First-Year Research in Earth Sciences: Dunes

Blowouts and Unmanaged Trails in Hoffmaster State Park, Michigan

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1. Abstract

Dune systems in public parks can be exposed to the pressures of high recreational use, but few studies have investigated the resulting changes to the dunes. Our study focused on human impacts at Hoffmaster State Park, MI by investigating the unmanaged trails and blowouts along a dune ridge. We mapped all trail segments with GPS, recorded their characteristics, and categorized each segment as either leading into a blowout, near a blowout, or not near a blowout. We mapped all blowouts with GPS including their deflation and deposition areas, recorded blowout characteristics and categorized each blowout as either saucer or trough. We analyzed the data to see if there were any relationships between the unmanaged trails and blowouts. Our study area contained 54 trail segments and 23 blowouts. Trail segments were mostly wide and bare of vegetation. The trails “not near” blowouts had a greater vegetation height than the trails near or through blowouts. Most blowouts were saucer-shaped and had at least one trail. Blowouts which contained one or more trail intersections tended to have larger deflation areas. Our results suggest that human disturbance along the dune ridge can cause larger amounts of instability on the dune surface.

2. Introduction

Lake Michigan coastal dunes draw many people for the recreational opportunities such as walking along the beach or climbing on the dunes. However, large numbers of visitors make the coastal dunes more susceptible to human impacts (van Dijk and Vink 2005). Networks of unmanaged trails and blowouts can form from human disturbances to the dunes. Even naturally-occurring blowouts can be enlarged by the trampling of vegetation (Bate and Ferguson 1996). Catto *et al.* (2002) suggests that an increase in unmanaged trails increases the number of blowouts. However there are few studies of the relationship between unmanaged trails and blowouts along coastal dunes. We investigated unmanaged trails and blowouts along a dune ridge in a Michigan state park. The objectives for this study were to:

1) Map unmanaged trails and blowouts along the dune ridge,
2) Measure and record characteristics of unmanaged trails and blowouts, and
3) Analyze the data for patterns between unmanaged trails and blowouts.

3. Study Area

P.J. Hoffmaster State Park is located on the east coast of Lake Michigan, north of Grand Haven and south of Muskegon (Figure 1). The park contains 486 ha (1200 acres) with approximately 4 kilometers of sandy beaches along the Lake Michigan shoreline (Gillette Nature Association, 2014).

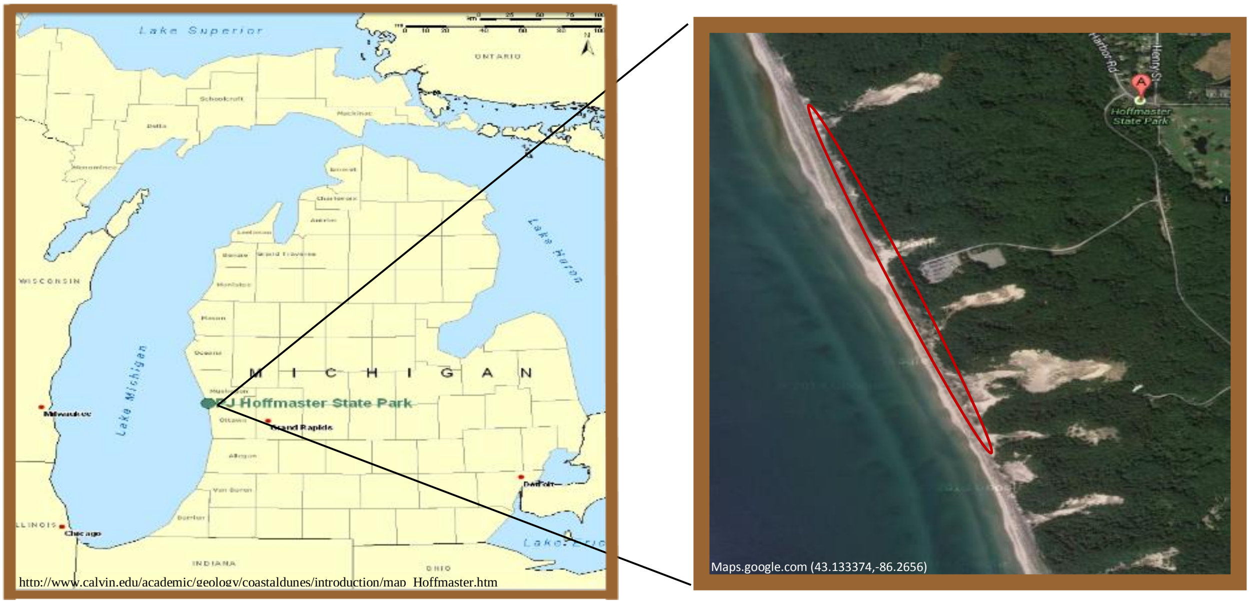

Figure 1. Location of Hoffmaster State Park and study area (outlined in red) within the park.

This park receives significant attention due to its size and accessibility to the lake. Just over half a million people visited Hoffmaster State Park in 2013 for day and campground use (Brockwell-Tillman, 2014). The park maintains three trails, but a network of unmanaged trails has also developed.

The coastal dunes of Hoffmaster include large parabolic dunes, foredunes and dune ridges. A foredune is a low and elongated dune formed by aeolian deposition of sand within vegetation (van Dijk 2014). The foredune is highly vulnerable to water level changes, vegetation erosion, and human trampling (van Dijk 2014). A dune ridge (established foredune) exists parallel to the beach and lies between the foredune and the large parabolic dunes. The dune ridge is more stable than the foredune, with a greater variety of vegetation and less sand movement (van Dijk 2004). The dune ridge at Hoffmaster State Park has sections of open dune where the dune is stabilized by early succession growth as well as sections of forested dune where the dune contains a mixture of beech-maple-oak communities (van Dijk 2004). Parabolic dunes are U-shaped dunes with arms pointing upwind. The *2002 Geomorphic Inventory of Coastal Dunes in P.J. Hoffmaster State Park, MI* reported that Hoffmaster dune heights range from several meters (foredunes) to over 80 m (the largest parabolic dunes), with parabolic dune lengths extending up to 1.5 km (Bierma *et al.* 2003).The coastal dunes of Hoffmaster State Park also include blowouts of various sizes and shapes on the dune ridge and parabolic dunes.

The dunes at Hoffmaster are affected by Lake Michigan’s lake level changes as well as day-to-day variability in weather (van Dijk 2004). The changes in lake level affect the width of the beach, ultimately affecting the dune processes. When the beach is wider more sand can be moved around which creates active and growing foredunes. Conversely if the beach is narrow then less sand can be moved around which slows down foredune activity (van Dijk 2014). Seasonal factors such as snow, ice, thawing and ground freezing, as well as climatic factors such as, wind, temperature and precipitation all have a role in dune activity (van Dijk 2014).

4. Background

A blowout is an opening in vegetation cover which enables erosion of the bare dune surface through strong winds. Bate and Ferguson (1996, p. 215) state that "as a result of wind action and the dynamics of aeolian transport, the initial openings in the vegetation enlarge and extend downwind to form the blowouts". The combination of sparse vegetation and high winds results in blowout development (Gares 1992). A deflation area on the windward slope and a downwind depositional area also characterize a blowout. Gares (1992, p 589) goes on to say that "blowouts are the most dynamic areas within the system because large changes take place in a relatively short time. Blowouts have distinct shape and exist in a variety of places in the dune system". Patrick Hesp (2002) identifies seven ways in which blowouts can be formed: (1) wave erosion along the seaward face of the dune; (2) topographic acceleration of airflow over the dune crest; (3) climate change; (4) vegetation variation in space or change through time; (5) water erosion; (6) high velocity wind erosion, sand inundation and burial; and (7) human activities.

If human trampling is linked to the formation of blowout activity, then what role do unmanaged trails play in blowout formation? There has been very little investigation on the topic of unmanaged (unplanned) trails. However human trampling, a known cause of unmanaged trails, has received more attention. Bowles and Maun (1982) reported that coastal dune environments are "among the most fragile natural systems" and are easily disturbed by wind patterns and destroyed by human trampling. Human trampling destroys dune vegetation, which can have an adverse effect on the ecological community (Santoro *et al.* 2012). Trampling damage is dependent on "the intensity of use, the time of the year at which the use takes place and on the topography of the area" (Hylgaard and Liddle, 1981, p. 559). Bowles and Maun (1982) correlated vegetation damage with the number of times trampling had occurred. Their results found that "after 50 trampling passages […] a path was plainly visible" but "the effects were not long-lasting and when the trampling pressure was removed, sites appeared normal within one year of the treatment" (Bowles and Maun, 1982, p. 278). However with heavier trampling pressure of about 200 passages, they found that it affected the vegetation growth the next season. They concluded that "species which show rapid recovery after a single trampling event may be much more seriously affected by prolonged exposure to trampling pressure where no time for recovery is allowed" (Bowles and Maun, 1982, p. 281). Other studies have found that 2000 or more passages result in 100% loss of vegetation (Boorman and Fuller, 1977).

5. Methods

In October and November of 2013, we documented characteristics of unmanaged trails and blowouts in Hoffmaster State Park. The data collecting methods were twofold: 1) map the geospatial patterns of the unmanaged trails and blowouts with Juno Trimble GPS units, and 2) record and compare blowout and unmanaged trail characteristics. The blowout data was collected along a 1.5 km section of the dune ridge. The trail data was collected within a 0.67 km section of the blowout study area.

Collecting Data

We used Juno Trimble Global Positioning Systems (GPS), with *Terrasync* software, to record unmanaged trails and blowout locations. The trails were divided into trail segments, defined as "the visible path from one trail intersection to the next" (Vander Bilt *et al.*, 2013, p. 12). Each trail segment was mapped as a *line* feature and each trail intersection was mapped as a *point* feature. We mapped the blowout boundaries of both the deflation and deposition areas by creating an *area* feature. In addition to the GPS data, we measured trail width at two locations for each segment: 1 m in from each endpoint. We also measured vegetation characteristics on and off the trail (Table 1).

Characteristics	Categories
Vegetation Density (on and off trail)	No vegetation
	Sparse vegetation
	Mostly vegetated with bare portions
	Completely vegetated
Vegetation Condition (on and off trail)	No vegetation
	Poor (heavily trampled vegetation)
	Fair (slightly trampled vegetation)
	Average (trampled and growing vegetation)
	Good (infrequent trampling)
	Excellent (no signs of trampling)

Table 1. Vegetation characteristics recorded for each trail segment.

The blowout characteristics were recorded using a slightly modified version of the Blowout Features Inventory (BFI) developed by Stratz *et al.* (2012; Appendix A). The Dune Activity section of the Dune Features Inventory (DFI) was also used to characterize the activity level of each blowout (Appendix B). Both the BFI and the DFI were used in order to record distinctive blowout characteristics (Table 2). Deposition area was recorded for six of the twenty-three blowouts but all blowouts had the deflation area recorded.

Analyzing Geospatial Data

In order to analyze our collected data we downloaded and post-processed all *line*, *point* and *area* features into ArcGIS 10 (ArcMap). We mapped these features as layers on top of an aerial base map. This allowed us to visualize and analyze the spatial relationship between unmanaged trails and blowouts.

Characteristic	Description	Measurements
Blowout type	Categorized as trough or saucer	Identified by shape in field
Depth	Amount of blowout surface lowering compared to nearby dune surface	Measured with a 7m stadia rod and hand level
Width	Longest distance across blowout deflation area (measured perpendicular to blowout axis)	Boundary of deflation area mapped with GPS; width measured using tools in ArcGIS Online software
Area	Area of blowout deflation area	Boundary of deflation area mapped with GPS; area calculated using tools in ArcGIS Online software
Length	Distance along blowout axis	Boundary of deflation area mapped with GPS; length measured using tools in ArcGIS Online software
Activity level	Categorized as inactive, slightly active, moderately active, active, or very active	Recorded from field observations using checklist and categories in Dune Features Inventory (Appendix B)
Location of trail in relation to blowout	Categorized as “leading directly into a blowout” or “near a blowout”	Observed in the field

Table 2. Data collected for each blowout.

6. Results

We collected blowout data for 23 blowouts in a 1.5 km portion of the dune ridge. The blowouts ranged in area from 32 m^2 to 1449 m^2 with an average area of 319 m^2. The 23 blowouts had an average height of 7.5 m, an average width of 20 m and an average length of 16.8 m (Table 3). The blowouts tended to have rounded, rather than elongated, shapes. Therefore the blowouts were predominately identified as saucer (Figure 2). The deflation areas of the twenty-three blowouts were along the windward as well as the crest of the dune ridge. Deposition areas, measured for six of the blowouts, continued onto the leeward slope of the dune ridge.

	Maximum	Minimum	Average
Height (m)	28.6	1.1	7.45
Length (m)	46	5	16.86
Width (m)	50	5	20.34

Table 3. Summary statistics for 23 blowouts in study area.

The majority of our recorded blowouts, 20 of 23, had mostly bare-sand deflation areas with low amounts of vegetation (Figure 3). The six blowouts with activity levels assessed using the DFI were categorized as "active" blowouts. The active category indicates that the blowout surface is composed primarily of bare sand with low levels of vegetation (see Appendix B). Although the DFI was not applied to the remaining 17 blowouts, observations indicate that they have similar characteristics and blowout activity levels.

Figure 2. A saucer blowout on the dune ridge.

Figure 3. Typical blowout vegetation cover.

Mapping the blowouts shows two distinct clusters at the end of the study area (Figure 4). The north end contains 10 blowouts and the south end contains 13 blowouts. Overall both clusters have similar spatial patterns: the smaller blowouts tend to be grouped together whereas the larger blowouts stand alone. On the map, there is approximately a 391 m gap between blowouts at the north and south ends of our study area. This gap contains a large bare sand area which was too expansive to outline as a blowout and not vegetated enough to identify distinct trails.

Figure 4. Mapped blowouts occur in two clusters (indicated in red).

We collected data on 56 unmanaged trail segments along a 688 m section of the dune ridge (Figure 5). The trail widths varied between 0.45 m and 1.8 m with an average trail width of 0.97 m wide. The total length of trail segments was 1750 m. Segment lengths varied between 6 m and 224 m with an average trail segment length of 31 m. Of the 56 trail segments, 36 segments were within 200 meters of the parking lot. Our data shows that the trail segments were clustered around the parking lot and then again between dunes 4 and 3.5.

Figure 5. Mapped unmanaged trail segments.

Vegetation on and beside the trails had different characteristics (Figure 6). Our trail segments varied between having no vegetation, sparse vegetation, mostly vegetated and completely vegetated. The on-trail vegetation ranged between 0.1 m and 0.8 m high with an average height of 0.28 m. The off-trail areas were heavily vegetated with dune grass as the common vegetation. The off-trail vegetation ranged from 0.21 m to 1.34 m high with an average height of 0.78 m.

Trail characteristics were mostly similar when compared between trail segments that went into blowouts, trail segments that were near blowouts, and trail segments that were not near blowouts (Figure 7). Trails were widest when they were "not near" blowouts.

Figure 6. Unmanaged trails are visible because their vegetation characteristics are different from the vegetation around the trail.

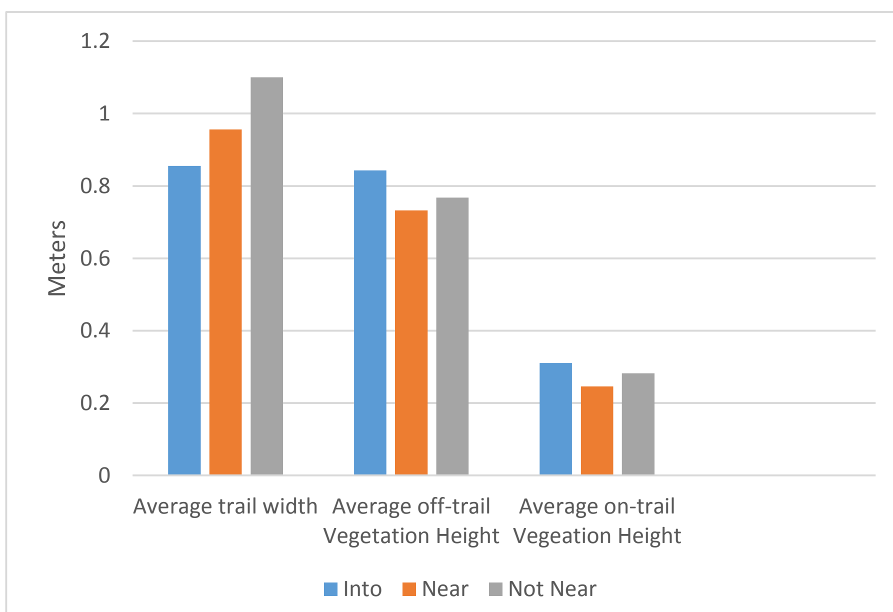

Figure 7. Trail characteristics related to blowout locations.

The unmanaged trail data collection overlapped with six blowouts (Figure 8). The dune ridge trail ran along the leeward crest of the six blowouts. Two of the six blowouts had spur trails running through their center (Figure 9). The number of trails through a blowout did not seem to affect the shape of the blowout (Figure 10).

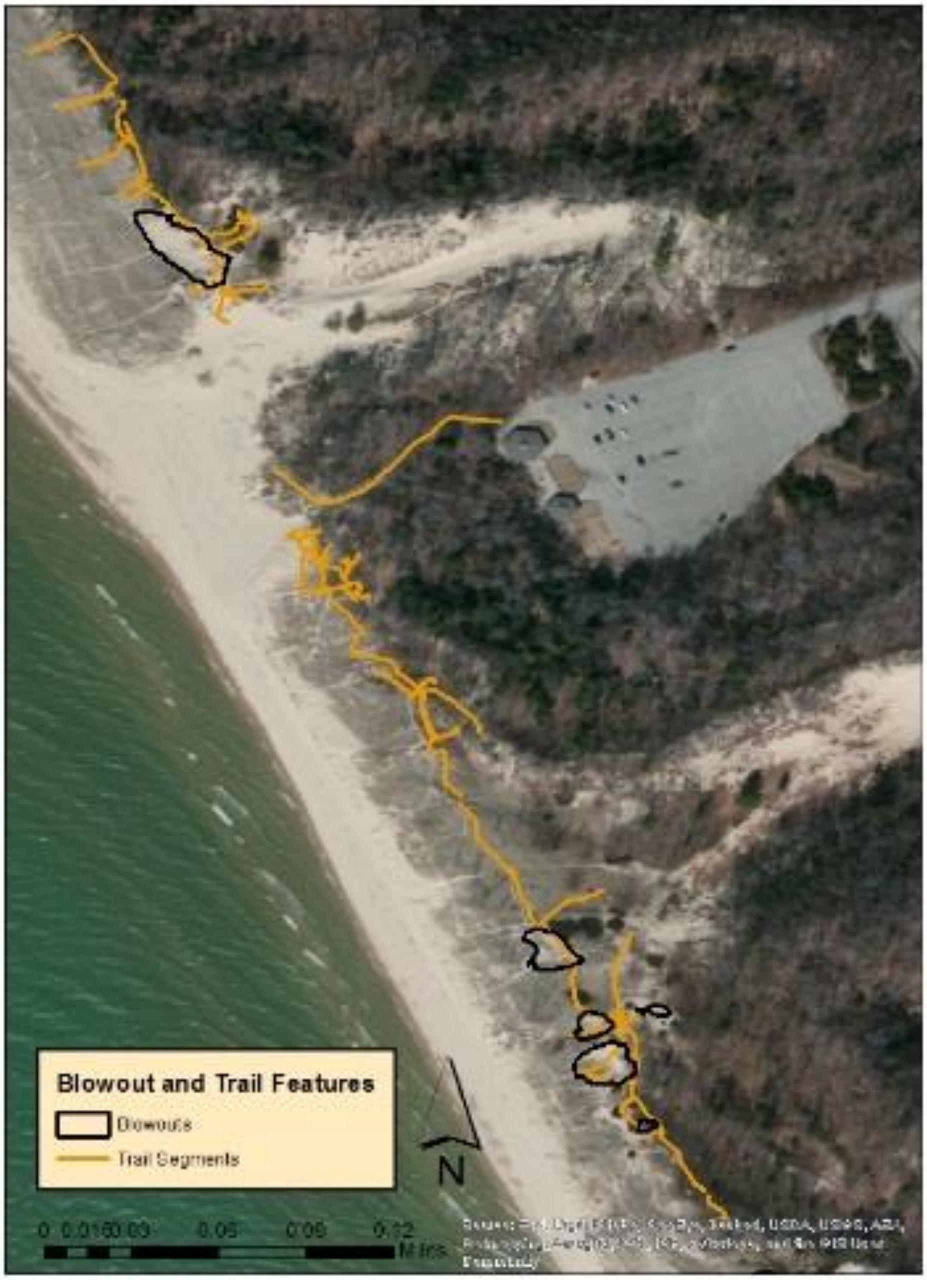

Figure 8. Unmanaged trail segments and blowouts on the same map.

Figure 9. Two blowouts with spur trails running down their centers.

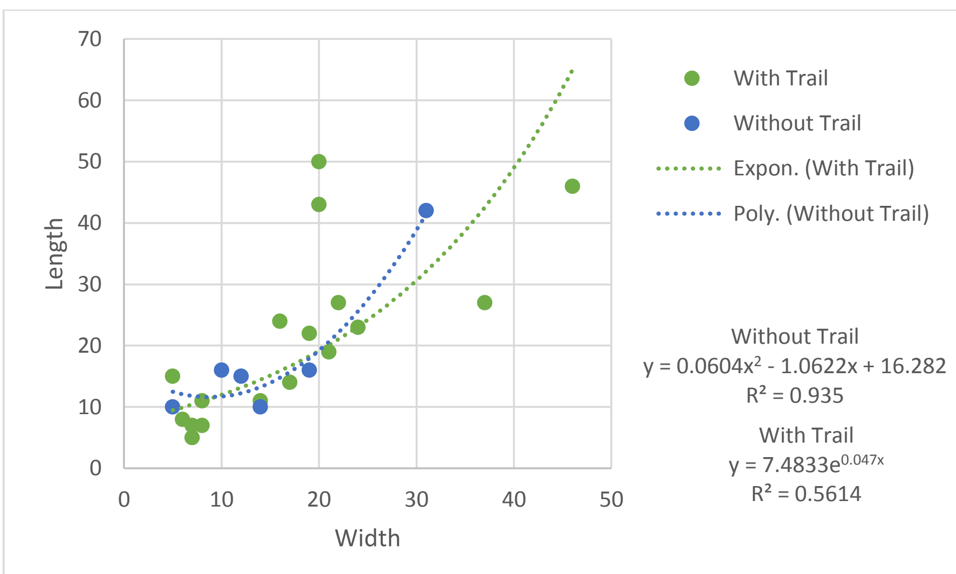

Figure 10. Shape of blowouts for blowouts with trails and blowouts without trails.

7. Discussion

The intersection of most blowouts with trails suggests that blowouts may develop from trails. The transformation from trail to blowout goes through four stages: 1) vegetation trampling, 2) noticeable trail within vegetation, 3) trail widening, and 4) blowout emerging. The time frame of our study was not long enough to be able to see the evolution from trail to blowout, but we saw various stages of the process along the dune ridge (Figure 11). We recommend that a prolonged study, over the course of a few years, monitor several likely trails to see if they show changes indicating a transition from trail to blowout.

Figure 11. Examples of stages in transition from unmanaged trail to blowout.

Interpretation of our collected trail data can suggest an estimate of the number of people using the trails. Many of the trails are sparsely vegetated or bare sand. Based on previous research (Boorman and Fuller, 1977) the lack of vegetation indicates that approximately 1000-2000 passages per year are taking place along the pathways.

Our findings suggest that high levels of visitor trampling could be playing a role in the formation of blowouts in Hoffmaster State Park. The close proximity of our study area to a parking lot may generate more foot traffic than at less accessible parts of the beach. A previous study links aggressive trampling with proximity to beach access (Bowles and Maun, 1982).

The large trampled area near the designated swimming beach and the managed trail to the parking lot is an interesting feature of our study site (Figure 12). We would describe this area as an 'altered dune area' rather than a blowout because the area does not have a typical blowout shape. Instead the irregular edges of the bare sand area appear related to numerous pathways that visitors take into and out of the area. Management of the altered dune area faces several options.

1. Managers can consider the area to be a 'sacrificial' dune area—an area of concentrated visitor activities and impacts, thereby reducing visitor activities and impacts in other areas of the park. This approach allows dune managers to put their resources into protecting other dune habitats which are less altered and have less visitor pressure.
2. Managers can try to restore the area back to a more natural dune environment. Any restoration effort needs managers to enforce strong limits on human trampling throughout this area. The proximity to the parking lot would make this a challenging task. As well, visitor pressures and impacts could increase on other dune areas (with destructive consequences) when visitors no longer have access to this area.

Figure 12. Large trampled area.

Although our investigation of blowouts has produced interesting results in terms of blowout characteristics and spatial patterns, we recommend further study of the blowouts in Hoffmaster State Park to answer additional questions. In particular, we recommend using the DFI to assess the activity level for each blowout, mapping both deflation and deposition areas for each blowout, and taking pictures of each blowout as references for future comparisons to see if and how the blowouts are changing.

We also recommend further research of the relationship between unmanaged trails and blowouts in order to compare data and identify larger patterns. Data collected from areas that are a greater distance from parking lots and other park visitor focal points would provide a useful comparison to this study.

8. Conclusions

After mapping 23 blowouts and 54 trail segments on the dune ridge of Hoffmaster State Park, we conclude that there appears to be a relationship between the unmanaged trails and blowout formation. The lack of on-trail vegetation suggests that the unmanaged trails are heavily used. Almost all of the blowouts had at least one trail intersecting with the blowout. Trails with bare sand areas are susceptible to wind erosion which can lead to the formation or enlargement of blowouts. The proximity to public parking may be a factor in the amount of foot traffic throughout our mapped trail segments. Continued research on the blowouts and unmanaged trail segments within Hoffmaster State Park will help with better understanding the relationships between natural dune systems and visitor activity in the park.

9. Acknowledgments

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Appendix A: Blowout Features Inventory (BFI) Checklist

A. Site Information

1. Dune Name: ____
(Dune number or description of location Ex. Dune 6 or between Dune 4 and Dune 5)

2. Blowout Letter: ____________________ 3. Trail Number: ____________________

B. Field Data Collection Information

1. Observer(s): ____

2. Date: ____________________ Time In: ______________ Time Out: ______________

4. Weather conditions:
   Wind speed (avg): Wind direction:

C. Natural Features: Geomorphology

1. Site has:
☐ Blowout ☐ Trail ☐ Both

2. Proximity to public access:____________

3. Type of blowout:
☐ Trough ☐ Saucer

4. Number of trails at site:____________

5. Orientation of trail: ____________
(If sinuous, take multiple measurements)

7. Height of blowout (m): ____________
(Measure from lowest point to highest)

8. Width of blowout (m): ____________
(Measurement perpendicular to shoreline)

9. Length of blowout (m): ____________
(Measurement parallel to shoreline)

10. GPS data collected for:
☐ Blowout (polygon)

D. Natural Features on Blowout: Ecology

1. Ecological communities (check all that apply)
☐ Bare Sand
☐ Beach Grass/Early Colonizers
(Ex: American beach grass)
☐ Shrubland/Early Succession
(Ex: sand cherry, juniper, aspen, cottonwood)
☐ Forest/ Late Colonizers
(Ex: pine, red oak, aspen, red maple)

2. Locations of vegetation on blowout:
______________________ (Description)

5. Density of vegetation on the dune ridge:
☐ High (75%-100% vegetation cover)
☐ Moderate (25%-75% vegetation cover)
☐ Low (0%-25% vegetation cover)

Appendix B: Dune Features Inventory (DFI) Checklist - Activity

D. Natural Features: Dune Activity

1. Is the dune 100% (or almost entirely) vegetated?
☐ Yes ☐ No

2. Are active blowouts present?
☐ Yes ☐ No

3. Are substantial areas of the dune active?
(Ex. large blowouts, sand moving over dune crest, etc)
☐ Yes ☐ No

4. Is the dune advancing?
(Evidence of sand deposits reaching bottom of slipface.)
☐ Yes ☐ No

5. Is the dune surface mostly composed of bare sand and early colonizers?
☐ Yes ☐ No

6. Classify dune activity level (see DFI Guide)
☐ Inactive/Stable
☐ Slightly Active
☐ Moderately Active
☐ Active
☐ Very Active

7. Classify foredune activity (see DFI guide)
☐ Active ☐ Stable

From the Guide to Completing the DFI: D. Natural Features: Dune Activity

Active blowouts have an area of bare sand (the deflation area) which serves as the area of wind erosion. You may also see a downwind area of sand deposition. Bigger or very active blowouts may have a visible slipface; for smaller or less active blowouts, the sand may be deposited on the slopes/vegetation downwind of the blowout.
Substantial areas of dune activity include:

- one or more large blowouts (10s of meters in size)
- a large number (>5-10) of small blowouts (<10 m in length or width)
- evidence that sand moves over the crest of the dune: this includes a bare sand area on the (upper) windward slope of the dune, bare sand areas on the dune crest, and a deposition area on the (upper) slipface of the dune
- evidence that sand has moved a significant distance from a sand source: deposition area of blowout(s) extends more than 10 meters from the blowout, fresh deposition on slipface reaches at least half-way down the slope or more.

Evidence of dune advance includes fresh sand deposits reaching the bottom of the slipface (ie without leaf litter or soils on the surface of the sand) and/or burial of vegetation/leaf litter/soils at the bottom of the slipface.

Level of Foredune Activity	Responses to Questions 1-5	Description of Dune Characteristics
Active	1. No or Yes 2. No or Yes 3. No or Yes 4. No or Yes 5. Yes	Active foredunes have evidence of sand movement (vegetation burial, fresh sand deposits, leaf/plant litter is buried by sand) and vegetation consists of pioneering species that may not completely cover the dune surface. Scarping of the windward foredune slope is an indicator of recent wave erosion.
Stable (Inactive)	1. Yes 2. No (possibly Yes) 3. No 4. No	Stable foredunes may have more complete vegetation coverage, less vigorous pioneering species (eg. duller color), greater species diversity from plant succession, and leaf/plant litter on

	5. No	ground beneath active plants. Another dune between the foredune and the beach is often an indicator of stability.

Classifying Dune Activity for dunes other than foredunes

Level of Dune Activity	Responses to Questions 1-5	Description of Dune Characteristics
Inactive (Stable)	1. Yes 2. No 3. No 4. No 5. No	Inactive (stable) dunes are fully vegetated with no locations of sand movement by wind. Dune surfaces have soils and leaf litter on them. Vegetation may be a climax forest community.
Slightly Active	1. No 2. Yes 3. No 4. No 5. No	Slightly active dunes have mostly stable (vegetated) surfaces with localized areas of sand movement. Sand movement occurs from small blowouts with sand deposition occurring within several meters of the blowout.
Moderately Active	1. No 2. Yes 3. Yes 4. No 5. No	Moderately active dunes have stable (vegetated) surfaces with substantial areas of activity in the form of large blowouts and/or sand moving over the crest of the dune. Deposition occurs on the slipface, but sand does not reach the bottom of the slope to cause dune advance. A dune may also be considered moderately active if it contains a very active nested dune on an otherwise stable surface.
Active	1. No 2. Yes 3. Yes 4. Yes 5. No	Active dunes show signs of substantial sand movement (large blowouts, sand moving over the crest of the dune) and the dune is advancing over the underlying landscape (shown by fresh sand deposits reaching the bottom of the slipface). Active dunes often have significant portions of the windward slope with little or no vegetation.
Very Active	1. No 2. Yes 3. Yes 4. Yes 5. Yes	Very active dunes have little or no vegetation and evidence of significant sand movement including significant dune advance. The windward slope and crest of the dune have substantial unvegetated areas for wind erosion and sand transport. The slipface shows many signs of activity (fresh sand deposits reaching the bottom of the slope, burial of vegetation, colonizing species of vegetation). Very active dunes will have rapid advance rates (> 1 m/year).