First-Year Research in Earth Sciences: Dunes

Efficacy of Sand Fences in Stabilizing a Steep Active Dune Blowout, Castle Park Reserve, Michigan

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ABSTRACT

Sand fences are a common management technique used to mitigate wind erosion and stabilize sand dunes. This project investigates the efficacy of sand fences in stabilizing an active dune blowout on the eastern shore of Lake Michigan. Research was conducted on a 50-meter high active dune at the Castle Park Reserve south of Holland, Michigan. In the spring of 2012, two sand fences were placed on the steep windward face of the dune in an attempt to stabilize the dune surface. In the fall of 2011 and 2012, erosion pins were used to measure rates of sand erosion and deposition along the axis of the dune. In the fall of 2012, Leatherman sand traps and grids of erosion pins were used to assess sand movement in proximity to the new sand fences. Along the axis of the dune, rates of sand erosion and deposition showed a decrease from 2011 to 2012, although there was little visual evidence of sand accumulation around the sand fences. Sand trap measurements demonstrated greater aeolian sand movement on the windward side of sand fences than the leeward side. However, rates of erosion and deposition near the sand fences were variable, showing areas of both erosion and deposition. Visual observations noted the tendency of deposited sand to slide down the steep face of the blowout. This study demonstrates that sand fences appear to be effective at reducing aeolian sand movement at this site, but they appear to be having a more limited effect on reducing the overall movement of sand on the active blowout face. When stabilizing steep slopes, dune managers should consider using sand fences in conjunction with another technique that reduces the downslope mass movements of sand.

INTRODUCTION

The eastern shore of Lake Michigan boasts numerous distinctive coastal sand dunes. Many of these dune systems are stable and vegetated, but some individual dunes known as blowouts are unvegetated and actively moving. Although a blowout can originate from many causes, human activity conspicuous along the developed shore of Lake Michigan is capable of initiating blowouts and causing degradation to the dune ecosystems. In an attempt to mitigate the degenerative effects of human activity and restore dune blowouts to a stable vegetated state, dune managers often rely on management intervention techniques such as sand fences.

One such example of an actively managed dune blowout is at the Castle Park Reserve in Allegan County, Michigan. The dune blowout at Castle Park is believed to be of anthropogenic origin and is currently undergoing active management towards restoring a stable vegetative community (Manion 2010). In an effort to first stabilize the dune surface, dune managers have installed sand fences on the active face of the dune in the spring of 2012. Consequently, the objective of this study is to assess whether the sand fences on the Castle Park dune are effective at stabilizing the dune surface.

BACKGROUND

Due to their low cost and easy implementation, a common and effective management practice to mitigate sand erosion is the installation of sand fences (Nordstrom *et al.* 2000). Sand fences are vertical barriers that disrupt wind flow across a surface, causing wind-borne sand to deposit just downwind of the fence (Hotta *et al.* 1987). Sand fences are commonly composed of vertical wood slats, plastic netting, or biodegradable fabric. Fence characteristics, as well as fence placement, play a critical role in determining the subsequent morphology of sand deposits and the vegetative communities that survive on them (Grafals-Soto 2012). Numerous studies have shown that sand fences have aided in the restoration of degraded beach landscapes (Mendelssohn *et al.* 1991; Nordstrom *et al.* 2000; Miller *et al.* 2001; López and Marcomini 2006). However, these studies focus on the use of sand fences in controlling beach erosion and do not investigate the efficacy of sand fences on other geomorphic features, namely steep dune blowouts.

The geomorphology of dune blowouts provides additional challenges for the mitigation of dune erosion. Of major concern is the effect of windflow through dune blowouts. The bowl-shaped morphology of dune blowouts channel winds along the axis of the dune, creating greater erosion potential along the deflationary floor of the blowout (Fraser *et al.* 1998). Additionally, mass movements of sand down the windward slope of a blowout both expand the deflation area of the blowout and increase the amount of sand available to be transported over the dune crest (Fraser *et al.* 1998). Such mass-wasting scenarios are not considered in beach stabilization studies. Furthermore, the aeolian movement of sand over the dune crest takes large quantities of sand out of the sediment budget of the dune system, leading to a net loss of sediment for future sand accretion and dune building (Olyphant and Bennet 1994). Wind erosion on Great Lake dunes is also highly seasonal, with the majority of erosion occurring during storm events in the late fall and early winter along the eastern shore of Lake Michigan (van Dijk 2004).

To mitigate environmental degradation, dune management strategies require both social and technical approaches. For long term dune sustainability, management techniques that educate visitors and control their behavior will have the greatest impact on dunes with significant anthropogenic impacts (Peach 2006). However, dunes that are already degraded necessitate technical solutions to restore the dune to higher ecological function. Technical solutions to dune restoration should focus on reducing wind speed, reducing sediment transport, and encouraging sediment deposition (Brookes and Agate 2001).

In terms of restoring a dune to a stable condition, planting vegetation fulfills the three criteria for a technical approach to dune management. However, the success of vegetative restoration is first highly dependent upon dune surface stabilization. Sand fences, which cause the accretion of sand, are the primary factor that aids in such vegetative restoration (Disraeli 1984; Nordstrom *et al.* 2007). Indeed, vegetation shows decreased to no recovery without the aid of sand fences (Mendelssohn *et al.* 1991; Miller *et al.* 2001). Consequently, a crucial first step in blowout restoration is stabilizing the dune surface to begin the process of sand accretion and dune building.

STUDY AREA

The study site is located in Castle Park Reserve, a 1.8 ha (4.6 acre) shoreline, dune, and forest preserve located on the eastern shore of Lake Michigan, south of the city of Holland (Figure 1). The Land Conservancy of West Michigan has been managing the property with the goal of restoring natural ecological processes since the donation of the property in 2003 (Manion 2010). Castle Park Reserve is surrounded by both single family residential developments and undeveloped land protected by conservation easements (Figure 2). As there is no direct public access, recreational use of the property is minimal, aside from light use by area residents.

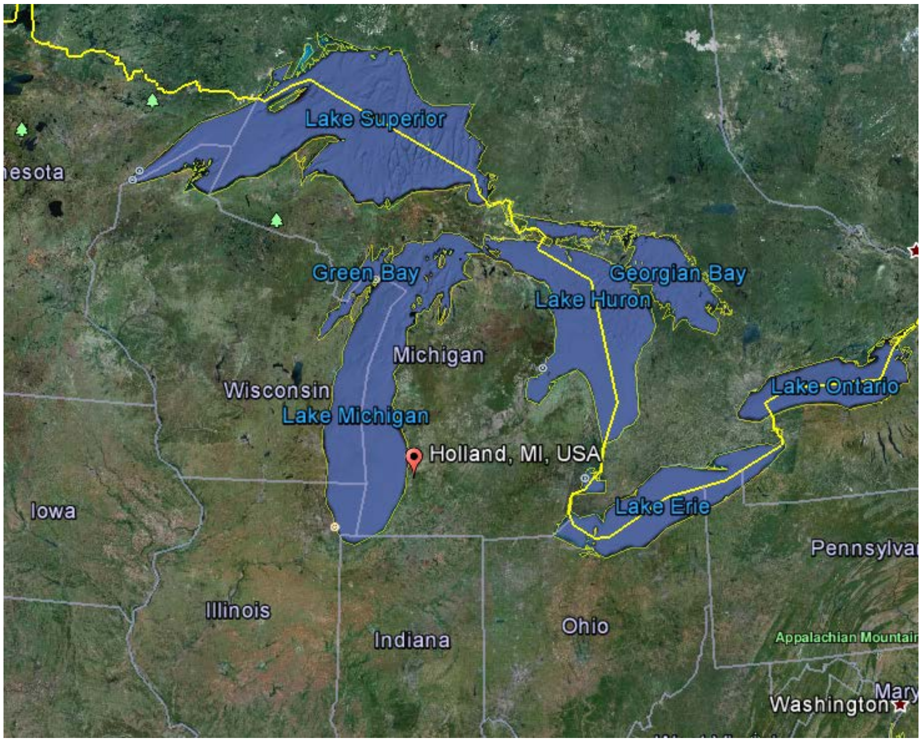

Figure 1: Castle Park Reserve is located on the eastern shore of Lake Michigan, south of the city of Holland. Source: Google Earth imagery ©2013.

Figure 2: Aerial view of Castle Park Dune, displaying surrounding development (dune blowout highlighted). Source: Google Maps imagery ©2013.

The major feature of Castle Park Reserve is a 50-meter high active dune blowout (Figure 3). The blowout is asymmetrical and irregular in shape, approximately 30 meters wide by 70 meters long with a primary dune axis in an east-southeast direction (Figure 4). The dune is steep,

Figure 3: View of windward slope of Castle Park Dune showing the 50-meter high blowout and the two sand fences installed in April 2012. Photo taken November 2012.

Figure 4: Aerial view of the Castle Park Dune blowout showing the irregular profile of the active face. Source: Google Maps imagery ©2013.

with surface slope angles ranging from 21^o to 30^o and no vegetation present in the active blowout area. The Land Conservancy suspects that the blowout originated from human disturbance on the dune (Manion 2010).

Since acquisition of the property in 2003, the Land Conservancy has been implementing management techniques to stabilize the dune surface. In 2009, straw bales and discarded Christmas trees were placed on the blowout surface in order to trap sand; these items presently remain on the dune surface (Figure 5). In April 2012, two sand fences made of plastic netting were installed on the dune; one fence was placed at the base of the blowout and the other fence was placed two-thirds of the way up the blowout (see Figure 3). Beach grass was also planted leeward of the lower fence in April 2012, but it had not yet firmly rooted by the time of this study in October-November 2012. In the fall of 2011, the Land Conservancy commissioned a study investigating the relationship between sand erosion and invasive species at Castle Park Reserve (Whalley *et al.* 2012). This study classified the dune as active (Whalley *et al.* 2012).

Figure 5: Straw bales placed on the dune in 2009 for surface stabilization remain present in 2012. Photo taken November 2012.

METHODS

Over a two-week time period in the fall of 2012, sand movement on the blowout surface was assessed using both erosion pins and Leatherman sand traps. On October 25, all erosion pins and sand traps were positioned on the dune face (Figure 6). Measurements on erosion pins were taken to serve as a baseline for surface level changes. On November 1 and November 8, heights of erosion pins were re-measured and deposited sand in the sand traps was collected. The collected data provides a record of sand movement for two individual one-week time periods. Throughout the study, visual observations and photographs were taken of the sand fences and sand transport activity.

Rates of erosion and deposition along the axis of the dune were measured at a transect of wooden erosion pins (Figure 6). Starting at the base of the dune, one erosion pin was placed along the dune axis every 5 meters until the crest of the dune was reached, using sixteen erosion pins in total. The lower sand fence crossed the transect between erosion pins 1 and 2; the upper sand fence did not physically cross the transect of erosion pins, but the extended line of the fence would have crossed after pin 10. The height of each erosion pin above the dune surface was

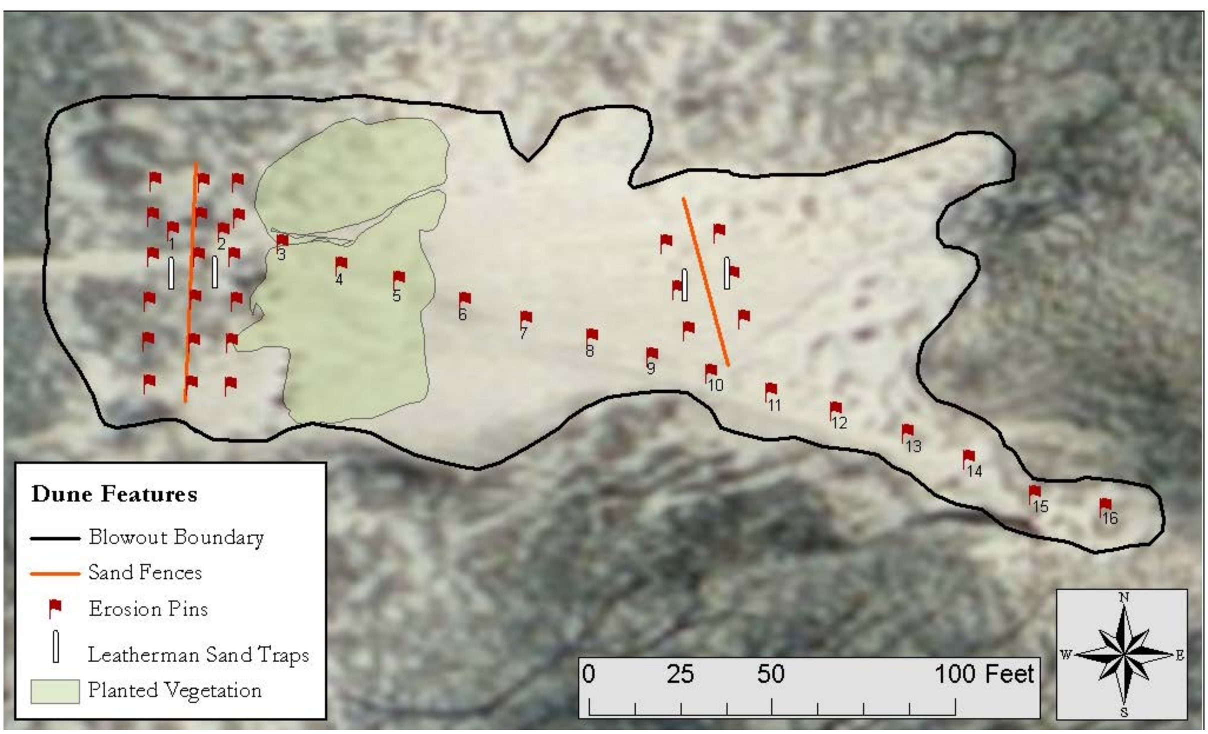

Figure 6: Experimental setup of erosion pins and sand traps on the blowout face. Erosion pins from the axis transect are numbered.

measured on the aforementioned dates. Changes in the height of the erosion pin exposed above the dune surface indicated whether erosion or deposition had occurred.

Rates of erosion and deposition in proximity to both sand fences were assessed using erosion pins arranged in a grid formation surrounding the sand fences (see Figure 6). Along the lower fence, 18 erosion pins were placed in a 3x6 grid with each erosion pin placed 5 meters apart. The first row of erosion pins was placed 5 meters upwind of the fence, the second row of erosion pins was placed directly downwind of the sand fence, and the third row of erosion pins was placed 5 meters downwind of the fence. Along the upper sand fence, six erosion pins were placed in a 2x3 grid with each erosion pin placed 5 meters apart; these erosion pins were placed equidistantly on each side of the sand fence. The heights of the erosion pins above the dune surface were measured on the aforementioned dates.

Rates of aeolian sand movement along the face of the dune were measured with Leatherman sand traps. At the center point of both fences, a sand trap was installed 2.5 meters upwind of the fence with another sand trap being installed 2.5 meters downwind of the sand fence (see Figure 6). The openings of the sand traps were oriented parallel to the sand fences in order to collect any sand that would pass through the sand fence. Sand collected in the traps was retrieved on the aforementioned dates. Collected samples were taken back to the lab to be dried and weighed. These measurements were quantitatively compared.

Wind data was obtained from F6 reports by the National Weather Service station in Muskegon, Michigan, which is located at the Muskegon County Airport approximately 5 km (3.2 miles) inland from Lake Michigan and 50 km (32 miles) north of Castle Park Reserve. Wind data were analyzed for daily average and daily maximum wind speeds for the duration of the 2012 study period. Wind data from 2011 was also analyzed to determine the comparability of wind conditions during the two study periods.

Collected data on the erosion pins were analyzed through visual interpretation of graphed surface level changes at each erosion pin for each week. When appropriate, quantitative comparisons were made. In instances where erosion pin measurements did not show either consistent erosion or deposition from week 1 to week 2, quantitative comparisons used the absolute value of surface change. Additionally, data on the axis erosion pins were graphically and quantitatively compared to a similar setup of axis erosion pins in the 2011 study. Data for

2011 was provided by Whalley *et al.* (2012). Although erosion pins from 2011 were placed similarly along the axis of the blowout, it should be noted that the pins were placed 10 meters apart and their GPS location on the dune was not recorded. The 2012 study attempted to recreate the same axis of the 2011 study, with erosion pins being placed 5 meters apart instead of 10 meters apart.

RESULTS

Measurements from erosion pins along the axis of the dune reveal patterns of sand movement on the blowout face, confirming that the dune is still active. Individual erosion pins experienced erosion and/or deposition depending on the week of the study and location of the erosion pin (Figure 7). In general, weekly changes in sand level were small, averaging 2.3cm/week (absolute value of change), although a weekly surface change as large as 8.3cm erosion at a midslope location was observed. There is a trend of greater erosion and deposition

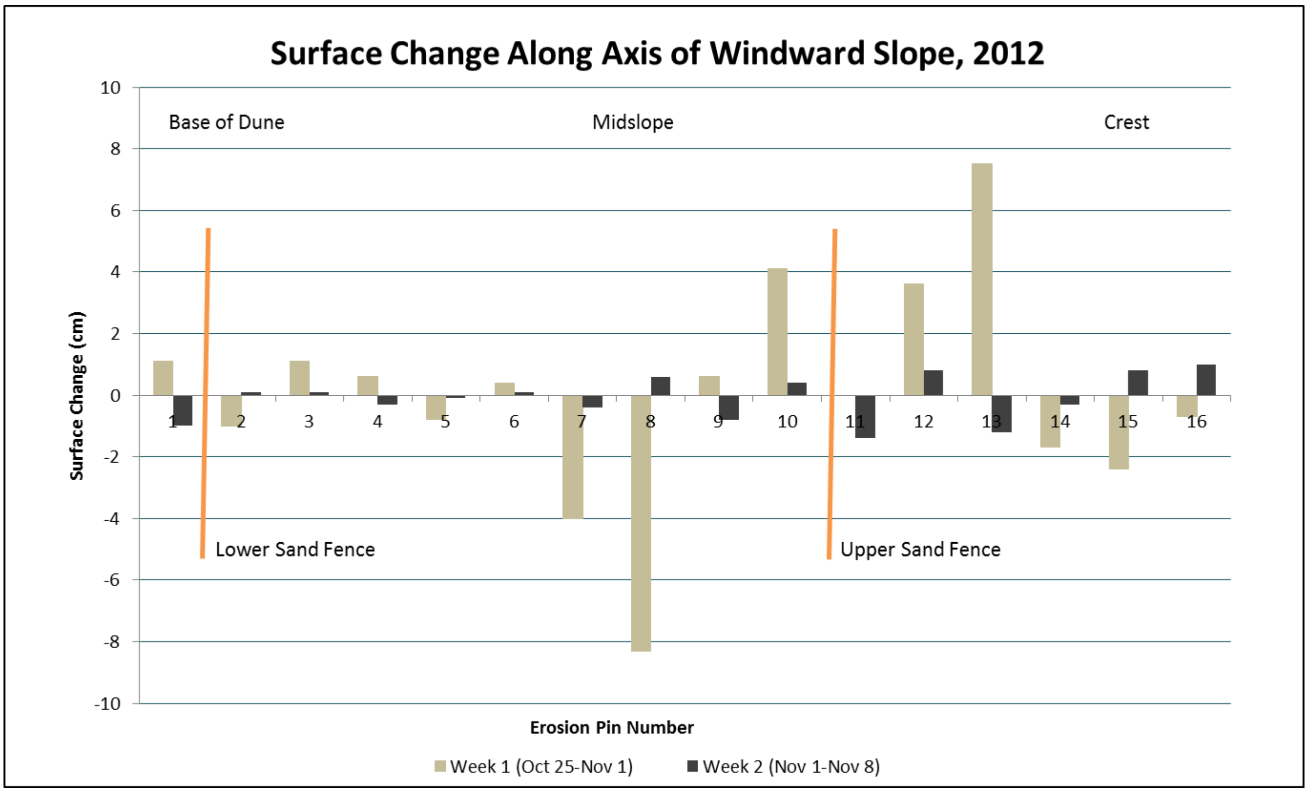

Figure 7: Weekly change in surface level at each erosion pin on the windward slope, October 25 to November 8, 2012.

activity toward the midslope of the dune. For the lower sand fence, there was no noticeable increased sand accretion immediately downwind of the sand fence; weekly absolute values of surface change directly behind this fence (0.95 cm/week) were comparable to surface changes in front of the fence (0.6 cm/week) and further behind the fence (0.73 cm/week). Conversely, there was a small but noticeable difference in surface change near the upper sand fence; weekly absolute values of surface change directly downwind of this fence (0.7 cm/week) were much lower than surface changes upwind of the fence (4.2 cm/week) and further downwind of the fence (3.7 cm/week).

The grids of erosion pins around the sand fences showed variable results for both upper and lower sand fences (Figures 8 and 9). Week 1 showed all rows of erosion pins experienced net erosion, but the ensuing Week 2 reversed this trend with 4 of 5 rows of erosion pins experiencing net deposition. The absolute value of weekly surface change was lower at the lower fence (0.41 cm) than at the upper fence (0.83 cm).

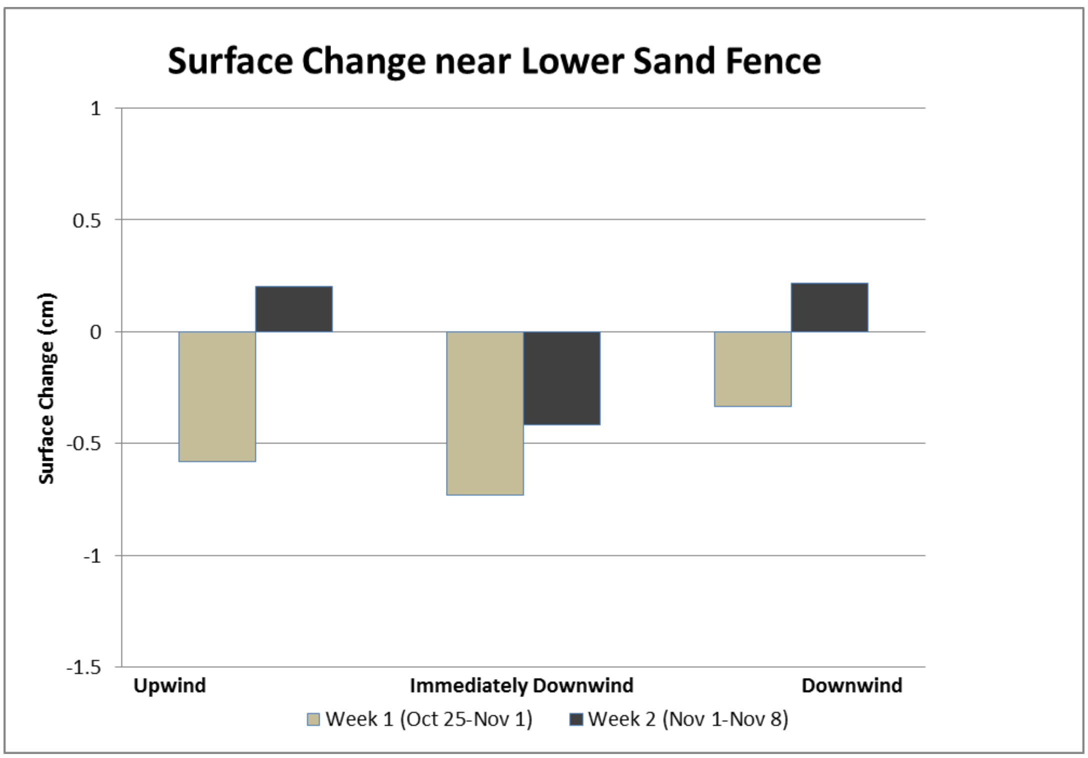

Figure 8: Weekly change in surface level for rows of erosion pins near the lower fence.

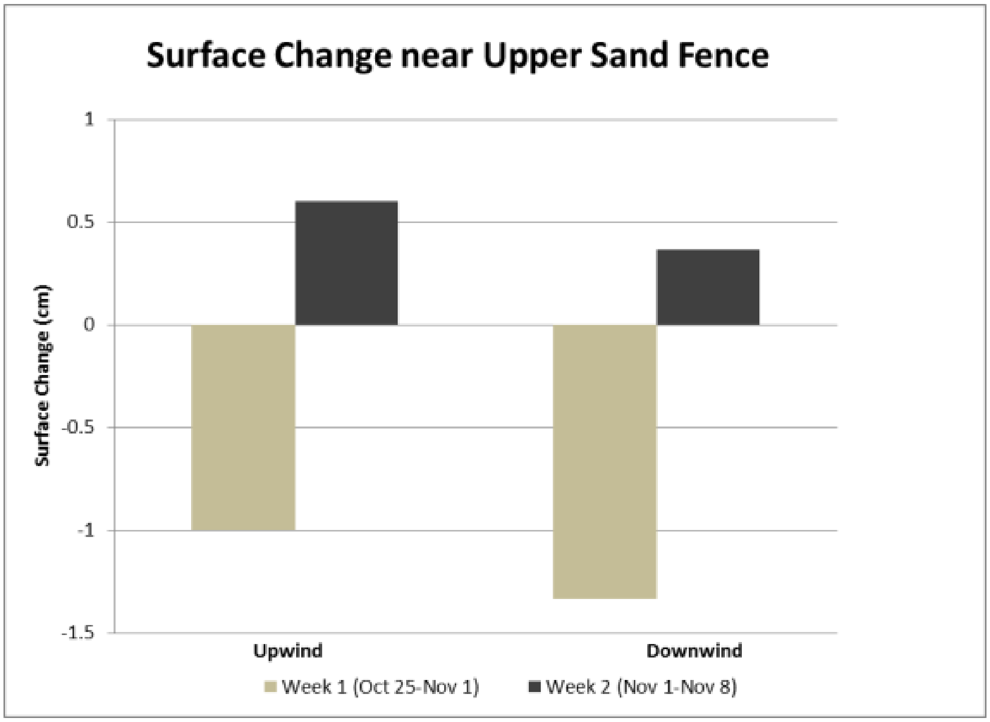

Figure 9: Weekly change in surface level for rows of erosion pins near the upper fence.

Sand transport amounts measured by Leatherman sand traps revealed that aeolian sand movement varied greatly with respect to both location of the fence on the dune and to the location of the sand trap in relation to the sand fence (Table 1). For both weeks, each trap windward of the sand fences collected a considerably greater amount of sand than their corresponding leeward trap. Additionally, the sand traps positioned along the upper sand fence collected a considerably greater amount of sand than the traps positioned along the lower sand fence. There was also a considerably greater amount of sand collected in all traps during Week 1 compared to Week 2.

Sand Movement (g/m-width per week)		
	Week 1	Week 2
Windward, Lower Fence	157.7	7.9
Leeward, Lower Fence	5.7	0
Windward, Upper Fence	21993.86	943.43
Leeward, Upper Fence	3085.14	32.57

Table 1: Rates of sand movement on windward slope by location and week.

Several relevant observations on the dune were noted during the study period. Primarily, the dune surface was steep (average angle of 27^o), which made deposited sand prone to mass wasting events. Sand that was deposited on the slope of the dune tended to slide down the dune face, unless the sand encountered a stable object embedded in the dune, such as a straw bale or Christmas tree (Figure 10). Furthermore, sand easily slid under the flexible plastic netting of the sand fences (Figure 11). Vegetation planted in April 2012 was still alive, yet not firmly rooted. Finally, the two sand fences, installed in April 2012, were already showing signs of deterioration. The ends of the fences were beginning to fall over and small rips were present in the fencing material itself (Figure 12).

Figure 10: Deposited sand on the blowout face tended to slide downslope, unless it encountered solid objects like straw bales or Christmas trees embedded in the dune. Photo taken April 2012.

Figure 11: Deposited sand easily slid under the flexible plastic netting of the sand fences. Photo taken November 2012.

b)

Figure 12: Although installed in April 2012, by November 2012 the sand fences already showed signs of deterioration. (a) lower sand fence (b) upper sand fence. Photos taken November 2012.

In comparison with the 2011 transect study, the rate of change in erosion and deposition of sediment has decreased (Figure 13; compare to Figure 7). Data from 2012 showed the average absolute value of weekly surface level change was 2.3cm, with 21 of 32 (65.6%) erosion pin measurements showing a change less than +/- 2cm. Comparatively, data from 2011 showed the average absolute value of weekly surface level change was greater at 3.0cm, with only 5 of 16 (31.3%) weekly erosion pin measurements showing a change less than +/- 2cm. Along the axis of the dune, surface level change showed similar spatial patterns to the 2011 study, with greater surface movement occurring at dune mid-slope. Surface level changes were smallest towards the base of the dune and towards the crest.

Analysis of 2012 wind data revealed that Castle Park Dune experienced a major storm event when the remnants of Hurricane Sandy passed over the location (Figures 14 and 15). This storm had daily wind speeds averaging 6.5 m/s with a daily average maximum speed of 11.6 m/s (maximum 14.8 m/s) from October 25 to October 31; daily average wind speed over the remainder of the 2012 study was 3.1 m/s with daily average maximum wind speed of 7.2 m/s (maximum 9.8 m/s) (National Weather Service 2013).

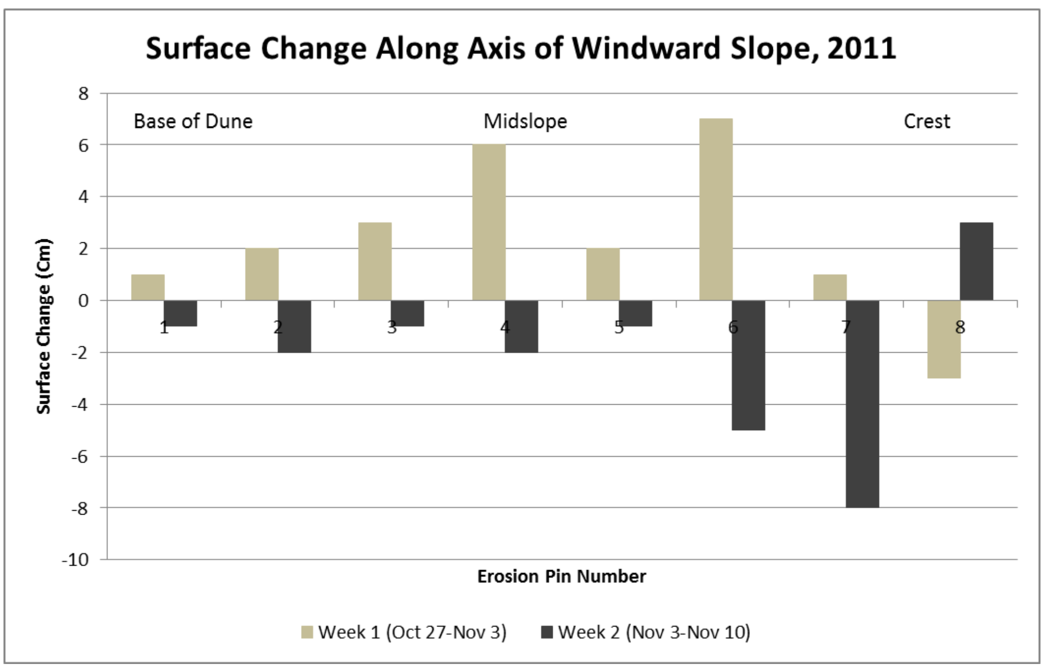

Figure 13: Weekly change in surface level at each erosion pin on the windward slope, October 27 to November 10, 2011. Data from Whalley *et al.* (2012).

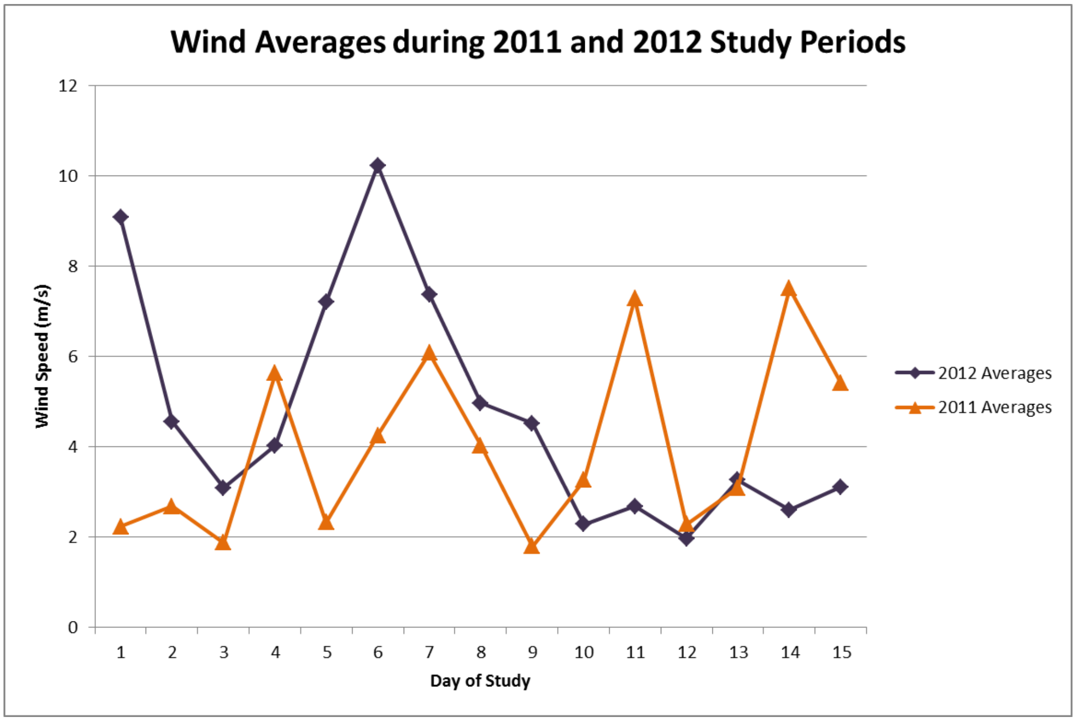

Figure 14: Comparison of daily average wind speeds for the 2011 and 2012 study periods. Data from the Muskegon, Michigan station (National Weather Service 2013).

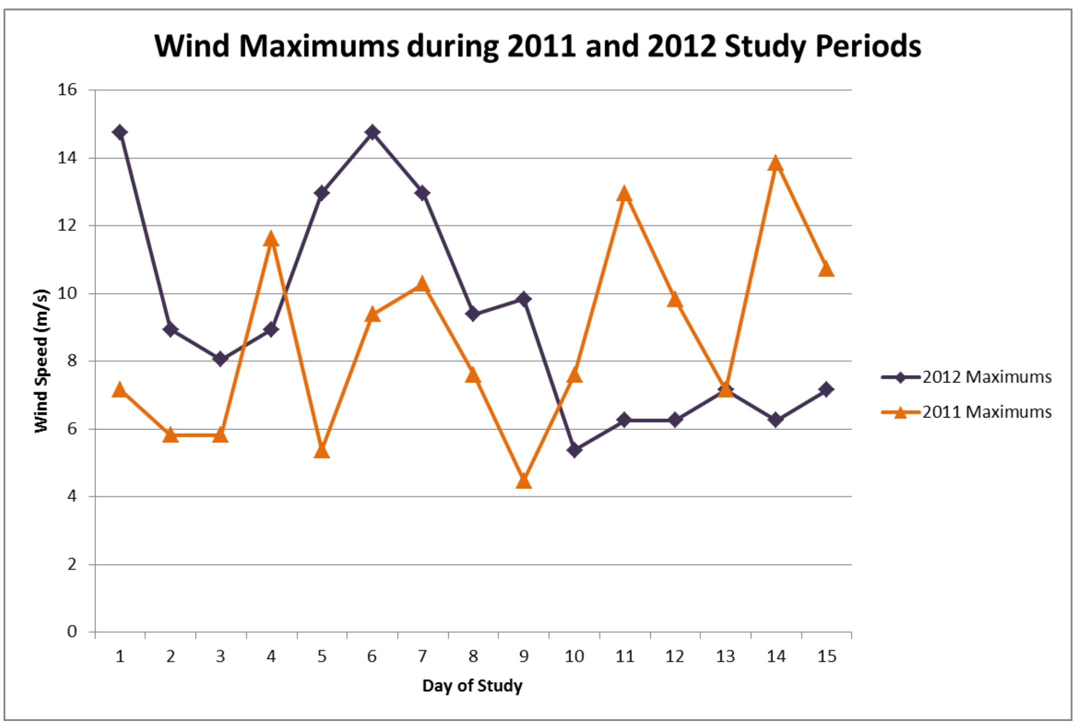

Figure 15: Comparison of daily maximum wind speeds for the 2011 and 2012 study periods. Data from the Muskegon, Michigan station (National Weather Service 2013).

Overall wind activity during the 2011 study was less than the 2012 study. Daily average wind speed was 4.0 m/s and daily average maximum wind speed was 8.6 m/s (maximum 13.8 m/s) from October 27 to November 10; however, there was a smaller storm event in 2011, with daily wind speeds averaging 5.1 m/s and daily average maximums of 10.9 m/s (maximum 13.8 m/s) from November 6 to November 10 (National Weather Service 2013).

DISCUSSION

Results of this study indicate that the sand fences installed on the Castle Park Dune are effective at reducing aeolian sand transport, but still appear to fall short of stabilizing the dune surface. In his seminal work on Lake Michigan dune development, JS Olson (1958) recognized that surface obstacles, such as topography and vegetation, greatly increase the surface roughness of a dune, consequently disrupting the intensity of the windflow that contributes to dune erosion. Such disruption of windflow is great enough to make the difference between an active or stable dune (Olson 1958). On the Castle Park Dune, the installed sand fences are serving as a source of surface roughness on an otherwise smooth blowout face. Thus, after wind with air-borne sand passes through each sand fence, the intensity of the wind is reduced, and the wind deposits some of its sediment. However, the blowout appears also to be funneling winds and increasing surface erosion towards the crest of the dune (Byrne 1997). Hence, by the time the wind reaches the upper sand fence, it has already picked up more sediment than was carried in the wind passing through the lower fence. Consequently, the sand fences on Castle Park Dune appear to have a limited effect in stabilizing the blowout.

Overall, the reduction in the rate of surface level change from 2011 to 2012 indicates that the sand fences have had a positive impact in reducing the severity of dune surface movement; this occurred despite greater wind activity in 2012. However, the windward face still appears to be active. Management efforts over the previous year have reduced the severity of erosion and deposition on the dune face, thus significantly contributing to the process of dune restoration. With continued management efforts and the growth of the dune grass planted in spring 2012, the dune surface appears to be headed towards stabilization.

However, at the leeward side of the sand fences, where sand is expected to accrete (Hotta *et al.* 1987), the results do not conclusively demonstrate a trend of either erosion or deposition.

The upper sand fence, being on a steeper slope with less wind obstacles, experienced greater rates of surface level changes overall than the lower fence. The lower fence, which lies in close proximity to vegetation, experienced lower rates of erosion overall. Furthermore, the lower sand fence is on a much less steep slope (21^{o}) than the upper fence (30^{o}), which decreases the likelihood of mass wasting of sand once it has been deposited from the air. From observations during the course of the study, sand that is deposited has the tendency to slide down the steep dune slope, especially at the upper fence. This tendency, alongside the greater movement of wind-borne sand past the upper fence, likely explains why the upper sand fence experiences greater variation in weekly surface level changes.

Given the collected data and observations in the field, the Land Conservancy of West Michigan should reanalyze its management resources and priorities on the Castle Park Dune. The sand fences are reducing aeolian sand transport effectively, but these sand fences fail to maintain accumulations of sand after it is deposited. From the observation that deposited sand slides downslope unless it is stopped by a stable obstacle, we suggest that the Land Conservancy invest in methods that capture deposited sand on the slopes. For example, the Land Conservancy could invest in sturdier wooden sand fences that would stop the downward movement of sand with greater efficacy than the current plastic mesh fences. Alternately, the Land Conservancy could scatter additional Christmas trees or straw bales on the dune surface to stabilize sliding sand.

Additionally, given that management efforts are proving more effective on the lower slope of the blowout, the Land Conservancy should focus management efforts at that location. At the base of the dune, the surface is stable enough to allow vegetation to regenerate; towards the midslope and crest of the blowout, the dune surface is yet too unstable for managers to invest reliably in vegetative plantings. Furthermore, given that the upper sand fence is not actively accreting sand, it may be best to use fence resources lower on the dune slope where sand accretion is possible. Overall, at this point in time the upper surface of the Castle Park dune appears too unstable to achieve success in stabilization. Management efforts should start by stabilizing the base of the dune, and then moving efforts towards the crest. Because the process of dune restoration requires a long time period, early restoration efforts should concentrate on the most achievable restoration goals.

However, regardless of their actual efficacy at causing sand accretion, the presence of sand fences has the benefit of reducing human traffic on the dune (Grafals-Soto and Nordstrom 2009). Although the Castle Park dune is not heavily used as a recreational area, human foot traffic can cause significant mass wasting on the steep dune face and create a hindrance at restoration efforts. Additionally, continual human traffic adversely affects the recovery and integrity of stabilizing dune vegetation (Boorman and Fuller 1977). Thus, the presence of sand fences alone demonstrates to the public that the dune managers are intentional about dune restoration efforts, and this will likely hasten dune restoration.

CONCLUSIONS

The installation of sand fences on the active blowout of the Castle Park Dune is effectively reducing aeolian sand activity, but is less effectively causing sand accretion and surface stabilization. Compared with the 2011 study of dune movement before the sand fences were installed, changes in rates of erosion and deposition on the dune surface have been reduced, but the dune has still not been stabilized. The Land Conservancy should thus focus their management resources on the lower slope of the blowout, which shows greater potential for restoration. Overall, the process of restoration of the Castle Park dune will be a long-term commitment for all parties involved.

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