Investigating Elevated Pitcher Mortality Rate in *Sarracenia purpurea*
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Abstract

Understanding the effects of climate change-induced drought on ecological systems is crucial to any effort that hopes to mitigate the damage done to ecosystems as drought becomes increasingly prevalent. The purple pitcher plant, *Sarracenia purpurea,* is a carnivorous wetland species particularly susceptible to long bouts of dry weather due to its multi-fold reliance on an abundance of water. This makes *Sarracenia purpurea* a perfect indicator species that may increase our understanding of how drought will affect wildlife communities at risk of mortality due to a lack of moisture. During the spring of 2012, abnormally high pitcher mortality was noted in the population of *S. purpurea* at Grass Bay Preserve in Cheboygan County, Michigan. It was hypothesized that abnormally dry conditions in northern Michigan during the summer of 2011 may have caused this unusually heightened senescence of pitchers. In this study, 100 *S. purpurea* were selected to be our sample population. We took measurements of moisture availability, pitcher temperature, and plentitude of competitive root biomass for each of the 100 *Sarracenia purpurea* or, in some cases, a subset of 40 plants. We also took "pitcher mortality" measurements consisting of counting the number of dead pitchers, live pitchers, new pitchers, damaged pitchers, flowers, and diameter for each plant. We found no correlation between moisture availability and pitcher mortality, suggesting an optimistic outlook for wetland plant species if current levels of drought frequency and intensity are sustained.

Introduction

The harmful effects on the Earth's weather systems due to ongoing global climate change are the subject of intense research. Many models have predicted significantly increased periods of drought across the globe if current patterns of global climate change continue to persist (Dai 2011). Global average temperature rose ~0.6º C between 1903 and 2003 (Root et al. 2003), with the greatest warming in Northern Asia and Northern North America. This pattern of temperature increase may be linked to an increase in global aridity, or dryness, since precipitation decreased across the globe over the same period (Dai 2011). For example, significant regional evidence of increasing drought deficit volume was seen in the United Kingdom, Spain, and parts of Eastern

Europe from 1962-1990 (Hisdal *et al.* 2001). Also, southern and southeastern Europe have been identified as high-risk areas for increased drought in the near future. In these regions, intense droughts that currently occur approximately once every 100 years may occur as often as once every 10-50 years by 2070 (Lehner *et al.* 2006).

Severe drought has sweeping detrimental effects across a variety of ecosystems. For instance, according to the Texas parks and Wildlife survey, as a result of "exceptional drought" in 2011, Texas experienced lower reproduction rates and plummeting population sizes in wildlife. In some areas of the northeastern panhandle and North-Central Texas, only five quail were found when there are usually 21 on average. Deer and antelope experienced similar problems in terms of reproduction. Researchers recorded 16 fawns for a sample of 100 does, compared to a five-year average of 35. For deer in southeast and central Texas, 66 fawns were counted for 244 does—only a 27 percent reproduction rate. Also, during an earlier extreme drought in the summer of 2006, decreased water volume and flow in the Trinity River Watershed in northeast Texas "resulted in greater crowding, more intense biotic interactions, and environmental stress" for local fish species (Pease *et al.* 2011). However, the ecological impacts of less severe drought are not as well understood. The least intense category of drought, "abnormally dry", typically affects more area than the more intense categories. According to the U.S. Drought Monitor, for instance, as of May 29, 2012, more of the U.S. (64.02%) was "abnormally dry" than in "moderate drought" (37.37%), "severe drought" (18.94%), "extreme drought" (5.22%), or "exceptional drought" (0.66%). Therefore, it is important to know how species may be affected by abnormally dry conditions. The northernmost portion of Michigan's lower peninsula was "abnormally dry" during 2011 for fifteen consecutive weeks, starting on February 1st (USDM 2012), which likely is a harbinger of future conditions, if large reductions in greenhouse gas emissions are not enacted quickly.

Wetlands, which include bogs, swales, and fens, are defined by soil that has high moisture content. For example, a past study showed that a fen near Carlton, Minnesota contained soil that had 94-96% moisture content by weight (Eleuterius and Jones 1969). Soil moisture contents of this magnitude are not found outside of wetland areas, making them a highly specialized habitat for many species of plants. However, while the high soil moisture of wetlands make them ideal growing environments for a variety of unique plants, it may also make them highly sensitive to

the effects of drought (Kim *et al.* 2008). If the water table drops below a wetland plant's root system, the plant will undergo moisture stress and transpire more water than it can absorb through its roots (Jacobs *et al.* 2002). It is clear that the increased prevalence of drought can act as a stressor on wetland plant species, and could potentially lead to a decrease in the availability of suitable habitats. Since they have evolved under conditions of high water availability, wetland organisms, and especially wetland plants, are highly sensitive to environmental fluctuations in available moisture. As such, they face elevated danger from climate change induced drought relative to plants existing in other ecosystems (Johnson *et al.* 2005). By studying the effects of drought on organisms which are more sensitive to fluctuations in moisture availability and overall precipitation, we might better forecast and mitigate damage caused by prolonged drought due by global climate change.

The purple pitcher plant, or *Sarracenia purpurea*, a common wetland species in northern Michigan, may be particularly susceptible to drought for two reasons. First, in order to capture insect prey, on which it relies for approximately 65% $\pm$ 3% of its nitrogenous nutrients (VanderKolk 2005), *S. purpurea* requires that rainwater collects within the plant's pitchers (Gallie and Chang 1997). The water held in the pitchers creates a habitat that largely defines the *S. purpurea*'s mode of nutrient acquisition (Kneitel and Miller 2003). Arthropods are contained in the pitcher fluid along with various commensal organisms and bacteria that also feed on the captured arthropods, which in turn provide digestible nutrients to the pitcher plant (Harvey and Miller 1996). Second, the purple pitcher plant, along with most other species of carnivorous plants, only have shallow, sparse root networks because they are adapted to living in high-moisture wetland environments. The roots of the *Sarracenia purpurea* are only about 30 cm deep (Chapin and Pastor 1995). If a drought were to occur in the *S. purpurea*'s habitat, the top portion of the soil would be most affected by the increased dryness, making the purple pitcher plant highly susceptible to changes in soil moisture level (Padilla and Pugnaire 2007). Clearly, carnivory and the shallow roots of *Sarracenia purpurea* make it highly reliant on an abundance of water.

In May 2012, we observed an unusually high level of pitcher mortality in a population of *S. purpurea* in Grass Bay, Cheboygan County, MI. We hypothesized that a variety of moisture-related factors affected the ability of *Sarracenia purpurea* plants to cope with the stress of an

abnormally dry growing season in 2011. To test this hypothesis, we examined the relationship between pitcher mortality, defined as the number of dead pitchers divided by the total number of pitchers on the plant, and variables that could be affected by the increased prevalence of drought. We reasoned that pitcher plants would be less adversely affected by the abnormal dryness of the summer of 2011 if they were:
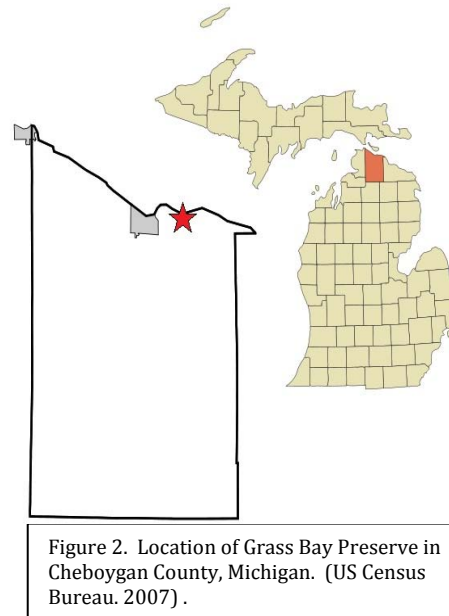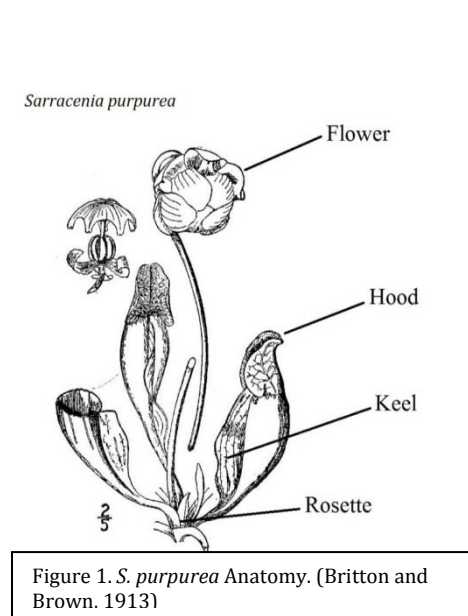
a) nearer to water, since water would have been more readily available,

b) in areas with higher levels of soil moisture, since high soil moisture would also be an indicator of better access to water,

c) to experience lower temperatures at plant level, since low-lying plants like the *S. purpurea* may experience an increasing degree of temperature-driven water stress due to an unfavorable increase in transpiration,

d) in areas with less competitive root biomass, since pitcher plants in areas of greater competitive density would have to compete more strongly for moisture as it became limiting.

Based on these variables we were able to formulate four specific questions regarding the response of *S. purpurea* to recent dryness. Specifically, in this study we asked:

1. Is the percent of dead pitchers on a plant positively correlated with the distance between the plant and the nearest standing water?

2. Is the percent of dead pitchers on a plant negatively correlated with the relative amount of soil moisture?

3. Is the percent of dead pitchers positively correlated with the average temperature at plant level?

4. Is the percent of dead pitchers positively correlated with the relative amount of competitive root biomass?

The response of *S. purpurea* to the recent abnormal dryness in northern Michigan could foreshadow an emerging trend in plant mortality due to climate change-induced drought.

Materials and Methods

Figure 1. *S. purpurea* Anatomy. (Britton and Brown, 1913)

Figure 2. Location of Grass Bay Preserve in Cheboygan County, Michigan. (US Census Bureau. 2007).

Sampling

We selected 100 *Sarracenia purpurea* (Figure 1) in an interdunal swale in Grass Bay Preserve outside of Cheboygan, Michigan (Figure 2) to be our sample population. The plants were selected to include a wide range of distances from the nearest significant source of water, that is, any source of water that is more than 3 inches deep. We also selected pitcher plants that showed varying degrees of pitcher mortality. We counted all live and dead pitchers for each individual. A dead pitcher was determined to be one that, at the very least, had its hood completely dried out. We calculated mortality as the ratio of dead pitchers to total pitchers. We also measured the amount of new pitchers on each plant. A new pitcher was defined as a leaf that had begun to develop a keel, but whose hood was not yet open. Additionally, we recorded the number of flowers for each individual plant, the number of damaged but still living pitchers, the diameter of each plant at its widest length and at the length perpendicular to that.

Is pitcher mortality correlated with access to water?

In order to determine if plant mortality increases with distance from water, we measured the distance from the plant to the nearest spot with at least three inches of standing water, a depth we assumed would have been sufficient to retain water during the dry summer of 2011. We then took soil core samples that were 2.54 cm in diameter and 40 cm deep. Samples were taken 25 cm away from each plant towards the nearest significant source of water. Wet samples were weighed shortly after collection, then placed in a drying oven for 24 hours and reweighed. The difference in wet and dry weights was used to calculate soil moisture under the assumption that

any difference in soil moisture between plants exhibited now, in May 2012, were comparable to how they were in the summer of 2011. We also assumed that relative temperature and competitive root bio-mass would be comparable conditions in past years.

Is pitcher mortality influenced by temperature?

In order to determine if pitcher mortality is related to the temperature experienced by the plant, we recorded the temperature inside four pitchers per plant: one each on the north, south, east, and west sides. For pitchers on the north and south sides, we placed the thermocouple inside the outermost pitchers. For pitchers on the east and west sides, we used the innermost pitchers. We also recorded temperature at the center of the pitcher rosette.

Is pitcher mortality influenced by competition with other plants?

To determine of pitcher mortality increases with increased competition from surrounding plants, we took soil core samples using the same methods described above to assess soil moisture. Samples were taken 25 centimeters away (to minimize counting the plant's own roots as competitive biomass) from each of 40 plants. Core samples were taken in two positions around the plant that were 180° apart. The samples were sifted to expose plant matter, which was then collected and weighed. A relative ratio of dry root mass to soil mass was recorded for each sample.

Statistical Analysis

Linear regression was used to detect relationships between pitcher mortality vs. distance to water, average pitcher temperature (using the average of all temperature measurements for each plant), average soil moisture, and relative competitive root biomass. R-squared values were compared among independent variables to analyze relative effect of each variable. Scatterplots were generated to visually investigate trends.

Results

Is pitcher mortality correlated with proximity to water?

It was hypothesized that the plants at further distances from water would exhibit a higher percentage of dead pitchers to live pitchers. The *S. purpurea* sampled from Grass Bay Preserve experienced a range of distances to water from 45.0 cm to 1610.0 cm with a mean distance to water of 739.8 cm. There was no statistically significant correlation between the distance to a sizable source of water and pitcher mortality ($R^2 = 0.007$, B = -0.0000359, p = 0.392, Figure 3).
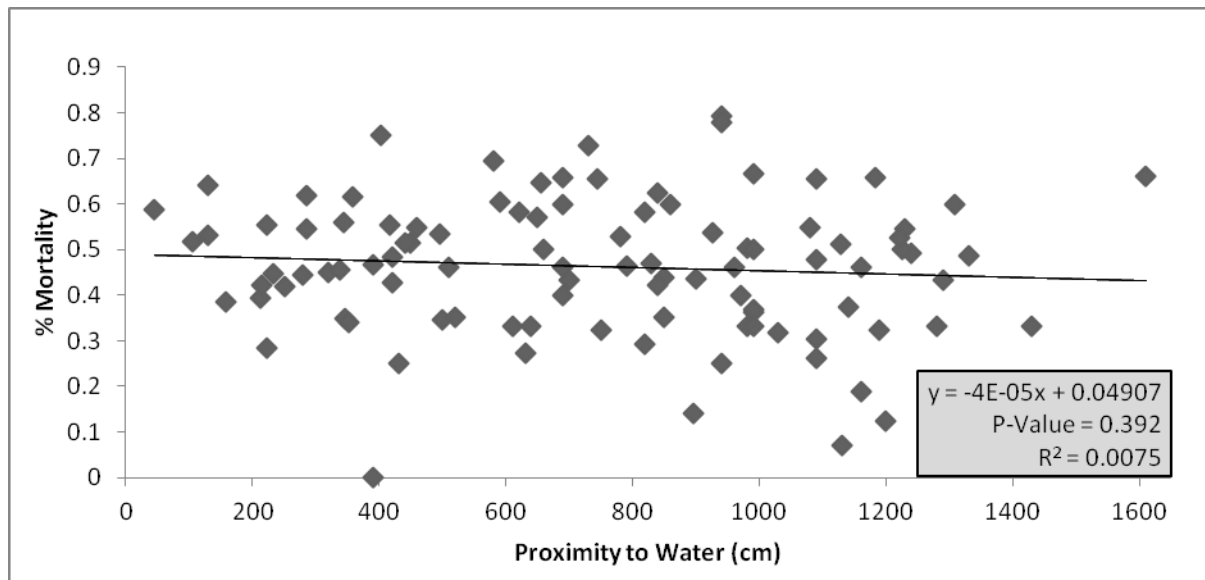

Figure 3. Percentage of pitcher mortality in relation to proximity to water.

Is pitcher mortality influenced by soil moisture?

It was hypothesized that the plants with a lower level of soil moisture in their immediate vicinity would have a greater percentage of pitcher mortality. The *S. purpurea* sampled from Grass Bay Preserve experienced a range of soil moistures from 17.7% to 49.9% with a mean soil moisture value of 28.0%. There was no statistically significant correlation between the average soil moisture and pitcher mortality ($R^2 = 0.050$, B = -0.612, p = 0.190, Figure 4).
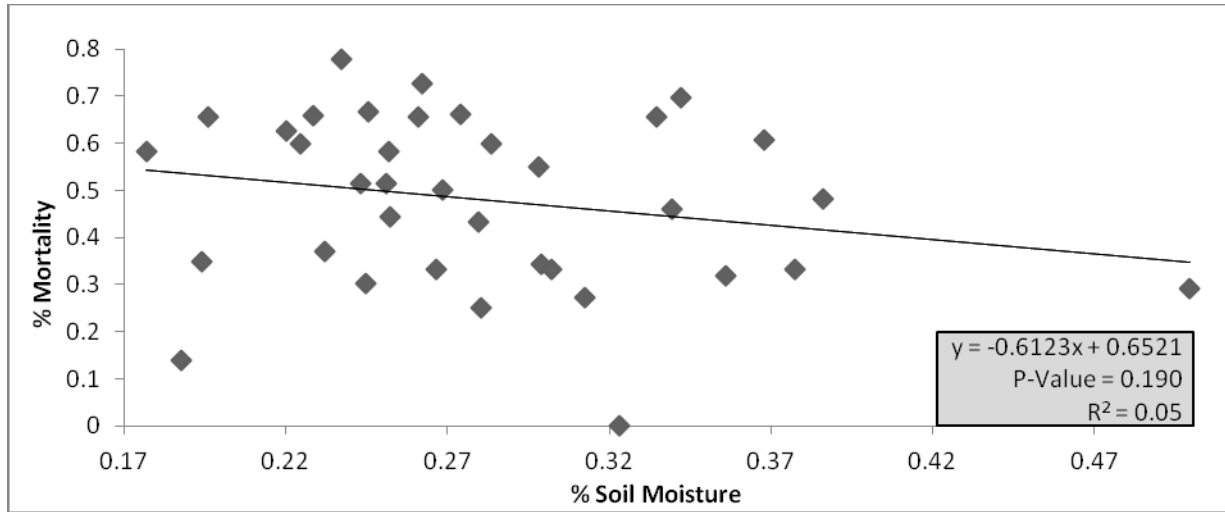
Figure 4. Percentage of pitcher mortality in relation to percentage of soil moisture.

Is Pitcher Mortality Influenced by Temperature?

It was hypothesized that plants that experienced higher average temperatures at plant level would exhibit a higher proportion of dead pitchers to total pitchers. The *S. purpurea* plants sampled from Grass Bay Preserve experienced a range of average pitcher temperatures from 18.15°C to 31.9°C with a mean average pitcher temperature of 24.03°C. There was no statistically significant correlation between the average pitcher temperature and pitcher mortality ($R^2 = 0.006$, B = -0.004, p = 0.452, Figure 5).
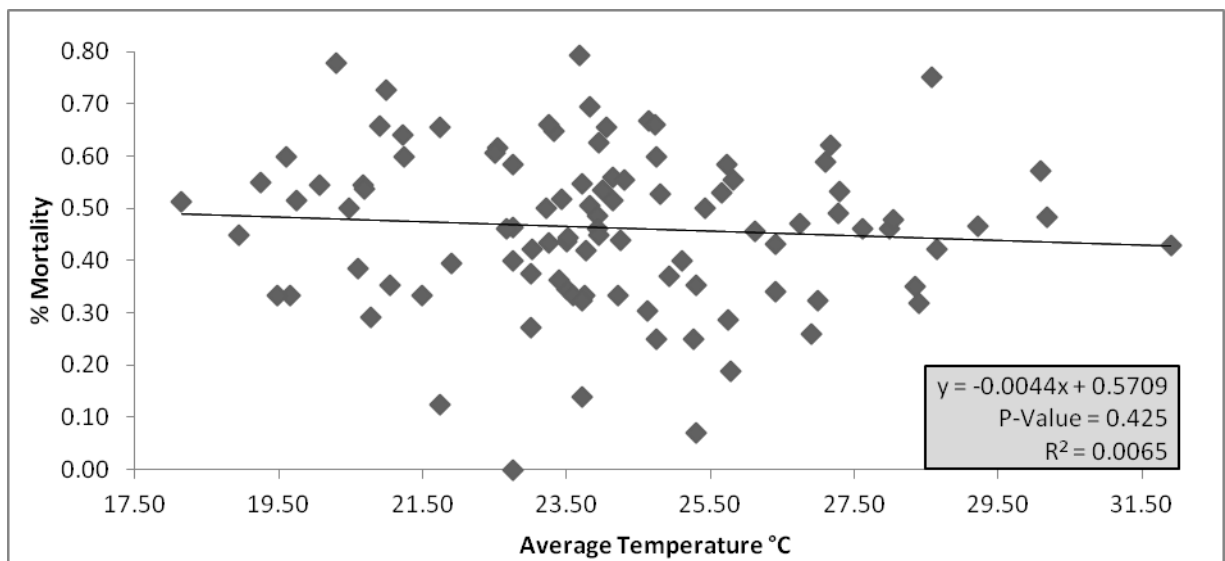
Figure 5. Percentage of pitcher mortality in relation to average temperature of pitchers.

Is pitcher mortality influenced by competition with other plants?

It was hypothesized that plants with a greater percentage of surrounding competitive root biomass to soil mass would exhibit a higher proportion of dead pitchers to total pitchers. The *S. purpurea* plants sampled from Grass Bay Preserve experienced a range of competitive root biomass percentage from 0.41% to 19.44% with a mean percentage of 4.64%. There was no statistically significant correlation between the percentage of competitive root biomass and pitcher mortality ($R^2 = 0.000$, B = -0.053, p = 0.941, Figure 6).
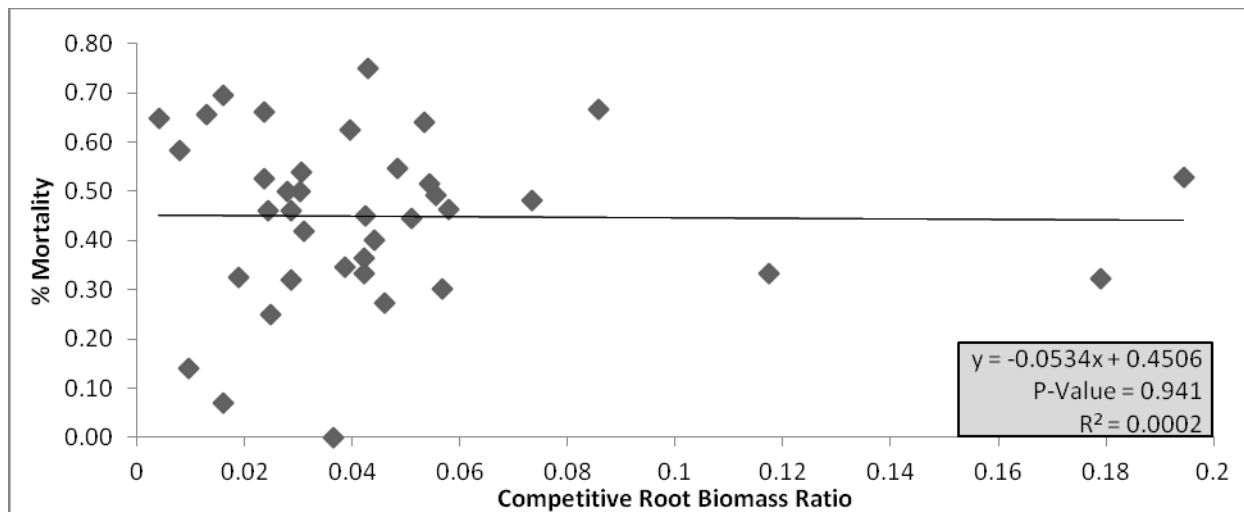

Figure 6. Percentage of pitcher mortality in relation to competitive root biomass ratio.

Further Analysis

To infer more about less significantly correlated variables, like the ones proposed in our hypotheses, stepwise regression was used. Stepwise regression examines the correlation between two variables with the correlative effects of other variables removed. In general, larger *S. purpurea* had a higher percentage of dead pitchers. Plant size was approximated as the surface area of ground covered by the plant. This was calculated by multiplying the two perpendicular rosette diameter measurements. The sample *S. purpurea* plants showed a size range from 120 cm^2 to 2940 cm^2, with a mean plant size of 790 cm^2. Using stepwise regression with pitcher mortality as the dependent variable, we found that plant size was the most significantly

correlated independent variable (B = 0.000, p = 0.215, Figure 7). The stepwise analysis then examined the correlation between plant size and pitcher mortality with the correlative effects of soil moisture and competitive biomass removed (B = 0.000, p = 0.100, Figure 7).

	Model	B	P-Value
1.	Plant Size	0.000125	0.215
2.	Plant Size	0.000225	0.1
	Soil Moisture	-1.1	0.269
	Competitive Root Biomass Ratio	2.473	0.301

Figure 7. Stepwise regression for pitcher mortality with plant size, soil moisture, and competitive root biomass ratio.

Additional Questions

Resource allocation to either growth or reproduction can vary with an organism's life expectancy. A single variable explaining resource allocation was represented by number of flowers divided by number of new pitchers. Life expectancy can be represented by pitcher mortality rate or by proportion of live pitchers to total pitchers. Based on knowledge of life history theory, it was hypothesized that plants with higher pitcher mortality or a lower proportion of live pitchers would show a greater amount of flowers relative to new pitchers. *Sarracenia purpurea* plants that had a higher ratio of live pitchers to total pitchers also showed a higher ratio of flowers to new pitchers. While there was no significant correlation between resource allocation and pitcher mortality (R^2 = 0.0209, B = 0.569, p = 0.182, Figure 8), there was a statistically significant correlation between the ratio of new pitchers and resource allocation ratio (R^2 = 0.5935 B = 0.2784 p = 0.018, Figure 9).
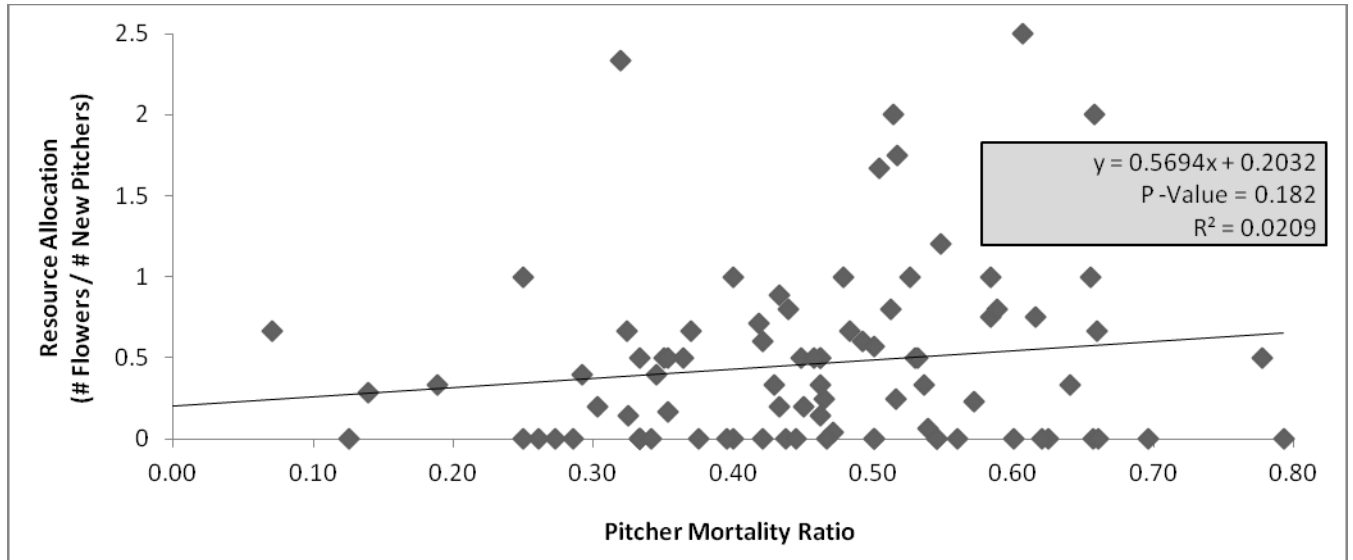
Figure 8. Resource allocation strategy in relation to pitcher mortality ratio.
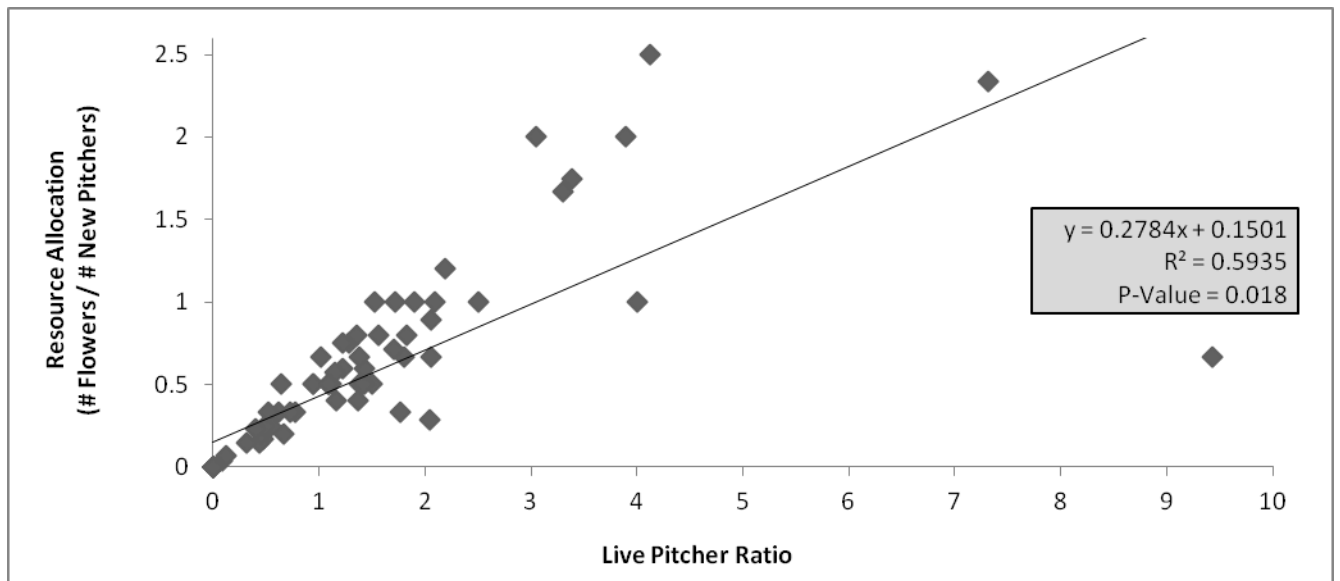

 Figure 9. Resource allocation strategy in relation to live pitcher ratio.

Also *S. purpurea* plants that showed a higher degree of pitcher mortality also showed a lower proportion of new pitchers. This correlation was statistically significant (R^2 = 0.071, B = -0.148, p = 0.007, Figure 10).
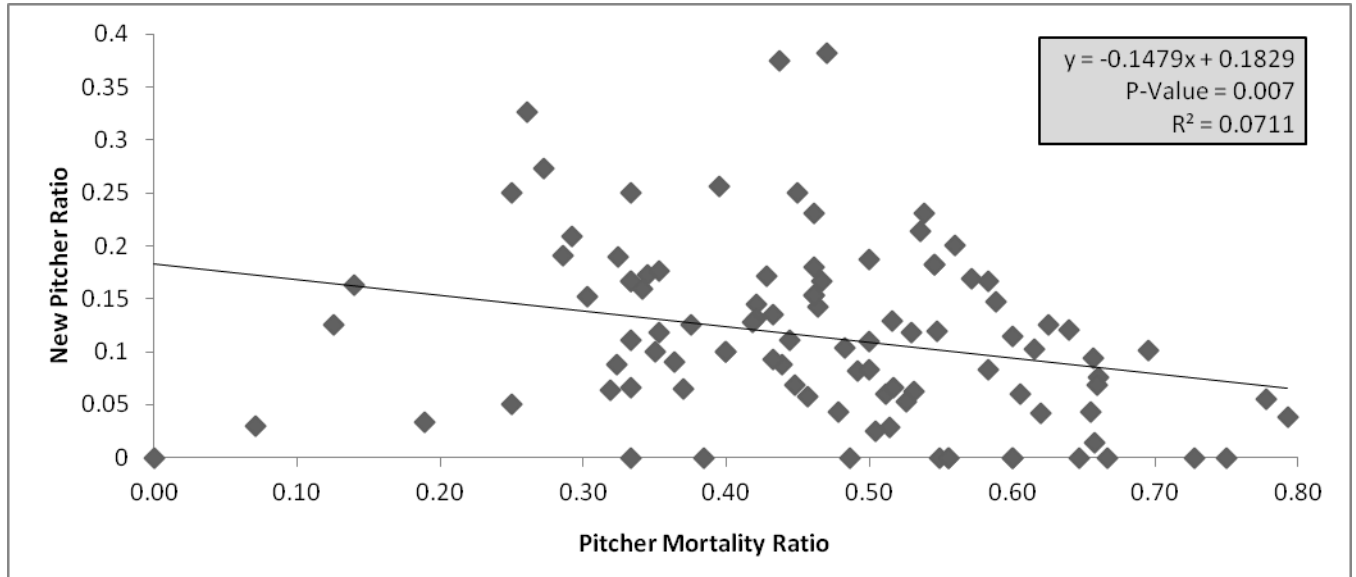
Figure 10. New pitcher ratio in relation to pitcher mortality ratio

While it did not explain the elevated mortality levels in our pitcher population, the temperature at the center of the rossette showed a statistically significant corralation with the number of new pitchers produced by the pitchers ($R^2 = 0.0216$, B = 0.1994, p = 0.045), potentially indicitive of the effects of temperature of soil resperation rates.
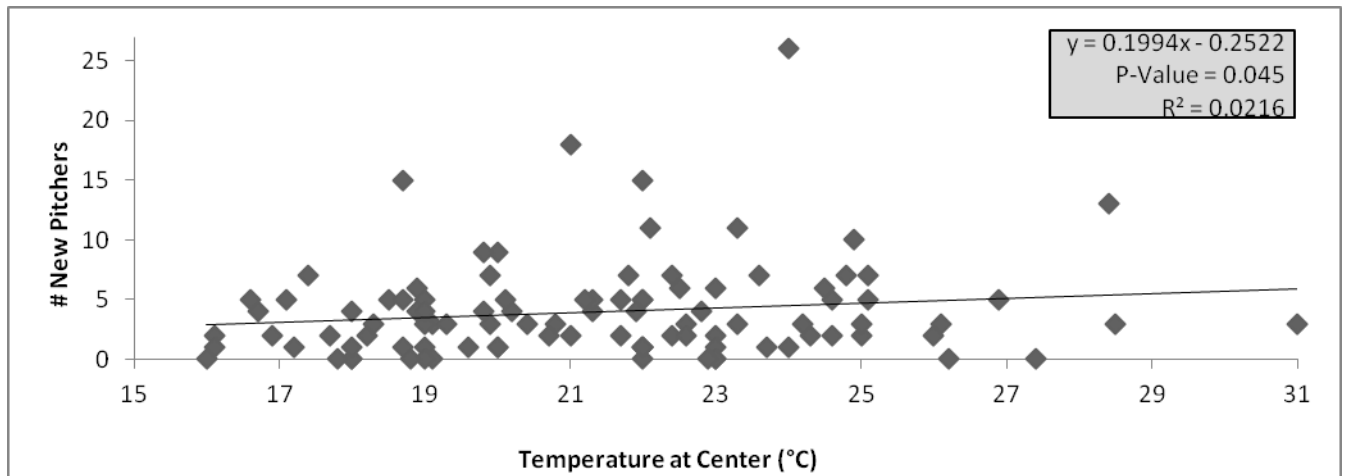

Figure 11. Number of new pitchers in relation to temperature at center of pitchers.

Furthermore, we were also able to investigate the effects of interspecies competition on the success of individual pitcher plants. Our anaysis showed a significant negative relationship between overall plant size and the relative competitive root biomass ratio ($R^2 = 0.1075$, B = -3706.8, p = 0.044).
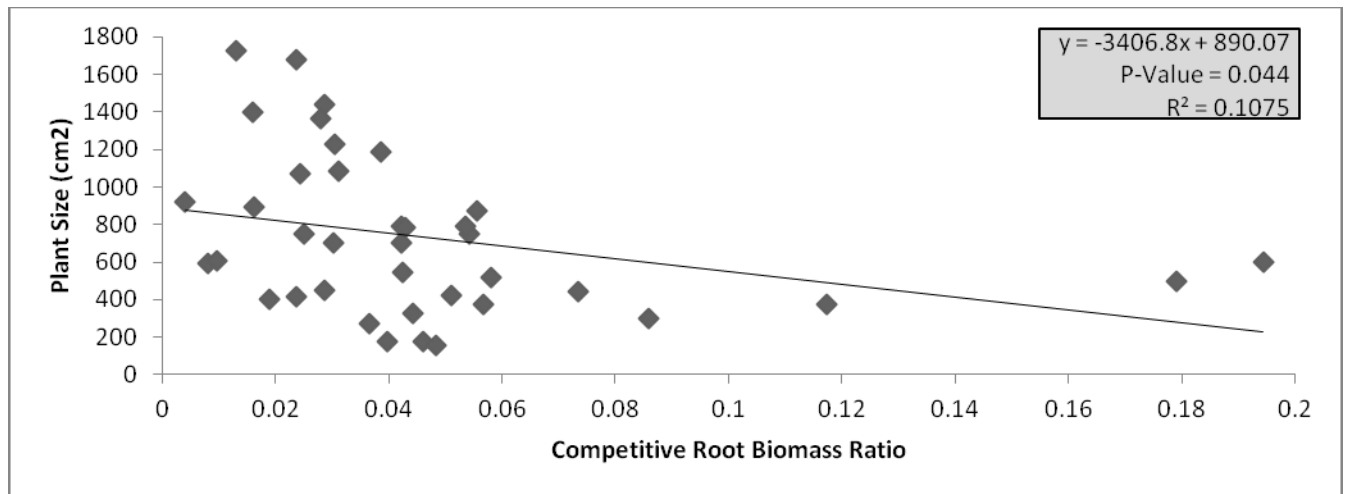

Figure 12. Plant size in relation to competitive root biomass ratio.

Discussion

In May 2012, a marked increase in *S. purpurea* pitcher mortality was noted. It was hypothesized that the fifteen consecutive weeks of abnormal dryness in northern Michigan in the early summer of 2011 could have been the cause of the pitcher mortality (USDM 2012). Economically, increased drought could have tremendous detrimental effects on global food supplies (Battisti and Naylor 2009). Many other ecosystems and their associated organisms are similarly threatened by these changes in climate. Past studies have found significant short term reductions in biodiversity among grassland communities as a result of drought (Tilman and Downing 1994). Currently, predictions on the rate and overall extent of loss caused by climate changed-related drought are difficult to predict. By studying the effects of drought on organisms which are more sensitive to fluctuations in moisture availability and overall precipitation, we hoped to better forecast and mitigate damage caused by prolonged drought due to global climate change.

However, after testing this hypothesis, there was no significant correlation found between proximity to the nearest source of water and pitcher mortality. This suggests that differential access to water was not the cause of the rise in pitcher mortality of the *S. purpurea* plants at Grass Bay Preserve. It is not certain, however, whether proximity to water most affects a pitcher plant's access to water or its access to insect prey, as studies have suggested that proximity to water is negatively correlated with insect population abundance (Heller 2005).

Additionally, to further test the hypothesis of moisture stress affecting *S. purpurea* pitcher mortality, moisture content of the surrounding soil was analyzed for the plants at Grass Bay. Similarly, there was no significant correlation found between the soil moisture content and pitcher mortality. This suggests that a differential amount of soil in the plants' immediate vicinity did not influence the rate of pitcher death. It appears that, based on the lack of significance of these two moisture-related correlations, that moisture stress was not the root cause of the abnormal rise in pitcher mortality. Past research also showed that carnivorous plants of the genus *Pinguicula* thrive in the rocky, limestone environments of the Mediterranean. Here, the *Pinguicula* plants are able to thrive in both dry, exposed areas and wet, shaded ones (Ellison et. al 2003). However, further drought and temperature-related stressors were analyzed in an attempt to ascertain the reason for the pitcher mortality increase.

As greenhouse gases continue to be emitted into the atmosphere from the burning of fossil fuels, global average temperatures are expected to rise. Even small increases in average temperature could have drastic effects on low-lying, moisture-dependent plants like *S. purpurea*. At ground level, temperatures can be much higher than at a human's face level. In addition, since *S. purpurea* is dependent on collecting water in its pitchers for prey capture, it is highly sensitive to evaporation. However, our findings suggested no significant correlative relationship between the average temperature at plant level and pitcher mortality. This suggests that differences in average temperature within the observed range of 18.15°C to 31.9°C do not significantly affect pitcher mortality rates in the *S. purpurea* at Grass Bay. It appears that *S. purpurea* are capable of withstanding temperature variations within in this range without affecting pitcher mortality. Other recent research, however, has shown temperature to be a factor in accelerating drought-dependent mortality. A ~4°C increase in temperature was shown to shorten the time it took for *Pinus edulis* to succumb to drought by one-third (Adams *et al.* 2009).

In order to further examine the effects of potential moisture stress on *S. purpurea* pitcher mortality, a measure of interspecific competition was assessed. When a resource like water is not limiting, meaning there is enough of it for all the organisms in the vicinity, competition does not occur. But, if the abnormal dryness of the summer of 2011 caused water to become a limiting resource for the *S. purpurea* plants at Grass Bay, then competition for water could have potentially become a factor in determining the increase in pitcher mortality. However, as was the case with the previous hypotheses, no significant correlation was found between the mass of competitive roots surrounding the study plants and their rate of pitcher mortality. These findings suggest that during the fifteen weeks of abnormal dryness during the early summer of 2011 it may not have become dry enough at Grass Bay for water to become a limiting resource for the *S. purpurea* plants. However, past research on plant competition in *Stipagrostis uniplumis* grasses has shown that an increased level of competition, measured by neighboring plant density, was associated with higher mortality rates (Zimmermann *et al.* 2010).

While none of these variables (proximity to water, soil moisture, average temperature, or competitive biomass) showed a statistically significant correlation with pitcher mortality, further statistical analysis was performed in order to assess the potential effect of several independent variables with the effects of other potential confounds removed. Using stepwise regression, plant size exhibited the strongest correlation with pitcher mortality when the correlative effects of soil moisture and competitive root biomass removed. Even still, with a p value of 0.100, this correlation was still not statistically significant. However, for the purposes of this study, a p-value of 0.100 was considered marginally significant. Since the B-value (slope) of the regression line was positive, this indicates a positive correlation between plant size and pitcher mortality. This suggests that, of the *S. purpurea* plants at Grass Bay, the larger plants experienced a greater percentage of pitcher mortality. This could potentially be indicative of moisture stress because, presumably, larger plants need more water to supply their greater tissue. Additionally, since larger plants have more pitchers of greater volume, they also need to collect more water in order to effectively capture insect prey in order to obtain nitrogenous nutrients. Since smaller plants may need a smaller volume of available water to survive, this could explain the observed relationship that smaller plants exhibited a lesser degree of pitcher mortality if the moisture stress of the abnormally dry conditions of 2011 did, in fact, affect pitcher mortality.

Although it was not our original intent, our data allowed us to explore further questions regarding the response of *S. purpurea* to recent moisture stress. Life history theory states that when an organism's life expectancy is low it may be advantageous to invest more of its resources in reproduction than in growth. In *S. purpurea*, especially after a period of abnormal moisture stress, there may be a similar trade-off between allocation of resources for reproductive structures and growth. For the purposes of this study, allocation of resources to reproduction was represented by the proportion of flowers to new pitchers and the growth resources was represented by the proportion of new pitchers to total pitchers. Based on knowledge of life history strategies, it was hypothesized that plants with a lower life expectancy (i.e. greater pitcher mortality) would devote more resources to reproduction rather than growth, by producing more flowers than new pitchers. It was observed that *S. purpurea* plants with high rates of pitcher mortality produced a greater ratio of flowers to new pitchers, but the correlation was not statistically significant. However, life expectancy could also be reasonably modeled by the ratio of live pitchers to total pitchers. Percentage of live pitchers could also serve as a proxy for life expectancy because it would give a measure of both photosynthetic and prey-capturing tissues, which both likely contribute to an individual plant's fitness. A statistically significant correlation was found between the ratio of live pitchers and the plants' resource allocation strategy. However, this observed relationship actually showed a positive correlation between the percentage of live pitchers and relative flower production. This observed correlation could be due to the fact that *Sarracenia purpurea* plants do not have the mechanisms to assess their own life expectancy. Taking this into account, it would be more plausible for the plants with the greatest amount of live pitchers to produce the most flowers simply because they have the resources available to do so. Also it could be that the presumed stress on the plants' life expectancy was simply not strong enough to engage an observed response in resource allocation strategy. Interestingly, however, recent research into plant life history strategy showed that *Zostera marina* produced more seeds after being cut. This indicates that as the *Zostera marina*'s presumable life expectancy was shortened, they were able to compensate by investing more resources into reproduction (Ruesink *et al.* 2012).

Contrary to our initial predictions, temperature demonstrates a positive correlation with overall plant fitness, measured by number of new pitchers produced. This suggests that elevated

evaporative rates caused by hotter surface temperature do not have a significant impact on pitcher health (Atchley and Maxwell 2011). Instead, increased surface temperature appears to provide at least a short-term benefit to the plant, perhaps in part by increasing the rate of soil respiration. The positive effects of temperature on the rate of soil respiration has been well documented, and may cause unexpected outcomes on the fitness of plants as a result of global warming (Rustad *et al.* 2000).

Another interesting trend in our results was the negative correlation between competitive root biomass ratio and plant size. While it is intuitive that plants with reduced competition should do relatively better, our data did not have a statistically significant correlation with competitive root biomass and number of new pitchers. Thus, it might be possible that while competition prevents pitchers from grown dimensionally larger, it does not affect the plants' ability to produce new pitchers, so that the plants primary limiting resource is space and not nutrition. Our findings seem to complement past research, which has shown that plants grown at higher densities tend to be smaller and show greater size variation than similar plants grown at low densities over the same time period (Miller and Weiner 1989).

Although we carefully developed our methods so to ensure the quality of the data, both through large sample size and multiple tests for potentially confounding variables, it was still possible that error could have influenced the results. Some potential sources of noise in the data include variation the soil composition across the swale. In our sampling of the soil surrounding the *S. purpurea* plants we found that there was a wide variation in its consistency, from sandy to muddy. The differential soil composition and particle size could have contributed to a varying degree of nutrient leaching, especially since some of the soil was quite moist, which could have potentially had an effect on pitcher morality. Also, further noise in the data could have arisen from the fact that older *S. purpurea* plants may have had an accumulation of dead pitchers dating back to before the abnormally dry summer of 2011. Since older plants would have presumably had more pitchers before the summer 2011, they would also have had a greater amount of dead pitchers even before the bout of dryness. This would have led to a higher perceived pitcher mortality rate for older plants during data collection in May, 2012 which would have caused some degree of noise within the pitcher mortality data

Further areas of research would logically lead to manipulative experimentation of *S. purpurea* growing conditions, rather than the correlative observation performed in this study. For example, soil moisture conditions could be manipulated, with other variables held constant, in order to see definitively if moisture was a factor in influencing differential pitcher mortality. Manipulative experimentation involving other variables, such as growing temperature or competitive density, could also tell us about other factors that may contribute to pitcher mortality. It may also be worthwhile to examine similar correlative relationships in *S. purpurea* plants in habitats that experienced more severe drought than Grass Bay Preserve. This may provide more informative findings, especially if water became a limiting resource only during drought more severe than the abnormal dryness observed in northern Michigan last summer. Finally, in order to further investigate the life history strategy of *S. purpurea*, a further manipulative study could be performed in which varying levels of life-threatening disturbance could be imposed on *S. purpurea* plants in order to examine whether preferential resource allocation to either growth or reproduction occurs.

The *Sarracenia purpurea* plant can act as a potential harbinger for future effects on local flora due to global climate change. While our findings at Grass Bay led to several interesting conclusions, they also raised some pertinent questions about future plant responses to climate change. When considered in conjunction with one another, our findings for various drought-related variables suggest that *S. purpurea* plants are capable of withstanding and recovering from at least one summer of intermittent abnormal dryness. Based on the results of this study, it appears that the root explanation for the increased pitcher mortality seen at Grass Bay was unrelated to the abnormally dry conditions of last summer. These findings may actually indicate an optimistic outlook on the current effects of global climate change on moisture-sensitive plants. While there is no doubt that greenhouse gas emissions are contributing to the warming of the planet, it appears that if the degree of warming and drought prevalence were to be maintained at today's levels, then even drought-sensitive species like the *Sarracenia purpurea* may not yet be facing extinction due to climate change. Since global carbon emissions are continually increasing, much work must still be done in order to prevent the state of climate change from advancing far beyond its current level.

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