The Ability of Three-Square Bulrush (*Schoenoplectus Pungens*) to Expand at the Same Rate as the Climate Change Driven Decline in Great Lakes Levels

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Abstract

The declining lake levels in the Great Lakes fit with current climate change models. Costal marshes are especially susceptible to drying events with small changes in lake levels. The three-square bulrushes (*Schoenoplectus pungens*) hold important roles of habitat, erosion control, and anthropogenic pollution control within coastal wetlands. The measurement of gradient change perpendicular to the shoreline estimated the ability of bulrush to respond to declining levels. Through sampling of two coastal marshes dominated by *S. pungens,* we determined the growth pattern in three inundation zones: 1. Dry- dry year round and has been dry for many years, 2. Shore- fluctuating level of water year round and has been dry in the previous years, and 3. Deep- continuously inundated year round and has been for many years. Through sampling, the relative importance of inundation levels and zone characteristics was determined to affect the relative growth with higher inundation perceived to lead to higher growth. The Deep zone had the greatest growth potential with the Shore and Dry zones showing a significant difference only at the terminal node. Zones showed differences in growth patterns between horizontal main rhizome growth and vertical short shoot growth. The rate of growth seems inadequate to respond to declining lake levels.

Introduction

The Great Lakes have experienced a period of abnormally low water levels since 1997. Water levels dropped around 1.1 meters between 1997 and 2000 (NOAA 2008 and Sellinger

2008), and water levels have not rebounded between 2000 and 2008. While the Great Lakes have experienced fluctuations in levels for thousands of years, the current drop fits with climate change predictions (Sellinger 2008), leading to concerns that level will not rebound. The Great Lakes rely on precipitation as the main source of water (Sellinger 2008 and Croley & Lewis 2006); the increased precipitation from 1980 to 1997 may have masked a 33-year trend of increased evaporation due to climate change (Sellinger 2008). In a more extreme model, Croley and Lewis (2006) estimate that Lake Michigan with become a terminal lake (completely dry) if temperatures reach 14°C above current temperatures or precipitation drops 63%, or a mixture of decreased precipitation and increased temperature as modeled by $4.5T+P>63$. These drops in lake levels have exposed broad expanses of many ecologically important shoreline ecosystems to dry conditions. These ecosystems play many important roles in the ecological integrity of the aquatic systems of the Great Lakes (Bachand et al. 2000; Li et al. 2008; Castellanos and Rozas 2001; Thorn and Zwank 1993; Nelson et al. 2000; Pierce et al. 2007; Uzarski et al. 2005; and Bhagat et al. 2007).

One important role of shoreline wetlands is the removal of anthropogenic pollutants before they reach the Great Lakes or other aquatic systems. Bachand et al. (2000) found that aquatic marshes could remove from 261 mg N m^{-2} day^{-1} to 835 mg N m^{-2} day^{-1} depending on the species composition of the lakeshore marsh. Shoreline marshes are playing an increasingly important role in pollution treatment because of the reduced cost and increase effectiveness of constructed marshes compared to conventional treatment options (Bachand et al. 2000). A mixture of *Typha latifolia* and *Scirpus validus* create a suitable substrate for the survival of bacteria species that reduce soluble chemical oxygen demand (SCOD) (Li et al. 2008). The amount of SCOD was inversely correlated (R=.96) with species richness using Shannon-Wiener Index (Li et al. 2008).

In many regions, three-square bulrush (*Schoenoplectus pungens*) plays an important habitat role in shoreline marshes where it grows. Castellanos and Rozas (2001) found many species of nekton (fish and decapod crustaceans) using *S. pungens* beds for shelter and food in the freshwater tidal ecosystem of the Atchafalaya river delta in Louisiana. In addition, migratory birds like the cinnamon teal use *S. pungens* marshes in the Bosque del Apache National Wildlife

Refuge of New Mexico for food during migration (Thorn and Zwank 1993). The loss of these important feeding habitats would greatly reduce the fitness of the cinnamon teal (Thorn and Zwank 1993). Monocultures of constructed *S. pungens* marshes have high species richness of macroinvertebrates with abundance of close to 500 individuals caught per one-minute sweep (Nelson et al. 2000). These macroinvertebrates are important food sources for many species of birds and fish (Nelson et al. 2000).

Pierce et al. (2007) found that muskellunge used bulrush beds to spawn; the study used transplanted radio transmitters to determine where fish spawned in lakes of Minnesota. The shoreline bulrush marshes of Michigan are important habitats for many species in Lake Michigan. Yellow perch (Perca flavescens) spawn on bulrush stems in the northern Great Lakes (Albert 2003). Bhagat et al. (2007) and Uzarski et al. (2005) found a diversity of species of shiners, perch, bullhead, and suckers in bulrush marshes around Lake Michigan. Bulrush dominated marshes buffered species from anthropogenic pollutions up to a set threshold level of "N input value of 244 kg/km2/y and a total phosphorus input value of 14 kg/km2/y from agricultural sources" and "194 kg/km2/y and a total phosphorus input of 15 kg/km2/y from non-agricultural sources" (Bhagat et al. 2007). Once these levels are exceeded, the species richness sharply declines.

S. pungens is an emergent perennial from the family Cyperaceae that primarily expands asexually through rhizome growth (Poor et al. 2005). The rhizomatous response to changing environmental conditions is poorly studied. The specie showed foraging tactics in nutrient heterogeneous environments where the rhizome forages toward the nutrient rich soils (Poor et al. 2005). *S. pungens* is phenotypically plastic in different environment as shown by Seliskar (1989) through controlled experiments of growth with plants taken from different inundation zones. The recorded responses included increased percent aerenchymatous tissue in waterlogged treatments and increased growth in buried treatments (Seliskar 1989).

Through modeling of the Great Lakes water level change and vegetation sampling in shoreline marshes, we hope to determine the ability of *S. pungens* to respond to water level

fluctuations linked to the changing climate. The recession of the shoreline of the Great Lakes has been an issue of concern because the drop in level is consistent with climate change models (Sellinger 2008). We also hope to determine the conditions that are ideal for seedling recruitment of *S. pungens.* The development of a model of the amount of wetland exposed per centimeter drop in the Great Lakes will determine the capacity of *S. pungens* to respond to changing conditions. We predict that the rate of water-level decrease will be too rapid for *S. pungens* to respond through rhizome growth, resulting in decreased width of the flooded bulrush zone, where we also predict the greatest growth rates for rhizomes. We assume that seedling recruitment will occur in recently exposed marsh, where oxygen-rich conditions are optimal for germination, but that seedlings will not be able to move lake-ward as fast as lake levels retreat, thus resulting in continual shrinkage of the amount of flooded bulrush marsh. Based on preliminary vegetation sampling, we predict there will be variation in growth patterns directly related to the inundation level: the Deep zone will have the highest rate of growth, the Shore zone intermediate growth, and the Dry zone the lowest rate of growth.

Material and Methods

Plants were sampled from two shoreline marshes along the Michigan-Huron Lake shore. The sample sites were: 1) a marsh north of Cheboygan, Michigan, and 2) Cecil Bay near Wilderness State Park (Figure 1). *S. pungens* dominance characterized the sampled sites.

An elevation profile of each wetland was determined using GPS, a meter stick, a transit, a 3 meter story pole, and a transect tape. Water depth was measured every 10 meters along a transect perpendicular to the shoreline for the vegetated marsh zones using a meter stick. The elevation profile of the upland was measured with transit readings every 10 meters for 100 meters perpendicular to the shoreline.

A soil sample was taken at every Dry zone sample point. The soil composition in the Shore and Deep zones was assumed to not to vary between samples. The soil samples were analyzed for type and composition using an estimate of percent composition of sand, clay, and presence/size of rocks.
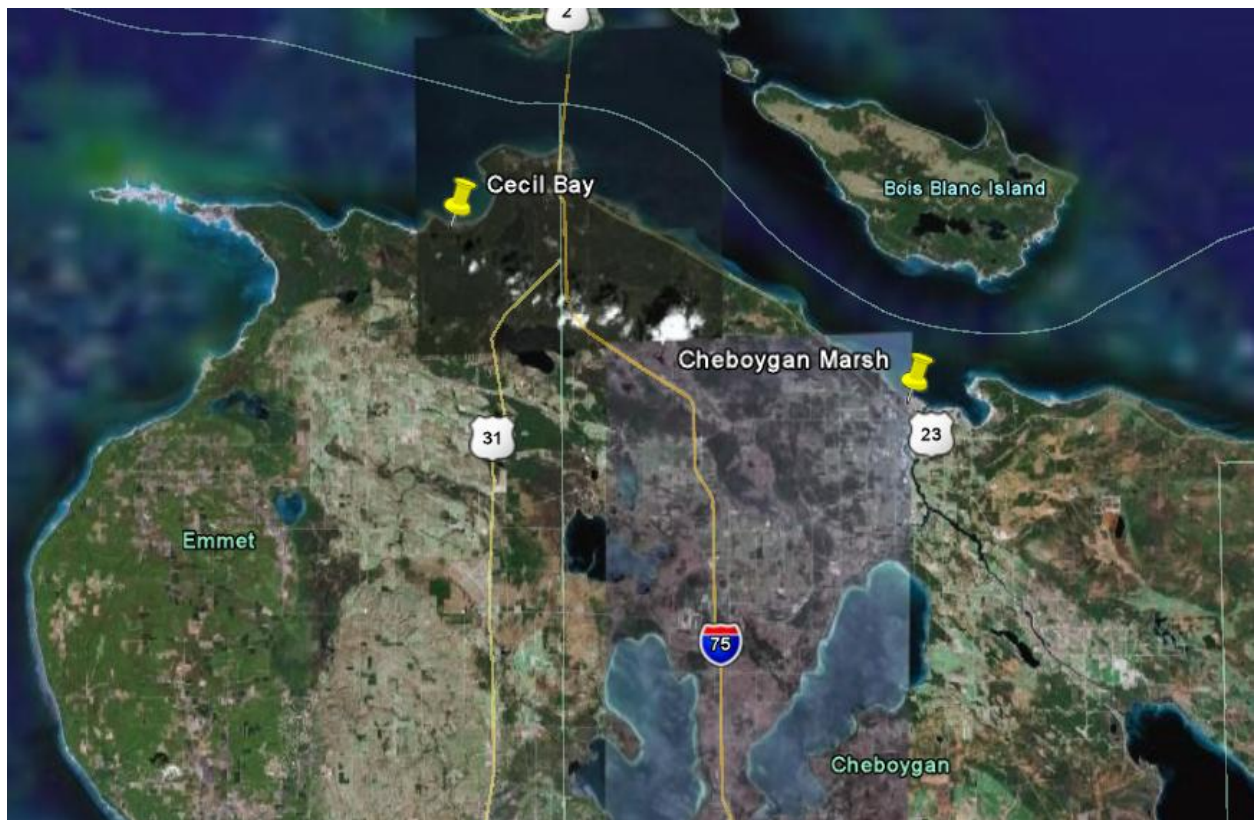
Figure 1: The two study sites: Cheboygan Marsh and Cecil Bay (Google Earth).

Each sample site was divided into three zones for three-square rhizome sampling (Figure 2): 1) Dry Zone- that has not been inundated in the past years, 2) Shoreline Zone- where the current waterline meets the dry zone, and 3) Inundated Zone- that is inundated year round and has been for many years. In each zone, 10 bulrush rhizomes were sampled from the middle of one-meter-by-one-meter quadrates using a random number table to locate sampling quadrates along a transect (Figure 3 and 4). We uprooted the rhizome until we encountered the terminal ramets and rhizome, regardless of whether these were outside of the quadrat where we began examining the rhizome. If we were unable to find the terminal end of a rhizome in the Deep Zone, our protocol was to remove a rhizome with at least five annual internodes (distance between annually produced ramets) and averaged these internode distances. In these cases, we assumed that the conditions in the Deep zone have not varied greatly in the last eight years. Only terminal rhizomes were sampled from the Shore zone because the conditions have greatly varied over recent years.
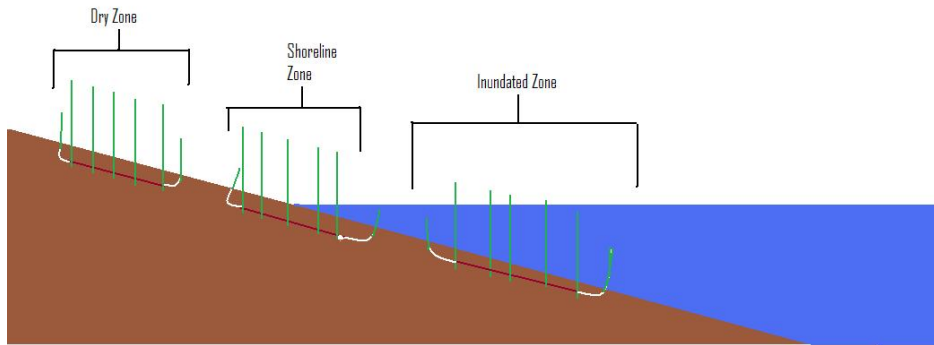
Figure 2. The three inundation zones: Dry Zone is characterized by dry conditions year round, Shoreline zone is characterized by daily fluctuations between inundated and dry through wave action and seiche events, and the Inundated Zone is characterized by inundated conditions year round.

Figure 3. The positions of the transects in each zone at Cheboygan Marsh. The transects were chosen for continuous beds of *Schoenoplectus pungens.* When there was not 50 meters of continuous bed, the transects for each zone were moved off the original transect where the elevation profile was drawn (Google Earth).

Figure 4. The position of the transect in each zone of the sample site at Cecil Bay. The transects were chose for continuous beds of *Scheonoplectus pungens.* When there was not 50 meters of continuous bed, the transects for each zone were moved off the original transect where the elevation profile was drawn (Google Earth).

Terminal rhizomes were sampled using trowels and a Honda WX10 4-stroke water pump to free the rhizomes from the sediments. Sampled genets and soil samples were bagged and labeled, then taken back to the lab for measurement and analysis. Each terminal rhizome or average of internodal growths was measured and recorded.

Competition was measured using one-meter-by-one-meter quadrates at each Dry Zone sample. The Inundated and Shore zones contained little to no competition. The amount of seedling recruit was measure through 0.5-meter-by-0.5-meter quadrate at random positions along a transect in the Shore zone of Cecil Bay.

The lengths of the internodal growth of each rhizome was normalized through log based 10 for statistical analysis. I analyzed each zone using two-way ANOVA's of site and zone

interaction and I ran a linear regression for the interaction of change in water level since 2008 and internodal lengths with SPSS version 15. The past lake levels, predictions of future lake levels, and measured gradients were compared with mean rates of growth of the terminal rhizome to determine the ability of the plant to respond to the lake level recession. The gradient of the marshes was graphed in Excel.

Marsh Gradient Results

Cheboygan Marsh experienced a small elevation change from the base of the upland ridge to the end of the bulrush bed at 120 meters from the shore (Figure 5). The estimated positions of shoreline for each year from 1997 to 2008 are marked using historic water-level data from the NOAA station at De Tour Village, MI. The 1997 water levels were very near the top of the beach ridge.
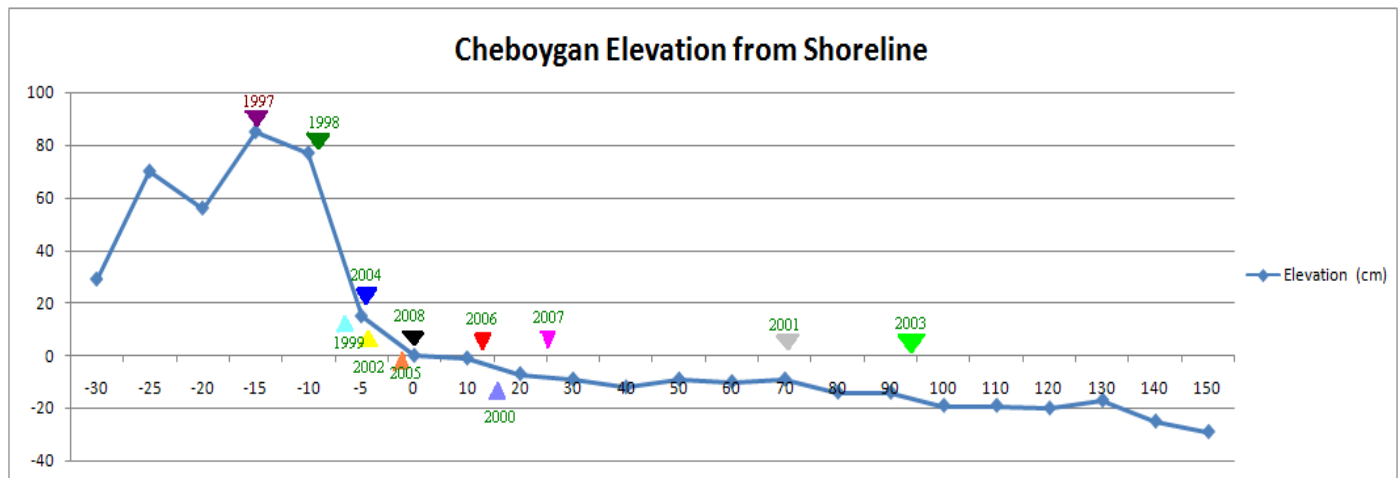

Figure 5. A graph of the bottom profile of Cheboygan Marsh created with data from transit and depth readings. The yearly position of the shoreline is labeled, showing that a very small variation in water levels leads to large horizontal changes in the position of the shoreline.

The marsh at Cecil Bay exhibited a similarly small elevation change from the base of the upland ridge to the end of the bulrush bed at 31 meters from the shore (Figure 6). The estimated positions of shoreline for each year from 1997 to 2008 are marked using historic water-level data from the NOAA station at De Tour Village, MI.
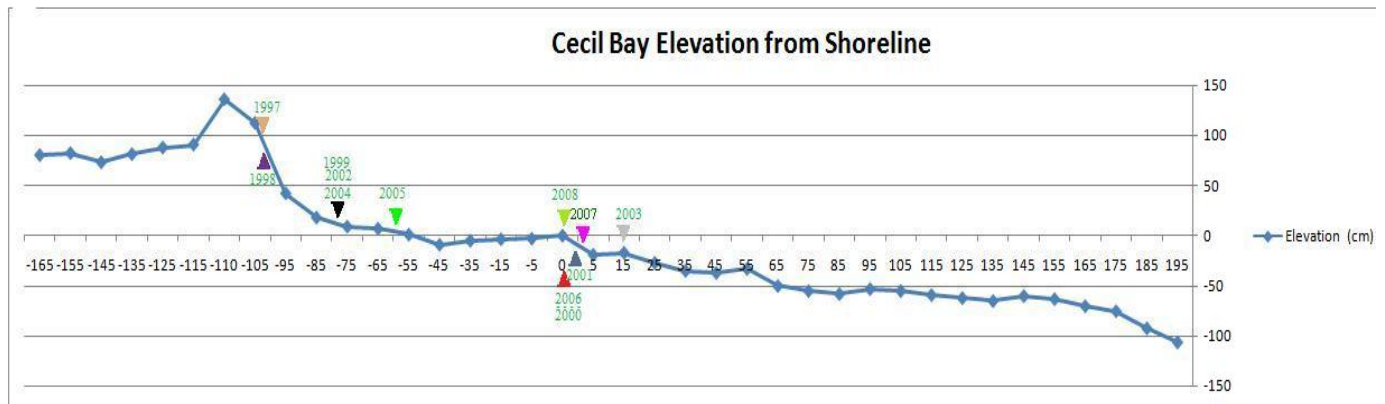
Figure 6. A graph of the bottom profile of Cecil Bay created with data from transit and depth readings. The yearly position of the shoreline is labeled, showing that a very small variation in water levels leads to large horizontal changes in the position of the shoreline.

Growth Results

The terminal (2008) internodal growth summed by zone was significantly different (p=.001) between all three zones (Figure 7). The Deep zone experienced the greatest growth, with the least growth in the Dry, and intermediate growth in the Shore zone. The deep zone shows expansion only along the main rhizome and the other two zones show a mixture of growth of the main rhizome and short shoot growth. The Shore zone had a mixture of stems growing from the main rhizome and stems growing from the short shoots. The Dry zone had a large majority of stems growing from short shoots and very few growing from the main rhizome. The only seedlings encountered were in the Shore zone of Cheboygan marsh.
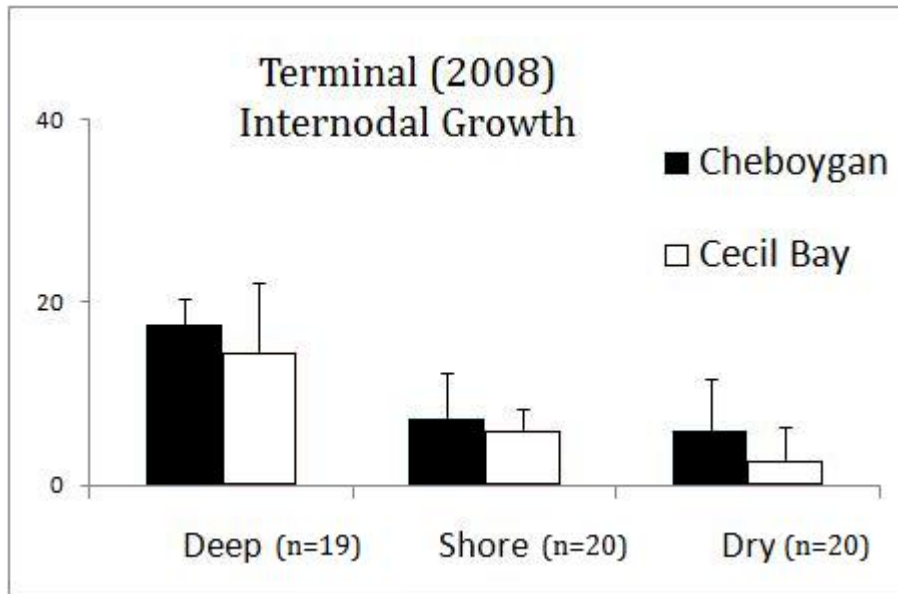
Figure 7. A bar graph of the mean lengths of rhizome growth for 2008 by zones, combining data for both sites. The growth in all three zones was significantly different (p =.001).

The 2007, 2006, 2005, and 2004 internodal growth showed a significant difference between the Deep Zone and the other two zones, with the Deep zone showing the greatest growth (Figure 8). The longest internode growth rate measured for the Deep zone was 30.5 cm in 2005. There was no statistical difference between the Shore and Dry zone for any of the years. The Deep zones showed only expansion of the main rhizome, while the other two zones show a mixture of main rhizome growth and short shoot growth. The Shore zone had a mixture of stems growing from the main rhizome and stems growing from short shoots. Most of the stems in the Dry zone grew from short shoots, and very few grew from the main rhizome.
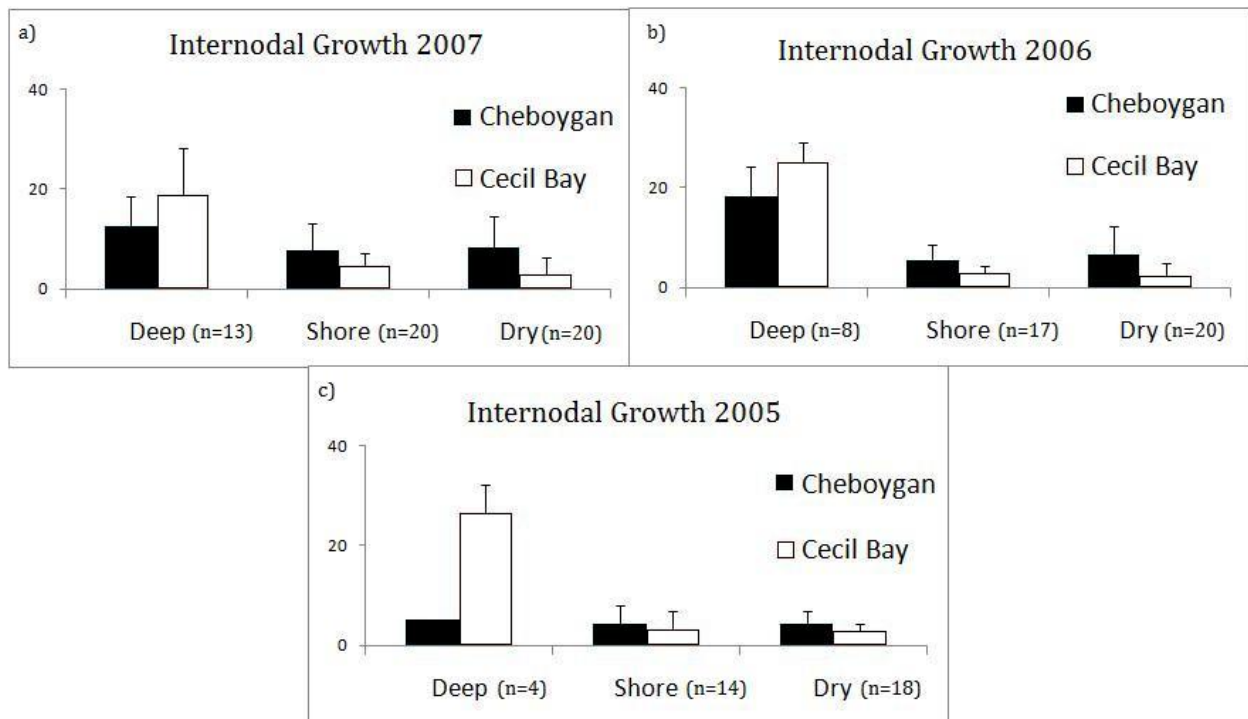
Figure 8: A bar graph of the mean lengths of rhizome growth for a) 2007, b) 2006, and c) 2005 by combining data for both sites. For years 2005-2007 the annual growth in the Deep zone was significantly different from in the other two zones (p=.001 for all years). a) The 2007 mean internodal difference between the Shore and Dry zone was not significantly different (p=.371), b) the 2006 mean internodal difference between the Shore and Dry zone was not significantly different (p=.936), and c) the 2005 mean internodal difference between the Shore and Dry zone was not significantly different (p=.904).

The combined internodal growth pre 2008 (not including the terminal rhizome) and the combine internodal growth from 2008 to the oldest node (including the terminal) from each zone showed a significant difference between the Deep zone and the other two zones with the Deep zone showing the greatest growth (Figure 11 and 12). There was no difference between the Shore and Dry zones. The deep zone shows only main rhizome expansion and the other two zones show a mixture main rhizome growth and short shoot growth. The Shore zone had a mixture of stems straight from the main rhizome and stems from short shoots. The Dry zone had a large majority of stems from short shoots and very few from the main rhizome.
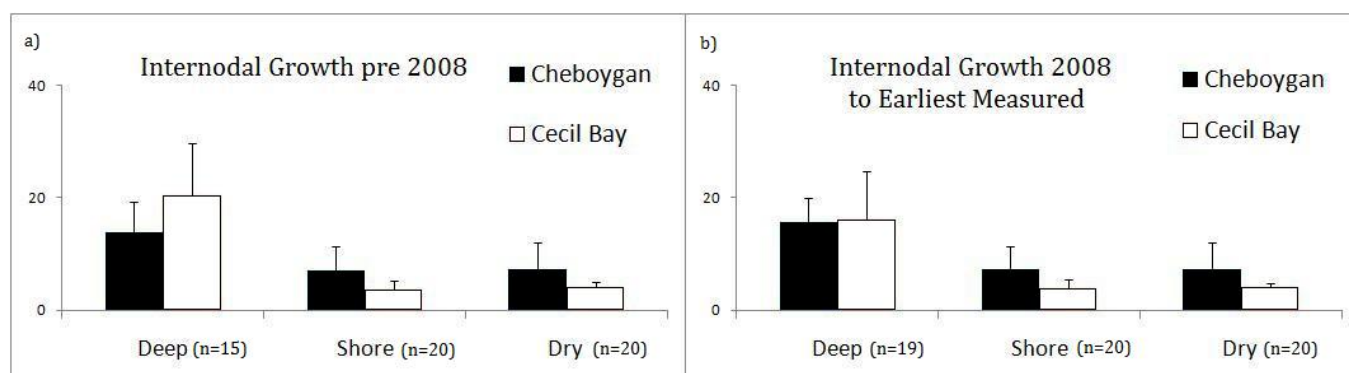
Figure 11: A bar graph of the mean lengths of rhizome growth for a) pre 2008 and b) 2008 to oldest node collected, by combining data for both sites. The growth in the Deep zone was significantly different from the other two zones for pre 2008 and 2008 to oldest measured node (p=.001). a) The pre 2008 difference between the Shore and Dry zone were not significantly different (p=.923) and b) the 2008 to oldest node difference between the Shore and Dry zone were not significantly different (p=1).

The yearly-paired internodal growth showed significant difference in three pairs in the Shore zone (Table 1). The other paired years in the Shore zone and all of the paired years in the other zone showed no significant differences. The linear regression of the relationship between internodal growth and yearly variation in water levels for the month of June was not significant.

Table 1: Significant paired comparisons found between years in the Shore zone. No other zones or years had significantly different pairs.

Paired ID (Shore Zone)	p-value
Terminal (2008)–Year 2006	.009
Terminal (2008)–Year 2005	.022
Terminal (2008)–Year 2004	.006

Disscussion

The persistent low-water period between 1998 and 2008 appears to fit with current climate change models (Sellinger 2008). If that is the case, the current low levels may never return to the long-term average we have experience for the last hundred years. Under the Sellinger model, the marshes that have recently been exposed to dry conditions will remain dry.

In an extreme model, climate change will drive conditions close to desertification, 63% less precipitation or 14°C higher temperature than current. Under these conditions, Lake Michigan and Huron will completely dry and become terminal lakes (Croley & Lewis 2006).

The extremely low slopes of the marshes make them prone to drying events. A drop of 20 cm in water level would expose 120 meters of Cheboygan Marsh bed to dry conditions. A drop of a half of a meter in water level would expose 95 meters of Cecil Bay marsh bed to dry conditions. The drop in lake levels from 1997 to 2000 was 5 times this decline, so a 20 or 50 cm drop is more than plausible.

From 1997 to 2000, one genet on the base of the beach ridge at Cheboygan Marsh underwent changing conditions from the flooding of the Deep zone to the dry conditions characteristic of the Shore zone. This genet currently has to deal with of daily variations in water level and an increase in competition from plant species suited to drier conditions (Wilcox and Nichols 2008). From 2000 to 2003, this same genet undergoes a change from the Shore zone to the new conditions in the Dry zone. Water scarcity characterizes this zone because of the now much deeper water table. With these still drier conditions, the genets exposed to much more competition for sunlight from upland species that move into the newly exposed marsh. Thus, with water level changes over six years, a plant goes from growing in the inundated conditions with little competition to dry conditions with substantial competition.

This year's growth (2008) shows the expected pattern of significant variation between zones. The deep zone is characterized by competition from only *Schoenoplectus acutus* (Wilcox and Nichols 2008) and no water scarcity. This appears to be ideal for the growth of *S. pungens,* since it shows the most annual growth in the Deep zone. It appears that deposition of sand and organic material is not a problem in the Deep zone because terminal rhizome growth continued in the horizontal direction rather than changing to the vertical short shoot growth as seen in Shore and Dry zones. The primary deleterious characteristic of the deep zone appears to be increased wave action that can cause uprooting of rhizomes and therefore death of the plant. This wave action appears to eliminate competition from other species.

We expected the growth of the Shore zone to be intermediate between the growth rates in the other two zones. The conditions in the Shore zone are intermediate. The variability in water keeps the genets inundated for short periods, with the water table relatively close to the rhizome at other times. The bulrush bed in the deeper zone creates a barrier to the wave action that is characteristic of the outer zone. This lack reduced wave action allows for deposition of sand and organic matter. Rhizomatous species typically respond to increased sediment deposition through vertical growth (Antos and Zobel 1985). Three-square bulrush appears to respond to increased sediment deposition through short shoot production. These short shoots grow vertically, not horizontally like the growth from the terminal end of the main rhizome.

The lack of seedlings found at Cecil Bay points to the need for a better sampling method to estimate the amount of seedling in a given zone and site. In addition, the lack of seedling may indicate the scarcity of seedling recruitment.

The Dry zone showed the least terminal rhizome growth of all of the zones. Higher levels of competition from upland species and a deeper water table characterize the Dry zone. The water table is below the elevation where short shoot rooting occurs, but the main rhizome appears to remain in moister soil conditions farther bellow the current soil surface. Ground water flow from farther inland appears to provide moisture for these deep rhizomes. The characteristic scarcity of water where surface short shoots root and increased competition appear to lead to the low level of growth.

The Deep zone consistently showed the highest growth because of the lack of variation in conditions and competition. The internodal growth in the other two zones varied greatly over a several year period. The Shore zone experiences a gradient of conditions over a short horizontal distance due to marsh micro-topography. Wilcox and Nichols (2008) found a greater level of competition in the Shore zone than in the other two zones. The yearly variation of the shoreline may compound the variation in competition and therefore, compound the variation

in growth. The daily variation in water level may affect genets differently due to the micro-topography.

Some of the variation in growth encountered in the Dry zone may be from the differences in soils within which the genets grow. Four samples from Cheboygan appear to have had increased growth rates because of the decomposing organic storm beaches on which they grew. The organic matter appears to keep the rhizomes much moister than nearby genets and increases nutrient availability. While our sampling focused on growth rates of major horizontal rhizomes, in both the Dry and Shore zones there could have accidental inclusion of short shoots into the samples; the short shoots have a much shorter internodal growth pattern than the internodal growth of most main rhizomes. Although, under dry conditions annual growth rates of the main rhizome appeared to approach that of vertical short shoots and direction of growth became more vertical.

In Shore zones, the yearly differences in growth on individual genets showed an opposite response than what we hypothesized for two paired years. The growth in 2006 showed the expected pattern of decreased growth with decreased water level. The growth of 2004 and 2005 were less than the 2008 terminal growths, but these years had slightly higher lake levels than 2008. There could be a lag in the response where the previous year's conditions affect the next year's growth. There needs to be more extensive sampling to determine the patterns of growth.

S. pungens' growth rate does not allow it to grow lake-ward at the same rate of lake level decline that we are currently seeing. In Cheboygan Marsh, the lake levels would only need to drop two cm yearly for the entire bulrush bed to be exposed to dry conditions by 2020. At the highest measured rate of growth on the rhizome, a genet would only be able to grow 3.66 meters in those 12 years. For Cecil Bay, the lake levels would need to decline at a rate of roughly 3 cm per year for the bed to be completely exposed. If the lake levels experience another drop like the one between 1997 and 2008, the entire bulrush bed at both sites will be in the Dry zone. The only other response *S. pungens* can use to follow the receding shoreline

would be dispersal through seedlings, but seedlings seem very sparse in the Shore zone and are non-existent in the Deep and Dry zones. The seedlings that we have encountered grow at a reduced growth rate, and they can only establish in moist, not flooded conditions; limiting their ability to effectively recolonize a drying marsh.

The loss of these important emergent marshes means a loss of important habitat, erosion control, and anthropogenic pollution control (Bachand et al. 2000; Li et al. 2008; Castellanos and Rozas 2001; Thorn and Zwank 1993; Nelson et al. 2000; Poor et al. 2005; Pierce et al. 2007; and Bhagat et al. 2007). *S. pungens* forms the habitat of frog species like Leopard Frogs, bird species like woodcock, and young of the year fish populations (Personal observations). In other parts of the country, *S. pungens* provide food for migrating cinnamon teals (Thorn and Zwank 1993) and the macroinvertebrate populations within the marshes are important food source for many other aquatic and terrestrial species (Nelson et al. 2000). The rooting structure of *S. pungens* has been seen to reduce the erosion caused by wave action at both Grand Traverse Bay and Saginaw Bay (Personal communication Dennis Albert). Bulrush beds play a limited but important role in pollution control (Li et al. 2008; Bachand et al. 2000; Uzarski et al. 2005; and Bhagat et al. 2007).

Future Research

For a better understanding of the ability of three-square bulrush to respond to the increase rate of declining lake levels there needs to be a better characterization of the species. In order to determine seedling recruitments role in dispersal extensive sampling would greatly add to the knowledge of *S. pungens*' modes of expansion. A quantification of relative number of short shoots per genet per zone would better the understanding of the role of short shoots. Testing the roles of the main rhizome versus shoot shorts in the Dry zone may allow researchers to determine if short shoots hold a photosynthetic role, while the main rhizome maintain the role of providing water. The role of water level changes in relationship to change in growth would be better determined with a larger number of rhizome samples and longer rhizome samples with more years of growth per genet.

Acknowledgement

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