First-Year Research in Earth Sciences: Dunes

Investigation of Variables Affecting a Rare Plant Species, *Cirsium pitcheri*, on Mt. Baldy in P.J. Hoffmaster State Park

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FYRES: Dunes Research Report # 18
June 2016

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1.0 Abstract

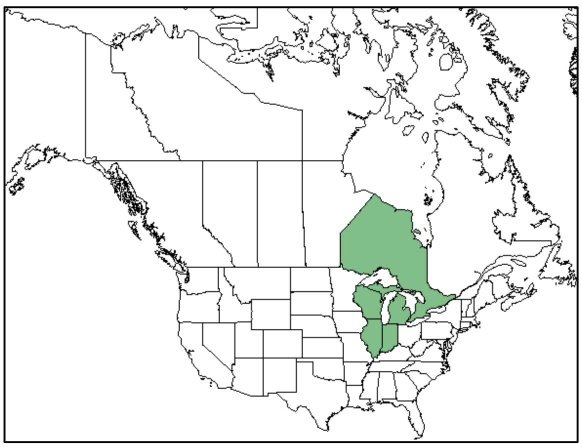
Cirsium pitcheri, an endangered plant found only in specialized dune conditions, serves as an exemplar of environment-vegetation interactions. We investigated these interactions by focusing on variables that might affect the survival and growth of *C. pitcheri* on Mt. Baldy in P.J. Hoffmaster State Park, Michigan. Our objectives were to document plant characteristics and investigate the optimal conditions for plant growth. Using GPS units and ArcGIS visualization, we mapped the locations of the plants and dune sub-environments. Measurements of leaf length, plant health, slope angle, and aspect were recorded for each located plant. In addition, vegetation density and diversity were measured and recorded in each dune sub-environment. Study results showed *C. pitcheri* was abundant in several dune sub-environments, including dune ridges and slipfaces, as well as deflation areas of blowouts. A majority were found on south-facing slopes and these were also the healthiest individuals. No significant relationship was found between slope angle and maximum leaf length or plant health, but results did show a majority of individuals growing on slopes of less than the angle of repose. This research offers a means to better understand the interactions of *C. pitcheri* with its dune environment and could assist restoration efforts by suggesting dune locations where *C. pitcheri* would most likely thrive.

2.0 Introduction

Cirsium pitcheri (commonly known as Pitcher's thistle) is an endangered plant found only in specialized dune conditions and it serves as an exemplar of environment-vegetation interactions (Gauthier *et al.* 2010). This species is threatened by human activity, habitat loss, herbivory and climate change (Havens *et al.* 2012). Previous research has identified various factors influencing the plant's growth, including sand burial (Maun *et al.* 1996) and light availability (Jolls *et al.* 2015); however, many possible influential variables have not yet been investigated. Our study aimed to identify additional dune characteristics and variables that influence the location and growth of *C. pitcheri* on a large Great Lakes dune. Our objectives were to (1) document individual *C. pitcheri* characteristics in several dune environments, (2) collect data on variables that affect *C. pitcheri*, and (3) examine data for patterns which show the optimal conditions for the growth of *C. pitcheri*.

3.0 Background

C. pitcheri is a federally-threatened thistle endemic to the sand dunes of the Great Lakes region (figure 1; Gauthier *et al.* 2010). It is a monocarpic, herbaceous plant (Fant *et al.* 2013) that can be identified by its silvery-green leaves and rosette growth formation (figure 2; Rowland and Maun 2001). *C. pitcheri* is particularly vulnerable to impacts from humans, herbivory and climate change (D'Ulisse and Maun 1996; Staehlin and Fant 2015) due to the nature of its life cycle and the specificity of its habitat.



a) b)

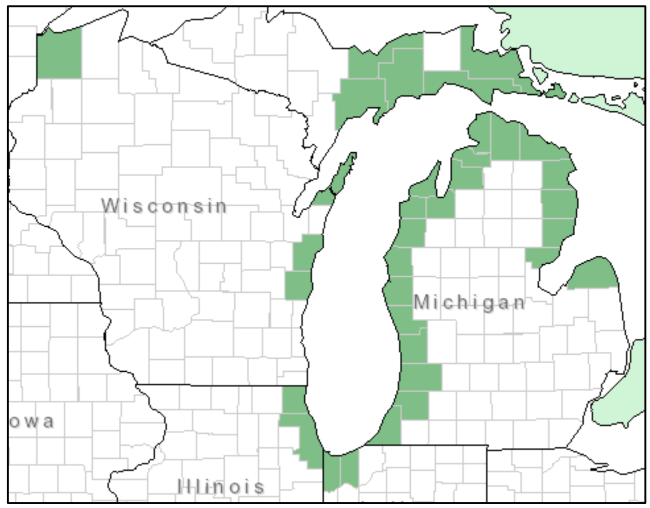


Figure 1: *Cirsium pitcheri* habitat range in a) the United States and b) the Great Lakes Region (USDA 2014).

Figure 2: *Cirsium pitcheri* rosette.

C. pitcheri flowers and dies after 5-8 years in the juvenile stage (Baskett *et al.* 2011). Upon dying, its flower heads fall, with seeds either being dispersed by the wind or remaining close to the parent (D'Ulisse and Maun 1996). Seed dispersal enables the species to persist in dune environments including the foredune and dune ridge (Gauthier *et al.* 2010). The plant's growth is dependent on burial by and disturbance of sand (Rowland and Maun 2001) therefore limiting its habitat to active parts of the dune.

The current small and diminishing *C. pitcheri* populations found in the Great Lakes regions, and their great susceptibility to human and other impacts, suggests the particularity of the environment and conditions needed for the growth and survival of this thistle. Previous studies have attempted to identify what factors contribute to and influence the growth of *C. pitcheri*. These factors include: shade; sand burial; herbivory; sand texture; vegetation cover; climate change; and various topographical factors (table 1).

Understanding the optimum conditions and environment in which *C. pitcheri* grow and thrive is key to the planning and undertaking of restoration efforts. Rowland and Maun (2001) offer a strong foundational investigation of variables that influence the survival and growth of

Table 1: Previous studies and their findings on variables influencing the growth of *C. pitcheri*

Variable	**Influence on growth of *C. pitcheri***	**Study**
Shade	Inhibits growth and survival	Rowland and Maun 2001; Jolls *et al.* 2015
Sand burial	Small amounts stimulate plant growth, but large amounts inhibit seedling emergence and survival	Maun *et al.* 1996; Rowland and Maun 2001
Herbivory	Temporary set-back of growth; re-growth of eaten shoots after herbivory causes decreased belowground biomass	Rowland and Maun 2001; Havens *et al.* 2012
Sand texture	No effect	D'Ulisse and Maun 1996
Vegetation cover	Increased vegetation cover may inhibit growth due to increased competition for water and resources; increased density of vegetation decreases abundance of *C. pitcheri*	D'Ulisse and Maun 1996; Marshall 2014
Climate change	Increased temperatures inhibit growth	Havens *et al.* 2012; Staehlin and Fant 2015
Topography	Increased dune aspect and slope correlated with increased abundance of *C. pitcheri*	Marshall 2014
Habitat loss	Inhibits growth and survival	Havens *et al.* 2012
Human activity	Inhibits growth and survival	Havens *et al.* 2012

C. pitcheri. Rowland and Maun (2001) suggest how their findings should influence the ways in which the restoration of *C. pitcheri* populations is carried out. However, this study focused on only four variables. Thus there is a need to investigate additional variables in order to produce the best restoration results.

4.0 Study Area

This study was conducted on Mt. Baldy in P.J. Hoffmaster State Park, along the eastern shore of Lake Michigan (figure 3). P.J. Hoffmaster State Park has an area of approximately 1200 acres (MDNR 2016) and contains eight dunes, of which Mt. Baldy is the largest. *C. pitcheri* is found throughout the park, with significant populations on Mt. Baldy. At this site, we chose two large study areas that could be divided into dune sub-environments based on their characteristics.

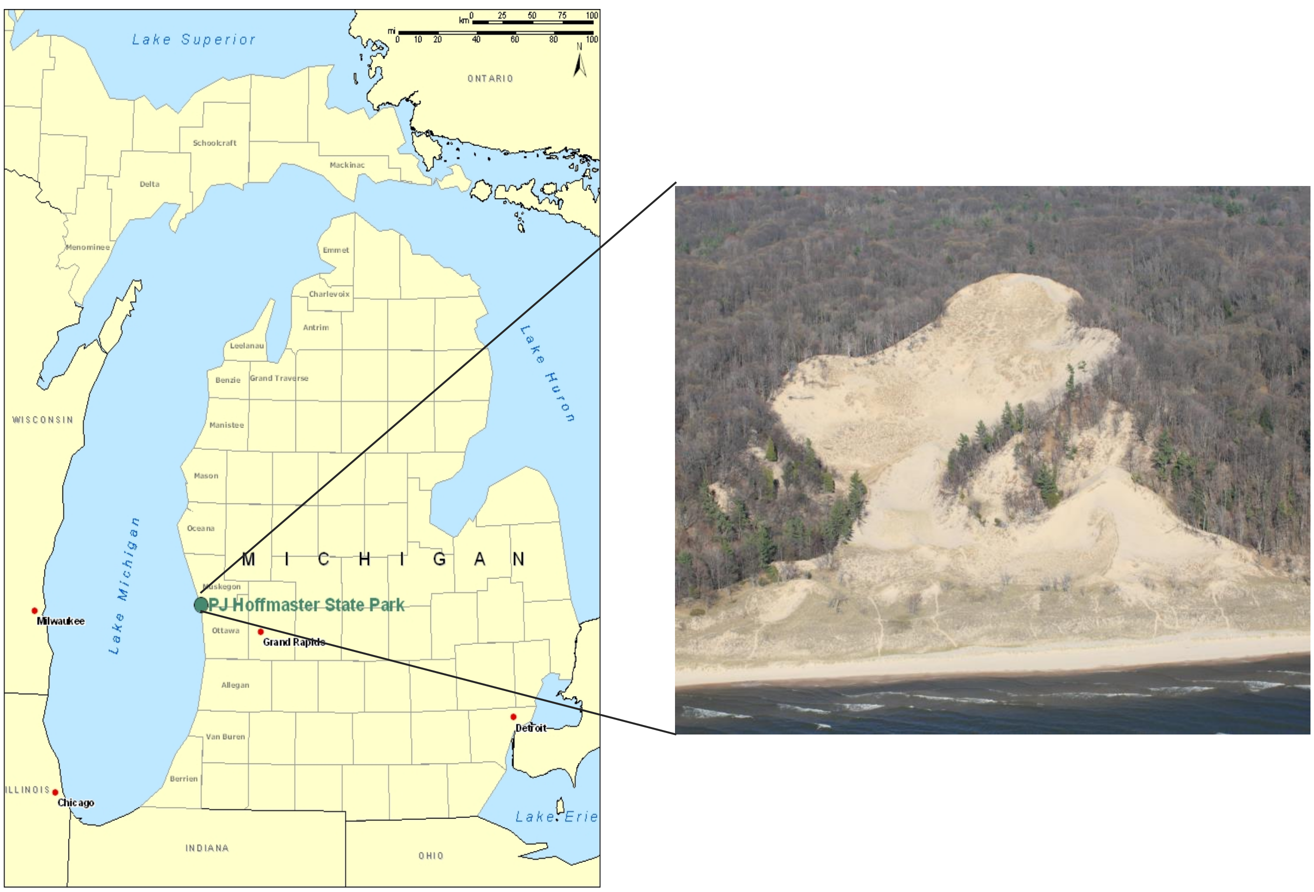


Figure 3: Location of P.J. Hoffmaster State Park in Michigan (Cartographer Matt Holly) and oblique view of study site (USACE 2012).

5.0 Methods

Our study was conducted from late October to early November, 2015. At the beginning of each site visit, starting field conditions were recorded, consisting of temperature, wind speed and wind direction. A variety of methods were then used for data collection at each study area to address our study objectives. The methods can be categorized into three groups according to the subject of data collection: individual plant characteristics, dune characteristics, and surrounding vegetation characteristics (table 2).

Table 2: Summary table of variables for data collection.

Individual Plant Characteristics	Dune Characteristics	Surrounding Vegetation Characteristics
• Location • Number of leaves • Maximum leaf length (cm) • Is the plant shaded? • Evidence of damage by herbivores? • Health rank • Age class	• Slope angle at each plant location (degrees) • Aspect at each plant location (degrees and direction) • Dune environment at each plant (description) • Location of trails	• Vegetation density in sub-areas • Vegetation diversity in sub-areas

5.1 Individual Plant Characteristics

Within each study area, *C. pitcheri* individuals were located and flagged. Using Trimble Juno GPS units, the location of these individuals was recorded. GPS data was downloaded, post-processed, and spatially visualized using ArcGIS desktop software.

For each individual, a number of other measurements and observations were recorded. The number of leaves on each plant was counted and the length (cm) of the longest leaf was measured; from these two variables, the age of each individual was determined using classification adapted from the U.S. Fish and Wildlife Service 2010 5-year Pitcher's thistle review (table 3). The health of each plant was ranked on a 5-point scale, with 1 indicating unhealthiest and 5 indicating healthiest. Additional observations were made of evidence of herbivory and whether the plant was shaded or not.

Table 3: Age class distinctions adapted from the U.S. Fish and Wildlife Service (USFWS 2010).

Age Class	Classification/Indicator
Seedling	4 leaves or less
Small juvenile	>4 leaves & <12 inches
Large juvenile	>4 leaves & >12 inches
Adult	In flower or standing dead

5.2 Dune Characteristics

We recorded characteristics of the dune environment in which each plant was situated. The slope angle and slope aspect of the dune at each plant location were measured using an Abney level and compass, respectively. Aspect measured in degrees was later classified into compass direction (315°-45° = north; 45°-135° = east; 135°-225° = south; 225°-315° = west). The dune environment at each plant was recorded as a description, for example “foredune” or “slipface”. We were also able to use the Trimble Juno GPS units to record the boundaries of our study areas and the location of trails within our study areas. This information was downloaded, post-processed, and spatially visualized using ArcGIS. During post-processing and spatial visualization, some boundaries of the study areas were re-drawn within the ArcGIS environment due to misalignment issues.

5.3 Surrounding Vegetation Characteristics

The characteristics of the vegetation surrounding the *C. pitcheri* populations were recorded within the dune sub-environments of each of the two large study areas. A quadrat was thrown into each sub-environment three times; with each throw, the vegetation density and diversity was recorded. Using these measurements, the mean density and diversity was calculated for each sub-environment. The boundaries of each sub-environment were recorded using the Trimble Juno GPS units, and this information was downloaded, post-processed, and spatially visualized as described previously.

5.3 Analysis

The collected data was pulled into Excel and formatted clearly. Graphs and statistical tests were used to compare variables and analyze them for significant relationships. These tests were conducted in SPSS and Stata and included correlation tests such as Spearman’s Roh and Kendall’s tau, and variances tests such as the Kruskal-Wallis H test.

6.0 Results

6.1 Characteristics of *C. pitcheri* Individuals on Mt. Baldy

In total, 131 *C. pitcheri* individuals were mapped (figure 4), though many more were observed on Mt. Baldy. Individuals were found in several different dune environments, including dune ridge, slipface, windward slope, and blowout deflation area. The plants often occurred in clusters; the mean and median distances between *C. pitcheri* individuals were 1.5m and 1.2m, respectively.

In addition, individuals were observed growing at a variety of distances from a trail; 55% were within 7m of the nearest trail, and the mean and median distances from individuals to the nearest trail were 8.3m and 6.5m, respectively.

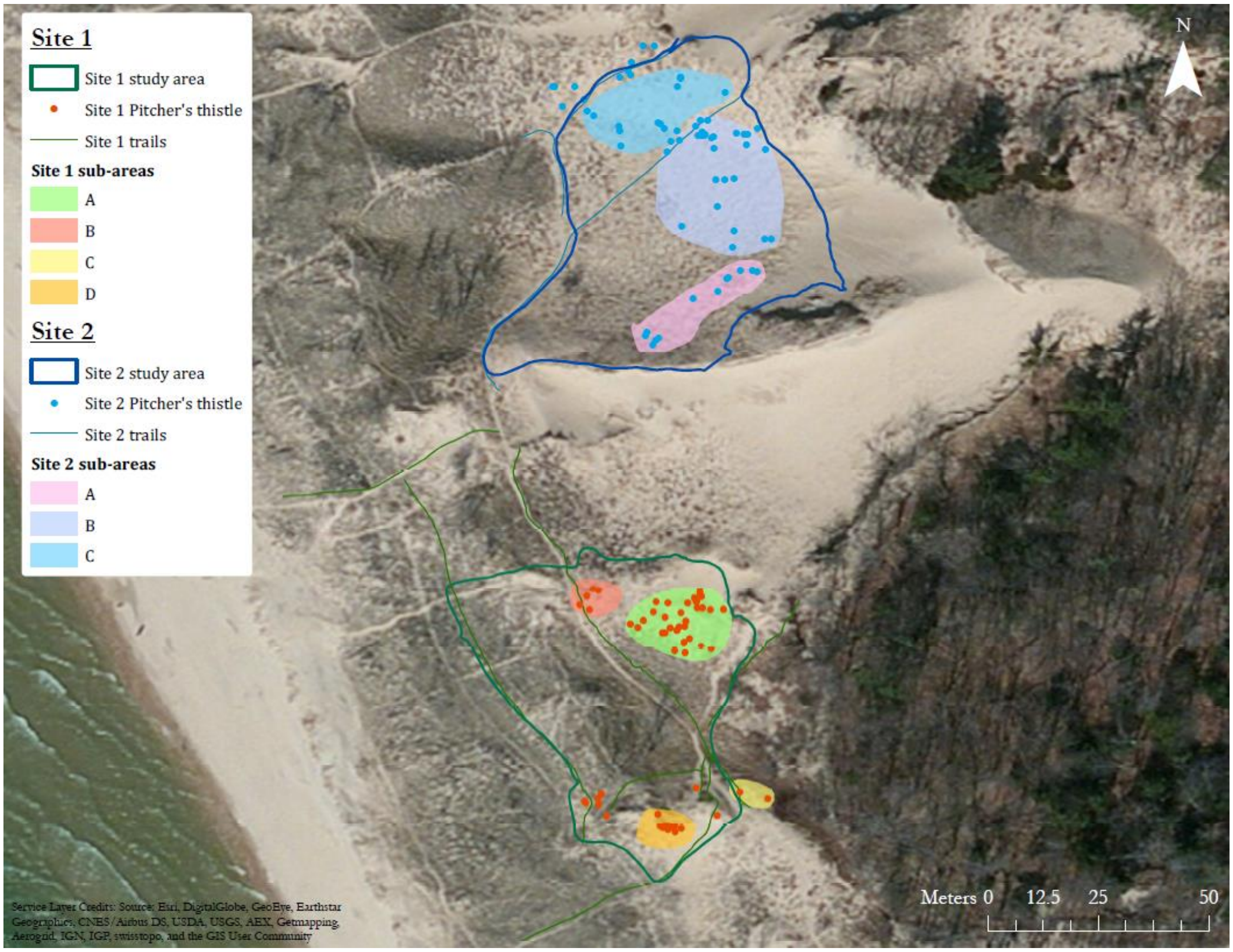


Figure 4: Study sites, sub-environments, observed *C. pitcheri* individuals, and location of trails on Mt. Baldy, P.J. Hoffmaster State Park.

C. pitcheri on Mt. Baldy varied in size and age, with the length of the longest leaf ranging from 1.5 to 33.6 cm. The majority of individuals were small juveniles (63%) and seedlings (33%), with very few large juveniles and dead adults observed (figure 5).

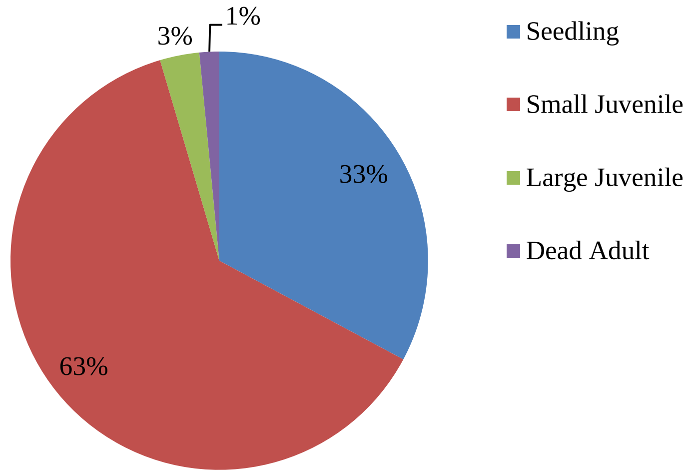


Figure 5: Age of observed *C. pitcheri* individuals on Mt. Baldy, P.J. Hoffmaster State Park.

6.2 Dune Characteristics

C. pitcheri individuals were observed to be located almost equally between gentle (0-10°), moderate (11-20°), and steep (21-30°) slopes, with only 8% located on very steep (>30°) slopes (figure 6). There was no correlation between the number of individuals and the slope angle (figure 7). The relationship between the angle of the dune slope and the health of the individuals was statistically insignificant (Spearman's roh, p = 0.3166; Kendall's tau p-value = 0.2633). In addition, the relationship between the dune slope angle and length of the longest leaf was statistically insignificant (R^2 = 0.0326).

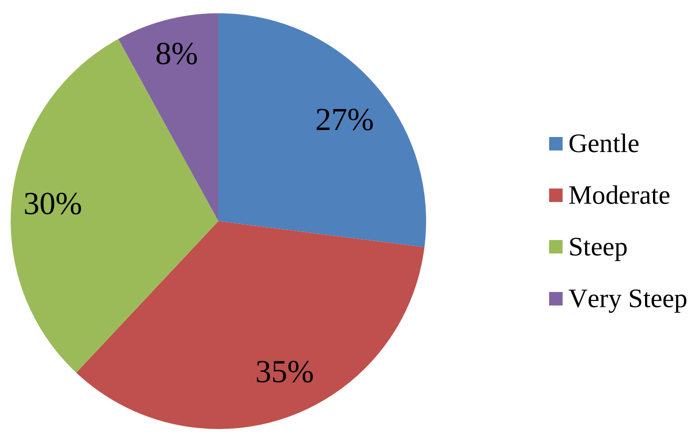


Figure 6: Distribution of *C. pitcheri* individuals by slope steepness.

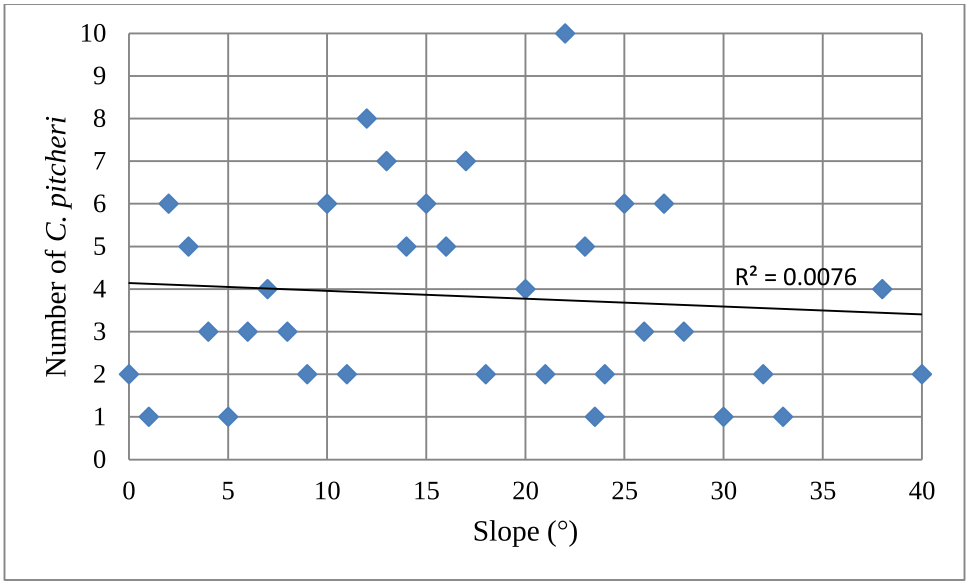


Figure 7: Distribution of *C. pitcheri* individuals by slope angle.

Almost half (45%) of *C. pitcheri* individuals surveyed were located on south-facing slopes (slopes with an aspect of between 135° and 225°), with the other half distributed on north-, east- and west-facing slopes or on a flat surface (figure 8). There was no significant relationship between slope aspect (measured in degrees) and length of longest leaf (R^2 = 0.0124) and there was no significant relationship between slope aspect (compass direction) and length of longest leaf (one-way ANOVA, p = 0.267). A Kruskal-Wallis H test to determine if there was a difference in health of *C. pitcheri* dependent on slope aspect (compass direction) showed that there was a statistically significant difference (p = 0.0010). Following this, a Bonferroni pairwise comparison of means between groups (slope direction) was conducted in order to determine which specific groups were different. The pair which gave a statistically significant result was the comparison of north-facing and south-facing slopes (p = 0.044).

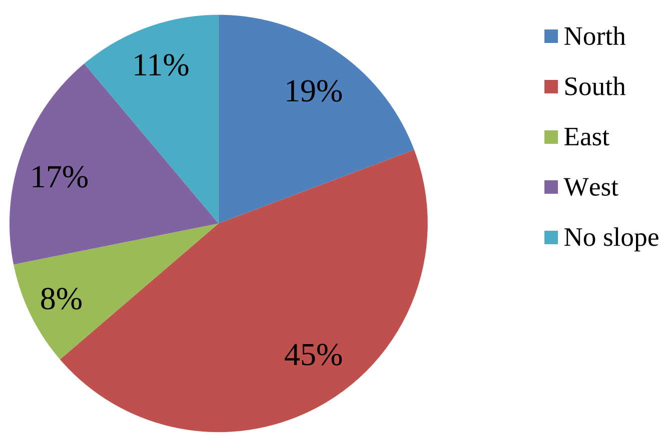


Figure 8: Distribution of *C. pitcheri* individuals by slope aspect.

6.3 Surrounding Vegetation Characteristics

Mean density of vegetation surrounding *C. pitcheri* within the four dune sub-environments of site 1 ranged from 10.7 plants per m^2 to 32 plants per m^2. Vegetation density appears weakly correlated with the number of *C. pitcheri* individuals (figure 9). Mean density of vegetation within the three sub-environments of site 2 ranged from 21.3 plants per m^2 to 66.7 plants per m^2.

Mean diversity of vegetation surrounding *C. pitcheri* within the dune sub-environments of sites 1 and 2 was consistently between one and two species, including *C. pitcheri* (figure 10).

Figure 9: Vegetation density and number of *C. pitcheri* individuals by sub-environment (A, B, C, and D).

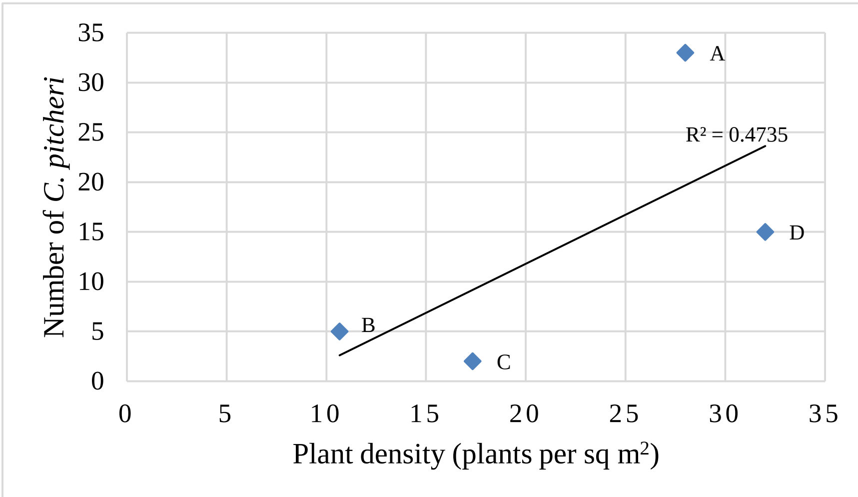


Figure 10: *C. pitcheri* surrounded by dune grass.

7.0 Discussion

7.1 Characteristics of *C. pitcheri* on Mt. Baldy

The distribution of *C. pitcheri* on various parts of the dune is not unlike that found in previous studies, such as D'Ulisse and Maun (1996) who found *C. pitcheri* in active areas of the dune, including blowouts and dune ridges. Additionally, the small distance between *C. pitcheri* individuals exemplifies the nature of the species' distribution and its tendency to grow in clusters. This corresponds with Keddy and Keddy's (1984) findings that individuals grow "close to the parent plants" (p. 66), due to the way seeds are dispersed.

The larger distance between *C. pitcheri* individuals and trails, compared with the distance between individuals, suggests that the trampling associated with the presence of trails may have a negative influence on the establishment and growth of the species (Yorks *et al.* 1997). A more detailed study of trails and their influence on *C. pitcheri* is required to reach a firmer conclusion.

The abundance of small juveniles and seedlings indicates that individuals are either dying young and therefore not reaching older age classes due to negative impacts, or that many individuals in the previous generation successfully flowered and died creating an abundant new generation. Many dead individuals were observed in the study areas, their presence supporting the latter explanation. However, previous research has suggested that the lack of large juveniles in a population is indicative of a "relatively high mortality during the juvenile phase of the species" (D'Ulisse and Maun 1996, p. 1704), supporting the former explanation. The small sample size and particularly short study period makes it difficult to determine the correct explanation. A longitudinal study of the populations in this particular study area would provide the necessary data to reach a conclusion.

7.2 Dune Characteristics

Earlier research by Marshall (2014) on the influence of topography on *C. pitcheri* assessed the effect of slope angle on thistle and found that an increase in slope angle "resulted in increased abundance of *C. pitcheri*" (p. 29). However, the study of the *C. pitcheri* populations on Mt. Baldy in P.J. Hoffmaster State Park found contradictory results, with no significant difference of abundance between slope angles. Abundance was only significantly lower on slopes with an angle greater than 30°, the lower bound of the angle of repose (30-34°). Slopes steeper than the angle of repose are much less stable than those with angles of less than 30°, which could make it more difficult for plants such as *C. pitcheri* to establish themselves.

Slope angle seems to have no significant effect on health or length of longest leafs of individuals. This may be due to the greater influence of another factor over the growth of *C. pitcheri* in these areas, or that this species is adapted to grow well on a wide range of slope angles.

Compared to previous research, the results of distribution of *C. pitcheri* by aspect are inconsistent. Whilst Marshall (2014) found the greatest proportion of *C. pitcheri* on slopes facing "between 210-300°" (p. 33), which would be classified as west-facing slopes, our results found the greatest proportion on south-facing slopes. This difference in results is likely due to the difference in study sites; the *C. pitcheri* populations at our study location of P.J. Hoffmaster State Park are likely subject to different additional influencing factors than those in Grand Sable Dunes, which Marshall studied.

In addition to the high proportion of individuals found on south-facing slopes, results also indicate that there was a significant difference in plant health between north- and south- facing slopes. It is most likely that the healthiest plants were found on south-facing slopes which have greater available light than other aspects. This is due to the northern hemisphere location which gives more sunlight to south-facing slopes and therefore allows for plants to photosynthesize and grow well.

7.3 Surrounding Vegetation Characteristics

Whilst results suggest that vegetation density is positively correlated with the number of *C. pitcheri* individuals, this is based on a very small sample size (n = 4), therefore no statistically significant conclusions can be made. If the patterns suggested by our results are true for the whole population, they contradict expectations that higher vegetation density would lead to a lower number of *C. pitcheri* individuals due to reduction of bare sand areas and competition for resources (Maun 1997).

8.0 Conclusions

Mt. Baldy in P.J. Hoffmaster State Park is home to a large number of *C. pitcheri* suggesting the habitat must be a sufficiently suitable environment for the growth of this threatened species. The sampled populations that we studied exhibits a clustered distribution, which is characteristic of the species

Assessing various factors that could be influencing the growth and health of *C. pitcheri* on Mt. Baldy returned few conclusive results. However, slope aspect (and therefore light availability) seems to significantly influence the growth of this species, with the highest number and healthiest individuals found on south-facing slopes.

There seems to be the potential for surrounding vegetation diversity and density to influence the growth and health of *C. pitcheri*; however, a more extensive investigation is required at this study site to make any further conclusions.

A more in-depth and long-term study of the aforementioned variables would be invaluable to creating a deeper understanding of the complex environment-vegetation interactions occurring and in order to provide a firm foundation of knowledge upon which to base restoration efforts.

9.0 Acknowledgements

The authors would like to thank the Michigan Space Grant Consortium, Calvin College, and the GEO Department of Calvin College for funding this project. In addition, thank you to the Michigan Department of Natural Resources and P. J. Hoffmaster State Park for allowing access to Mt. Baldy to conduct the study. Finally, thank you to Dr. Deanna van Dijk for assisting in this study.

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