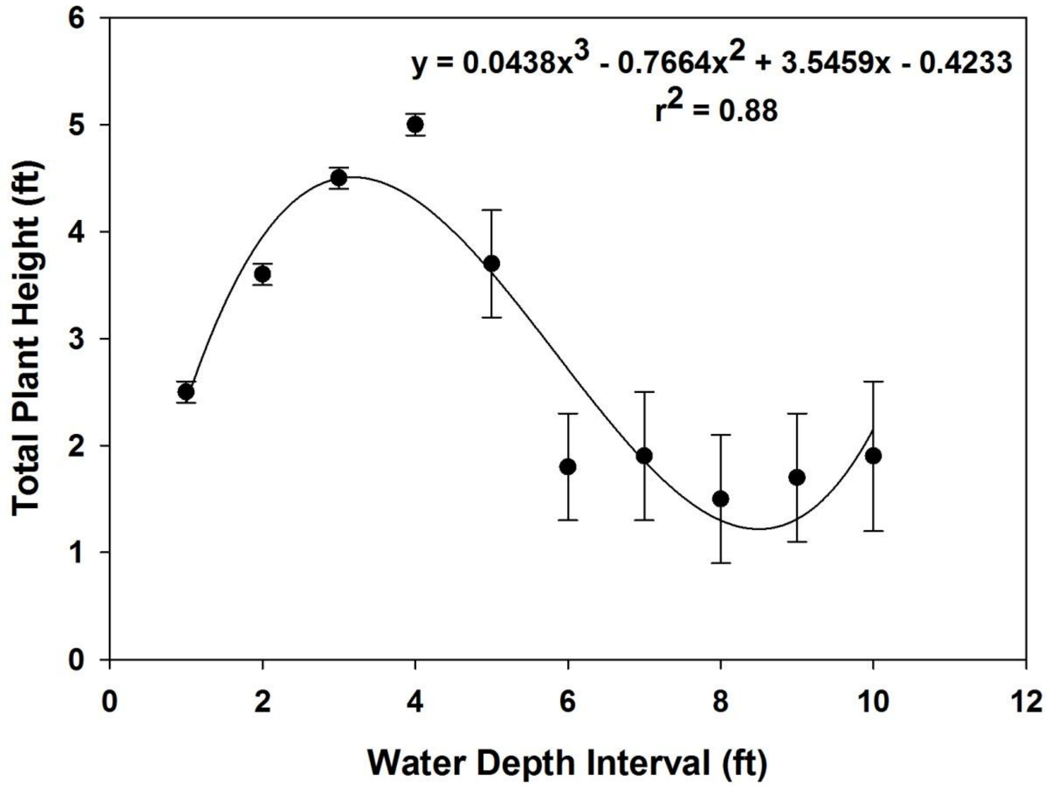

Figure 9. Flowering rush total (from bottom to tip of leaf) plant height (feet) by depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

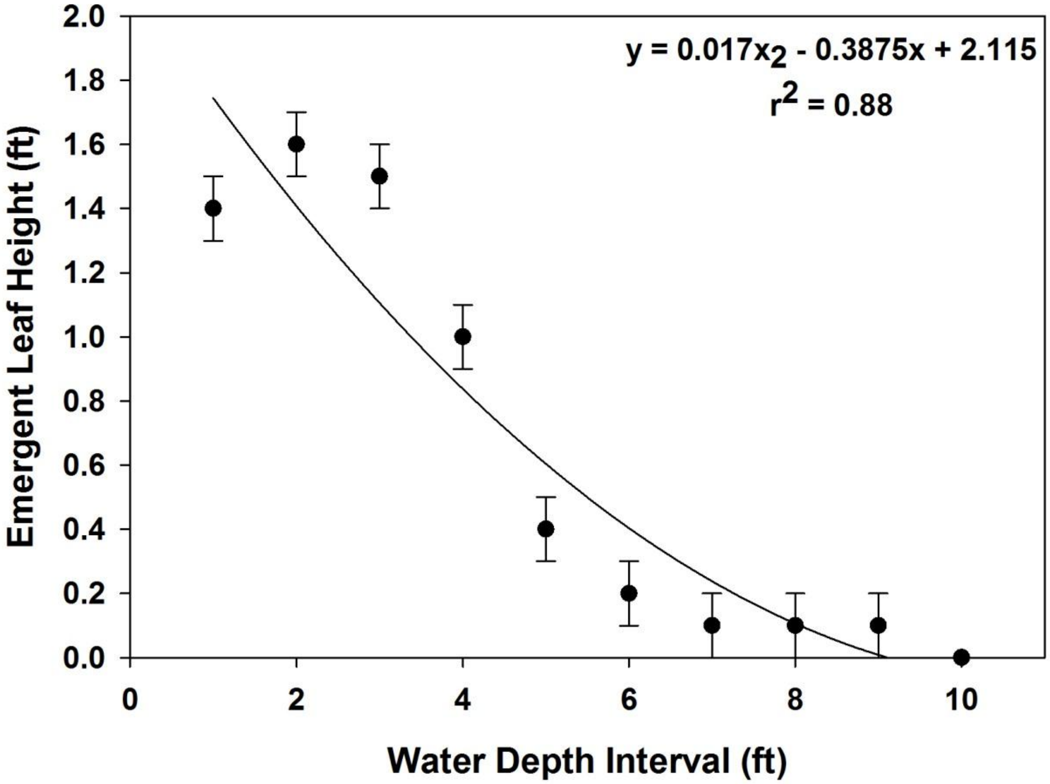

Figure 10. Flowering rush plant height (feet) above water surface ("emergent") by depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

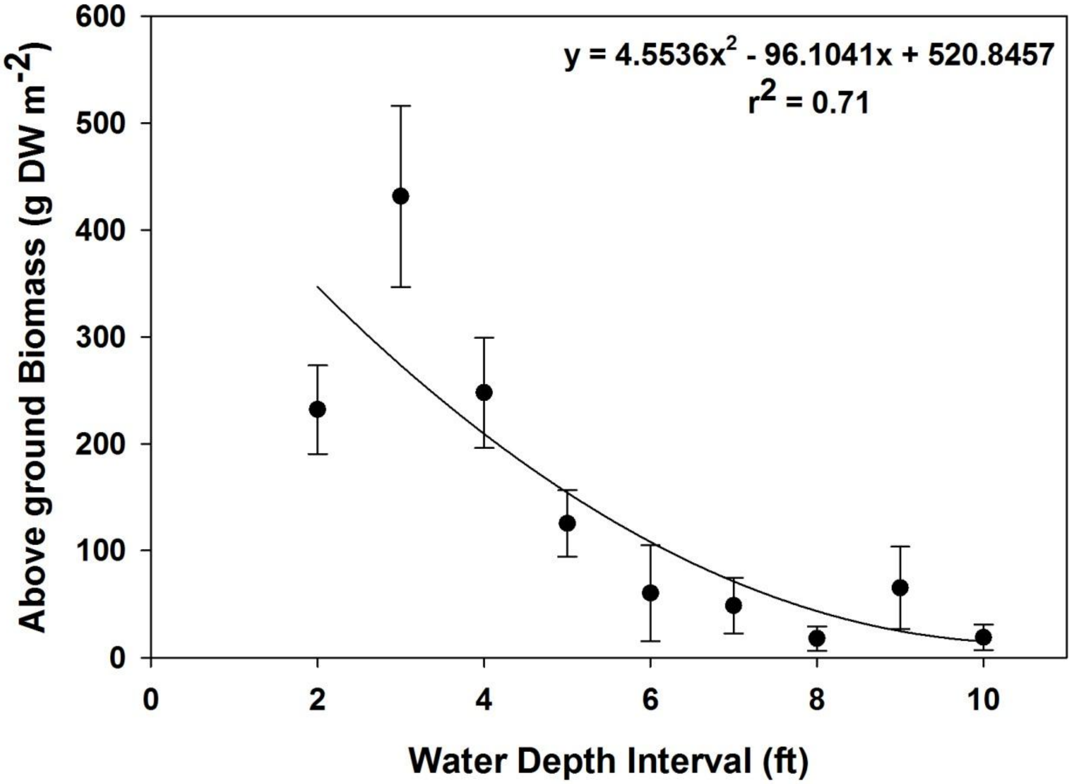

Figure 11. Flowering rush aboveground biomass (gDW / m^2) by water depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

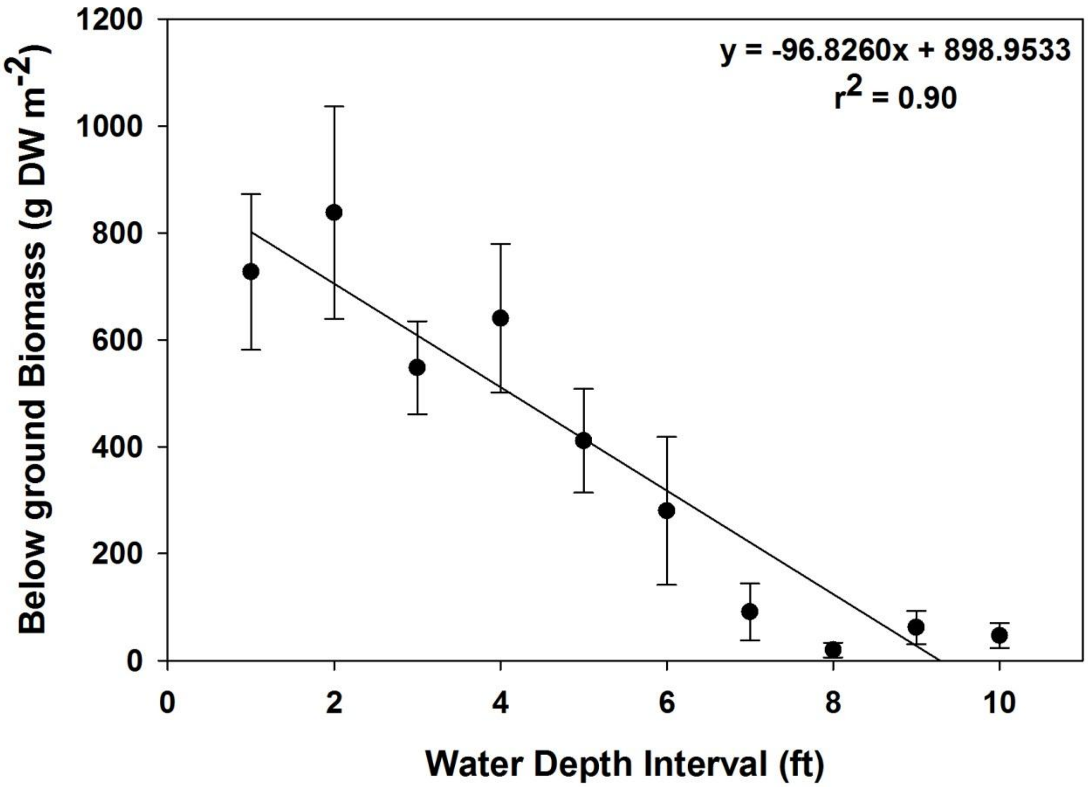

Figure 12. Flowering rush belowground biomass (gDW / m^2) by water depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

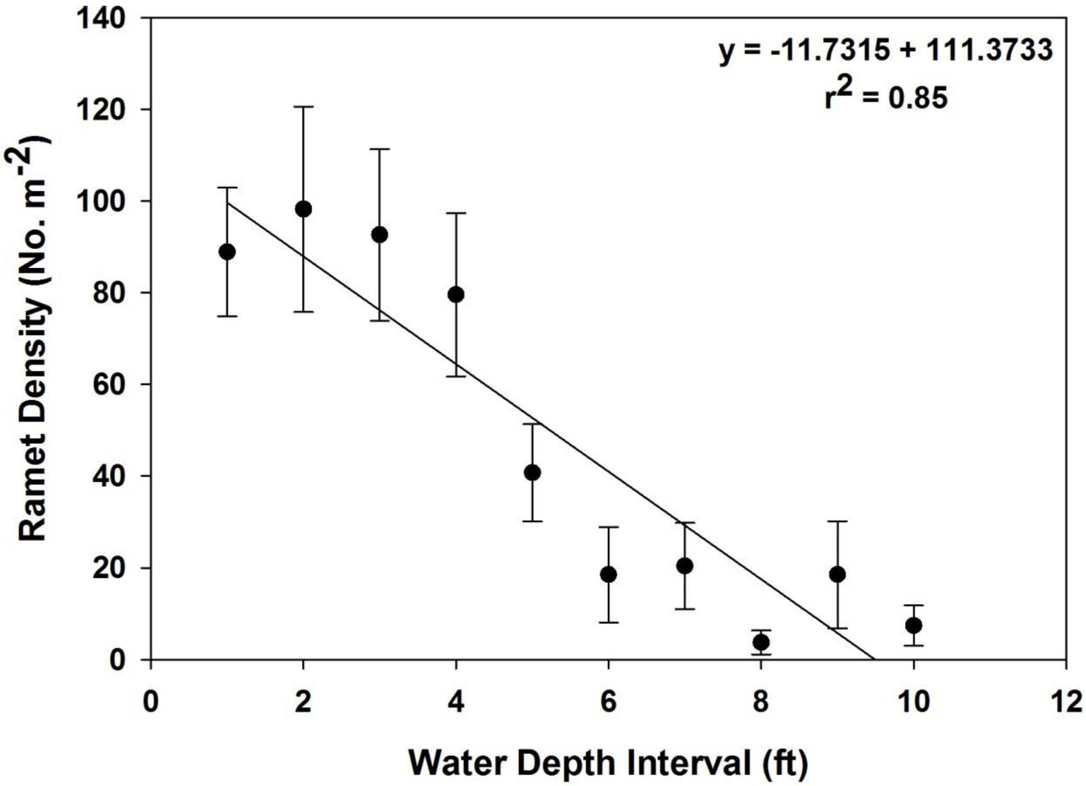

Figure 13. Flowering rush ramet density (N / m^2) for depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

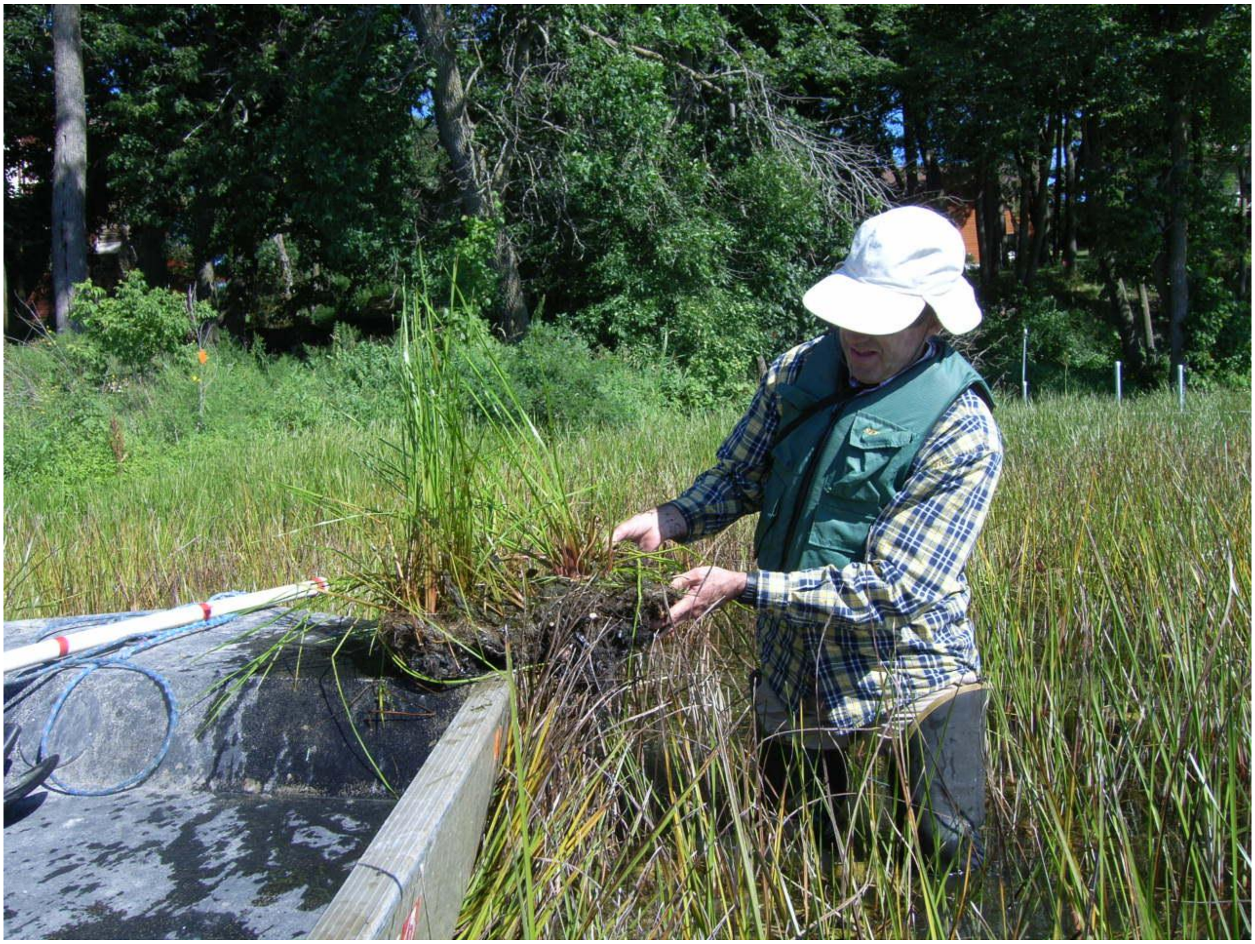

Figure 14. Chip Welling, Minnesota Department of Natural Resources, lifts a turf or mat section of flowering rush onto the front deck of our sampling boat in Curfman Lake in 2011. The rhizomes and roots grow so intermeshed that the plants form a virtual turf. Further out on this transect, the mat was suspended as a false bottom several feet above the original lake bottom.

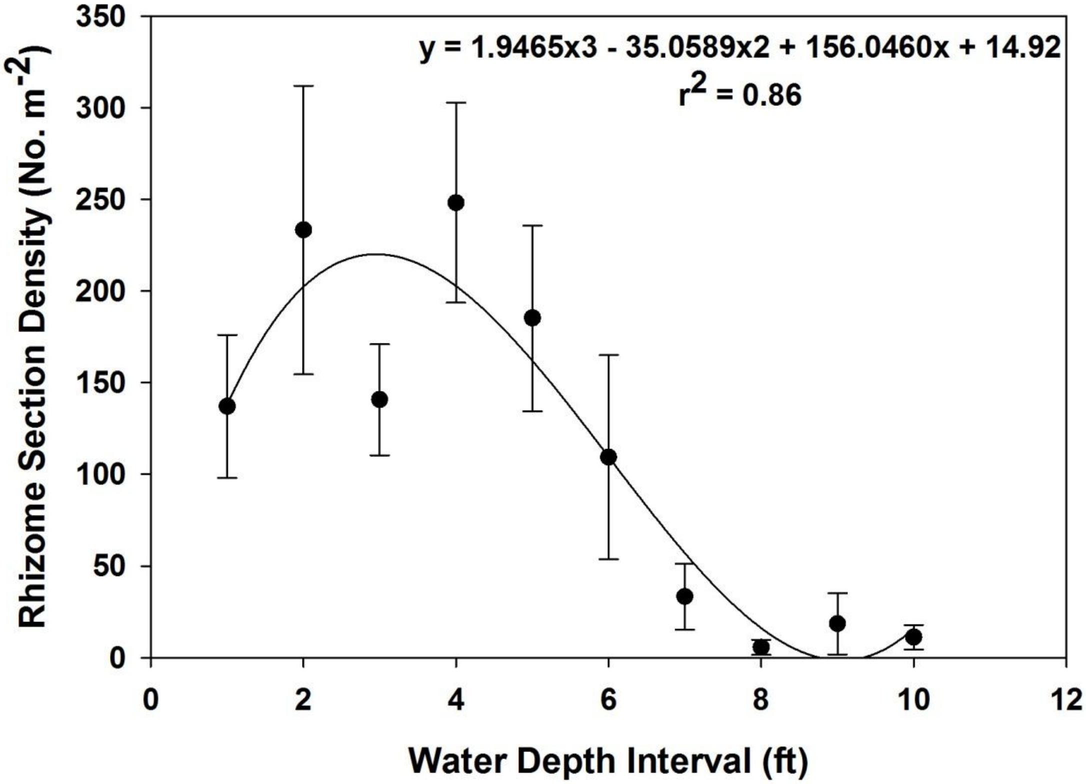

Figure 15. Flowering rush rhizome density (N / m^2) by water depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

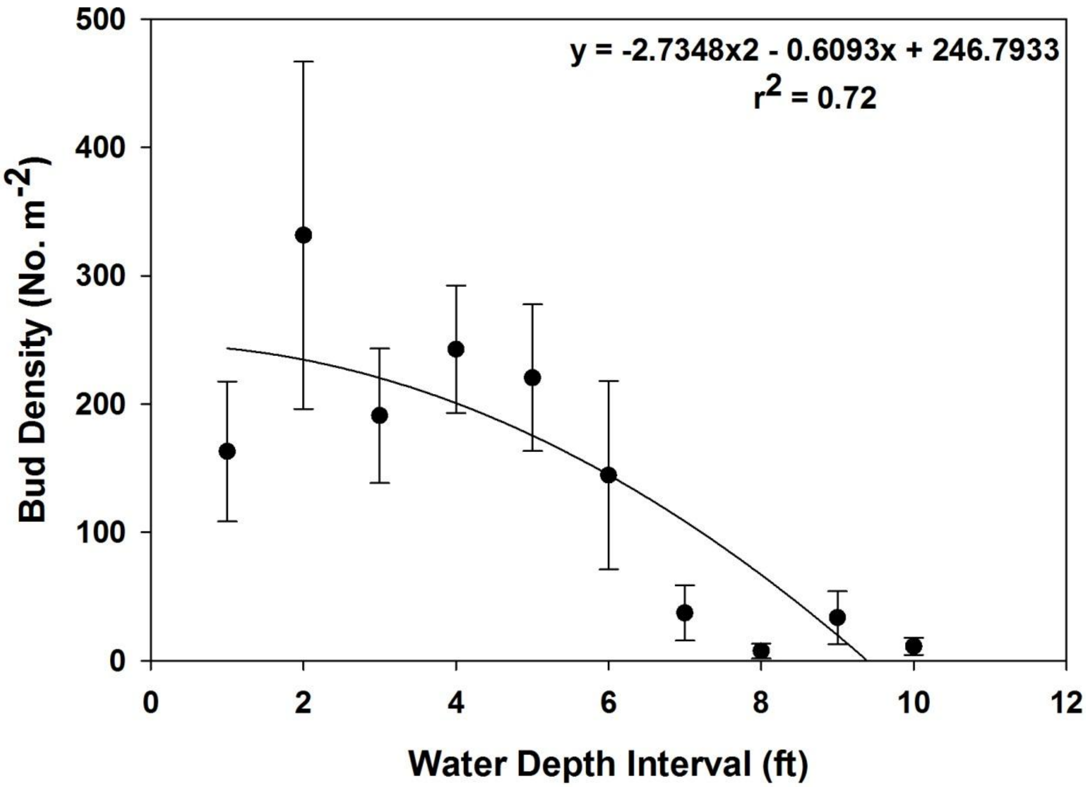

Figure 16. Flowering rush bud density (N / m^2) by water depth (feet) for biomass samples collected along depth transects in Detroit Lakes in 2011.

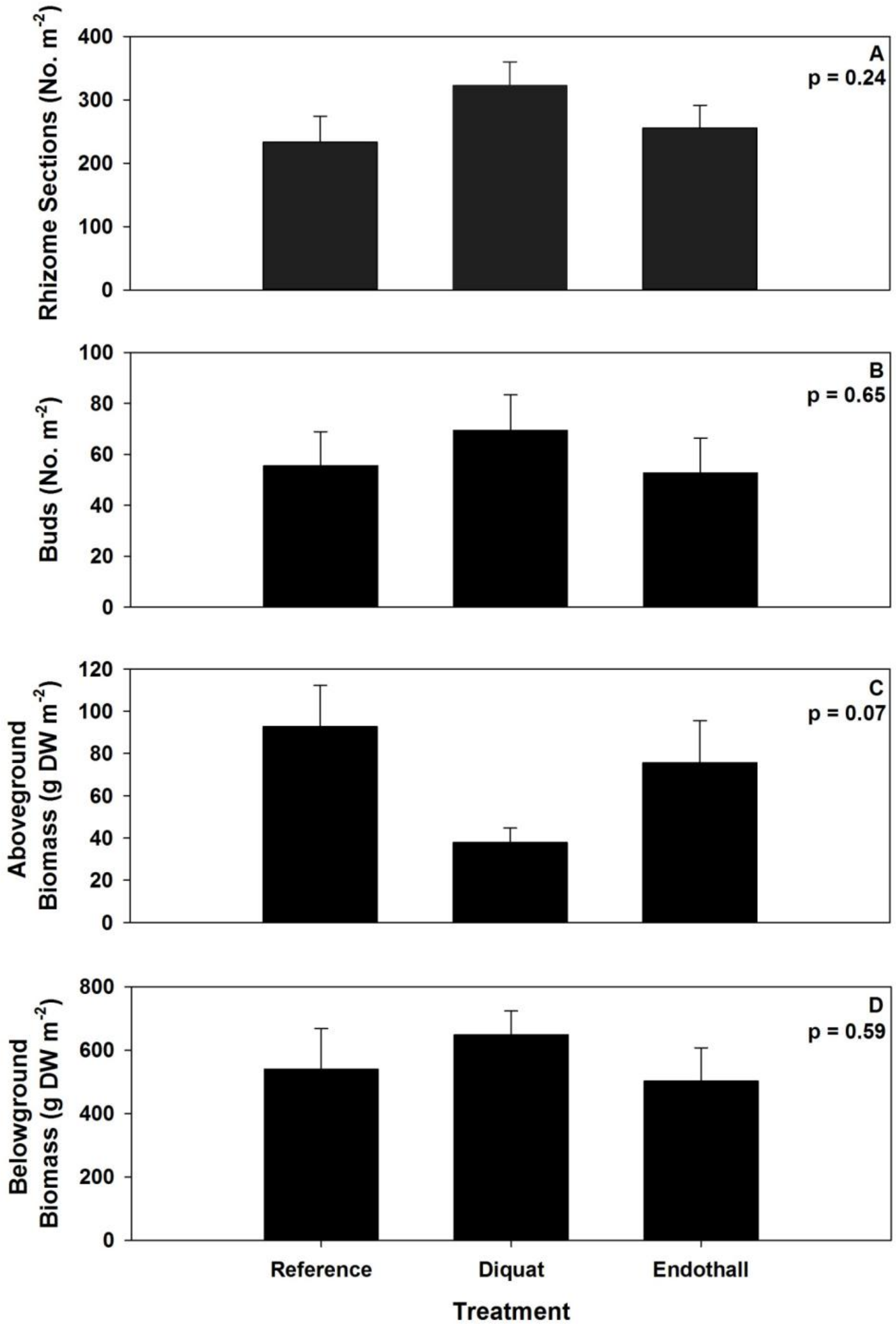

Figure 17. Pretreatment (June 2011) flowering rush biomass for reference, diquat, and endothall plots in Detroit Lakes: A., Rhizome sections (N/m^2); B., Bud density (N/m^2); C., Aboveground biomass (g DW / m^2); and D., Belowground biomass (g DW / m^2). P-value given for one-way ANOVA comparison between treatments.

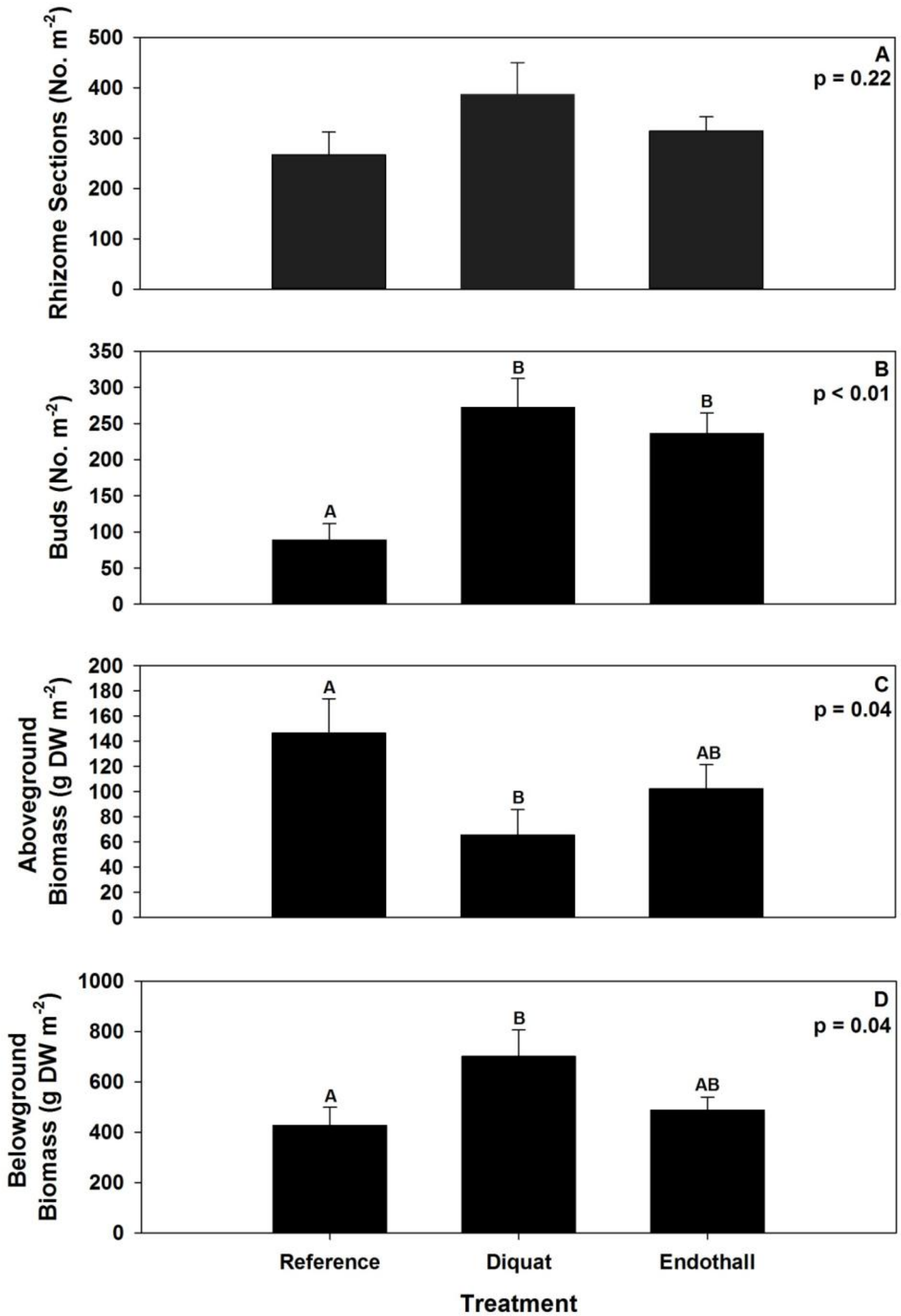

Figure 18. Four WAT (July 2011) flowering rush biomass for reference, diquat, and endothall plots in Detroit Lakes: A., Rhizome sections (N/m^2); B., Bud density (N/m^2); C., Aboveground biomass (g DW / m^2); and D., Belowground biomass (g DW / m^2). P-value given for one-way ANOVA comparison between treatments.

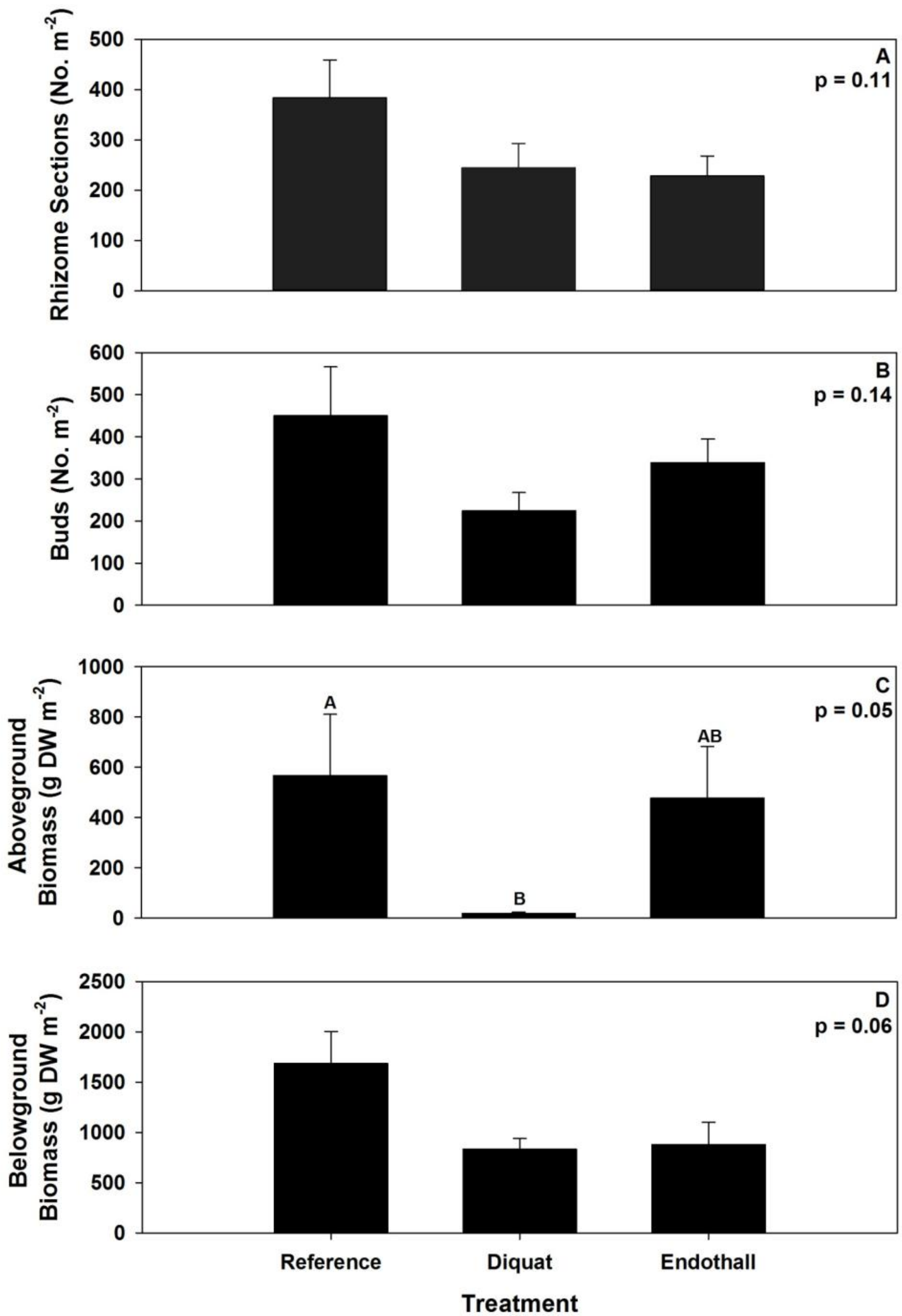

Figure 19. Eight WAT (August 2011) flowering rush biomass for reference, diquat, and endothall plots in Detroit Lakes: A., Rhizome sections (N/m^2); B., Bud density (N/m^2); C., Aboveground biomass (g DW / m^2); and D., Belowground biomass (g DW / m^2). P-value given for one-way ANOVA comparison between treatments.

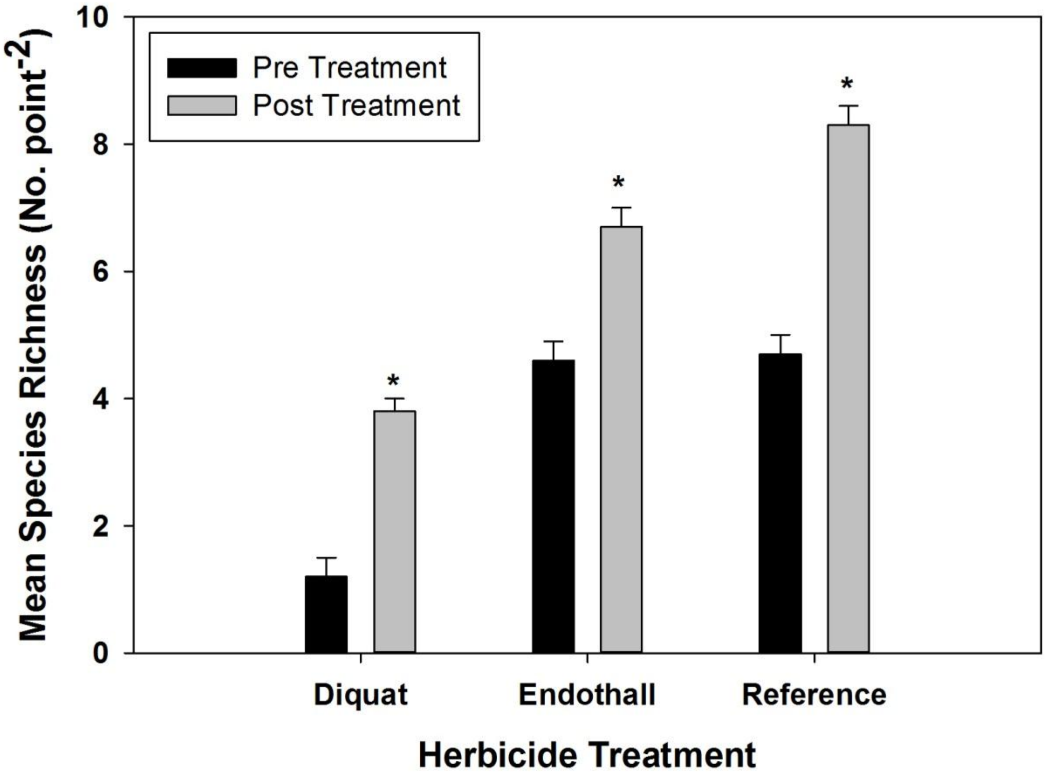

Figure 20. Total mean species richness for diquat, endothall, and untreated reference plots in Detroit Lakes for 2011. Black bars are pretreatment richness, and gray bars are eight weeks posttreatment values. Asterisk indicates a significant difference between post- and pre-treatment values. Y-axis label should read (Number/Point).

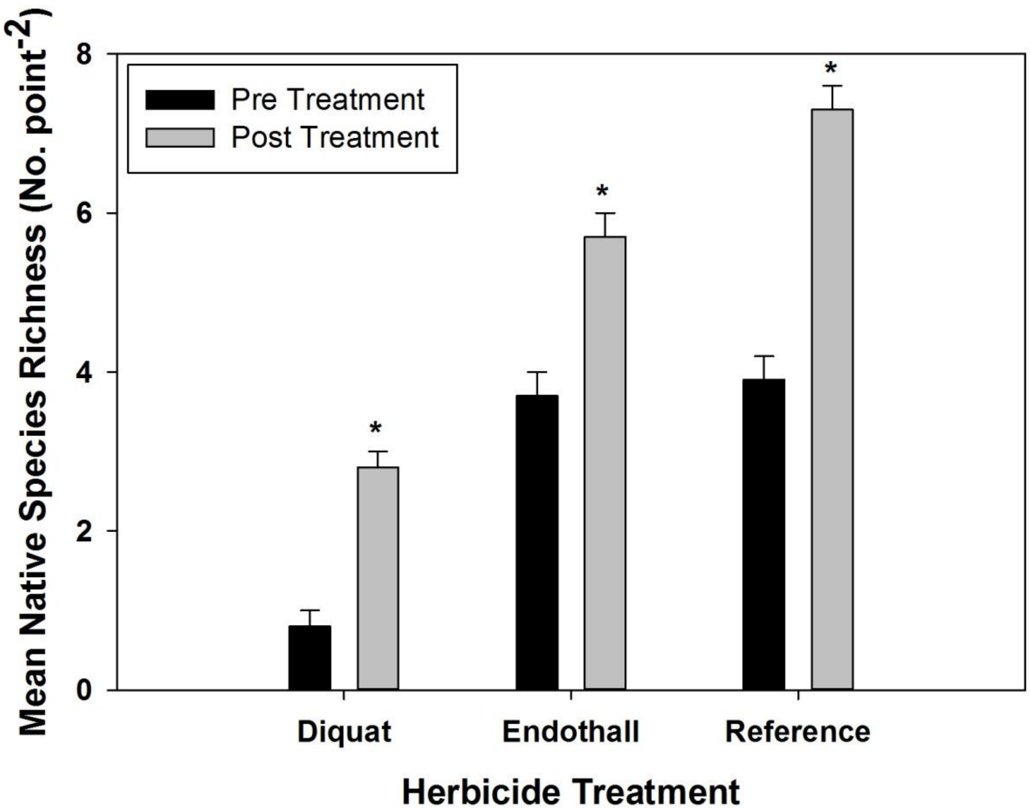

Figure 21. Mean native species richness for diquat, endothall, and untreated reference plots in Detroit Lakes for 2011. Black bars are pretreatment richness, and gray bars are eight weeks posttreatment values. Asterisk indicates a significant difference between post- and pre-treatment values. Y-axis label should read (Number/Point).