First-Year Research in Earth Sciences: Dunes

Sand Transport and Vegetation on Two Lake Michigan Blowouts in Ottawa County, Michigan

by James Karsten, Gabriel LePage, Michael Messina, Daniel Shisler and Jory Smith

FYRES: Dunes Research Report #8
June 2013

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

ABSTRACT

Sand transport and vegetation are important influences on blowout evolution, but little research has focused on their effects on Lake Michigan coastal blowouts. This study investigated the patterns of vegetation and sand transport on two large, saucer-type blowouts in Kitchel-Lindquist Dunes Preserve, Ottawa County, Michigan. A variety of methods were used including erosion pins, sand traps, GPS mapping, and observation and classification of vegetation. The two blowouts are active, with sand movement from exposed deflation areas over the blowout rims to deposition areas on the vegetated leeward slopes. There was no evidence of sand moving into the blowouts from the west. Blowout vegetation was concentrated on the rims and leeward slopes, with very little vegetation in the windward deflation areas. Most of the vegetation was American beach grass (*Ammophila breviligulata*) and little bluestem bunchgrass (*Schizachyrium scoparium*), along with dune-building shrubs on the leeward slopes. These plant communities are consistent with active blowouts with significant amounts of sand movement. Some of the species suggest that surfaces went through periods of stability before the present active stage. The northern blowout is less active than the southern blowout, and it might be in undergoing a period of natural stabilization. Interactions between processes and vegetation on the Kitchel-Lindquist blowouts illustrate the dynamic nature of Lake Michigan coastal dunes.

INTRODUCTION

Sand transport and vegetation are two important variables on coastal dunes. Sand transport is essential because without sand moving, there would be no dune created. Vegetation influences dune type and shape, and the absence or disturbance of vegetation is a crucial factor in the genesis of blowouts. Although there has been study done on these two variables, not many studies have looked at how they affect Lake Michigan coastal dunes and blowouts. This study is focused on two saucer-type blowouts in the Kitchel-Lindquist Dunes Preserve to investigate the following research questions. What are the patterns of sand transport and vegetation on the blowouts? What do these patterns tell about the past, present, and future of the blowouts?

The objectives for this study were to 1) observe and study the sand transport patterns in the blowouts, 2) investigate the vegetation patterns and determine from plant colonies the successional stages present on the blowouts, and 3) analyze the data to interpret the past, present and future of the blowouts.

BACKGROUND

Blowouts are depressions or hollows formed by wind erosion on pre-existing sand deposits (Gares and Nordstrom 1995; Hesp 2002). They come in a variety of sizes and shapes including shallow, saucer-shaped depressions and deep, elongated troughs (Trenhaile 1997) known as saucer blowouts and trough blowouts, respectively. The blowout includes both the area of wind erosion (also known as the deflation area) and the adjoining deposit of sand known as the "depositional lobe" (Hesp 2002). Blowouts begin to form when some disturbance creates an opening in the vegetation cover of an existing dune, thereby allowing the interaction of strong winds with the exposed dune surface (Gares 1992; Hesp 2002). Hesp's (2002) study on the initiation and dynamics of blowouts identifies vegetation die off and trampling of vegetation as some of the main ways in which blowouts are created. Other possible causes of blowouts include human activities (such as driving) and animal activities (such as grazing) that affect vegetation, weather variations such as droughts or damage from storms, wave erosion, fire, wind storms or acceleration of wind over dune topography, and sand movement and burial of vegetation.

Once a blowout has started, interactions between wind, sand supply and vegetation affect the dynamics and shape of the dune. Wind action can enlarge the opening in vegetation and move sand to form the depositional lobe. The topography of the blowout affects wind patterns, with topographic acceleration as the wind moves up the dune slope (Trenhaile 1997), and topographic steering possible in deep or large trough blowouts (Fraser et al. 1998; Hansen et al. 2009; Hesp and Hyde 1996). A deflation area may have a lower limit for wind erosion because the erosion reaches the groundwater surface or a pebble lag surface develops (Bauer and Sherman 1999). Vegetation also reduces the susceptibility of a surface to wind erosion, and the spread of vegetation in the deflation area can stabilize a blowout. Hugenholtz *et al.* (2006) found that a limited sand supply leads to more vegetation on a dune surface, and more vegetation leads to sand deposition. The positive feedback between vegetation growth and sand deposition may end the cycle of blowout initiation, growth and healing (Bauer and Sherman 1999). Other influences may also be present and blowout life-spans can be short; Trenhaile (1997) reported that the rapid colonization and protection of algae resulted in many blowouts in the Netherlands not surviving more than five years.

The interaction between vegetation and blowout processes has two directions: vegetation influences sand erosion, transport and deposition patterns, and sand movement influences vegetation patterns such as species and health. Olson (1958) studied the interactions between dune ecology and activity at Lake Michigan coastal dune sites, with a focus on dunes at the south end of the lake. Following in the footsteps of Cowles' (1899) pioneering work on dune succession combined with his own observations, Olson (1958) identified patterns of ecological succession for several types of dune areas, including blowouts (Figure 1). Specific types of vegetation or ecological communities can be used as indicators of stages of activity and/or stabilization in a dune's history. For example, pioneering species populate a dune or blowout in its first stages of activity and either tolerate or thrive on burial by sand (Cowles 1899; Olson 1958). When deposition rates decrease, the pioneering species do not do as well and other species suited to the new conditions become established. Examples of Lake Michigan dune species and the environments in which they are found are given in Table 1. As a result, investigating the vegetation patterns on a blowout can provide information on dune activity.

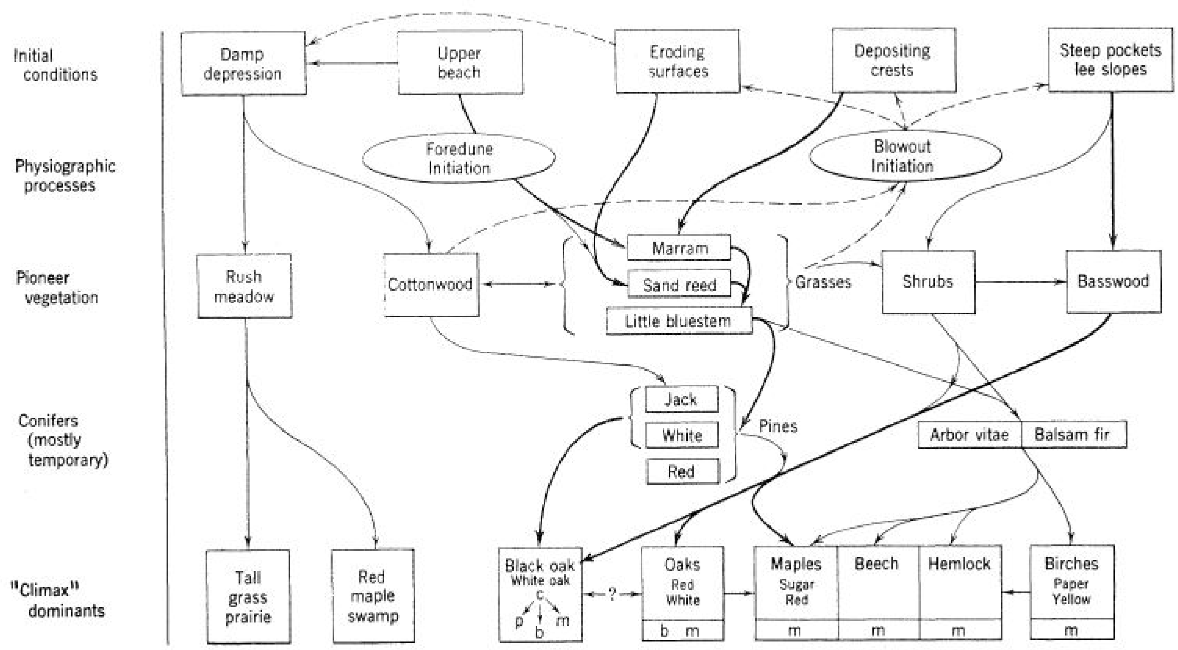

FIG. 12.—Alternative dune successions. Beaches, foredunes, and blowout dunes provide diverse sites which undergo different successions. Center of diagram gives oversimplified outline of "normal" succession, from dune-builders to jack or white pine to black oak–white oak with several undercover types: choke-cherry–poison ivy (c), "prairie" (p), blueberry-huckleberry (b), or mesophytic herbs (m), depending on topography, water table, and biotic and fire history. Wet depressions (*left*) and protected lee slopes and pockets (*right*) may lead to richer forests including basswood, red oak, and many mesophytic trees and herbs. Beech and hemlock are added in mesophytic pockets of Michigan and become more widespread northward; in northern Michigan red oak–white oak–blueberry (b) may take place of black oak on some dry dunes; pines, including red pine, are more widespread, and fir joins arbor vitae, basswood, and birches near lake. (Diagram published in *Elements of Ecology*, by G. L. CLARKE, from data of present writer. Reproduced here by permission of John Wiley & Sons, New York.)

Figure 1: Olson's (1958: 152) illustration of types of vegetation characteristic of different dune stages.

Vegetation Type	Examples from Lake Michigan Dunes	Dune Activity/Environment
Pioneer vegetation (may occur in mixtures or segregate into nearly pure stands)	*Ammophila breviligulata* (American beach grass or marram grass) *Calamovilfa longifolia* (prairie sand reed) *Adropogon scoparius septentrionalis* (little bluestem grasses)	Active deposition areas; has been shown to tolerate more than a meter deposition per year. Active deposition areas; can not tolerate as much deposition as *A. breviligulata* but tolerates some erosion and persists for decades longer than *A. breviligulata.* Invades an area when deposition rate slows down; can tolerate considerable deposition once plants are established.
Burial-tolerant trees	*Populus deltoides* (cottonwoods) *Tilia Americana* (basswood)	Seed germination requires damp sand; tolerates sand deposition. Found on leeward slopes with sand deposition.
Dune-building shrubs	*Prunus pumila* (sand cherry) *Cornus stolonifera var. baileyi* (red osier dogwood) *Salix syticola, S. glaucophylloides* var. *glaucophylla, S. interior* (dune willows)	Succeeds *A. breviligulata*; roots use organic material left in soil. A minor shrub but may dominate extensive thickets on some active lee slopes. Requires damp sand for seed germination; can accumulate sand in extensive thickets.
Trees and shrubs indicating dune succession	*Pinus banksiana* (jack pine) *Pinus strobus* (white pine) *Prunus virginiana* (choke-cherry) *Quercus velutina* (black oak)	Quickest invasion and most dense communities in moist "pine bottoms" of blowout depressions. More common on steeper blowout or wave-cut dune slopes; on young dune sands, first-generation pine stands are rapidly replaced by oak. Will not reach greatest abundance until forest cover is well developed, but exhibits great vigor when sand is deposited over previously established shrubs. Climax forest species; oak replaces pine or squirrels may bring acorns to grass/shrub areas.

Table 1. Vegetation types, examples from Lake Michigan dunes, and descriptions of dune environments and constraints. (Information from Olson 1958)

STUDY AREA

The study area encompasses two blowouts located on the coast of Lake Michigan in Ottawa County (Figures 2 and 3). The two blowouts are located on the southern end of Kitchel-Lindquist Dunes Preserve, which is north of Grand Haven and the channel of the Grand River. West of the Preserve, a road with houses on one or both sides separates the Preserve from Lake Michigan. The southern blowout, referred to as Blowout 1 in this study, is immediately north of the parking lot and educational building for the Preserve. Blowout 2 is just north of Blowout 1 and in fact shares a ridge with Blowout 1. Neither of the blowouts have been the focus of previous studies.

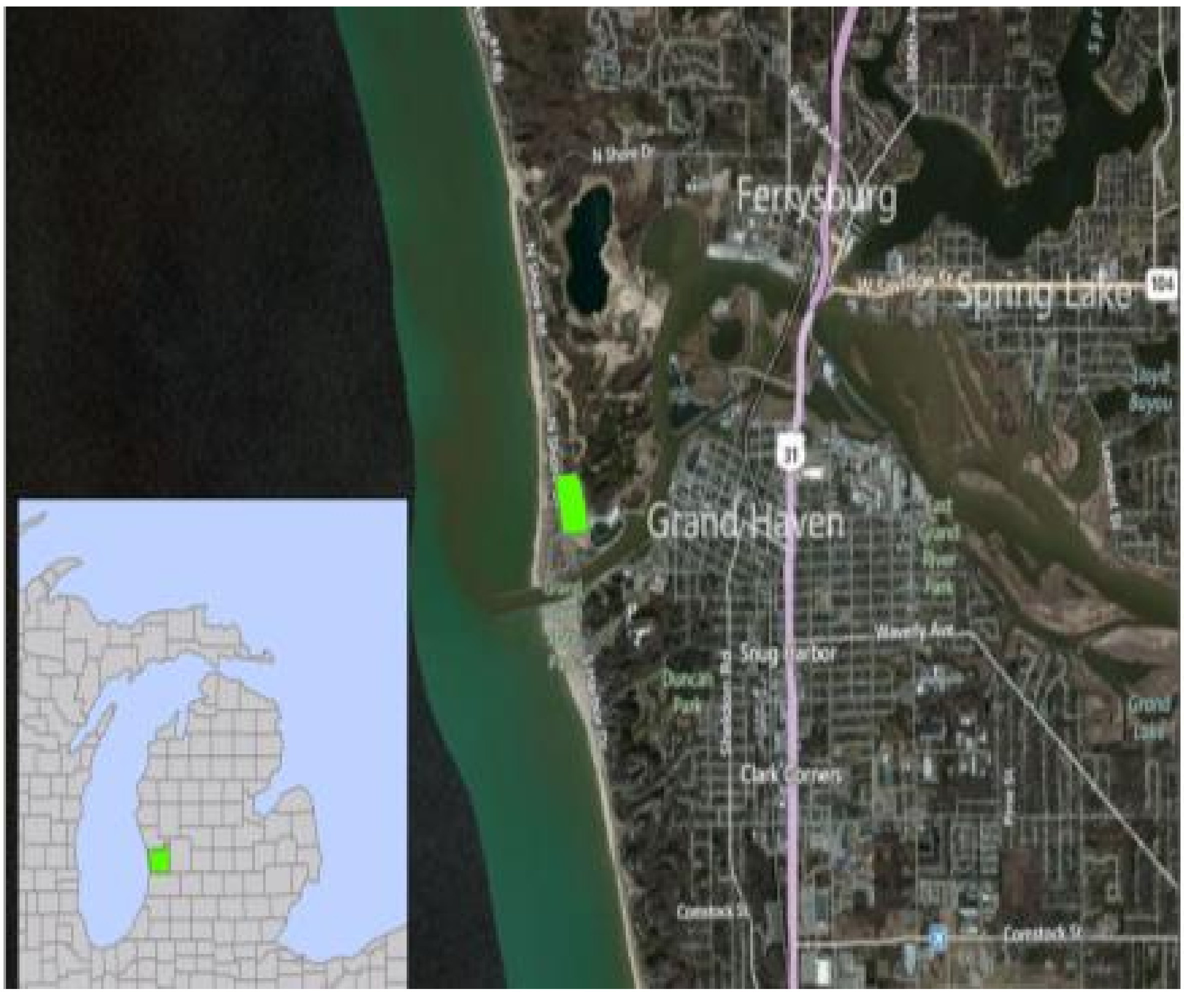

Figure 2: Location of study area in Ottawa County just north of Grand Haven and the Grand River channel

Figure 3: Blowout 1 (right) and 2 (left) as viewed from North Shore Drive in June 2013.

METHODS

We used a variety of methods to investigate blowout characteristics, vegetation and dune activity in our study area. Field data collection took place during three weeks in the fall of 2012 (October 25 – November 17). As part of our investigation, we recorded blowout characteristics including size, shape and blowout orientation, along with the characteristics of the surfaces surrounding the blowouts.

We used sand traps to measure dune activity in the form of sand transport by wind. Winter sand traps (Figure 3) were set up at blowout locations, with traps facing directions according to wind conditions or specific research questions (see Table 2 for details of October 25 sand trap measurements). The times of sand trap installation and take-down were recorded. Sand captured by the traps was taken back to the lab, where it was dried and weighed.

Figure 3: Sand Trap C placed on the floor of Blowout 1 with the opening facing SW.

Sand Trap	Location	Trap opening faces:	Reason for trap direction:
A	Blowout 1, crest	southwest	wind direction is southwest at time of measurements
B	Blowout 2, crest	southeast	to investigate possible topographic steering of wind and sand transport
C	Blowout 1, floor	southwest	wind direction is southwest at time of measurements
D	Blowout 2, floor	west	to investigate whether sand is entering blowout from the east

Table 2: Sand trap locations and directions for October 25, 2013.

Leatherman sand traps were also installed at the study site for longer-interval measurements, but results are not reported because the sand traps were vandalized between site visits.

To measure dune activity in the form of surface changes, we installed 50 erosion pins (25 on each blowout) in transects across the blowouts to measure surface changes. The transects were set up so that one transect followed the main axis of the blowout and a perpendicular transect went across the blowout from arm to arm (Figure 4). We also recorded other evidence of sand movement such as areas of erosion (where roots or sediment layers were exposed), areas

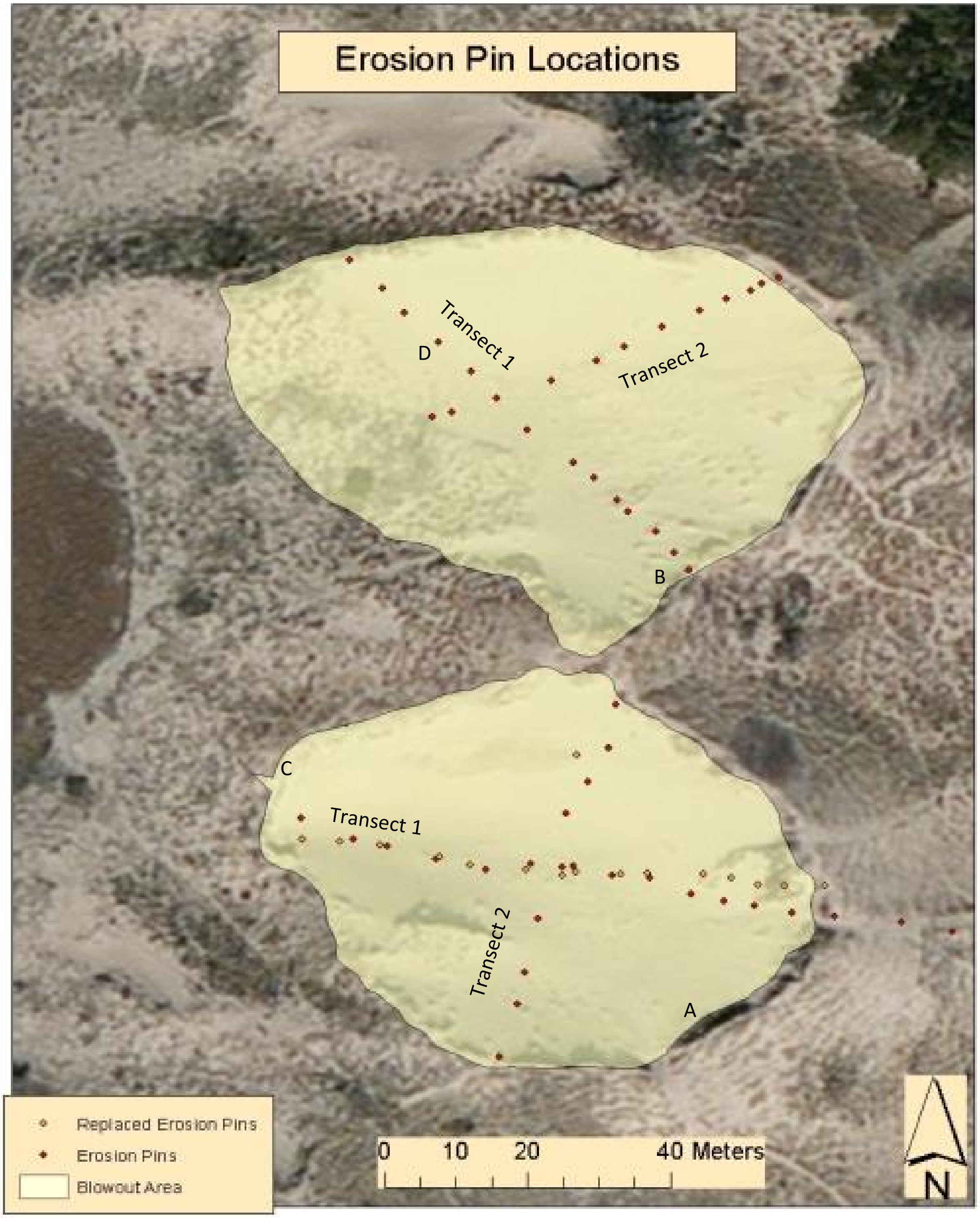

Figure 4: Map showing the deflation areas of the blowouts with erosion pin locations (including locations of pins replaced after vandalism). A, B, C, D indicate sand trap locations on October 25.

of deposition (where sand was deposited around vegetation), and areas of surface stability (where leaf litter and/or soils were observed on dune surfaces).

To investigate wind conditions during our study, we obtained data from an instrument tower located at a foredune research site in Hoffmaster State Park approximately 5 kilometers north of our study site. Data included measurements of wind speed and direction from instruments at a height of 4.5 meters above the dune surface. We looked at daily wind speeds and directions to compare wind patterns with surface changes at our site. We also looked at wind speeds and directions at the times of our sand trap measurements.

We investigated vegetation by mapping vegetation locations and identifying types of vegetation and plant communities. We used a Trimble GPS to map vegetation areas, along with dune features (such as blowout boundaries) and measurement locations (such as erosion pins). We observed and classified different species of plants and different plant communities on the blowouts in order to interpret dune activity and history, along with likely future activity.

RESULTS

Blowout Characteristics

The two blowouts share many similar characteristics, but they have different orientations (Table 3). Both blowouts are approximately 14 meters tall and have saucer-shaped deflation areas (Figure 5). Blowout 1 faces west while Blowout 2 faces northwest. Blowout 1 has a longer deflation area than Blowout 2, but the deflation areas are approximately the same width. At the west end of the deflation area of Blowout 1 there is a small (approximately 2 meters across) but deep (> 1.5 meters) depression that appears to have been scoured by the wind. Both blowouts are surrounded by vegetated dunes and interdunal areas. The road and the row of residences to the west of the Preserve interrupt the dune system and separate the blowouts from the sandy beach on Lake Michigan.

	Blowout 1	**Blowout 2**
Height	14.5 meters	14 meters
Orientation (direction of main axis)	east-west	northwest-southeast
Windward slope faces:	west	northwest
Length of deflation area (along main axis)	78 meters	68 meters
Width of deflation area (perpendicular to main axis)	18 meters	18 meters

Table 3: Characteristics of the two blowouts.

Figure 5: Blowout 1 (top) and Blowout 2 (bottom) viewed from the west.

Wind Patterns and Blowout Activity

Our study period included both strong and weak winds with a variety of directions (Figure 6). The three periods of significant winds were 1) the beginning of the study with two days of average winds over 6 m/s from the S and NW, 2) an extended period of strong winds from the NNW (daily averages greater than 5 m/s) which occurred as the remnants of Superstorm Sandy moved across Michigan, and 3) the strongest wind event on November 11-12 which included daily average winds greater than 8 m/s from the WSW on November 12.

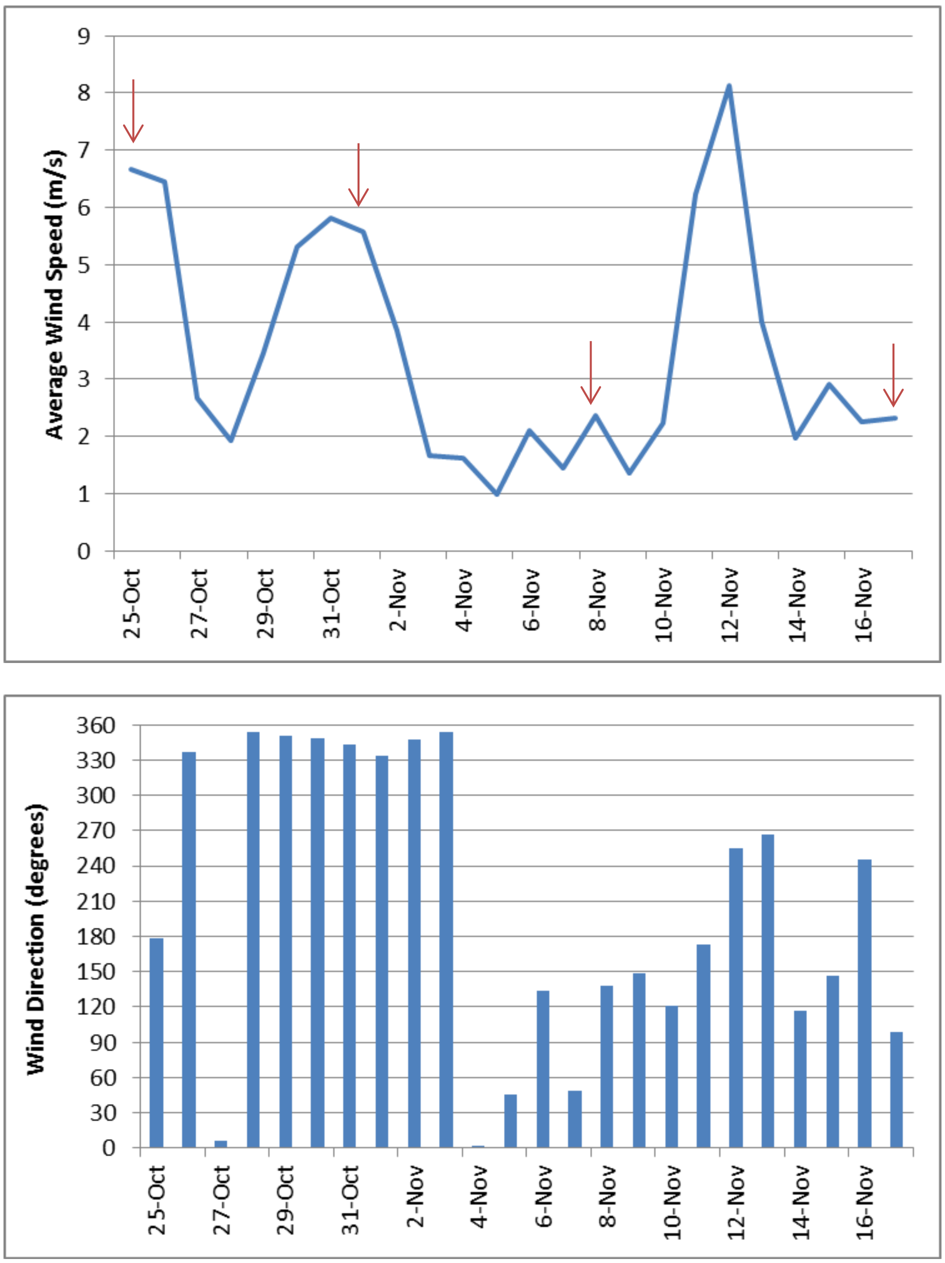

Figure 6: Daily wind speeds and directions measured at Hoffmaster State Park during the study period. Arrows indicate the dates of the measurements at the Kitchel-Lindquist blowouts.

Sand transport was observed and measured with sand traps during our first site visit on October 25, 2012 (Figure 7). The sand trap results show that active sand transport in both blowouts during the measurement time of 4:30-5:30pm. More sand was moving over the crest of each blowout compared to the floor of each blowout. More sand transport was measured in Blowout 1 compared to Blowout 2. No sand transport was measured on the floor of Blowout 2 near the west edge of the deflation area. Average wind speeds during this measurement period ranged from 5.2 – 6.6 m/s with a maximum wind speed of 9.8 m/s. The wind direction at the Hoffmaster State Park instrument tower was 170 degrees (S) although we recorded a wind direction of SW at the blowout.

On subsequent site visits, sand transport was observed when strong winds were present. On November 1, sand transport was recorded at traps on both blowout crests as well as in the deflation bowls of both blowouts. More sand was captured by the traps in Blowout 1, and there were greater amounts of sand captured in the sand trap lower in the deflation area compared to a sand trap on the blowout crest. Rates of sand transport cannot be calculated from these measurements because of some missing data. On November 8, no sand transport was observed, and the sand traps were not used because of low wind speeds.

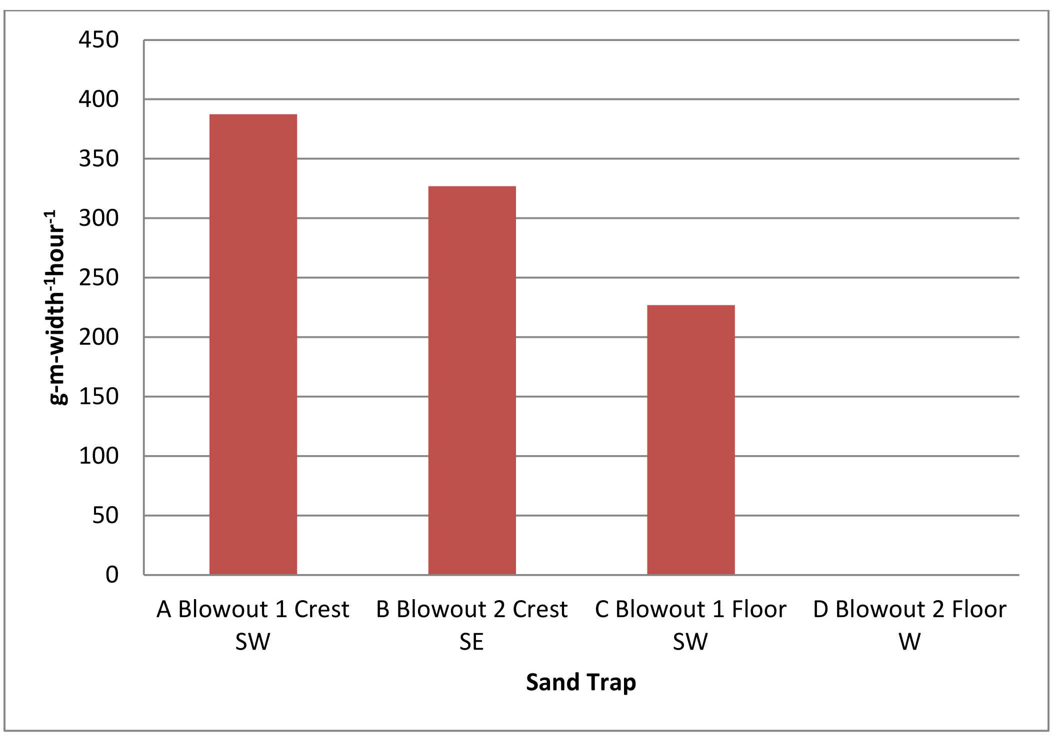

Figure 7: Sand transport rates at sand traps Thursday, October 25 from 4:30 to 5:30pm.

Surface change occurred at most of the erosion pins. In Blowout 1 along the main axis (Transect 1, Figure 8), both erosion and deposition occurred at pins, with the greatest amounts of change taking place on the upper windward slope of the blowout. Pin 13 was the site of both the greatest amount of deposition (almost 9 cm in Week 1) and the greatest amount of erosion (over 12 cm in Week 3). Most of the cumulative change during the study period was erosion. Transect 2 shows similar variability and amounts of erosion and deposition at pins (Figure 9). Both transects show the least amount of surface change in the middle of the blowout.

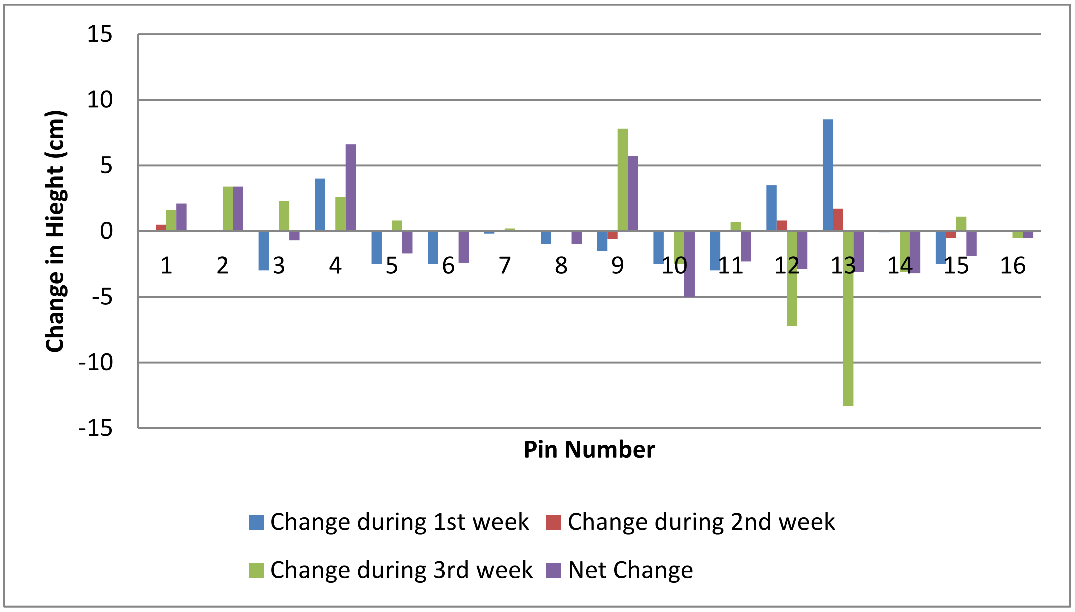

Figure 8: Surface changes measured at erosion pins along Transect 1 in Blowout 1.

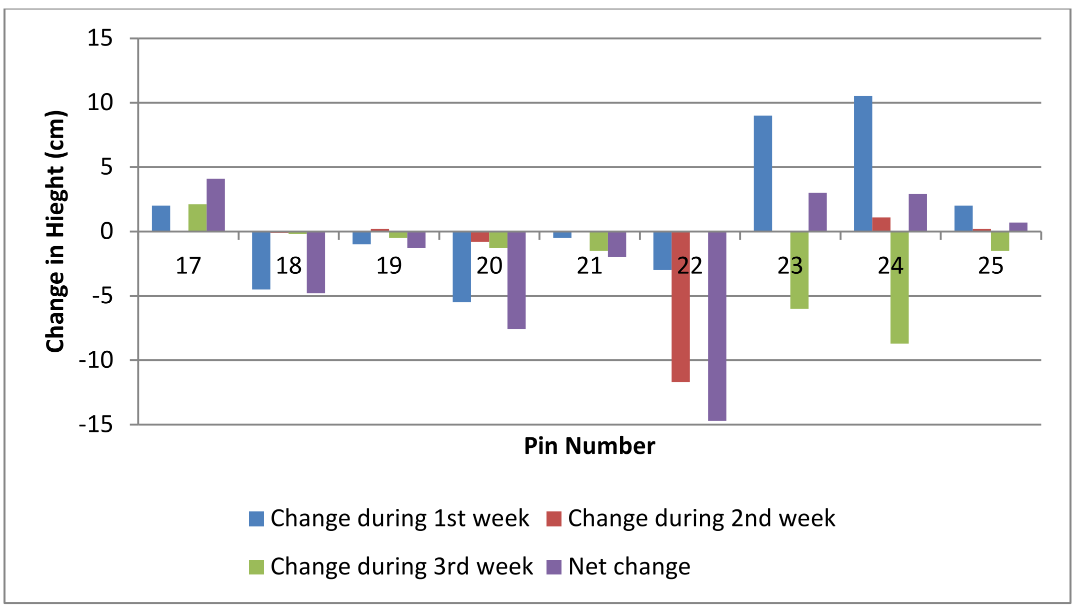

Figure 9: Surface changes measured at erosion pins along Transect 2 in Blowout 1.

Smaller amounts of erosion and deposition were recorded at the erosion pins in Blowout 2. Along Transect 1 (Figure 10), net change was small amounts of deposition (< 1 cm) at the lower pins, followed by erosion at pins 5-11 (the middle and upper blowout slope) and deposition at pin 12. The greatest net surface change was 5 cm of erosion at pin 11, but most of the surface changes were 2 cm or less along this transect. Along Transect 2, most of the surface changes were erosion, with larger amounts (up to 8 cm) at the west edge of the transect (pins 14-18) compared to the eastern part of the transect (Figure 11)..

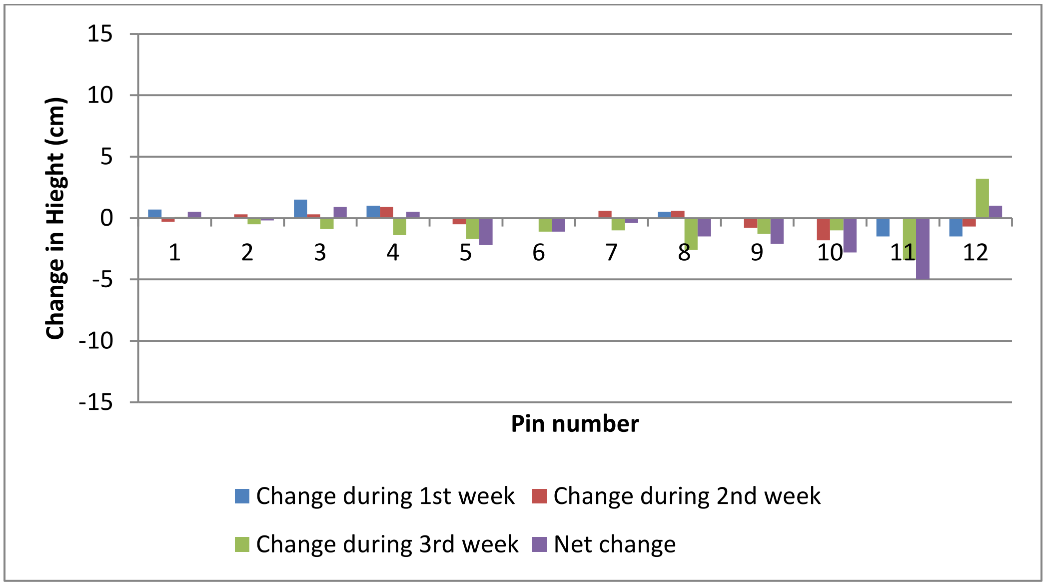

Figure 10: Surface changes measured at erosion pins along Transect 1 in Blowout 2.

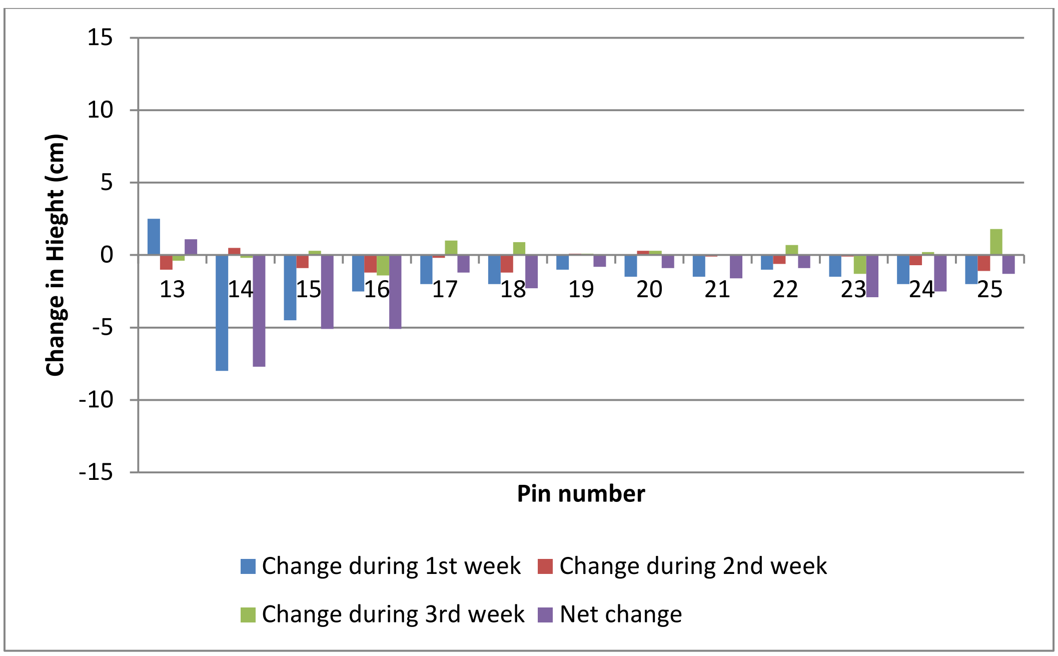

Figure 11: Surface changes measured at erosion pins along Transect 2 in Blowout 2.

Both blowouts had visible evidence of erosion and deposition. We observed sand transport on the bare sand in the deflation areas of each blowout. Transport and wind scour were observed in the depression at the west end of the Blowout 1 deflation area (Figure 12). On the upper slopes of the deflation areas, we observed exposed bedding structures, along with scarps (near-vertical slopes) and exposed roots near the rim of the deflation areas (Figure 13). We observed sand deposits that were partially burying vegetation on the upper leeward slopes of both blowouts (Figure 14). No sand was observed moving into the blowouts from the west; the adjacent dune surfaces were almost completely vegetated between the blowouts and a vegetated dune ridge near the road.

Figure 12: Arrow points to scoured depression at the west end of Blowout 1, visible behind researchers in this view looking west from the crest of the blowout.

Figure 13: Scarping and exposed bedding and roots on the upper windward slope of Blowout 1.

Figure 14a: Upper deflation area of Blowout 2 (note bare sand and exposed roots) and sand deposits partially burying the vegetation on the slip-face. (Photo taken from the south.)

Figure 14b: Slip-face of Blowout 1 (as viewed from north) has sand deposits partially burying vegetation; the deposits that reach nearly to the bottom of the slip-face.

Blowout Vegetation

All areas of the vegetation within the deflation areas of the blowouts appear on the map (Figure 15), along with sample areas of vegetation on the crest and slip-faces of the blowouts. Where time did not permit mapping all vegetation on the slip-faces, locations of vegetation are

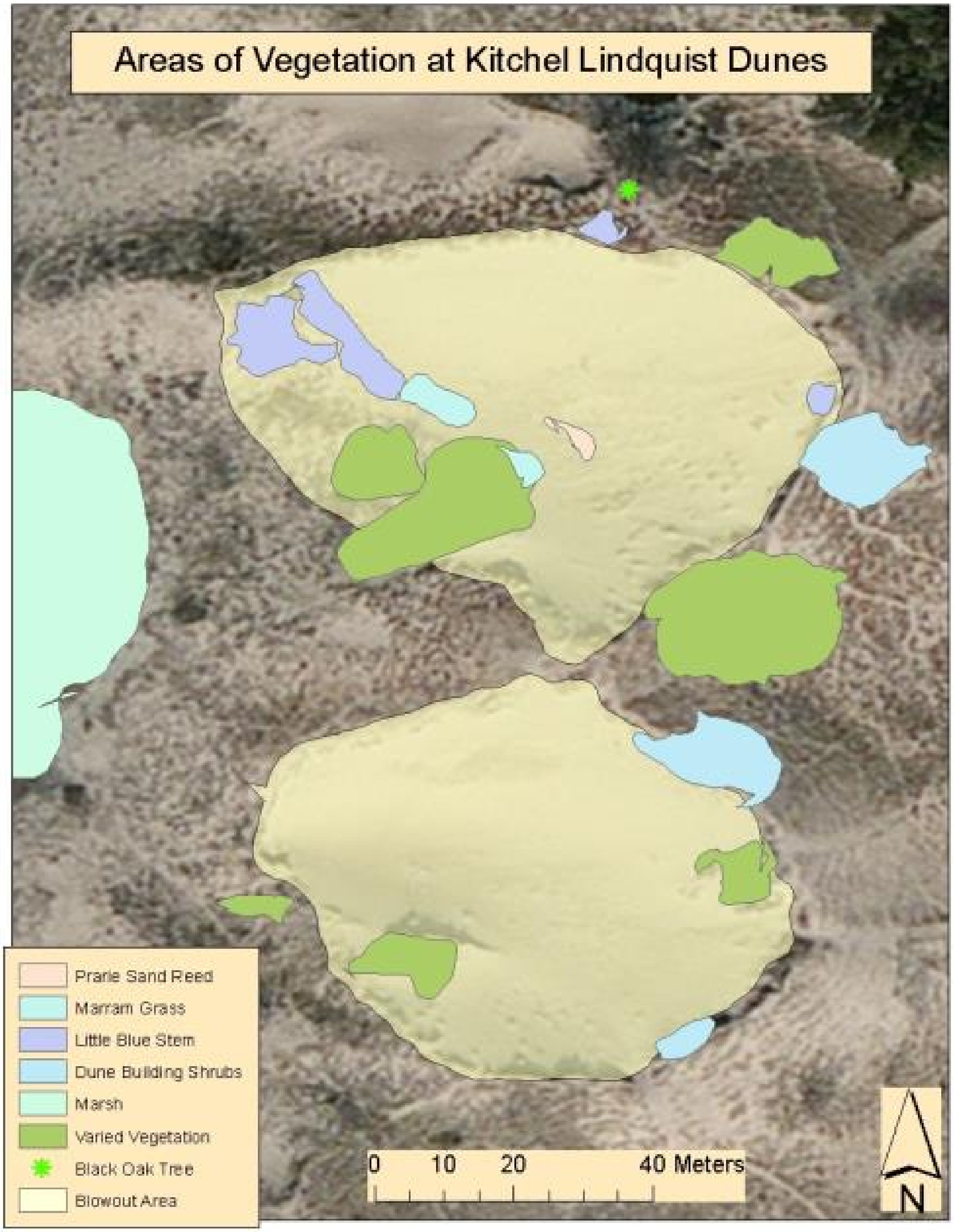

Figure 15: Map of areas of vegetation on Blowouts 1 and 2.

visible on the aerial photo underlying the vegetation map. The blowouts were mostly bare of vegetation in the deflation areas, although Blowout 2 had more vegetation present within the deflation area than Blowout 1. For both blowouts, the vegetation was concentrated on the dune rims and crests, as well as the slip-faces. The vegetation density was greater on Blowout 2 than on Blowout 1.

Vegetation occurred in some areas of single species (such as *Ammophila breviligulata* or marram grass areas) as well as areas of mixed vegetation. The areas of mixed vegetation were mostly made up of *Ammophila breviligulata* (marram grass), *Calamovilfa longifolia* (prairie sand reed), and *Schizachyrium scoparium* (little bluestem bunchgrass), with some *Populus deltoides* (cottonwood) trees (Figure 16). Slip-face vegetation included grasses and dune-building shrubs along with occasional trees. There was one partially-buried *Quercus velutina* (black oak) tree on the slip-face of Blowout 2 (Figure 17).

Figure 16: *Populus deltoides* (**c**ottonwood) and *Calamovilfa longifolia* (prairie sand reed) on Blowout 1.

Figure 17: This *Quercus velutina* (black oak) tree is substantially buried by sand deposits.

DISCUSSION

The two blowouts we investigated in Kitchel-Lindquist Dune Preserve are active, saucer-shaped blowouts with well-defined deflation and deposition areas. Strong winds, particularly from the west and southwest can erode sand from the west and southwest-facing bare sand surfaces of the deflation areas, transport the sand up the dune slope and over the crest, and deposit the sand on the blowout slip-faces among vegetation species that tolerate some amounts of sand burial. Although we made a very limited set of sand trap measurements, our study measured substantial rates of sand transport, particularly at the crest of both blowouts and in the deflation area along the main axis of the dune during a strong wind event. Differences in sand transport amounts between the floor of the deflation areas and the blowout crests are to be expected as wind speed (and therefore sand transport) typically accelerates as the wind moves up a dune slope and over the dune crest. Deposition on the blowout slip-faces is consistent with the lower wind speeds in those areas, again because of dune topography (the faster wind flow separates from the dune slope, creating a zone of little or no wind on the slip-face).

Activity in both blowouts appears to be the result of winds reworking the sand of the blowouts themselves, rather than the blowouts receiving inputs of sand from upwind locations. There was no evidence of sand movement in the vegetated dune areas to the west of the blowouts. In addition, there was no evidence of links in sand transport between the Lake Michigan beach and the blowouts—the intervening area includes houses, a road, and a vegetated dune ridge. Although there are visual indications that sand moves past some of the houses and onto the road, there was no evidence that sand moves past the dune ridge east of the road.

There are a number of indicators that Blowout 2 is less active than Blowout 1. Measured sand transport amounts were lower on Blowout 2, as were the measured amounts of surface change. The pin that showed the greatest surface change on Blowout 2 was located in vegetation southwest of an unmanaged trail and might have received deposits of sand from people walking along the trail. There is more vegetation present on Blowout 2, including more vegetation in the deflation area of the blowout.

The decreased activity of Blowout 2 (compared to Blowout 1) may be an indicator that this blowout is undergoing a period of stabilization. Factors that could promote stabilization are increased vegetation, decreased wind influences and decreased human impacts. Our study shows that there is more vegetation present on Blowout 2. The different orientation of the two blowouts may result in less wind influences in Blowout 2—this possibility deserves further study. Blowout 2 is further from the path and parking lot than Blowout 1, and therefore it may receive less visitor presence and human impacts. We note that vandalism of our equipment occurred on Blowout 1 and not Blowout 2. But even if Blowout 2 is becoming more stabilized, its current characteristics and activity indicate that it is an active blowout with substantial amounts of sand erosion, transport and deposition.

The plant species present on the blowouts affirm that both blowouts are active and that Blowout 2 is slightly more stable than Blowout 1. Most of the plants are pioneering species that either tolerate or thrive in areas of sand deposition. Little bluestem bunchgrass is an indicator that areas were stable enough for the plant to become established even if current rates of sand movement are high in the area. A greater variety of species, dune-building shrubs, and the few scattered trees on the deposition lobes of the blowouts indicate a greater level of stabilization in these areas. Because the shrubs and trees take some time to move in to areas previously colonized by pioneering species, they indicate that these dune slopes have existed for decades at least. While the plants suggest a lower boundary (even though “decades” is quite broad) for the ages of the surfaces, we have no evidence for an upper age boundary. If dune activity persists, pioneering species could thrive on a dune surface for decades, and as long as some small amounts of deposition continue, the secondary species will persist in an area without succession to a mature forest. The *Quercus velutina* (black oak) tree is an indicator of a dune surface with a time period of stability in its past, as well as a surface that has persisted for the length of time needed for the black oak to grow to maturity. (Obtaining a tree core from the black oak and counting the rings would provide an absolute age for this tree and the time period of stability that permitted it to grow.) Deposition around the black oak tree indicates a subsequent and more recent period of activity.

CONCLUSIONS

From our study, we can conclude that both Blowouts 1 and 2 are active dune systems in which sand movement is local, rather than the blowouts receiving sand inputs from upwind dune areas. Blowout 1 is more active than Blowout 2, which is possibly beginning to stabilize. Dune vegetation is concentrated on the rims and slip-faces of the blowouts. Most of the species present on the blowouts are either pioneering or dune-building species that thrive or tolerate sand movement and deposition. Some species indicate periods of stability before current levels of blowout activity, and the maturity of the scattered trees indicate that some blowout surfaces are older than several decades. Further analysis of the vegetation patterns relative to wind patterns and sand movement may provide additional clues about the history of the blowouts. Future monitoring will show whether Blowout 2 is indeed stabilizing, or whether it is persisting at a slightly lower level of activity than Blowout 1.

ACKNOWLEDGEMENTS

Special thanks to the Kitchel-Lindquist Dunes Preserve for permission to conduct research in the preserve. Thanks to Dr. Deanna van Dijk for providing support and advice during all stages of research. Thanks to Calvin College: Department of Geology, Geography, and Environmental Studies for providing materials and facilities used in this study. This study was funded by NSF Grant #0942344.

WORKS CITED

Bauer, B. O., and D. J. Sherman. 1999. "Coastal dune dynamics: Problems and prospects." In *Aeolian Environments, Sediments and Landforms*, edited by A. S. Goudie, I. Livingstone and S. Stokes, 71-104. Chichester: John Wiley & Sons, Ltd.

Cowles, Henry Chandler. 1899. "The ecological relations of the vegetation on the sand dunes of Lake Michigan." *Botanical Gazette* no. 27:95-117, 167-202, 281-308, 361-391.

Fraser, Gordon S., Steven W. Bennett, Greg A. Olyphant, Nancy Bauch, Victoria Ferguson, Christopher A. Gellasch, Clayton L. Millard, Barbel Mueller, Patrick O'Malley, J. N. Way, and Margaret C. Woodfield. 1998. "Windflow circulation patterns in a coastal dune blowout, south coast of Lake Michigan." *Journal of Coastal Research* no. 14 (2):451-460.

Gares, Paul A. 1992. "Topographic changes associated with coastal dune blowouts at Island Beach State Park, New Jersey." *Earth Surface Processes and Landforms* no. 17:589-604.

Gares, Paul A., and Karl F. Nordstrom. 1995. "A cyclic model of foredune blowout evolution for a leeward coast: Island Beach, New Jersey." *Annals of the Association of American Geographers* no. 85 (1):1-20.

Hansen, E., S. DeVries-Zimmerman, D. van Dijk, and B. Yurk. 2009. "Patterns of wind flow and aeolian deposition on a parabolic dune on the southeastern shore of Lake Michigan." *Geomorphology* no. 105:147-157.

Hesp, P. A., and R. Hyde. 1996. "Flow dynamics and geomorphology of a trough blowout." *Sedimentology* no. 43:505-525.

Hesp, Patrick. 2002. "Foredunes and blowouts: initiation, geomorphology and dynamics." *Geomorphology* no. 48:245-268.

Hugenholtz, C. H., and S. A. Wolfe. 2006. "Morphodynamics and climate controls of two aeolian blowouts on the northern Great Plains, Canada." *Earth Surface Processes and Landforms* no. 31:1540-1557.

Olson, Jerry S. 1958a. "Rates of succession and soil changes on southern Lake Michigan sand dunes." *Botanical Gazette* no. 119 (3):125-170.

Trenhaile, A.S. 1997. *Coastal Dynamics and Landforms*. Oxford: Clarendon Press.