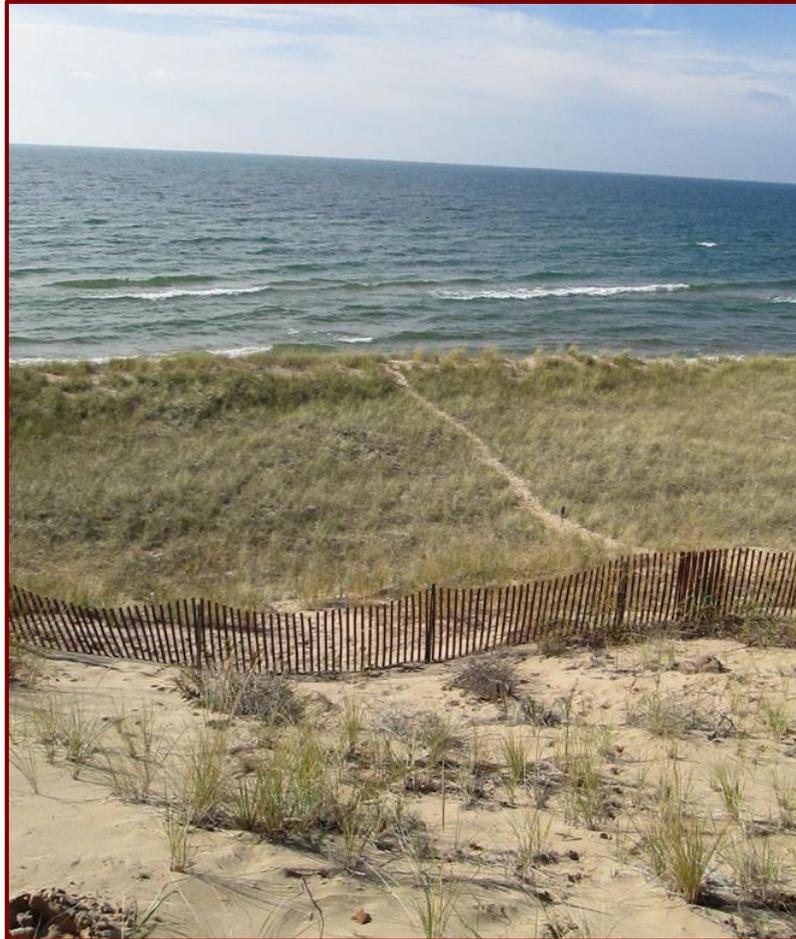


# First-Year Research in Earth Sciences: Dunes



## **Efficacy of Planted Vegetation and a Sand Fence at Castle Park Dune Preserve**

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## ABSTRACT

Lake Michigan coastal dunes are dynamic environments often requiring management strategies to mitigate human impacts. This study investigates the efficacy of a sand fence and planted vegetation as management techniques at Castle Park Dune Preserve in Michigan. The vegetation and sand fence were established on the windward slope of the dune between 2012 and 2014. During the fall of 2014, we documented dune features by measuring slope angles and using GPS to map boundaries between bare sand and vegetation. We set up and monitored erosion pins upwind and downwind of three areas of planted vegetation to gauge sand deposition. We also measured vegetation characteristics in five randomly-selected quadrats within each of the three planted areas. Results show that although *Ammophila breviligulata* was the species introduced initially, one or two additional species were present in all of the planted areas. The greatest rate of aeolian movement occurs upwind of the fence and in unvegetated regions downwind of the fence. Vegetated areas experienced less transport, with areas of greater average density and number of stems experiencing the least movement. This suggests that increasing vegetation density, coupled with the current sand fence, would be most effective for stabilizing the surface.

## INTRODUCTION

Dune management strategies are used worldwide to protect and stabilize vital landscapes and ecosystems. While certain practices, such as boardwalk establishment, sand fence placement, and vegetation planting have become commonplace in a variety of geographic locations, little research has investigated management practices in Lake Michigan coastal dune systems. Additionally, few studies have evaluated how to best implement management strategies on steep coastal dunes. Our study was conducted on Lake Michigan's eastern shore across Castle Park Dune Preserve's steep dune blowout south of Holland, MI. The focus was to evaluate the efficacy of sand fence placement and vegetation planting of this Lake Michigan ecosystem.

Our objectives were to (1) document locations and characteristics of planted vegetation areas and sand fences, (2) evaluate dune topography and slope steepness, (3) measure sand movement in respect to vegetation and fences, and (4) assess the relationships between sand transport and currently implemented management strategies.

## BACKGROUND

Blowouts and bare surfaces on dunes occur when wind erodes exposed surfaces of sand. Taking various shapes and sizes, blowouts typically result from disturbances such as wave erosion, topographic acceleration of wind over the dune surface, climate change, vegetation variation, or human activities (Hesp 2002). Blowouts may cause large movements of sand, and anthropogenic blowouts may degrade dune landscapes. As dunes are some of the most fragile natural systems (Bowles and Maun 1982), learning how to manage blowouts is necessary for preservation efforts.

Sand fences have long been used as a management strategy to slow down aeolian movement of sand and stabilize coastal dune environments. Typically cost-efficient and easy to implement, sand fences serve as physical barriers which interrupt wind flow across a dune surface (Nordstrom *et al.* 2000). Due to this disruption, sand accumulates immediately downwind of the fence instead of moving across the face of the dune (Anthony *et al.* 2006). This stabilization strategy has been utilized and studied across a full range of geographic locations with varying levels of success (Grafals-Soto and Nordstrom 2009; Gómez-Pina *et al.* 2002; Miller *et al.* 2001; Zhang *et al.* 2003).

Fences used for dune management can be constructed of various materials. Most commonly, however, they are built from vertical wood bars, plastic netting, or biodegradable fabric (Bleeker *et al.* 2013). Sand fences can also be established in various patterns, both laterally across the dune as well as perpendicularly and diagonally (Figure 1). A 2001 study focusing on rapid accumulation following a hurricane overwash in the Gulf of Mexico concluded that wooden fences arranged in a lateral pattern were most successful at stopping sand movement and stabilizing bare dunes (Miller *et al.* 2001). However, all fences studied, regardless of composition or pattern, were found to be effective in this vulnerable environment (Miller *et al.* 2001).

In addition to sand fences, revegetation techniques with native beach grass have been utilized by dune managers. Worldwide, this combination has been put into place and studied with

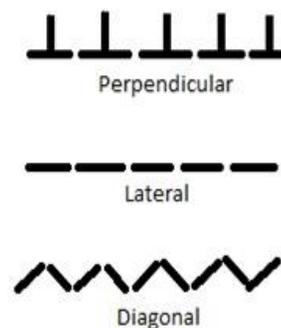


Figure 1: Depiction of various fence establishment patterns (Adapted from Miller *et al.* 2001).

adequate results in Denmark, the Netherlands, Italy, France, and Spain (Gallego-Fernandez *et al.* 2011). When planted in a dune surface, vegetation causes wind to decelerate near the surface. Sand is then deposited within vegetated areas (Sarre 1989).

The species most often used for re-vegetation efforts belong to the *Ammophila* family, as this beach grass is dynamic, fast-growing, well-adapted to large amounts of sand transport, and a capable sand binder (Hertling and Lubke 1999). Thus, *Ammophila* is often planted first as an early colonizer to slow sand movement and stabilize the surface in order for other, more vulnerable plants to move into the ecosystem successionaly. In the Great Lakes ecosystem, the native *Ammophila breviligulata* (American beach grass) is typically used to begin colonization and succession. Vegetation restoration can then lead to greater plant diversity, and with time, degraded dune landscapes can become more and more like existing plant communities.

In order to encourage this process, however, studies have shown that only a small amount of planted vegetation is actually necessary (Buckley 1987). A study on the dunes of South Padre Island, Texas found that dune erosion was no greater in areas with 12.5% cover than areas with 57% cover (Judd *et al.* 2008). For dune managers, the implications of these findings suggest that vegetation cover of only 12-17% over sand surfaces is necessary to significantly reduce sand transport and stabilize the dune blowout (Judd *et al.* 2008).

## STUDY AREA

The study site is located in Castle Park Dune Preserve located on the eastern shore of Lake Michigan south of the city of Holland (Figure 2). The land is part of an approximately 0.02 km<sup>2</sup> plot owned and managed by the Land Conservancy of West Michigan since 2003. The exact history of the dune's use and human interaction prior to ownership by this organization is unknown, although logging and some human disturbance are suspected (Manion 2010).

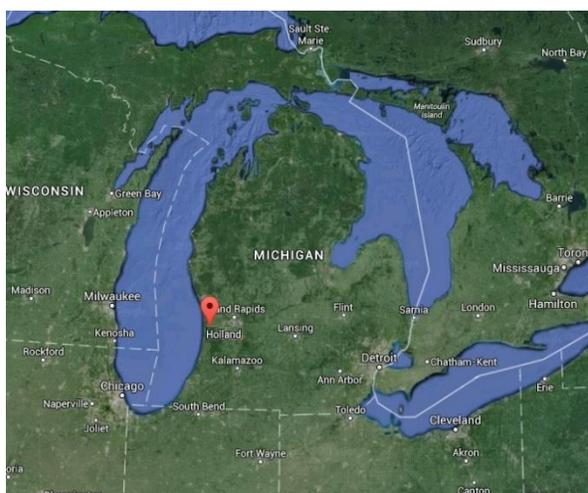
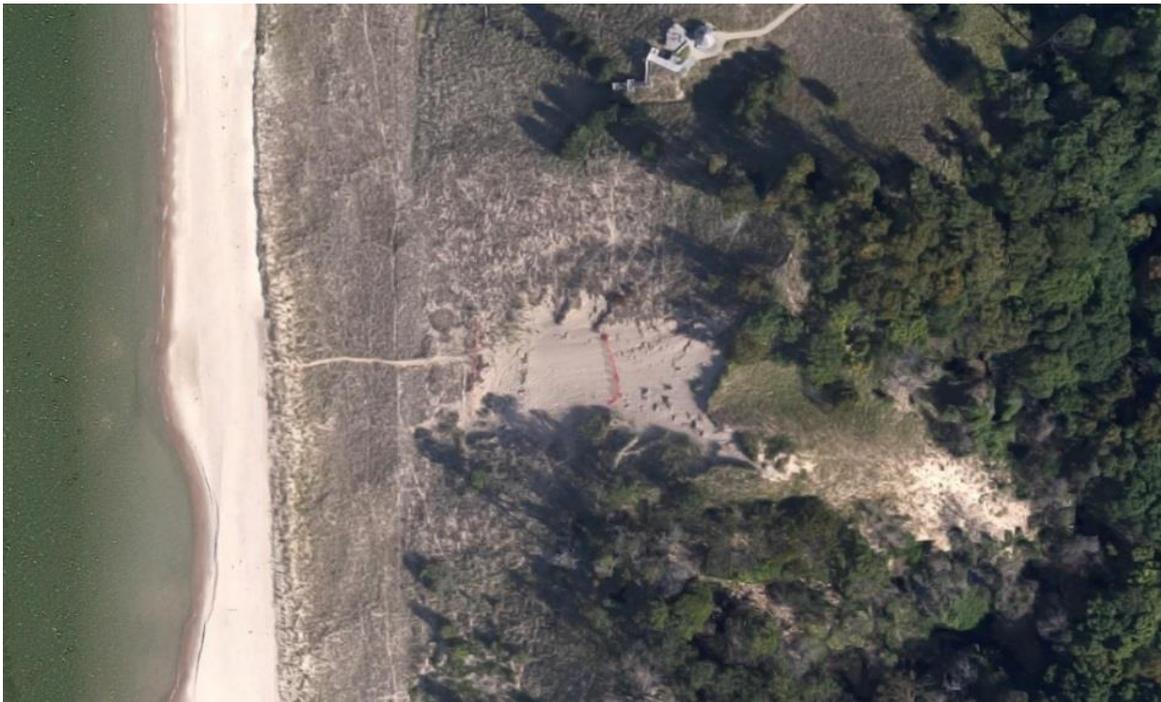


Figure 2: Location of Castle Park Dune Preserve in western Michigan, south of the city of Holland. Source: Google Earth Imagery 2015.

The dune is an approximately 50-meter high blowout of irregular and asymmetrical shape (Bleeker *et al.* 2013). It features a steep slope and a unique two-pronged crest created by suspected human disturbance (Figure 3). The slip face of the dune is heavily forested and features populations of *Celastrus orbiculatus* (Oriental Bittersweet), which is an invasive species on West Michigan coastal dunes (Whalley *et al.* 2012). Surrounding the blowout to both the north and the south are other vegetated dunes with some residential property. To the east of the blowout are forested dunes featuring species indicating a late stage in ecological succession.



*Figure 3:* Aerial image of Castle Park Dune Preserve blowout showing irregular shape of the dune.  
Source: Google Maps Imagery 2013.

Since the land was acquired by the Land Conservancy, various management strategies have been attempted to stabilize the exposed dune surface (Figure 4). Straw bales and Christmas trees were scattered across the blowout surface in 2009 with hopes of trapping sand. In April 2012, two orange plastic fences were placed on the windward face of the dune. One was established at the base of the blowout, while the other was placed midway up the dune face. Additionally, *A. breviligulata* samples were transplanted from the foredune in April and December of 2012. They were planted downwind and upwind of the first sand fence. A study in 2013 found the orange plastic fences to be largely ineffective and recommended additional

plantings and continued management efforts (Bleeker *et al.* 2013). Thus, in the spring of 2013, the Land Conservancy removed both orange plastic fences and placed a wooden, laterally shaped fence at the base of the dune. Additionally, more than 1000 *A. breviligulata* plugs were planted around the edges of the face to continue re-vegetation efforts.

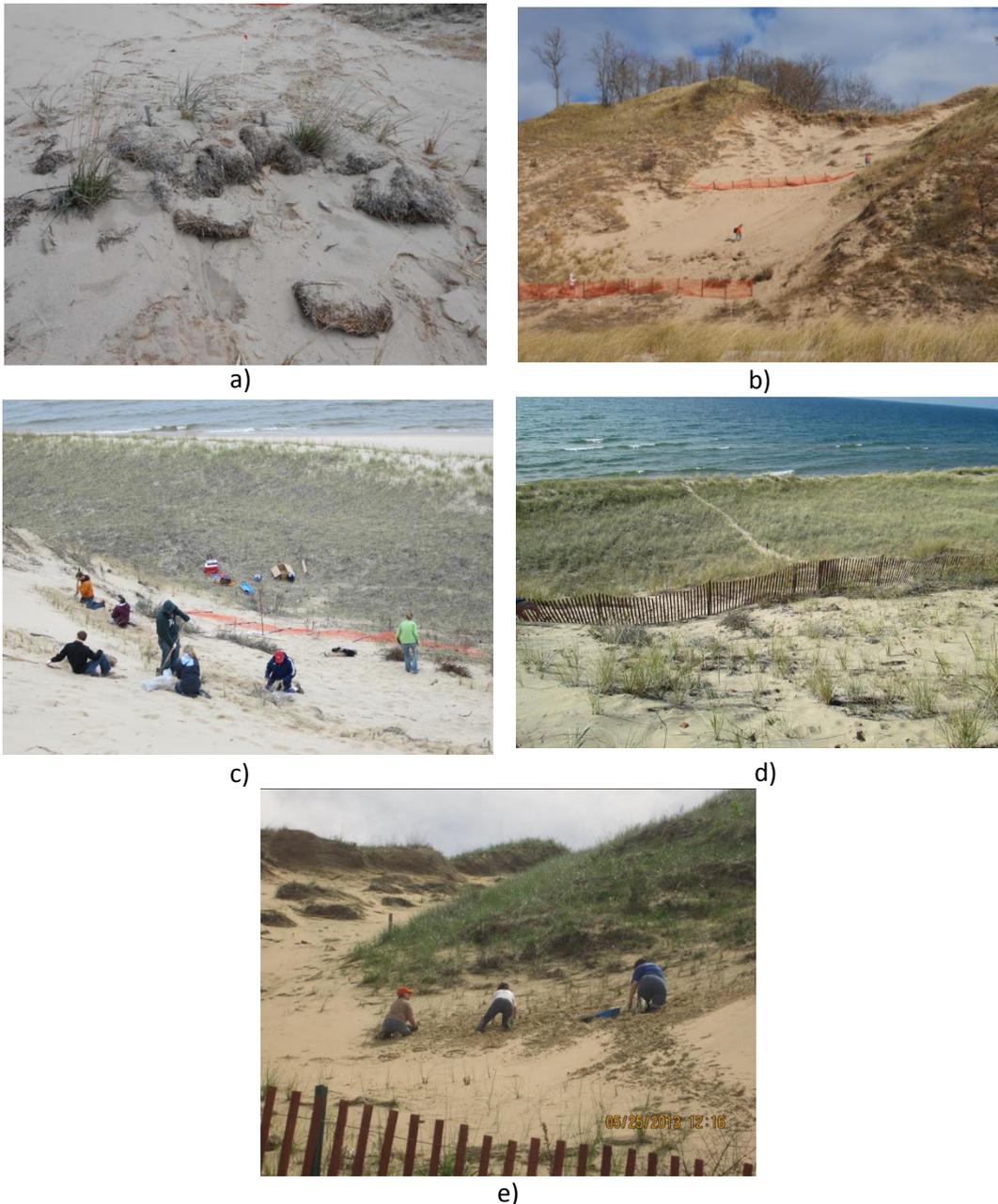


Figure 4: Historical management strategies include a) straw bales on dunes (Photo from Bleeker *et al.* 2013); b) orange plastic fences (Photo from Bleeker *et al.* 2013); c) *A. breviligulata* transplants (Photo from Land Conservancy of West Michigan 2012); d) wooden sand fence (Photo taken in October 2014); and e) *A. breviligulata* plug plantings (Photo from Land Conservancy of West Michigan 2012).

## **METHODS**

Data was collected between October 23 and November 6, 2014 through a variety of methods to investigate surface characteristics and vegetation traits within the study area.

### *Dune Characteristics*

Beginning at the lakeward base of the dune, we installed 21 reference pins to create a straight line running east-west up the windward slope of the dune. On October 23, the team used a stadia rod and hand level to measure elevation at each point. Distance and elevation changes between the markers were recorded. Using the Pythagorean Theorem, we calculated the horizontal distance based on collected slope and vertical distance data. Cumulative horizontal distance and elevation changes were graphed to create a cross-section profile of the dune's slope.

The team used two Juno Trimble GPS units to record locations of the sand fence, erosion pins, vegetation areas, and overall study area. Maps were created using ArcGIS software to help assess study site. Additionally, digital photographs were taken of the study site and methods used to enhance research project and provide reference.

### *Wind Speed*

Wind data was obtained from local climatological data collected by the National Weather Service at the Holland/Tulip City station. Daily average wind speeds were analyzed for relationships between wind and sand movement during the study period.

### *Surface Change*

We measured rates of erosion and deposition in the study site from three erosion pin transects running east-west (Figure 5). On October 23, starting upwind of the fence, the team placed 39 wooden pins at two meter intervals up the face of the dune. The center transect line had a total of 19 erosion pins, with 6 located upwind of the sand fence and 13 located downwind. Both the northern and southern transect lines had a total of 10 pins, with 3 located upwind of the fence and 7 located downwind. On the week of October 30, a smaller, fourth transect with 3 erosion pins at two meter intervals was established on the southern arm of the dune. A total of 42 erosion pins were used at the site.

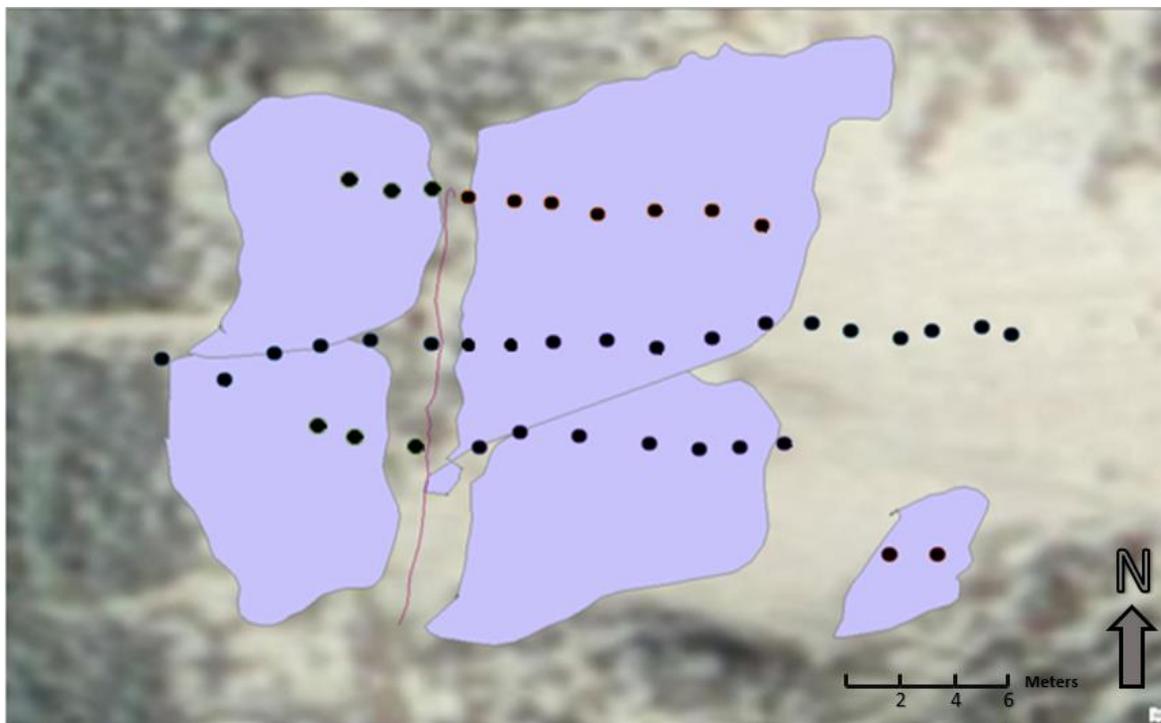


Figure 5: Study site depicted with black erosion pins, red sand fence, and purple vegetated areas at Castle Park Dune Preserve.

The team recorded the initial heights of the pins from the dune surface immediately after installation and in each subsequent week during the study period. The difference in pin height from one measurement to the next provide a measure of the surface change – either erosion or deposition – at that location.

Averages of erosion and deposition at each pin were found. Additionally, we divided the erosion pins into categories based on proximity to the sand fences (pre-fence, post-fence, and away from fence) as well as vegetation (planted and bare). Based on these categories, the team calculated the absolute value of the changes in erosion pin height to determine the range of surface change. Data was analyzed to understand the relationship between accumulation and deposition amounts and management strategies.

### *Vegetation Characteristics*

Using observed vegetation patterns, we established three grids across the dune surface in areas of varying vegetation density (Figure 6). On the week of October 30, two grids of 6 x 8

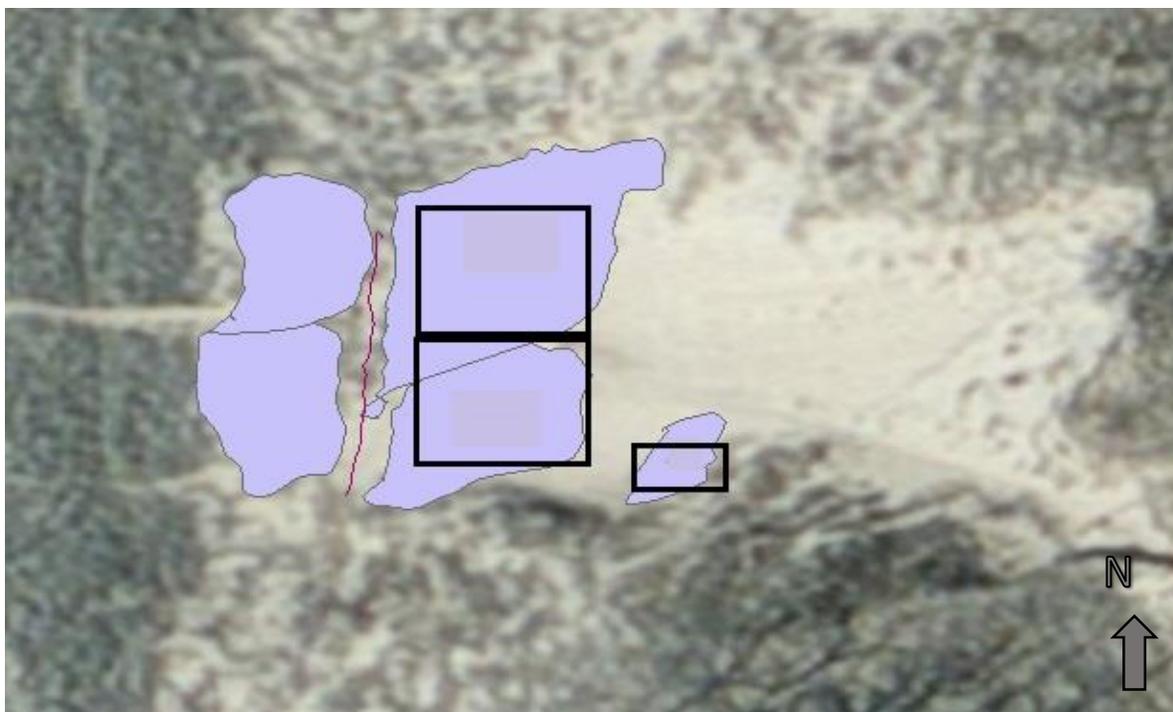


Figure 6: Approximate vegetation grid locations (top-to-bottom: north, south, hill)

two-meter squares divided by the center transect line were established immediately upwind of the sand fence. The north grid and south grid featured medium and light vegetation density, respectively. The third 2 x 4 two-meter square grid was created on the southern arm of the dune upon a steep hill with light vegetation. Each square was assigned a number, and the team used a random number generator to select locations to survey. In the north and south grids, 11 squares were selected. In the hill grid, 3 squares were selected (Figure 7).

1	9	17	25	33	41
2	10	18	26	34	42
3	11	19	27	35	43
4	12	20	28	36	44
5	13	21	29	37	45
6	14	22	30	38	46
7	15	23	31	39	47
8	16	24	32	40	48

49	57	65	73	81	89
50	58	66	74	82	90
51	59	67	75	83	91
52	60	68	76	84	92
53	61	69	77	85	93
54	62	70	78	86	94
55	63	71	79	87	95
56	64	72	80	88	96

1	3	5	7
2	4	6	8

Figure 7: Diagram depicting vegetation grids established on the windward dune slope (from left to right: north, south, hill). Yellow highlighting indicates grid location randomly selected by number generator and sampled by team.

In each selected square, the team threw a half-meter-square wooden quadrat to identify a survey area. We then measured the slope angle, number of stems, species, average ground cover percentage, average plant height, average leaf length, and inflorescence length in the quadrat.

Averages were found for each grid to identify patterns in vegetation characteristics between northern, southern, and hill grids. These categories provided insight to vegetation variation based on planting date and location. Furthermore, significant averages were compared to surface change measurements to identify which vegetation grids led to successful sand movement reduction.

## RESULTS

### *Dune Characteristics*

The windward slope of the Castle Park dune is mostly bare sand with vegetation along the edges, dune crest, and lower windward slope. Plotted points reveal a relatively constant upward rise of the dune face. The average slope of the dune was 1.2 vertical meters per horizontal meter, with the steepest portions farther downwind and the least steep portions upwind (Figure 8). The total measured dune height was approximately 40 meters from base to crest.

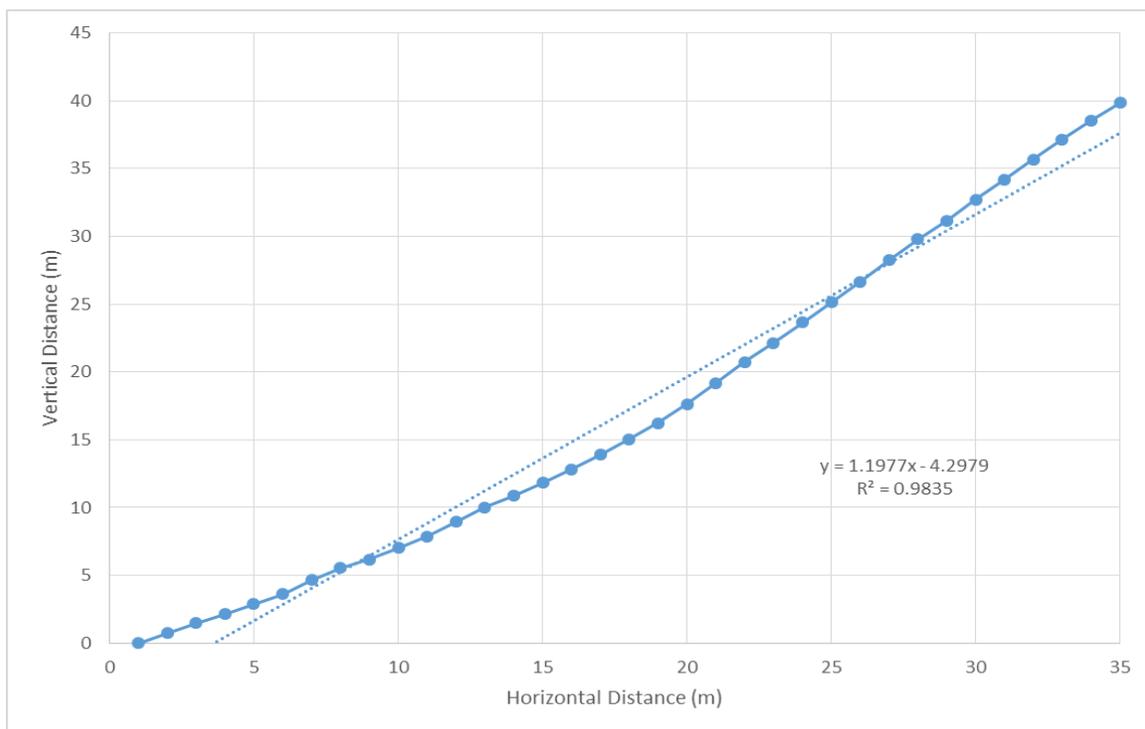


Figure 8: Profile of the windward slope at Castle Park Dune Preserve, Holland, MI.

### Wind Speed

The average wind speed throughout the study period was 4.35 meters per second. Gusts ranged from 5.81 meters per second to 15.64 meters per second (Figure 9). An average wind speed of 3.95 meters per second occurred during the first week of the study, while an average wind speed of 4.82 occurred during the second week of the study. Winds mostly blew from southwest (Figure 10).

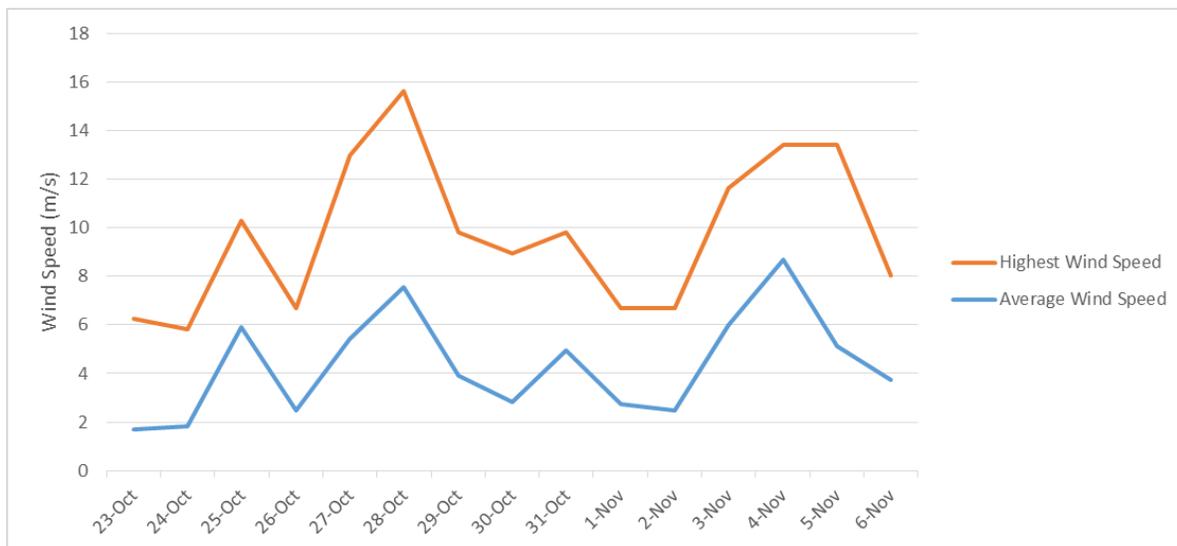


Figure 9: Comparison of daily average and maximum wind speeds in Holland during the study period. Data collected from the National Climatic Data Center in 2015.

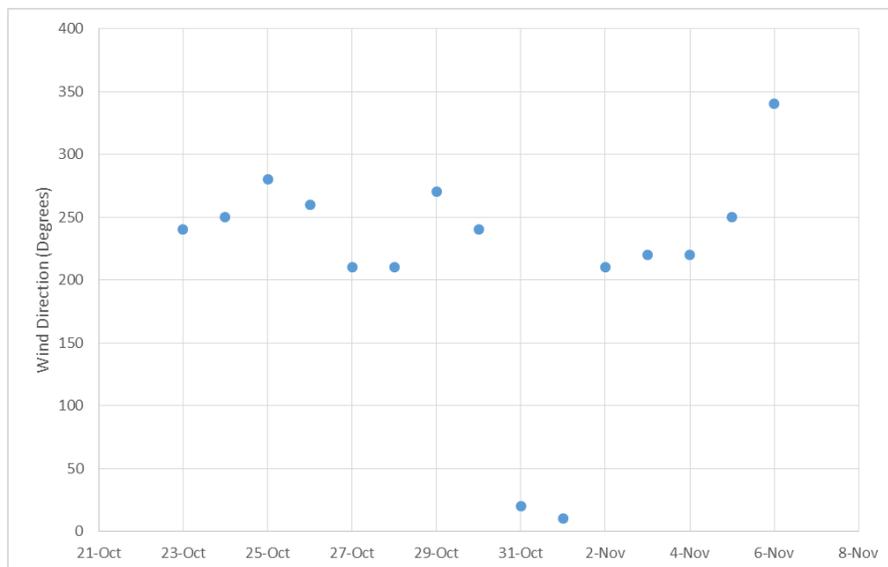


Figure 10: Average daily wind direction in degrees in Holland during the study period. Data collected from the National Climatic Data Center in 2015.

## Surface Change

The amounts of average surface change varied across the erosion pin transects during the duration of the study (Figure 11).

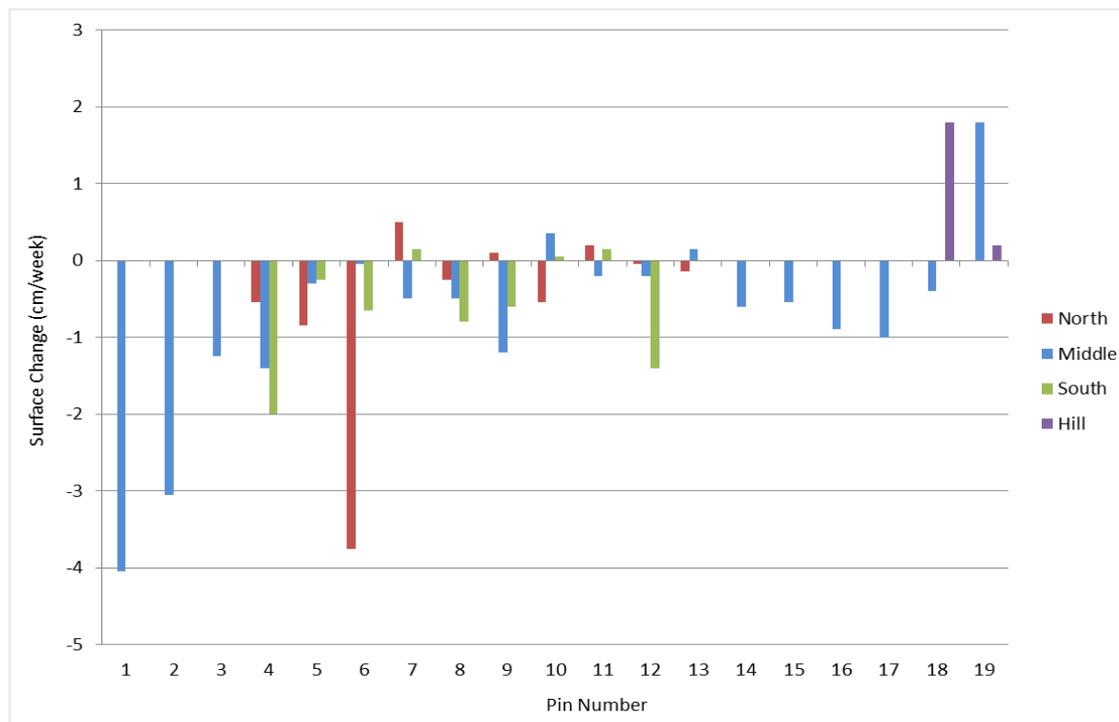


Figure 11: Average erosion and deposition measured from October 30 to November 6, 2014 over four transects at Castle Park Dune Preserve, Holland, MI. Sand fence is located after Pin 6.

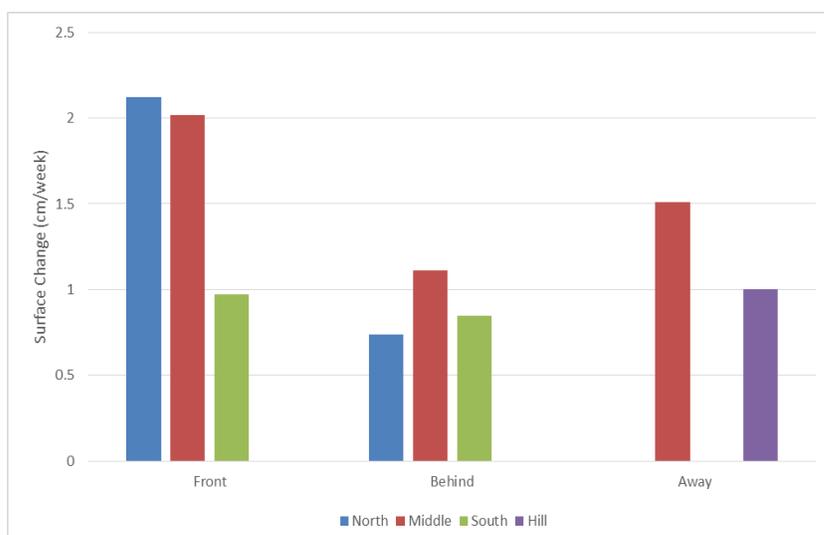
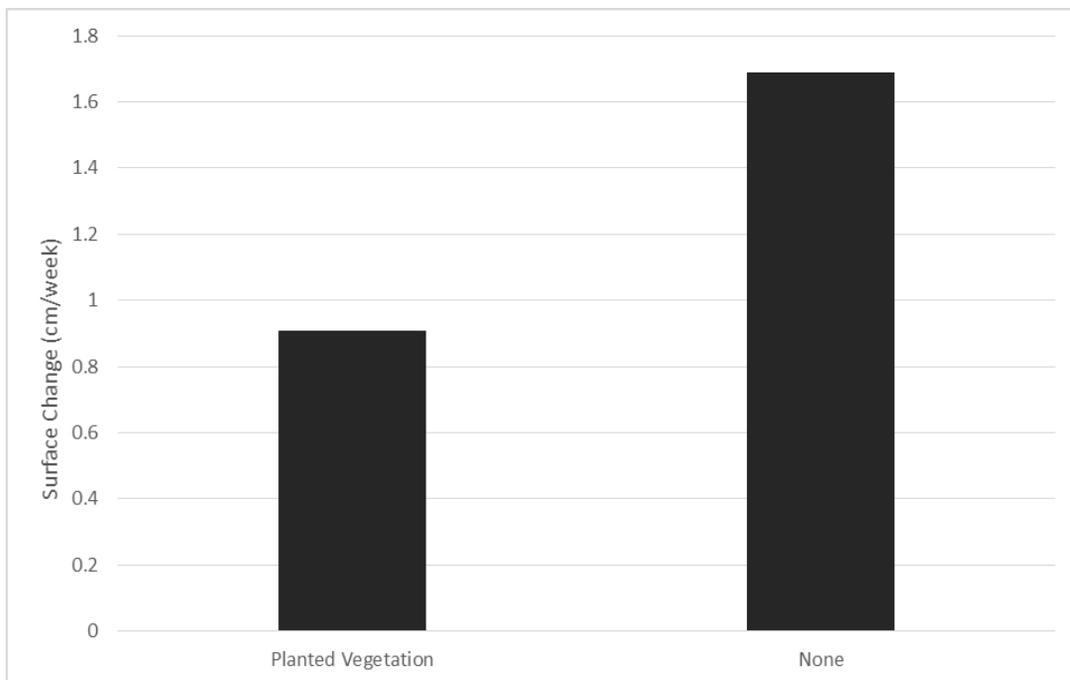


Figure 12: Average surface change (absolute value) based on proximity to sand fence during a two-week study period in Castle Park Dune Preserve, Holland, MI.

An average surface change of 1.2 cm/week (absolute value of change) was recorded across the dune surface, but notable differences were observed between pins located upwind, or in front, of and downwind, or immediately behind, of the sand fence (Figure 12). Upwind, or in front,

of the fence, an average of 1.7 cm/week of surface change was recorded, although up to 7 cm of erosion was observed during the study period. Immediately downwind of, or behind, the fence, surface change was reduced to an average of 0.9 cm/week with no weekly change observed greater than 2 cm. Increased sand accretion was recorded across the erosion pin lines immediately downwind of the fence for up to 14 meters. However, as distance from the sand fence increased, a correlation was observed between decreasing deposition and increasing surface change amounts.

Areas of planted vegetation recorded significantly lower transport rates than those without planted vegetation ( $p=0.004$ ). An average sand transport of 0.91 cm/week was recorded in areas with planted vegetation, while an average sand transport of 1.6 cm/week was recorded in areas without (Figure 13). This included all four transect lines, regardless of when the planting occurred.



*Figure 13:* Average surface change (absolute value) based on pin location in vegetation. Data was collected over a two-week study period in Castle Park Dune Preserve, Holland, MI. Means are significant at  $\alpha=0.05$ .

### Vegetation Characteristics

*Ammophila breviligulata* was the dominant species in all of the study sites. Average height of *A. breviligulata* across the dune was found to be 55.2 cm. Average leaf length was recorded across the dune as 43.2 cm. Average number of stems was found to be 6.2 stems per quadrat. Additionally, the average percentage of covering was found to be about 30% and the average slope across the dune was 24.7 degrees.

The characteristics of the *A. breviligulata* population displayed significant differences between stalk number, percentage cover, and slope within three vegetation areas (Figure 14). The number of stalks found within a quadrat was significantly higher in the north grid than in the hill grid ( $p=0.001$ ). The percentage cover of vegetation over the sand was significantly higher in the north grid than either the south or hill grids ( $p=0.005$  and  $p=0.0001$ ). Additionally, the slope of the quadrats was significantly higher in the hill grid than the north or south ( $p=0.0004$  and  $p=0.0003$ ). There were no significant differences, however, found in height or leaf length of *A. breviligulata* in any of the three grid systems.

In addition to *A. breviligulata*, *Calimovilfa longifolia* and *Artemisia campestris* were found within randomly sampled quadrats. During planting management at the park, *A. breviligulata* was the only species used for re-vegetation, and all sites were bare before the plantings.

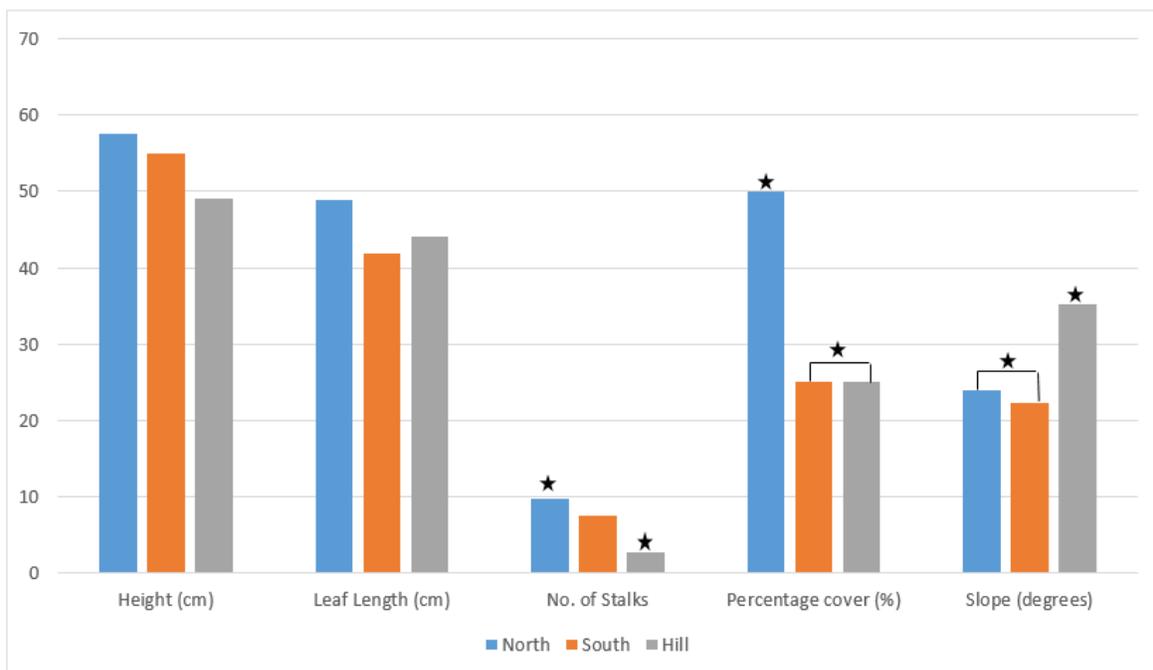


Figure 14: Average *A. breviligulata* characteristics observed on Castle Park Dune, Holland, MI. Stars indicate statistical significance at  $\alpha=0.05$ .

## DISCUSSION

Results of this study suggest that both the sand fence and the planted vegetation are successfully reducing sand transport and are beginning to stabilize the steep dune surface at Castle Park. Erosion pin locations established upwind of the sand fence experienced much greater average rates of surface change over the study period than of those located downwind. Erosion and deposition data collected during a study on Castle Park in 2012 reported two to three times as much surface change at similar locations under similar wind conditions (Bleeker *et al.* 2013). This suggests that recent management efforts are successful at slowing down sand transport and erosion across the dune. Additionally, areas of planted vegetation were significantly correlated with decreased surface change. Pins located across all four of the transects followed this pattern, suggesting that the presence of all planted vegetation is helpful, and effective at Castle Park, for decreasing rates of erosion and deposition.

Furthermore, the appearance of some positive average surface change values immediately downwind of the fence in medium-density vegetated areas suggest that accretion is happening in small increments due to both the sand fence and the planted vegetation. This is consistent with trends and expectations of successful management efforts (Anthony *et al.* 2006; Hotta *et al.* 1987).

The measured vegetation characteristics reveal no significant patterns which can be correlated with significant surface change data. Although differences in number of stalks, percentage cover, and slope were observed throughout vegetation survey areas, these differences did not align with any observed differences in dune surface change. This supports previous studies that suggest only small amounts of vegetation density are needed to begin dune stabilization (Judd *et al.* 2008). All areas of planted *A. breviligulata* appear to be effective, regardless of their relative density.

Identification of *C. longifolia* and *A. campestris* in addition to *A. breviligulata* suggest that ecological succession is occurring as unplanted species move into the dune from surrounding vegetated areas. This is unique, as monoculture plantings of *A. breviligulata* typically suppress plant diversity in restored areas (Cheplick 2005; Emery and Rudgers 2010). Particularly, the identification of *A. campestris* in relatively constant levels across the dune is distinctive: previous studies have concluded that natural establishment of this species on restored

dune sites is rare and planting seedlings may be the only way to build populations of the species (Emery and Rudgers 2010).

The steep slope observed on Castle Park dune brings inherent management difficulties. Sand can easily erode or slide in mass amounts down a steep slope, causing fast erosion and destroying vegetation trapped underneath (Wilcock and Carter 1977). For this reason, it is suggested that beach grass plantings be combined with other management strategies and carefully monitored during establishment (Wilcock and Carter 1977).

Bearing this in mind, the Land Conservancy of West Michigan has two possible management strategies for the future. If the motivation is to continue to stabilize the dune, additional wood, lateral sand fences and continued planting of *A. breviligulata* is recommended for the upper slope of the dune where there is no decreased erosion due or any stable vegetation populations. Due to the relatively constant, smooth slope of the dune face, it is likely that successful management strategies downslope could also be used upslope. However, if the motivation of dune managers is to restore the site and encourage further ecological succession similar to the surrounding area, then leaving the lower slope in its current state is suggested. This would protect current diversity located on the lower slope and allow for continued succession to likely occur.

## CONCLUSIONS

The steep slope at Castle Park Dune Preserve on Lake Michigan's coast presents inherent management challenges which will require continued observance in the future. Current management strategies including *A. breviligulata* plantings and an established sand fence appear to be effectively causing sand deposition and decreasing overall surface change. The lack of significant correlations between surface change values and vegetation characteristics of different planting areas suggest that all plantings are successful and limited ground cover is necessary to aid in the stabilization process of the dune. Furthermore, the presence of two new species on the dune surface suggest ecological succession is occurring on the lower slope of the dune.

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