First-Year Research in Earth Sciences: Dunes

Can *Cirsium Pitcheri* Patterns be Used to Assess Blowout Activity?

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Abstract

Cirsium pitcheri is known for tolerating a narrow range of surface disturbance in dune environments. In Rosy Mound Natural Area, Michigan, the relationship between *C. pitcheri* and the spatial patterns of dune surface changes was investigated in a blowout. We recorded dune characteristics with GPS mapping and a straight-line survey. Sand transport was measured with erosion pins and sand traps. The locations of *C. pitcheri* were mapped and plant ages were documented by categories. The 29-meter-high blowout has a saucer shape with a steep windward slope. Most dune areas showed evidence of sand movement with the highest amounts occurring along the north arm and crest. More than 200 *C. pitcheri* are living on the dune, with the largest numbers found near the bottom of the blowout and on the south side of the blowout. A small number of *C. pitcheri* were found on the slipface. Roughly half of the *C. pitcheri* recorded are small juveniles, suggesting the population is increasing. The widespread presence of *Cirsium pitcheri* suggests that most areas of the blowout are experiencing moderate levels of sand transport, except for the upper windward slope and crest where sand transport amounts are too large for *C. pitcheri* to tolerate.

Introduction

Michigan coastal dunes are active ecosystems that support several rare fauna and flora. Some of these rare flora are known for tolerating a narrow range of conditions. One such species is *Cirsium pitcheri,* also known as Pitcher's thistle. *C. pitcheri* is a federally protected plant and the focus of a number of restoration efforts in several states. There have also been several studies done on *C. pitcheri* characteristics, such as the range of disturbance necessary for survival (Maun *et al.* 1996). Our study focused on the relationship between *C. pitcheri* and the spatial patterns of dune surface changes in a blowout.

Our study objectives were to:

- Map and measure the characteristics of the blowout.
- Measure sand movement in the blowout.
- Observe and map *Cirsium pitcheri.*
- Analyze patterns of *Cirsium pitcheri* in relation to surface changes.

Background

Blowouts

Blowouts are "depressions that commonly develop in dune systems as a result of the deflation of unconsolidated dune sediment by aeolian processes" (Gares and Nordstrom 1995: 1). The morphology of a blowout varies from dish-shaped in a dune ridge to a trough-like incision through a dune crest to large-scale parabolic dune systems (Gares and Nordstrom 1995). The two primary types of blowouts are defined as a saucer or trough (Hesp 2002). Saucer blowouts are characterized as round and wide, while trough blowouts are generally more elongated, with deeper deflation basins, and with steeper, longer erosional slopes (Hesp 2002). Other types have been defined as cigar-shaped, v-shaped, cauldron, pit and elongated notches (Hesp 2002).

After a blowout forms, wind interaction with the surface affects its development. Blowout formation may be initiated in a variety of ways including wave erosion along the seaward face of the dune; topographic acceleration of airflow over the crest of a dune; vegetation variation; or human activities (Hesp 2002). Once a blowout is initiated, the wind erodes the sand

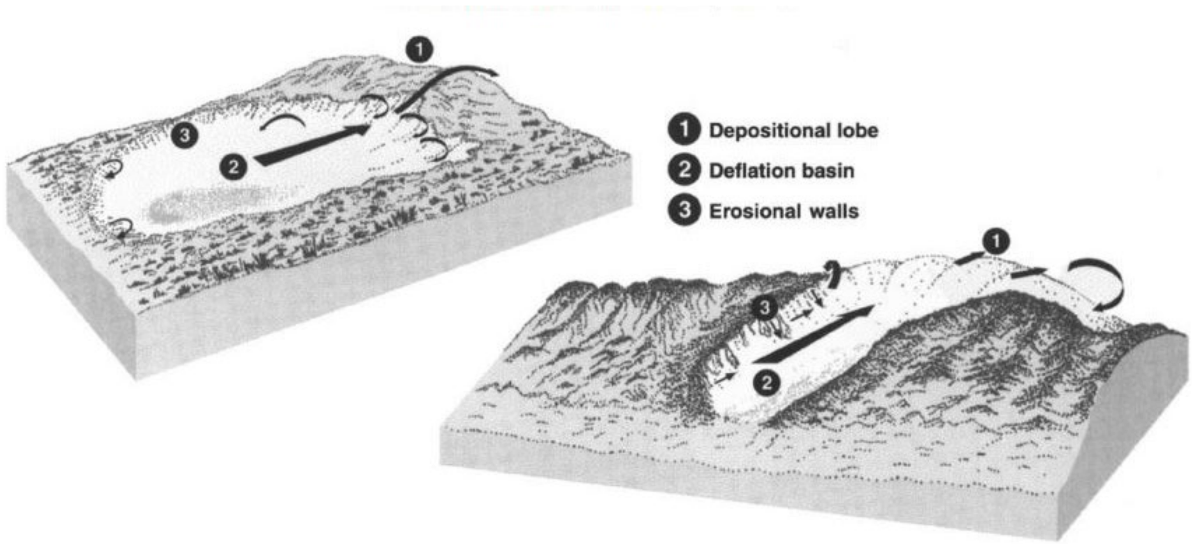


Fig. 1: Wind flow patterns in saucer and trough blowouts (from Hesp 2002)

in the deflation zone, carries it up and over the crest, and then deposits it on the slipface or the deposition zone (Fig. 1). The wind moves the sand, but the topography of a blowout has several effects on wind patterns. Topography may alter the velocity of wind streams, such as when wind enters the deflation zone it slows down, but as the wind exits the deflation zone it speeds up (Hugenholtz and Wolfe 2006). In addition, blowouts have been shown to alter the direction of wind flow (Fraser *et al.* 1998). Wind patterns within a blowout are often directed by several factors including localized low pressure and funneling caused by the windward walls (Hesp 2002). The amount of steering by the blowout is dependent on the "angle of incidence between the approach wind and the long-axis of the blowout" (Hugenholtz and Wolfe 2009: 927). The dominant wind patterns of a region have been found to be related to the size and shape of blowouts (Gares and Nordstrom 1995). As blowouts destabilize coastal dune ridges, they 1) compromise the ability of dunes to act as barriers during periods of high water, 2) remove sand that serves as a reservoir during periods of coastal erosion, and 3) form the core of parabolic dunes that migrate inland burying structures and vegetated areas (Fraser *et al.* 1998).

There are several broad categories of vegetation communities found in coastal dune systems including bare sand, pioneering vegetation, early-succession vegetation, and secondary-succession vegetation. Bare sand consists of an area with no visible plants although there are microscopic organisms that tolerate temperature extremes, and drought or wet conditions. The pioneering community consists of grasses and other types of plants that need sand burial to thrive. The early-succession community consists of grasses, shrubs, and other plants that need more stability to thrive. The secondary-succession community consists of plants, often including trees, that need nearly to completely stable environments to thrive.

Cirsium pitcheri

Cirsium pitcheri, commonly known as Pitcher's thistle, is a plant indigenous to the Great Lakes region. It is a monocarpic perennial herb which grows as a rosette for 5-8 years, flowers, and then dies (Girdler and Radtke 2006). It is primarily found in foredune habitats containing 70% or more open sand in plant communities dominated by *Ammophila breviligulata, Calamovilfa longifolia,* and *Andropogon scoparius* (Maun *et al.* 1996). *C. pitcheri* is known for tolerating a narrow range of disturbance, but it needs burial to increase growth stimulation and improve total chlorophyll content, chlorophyll a:b ratio, and leaf thickness (Maun *et al.* 1996). Maun *et al.* (1996) showed that plants can tolerate a one-time burial of approximately 15 cm or 75% of its height. As reported by Maun *et al.* (1996), McEachern (1992) showed that large plants may survive approximately 20 cm of deposition. The flowering stem grows to a height of approximately 1 m in May and then flowers from late June to early September. This stem produces 1 to 35 pink to creamy-white flower heads per plant, and each head averages 85 protandrous disk florets that are pollinated by insects (Havens *et al*. 2012). The protandrous disk florets are tiny tubular flowers, which have both male and female parts, at the center of the flower head (Dictionary.com LLC 2019). Colonization of new patches of *C. pitcheri* occurs through seed production and dispersal (Girdler and Radtke 2006). Flower head production varies among sites and years and it is related to plant size (Havens *et al*. 2012).

C. pitcheri populations have been decreasing to the point where the plants have protected status. *C. pitcheri* was listed as federally threatened in 1988. It is listed as threatened in Illinois, Indiana, and Michigan, and endangered in Wisconsin (Girdler and Radtke 2006). In Ontario, Canada, *C. pitcheri* was listed as rare (Girdler and Radtke 2006), but in 2011 the status was changed to threatened (Government of Ontario 2014). There are several reasons for the decline in populations at different levels. At the landscape level, sand mining, shoreline development, dune and shoreline stabilization, and disruption of shoreline currents that replenish eroded shorelines have devastated the habitat throughout its range (Girdler and Radkte 2006). At a local level, recreational impacts intensify effects of natural factors such as drought stress and herbivory (Girdler and Radkte 2006).

Study Area

Our study area is a blowout in Ottawa County Parks' Rosy Mound Natural Area (Fig. 2). Rosy Mound is located approximately 3 km (2 mi) south of Grand Haven, Michigan. The blowout is located in a system of blowouts and parabolic dunes along the western and southwestern edge of the park. The blowout is separated from Lake Michigan by a dune ridge and large open area with pine stands and various types of ground cover. The blowout is approximately 200 m from the nearest trail leading through the stand of pine trees.

The spatial context for our study area is a 164-acre dune preserve that is home to a beach, a small stand of white pines, and open and forested dunes overlooking Lake Michigan (Michigan TrailMaps.com 2019). A trail system of 3 km (2 mi) throughout the preserve begins at the parking lot, with managed boardwalks create the trails in the open areas of the preserve (Michigan TrailMaps.com 2019). Rosy Mound is bordered by private residential areas on its north, east and southern sides, with Lake Michigan marking the western border.

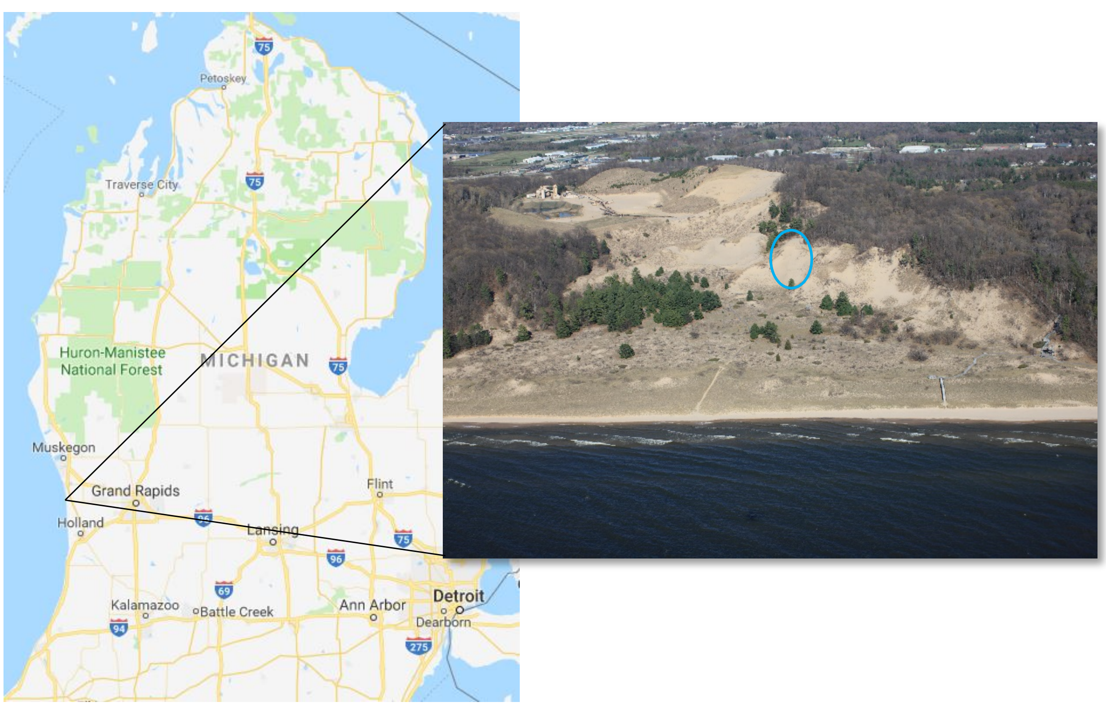


Fig. 2: Study area location and oblique aerial of Rosy Mound Natural Area (Photo Source: US Army Corps of Engineers 2012)

Methods

Map and Measure the Characteristics of the Blowout

We used Trimble GPS units to map the blowout boundaries and geomorphic areas of the blowout such as the crest and outer boundary area. Photographs were also taken of the various geomorphic areas. Using GPS Pathfinder Office, we downloaded the GPS data, applied a differential correction using a base station along the lakeshore, and exported the data to ArcGIS. After we mapped the outer boundary of the blowout using ArcGIS, we calculated the total area of the blowout and the areas of the deflation and deposition zones. Error, estimated at ±10%, was introduced into the area calculations due to the steep slopes of the blowout. Vegetation communities were mapped in ArcGIS from photographs, field observations and satellite imagery.

Blowout characteristics were determined by field measurements and lab or computer analysis. In the blowout, a straight-line survey was conducted using a stadia rod and hand level to create a dune profile of the dune height and slope angles. The survey began a few meters away from the lakeward edge of the deflation area and ended about halfway down the slipface on the southern side (Fig. 3). The line veered towards south of the main axis about halfway up the windward side introducing some error to our results. The type of the blowout was investigated by comparing our blowout's shape to the typical features of trough and saucer blowouts. To examine sediment characteristics, we collected sand samples at eight different points along a straight line in the blowout. The samples were dried in an oven and dry-sieved using a mechanical shaker to separate the sand grains into size categories. Using the graphical methods of Folk (1966), we determined the average grain size and the sorting characteristics.

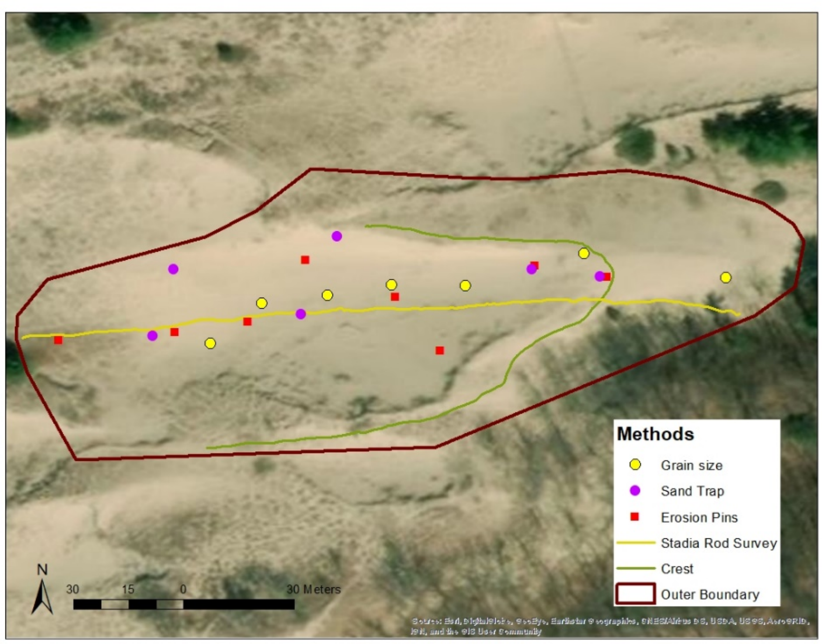


Fig. 3: Measurement locations in study area

Measure Sand Movement in the Blowout

Six Leatherman sand traps were placed in different locations in the blowout to measure the amount of moving sand (Fig. 4). This type of sand trap is buried in the ground until its collection tube is even with the ground surface. The tubes with collected sand were retrieved weekly over the two-week study period. The sand was taken back to the lab and dried over a period of two days. Once the sand was dry, it was weighed, and the amount was recorded. For each sand trap, the weight of sand was then put an equation (kg x 14.3 (m-width^{-1})/1,000(week^{-1})) to determine the rate of sand transport for each week.

Fig. 4: Leatherman sand trap

Eight erosion pins were placed in different areas of the blowout to measure the amount of surface change during the study period (Fig. 5). The pins were installed on October 25, 2018 and then the height of each pin was measured during site visits on November 1, 2018 and November 8, 2018. Surface change was calculated by difference in height readings between subsequent measurements.

Fig. 5: Erosion pin on dune

Wind speed and direction data (at 4.55 m height) were collected by anemometers and vanes at a reference location in P.J. Hoffmaster State Park. The data was then graphed in Excel and examined for strong wind events. We then compared the results between the two weeks and looked for a relationship between the wind data, and sand trap and erosion pin results.

Observe and Map Cirsium Pitcheri

The location of *C. pitcheri* plants were recorded with GPS units. In places with several plants close to each other, an area was recorded instead of individual plant locations. For each plant recorded an age category was assigned (Table 1). The mapping of plants was done on November 8, 2019 and January 15, 2019. On January 15th, the large and small juveniles were not distinguished due to the winter conditions.

Using ArcGIS, we first examined the locations of *C. pitcheri* for any patterns of where the plant is found on the dune. We then looked the ages of the plants to see if there is any correlation with the amount of surface change.

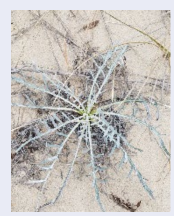
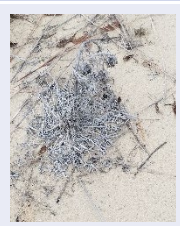
Age Category	Visual Indicators	Example Photographs
Seedling	4 leaves or less	
Small Juvenile	More than 4 leaves, length less than 12 inches	
Large Juvenile	More than 4 leaves, length more than 12 inches	
Adult	Flowering or dead	

Table 1. *Cirsium pitcheri* age categories. Descriptions are from the US Fish and Wildlife Service (2010) and photographs are from the study area.

Results

Blowout Characteristics

The blowout has an area of 8,820 m^2 and is a saucer shape with some tendencies towards a trough shape. The deflation zone has an area of 4,387 m^2. The deposition zone has an area of 2,310 m^2 (Fig. 6). The crest of the blowout is 156 m long, and the blowout has a width of 51 m.

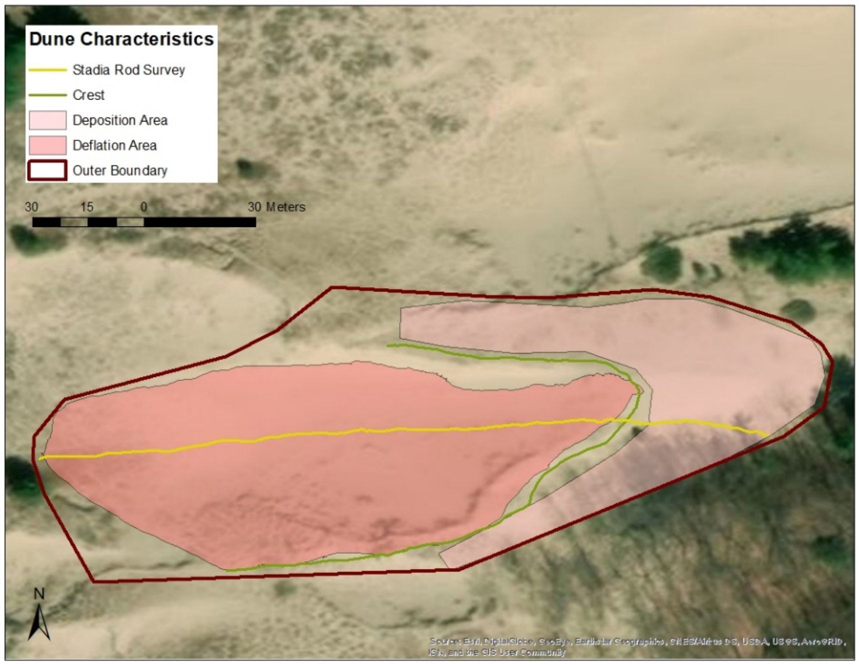


Fig. 6: Characteristics of the blowout as documented by GPS mapping

The profile shows the dune has a maximum height of 29 m (Fig. 7). Slope angles vary along the profile line, with gentle angles found on the lower windward slope and steeper angles on the upper windward slope where angles reach 42° near the crest.

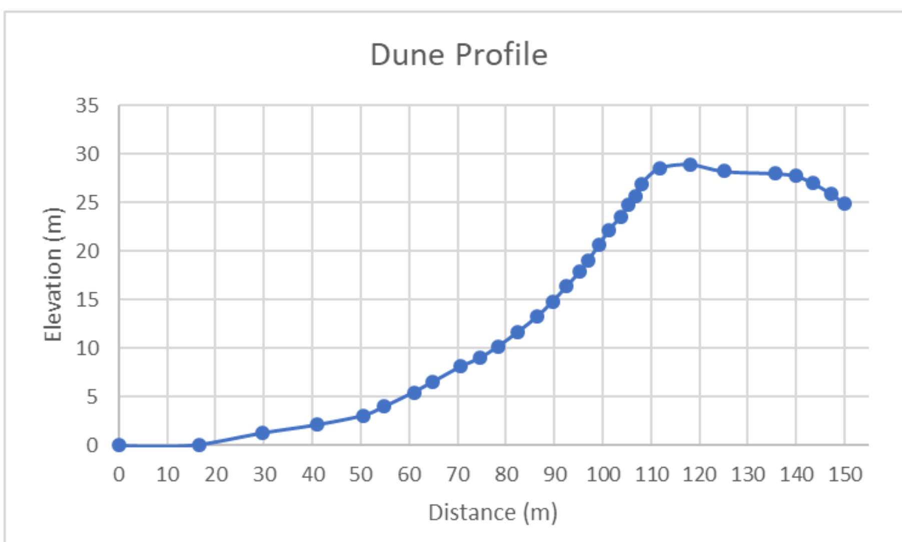


Fig. 7: Profile of the blowout along the stadia rod survey line shown in Fig. 6

The blowout has four main vegetation communities which consist of bare sand, pioneering vegetation, early-succession vegetation, and secondary-succession vegetation (Fig. 8). The bare sand community is found in the deflation zone and parts of the crest. The pioneering community is found to the west of the bare sand community, as well as near the crest. The early-succession community is found on the slipface, to the west of the pioneering community and on the windward slope of the south arm. The secondary-succession vegetation community is on the southwestern portion of the slipface.

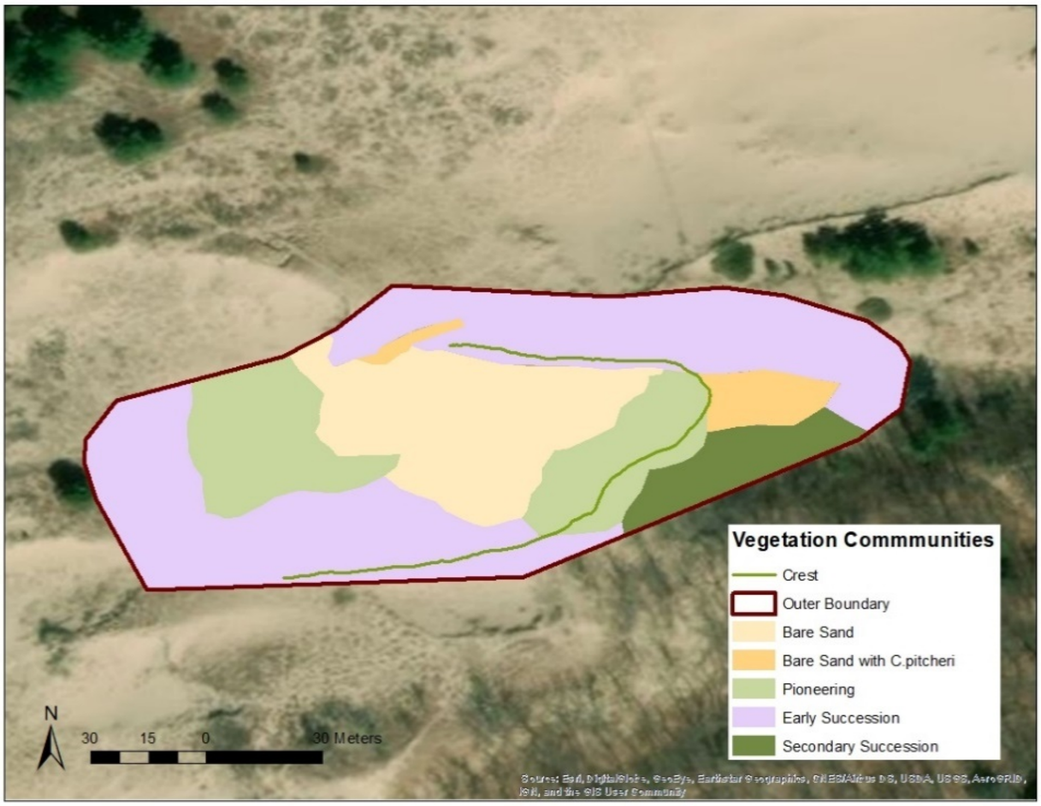


Fig. 8: Vegetation communities in the Rosy Mound blowout

Results of grain-size analysis on samples from the lower windward slope (#140) to the slipface (#147) show curves that follow a similar pattern with small variations by location (Fig. 9). As an example of the pattern, sand at the blowout crest (#146) is a medium sand with a mean grain diameter of 0.32 mm (or 320 micrometers). The sand is very well sorted but skewed a bit towards the finer grains. Analysis of a sample from sand collected in the sand trap at the dune crest shows similar characteristics. For sand this size, an estimated threshold velocity for movement by wind is 5 m/s.

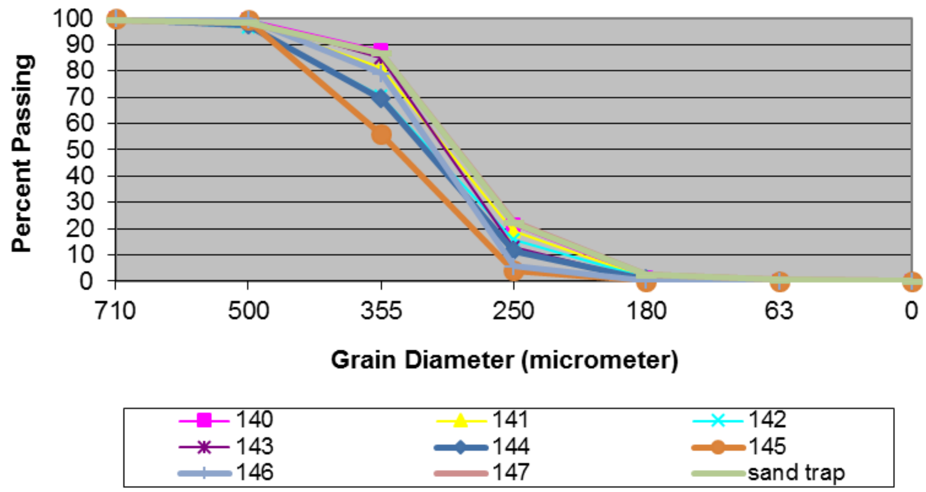


Fig. 9: Grain-size curves for samples collected at the dune surface and wind-blown sand collected in a sand trap. Sample 140 is from the lower windward slope, with subsequent sample numbers indicating locations further east and higher on the slope. The sand trap location was near the dune crest.

Wind Patterns and Sand Movement

A comparison of wind speeds for the two weeks of the field study shows that the strongest winds occurred in the second week (Fig. 10). Week one was relatively calm, with a small wind event towards the end of the week, in which wind speeds reached 10.9 m/s. The average wind speed reached a high of 4.4 m/s during this time frame as well. Week two followed

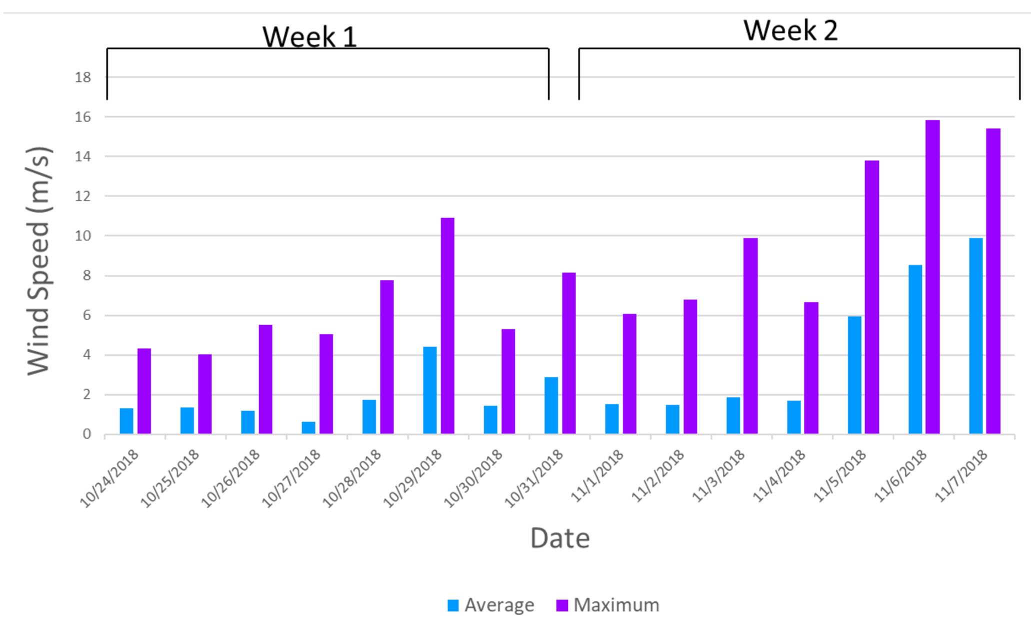


Fig. 10: Average and maximum wind speeds measured at Hoffmaster State Park during the study

a similar pattern, with calmer conditions in the beginning and active conditions in the latter half of the week. The highest wind speed recorded was 15.8 m/s and the average speed recorded a high of 9.9 m/s.

Most dune areas showed evidence of sand movement with the highest amounts occurring along the north arm and crest. In these areas, sand traps measured a transport rate of 21.3 kg/m-width/wk at the crest and a rate of 17.9 kg/m-width/wk near the north arm during the second week (Fig. 11). Erosion pins in the middle area of the deflation zone and at the crest also recorded substantial amount of erosion during the second week, with erosion amounts ranging from 11.8 to 30.0 cm of erosion (Fig. 12).

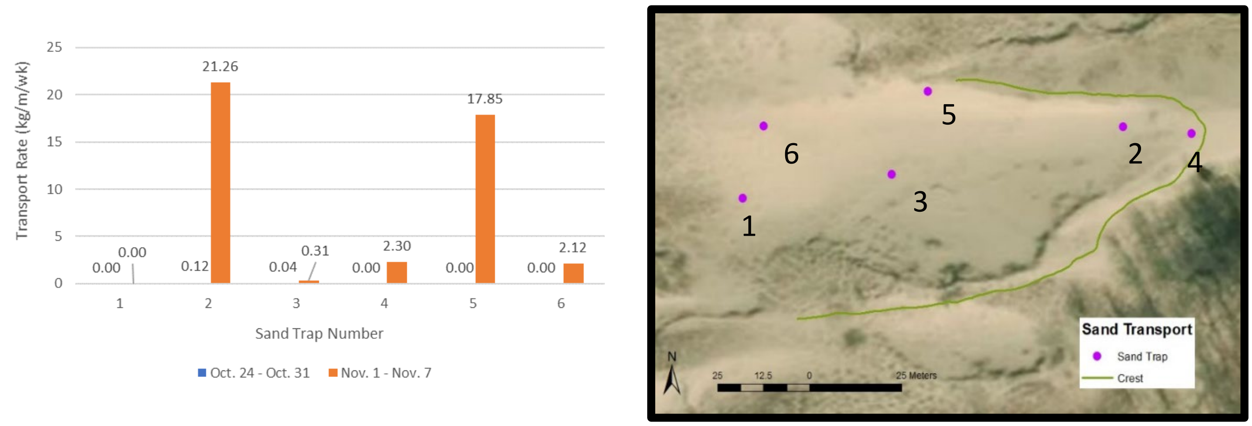


Fig. 11: Sand movement measured by sand traps at locations shown by number

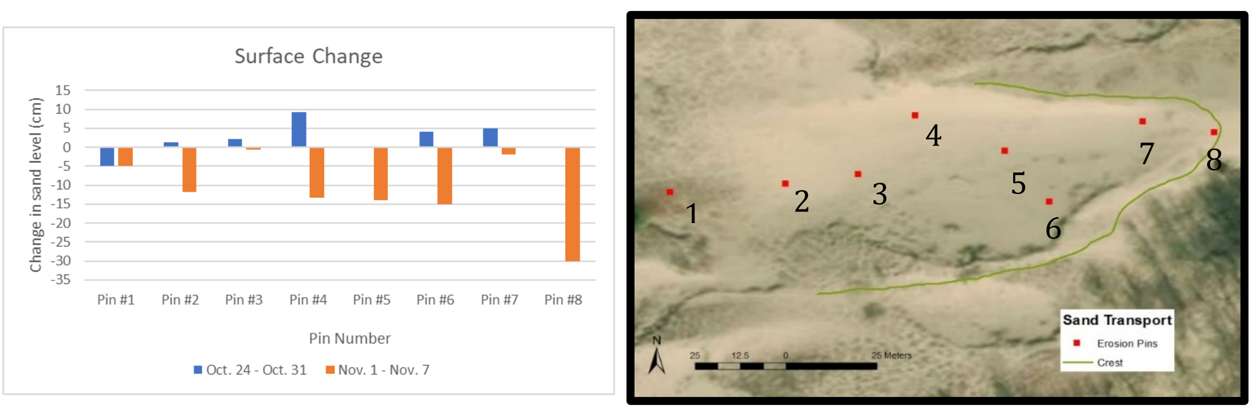


Fig. 12: Surface changes measured at erosion pins at locations shown by number

Cirsium Pitcheri on the Blowout

Cirsium pitcheri is well established with more than 200 *C. pitcheri* living on the blowout. The largest numbers were found near the western and southwestern edge of the deflation area (Fig. 13). *C. pitcheri* was also found on the crest, near the crest, and on the slipface. The majority of the plants recorded are juveniles found in all areas of the blowout (Table 2). Some *C. pitcheri* in the study area were not recorded due to time constraints.

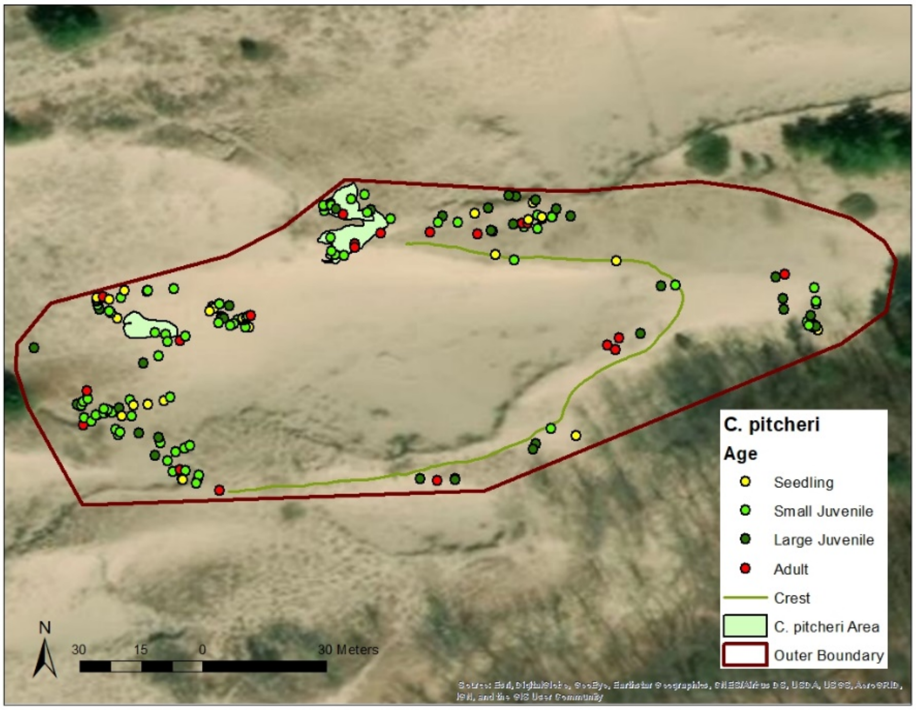


Fig. 13: *C. pitcheri* presence by age category in the study area

Age	Amount Recorded
Seedling	33
Small Juvenile	82
Large Juvenile	38
Unspecified Juvenile	31
Adult	31
Total	215

Table 2: Number of *C. pitcheri* plants recorded per category

Discussion

Dune characteristics suggest the blowout is in the process of changing to a more active state. The shape of the deflation zone suggests a saucer-type blowout with some trough-type tendencies, shown through the steep slope and the change in height from the bottom of the deflation zone to the crest. The deflation zone is mostly bare sand, with the east side of the zone and the south arm portion being vegetation with grass and other types of flora. The deposition zone is mostly vegetated by grasses, shrubs, and some other types of flora. The vegetation types found on the southeastern portion of the south arm, crest and slipface suggest that the blowout was more stable at one point.

The change in blowout activity level may be a response to how the blowout's active surfaces change with high-energy wind events. The wind data correlates with the data collected from the sand traps and erosion pins, showing higher transport rates during the strong wind events of the two weeks. The north arm and crest experience the highest level of activity. The north arm has a small incision through it (Fig. 14), which most likely helps funnel wind through this area and raises the sand transport rate. Due to the shape of the blowout with a wide base narrowing down at the crest, as well as a steep slope, the wind is funneled up the slope towards the crest increasing the amount of erosion and sand transport.

Fig. 14: Incision through the north arm of the blowout

C. pitcheri has a widespread presence on the blowout, which suggests that most areas experience moderate sand transport. Other studies show that *C. pitcheri* can only tolerate a onetime burial of approximately 15 cm or 75% of its height, although large plants may survive approximately 20 cm (Maun *et al.* 1996). On the Rosy Mound blowout, *C. pitcheri* was found in some unexpected places near the crest, at the crest, and on the slipface of the dune. Many of the plants in these areas are large juveniles and adults with few to no seedlings or small juveniles. This age distribution suggests that the dune activity level is increasing to a point that younger *C. pitcheri* cannot tolerate. When the lifespan (maximum 7-9 years) and lifecycle (large juveniles and adults at 4-7 years) of *C. pitcheri* are considered, we can interpret the timing of the changes. Areas which only show the presence of older plants suggests that 4-7 years ago the dune activity level was lower than present, and these plants were able to establish themselves and survive through the small juvenile stage. Because the large juveniles and adults can tolerate more deposition, their presence without seedlings suggests that the amount of sand movement has recently increased. Areas which include the presence of seedlings and small juveniles, that can only tolerate smaller amount of deposition, indicate where the current dune activity level is low to moderate.

Results of the current study can be compared to previous studies of *C. pitcheri* in Rosy Mound Natural Area. Three previous studies have focused on *C. pitcheri* in the park, with data collection in Oct-Nov 2013 (Strydhorst *et al.* 2014), Oct-Nov 2014 (Hughey *et al.* 2015), and Oct-Nov. 2015 (Messina *et al.* 2016). A map of the combined data from the studies shows that *C. pitcheri* has been mapped in multiple locations in the park (Fig. 15). On the map, the individual locations of *C. pitcheri* from each study were kept separate, while the vegetation communities were merged into one layer. The total number of mapped *C. pitcheri* is 666 over the four studies. (This calculation assumes that each mapping recorded unique plants, but it is likely that some plants were recorded in two or more of the studies, thereby introducing some error into the total number.) Several sections in Rosy Mound Natural Area have not been investigated for *C. pitcheri*, and some of the studies were unable to map all of the plants in their study area because of time constraints. Based on the combined mapping, with allowances for the errors, we estimate that Rosy Mound Natural Area contains a population of 1000 or more *C. pitcheri* plants.

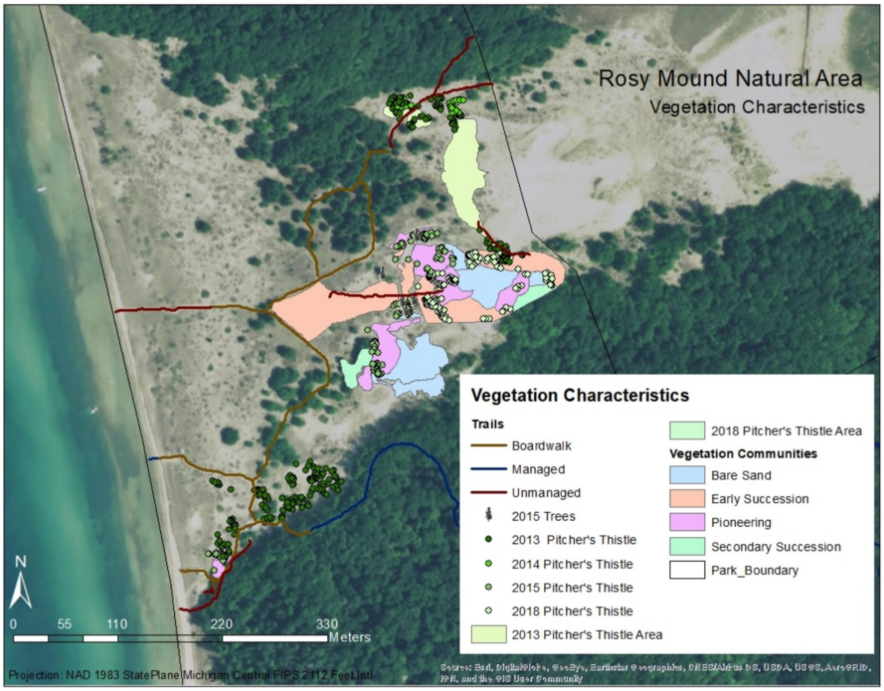


Fig. 15: Map of *C. picheri* and vegetation communities from 2013-2019 at Rosy Mound Natural Area

Conclusions

Our investigation concludes that the blowout is a 29-meter high, saucer-type blowout with some trough-type tendencies. *C. pitcheri* is doing well in this blowout with at least 200 plants recorded. The activity level of the blowout is moderate overall with higher activity levels on the windward slope and crest. The many species of vegetation found on the arms and slipface of the blowout suggest that the blowout was more stable in the past compared to its current activity level. The change in activity level is also indicated by the presence of large *C. pitcheri* juveniles and adults near the crest and at the crest with few to no seedlings or small juveniles. Our results suggest that population characteristics of *C. pitcheri* can serve both as local indicators of the general amount of sand movement and as local indicators of recent changes in activity level.

Acknowledgements

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