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Assessing the effects of climate change driven decreases in Great Lakes water levels on the distribution of three-square bulrush (*Schoenoplectus pungens*) in Cecil Bay, Michigan.

Abstract

Since the year 2000, Great Lakes water levels have been abnormally low, and they are projected to continue decreasing. Great Lakes coastal wetlands are particularly vulnerable ecosystems to water level decline because wetland plants that typically grow in standing water become subject to dry conditions. Three-square bulrush (*Schoenoplectus pungens)* is one of the few emergent wetland plants that can tolerate deep water, and it plays important roles in attenuating wave energy, retaining sediment, and providing habitat for many fish and bird species. The ability of three-square bulrush to remain an emergent plant with water level decline was evaluated by analyzing the relationship between rhizome growth and water level, and by comparing annual growth rate to projected future water level decreases in the Great Lakes. Rhizomes appear to grow more when they are dry than when they are submerged, and rhizome growth appears to be particularly strongly suppressed by high water levels in May. Assuming maximum rhizome growth rate, three-square bulrush will very likely not be able to keep up with projected water level decline in the future. This can result in ecosystem-wide consequences and predominantly threaten organisms that are exclusively dependent on emergent wetland vegetation.

Introduction

Water levels in the Great Lakes can fluctuate over a meter from year to year, causing corresponding changes in plant community, plant structure, and nutrient availability (Hanrahan et al. 2010). Although Great Lakes water levels have been changing for thousands of years, they are currently experiencing a period of decline that corresponds to climate change model predictions. In the past ten years, the water levels of Lakes Michigan, Huron, and Superior have been consistently lower than average (IJC Report 2009). The authors of the International Joint Commission study point to climate change as one of the major causes of this decline. Higher air and water temperatures and less winter ice coverage cause more evaporation over the Great Lakes, resulting in a decrease in precipitation within the Great Lakes basin and a consequential decline in water levels (IJC Report 2009). Another factor that is thought to have significantly contributed to the drop in water levels is the dredging of the St. Clair River, the primary outflow of lakes Michigan and Huron. Heavy dredging of this riverbed has increased erosion at the bottom of the river and has led to a permanent water level drop of 16 inches from Michigan and Huron's long-term average (Mier et al. 2011).

Great Lakes coastal wetlands are shoreline ecosystems and are therefore particularly vulnerable to declining water levels. For example, emergent wetland plants that typically grow in standing water become exposed to dry conditions as the water level recedes. Also, drops in water levels lead to newly exposed, moist sediment, which has been shown to be rapidly colonized by invasive species such as *Typha* x *glauca* (hybrid cattail), T. *angustifolia* (narrow-leaf cattail), *Phragmites australis* (common reed), and *Lythrum salicaria* (purple loosestrife) (Lishawa et al. 2010). Therefore, wetlands that experience water level decline are assumed to be more vulnerable to their invasion. Undisturbed wetlands play many important roles in ecosystems. For example, they attenuate wave energy to buffer the upland shores from large waves and erosion, provide habitat for many plant and animal species, and purify water by absorbing nutrients (Galatowitsch et al. 1999). One wetland plant that is of particular importance is three-square bulrush (*Schoenoplectus acutus).* It is among a small number of emergent wetland plants that can tolerate deep water, and it typically grows in the emergent zone where there is less plant diversity compared to the shallower, more protected inner marsh (Albert et al. 2013). In the emergent zone, three-square bulrush plays important roles in attenuating wave energy, retaining sediment, and controlling erosion. It also provides spawning habitat for many fish species and habitat for songbirds and waterfowl (Jude et al. 2005, Albert 2003). Three-square bulrush reproduces both clonally, from a below-ground rhizome that produces one vertical stem annually, and sexually from seeds. The annual length of horizontal rhizome growth can be determined by measuring the internode length (the distance on the rhizome between two stems). Three-square bulrush has shown to reproduce mainly by rhizome expansion and rarely by seed establishment in both brackish and fresh-water environments (Giroux and Bédard 1988, Albert et al. 2013). Horizontal growth of the rhizomes typically occurs in May, June, and July of each year (Albert et al. 2013).

At Cecil Bay, the Voss wetland transect was established in 1971 and runs 200m from E. Wilderness Park Drive into Lake Michigan. The water levels and plant distributions along this transect have been sampled annually through 2003. Data from the transect show three-square bulrush to be a dominant emergent plant in this wetland. These data also show that since 2000, the water levels have been low, and three-square bulrush has expanded its range out towards the water during that time. By 2012, the bulrushes had expanded farther out towards the lake than had ever been recorded.

In this study, I investigate whether rhizome growth is correlated with water level. Specifically, I ask: is annual rhizome growth correlated with water level during the growing season? If so, do water levels in any particular month appear to affect rhizome growth most strongly? Lastly, given climate change predictions of future water level decreases, can three-square bulrush grow fast enough to remain an emergent plant in Cecil Bay?

Materials and Methods

Sampling was conducted at Cecil Bay, near Wilderness State Park (Figure 1), along the (extended) Voss transect to 260m, which was the distance to Lake Michigan's water's edge on June 30, 2013. A 100m transect was laid down roughly perpendicular to the historic Voss transect at the 257m mark, which was the outermost extent of three-square bulrush along the Voss transect in June 2013 (Figure 2). A random number generator was used to identify ten different locations along the transect, and the three-square bulrush plant closest to each random location was sampled. If there was no plant within a 1m radius of the location, a new location was randomly generated. Plants within 5m of the Voss transect were not sampled, as to not disturb this transect. Once a plant was located for sampling, a trowel and shovel were used to dig into the substrate and uproot the entire plant, including the rhizomes (Figure 3). Ten plants were collected from this transect.

Plants were brought back to the lab, where they were examined to determine their age. The age of each plant, along with characteristic rhizome diameters indicate when and how it established, under the assumption that the plant produces one stem each year. The internode lengths of each plant were measured and recorded.

A CST/Berger LM30 Rotary Laser Level was used to measure the elevation difference between the water level at the lake edge and the landward extent of each plant's rhizome. These data were used to determine the minimum water level necessary to completely submerge each rhizome. These values were then compared to the NOAA water levels of each day in May, June, and July for each year to determine the number of days during each growing season that the rhizome was either submerged, dry, or uncertain (partially submerged).

IBM SPSS Statistics (Version 21) analytics software was used to run linear regressions, comparing the internode length for each year of each rhizome against the number of days a rhizome was submerged or dry in May, June, July, or all three months combined. The same program was then used to run paired t-tests, comparing the r^2 values of the linear regressions.

To estimate potential future Great Lakes water levels, three future climate change scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC), were considered. The B1, A1B, and A2 scenarios represent relatively low, moderate, and high emissions, respectively (Angel and Kunkel 2010). The laser level was again used to measure the bathymetry of Cecil Bay along the extended Voss transect from 200m to 480m. Using the bathymetry data, the GLERL future Great Lakes water level predictions were estimated as distances along the Voss transect. The predicted extent of three-square bulrush along the Voss transect was determined by using the maximum recorded growth of 34cm per year.

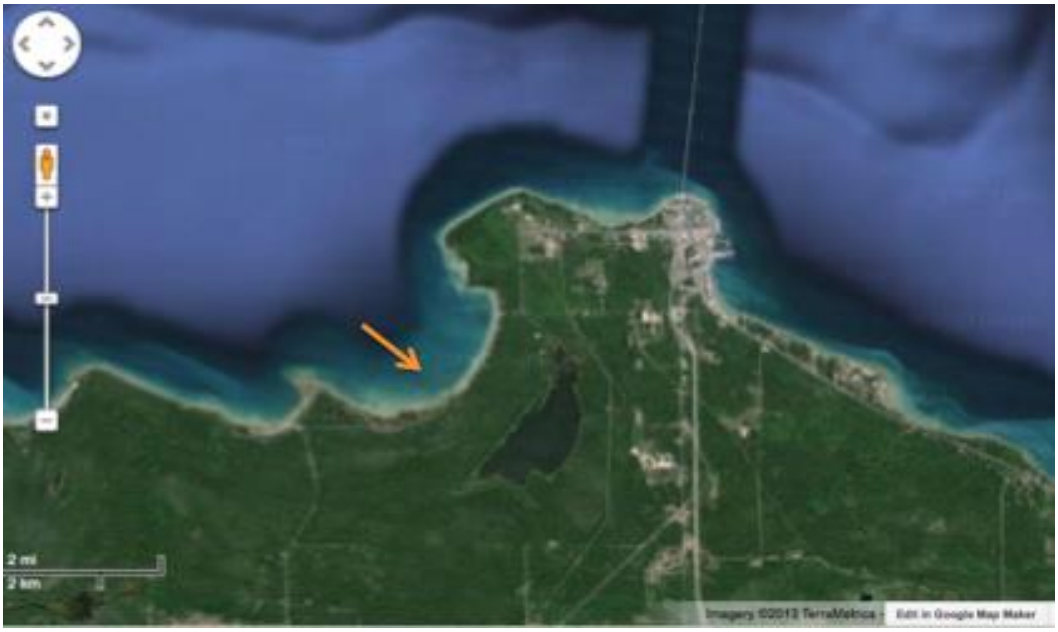

Figure 1: The sample site, Cecil Bay, is marked with the orange arrow.

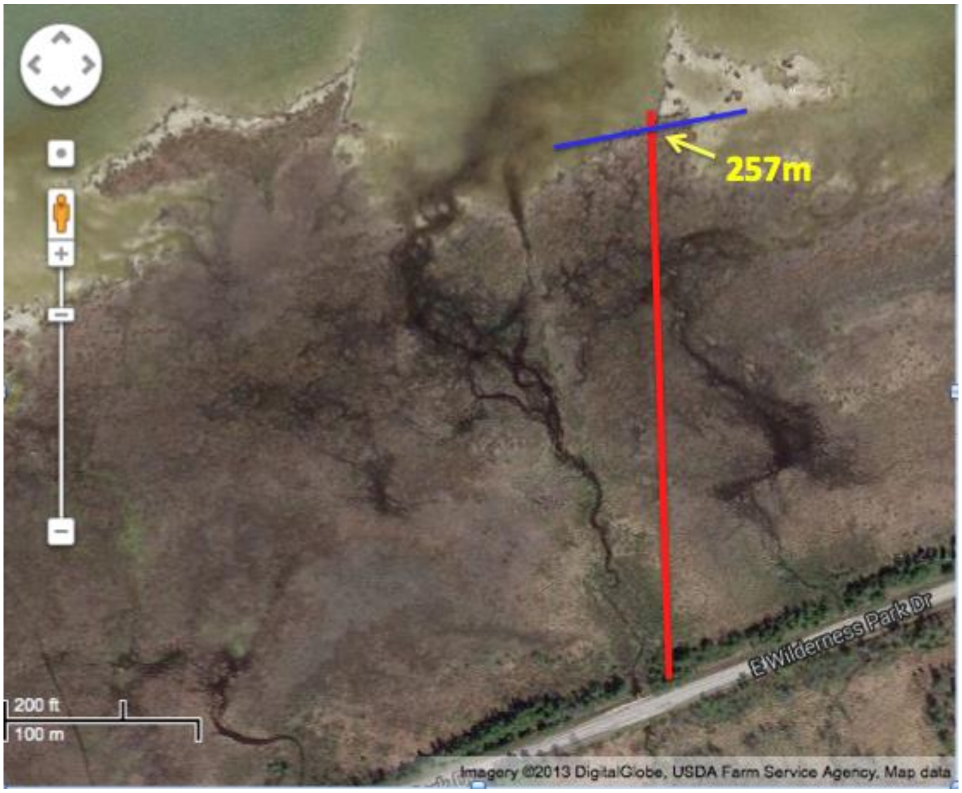

Figure 2: An aerial photo of the wetland at Cecil Bay. The red line is the Voss transect, and the blue line is the transect where plants were sampled.

Figure 3: Part of a *Schoenoplectus pungens* (three-square bulrush) plant excavated from Cecil Bay in 2012 (Photo by D. Albert).

Results:

Relationship between rhizome growth and water level:

Nine out of ten rhizomes showed a negative correlation between internode length and the number of days the rhizome was submerged in May through July (Figure 1). For four of the rhizomes, this negative correlation was significant ($p<.0005$, $p<.0005$, $p=.010$, $p=.005$).

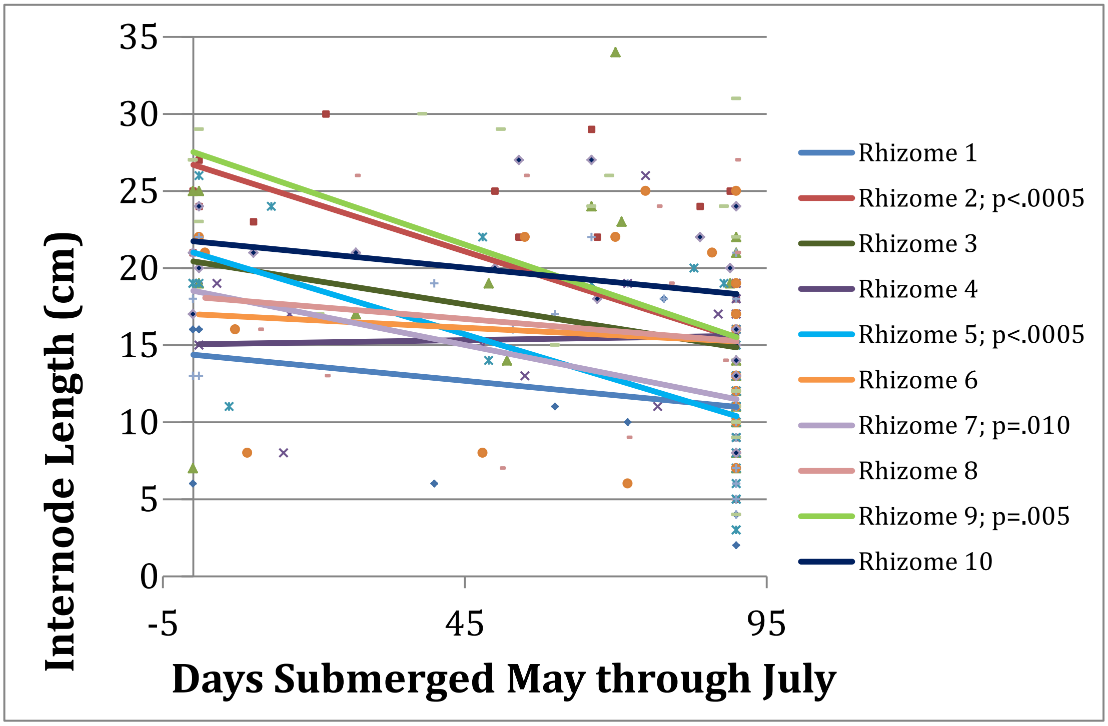

Figure 1. This linear regression represents the relationship between rhizome growth and the number of days a rhizome was submerged in May through July. P values of the four rhizomes for which this correlation is significant are shown in the legend.

Nine out of ten rhizomes showed a positive correlation between internode length and the number of days the rhizome was dry in May through July (Figure 2). For four of the rhizomes, this negative correlation was significant (p=.019, p<.0005, p=.047, p=.017).

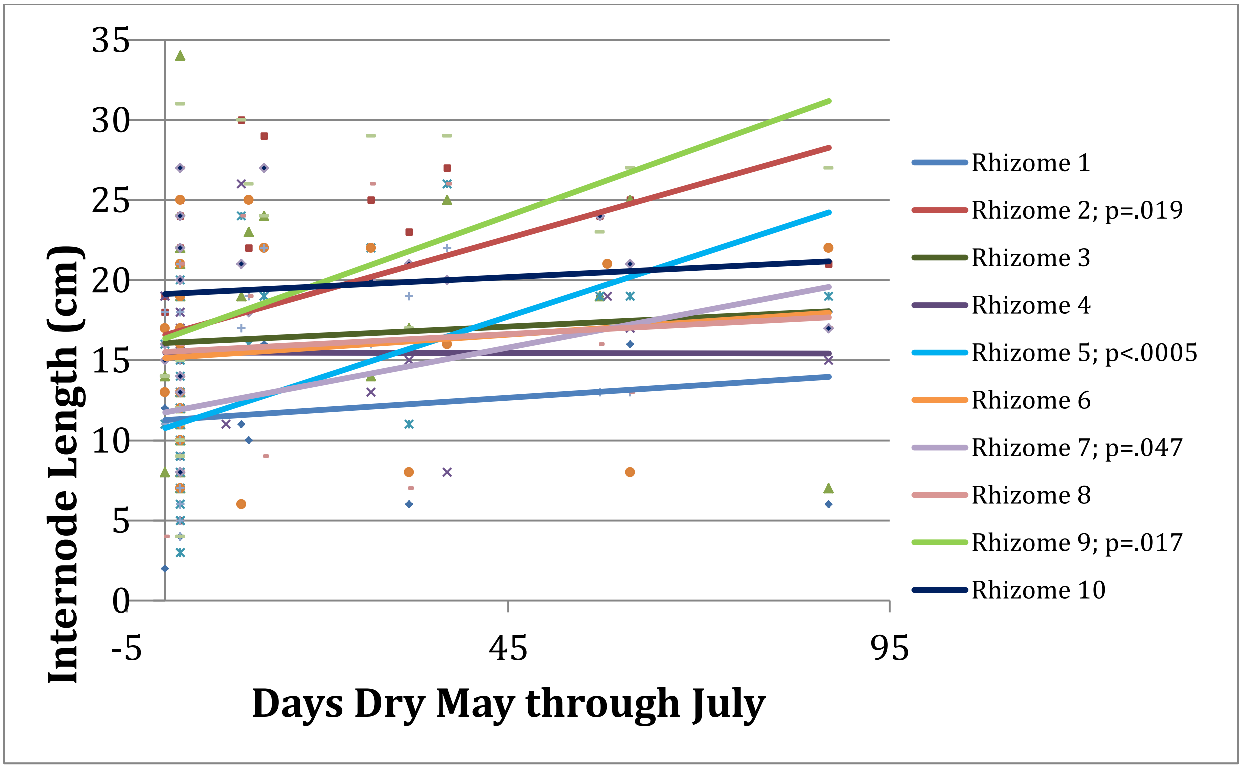

Figure 2. This linear regression represents the relationship between rhizome growth and the number of days a rhizome was dry in May through July. P values of the four rhizomes for which this correlation is significant are shown in the legend.

Effects of water level in a particular month on rhizome growth:

Regressions of internode length against the number of days a rhizome was submerged or dry in May, June, July, or all three months combined, were performed (Table 1). None of these comparisons were significant.

Variable correlated with internode length	**Average r-squared**	**Average p value**
Days submerged in May	0.24	0.23
Days submerged in June	0.12	0.30
Days submerged in July	0.09	0.35
Days dry in May	0.32	0.38
Days dry in June	0.04	0.52
Days dry in July	0.07	0.39
Total days submerged May through July	0.17	0.27
Total days dry May through July	0.09	0.41

Table 1. Average r-squared values for the regression of internode length against the number of days a rhizome was submerged or dry in May, June, July, or all three months combined.

Paired t-tests were performed to compare some of the r-squared values from the regression results. Based on these results, the number of days a rhizome was submerged in May explained approximately twice as much variation in internode length as the number of days it was submerged in June (May submerged $\bar{x}\ r^2=0.24$, June submerged $\bar{x}\ r^2=0.12$; paired t=3.80, df=9, p=.004; Table 2). The number of days a rhizome was submerged in May explained more than twice as much variation in internode length as the number of days it was submerged in July (May submerged $\bar{x}\ r^2=0.24$, July submerged $\bar{x}\ r^2=0.09$; paired t=3.61, df=9, p=.006; Table 2). The number of days a rhizome was submerged in June explained significantly more variation in internode length than the number of days it was submerged in July (June submerged $\bar{x}\ r^2=0.12$, July submerged $\bar{x}\ r^2=0.09$; paired t=2.34, df=9, p=.044; Table 2). The number of days a rhizome was submerged in May explained approximately twice as much variation in internode length as the number of days it was dry in May (May submerged $\bar{x}\ r^2=0.23$, May dry $\bar{x}\ r^2=0.32$; paired t=3.27, df=9, p=.010; Table 2).The number of days a rhizome was submerged in June explained nearly significantly more variation in internode length than the number of days it was dry in June (June submerged $\bar{x}\ r^2=0.12$, June dry $\bar{x}\ r^2=0.04$; paired t=2.46, df=9, p=.036; Table 2). The number of days a rhizome was submerged in July explained nearly significantly more variation in internode length than the number of days it was dry in July (July submerged $\bar{x}\ r^2=0.09$, July dry $\bar{x}\ r^2=0.07$; paired t=2.17, df=9, p=.058; Table 2). The number of days a rhizome was submerged in May explained significantly more variation in internode length than the total number of days it was submerged in May, June, and July (May submerged $\bar{x}\ r^2=0.24$, Total submerged $\bar{x}\ r^2=0.17$; paired t=3.59, df=9, p=.006; Table 2). The total number of days a rhizome was submerged in May, June, and July explained significantly more variation in internode length than the total number of days it was dry in May, June, and July (Total submerged $\bar{x}\ r^2=0.17$, Total dry $\bar{x}\ r^2=0.09$; paired t=3.25, df=9, p=.010; Table 2).

	May Submerged	**June Submerged**	**July Submerged**	**Total Submerged**
June Submerged	0.004			
July Submerged	0.006	0.044		
May Dry	0.010			
June Dry		0.036		
July Dry			0.058	
Total Submerged	0.006			
Total Dry				0.010

Table 2. P-values for paired comparisons of r-squared values for the regression of internode length against the number of days a rhizome was submerged or dry in May, June, July, or all three months combined. Only significant or nearly significant differences are shown. In all such cases, r-squared values were greater for the column variable than for the row variable.

The fate of three-square bulrush under future climate change scenarios:

Along the extended Voss transect, Cecil bay experienced a small elevation change from the water's edge to 280m out into the water (Figure 3).

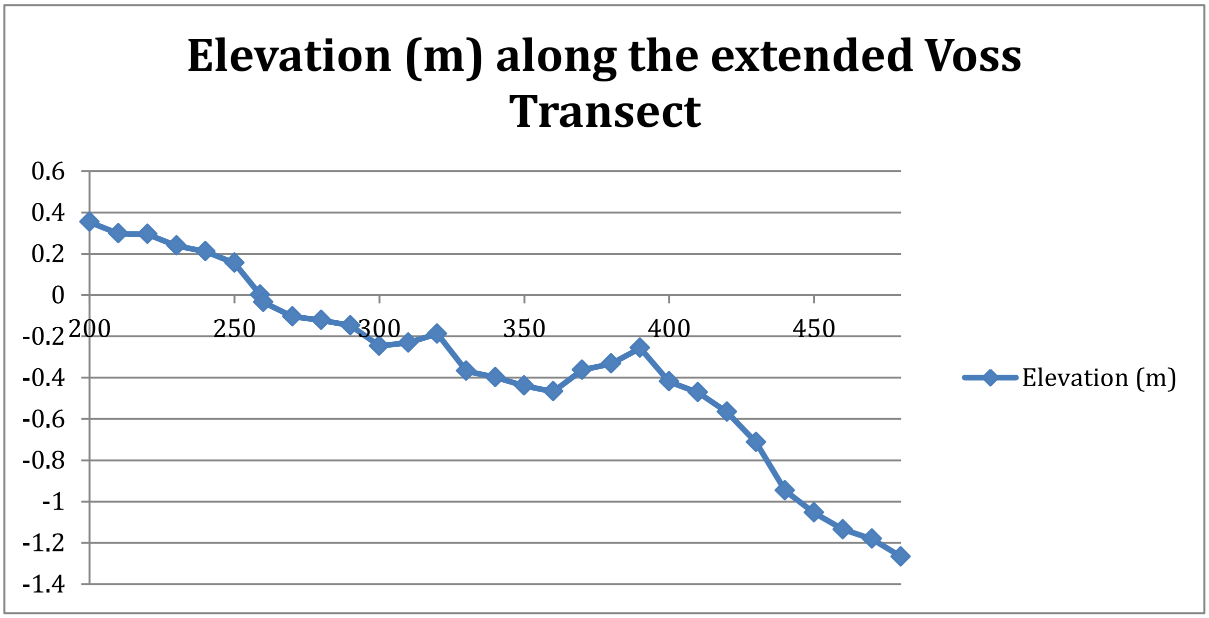

Figure 3. Elevation and bathymetry of the extended Voss transect were measured. The water line is at 260m, noted as 0m water depth.

Under the assumption that three-square bulrush reproduces primarily by rhizome expansion and that it will grow at its observed maximum growth of 34cm per year, it will not be able to remain part of the emergent vegetation by 2050 (Table 3). Depending on the different emissions scenarios, there will be different distances between the outermost extent of the bulrush and the water's edge. The most extreme example is under the A2 scenario in 2080, when there is predicted to be 192.06m of exposed sediment between the bulrush and the water's edge (Table 3).

	Projected water level on Voss transect (m)	Projected extent of bulrush on Voss transect (m)	Distance between bulrush and water level (m)
2050			
B1	292.99	269.58	23.41
A1B	326.05	269.58	56.47
A2	327.71	269.58	58.13
2080			
B1	323.83	279.78	44.05
A1B	433.56	279.78	153.78
A2	471.84	279.78	192.06

Table 3. Model simulated changes of Lake Michigan-Huron water levels (m) under different emission scenarios were transposed onto the Voss transect. The projected extent of bulrush on the Voss transect assumes maximum growth of 34cm/year.

Discussion

The first major finding of this study is that rhizomes appear to grow longer when they are under dry conditions than when they are submerged. A possible explanation for this pattern is that the rhizomes are drawn towards the water, as water uptake is necessary for the growth and survival of plants. During months that the water levels are low and the rhizomes are not submerged, they may grow longer in attempt to reach the water. On the other hand, rhizomes appear to be growing less when they are submerged because there may be no need for the rhizomes to invest more energy into horizontal rhizome growth if the plant already has access to water.

These results have strong implications for the ability of three-square bulrush to remain an emergent plant under conditions of decreasing water levels. They suggest that these rhizomes will be able to grow more each year because the projected water level drop will create dry conditions for the plant. This provides three-square bulrush a better chance of remaining part of the emergent vegetation under future water level declines.

The second major finding is that the number of days a rhizome is submerged in May is more strongly correlated with internode length than the number of days it is submerged in either June or July. Because rhizomes appear to grow less when they are submerged, rhizome growth appears to be particularly suppressed by high water levels in May. One characteristic of rhizomatous plants is that they can reallocate emphasizing either horizontal rhizome growth or vertical stem growth depending on the environmental conditions and available resources (Armstrong 1983). During the growing season, if three-square bulrush rhizomes are submerged, it may be more beneficial to invest in vertical growth than horizontal rhizome growth because is it already under water. As a consequence, the internode length will be shorter. My data suggest that this resource allocation is made in May.

If this is the case, then there are severe implications for three-square bulrush under future climate regimes. Climate change models predict that the Midwest will experience more precipitation and flooding in the spring (Hayhoe et al. 2013). Therefore, water levels are predicted to be highest in May, which is likely to suppress rhizome growth. These models also predict that the Midwest will experience more severe drought in the summer (Hayhoe et al. 2013). This represents the worst-case scenario for three-square bulrush because its horizontal growth would be suppressed during summer months of drought.

Lastly, analysis of future lake level decline under three emissions scenarios show that even if three-square bulrush rhizomes expand at their observed maximum rate, the plant will very likely not be part of the emergent vegetation by 2050. This can result in ecosystem-wide consequences. For example, the moist exposed sediment between the outer extent of the three-square bulrush and the water's edge is vulnerable to invasion by invasive plants (Lishawa et al. 2010). Four invasive plants that have been shown to rapidly invade many Great Lakes coastal wetlands are: *Typha* x *glauca* (hybrid cattail), T. *angustifolia* (narrow-leaf cattail), *Phragmites australis* (common reed), and *Lythrum salicaria* (purple loosestrife). Lishawa et al. (2010) found that water level decline promotes the invasion of *Typha x glauca* in Great Lakes coastal wetlands. Introduction of such invasive plants often results in a loss in biodiversity and can drastically alter nutrient cycling, soil organic matter, and other ecosystem community properties.

Another consequence of a loss of three-square bulrush in the emergent zone is a decrease in spawning habitat for fishes. More than 80 fish species in the Great Lakes depend on coastal wetlands for feeding, spawning, and for use as a nursery habitat (Jude et al. 2005). About 50 of these fish species, including brown bullhead *Ictalurus nebulosus*, mudminnow *Umbra lima*, and longnose gar *Lepisosteus osseus*, are residents and are therefore exclusively dependent on emergent wetland vegetation (Jude et al. 2005). The other ~30 fish species are migratory and depend on coastal wetlands for part of their life cycle. These migratory species include northern pike *Esox lucius*, common carp *Cyprinus carpio*, walleye *Stizostedion vitreum*, rainbow smelt *Osmerus mordax*, and rainbow trout *Oncorhynchus mykiss* (Jude et al. 2005). A study by Fracz and Chow-Fraser (2013) assessed the impacts of declining water levels on fish habitat in coastal wetlands of eastern Georgian Bay, Lake Huron, and found that sustained low water levels since 1999 have led to a significant loss in fish habitat. The recent period of water level decline and the projected future decline are predicted to have severe impacts on fish populations in the Great Lakes (Fracz and Chow-Fraser 2013).

There are a few ways in which this study could have been improved to allow more confidence in the findings. First, there may be a critical period during the growing season, other than either May, June, or July, for which water levels appear to affect rhizome growth most strongly. For example, it is possible that this critical period is a two-week period during the growing season as opposed to an entire month. An opportunity for future research could be to manipulate and analyze the database to determine whether there is a more specific time period for which water levels correlate most strongly with rhizome growth.

Another issue that can be explored with more research is whether this study is applicable to the greater Great Lakes. At Cecil Bay, the water level does not exceed 1m of for a distance of about 200m towards the open water. Any drop in water level at Cecil Bay will have a much larger change in water's edge than another part of the lake with a much steeper bathymetry. Therefore, three-square bulrush may have a better chance of keeping up with the declining water levels in areas with a steeper bathymetry.

The last question that would be interesting to explore is whether the direction of rhizome growth is affected by water level. The rhizome might be expected to grow more directly toward water when water levels are low, and more random when flooded.

In summary, although three-square bulrush rhizomes appear to grow more when they are dry than when they are submerged, they very likely will not be able to keep up with projected water level decline in the future. This can result in ecosystem-wide consequences with a particular detriment to organisms that are exclusively dependent on emergent wetland vegetation.

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