

First-Year Research in Earth Sciences: Dunes



Dune Environment Influences on a Rare Great Lakes Thistle: An Investigation in Ottawa County Parks' Rosy Mound Natural Area

**by Natasha Strydhorst, Carolina Angulo, Anna Camilleri,
Ethan DeVries, and Anna Selles**

**FYRES: Dunes Research Report #9
May 2014**

Department of Geology, Geography and Environmental Studies
Calvin College
Grand Rapids, Michigan

1.0 Abstract

Native to the Great Lakes dunes, *Cirsium pitcheri* is listed as threatened at both the state and federal level and is sensitive to changing environments. This study investigated the *C. pitcheri* population and its environmental conditions in Rosy Mound Natural Area on Lake Michigan's eastern shore. During the fall of 2013, we mapped selections of the population, unmanaged trails (both deer and human-caused), and the park's boardwalk using Trimble Juno GPS units. For each plant, we recorded surface conditions, longest leaf length, and whether deer trampling and/or grazing was evident. We also compared four plant population areas characterized by different features: the managed boardwalk, an unmanaged human trail, an unmanaged deer trail, and an open dune area. Significant evidence of deer was visible around the 253 individual plants mapped. Despite the deer presence, few indications of damage to *C. pitcheri* from trampling or grazing were observed. The thistles' density was similar near the boardwalk and human-caused unmanaged trail, and greater around the deer trail and open dune areas. Our results suggest that the deer population is ideally sized to provide the disturbance required by *C. pitcheri* without exerting undue strain on the population.

2.0 Introduction

Lake Michigan's sand dunes owe their distinctive shapes to wind patterns, sand availability, coastal conditions, and the various species of flora and fauna they support. One of these species is *Cirsium pitcheri* (Pitcher's thistle), which depends on the interactions between these same factors and many others for its continuing survival. *C. pitcheri* relies on the unique habitat of the Great Lakes dunes, and it does not thrive elsewhere. Our study was conducted on Lake Michigan's eastern shore, in Ottawa County Parks' Rosy Mound Natural Area. The focus of the study was the resident *C. pitcheri* population and its relation to some of the environmental factors shaping its habitat. Our objectives were to (1) map individual *C. pitcheri* in population clusters (2) observe plants for evidence of grazing and trampling, (3) map trails (both managed and unmanaged) and observe sand transport in several dune locations, and (4) determine the relationship (or lack thereof) between *C. pitcheri* and disturbances such as grazing, trampling, trails and sand movement.

3.0 Background

3.1 *Cirsium pitcheri*

C. pitcheri is a monocarpic perennial (Phillips and Maun 1996; Chen and Maun 1998; Girdler and Radtke 2006), recognizable by furry, pale blue-green leaves protruding in a rosette from the plant's center (figure 1). The thistles are typically under 1 meter tall and supported by an exceptionally long taproot—an adaptation well-suited to a



Figure 1: *C. pitcheri* rosette.



Figure 2: *C. pitcheri* in bloom (flowers highlighted).

environmental conditions unique to this region. These conditions include the presence of bare

dry, sandy environment such as the Lake Michigan dunes (Hamzé and Jolls 2000; Voss and Reznicek 2012, 384). *C. pitcheri* lives between four and eight years before flowering once (figure 2) and expiring (Loveless 1984; Havens *et al.* 2012). The thistle falls under Yorks *et al.*'s (1997) classification as a perennial forb growth form endemic to the dunes zone of the temperate climate belt. *C. pitcheri* thrives in the

sand areas (especially blowouts on dune ridges) found scattered throughout dune-stabilizing populations of early colonizing graminoids (grasses) (D'Ulisse and Maun 1996). Despite the relative stability provided by this vegetation, the dune zone is an inherently active environment of frequently moving substrate (Hamzé and Jolls 2000).

C. pitcheri is exclusively native to the Great Lakes region (figure 3): the U.S. states of Illinois, Indiana, Michigan, and Wisconsin, and the Canadian province of Ontario (Gauthier *et al.* 2010). The thistle is designated as threatened at the state and both federal levels. The national classifications were allotted in 1988 (Bevill *et al.* 1999), and are retained for the same reasons they were initially established: the loss of habitat, insufficiency of established regulations, and seed dispersal limitations. Due to the latter, the species requires sizeable populations to support its exclusively sexual reproductive strategy (Recce 1988, 27137-41; Havens *et al.* 2012).



Figure 3: The full habitat range of *C. pitcheri* (US Forest Service 2012).

3.2 The influence of trampling, grazing, and unmanaged trails on *Cirsium pitcheri*

Though *C. pitcheri* is adapted to a dynamic habitat, it is not adapted to one substantially altered by non-aeolian (and especially anthropological) activities (Carlson and Godfrey 1989). Trampling has been shown to disturb vegetative growth and decrease biodiversity in plant communities in a broad range of biomes. In particular, those locations in which the substrate is most liable to be deformed are considered the most noticeably vulnerable to the damaging effects of trampling (Yorks *et al.* 1997). *C. pitcheri* is also sensitive to overgrazing (D'Ulisse and Maun 1996) and large-scale human disturbances such as recreation and construction (Carlson and Godfrey 1989; Havens *et al.* 2012).

Although trampling as a result of any traffic (be it human, animal, or machinery) is generally deemed destructive, a moderate grazing presence may be considered benign or even beneficial. Small-scale observations by Kohyani *et al.* (2008) suggest that the adverse loss of plant biomass to animal browsing can be overcome by the benefits of moderate grazing: decreased competitive pressure and increased biodiversity. A particular proportion of predator (grazer) to prey (*C. pitcheri*) is suggested to paradoxically benefit both species.

Human influences on *C. pitcheri* and its habitat in the Great Lakes dunes frequently occur in the shape of unmanaged trails. These bare or sparsely vegetated areas are formed by habitual trampling of the foliage resulting in a loss of biomass in a distinct path through the dune's grassy areas. Human-caused unmanaged trails are the culmination of many trampling influences concentrated in a deliberate path, frequently leading to or from the beach area (Bowles and Maun 1982). Deer establish unmanaged trails in addition to isolated trampling and grazing effects. These trails reduce vegetation cover to a lesser extent than human or ORV (off-road vehicle) trails do (Carlson and Godfrey 1989) as they tend to be narrower.

Yorks *et al.* (1997) found that traffic in sensitive environments decreases the total number of species present when trampling is a regular occurrence. This gives a competitive advantage to those species with high resistance and/or resilience classifications. The growth forms with the highest resistance to trampling are trees, graminoids, and cryptophytes, while the highest resilience—the ability to recover quickly from the effects of a disturbance—is exhibited by graminoids, cryptophytes and forbs.

4.0 Study area

This study was conducted in Ottawa County Parks' Rosy Mound Natural Area (figure 4). The 164-acre dune preserve is located on the eastern shore of Lake Michigan, south of Grand Haven (Ottawa County Parks 2014b). The park exhibits diverse dune topography, containing hummocky foredunes, wooded dunes, a dune blowout and beach. A managed boardwalk winds 2.17 km (1.35 mi) through the study area (figure 4), which is connected to the parking lot by an additional 1.13 km (0.7 mi) of trail. Private residential zones border Rosy Mound Natural Area to the north, east, and south, while Lake Michigan marks its western edge.



Figure 4: Aerial photograph of study site (outlined in red) on Lake Michigan, Ottawa County. Inset map shows Ottawa County's location in Michigan (Ottawa County Parks 2014a).

5.0 Methods

Our primary method of data collection was mapping. Using Trimble Juno GPS units, we recorded the locations of individual *C. pitcheri*, informational signs, viewing platforms, and the eight erosion pins we positioned around the site. The GPS units were also used to record the locations and length of the boardwalk and a selection of the numerous unmanaged trails.

GPS data were downloaded and post-processed, then imported into ArcGIS to be arranged and displayed for spatial analysis. Four areas of *C. pitcheri* populations were identified for analysis, defined by proximity to the boardwalk, unmanaged (human) trail, unmanaged (deer) trail, and open dune area (figure 5). A surface sediment sample was collected from the foredune and grain-size analysis performed to measure the sand characteristics in Rosy Mound Natural Area.

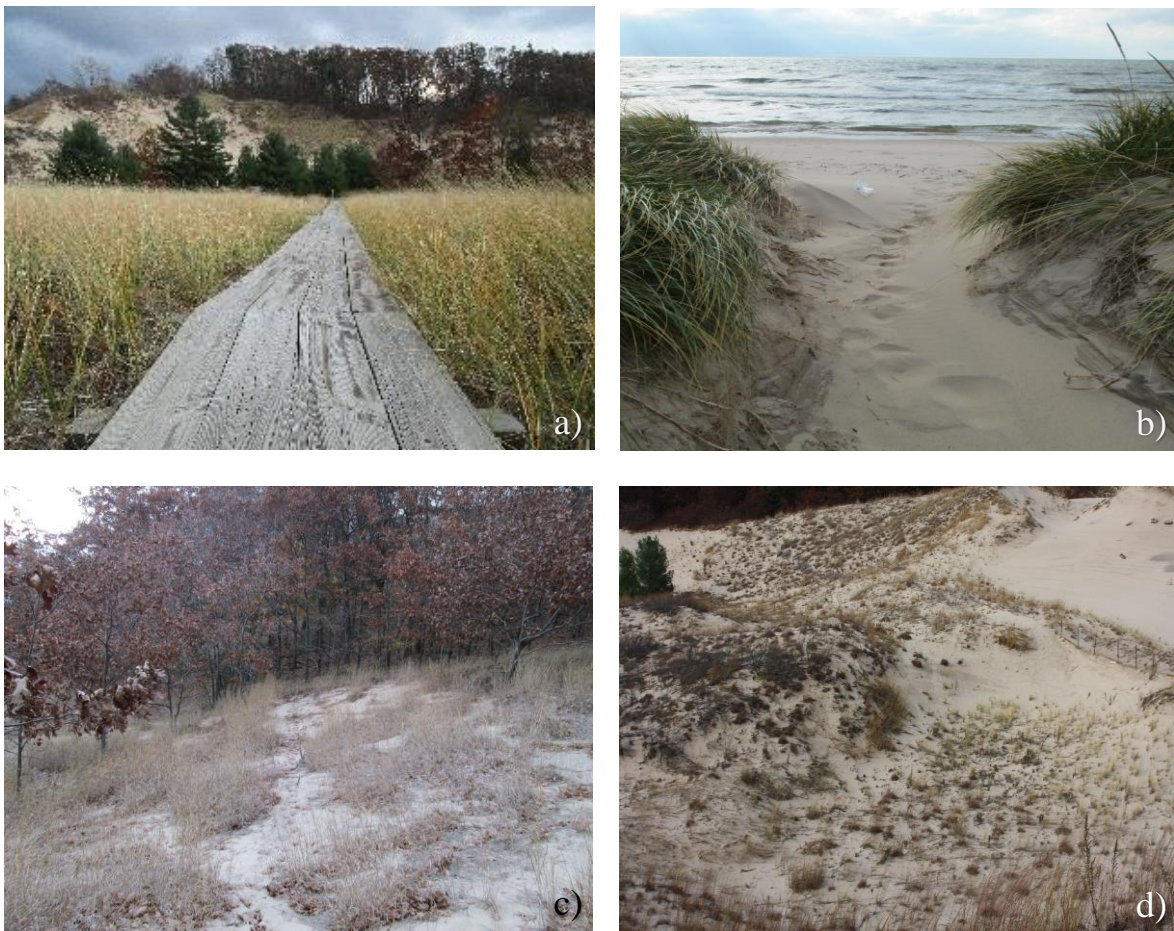


Figure 5: Examples of a) the park's managed boardwalk, b) a human-caused unmanaged trail, c) a deer-caused unmanaged trail, and d) an open dune area.

We studied *C. pitcheri* for evidence of trampling and grazing, as well as presence or absence of other vegetation in their near vicinities. These were recorded in the GPS units using pull-down menus to categorize characteristics such as damage to plants, surface conditions in the thistles' vicinities, and longest leaf lengths (table 1).

A partial sample, consisting of 36% of the thistles analyzed, was assessed to determine the immediate surroundings of the thistles in the hummocky dunes and dune ridge (excluding the blowout and trail network in the northern section of the study site).

Through field observations, we made note of each thistle's longest leaf length (recorded based on

Girdler and Radtke's (2006) prescribed method), likely causes of unmanaged trails, and erosion pin data collected during the final two site visits. Leaf lengths were not recorded for plants that had flowered and died. For living thistles, size classes were compared to Loveless' (1984) findings of stage-specific mortality to estimate the likelihood of the studied thistles surviving the year (Appendix A). Erosion pins were set at eight locations in the study site during the first week of observation, and measured each subsequent week to determine whether—and where—deposition and erosion had occurred. A basic weather survey at the beginning of each site visit recorded starting conditions: we noted maximum and average wind speeds, wind direction, and temperature. For each week of the study, the average temperature recorded by Weather Underground for the region was collected along with precipitation and wind data, and compiled with our site visit data.

Characteristics:	Categories:	Portion of Sample Observed:
Damages to plants	<ul style="list-style-type: none"> • Trampling • Grazing • Both • None 	92%
Surface conditions	<ul style="list-style-type: none"> • Bare sand • Early Colonizers • Other 	36%
Longest Leaf Length	<ul style="list-style-type: none"> • 0-10cm • 10-20cm • 20-30cm • 30+cm 	92%

Table 1: The *C. pitcheri* population sample was observed to determine damages, surface conditions, and longest leaf length to assess direct environmental factors. Dead thistles in the sample were excluded from these observations, and surface conditions were not analyzed for thistles in the northern half of the study site. Each percentage represents the proportion of the sample population assessed for each specific characteristic.

6.0 Results

6.1 Weather and environmental conditions

Data were collected at Rosy Mound Natural Area over three consecutive weeks from late October to early November, 2013. Winds in the range of 2.0-5.7 m/s blew in from the northwest or southwest during observation sessions, with temperatures ranging from 5.0-15.8°C. Cloud cover was significant throughout all three site visits, producing a substantial amount of rain during the second. The weather data from Muskegon Airport (averaged over each week of the study) served as a baseline for the specific site data from each day of field work (table 2).

WEEK 1:	Region Data (October 20-26)	Site Data (October 24)
Temperature (°C):	7.0	8.4
Precipitation (mm):	13.20	Not Collected
Average Wind Speed (m/s):	5.0	2.0
Wind Direction:	Predominantly WNW	NW (310°)
WEEK 2:	October 27-November 2	October 31
Temperature (°C):	9.0	15.8
Precipitation (mm):	37.34	Not Collected
Average Wind Speed (m/s):	3.89	2.1
Wind Direction:	Variable	SW (222°)
WEEK 3:	November 3-9	November 7
Temperature (°C):	8.0	5.0
Precipitation (mm):	19.30	Not Collected
Average Wind Speed (m/s):	5.56	5.7
Wind Direction:	Variable	WNW (293°)

Table 2: Region weather data were collected at Muskegon County Airport (Weather Underground 2014), approximately 18 km (11 mi) north of Rosy Mound Natural Area. Site weather data were collected at the beginning of each site visit, while region data were averaged over each week.

Rosy Mound Natural Area's sand is very well sorted and near-symmetrical, with a mean grain size of 0.29 mm (Appendix B). While open sand areas (particularly in the blowout vicinity), and wooded areas are present, sparse to moderately dense grasslands comprise the prevalent vegetation community in the study site.

Two erosion pins had fallen out or been removed by the second site visit. As a result, data were only collected from six of the eight pins originally placed. Between the first and third observation sessions, a small amount of deposition occurred at one pin site, erosion had occurred at four, and negligible change was observed at one. Deposition was noted only on the dune ridge in the northeast end of the study site, while erosion was observed in the hummocky dunes in the south and north ends of the park and the slipface and dune ridge adjacent to the northeast boundary of Rosy Mound Natural Area (figure 6).

Pin number:	Erosion or deposition:	Amount (cm):
1	Erosion	1.8
2*	(negligible) erosion*	0.1*
3	Erosion	1.3
4	Erosion	0.9
5	Deposition	1.1
6	Erosion	1.0



Figure 6: Erosion pin data and locations in the study site.

*Erosion at pin 2 was not considered a significant result, as the measurement was so low as to be negligible. It was therefore not included in erosion pin analysis.

**Pins 7 and 8 were located on the foredune, but were missing by the second site visit.

6.2 *Cirsium pitcheri* in Rosy Mound Natural Area

We recorded data for 253 individually-mapped *C. pitcheri* plants (figure 7) and observed that many were also present in areas of the park not included in this study. The vast majority of the thistles were located on the dune ridge and the hummocky dunes between it and the foredune. None were found on the beach or in the wooded sections of the dune.



Figure 7: Observed *C. pitcheri* are pictured above. Turquoise points indicate individual mapped thistles. The red perimeters mark areas that were analyzed for comparative density, and the blue outlines indicate where *C. pitcheri* was present, but not mapped.

The sizes of studied *C. pitcheri* varied (figure 8), with the greatest fraction of them (36%) falling within the range of 10-20 cm length for the plant's longest leaf. The sample size observed for leaf length comprised 92% of the plants analyzed, as it excluded the 29 dead *C. pitcheri*. From the leaf length data, we were able to determine that most of the thistles were at fairly low mortality risk at the time of analysis (based on Loveless' (1984) findings in Good Harbor and Sleeping Bear Park (Appendix A)). Of the thistles observed, 31% were in the lowest-risk group of 20-30 cm leaf length (table 3), while a full 76% were below a 10% mortality risk.

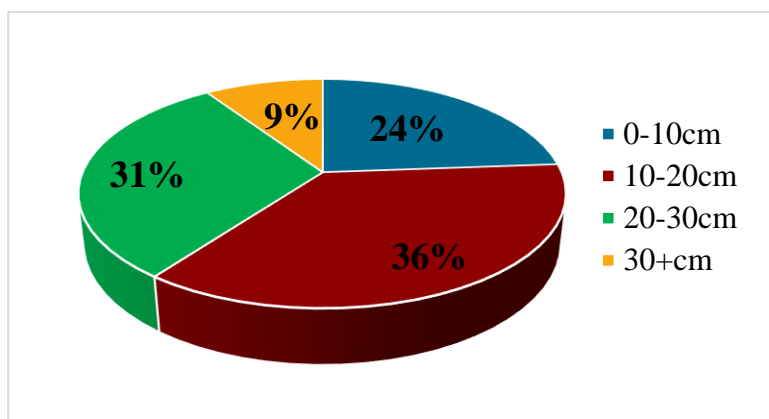


Figure 8: Leaf length distribution of observed *C. pitcheri* plants in the study site.

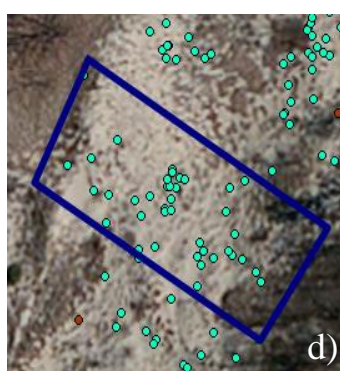
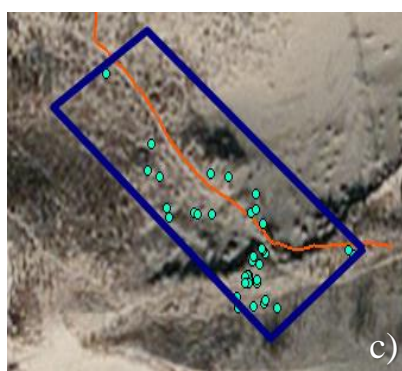
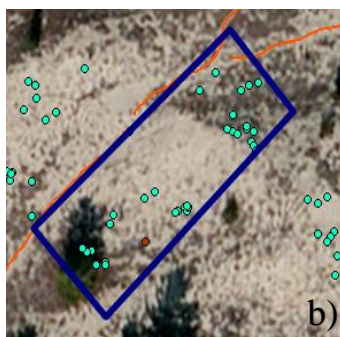


Figure 9: The observed *C. pitcheri* population clusters were adjacent to a) the boardwalk, b) a human unmanaged trail, c) a deer unmanaged trail, and d) an open dune area.

The populations indicated in the 20x50 m areas (figure 9) (collectively containing 53.8% of the total mapped) were analyzed and compared based on location relative to specific features. Observations indicate the presence of 30 thistles in the boardwalk proximity, 32 in the human unmanaged trail region, and 37 within the deer trail area. A fourth location in the open dune area served as a control area and contained 42 thistles at the time of analysis.

The partial sample investigated for the *C. pitcheri* immediate surroundings (Appendix C) contained 92 thistles—36% of the total observed. A full 76 of the 92 *C. pitcheri* comprising this sample were growing in the near vicinity of early colonizing graminoids, while 16 were observed in bare sand areas. Only one was located under the boughs of a small shrub in an otherwise bare sand area. No thistles were found in areas of dense early colonizer growth or of shrubland and forest growth.

6.3 Unmanaged trails, deer evidence and influences

Unmanaged trails were observed throughout the study area, with the majority around the northern end. The widest—and longest, at 153.4 m—of those mapped branched directly off the northernmost section of the boardwalk and split only once. The branched segment added an additional 60.3 m length. Deer trails were located almost entirely in the northern section of the study area, most notably along the north arm of the blowout (figure 10). These trails appeared narrower than those connecting directly to the boardwalk, and had many more segments. The longest measured deer trail was 142.2 m in length. The deer trail studied in relation to the *C.*



Figure 10: Unmanaged (deer) trails (highlighted in yellow) were clustered along the northern arm of the blowout.

pitcheri population was 101.6 m long. A total length of 577.4 m of unmanaged trails was recorded, with observations indicating that more trails were present throughout the site.

Despite significant indications of deer activity (shown most clearly by unmanaged trails, droppings, and individual prints), there was no evidence of their presence substantially damaging the *C. pitcheri* in the study area. A scant 0.08% of the living thistles exhibited evidence of trampling, while none showed signs of being grazed. Neither disturbance appeared to be the cause of death for the 29 deceased thistles observed in the course of the study.

7.0 Discussion

7.1 Environmental elements and effects

C. pitcheri flourishes in sparsely vegetated or non-vegetated dune areas such as blowouts (D'Ulisse and Maun 1996), and the studied population was no exception. All of the thistles observed were growing in either bare sand or thinly vegetated locations, primarily on the dune ridge. While *C. pitcheri* was located in the vicinity of all the studied trails, none were observed in the proximity of thick foliage or wooded sections of the dune system. This suggests that the thistles are more influenced by the ecological elements of the habitat than by the presence or absence of non-aeolian disturbances such as unmanaged trails. This corroborates with Havens *et al.*'s (2012) assessment that the factors of natural succession (namely debris build-up and shading) can reduce *C. pitcheri* recruitment rate by up to 40%.

The thistle density at Rosy Mound Natural Area was smaller than expected. D'Ulisse and Maun (1996) identified a density of 0.02 thistles/m² as very low, and our observed density was near that value at an average of 0.035 thistles/m². Since the observation period spanned only one season, and yearly density is known to exhibit significant variability (Rowland and Maun 2001), the observed density cannot be conclusively applied to the site as representative of its thistle population.

From the erosion pin data, we determined that *C. pitcheri* was present in each of the locations where sand movement occurred. This supports the general consensus of prior studies which affirm the thistles are adapted to a dynamic dune environment. In particular, Hamzé and Jolls (2000) identified burial as essential for both germination of *C. pitcheri* seeds and emergence of seedlings.

By comparing our studied population to Loveless', we deemed Rosy Mound Natural Area's thistles to be healthy, having a low mortality risk. This we attributed to a favorable size-class distribution.

7.2 Unmanaged trails, deer evidence and influences

Since the widest unmanaged trail (figure 11) branched directly off the boardwalk, we infer it was human-caused. The trails along the north arm of the blowout were surmised to be deer trails as they were narrower and did not connect to the boardwalk.

C. pitcheri was recorded in profusion in the vicinity of both sets of unmanaged trails, with a greater density in the proximity of the deer trails. While the greatest density was observed in the open dune area, the margin of divergence was very low—a count of only 12 plants separated the sparsest grouping from the densest.



Figure 11: The largest human unmanaged trail (blue) branches off the northernmost end of the boardwalk (yellow).

Our results are consistent with Yorks *et al*'s (1997) findings that forbs such as *C. pitcheri* are only surpassed in resistance to trampling by trees, graminoids, and cryptophytes. In their resilience (ability to recover following destructive impacts), they outstrip all but graminoids and cryptophytes. This is likely the reason there was so little divergence between the densities of the observed population groups.

The significant lack of grazing (and—to a large extent—trampling) damage to the *C. pitcheri* both within and outside the proximity of trails, coupled with the relative abundance of thistles in Rosy Mound Natural Area, suggests the environment's suitability for the threatened

species. The lack of substantial damage to *C. pitcheri* suggests that the thistles are not currently affected by an extensive grazing or trampling pressure. It is likely that both pressures adversely affect the thistle, but that there was not enough of either in this site to establish a negative effect.

The deer presence in Rosy Mound Natural Area was obvious and significant but, based on the lack of damaging influences, was likely not indicative of an overpopulation. The animals' influence may even have acted as a benefactor to *C. pitcheri* by causing moderate sand movement but negligible grazing and trampling damage.

8.0 Conclusions

Our team identified a healthy *C. pitcheri* population with a smaller than expected density considering the site's suitable environmental makeup. However, we also determined that said density may not fully represent the site or its population due to the limited observation timeframe.

Contrary to our initial predictions, this study found only tenuous indications of a negative correlation between *C. pitcheri* and the presence of unmanaged trails. The physical vegetation environment was a superior predictor of *C. pitcheri* survival and health than was the presence or absence of unmanaged trails in Rosy Mound Natural Area. *C. pitcheri* was observed in ample supply wherever the density of other vegetation species was low, regardless of proximity to a trail or boardwalk. Despite the evident deer presence, no grazing—and negligible trampling—evidence was observed affecting the thistle population. The Rosy Mound population was deemed healthy based on extrapolation from Loveless' 1984 findings in Good Harbor and Sleeping Bear Park.

Each of the factors observed in relation to *C. pitcheri* is likely a part of a delicate equilibrium that was present in Rosy Mound Natural Area at the time of this study. All of these factors are dynamic, just as the dune environment is, and therefore liable to change significantly. A deeper understanding of the interactions between trampling, grazing, sand movement and *C. pitcheri* necessitates further inquiry into the balance achieved at the study site and how fluctuations in that balance affect the interactions among its elements.

9.0 Acknowledgements

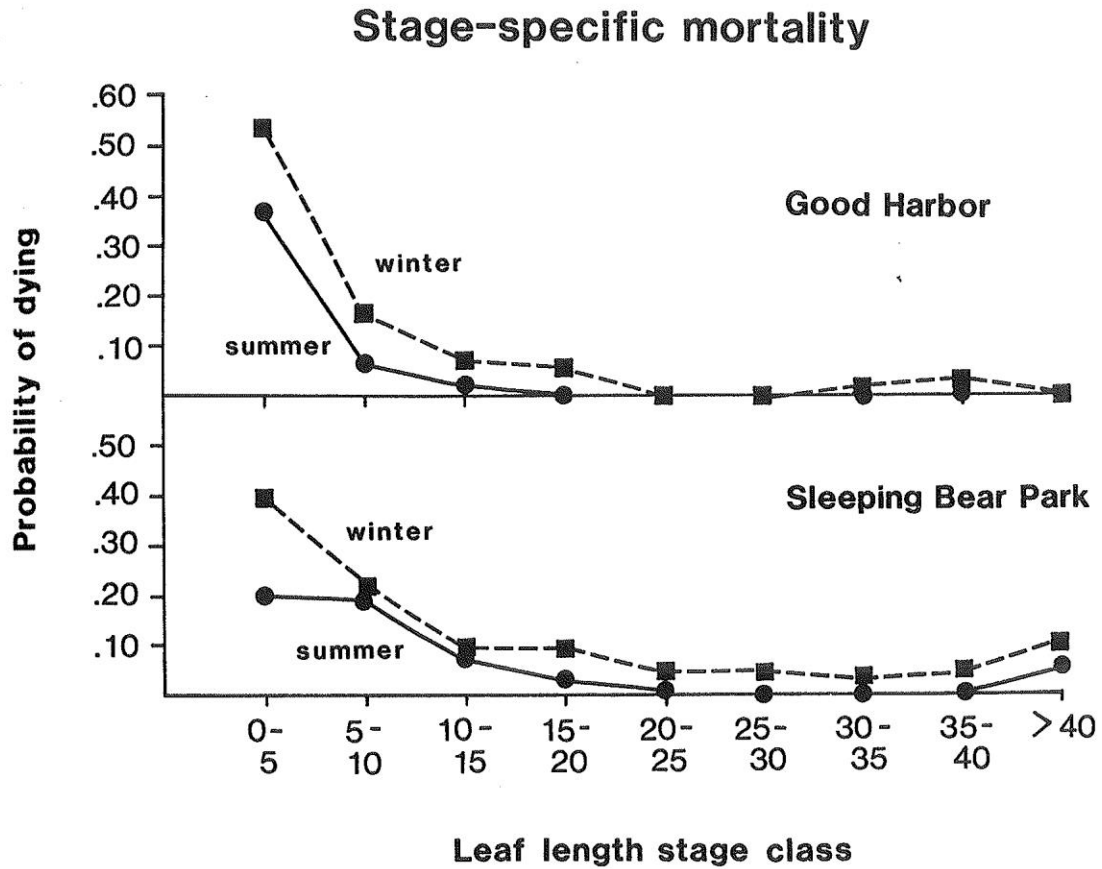
The research team thanks Ottawa County Parks for the use of their land for the duration of the study and Melanie Manion, Natural Resources Management Supervisor, for her support and assistance with this project. We extend our gratitude to Dr. Deanna van Dijk for invaluable mentorship and guidance throughout the research process. Our thanks go also to the National Science Foundation (Grant #0942344) and the Michigan Space Grant Consortium for the funding of this study and to the Calvin College Department of Geology, Geography, and Environmental Studies for the provision of this exceptional research opportunity.

10.0 Works cited

- Bevill, R.L., S.M. Louda, and L.M. Stanforth. 1999. "Protection from Natural Enemies in Managing Rare Plant Species." *Conservation Biology* 13 (6): 1323-31.
- Bowles, J. M., and M. A. Maun. 1982. "A Study of the Effects of Trampling on the Vegetation of Lake Huron Sand Dunes at Pinery Provincial Park." *Biological Conservation* 24: 273-283.
- Carlson, L.H., and P.J. Godfrey. 1989. "Human Impact Management in a Coastal Recreation and Natural Area." *Biological Conservation* 49 (2):141-56.
- Chen, H., and M.A. Maun. 1998. "Population Ecology of *Cirsium pitcheri* on Lake Huron Sand Dunes. III. Mechanisms of Seed Dormancy." *Canadian Journal of Botany* 76: 575-86.
- D'Ulisse, A., and M.A. Maun. 1996. "Population Ecology of *Cirsium pitcheri* on Lake Huron Sand Dunes. II. Survivorship of Plants." *Canadian Journal of Botany* 74: 1701-07.
- Gauthier, M., E. Crowe, L. Hawke, N. Emery, P. Wilson, and J. Freeland. 2010. "Conservation Genetics of Pitcher's Thistle (*Cirsium pitcheri*), an Endangered Great Lakes Endemic." *Botany* 88 (3): 250-57.
- Girdler, E. B., and T. A. Radtke. 2006. "Conservation Implications of Individual Scale Spatial Pattern in the Threatened Dune Thistle, *Cirsium pitcheri*." *The American Midland Naturalist* 156 (2): 213-28.
- Google Maps. 2014. "Rosy Mound Natural Area, Grand Haven, MI." 2014. Accessed January 9, 2014. <https://www.google.com/maps/preview/@43.0218158,86.2277567,1372m/data=!3m1!1e3>
- Hamzé, S.I., and C.L. Jolls. 2000. "Germination Ecology of a Federally Threatened Endemic Thistle, *Cirsium pitcheri*, of the Great Lakes." *The American Midland Naturalist* 143 (1): 141-53.
- Havens, K., C.L. Jolls, J. E. Marik, P. Vitt, A. K. McEachern, and D. Kind. 2012 "Effects of a Non-Native Biocontrol Weevil, *Larinus planus*, and Other Emerging Threats on Populations of the Federally Threatened Pitcher's Thistle, *Cirsium pitcheri*." *Biological Conservation* 155: 202-211.

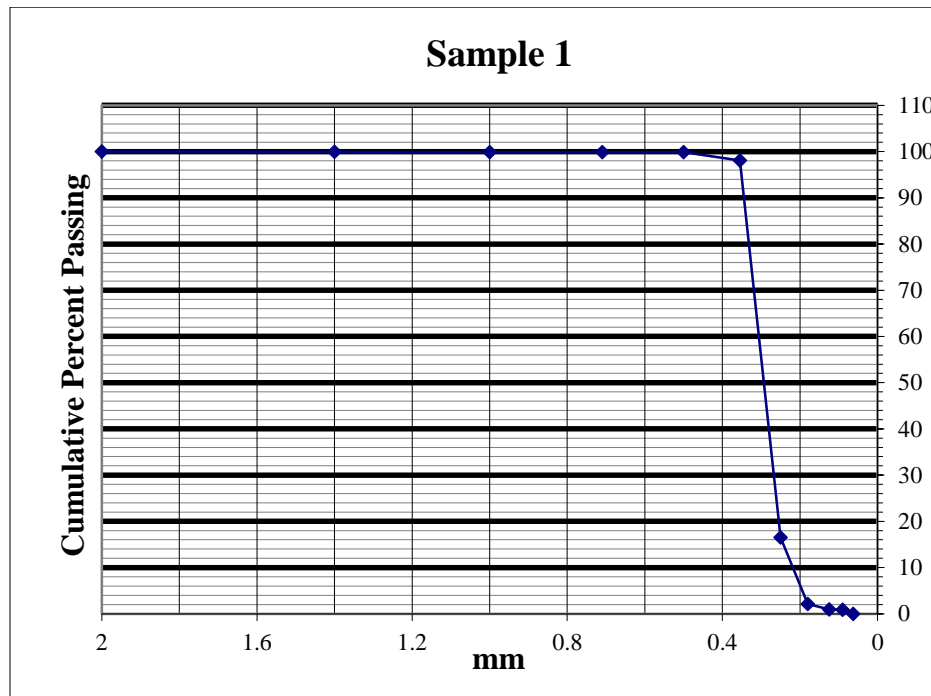
- Kohyani, P. T., B. Bossuyt, D. Bonte, and M. Hoffmann. 2008. "Grazing as a Management Tool in Dune Grasslands: Evidence of Soil and Scale Dependence of the Effect of Large Herbivores on Plant Diversity." *Biological Conservation* 141: 1687-94.
- Loveless, M. D. 1984. *Population Biology and Genetic Organization in *Cirsium pitcheri*, an Endemic Thistle*. Ph.D. University of Kansas.
- Ottawa County Parks. 2014a. "Map." Accessed January 10, 2014.
<http://www.miottawa.org/Parks/parks.htm>
- Ottawa County Parks. 2014b. "Rosy Mound Natural Area." Accessed January 9, 2014.
<http://www.miottawa.org/Parks/rosymound.htm#none>
- Phillips, T., and M.A. Maun. 1996. "Population Ecology of *Cirsium pitcheri* on Lake Huron Sand Dunes I. Impact of White-tailed Deer." *Canadian Journal of Botany* 74: 1439-44.
- Recce, S. 1988. *Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for *Cirsium pitcheri**. Federal Register Document 88-16061. Accessed January 13, 2014.
http://ecos.fws.gov/docs/federal_register/fr1444.pdf
- Rowland, J., and M.A. Maun. 2001. "Restoration Ecology of an Endangered Plant Species: Establishment of New Populations of *Cirsium pitcheri*." *Restoration Ecology* 9 (1): 60-70.
- US Forest Service. 2014. "Threatened, Endangered, and Proposed (TEP) Plant Profile: *Cirsium pitcheri*, Pitcher's Thistle." Accessed January 10, 2014.
http://www.fs.fed.us/wildflowers/rareplants/profiles/tep/cirsium_pitcherii/index.shtml
- Voss, E. G., and A. A. Reznicek. 2012. *Field Manual of Michigan Flora*. Ann Arbor: University of Michigan Press. 990 p.
- Weather Underground 2014. "Weather History for Muskegon, MI." Accessed January 23, 2014.
<http://www.wunderground.com/history/airport/KMKG/2013/10/20/WeeklyHistory.html>
- Yorks, T. P., N. E. West, R. J. Mueller, and S. D. Warren. 1997. "Toleration of Traffic by Vegetation: Life Form Conclusions and Summary Extracts from a Comprehensive Data Base." *Environmental Management* 21 (1): 121-31.

Appendix A: Loveless' 1984 *Cirsium pitcheri* mortality findings



Graph reproduced from Loveless (1984 figure 6).

Appendix B: Grain size analysis



	Phi	mm	Class Size (sieve #)	Diameter (in mm)	Diameter (in phi)	% Passing
95%	1.5	0.35	25	0.71	0.494	100.00
84%	1.57	0.34	35	0.5	1.000	99.86
75%	1.64	0.32	45	0.355	1.494	93.27
Median 50%	1.8	0.29	60	0.25	2.000	26.40
25%	1.92	0.26	70	0.21	2.252	10.73
16%	2	0.25	45	0.355	1.494	2.18
5%	2.28	0.21	60	0.25	2.000	0.43
			70	0.21	2.252	0.05
Mean =	1.79	0.29	80	0.18	2.474	0.03
St.Dev. =	0.22	0.86	120	0.125	3.000	0.90
Inc.StDev=	0.23	0.86	170	0.09	3.474	0.00
Skewness	0.07					
Inc. Sk =	-0.08					
Kurtosis =	1.14					

Sorting: very well sorted
 Skewness: near-symmetrical
 Kurtosis: leptokurtic

Appendix C: *Cirsium pitcheri* sample attribute table

Pitcher's Thistle					
FID	Shape *	Grazing_tr	Surface_co	Comment	
54	Point	None	Early_colonizers	1001	
55	Point	None	Early_colonizers	1002	
56	Point	None	Early_colonizers	1003	
57	Point	None	Early_colonizers	deer tracks	
58	Point	None	Early_colonizers	1005	
59	Point	None	Bare_sand	1006	
60	Point	None	Bare_sand	1007	
61	Point	None	Early_colonizers	1008	
62	Point	None	Early_colonizers	1009	
63	Point	None	Early_colonizers	1010	
64	Point	None	Early_colonizers	1011	
65	Point	None	Bare_sand	1012	
66	Point	None	Bare_sand	1013-dead	
67	Point	None	Bare_sand	1014	
68	Point	None	Bare_sand	1015	
69	Point	None	Early_colonizers	1017	
70	Point	None	Bare_sand	1018	
71	Point	None	Bare_sand	1019	
72	Point	None	Bare_sand	1020	
73	Point	None	Early_colonizers	1021	
74	Point	None	Early_colonizers	1022	
75	Point	Trampling	Bare_sand	1023	
76	Point	None	Bare_sand	1024	
77	Point	None	Early_colonizers	1025	
78	Point	None	Early_colonizers	1026	
79	Point	None	Early_colonizers	1027	
80	Point	None	Early_colonizers	1028-dead	
81	Point	None	Bare_sand	1029	
82	Point	None	Bare_sand	1030	
83	Point	None	Early_colonizers	1031	
84	Point	None	Bare_sand	1032	
85	Point	None	Early_colonizers	1033	
86	Point	None	Early_colonizers	1034	
87	Point	None	Bare_sand	1035	
88	Point	None	Early_colonizers	1036-dead	
89	Point	None	Bare_sand	1037	
90	Point	None	Early_colonizers	1038	
91	Point	None	Early_colonizers	1039	