First-Year Research in Earth Sciences: Dunes

Environmental Assessment of a *Cirsium pitcheri* Restored Population on the Coast of Lake Michigan

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ABSTRACT

Ecological restoration poses a greater challenge when rare plants depend on specific environmental conditions. Endemic to the Great Lakes region, *Cirsium pitcheri* is a federally-protected, monocarpic thistle species. As such, restoration efforts to maintain and re-establish populations may be essential to the survival of these native plants. This study compared the characteristics of *C. pitcheri* in a second-generation artificially-restored population and a natural population in order to assess management possibilities. During the fall of 2015, we mapped the two populations, recorded physical plant characteristics and measured surface characteristics of the surrounding environments. Plant height, width, health, sand slope angle, and sand pH were compared among both populations. Herbivory, animal impacts and proximate human activity were observed in each study area. The greater density of *C. pitcheri* was recorded in the artificially-restored population. This group also displayed a greater average plant height, health rating, and soil pH than the naturally-occurring population. Results suggest that well-selected environmental locations for *C. pitcheri* regeneration have the potential to be effective management strategies to restore populations and keep them healthy into future generations.

INTRODUCTION

The sand dunes of eastern Lake Michigan are habitat to many unique species of flora and fauna, including the threatened thistle species *Cirsium pitcheri* (Pitcher's thistle). As a federally protected plant, conservation and restoration of *C. pitcheri* have been undertaken by dune ecosystem managers, including restoration initiatives that involve planting new populations of the species. Historically, many studies have evaluated the population and environmental characteristics of *C. pitcheri* to better understand the plants' role in the ecosystem, but few have evaluated the success of using population restoration within those ecosystems. Our study was conducted in P.J. Hoffmaster State Park on Lake Michigan's eastern shore with a population of restored *C. pitcheri,* as well as population of naturally-occurring plants. The focus was to evaluate the success of *C. pitcheri* population restoration for vulnerable species conservation efforts.

Our objectives were to (1) record the physical characteristics of native and restored *C. pitcheri* populations, (2) identify environmental factors that influence the success of *C. pitcheri*, and (3) evaluate the effectiveness of greenhouse-raised and strategically-placed juvenile *C. pitcheri* as a restoration effort.

BACKGROUND

Cirsium pitcheri, a monocarpic perennial plant known colloquially as Pitcher's thistle, is endemic to the coastal sandy dunes of Lake Michigan (Phillips and Maun 1996; Hamzé and Jolls 2000). The species is characterized by long, slender, dusty blue-green leaves which fan out from the center of the plant in a rosette fashion (Figure 1). This rosette-like structure of *C. pitcheri* individuals persists for four to eight years, before the plant produces flowers in its last season and dies (Loveless 1984; Hamzé and Jolls 2000) (Figure 2). Seeds produced by *C. pitcheri* are the largest of any North American thistle, and their size and mass prevent long-distance dispersal (Fant *et al.* 2013). The nature of the plant's lifecycle coupled with its ability to only reproduce sexually makes successful seed production, pollination, and propagation essential for the survival of future generations.

Figure 1: *C. pitcheri* individual displaying rosette.

C. pitcheri individuals thrive in the dry, sandy environment of freshwater coastal dunes, with a range from the southern shore of Lake Michigan to Lake Superior in Southern Ontario (Pavlovic *et al.* 2000). The transient nature of dune habitats, where actively changing conditions are common, provide sufficient open sand areas where *C. pitcheri* flourish. Studies have shown that approximately 70% open sand is required for seedling establishment and survival (Bowles and Flakne 1993). Specifically, disturbance and sand movement on upper beaches, foredunes, and windward slopes provide good habitats for populations to exist (Bowles and Flakne 1993). Although they are disturbance-dependent plants, *C. pitcheri* population persistence is variable dependent on the magnitude and frequency of these disturbances (Pavlovic *et al.* 2000). Small and less common disturbances may be helpful for species survival, but large and frequently-occurring habitat disturbances are likely to cause population decline.

Figure 2: *C. pitcheri* individual flowering. Source: Whitsett 2011.

Because of the vulnerability associated with unique lifecycle and variable habitat of *C. pitcheri*, the thistle was designated at both the state and federal levels as threatened in 1988 (Bevill *et al.* 1999). Loss of habitat, seed dispersal limitations, and anthropogenic disturbance were especially culpable for determining this status, as they caused extirpation of a few known populations in the southern end of the thistle's range around the time the plant was listed as threatened (Hamzé and Jolls 2000). Many risks also occur for future populations, including shoreline development, recreation, introduced weevils, and possible impacts of climate change (Fant *et al.* 2013). Management efforts, signage, and educational improvement have been undertaken since 1988 to better protect the species into the future.

One of these methodologies includes reintroduction through planting. This has become an essential component of restoration ecology, especially for rare plant species (Fant *et al.* 2013). Regeneration activity typically occurs through augmenting current population numbers to reduce extinction probability, deterministic manipulations to develop a diverse cohort, or genetic crossing to increase diversity of the population size (Bell *et al.* 2003). This may either occur through translocation of seeds and young plants in existing populations or through transplanting individuals from botanic gardens or seed storage facilities.

Successful restoration of a rare species with specific environmental variables like *C. pitcheri* requires an adequate understanding of the network of interactions that occur within the species' ecological community (Rowland and Maun 2001). Ecologists have proposed that in these cases, scientists should (1) conduct careful study of the species' demography to assess population and (2) identify both intrinsic and extrinsic factors interacting within the plant's community (Pavlik 1994). Thus, in order for a newly introduced population to survive, understanding of the influencing environments on the population is required.

STUDY AREA

The study site is located in P.J. Hoffmaster State Park on the eastern shore of Lake Michigan in Muskegon County, Michigan (Figure 3). The park is approximately 4.9 square kilometers in area, with 4.8 kilometers of beach along its western edge bordering the lake (State of Michigan 2001-2003). Two specific study plots were chosen based on presence of *C. pitcheri* populations.

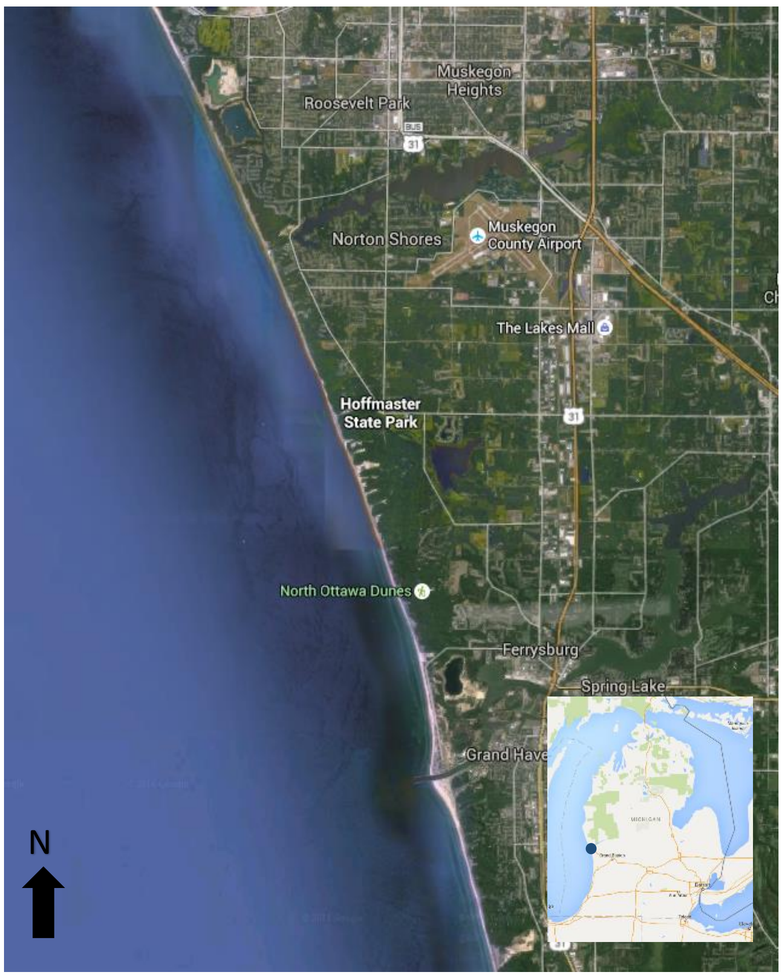

Figure 3: Aerial photograph of P.J. Hoffmaster State Park on Lake Michigan. Inset map shows P.J. Hoffmaster's location in Michigan. Source: Google Maps.

The first study area is located on Dune 4, inland from the lake on the downwind side of a blowout (Figure 4). In the early 2000, park managers planted a small population of *C. pitcheri* from greenhouse-grown juvenile plants. This population cycled through one monocarpic generation, and now exists as a second-generation restored population within the park.

The second study area is located on Dune 3.5, inland from the lake on the downwind side of an established foredune ridge (Figure 5). This site contains a substantial clustered population of naturally-occurring *C. pitcheri* of unknown age.

Figure 4: Aerial photograph of P.J. Hoffmaster State Park, showing the restored *C. pitcheri* study site on Dune 4 (outlined in black). Image source: Google Maps.

Figure 5: Aerial photograph of P.J. Hoffmaster State Park, showing the natural *C. pitcheri* study site on Dune 3.5 (outlined in black). Image source: Google Maps.

METHODS

Data was collected between October 29 and November 12, 2015 through a variety of methods aimed to describe vegetation traits and sand surface characteristics within two distinct study areas. Study sites were identified by locating a population of restored *C. pitcheri* and a naturally-originating population. Both sites measured 15 meters by 11 meters in areas of relatively similar vegetation density and location in the dune system.

Locations of the study areas and individual *C. pitcheri* plants in the sites were observed and recorded using a Trimble Juno GPS unit. GPS data measurements were downloaded and post-processed. Later, the data were imported into ArcGIS for further analysis and illustration of the study locations.

Vegetation characteristics of the populations were observed in both the restored and the natural population. Each *C. pitcheri* plant located in the study sites was marked by a flag and given a unique identification number. The plant height, rosette width, longest leaf length (recorded based on methodology outlined by Girder and Radtke 2006), and widest leaf width were all measured and recorded. In addition, we counted the total number of leaves and observed any herbivory present on individual plants. The overall health of each plant was evaluated by identifying health on a scale of 1-5, with 1 as the least healthy and 5 as the healthiest (Table 1). Size class distributions were created to compare average distributions of plant age and size between the two populations. Averages were calculated for each measured variable, and t-tests were administered to ascertain differences in plant characteristics between the two study sites.

	Category	**Description**
1	Poor	Many missing stalks, significant herbivory, and/or significant wilting and flattening
2	Below Average	Some missing stalks, some herbivory, and/or occasional wilting and flattening
3	Average	Broken stalks, no herbivory, and/or minimal wilting and flattening
4	Good	Few broken stalks, no herbivory, and/or no wilting or flattening
5	Excellent	No broken stalks, no herbivory, no wilting and flattening

Table 1: Scale used to estimate *C. pitcheri* health.

Physical environmental characteristics were observed in and compared between both sites. A 1 meter-square grid was defined for both study sites. Using a random number generator, five one-meter-by-one-meter grid squares from each grid were selected for environmental characteristic sampling (Figure 6). A Brunton compass was used to assess slope angle of the selected locations. Additionally, a soil pH test kit was used to determine pH of the sand and soil at each selected location. Averages were calculated for both variables and t-tests were administered to compare the physical environmental characteristics of the sand surrounding the two population areas.

Finally, potential impacts to plant health were evaluated in both study sites. Visible human impacts such as trash, trails, and footprints were mapped in their location relative to the study site using a Juno Trimble GPS unit. Visible animal impacts such as scat or fur patches were also mapped in their location using the GPS unit. Location data was imported into ArcGIS and mapped and analyzed for comparison with the study sites and their health.

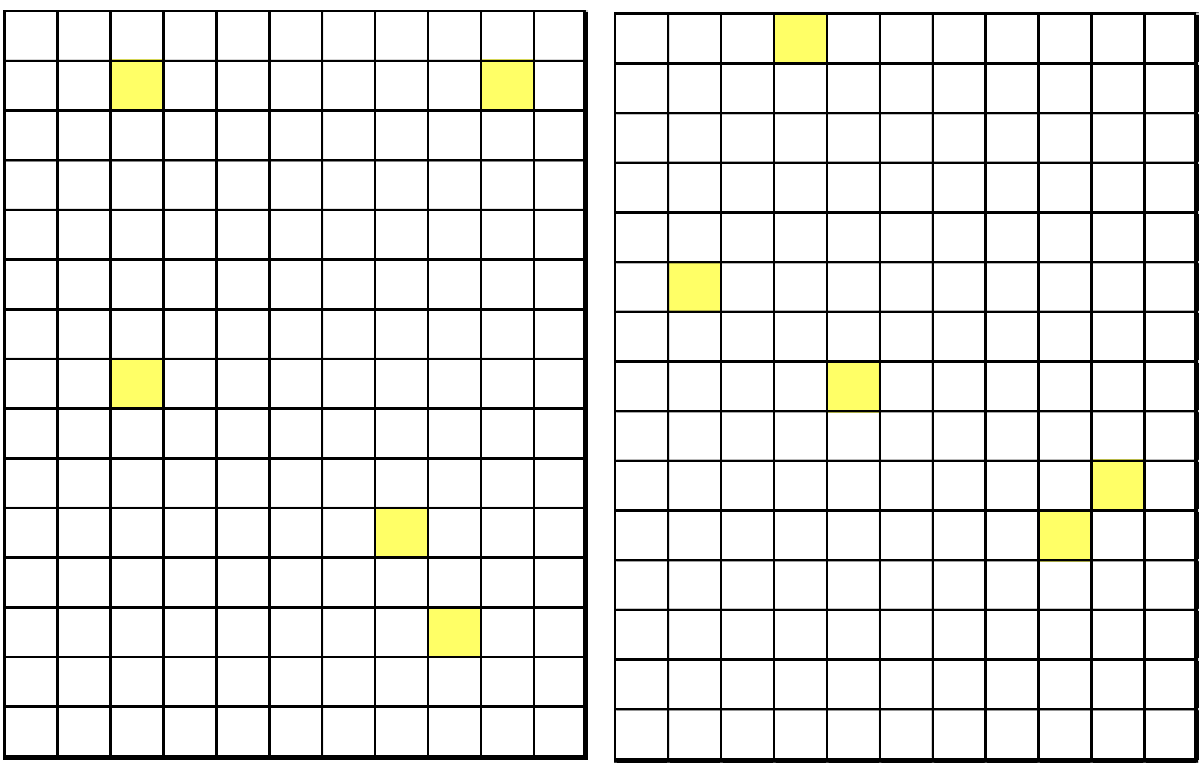

Figure 6: Diagram depicting grids established in both population sites (from left to right: restored, natural). Yellow highlighting indicates grid location randomly selected by number generator for sampling.

RESULTS

Both the restored *C. pitcheri* population plot and the naturally-occurring *C. pitcheri* population plot were located beyond the first dune crest, typically clustered among other grasses on the downwind side of the dune. In the restored population study site, 66 *C. pitcheri* individuals were identified, for an average plant density of 0.40 restored plants per meter². In the natural population study site, a total of 48 plants were identified for an average plant density of 0.29 natural plants per meter². Both populations had a random distribution with small clusters across the study sites (Figure 7). The surrounding environment was bare sand areas with low densities of early-colonizing graminoids existing with the *C. pitcheri* individuals.

Figure 7: Populations surveyed in P.J. Hoffmaster State Park.

Vegetation characteristics showed similarities and variations between the two groups. Population size-class distributions of the two populations show both were dominated by juveniles (Figures 8 and 9). After evaluating plant characteristics within both the restored and

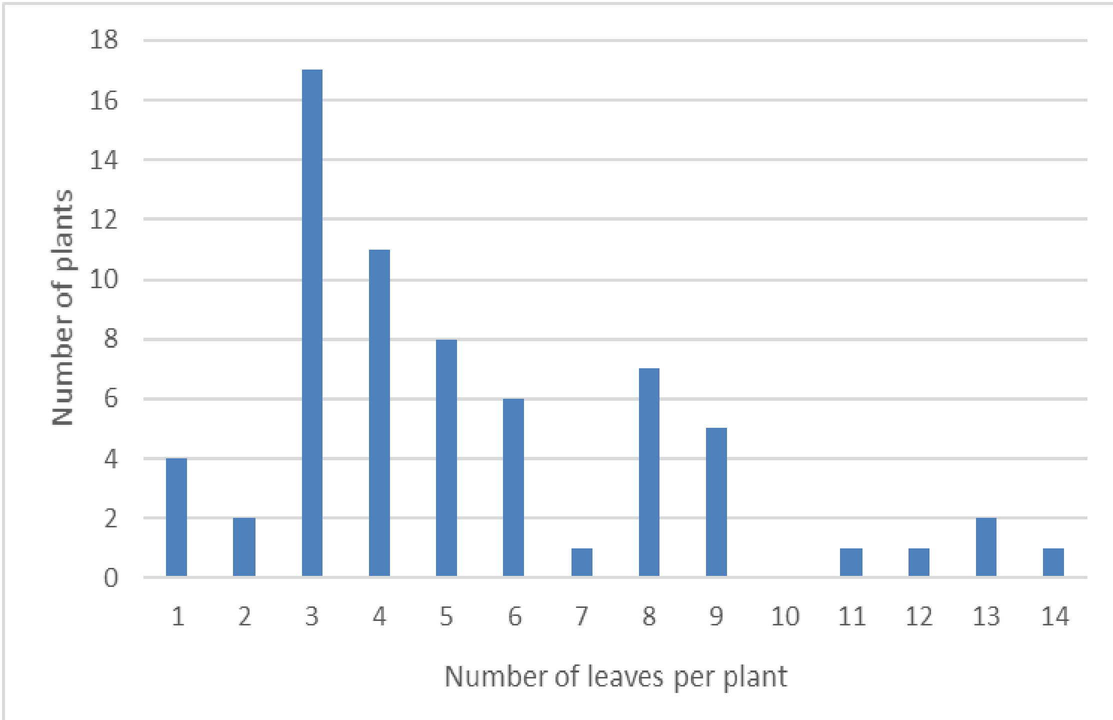

Figure 8: Size-class distribution of restored *C. pitcheri* individuals.

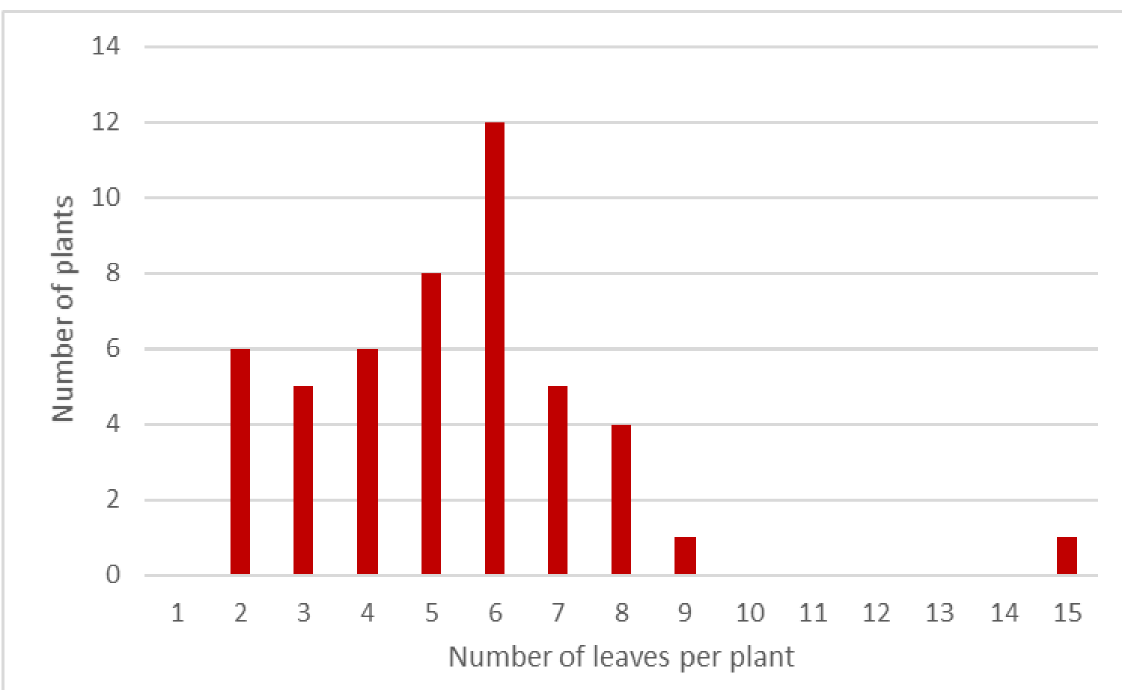

Figure 9: Size-class distribution of natural *C. pitcheri* individuals.

	Height	Width	Leaf Width	# of Leaves	Health	Herbivory	pH	Slope Angle
Restored	11.3	21.2	1.0	5.3	3.5	14%	7.2	15.8
Natural	7.3	15.3	2.4	5.3	2.9	8%	6.7	29.8
p-value	1.56E-05	0.00517	0.000196335	--	0.000528	--	0.006769	--

Table 2: Average recorded values for vegetation characteristics and p-scores resulting from t-test statistical analysis.

natural population, further differences were observed between both (Table 2). The plant height, rosette width, health score, and pH were significantly different between the two populations at α=0.05. Average restored plant height, rosette width and health were significantly higher in the restored population overall. Average leaf width was significantly smaller in the restored population than the natural population. Health rating distributions show some difference between the two populations, with the natural population displaying a normal distribution of health ratings across the population, and the restored population displaying a slightly right-skewed distribution (Figure 10).

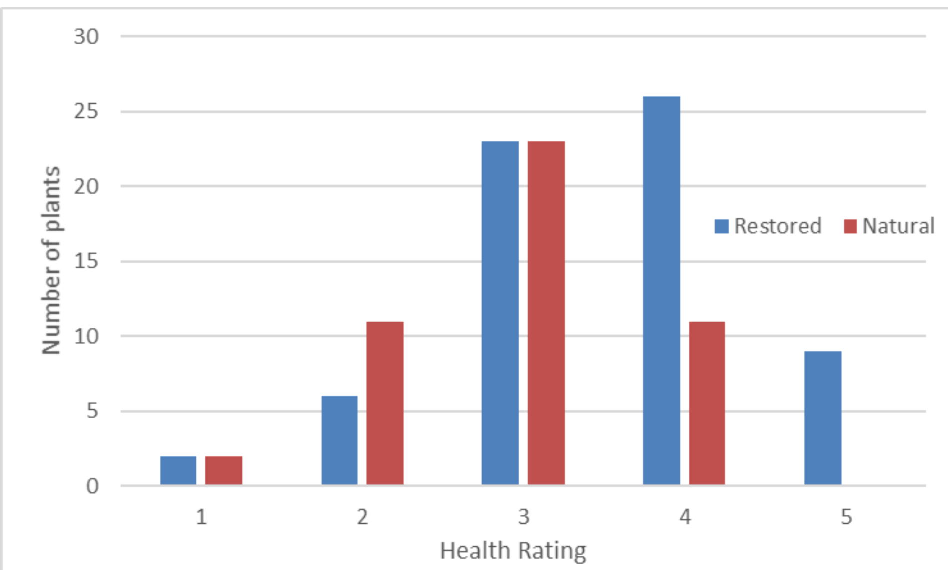

Figure 10: Health distribution of sampled *C. pitcheri* populations.

Environmental characteristics revealed some differences between the restored and natural populations as well. The average sand pH of the restored population was 7.2, while the average sand pH of the natural population was significantly lower (p=0.0068) at 6.7. The identified average slope angle in the restored population was 15.8 degrees, while the average slope angle in the natural population was 29.8 degrees. These surface slope angles did not differ significantly across the plots in each population, however.

Human and animal impacts were observed across the study sites of both populations. Low rates of herbivory were present in both populations. However, the average herbivory rate was not significantly different between the restored and natural communities (p=0.251). Other visible impacts of animal presence in the study sites were present, such as unidentified scat in the natural population study site (Figure 11). Additionally, human-created trails were observed near both study sites (Figure 12).

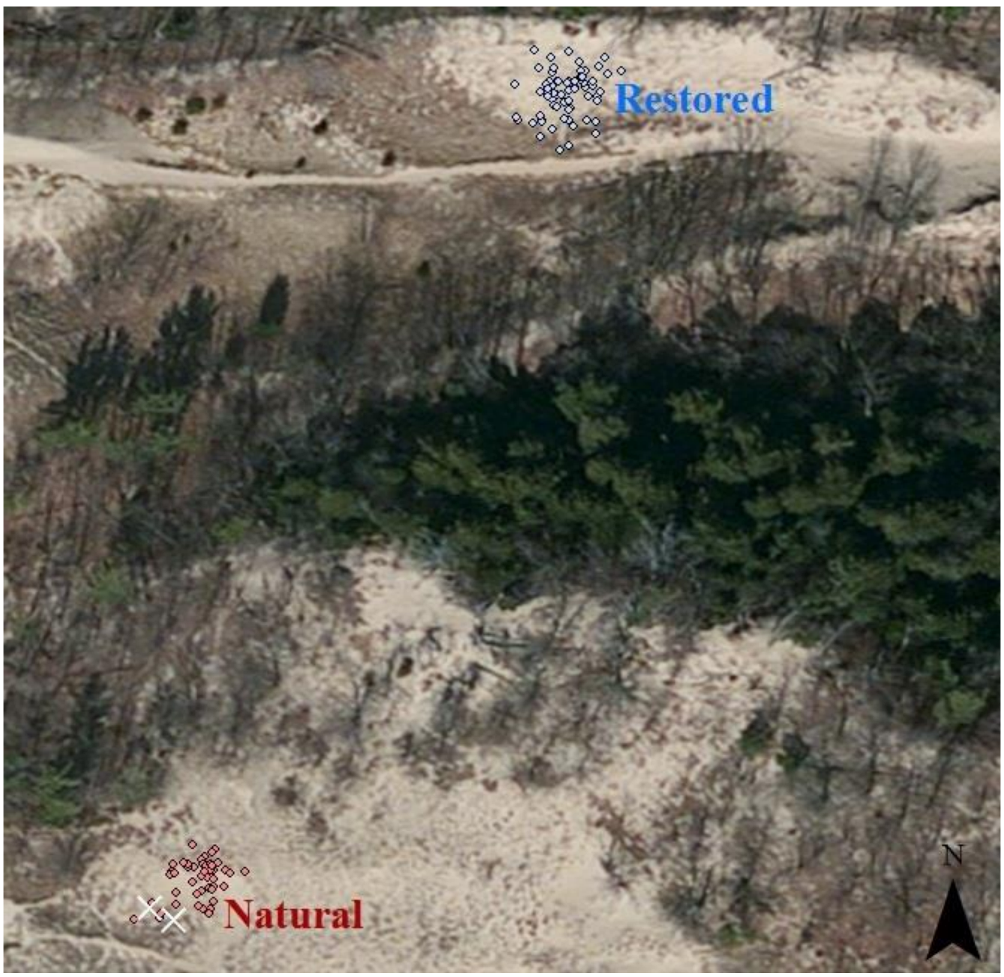

Figure 11: Populations surveyed at each site and animal impacts (white X).

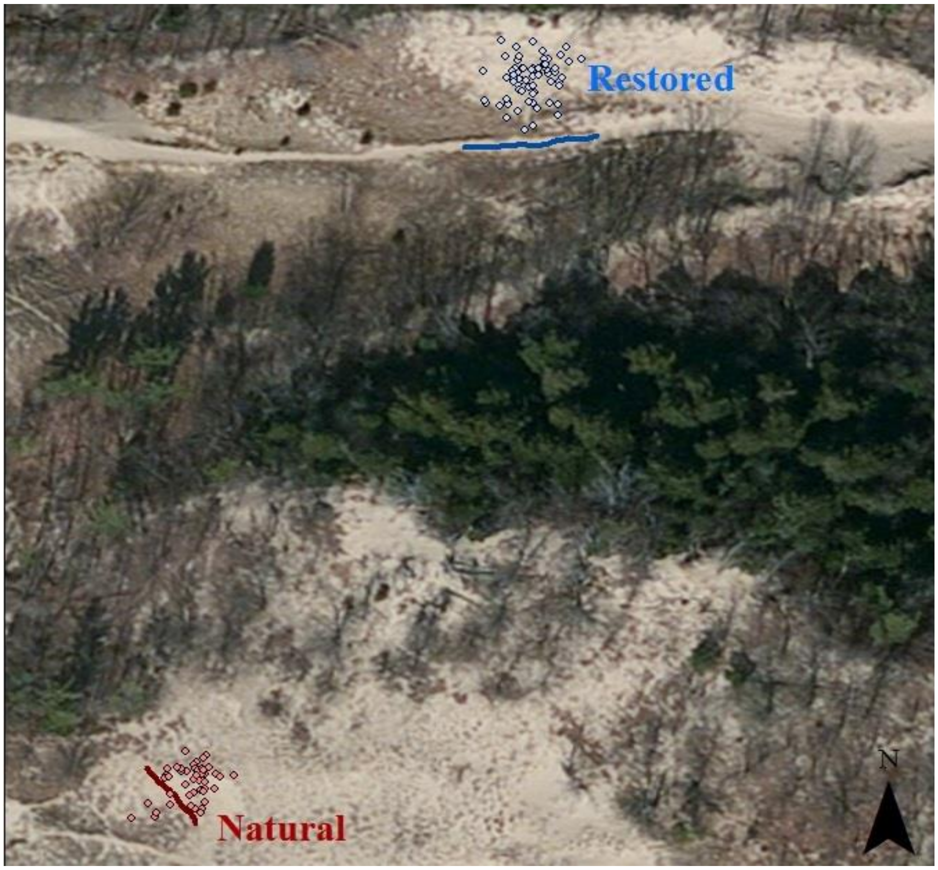

Figure 12: Populations surveyed at each site and human-caused trails (thick lines)

DISCUSSION

Results of the study suggest that the restoration efforts of planted *C. pitcheri* populations at P.J. Hoffmaster State Park are effective, even into a second generation. Our results demonstrate that the restored population is comparable to a natural population, as the average number of plant leaves found in both locations is not significantly different. Because the number of leaves can be used as a proxy for plant age, this implies that populations are roughly the same age and development level, allowing us to compare other variables accordingly (D'Ulisse and Maun 1996). The lack of statistically significant slope angle differences between the two sites suggests that the restored population location was selected well by park managers, existing in a place that would naturally harbor *C. pitcheri* individuals. Additionally, the presence of similar levels of herbivory, animal, and human interaction in the study sites suggest that placement of the restored *C. pitcheri* was well-founded and similar to naturally-selected conditions. Previous research on attempts to restore threatened and vulnerable plant species suggests that these knowledgeable decisions about plant placement are the most essential variable for plant success (Bowles and Flakne 1993; Emery and Rudgers 2010; Halsey *et al.* 2015).

Bearing this in mind, overall better health, rosette width, and height of plants was observed in the restored population, revealing general success and viability of the restored population as it currently exists. Differing pH levels in the soil of the two sites was observed also. In previous studies, higher pH has been correlated with higher *C. pitcheri* plant density, but these differences do not seem to be affecting the health or viability of the populations in P.J. Hoffmaster (Marshall 2014; Stanforth *et al.* 1997).

The difference in average leaf width, however, suggests that continued monitoring of the populations is required to make predictions about future success. Smaller average leaf length, as observed in the restored population, has been correlated with lower plant success in future generations (D'Ulisse and Maun 1996). Continuing to explore the dynamics and future propagation of the restored population will be essential to understand how forthcoming generations will survive.

Altogether, restoration of *C. pitcheri* populations with juvenile plants in P.J. Hoffmaster State Park seems to be a success at establishing a self-sustaining and successful group of individuals. This management strategy, coupled with knowledgeable site selection of dune managers, is likely a good option for conservation efforts in the future within the park.

CONCLUSIONS

Our team identified two study sites in P.J. Hoffmaster State Park, one with a population of artificially-restored *C. pitcheri* and one with a population of naturally-occurring individuals. Observing physical characteristics of each site and analyzing them shows the two populations are approximately the same age with the restored population appearing healthier than the naturally-occurring population. Environmental characteristics of the ecosystem surrounding the *C. pitcheri* populations are minimally different, demonstrating that the site chosen for the restored *C. pitcheri* population was knowledgeable and representative of a location which would help naturally-occurring populations to thrive as well. Based on these findings, restored *C. pitcheri* plantings appear to be a successful method to conserve and protect this vulnerable species, especially when met with wise selection of population location by park staff.

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