Ecology and Phenology of Flowering Rush in the Detroit Lakes Chain, Minnesota

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Abstract

Flowering rush, *Butomus umbellatus,* has been an increasing problem in the Detroit Lakes chain of lakes for more than 45 years. Flowering rush dominates ecosystems by crowding out native species including hardstem bulrush, *Schoenoplectus acutus*; a vital part of native ecosystems. Furthermore, flowering rush creates boating hazards and hampers recreational activities on the lakes. The phenological differences between flowering rush and the native hardstem bulrush were examined as part of a project determining the best management practices for controlling this invasive species. Biomass allocation, plant height, carbohydrate allocation and reproductive structures of flowering rush were examined in the Detroit Lakes system. Flowering rush and hardstem bulrush exhibited similar times of emergence, maximal growth and senescence,

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requiring careful management to protect the native species. Hardstem bulrush was

approximately one meter taller than flowering rush during mid-summer. Flowering rush

continually formed rhizome buds as its primary mode of reproduction and approximately one

15   bud per every two grams of rhizome, or 393 buds per m^2, were produced within the midst of a

flowering rush bed. This high density of rhizome buds may lead to further spread of flowering

rush as well as long-term treatment of this propagule bank. The number of leaves sprouting from

rhizomes was greatest in mid-summer in both 2010 and 2011. Throughout the sampling period

84% of the biomass of flowering rush plants was found below ground, indicating treatment

20   efforts will need to target a reduction of below ground material, potentially over several years.

Key Words: *Butomus umbellatus, Schoenoplectus acutus*, hardstem bulrush, invasive

macrophyte, phenology, carbohydrate analysis

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Introduction

Flowering rush (*Butomus umbellatus* L.) is an invasive species native to Eurasia and was

first discovered in North America in 1905 in Quebec (Les and Mehrhoff 1999). Flowering rush

30   has spread across the northern United States (Brown and Eckert 2005) and is a particular

problem in the Great Lakes area, Montana and Idaho. One region in Minnesota, the Detroit

Lakes Chain of Lakes, has been struggling with flowering rush for over 45 years as it has spread

through the chain of lakes since the 1960's. Since its introduction, different methods of

mechanical and chemical controls have been employed ineffectively.

35   Flowering rush is a perennial monocot from the Butomaceae family. The leaves of the plant are triangular in shape and vary in color from light to dark green. The leaves may be submersed or emergent. Both sexually reproducing diploid and asexually reproducing triploid varieties are found throughout the United States (Eckert et al. 2000) with the triploid form dominating the regions around Minnesota (Lui et al. 2005). New vegetative growth can occur

40   through primary rhizome fragmentation (Brown and Eckert 2005). The typical habitat of flowering rush is less than 1m, however, flowering rush is known to grow in water deeper than three meters (Hroudová 1989). Little has been previously reported about the preferred habitat of the plant, especially in northern lakes, or how those changes in habitat affect the growth pattern and spread of flowering rush. The relative allocation of biomass to above ground leaves,

45   hereafter AG, as well as to below ground material, hereafter BG, could impact its ability to spread, to compete with native vegetation and to withstand environmental fluctuations.

       Changes in global climate along with the growing human population will exacerbate existing stresses to freshwater resources (Shimoda et al. 2011). Climatic changes will affect the growth, phenology and geographical distribution of macrophytes and may limit the growth of

50   some species. Although it is unclear whether invasive plants are better able to thrive within introduced areas or survive equally well in all habitats (Parker et al. 2013), this additional competition may be detrimental to species diversity within aquatic habitats. It is also unknown whether climate change or invasive competitiveness (Wolkovich and Cleland 2011) will be more influential in the success of the native species in their annual interactions with the invasive

55   macrophyte species. Further understanding of the basic biology and phenology of invasive species in new environments is essential to the long-term control of the invaders.

       Phenological differences between invasive and native species may contribute to the

success of the invaders (Wolkovich and Cleland 2011). Phenological studies have assisted in coming up with treatment solutions for many other aquatic invasive plants including

60 alligatorweed (Weldon et al. 1968), curlyleaf pondweed (Woolf and Madsen 2003), Eurasian watermilfoil (Madsen 1997), hydrilla (Madsen and Owens 1998), waterhyacinth (Madsen et al. 1993), and waterchestnut (Madsen 1993). In this study the ecology of flowering rush was compared to that of the native hardstem bulrush (*Schoenoplectus acutus* (Muhl. Ex Bigelow) A. Löve & D. Löve) which is a species that occupies a similar ecological niche. Hardstem bulrush

65 is widely regarded by fisheries biologists as a significant habitat species in shallow littoral zones (Gardner et al. 2001). This phenological study also took place to determine the life history of flowering rush, especially in the northern region because little is known about its impact on native species in this region.

70 **Methods**

The Detroit Lake Chain of lakes is a series of lakes in northwestern Minnesota near the city of Detroit Lakes and includes Detroit Lake (1248 ha., 27.1 m. maximum depth), Lake Sallie (504 ha., 15.2 m. maximum depth), and Lake Melissa (741 ha., 13.1 m. maximum depth) (Table

75 1). Detroit Lake can be further subdivided into "Big Detroit" and "Little Detroit" which are partially separated by a sandbar, and "Curfman Pond", which is connected to "Big Detroit" by a channel (Wilcox 1907). The asexually reproducing triploid form of flowering rush is the variety that is currently plaguing the Detroit Lakes area (Eckert et al. 2000).

Water quality parameters were taken over the course of 2010 and 2011 using a Hydrolab

80 MS5 with Depth, Temperature, Conductivity, pH, Turbidity and dissolved oxygen sensors

(Hach, Inc., Loveland, Co). In 2011, thermistors were placed in Big Detroit Lake, Little Detroit

Lake, Curfman Pond, Lake Melissa, and Lake Sallie at docks located nearby the plot sites.

Additional water quality data was obtained from the Pelican River Watershed District. All

sampling sites remained above 80% oxygen saturation except for sampling in March of 2011,

85 where the oxygen content was approximately 55% below the ice. Data are summarized by site

for surface temperatures and oxygen content (Table 1, Figure 1).

Sampling started in May 2010, and continued through September 2011. Four phenology

plots were chose before the sampling began on the Detroit Lakes Chain; phenology plots were

located on the southeastern shores of Little Detroit, on the southwestern shore of Big Detroit, on

90 the eastern shore of Lake Sallie and on the eastern shore of Curfman Pond. Hardstem bulrush

plots were located on the southeastern shore of Little Detroit, the northeastern shore of Lake

Sallie, the southwestern shore of Lake Melissa and along the eastern shore of a shallow island in

the center of Curfman Pond. Two sampling strategies were employed throughout this study,

non-destructive and destructive, and sampling periods occurred every three weeks during the

95 summer and three times over the winter of 2010. Non-destructive sampling took place on the

flowering rush phenology plots and on four hardstem bulrush plots. During non-destructive

sampling, thirty flowering rush and twenty hardstem bulrush sites were measured for plant

height, leaf emergence out of water, and water depth.

Destructive sampling, or biomass sampling, was done using a 0.1524 m diameter coring

100 device constructed of PVC pipe and/or metal pipe to suction plant mass up from the ground

(Madsen et al. 2007). Plants were washed in the field, then more thoroughly back at the lab.

The majority of samples were collected in the dense part of the flowering rush beds at depths of

1-2 m. Plants were separated into AG and BG biomasses. For each sample collected, rhizome

buds, leaves, and ramets were counted and recorded. A flowering rush ramet is a single section

105   of leaves growing from a rhizome. There may be several ramets per rhizome. Wet weights were

recorded for AG and BG biomasses for each sample. The separated samples were then dried in a

forced air oven (60 °C) or lyophilized. Dry weights were then recorded and the samples were

ground into a fine powder using a blender and Wiley mill, mesh #60, for carbohydrate analysis.

Both starch and sugar samples were double extracted with a methanol, chloroform, and

110   formic acid solution. Soluble sugar standards were made using glucose. Starch standards were

made using potato starch and glucose. Carbohydrate concentrations were determined using a

spectrophotometer at λ=422 nm for both sugars (Gent 1984) and starch (Gent 1986).

Mean values for all parameters were found for each site at each lake. Data were tested

for normal distribution (K-S test or Shapiro-Wilk test) and variance homogeneity (Levene's test).

115   Extreme outliers were removed. A square root transformation was performed with carbohydrate

data that did not meet the tests for normality and homogeneity. For nondestructive sampling

variables: plant height and plant height above water; species, sampling date (date), and their

interaction term were used as explanatory variables in the 2-way ANOVA. The percentage of

plants that had emergent leaves was analyzed by logistic regression using a Poisson distribution

120   with species and date as explanatory variables. For destructive sampling variables, data were

averaged by site and analyzed using a one-way ANOVA with date as the explanatory variable.

Dry mass of plant material were used in all analyses. Response variables assessed were ramets

per m^2, ramets per g DW BG, buds per g DW BG, buds per m, leaves per m, buds per ramet,

buds per leaf. In order to determine the role of temperature and plant growth, we ran a linear

125   regression to compare water temperature with plant biomass. Square-root transformed

carbohydrate response variables, starch and sugar content were analyzed using a 2-way ANOVA

with plant part (type) and year and type by year as explanatory variables. Significant differences

were reported at α ≤ 0.05.

130   **Results and Discussion**

Hardstem bulrush and flowering rush followed very similar seasonal growth patterns. Both

plants emerged at the same time in May, reached their peak height in mid-summer and senesced

in the fall. Hardstem bulrush was approximately 1 m taller than flowering rush for a majority of

135   the growing season (Figure 2). Throughout the growing season hardstem bulrush had a

significantly higher percentage of leaf emergences (date: P<0.0001; species P<0.0001).

Flowering rush senesced below the water surface up to one month before hardstem bulrush

(Figure 2). Plant height above or below the water surface was significantly different by species,

date and their interaction term (species: df=1, F=91.17, P<0.0001; date: df=17, F=22.90,

140   P<0.0001; species by date: df=16, F=5.00, P<0.0001). There was a lower percentage of

flowering rush emergent compared to hardstem bulrush in 2010 and 2011; likely due to seasonal

variation.

Rhizome buds are the primary mode of reproduction for the triploid form of flowering

rush. Total bud production in the Detroit Lakes chain was generally very high within the 1-2 m

145   depth range with an average of 393 ± 22 buds per m^2. Rhizome buds were in their highest

density per m^2 in mid-summer and winter, however these differences were not significant (date:

df=17, F=1.17, P=0.1) (Figure 3). Bud size was not measured; therefore, high values may reflect

the early stages of bud production or buds nearly ready to leaf out and become separate plants.

Peak leaf and ramet production in mid-summer corresponded with the rhizome bud abundance,

150   indicating that mid-summer is when rhizome buds become large enough to produce separate

plants (leaf: df=6, F=7.78, P=0.0003; ramets: df=17, F=4.11, P<0.0001) (Figure 3). Because

plant density varied throughout a bed, we also compared bud production relative to BG biomass

and number of leaves. One rhizome bud was produced for every 2 g DW BG biomass (0.504 ±

0.037 buds per g DW BG biomass;) or 3 buds for every 2 leaves (1.52 ± 0.276 buds per leaf).

155   Variation in rhizome bud per g DW BG biomass and rhizome bud per leaf was observed over the

study period (buds per g DW BG: df=17, F=2.34, P=0.0104; buds per leaf: df=17, F=1.95,

P=0.0387).

        Height of flowering rush and hardstem bulrush above the water surface was positively

correlated with water temperature (flowering rush: F=44.3, P<0.0001; hardstem bulrush: F=43.0,

160   P<0.0001) (Figure 4). Plants remained emergent into the fall even when water temperatures

cooled. Based on this model of temperature and emergence time, hardstem bulrush emerged

from water at 16.5 °C, whereas flowering rush emerged when the water temperature reaches 21.5

°C. A more accurate model of degree days is needed before this trend could be considered a rule

by which to manage the plants.

165   Some significant differences were observed with DW AG biomass by date (df=17,

F=22.25, P<0.0001). As expected, AG biomass was highest over the summer and absent over

winter collections (Figure 3). DW BG biomass was found to be largely consistent throughout the

year (df=17, F=0.95, P>0.1) (Figure 3). On average, 84% ± 0.027 of the total biomass was

found to be BG biomass, with some variation by date (df=17, F=4.55, P<0.0001).

170   Biomass of AG material increased as the temperature increased (temp: F=13.7,

P=0.0005), but there was no relationship between BG biomass and temperature (P>0.1). The

positive relationship between temperature and leaves reflects the growth that occurred during the

summer. The absence of a relationship between temperature and BG biomass reflects the continually high biomass present in rhizomes that alters little with seasonal changes.

175   Starch content was significantly different by type (plant part), year and day by year (type: $df=3$, $F=7.72$, $P<0.001l$; year: $df=1$, $F=5.94$, $P=0.0156$; day by year: $df=1$, $F=10.84$, $P=0.0012$). Below ground rhizomes had significantly more starch than AG leaves. The low points in starch content occurred during late summer in both years, which may indicate an optimal time for treatment because this would be when plants have their lowest energy reserves (Figure 5).

180 Glucose content differed by plant part, year and day by type (part: $df=3$, $F=7.27$, $P<0.001$; year: $df=1$, $F=8.91$, $P=0.0032$; day by type: $df=3$, $F=3.48$, $P=0.0168$). As expected, glucose content peaked in early spring in AG and BG biomasses, indicating translocation from rhizomes. This trend was expected from the rapid spring growth occurring as photosynthesis supplied the growing plants with needed energy. AG biomass is found to have more glucose present

185 compared to BG biomass.

        In conclusion, flowering rush is well established in the Detroit Lakes Chain of Lakes in dense beds. These beds are characterized by dense mats of flowering rush rhizomes that may consist of more than 800 g per m^2. Rhizome buds are the primary mode of reproduction for this triploid form, producing one bud for every 2 grams of rhizome. Notably, buds are abundant

190 throughout the year, even below the ice, indicating a ready supply of new propagules each year and a need for long-term control. More work is needed to determine when rhizome buds become separate plants. However, bud separation likely occurs in mid-summer when ramet and leaf number is maximal. Further research is needed to determine which control options most successfully minimize the production of buds. Control options should seek to prevent the

195 establishment of new plants. Finally, we avoided destructive sampling of hardstem bulrush in

order to prevent damage to this valuable ecological resource. However, a sampling regime of

hardstem bulrush that includes a minimum of destructive sampling may provide for some better

comparisons regarding AG and BG biomass allocation and may provide more information

regarding when hardstem bulrush is least susceptible to herbicide treatments.

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Acknowledgements

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Figure 1. Averaged surface temperature (̊C) and dissolved oxygen content (mg/L) of Big

Detroit, Little Detroit, Curfman Pond, Lake Sallie, and Lake Melissa over 2010 and 2011.

Samples were taken in hardstem bulrush and flowering rush (plots) and in a nearby deep site

within each lake. Thermistor temperatures were taken at nearby docks.

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Figure 2. Mean (± 1 standard error) height above water for flowering rush and hardstem bulrush

for sampling periods in 2010 and 2011.

Figure 3. Mean (± 1 standard error) values of flowering rush dry BG biomass per m^2 (A), dry

AG biomass per m^2 (B) , number of buds per m^2 (C), ramets per m^2 (D) and leaves per m^2 (E)

produced in 2010 and 2011. Data are averaged over Big Detroit Lake, Little Detroit Lake,

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Curfman Pond and Lake Sallie. The majority of samples are from depths of 1-2 meters.

Figure 4. Regression of flowering rush and hardstem bulrush plant heights above the water vs.

water temperature are presented for spring and summer data.

Figure 5. Mean percentage of dry weight (± 1 standard error) starch content in AG and BG plant

material. Low points in starch content appear during late summer both years.

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