First-Year Research in Earth Sciences: Dunes

Dune Habitat Influences Threatened Thistle: *Cirsium pitcheri* at Rosy Mound Natural Area

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FYRES: Dunes Research Report # 21
June 2016

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ABSTRACT

Understanding the interaction between a plant and its surrounding environment is an important step towards evaluating the health of a population, particularly when a species is threatened or endangered. This study examined how habitat influences the health and distribution of *Cirsium pitcheri*, a state and federally threatened plant, at Rosy Mound Natural Area on Lake Michigan's eastern shore. In fall of 2015, we used GPS units to map 147 individual plants, collecting data on leaf length, number of leaves, and plant health. We sampled dune surface characteristics such as sand movement, plant density, and percent ground cover. Using the GPS units, we mapped various types of plant communities and dune features throughout the study area. *C. pitcheri* grew most abundantly in areas of sparse grasses, dune blowouts and slipfaces, hummocky dunes, and moderate disturbance. A small number of thistles were growing near a small stand of evergreen trees in an area with no obvious sand movement. The healthiest and most mature individuals tended to grow in sandy spots with little ground cover. Understanding how the local environment influences the growth of *C. pitcheri* could lead to improved management plans for Great Lakes parks to implement.

INTRODUCTION

Lake Michigan's coastal dunes hold a treasured space in the minds of Michigan natives and those who have the opportunity to visit them. They are part of a dynamic ecosystem that supports a number of rare fauna and flora. One example of such a rare species is *Cirsium pitcheri*, or Pitcher's thistle. *C. pitcheri* is endemic to the Great Lakes dunes and is found nowhere else in the world, relying on the unique habitat conditions these dunes provide to thrive. Our study, conducted in Ottawa County Parks' Rosy Mound Natural Area on Lake Michigan's eastern shore, investigates some of the specific environmental factors that influence *C. pitcheri*'s growth with the hopes that such information could contribute to continued conservation of the plant. We had four primary objectives for our study: 1) to collect data on individual plant characteristics; 2) to collect data pertaining to the surrounding vegetative community; 3) to collect data on local dune characteristics; and 4) to see how all these variables factored into *C. pitcheri* distribution patterns.

BACKGROUND

Cirsium pitcheri, or Pitcher's thistle as it is more commonly known, is a thistle endemic to the Great Lakes region (Girdler and Radtke 2006). Specifically, its range is from the southern tip of Lake Michigan to the northern shore of Lake Superior, and as far east as the western shore of Lake Huron (Hamzé and Jolls 2000; Chen and Maun 1998). The majority of the extant population is along the eastern shore of Lake Michigan (Hamzé and Jolls 2000).

C. pitcheri can reach 91 cm in height (US Fish and Wildlife Service 2001). Adult plants grow in the form of rosettes (Bowles *et al.* 1993). *C. pitcheri* has green leaves covered in long white hairs, giving it a silvery-white appearance (Rowland and Maun 2001). These hairs, along with a taproot that reaches up to 1.8 meters, are part of *C. pitcheri*'s adaptation to its beach environment; the hairs retain water and reflect sunlight, while the taproot reaches water deep beneath the plant (US Fish and Wildlife Service 2001). The plant grows on dry, sandy environments such as early successional dune environments with 30% vegetation cover or less (Hamzé and Jolls 2000; Havens *et al.* 2012).

C. pitcheri's life cycle is important to the species' continued survival (Fig 1). It only produces sexually, meaning that it needs to spread its seeds if the population is to continue to survive (Hamzé and Jolls 2000). *C. pitcheri* is also considered a monocarpic perennial, growing for 3-10 years before seeding, then dying (Girdler and Radtke 2006; Rowland and Maun 2001). The timing of when an individual goes to seed is determined by the size of the rosette, which in turn is determined by food storage capabilities and the habitability of the environment (Keddy and Keddy 1984).

Unfortunately, *C. pitcheri* is a federally-threatened species, as well as threatened or endangered at different state levels (Girdler and Radtke 2006). This listing is due in large part to continued habitat loss in its native range (Fig 2) (Hamzé and Jolls 2000). Human activities such as sand mining, shoreline development, and recreation all contribute to *C. pitcheri*'s habitat loss; other factors such as dune and shoreline stabilization, disruption of shoreline currents, and herbivory also contribute to habitat loss (Girdler and Radtke 2006). The danger has only increased for *C. pitcheri*, as some populations in its southern range have been extirpated completely; only reintroduction efforts have kept the thistle alive in Illinois (US Fish and Wildlife Service 2001). With climate change as a continued and looming threat, it appears that *C. pitcheri* will continue to decline into the foreseeable future (Havens *et al.* 2012).

Figure 1: *C. pitcheri*'s life cycle. Clockwise from the top left: *C. pitcheri* seedling, a mature *C. pitcheri* rosette, *C. pitcheri* in bloom, and a *C. pitcheri* after it has spread its seeds.

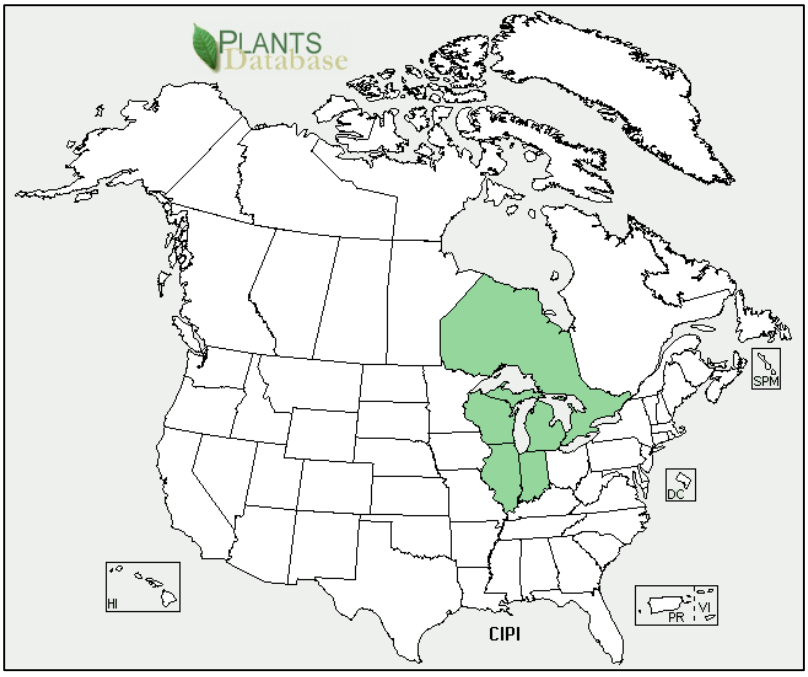

Figure 2: *C. pitcheri*'s full habitat range by state or province (US Department of Agriculture 2016). Much of this habitat is declining with increased human activity and development.

With the plant's future in question, researchers have been conducting more studies on *C. pitcheri*. In particular, scientists have been focusing more on the environmental factors that influence the plant's growth and distribution (D'Ulisse and Maun 1996; Maun 1997; Rowland and Maun 2001; Girdler and Radtke 2006; Jolls *et al.* 2015; Marshall 2014), including two previous studies conducted through the Calvin College First-Year Research in Earth Sciences (FYRES) program (Hughey *et al.* 2015; Strydhorst *et al.* 2014). While these studies contribute much to general knowledge about *C. pitcheri*, more information is needed if park managers throughout the plant's range are to implement effective conservation measures.

STUDY AREA

We conducted the study at Rosy Mound Natural Area in Grand Haven, Michigan, on Lake Michigan's eastern lakeshore (Fig 3). Rosy Mound's 164-acres are home to a variety of dune topographies, including a beach, hummocky dunes, wooded dunes, and open dunes

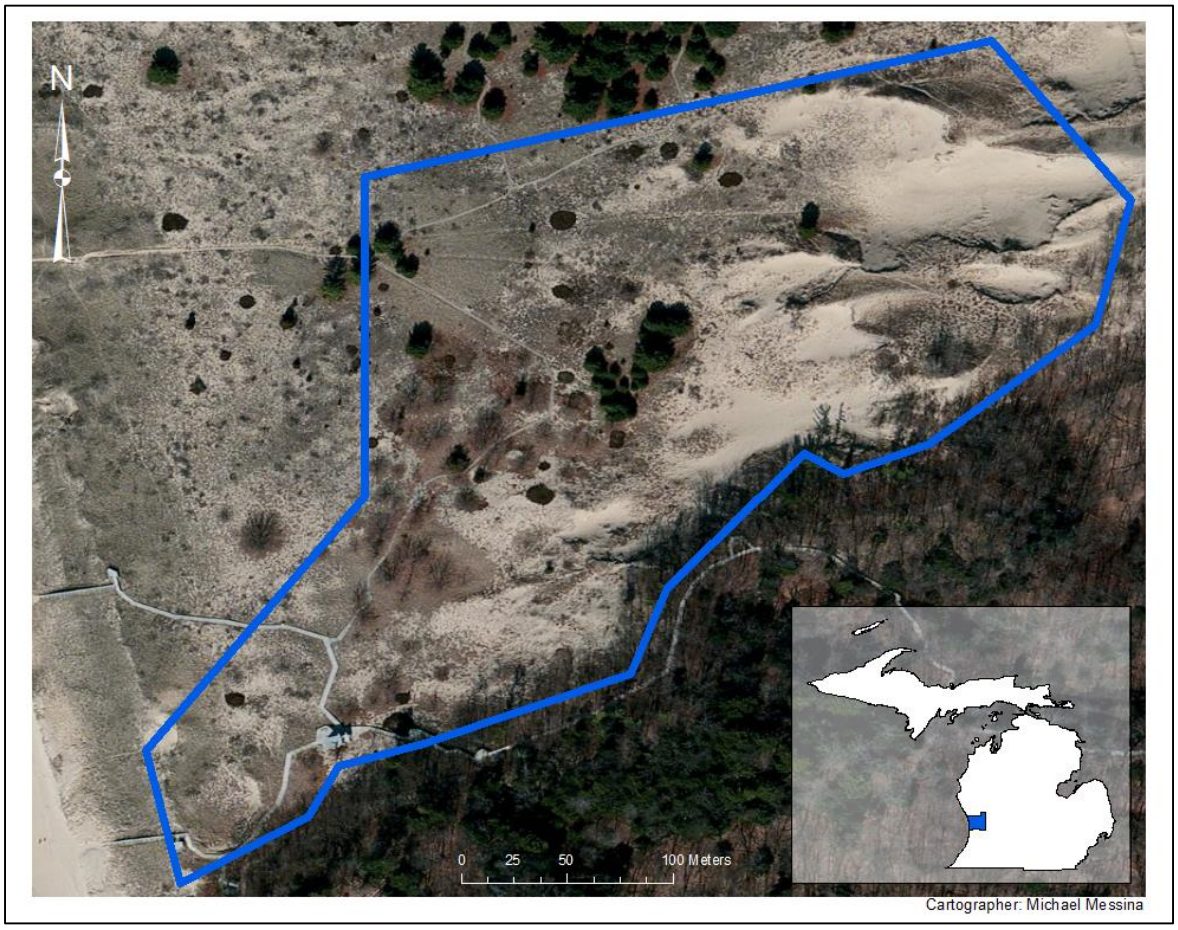

Figure 3: An aerial view of the study site, outlined in blue, in Ottawa County. Inset shows the location of Ottawa County in Michigan.

(Michigan Trail Maps 2016). The park also has a distinct human element, with nearly 2.5 miles of hiking trails and managed boardwalks winding throughout the park, beginning at the parking lot. Rosy Mound has private residential areas on its north, east, and southern borders, with Lake Michigan marking the western edge.

Two previous FYRES studies have been conducted at Rosy Mound Natural Area. In the fall of 2013, researchers investigated the relationships between *C. pitcheri* and grazing, trampling, trails, and sand movement (Strydhorst *et al.* 2014). They found that the disturbance caused by deer appeared to be ideal for the local *C. pitcheri* population, which was denser near deer trails than human trails. The 2014 study examined the influence of both natural and anthropogenic factors on *C. pitcheri* distribution (Hughey *et al.* 2015). This study found that topography directly influenced the plant's populations, while anthropogenic factors had an indirect influence.

METHODS

Data Collection

We divided our data collection into three parts: individual plant characteristics, the vegetation surrounding the *C. pitcheri*, and the dune characteristics of the study site.

Using Trimble Juno GPS units, we mapped as many individual *C. pitcheri* plants as we could. We did not have the time to map the entire population, but we did get a large sample.

While mapping the individual plants, folding meter sticks were used to measure the plant's height and the length of its longest leaf. Plant height was measured from where the base of the plant met the sand to the plant's highest point. Longest leaf length was measured from the leaf's base to its tip. We also counted the number of living leaves on each plant. Once these measurements were recorded, a qualitative assessment of the plant's health was taken. Individuals were rated on a scale from 1 to 5, with 1 being the lowest health rating and 5 being the highest.

Using the GPS units, we also mapped the various vegetation communities in and near where the *C. pitcheri* populations were situated. We identified various vegetation habitats based on the presence and density of the different plant types: bare sand (no vegetation), evergreen trees (a stand of trees), grasses (50% + of ground cover, mostly different grass species), grasses and scattered shrubs (an equal mixing of grass and shrub species), shrubs (majority of vegetation

are shrubs), and sparse grass (<50% grass species ground cover) (Fig 4). The density was based on a qualitative assessment.

Within each vegetation area, sample density was taken twice via .5 m x .5 m quadrat samples. For random sampling, quadrats were thrown from a central location within each vegetation area.

Figure 4: Top: Sparse grassland surrounded by grasses. Bottom: Shrub landscape.

Figure 5: An example of the hummocky dune landscape found at Rosy Mound Natural Area.

GPS units were also used to map Rosy Mound's dune characteristics. Dune landscape features (blowouts, blowout bowls, slipfaces, and hummocky dunes) were identified and mapped much like the various vegetation areas were mapped (Fig 5).

Twelve erosion pins were placed throughout the park. Three transects of four pins were placed among three different metapopulations of *C. pitcheri*. We collected data on two of these three populations. Each pin was mapped using the GPS units.

We also collected 7 sand samples from each of the sites throughout the park. We tested the samples for moisture content, weighing each one before and after drying them in an oven at a temperature of 105 degrees C. Each sample location was mapped using GPS units.

Data Analysis

The GPS data was post-processed and downloaded onto ArcGIS 10.1 for analysis. Spatial proximity between individual *C. pitcheri* and various vegetation areas and dune characteristics was noted.

After examining the GPS data, we decided it would be worthwhile to divide the larger Rosy Mound *C. pitcheri* population into 5 smaller metapopulations. These populations were divided based on the fact that each was located in a different combination of vegetation type and dune characteristic. Once divided, average number of leaves, average longest leaf length, and average health rating were calculated for each metapopulations. Those calculations and the ensuing graphs were calculated and created with Microsoft Excel. We checked for significance by using SPSS statistical software.

RESULTS

Individual Plants

We mapped a total of 147 individual *C. pitcheri* plants, varying in age from seedling to adults that had released seeds (see Fig 1). For 135 of those individuals, we collected data on number of leaves, longest leaf length, plant height, and plant data (see Appendix A). Nine of the individuals were dead, and at least four of those had gone to seed.

The majority of *C. pitcheri* individuals were rated as being of average health, a three on the scale (Fig 6). 45 individuals received a rating of three, 33 a rating of two, and 30 a rating of four. 17 plants were given a rating of one, at least nine of which were dead. 10 individuals were given a rating of five. Health rating was a qualitative assessment with no standardized method, so significance was not tested.

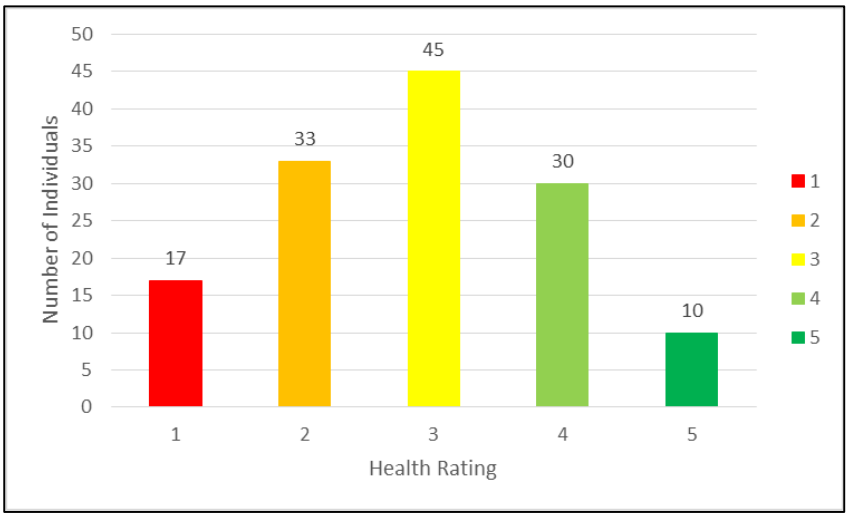

Figure 6: *C. pitcheri* health rankings.

The average number of leaves and the average longest leaf length was calculated for each health rating (Fig 7). The results roughly corresponded to each other; plants with a rating of five had an average of 15.7 leaves, with the average longest leaf length being 26.9 cm, more than and longer than any other rating. Plants with a health rating of two had the lowest average number of leaves and the shortest average longest leaf length, at 7.5 leaves and 14.2 cm.

General observations revealed that minor levels of herbivory occurred. Some *C. pitcheri* leaves displayed evidence of being eaten, and scat was found near the portion of the population by the stand of evergreen trees.

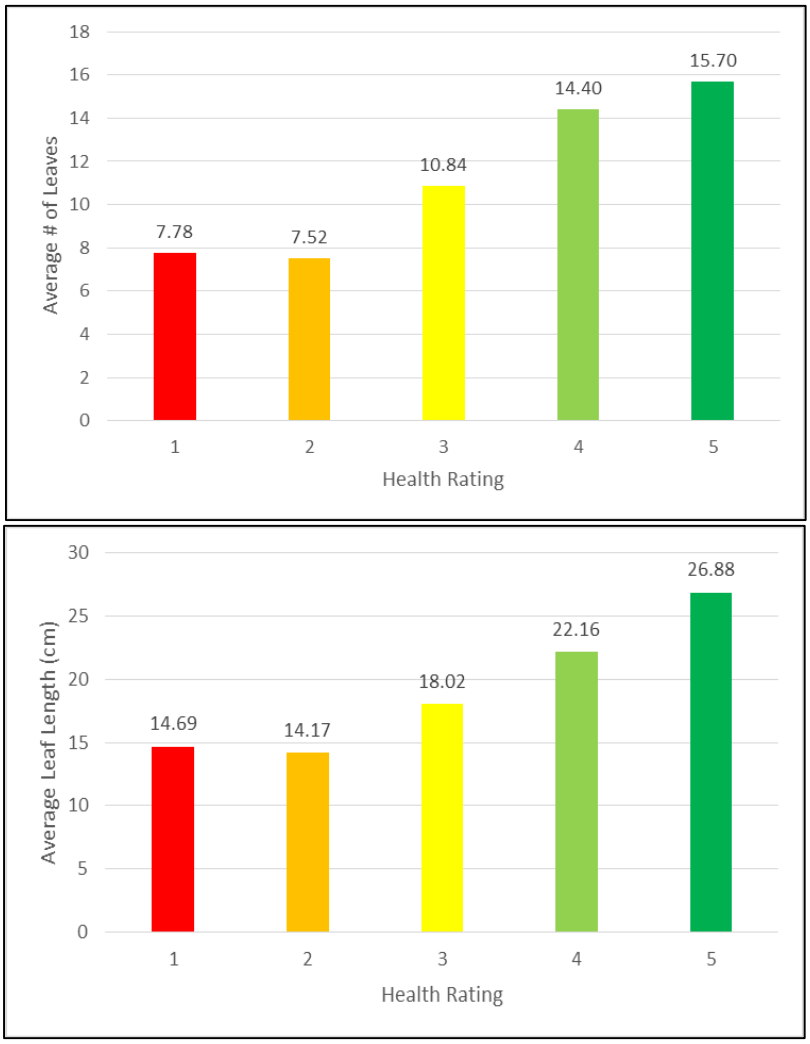

Figure 7: Top: A comparison of average number of leaves with average health rating. Bottom: A comparison of average longest leaf length with average health rating.

Vegetation Communities

C. pitcheri grew in a variety of different vegetative habitats. The majority of *C. pitcheri* grew in areas of sparse grass and shrubs (52 and 29, respectively) (Fig 8). 11 individuals grew in grassland areas, and a couple (2) also grew among a stand of evergreen trees. 14 individuals grew in bare sand areas, often near areas of sparse grass or shrubs.

The quadrat surveys enabled us to identify characteristics of the vegetation communities in which the *C. pitcheri* grew. Plant densities ranged from 0-100% in the bare sand, shrub, and dune grass communities. Nearby species included *Ammophila breviligulata, Calamovilfa longifolia,* and *Artemisia caudata,* as well as unidentified dogwood shrubs and evergreen tree saplings. *C. pitcheri* also grew in various dune environments, including on slipfaces, hummocky dunes, windward slopes, and in a trough blowout (see Appendix B).

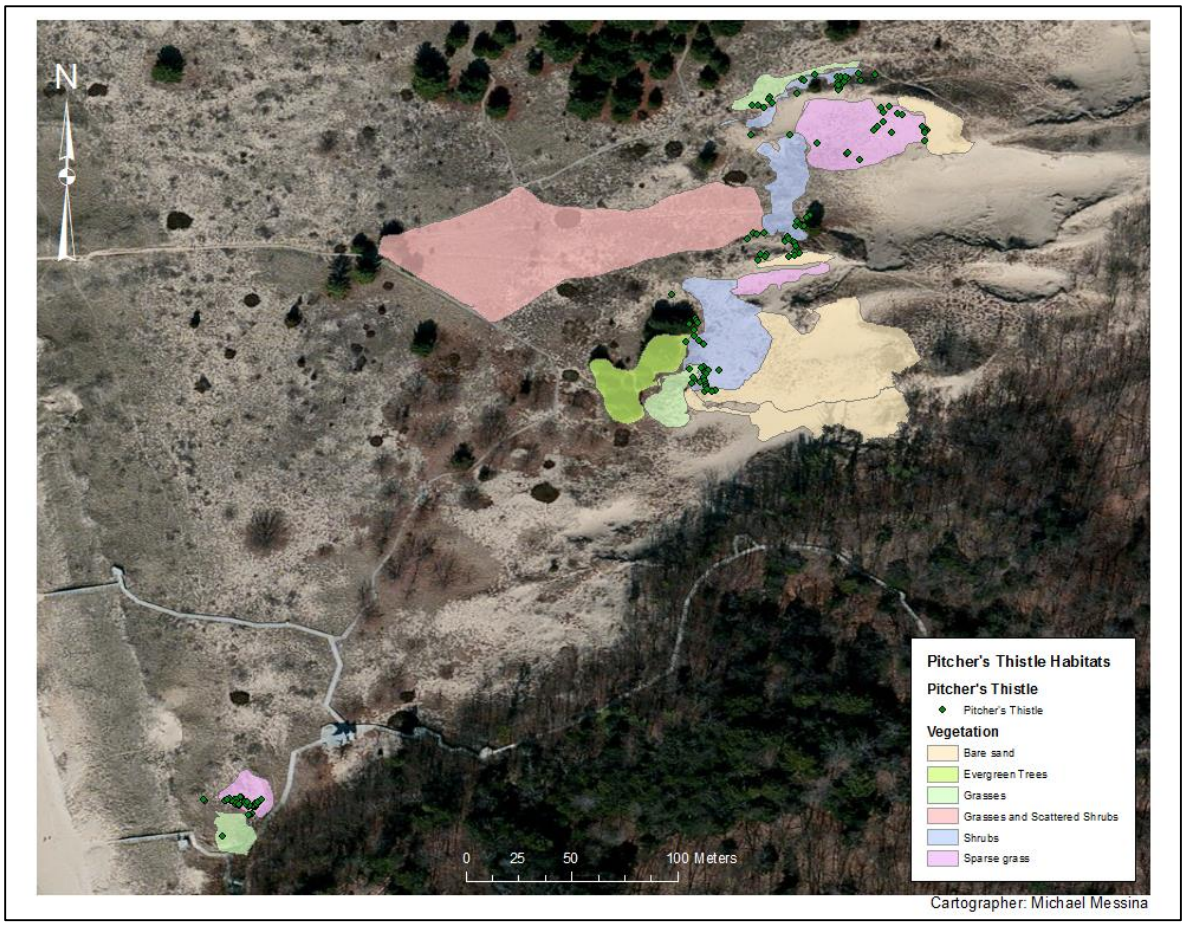

Figure 8: *C. pitcheri* location in relation to various vegetation communities.

Dune Characteristics

C. pitcheri also grew among a variety of different dune surface characteristics (Fig 9). The majority of *C. pitcheri* individuals were found in blowouts or blowout bowls. A number of others were found on dune slipfaces, and one recorded population was found in a hummocky dune area.

All the erosion pins recorded at least 1 centimeter of surface change over the course of two weeks. The greatest amount of change was 11 cm, and the smallest amount was 1 cm.

The soil moisture varied slightly from sample to sample. The lowest moisture percentage was 1.6%, and the highest was 5.7%. There was no apparent correlation between moisture content and *C. pitcheri* distribution.

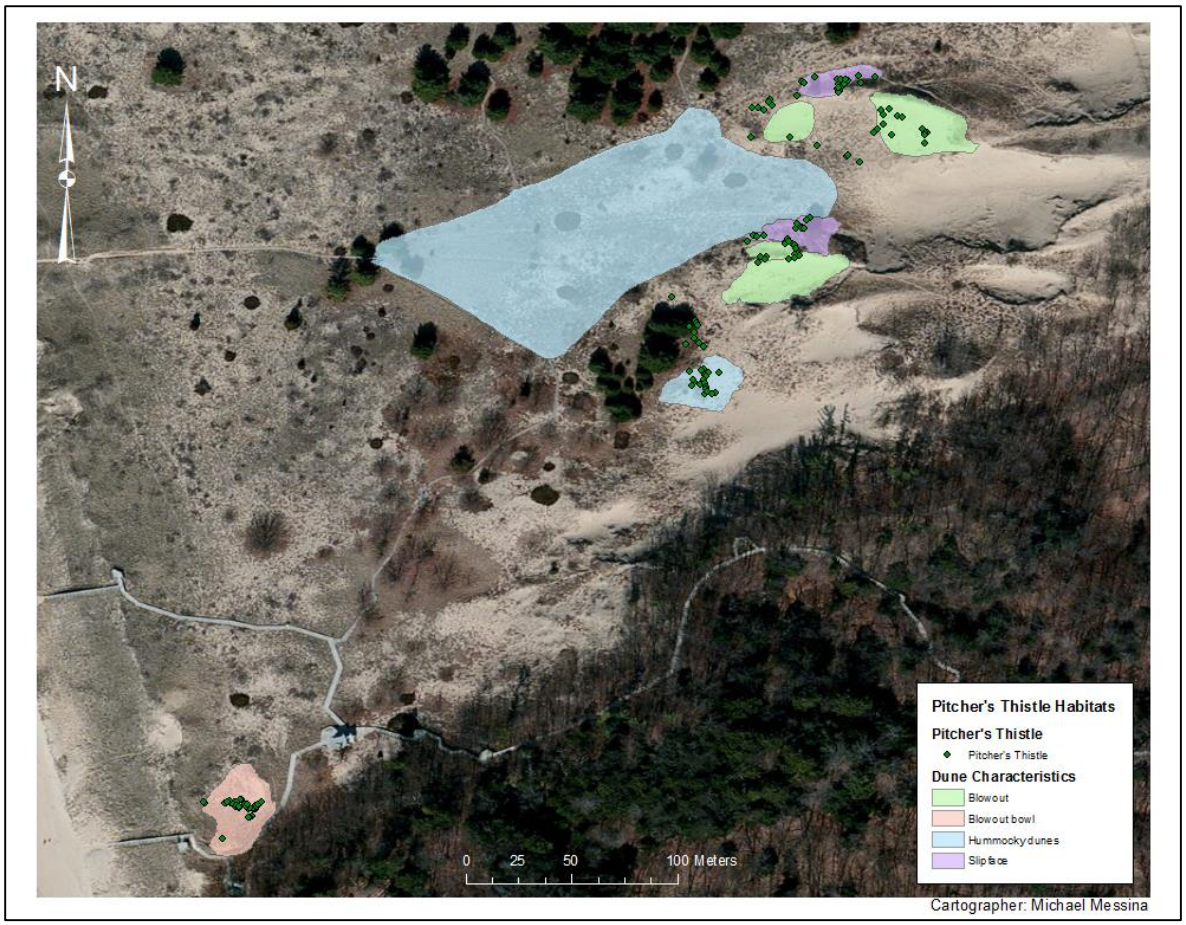

Figure 9: *C. pitcheri* location in relation to various dune characteristics.

Metapopulation Analysis

Based on varying habitat, the larger Rosy Mound *C. pitcheri* population was divided into 5 smaller metapopulations (Fig 10). These metapopulations had different combinations of vegetation and dune surface characteristics. Group 1 was on the slipface of an active dune among a shrub-dominant vegetation community. Group 2 was largely in the blowout of that same dune, and grew among bare sand and sparse grass communities. Group 3 was on the slipface and in the blowout of a different dune, growing among bare sand and shrub habitats. Group 4 was on a hummocky dune landscape with a shrub-dominant community. Group 5 was in a blowout bowl with sparse grasses and grassland.

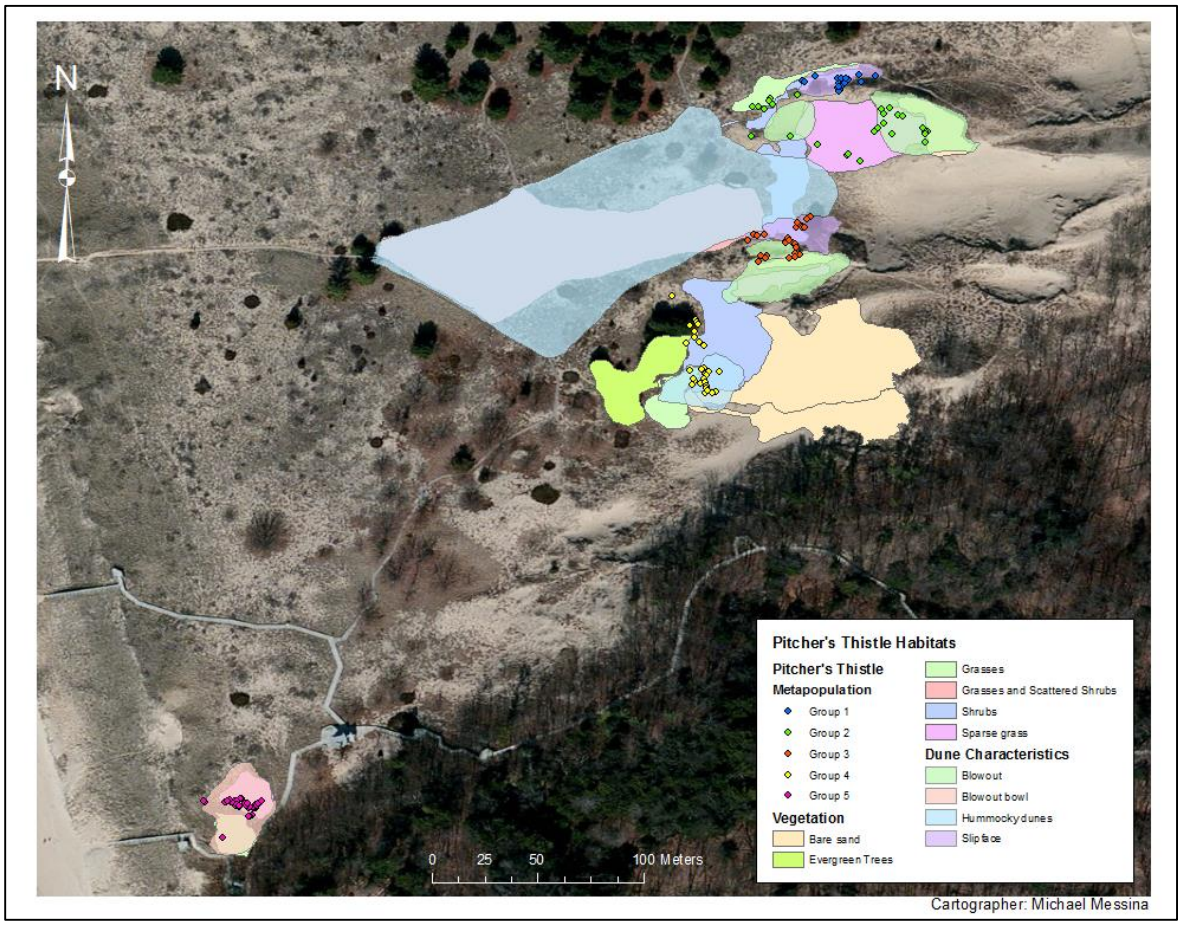

Figure 10: The five *C. pitcheri* metapopulations, as distinguished by differences in habitat.

Average number of leaves and average longest leaf length were compared for each metapopulation (Fig 11). In both cases, Group 4, which was located in a shrubby and hummocky dune area, had the highest numbers. Leaf length varied much less than the number of leaves for each population.

The differences in average number of leaves for each metapopulation lacked statistical significance. The differences in the average longest leaf length were statistically significant, with Group 2 differing significantly from Group 5, Group 3 differing significantly from Group 4, and Group 4 differing significantly from both Group 3 and Group 5.

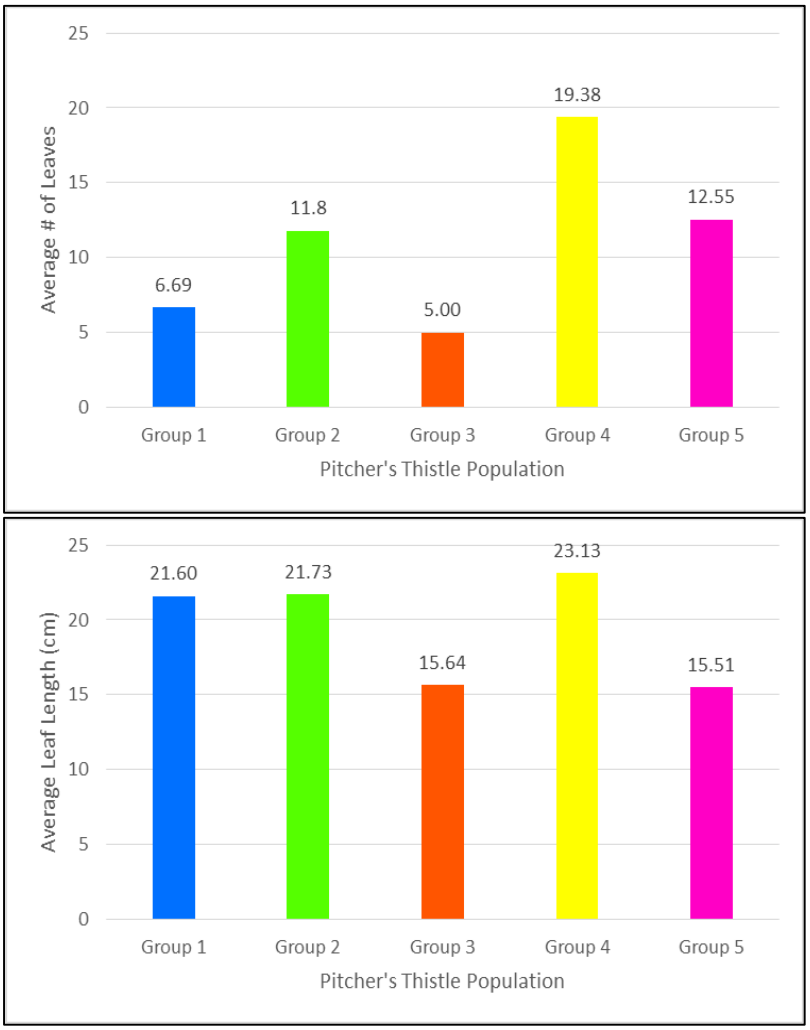

Figure 11: Top: Average number of leaves by metapopulation. Bottom: Average longest leaf length by metapopulation.

DISCUSSION

C. pitcheri at Rosy Mound Natural Area grew in a variety of habitats, which is consistent with previous findings. A majority of the population was found in areas that had high bare sand to vegetative cover ratios, which is essential for *C. pitcheri* to thrive (Havens *et al.* 2012; Hamzé and Jolls 2000). The areas dominated by shrubs or sparse grasses in particular were capable of supporting stable and healthy metapopulations.

These different habitats appeared to facilitate *C. pitcheri* growth throughout the park. Plants in the hummocky dune areas were more likely to reach maturity, as well plants growing in areas with some bare sand. Most of the mapped population grew in areas among plant communities that also had some consistent level of disturbance – as evidenced by the bare sand. *C. pitcheri* also grew in blowouts and on slipfaces, areas of activity in a dune system. These areas are ideal for *C. pitcheri* flourishing and propagation, since it requires sand burial for healthy growth (Maun 1997; Rowland and Maun 2001; Marshall 2014)

Rosy Mound Natural Area's *C. pitcheri* population has a wide range of maturity levels. This variety suggests a healthy overall population – plants are germinating, and enough are reaching full maturity to keep the overall population alive. This observation, combined with the large amount of hospitable habitat, suggests that Rosy Mound is an excellent place for continued *C. pitcheri* reproduction and survival.

There were a couple of exceptions to the expected distribution of *C. pitcheri*: the population on the hummocky dunes, and the individuals growing underneath the stand of evergreen trees. The population on the hummocky dunes does not necessarily contradict previous studies; rather, it is not something that previous researchers have noted. However, it does make sense that the *C. pitcheri* should be able to thrive, as long as the hummocky dune areas have enough consistent disturbance and bare sand. What is more unusual is the presence of two plants underneath the stand of evergreen trees (Fig 12). This finding directly contradicts the findings of Rowland and Maun (2001) and Jolls *et al.* (2015), who found that shade hinders *C. pitcheri* seedling emergence and overall growth. However, these individuals were not particularly healthy, and could be anomalous.

A potential concern for the Rosy Mound population would be the presence of white-tailed deer (*Odocoileus virginianus*). White-tailed deer will occasionally eat *C. pitcheri*, which

Figure 12: An individual *C. pitcheri* growing in the shadow of an evergreen tree is recorded by a researcher.

can have detrimental effects on the overall health of the individual and the population (Rowland and Maun 2001; D'Ulisse and Maun 1996). There was evidence of some herbivory on this population, but not enough to raise serious concern. A previous study found that the Rosy Mound deer population seemed to have a positive influence on *C. pitcheri* growth at the park (Strydhorst *et al.* 2014). Even so, Rosy Mound's management should remain alert and take appropriate action should the level of herbivory increase.

CONCLUSIONS

We found that the majority of *C. pitcheri* at Rosy Mound Natural Area is growing on areas with moderate to low levels of vegetative cover, as well as areas of consistent disturbance. Specifically, *C. pitcheri* grew most in sparse grasses and shrubs, as well as on dune blowouts and slipfaces. Plants growing in these habitats were more likely to reach maturation and reproduce than plants in other habitats.

A considerably large and healthy portion of *C. pitcheri* is growing on a patch of hummocky dunes. The large patches of open sand on the hummocky dunes provide the disturbance-based habitat *C. pitcheri* requires for its persistence. This previously unreported *C. pitcheri* habitat suggests that, overall, the environmental conditions at Rosy Mound Natural Area provide ideal habitat for *C. pitcheri* survival and flourishing.

Knowledge of *C. pitcheri*'s location and its local habitat can assist management decisions made at Rosy Mound. On a larger scale, these study results can provide insight into what desirable *C. pitcheri* habitat looks like.

ACKNOWLEDGEMENTS

The research team would like to thank Deanna van Dijk, Melanie Manion and Ottawa County Parks and Recreation, the Calvin College Department of Geology, Geography and Environmental Studies, and the Michigan Space Grant Consortium. Special thanks to Charlotte Reynolds' and Katy Gerber's research teams for helping with data collection in the field.

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APPENDIX A: Individual Plant Characteristics Data

Plant #/ID	Description of Plant	Dead/Alive	Leaf Length (cm)	Plant Height (cm)
A9	**Many dead leaves; seed pods**	**D**	**29.55**	**9.97**
A11	**Seed pods; many dead leaves**	**D**	**25.01**	**2.35**
A12	**Seed pods; many dead leaves**	**D**	**18.52**	**3.02**
A3	Mostly healthy; two chewed leaves	A	29.81	13.05
A10	One dead leaf	A	29.71	9.48
A5	Half leaves dead; none eaten	A	26.01	14.11
A1	Many dead leaves	A	25.75	13.32
A7	Half leaves dead; alive leaves discolored	A	24.99	9.55
A2	Half of leaves chewed down	A	24.1	3.65
A15	Half of leaves dead	A	23.15	11.59
A6	A lot of dead leaves	A	21.29	21.29
A4	Half of leaves dead	A	19.35	9.32
A8	Two dead leaves	A	19.06	8.35
A13	3 small plants; one dead leaf from each	A	15.51	9.85
A14	Small; no dead leaves	A	13.39	13.39
A16	Small	A	8.69	8.69
103	**Flowered; 16 flowers**	**D**	**63**	**0**
100	Brown spots	A	36.5	11
104	Thick/large	A	34.5	3
102	Thick/large	A	34	12
116	Trampled; white (partly?)	A	33	13
114	Dark green; white specks	A	33	16
107	Brownish at base; white tip	A	30	11
111	Very light/yellow	A	29	14
118	Trampled/white/thick	A	28	11
113	Skinny light green	A	26	7
119	Green/ light brown specks	A	25	9
105	Very white	A	23	4
109	Green base; white tip	A	22	12
112	Thicker leaves; small	A	21	7
108	Green base; white tip	A	21	13
124	Thicker; green	A	20	5
106	Very thin	A	19	6
101	Small	A	16.25	9
117	Tiny; white	A	16	2
110	Green base; white tip	A	14	5
115	Puny/white	A	14	10
120	Healthy/small	A	13	9
125	Light green; white/brown spots	A	13	13
121	Small/white	A	12	11
123	Small/healthy	A	5	5
122	Small/healthy	A	5	5
B4	**Dead**	**D**	**27**	**17**
B3	Herbivory	A 1/2	21.4	13
B2	Some dead	A 1/2	18.1	12

Plant #/ID	Number of Leaves	Health Rating (1-5)	Ground Cover	Surrounding Community
A9	**0**	**1**	**Bare sand**	**Grasses and shrubs**
A11	**0**	**1**	**Bare sand**	**Grasses and shrubs**
A12	**0**	**1**	**Bare sand**	**Grasses and shrubs**
A3	17	4	Dead veg	Sparse grasses
A10	9	4	Bare sand	Grasses and shrubs
A5	5	3	Leaf litter	Grasses and shrubs
A1	14	3	Leaf litter	Sparse grasses
A7	6	3	Bare sand	Grasses and shrubs
A2	6	2	Sparse veg	Sparse grasses
A15	7	3	Grasses	Grasses and shrubs
A6	1	2	Grasses	Grasses and shrubs
A4	6	3	Bare sand	Grasses and shrubs
A8	6	4	Bare sand	Grasses and shrubs
A13	3	4	Bare sand	Grasses and shrubs
A14	4	5	Bare sand	Grasses and shrubs
A16	3	5	Bare sand	Grasses and shrubs
103	**6**	**1**	**Sandy; sparse grass**	**More grass**
100	36	4	Sandy; sparse grass	Grass/small shrubs
104	11	5	Sandy; sparse grass; dead sh	Sand/dead shrubs
102	9	5	Sandy; sparse grass	More grass
116	14	4	?	Shrub
114	20	3	Less grass	Steep - Mod incline
107	25	4	Sand flat	Shrub growing out of
111	17	3	Sand; sparse grass	Higher incline
118	13	4	Sparse vegetation	Veg/incline
113	18	3	Less grass	Steep - Mod incline
119	20	4	Grass/sand	Inclined
105	11	4	Sand	Veg further away?
109	6	4	Sand flat	Shrub growing out of
112	9	4	Less grass	Steep - Mod incline
108	7	4	Sand flat	Shrub growing out of
124	9	4	Bare sand	Nearer to grass
106	8	3	Sand	Veg further away?
101	16	3	Sandy; sparse grass	Grass/small shrubs
117	5	2	?	Shrub; steeper
110	10	4	Grasses	Slight incline grasses
115	5	2	?	Shrub
120	5	5	Plant right next to it	Plant right next to it
125	7	3	Bare sand	Bare sand; debris
121	7	4	Bare sand	Bare sand
123	4	3	Bare sand	Bare sand
122	3	3	Bare sand	Bare sand
B4	**15**	**1**	**Sand reed**	**Sand reed**
B3	22	1.5	Sand reed	Sand reed
B2	9	2	Sand reed	Sand reed

Plant #/ID	Description of Plant	Dead/Alive	Leaf Length (cm)	Plant Height (cm)
B28	Large	A	39.9	14
B45	Herbivory	A	37.8	20.5
B27		A	33	13.5
B35	Herbivory	A	32.5	20
B7		A	32.3	16
B6	Spots	A	30.2	2.8
B23	Shriveled leaves	A	25.9	13
B24	New sprouts	A	25.7	9
B21		A	23.7	23.5
B9		A	23	12
B5	Spots	A	20	14
B26	Spots	A	19.1	13
B11	Spots	A	18.5	8
B44	Herbivory	A	18.4	9.5
B1	Spots	A	17.4	13.5
B18		A	16.1	14.5
B8	Small	A	14	7
B16	Spots	A	14	12
B22		A	13.6	7
B19	Spots	A	11.3	5.5
B39		A	10.9	6.5
B10	Small	A	10.4	2
B25	1/2 dead	A	10.3	5.5
B42	Cluster	A	10.1	4
B36		A	10.1	5
B30	Small	A	9.3	8
B34	Spots	A	9.1	6.5
B38	Herbivory	A	8.8	7.5
B14	Small	A	8.6	7
B31	Small	A	8.2	8
B40	Small	A	8	8
B32	Small	A	8	5
B33		A	7.9	3
B17	Small	A	7.4	6
B15	Small	A	7.2	6.5
B29	Small	A	7	3.5
B12	Small	A	6.9	5.5
B43	Herbivory	A	6.7	4
B41	Cluster; small	A	6.6	5
B13	Small	A	6	6
B20	Very young	A	2.9	2
C4	Low health	D	24	10
C124	Med. health	A	27	23
C129	Good health	A	23	15
C147	Med. health	A	22	7

Plant #/ID	Number of Leaves	Health Rating (1-5)	Ground Cover	Surrounding Community
B28	28	5	Dead matter	Dead matter
B45	20	4	Amm.	Amm.
B27	22	5	Sand	Sand
B35	35	3	Dead matter	Dead matter
B7	18	5	Sandy	Sandy
B6	19	3	Sandy	Sandy
B23	15	3	Sand reed/dead	Sand reed/dead
B24	19	4	Sand reed	Sand reed
B21	19	4	Dead plant	Dead plant
B9	14	4		
B5	11	2	Sand reed	Sand reed
B26	10	3	Sand reed	Sand reed
B11	10	3	Sandy	Sandy
B44	21	4	Amm.	Amm.
B1	4	3	Beach grass	Beach grass
B18	11	2	Dead plant matter (DPM)	Dead plant matter
B8	12	3	Sandy	Sandy
B16	7	3	Dead plant matter (DPM)	Dead plant matter
B22	9	4	Sand reed	Sand reed
B19	10	1.5	Sand	Sand
B39	10	2	Sand	Sand
B10	6	2	Sandy	Sandy
B25	9	2	Sand reed	Sand reed
B42	40	3	Sand	Sand
B36	9	2	Sand	Sand
B30	5	2	Dead matter	Dead matter
B34	8	2	Dead matter	Dead matter
B38	9	2	Sand	Sand
B14	8	3	Dead plant	Dead plant
B31	9	2	Dead matter	Dead matter
B40	8	3	Sand	Sand
B32	3	2	Dead matter	Dead matter
B33	5	2	Dead matter	Dead matter
B17	6	2		
B15	6	3	Dead plant	Dead plant
B29	4	4	Dead matter	Dead matter
B12	3	4	Sand reed	Sand reed
B43	9	2	Sand	Sand
B41	20	2	Sand	Sand
B13	6	3	Dead matter around	Dead matter around
B20	2	3	DPM and sand	DPM and sand
C4	6	1	Sand	B. grass
C124	8	2	Sand	B. grass
C129	8	3	Sand	B. grass
C147	8	3	Pine	B. grass

Plant #/ID	Number of Leaves	Health Rating (1-5)	Ground Cover	Surrounding Community
C130	3	2	Leaves	B. grass
C2	2	3	Sand	B. grass
C3	1	3	Sand	B. grass
C11	6	2	Sand	B. grass
C111	3	2	Sand	B. grass
C145	3	2	Pine needles	B. grass
C146	9	3	Pine	B. grass
C1	7	2	Sand	B. grass
C107	6	2	Sand	B. grass
C10	5	2	Sand	B. grass
C112	4	2	Pine	B. grass
C110	3	1	Pine	B. grass
C46	9	3	Sand	B. grass
C9	5	3	Sand	B. grass
C140	8	1	Sand	B. grass
C17	4	1	Sand	B. grass
C6	2	4	Sand	B. grass
C14	7	2	Sand	B. grass
C12	4	2	Sand	B. grass
C8	4	1	Sand	B. grass
C133a	5	3	Sand	B. grass
C109a	3	3	Sand	B. grass
C109	4	1	Sand	B. grass
C122	4	1	Sand	B. grass
C133	5	3	Sand	B. grass
C86	**12**	**1**	**Pine needles**	**8 species**
C85	**11**	**1**	**Pine needles**	**7 species**
C87	**5**	**1**	**Pine needles**	**6 species**
C70	44	5	Tree leaves; sand; plants	3 species
C61	15	3	Tree leaves; sand	0 species
C98	47	4	Dead leaves	4 species
C99	19	4	Sand; leaves	3 species
C51	36	4	Sand/vegetation 50%	4 species
C88	15	3	Sand; branches	2 species
C54	37	3	Dead tree leaves	5 species
C57	6	3	Pine needles	5 species
C95	9	3	Sand; dead leaves	4 species
C91	14	2	Bare sand	0 species
C97	13	5	Sand; dead leaves	3 species
C100	8	4	Sand	4 species
C53	17	3	Sand; little vegetation	2 species
C89	11	3	Dead branches	2 species
C36	10	3	Sand; dead leaves	2 species
C96	9	4	Bare sand	0 species

Plant #/ID	Description of Plant	Dead/Alive	Leaf Length (cm)	Plant Height (cm)
C130	Low health	A	21	18
C2	Med. health	A	20	7
C3	Med. health	A	20	2
C11	Low health	A	20	10
C111	Low health; red coloring	A	20	7
C145	Med. health	A	20	19
C146	Med. health	A	19	9
C1	Low health	A	18	6
C107	Low health	A	18	10
C10	Low health	A	17	5
C112	Med. health	A	17	6
C110	Low health	A	17	2
C46	Med. health	A	15	5
C9	Med. health	A	15	7
C140	Low health	A	15	5
C17	Low health	A	13	5
C6	Good health	A	12	35
C14	Low health	A	11	5
C12	Low health	A	11	4
C8	Low health	A	9	4
C133a	Med. health	A	8	4
C109a	Med. health	A	8	1.5
C109	Low health	A	8	3
C122	Low health	A	8	5
C133	Med. health	A	6	2
C86	**Dead**	**D**	**37**	**14**
C85	**Dead**	**D**	**37**	**17**
C87	**Dead**	**D**	**25**	**12**
C70	Healthy	A	43	17
C61	Healthy but has dead leaves	A	31	14
C98	Possibly eaten	A	30	13
C99	Some dead leaves	A	29	14
C51	Healthy; well developed	A	27	15
C88	Few not healthy leaves	A	26	17
C54	Brown spots	A	25	12
C57	1/3 of plant was dead	A	24	11
C95	Healthy	A	20	10
C91	Possible trampling	A	18	12
C97	Healthy; few dead leaves	A	17	11
C100	2 dead leaves	A	17	11
C53	Healthy; some dead leaves	A	17	10
C89	Moderately healthy	A	16	10
C36	Possibly eaten	A	16	9
C96	Healthy; young	A	14	8

APPENDIX B: Quadrat Field Notes

November 12, 2015 (Transcribed May 20, 2016)

Quadrat Number	Dune Characteristics	Vegetation/Other	Ground Cover
1	Slipface	1 tree, 1 red grass, 1 dune grass	Moderately veg
2	Grassy slipface	Dune grass (dead/alive), brown-black bush/shrub	Heavy veg
3	Hummocky dunes	Bare sand, dead foliage/other, Pitcher's thistle	
4	Hummocky dunes	Baby pine, dune grass, mint, dogwood, near treeline	Low-medium veg
5	Trough blowout	Dogwood, shrub, dead stuff, leaves, scat (deer?)	Sparse veg
6	Trough blowout	Nothing/grass	2%-0% density
7	Windward face	Dune grass, mint (a bunch), shrub	90% density
8	Windward face	Under tree, pitcher's thistle (2), dune grass, fake P thistle (wormwood)	100% density
9	Hummocky/successive small dunes	Dune grass, dead pitcher's, dead dune grass	30% density
10	Blowout	Bare sand	
11	Windward slope, dune ridge	Dead branches, dry grass	
12	Windward slope, dune ridge	Flowering plants, grass, dead PT, dead grass, under tree, brown/black shrub	