First-Year Research in Earth Sciences: Dunes

Characteristics of a Partially-Vegetated Slipface as Indicators of Dune Advance

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ABSTRACT

There are few direct measurements of advance rates of large parabolic dunes in Michigan. However, spatial characteristics of the dune slipface may indicate its advance patterns. This study investigated the characteristics of the partially-vegetated slipface of a large parabolic dune: Mt. Baldy in P.J. Hoffmaster State Park. Monitoring posts placed along the slipface edge were measured over two years to find the dune advance rate. Surface changes were measured to find amounts of erosion or deposition and slope angles at different sites on the slipface. The vegetation of the slipface was mapped, and plant cover and species richness were measured using quadrats in each distinct area of vegetation. The slipface had two different areas of vegetation: an upper grassy area in which both density and species richness increased further down the slope and a lower wooded area that was partially buried by the dune's advance. Measured dune advance rates were low and variable in the two years of the study, with greater rates of advance observed where buried wooded area made up a greater proportion of the slipface. These results show that spatial characteristics of this parabolic dune are related to advance rates and have the potential be used as indicators of advance on similar dunes.

INTRODUCTION

Few studies of large parabolic dunes in Michigan have focused on the dune slipface or directly measured dune advance rates. Indicators of dune advance rates may include patterns of vegetation and other characteristics of the slipface. In 2014, P.J. Hoffmaster State Park installed six monitoring posts along the edge of the slipface of Mt. Baldy, a large parabolic dune close to the park's Visitor Center. The installation of these monitoring posts created the opportunity to directly measure dune advance. This study sought to determine the rate and pattern of advance on Mt. Baldy and whether spatial characteristics of the slipface, especially vegetation characteristics, can be used as indicators of advance patterns. A secondary goal of the study was to determine the characteristics, spatial or otherwise, of Mt. Baldy's slipface.

Objectives

Our research objectives were to:

1. Directly measure the dune advance rate and direction,
2. Measure surface characteristics of the slipface,
3. Measure and map vegetation characteristics of the slipface, and
4. Determine where and how Mt. Baldy is advancing in relation to vegetation areas and other areas of the slipface.

STUDY AREA

Mt. Baldy is a large parabolic dune located in P.J. Hoffmaster State Park on the western coast of Michigan (Figure 1). The dune is northwest of the park's Visitor Center (circled in Figure 1). Of the eight large parabolic dunes in the park, Mt. Baldy is the largest in terms of size, with a height of 60 meters and a length of 582 meters from dune ridge to leading edge of slipface (Meyer and van Dijk 2007). On average, 39% of the surface of Mt. Baldy has been bare sand since 1938 (Belford *et al.* 2014). This study focuses on the slipface of Mt. Baldy, which is partially vegetated (Figure 2).

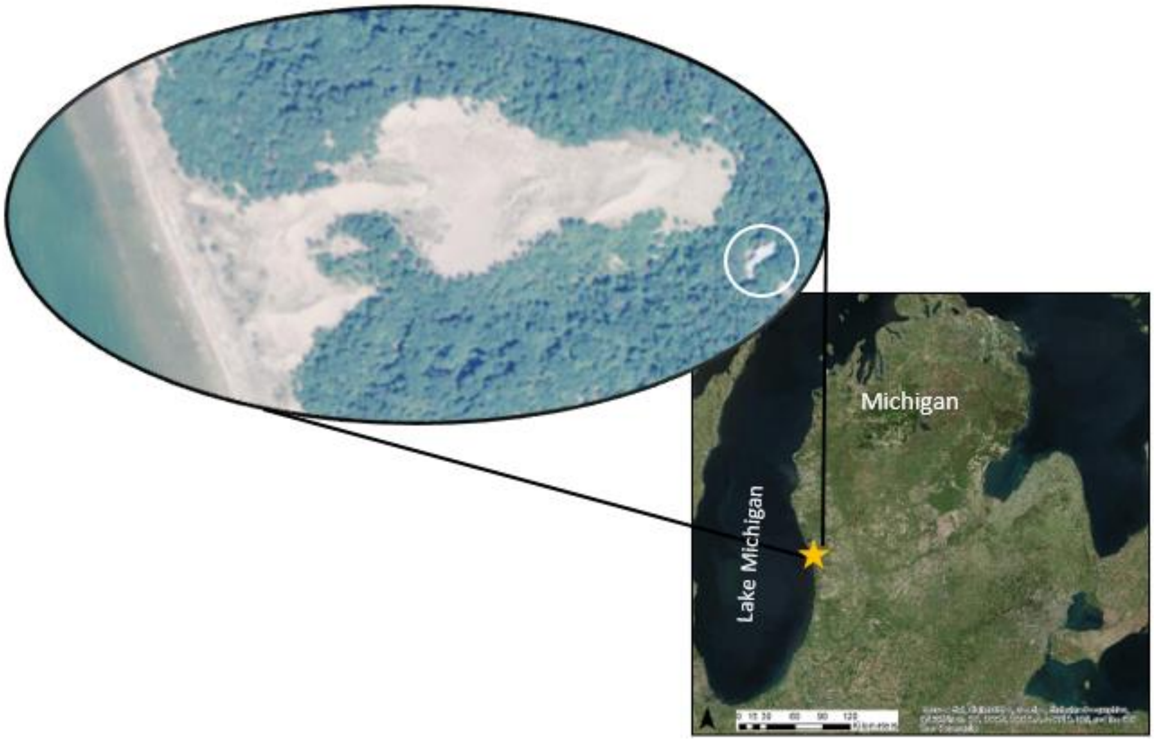

Figure 1. Location of study area in Michigan and aerial image of Mt. Baldy. Hoffmaster State Park's Visitor Center is circled on the aerial image.

Figure 2. View of the slipface of Mt. Baldy from the bottom of the slope. The lower slope is wooded and the upper slope is vegetated with grasses.

BACKGROUND

The coastal parabolic dunes of eastern Lake Michigan vary in advance rates and activity. Some are completely stable and vegetated. Others are slightly or moderately active, experiencing local sand movement but not advance of the entire dune. Many of the large parabolic dunes in P.J. Hoffmaster State Park fit the latter description (Meyer and van Dijk 2007).

Other large parabolic dunes are considered active or very active. Sand that has moved onto the slipface will move downslope by slope processes, causing advance of the entire dune (Meyer and van Dijk 2007). Green Mountain Beach dune, south of Holland, Michigan, had a directly measured advance rate of 1.6 m in a year at its axis, with decreased rates on its limbs (Hansen *et al*. 2009). Sand deposition occurred mainly in the fall and winter, but forward migration of the dune occurred in a short period of time in the spring after sand frozen on the slipface had thawed (Hansen *et al*. 2009). In P.J. Hoffmaster State Park, two large parabolic dunes, including Mt. Baldy, are categorized as active or very active (Meyer and van Dijk 2007).

A variety of spatial analysis tools and methods has been used to study coastal dune advance. Analysis of aerial imagery of large parabolic dunes and dune fields has been used to construct long-term histories of characteristics and advance of these features based on bare sand area and other visuals (Kilibarda and Shillinglaw 2015; Hesp *et al*. 2011; Hernández-Cordero *et al*. 2015). Aerial imagery can also be used to monitor the activity of a dune undergoing change (Pelletier *et al*. 2009). In these studies, the bare sand edge was assumed to be the edge of the slipface or representative of the edge of the slipface.

Edge detection software has also been used in combination with aerial images to measure the advance of coastal dunes, including our study area. Mt. Baldy has been active since the earliest air photo was taken of it in 1938 (Belford *et al*. 2014; Meyer and van Dijk 2007). The advance of the bare sand edge consistently moved eastward at an average rate of 0.84 meters per year from 1938 to the early 1990's, but was found to be low and variable since 1996 (Belford *et al.* 2014). In this study, the bare sand edge was not the edge of the slipface, but was a vegetation boundary on the dune crest or slipface.

Spatial analysis technology has also been used to study dune vegetation. Aerial imagery can be used to produce maps of dune vegetation that was present in the past (Hesp *et al*. 2011). These images can be used to produce a scale of lighter to darker ground cover, where darker ground cover is assumed to be thicker vegetation (Duran *et al.* 2008).

Vegetation has been found in zones on previously studied slipfaces. Grasses that thrive with sand burial were found in more active areas of the slipface, while a more diverse community of shrubs and grasses was found at more stable sites (Dech and Maun 2005). Trees that are being buried by sand advance can live for up to twenty years and survive several meters of sand burial (Dech and Maun 2005). However, survival is not the same as thriving. Scots pines in these conditions of burial have been found with thinner and more abnormal rings than healthy trees of the same species (Koprowski *et al.* 2010).

METHODS

Time Frame

The field measurements of this study took place over two weeks, with three site visits on October 27, November 3, and November 10, 2016. While the data collected during this time period comprises the bulk of the results of this study, another source of data came from dune advance measurements that were collected beginning in 2014.

Dune Advance

In September 2014, six monitoring posts were installed along the edge of the slipface of Mt. Baldy. To measure the advance rate and direction of Mt. Baldy, the distance between the edge of the slipface and each monitoring post was measured with a folding ruler (Figure 3). The distances were measured at semi-regular intervals for two years, with measurements generally taken in December, one of the spring months, and September (Appendix A). These data were combined with three additional measurements at the posts on October 27, November 3, and November 10, 2016.

Figure 3. A researcher measures the distance from the monitoring post to the edge of the slipface.

The advance rates for each year were found by tracking the change of the distance from the monitoring post to the slipface throughout the two years of the study. One measurement per year was selected, with dates chosen at approximately the same time of the year: October 13, 2014; December 24, 2015; and November 10, 2016. The measurements taken at earlier dates were subtracted from measurements taken later, giving the difference between the two dates. If the difference was positive, the dune had advanced. If the difference was negative, there appeared to be a regression of the slipface edge at that point.

During the October to November 2016 measurements, a modification to the measured sites was required. After the first year of data collection, Post 2 went missing. In November 2016, this post was found far from its original location, where it had been moved for an unknown reason. Because this post had been removed from its location, a tree was chosen to replace this post so that measurements at its approximate location could be obtained. This tree was marked with flagging tape and measured in place of Post 2 over the course of our two-week period of measurement (Figure 4). It was later discovered that this tree had been used as a replacement at one other time in the data collection from the year before, but this was not known by the team when the tree was chosen. This measurement was not worked into the results of this study because the tree was only used on April 15, 2016 and during the October to November 2016 measurements, so it was not useful for annual comparison.

Figure 4. This tree was used as a replacement for Post 2. Post 2, which was found far from this location during our study, is pictured leaning against the tree.

Posts 1, 3, 4, and 5 were chosen to analyze the advance of Mt. Baldy (Figure 5). Post 2 was excluded because it went missing in between the two years of advance measurements. Post 6 was excluded because the measurements at this site were highly variable, even over the two weeks in 2016. The variability is attributed to the rounded edge of the slipface as it meets another dune at this site, which made precise measurement difficult.

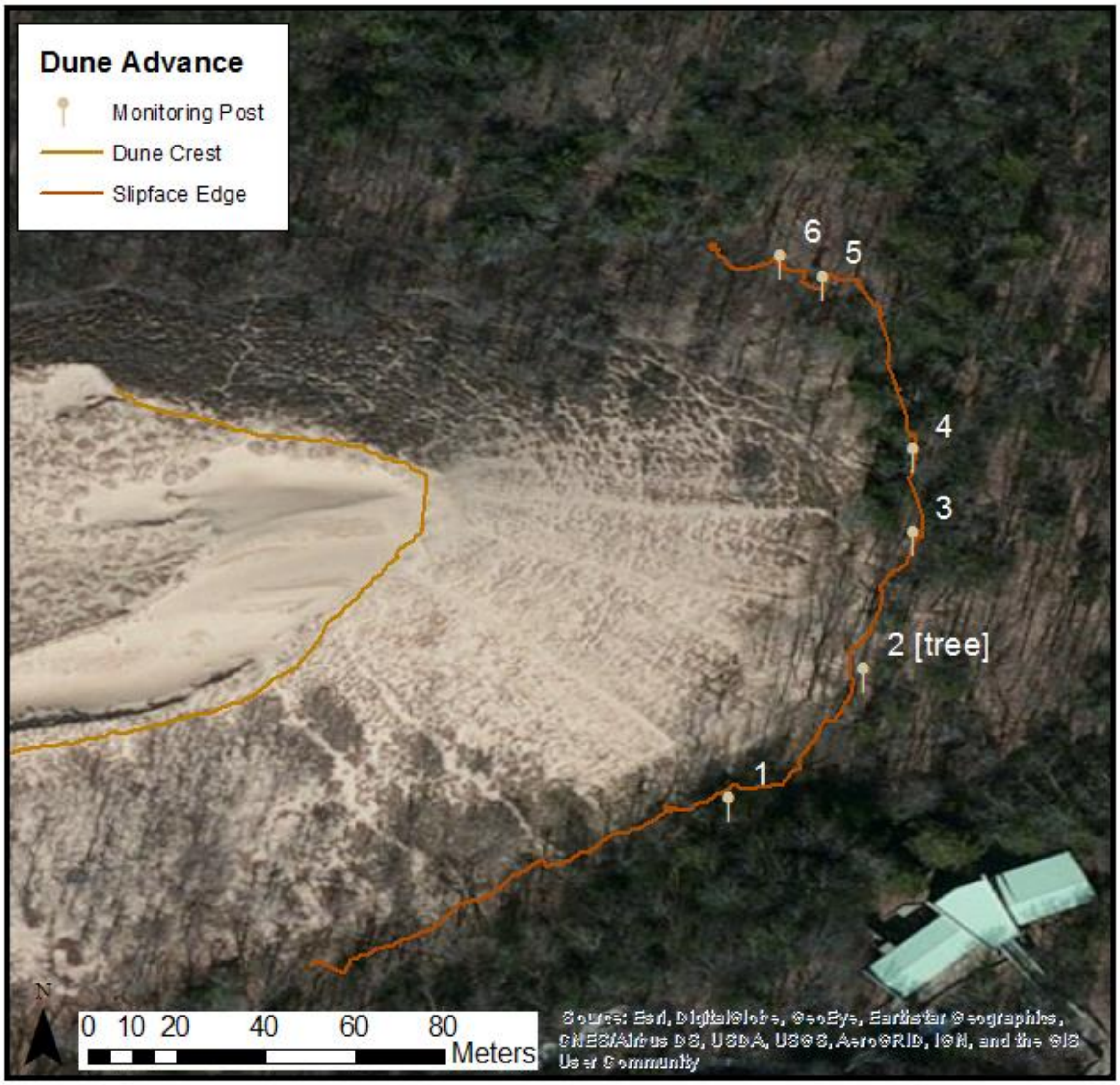

Figure 5. Position of measured monitoring posts on October 27, 2016. The post labelled "2 [tree]" was the tree used instead of Post 2.

Surface Characteristics

To measure surface change of the slipface, erosion pins were installed at regular intervals on the slipface (Figure 6). The distance from the top of the erosion pin to the surface of the slipface was measured during each of the three site visits in order to determine whether erosion, deposition, or no change was occurring at the surface at each of these sites. At each location that an erosion pin was set up, the slope angle was measured in the last two site visits.

The surface characteristics of Mt. Baldy's slipface were mapped with Juno Trimble GPS units. The edge of the slipface and the crest of the dune were mapped, as well as blowouts found at the crest and trails down the slipface of the dune.

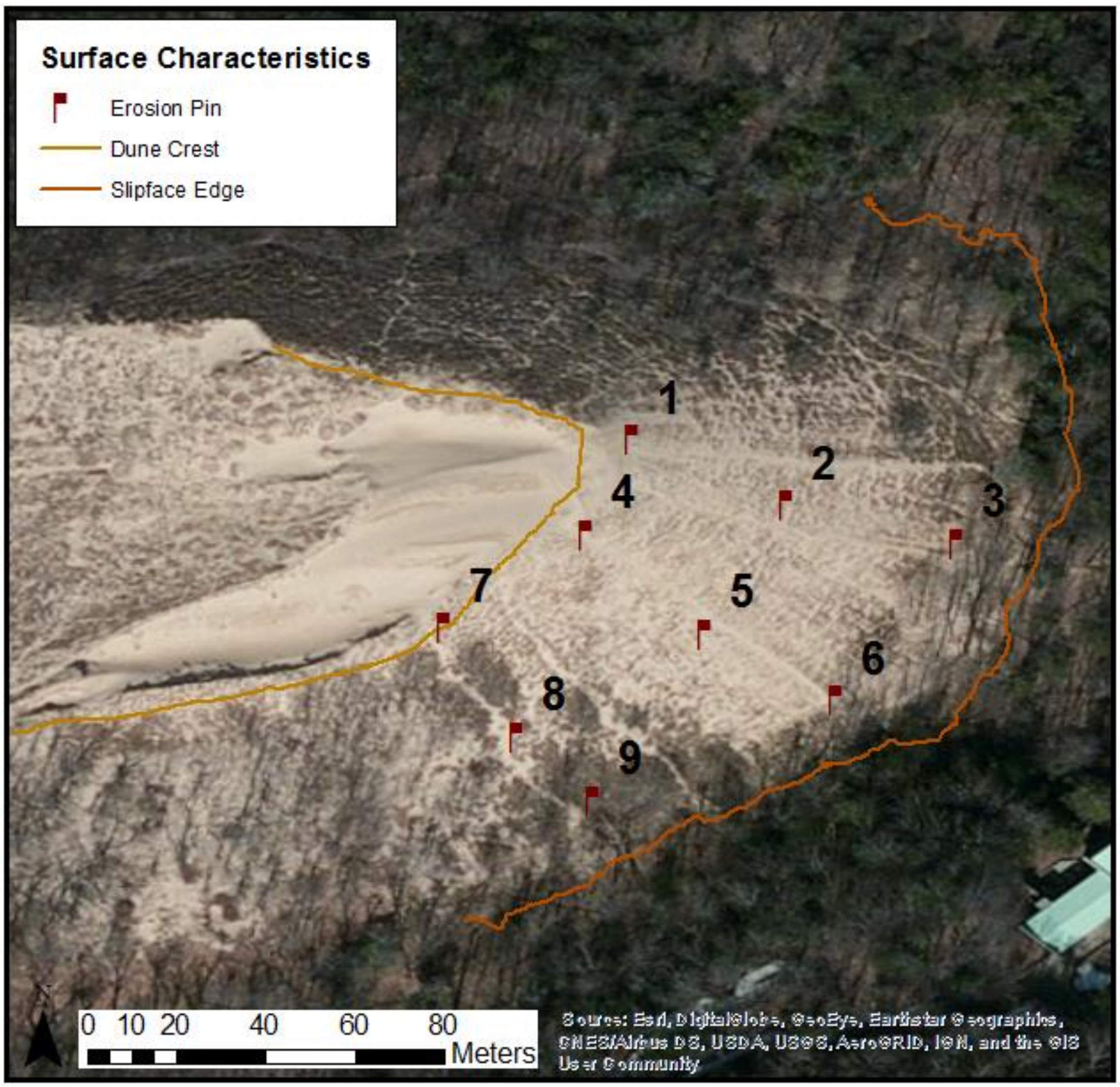

Figure 6. Positions of erosion pins on the slipface.

Vegetation Characteristics

To measure the slipface vegetation characteristics, a line was mapped that marked the distinctive boundary between areas of the slipface that were wooded and those that were primarily covered in grasses. In each of these areas, the general characteristics of the vegetation were measured using 0.5 m x 0.5 m quadrats (Figure 7). The quadrats were thrown rather than placed to randomize the sample. In the upper part of the grassy area near the crest of the dune, ten were thrown, while in the lower part of the grassy area near the wooded area, twenty were thrown. Ten were thrown in the wooded area.

In each quadrat location, the number of plants and the number of species within the quadrat were recorded. In most of the quadrats, the types of species were also recorded. In the wooded area, the distance from the quadrat to the nearest tree was recorded.

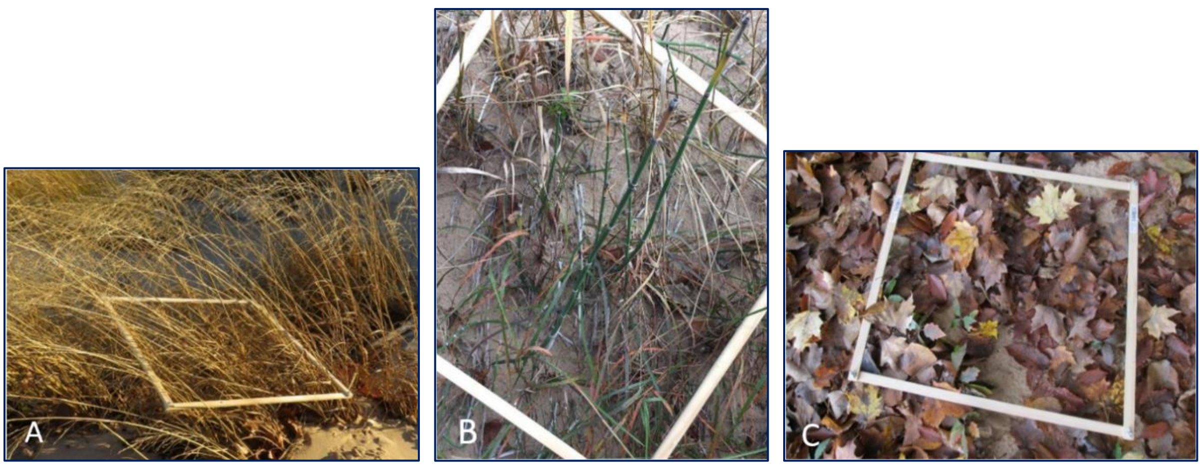

Figure 7. Examples of quadrats thrown in each of our vegetation sampling areas: A) upper grassy area, B) lower grassy area, and C) wooded area.

Advance and Characteristics Relationships

The vegetation of the slipface was also analyzed with ESRI ArcMap software. The lines mapping the crest of Mt. Baldy, the edge of its slipface, and the line that marked the boundary between the wooded and grassy areas were imported to ArcMap. The distance from the edge of the slipface to the crest and to the tree line were measured at each mapped monitoring post with the measure tool in ArcGIS. By dividing the distance through the wooded area by the total distance to the crest, the proportions of slipface area that were wooded were found. These proportions were compared to the advance rates measured at each monitoring post.

RESULTS

Dune Advance

Measured dune advance rates were low and variable in the two years of our study (Figure 8). From 2014-2015, low but positive rates of advance were measured. Rates in the first year increased steadily to the north. The maximum amount of advance in this year was 0.34 meters at Post 5. In the second year rates were much lower, with a maximum measurement of 0 meters at Post 4. Measurements of regression are also seen in this year.

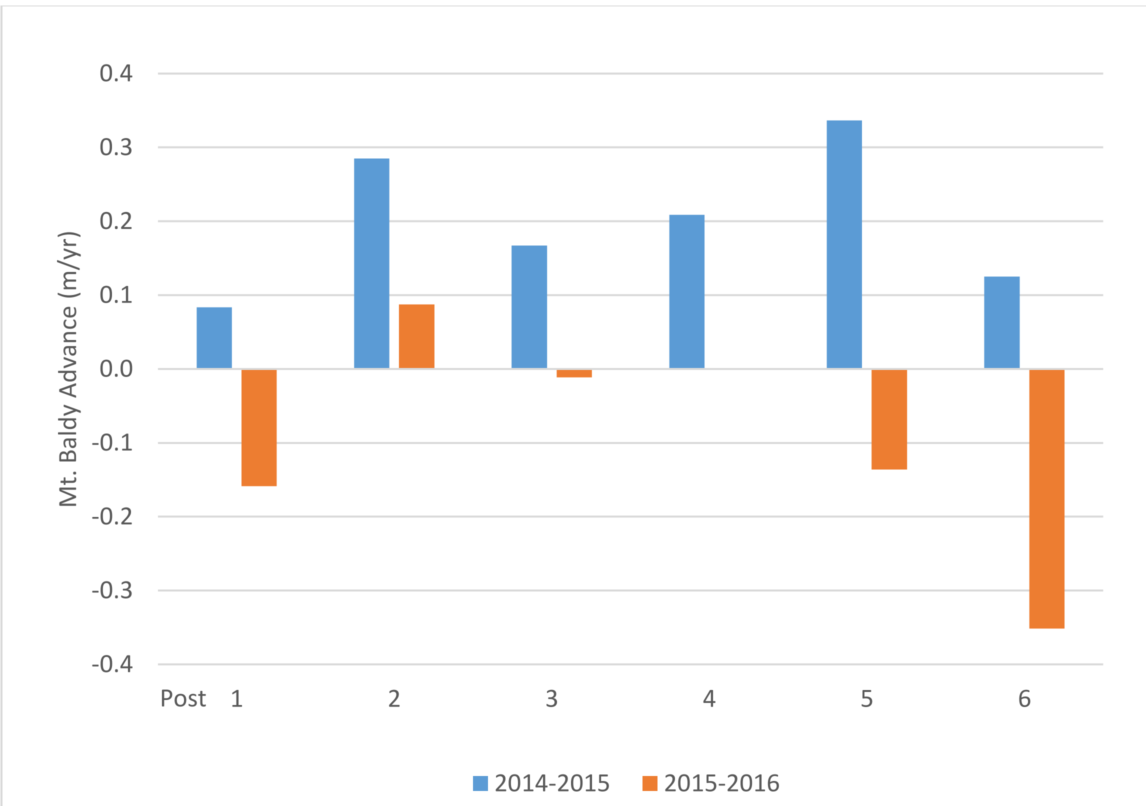

Figure 8. Dune advance rates from 2014-2016.

Surface Characteristics

From October 27 to November 10, 2016, there was little to no erosion or deposition at our erosion pin sites. Using a ±5 mm surface change as a scale of significance, only one site experienced a significant amount of change during these two weeks (site 7 on Figure 9). This site was on the edge of the largest blowout at the crest. A total of 9 cm of sand was eroded from this site in two weeks.

The slope angles of the slipface ranged from 27° to 33°. Measured slope angles remained consistent over the two weeks of the study. The greatest slope angle change was -4° and the smallest change was 0°. No positive change was recorded. These results are true of all our sites except for one outlier, at which a slope angle of 20° was recorded (site 8 on Figure 9).

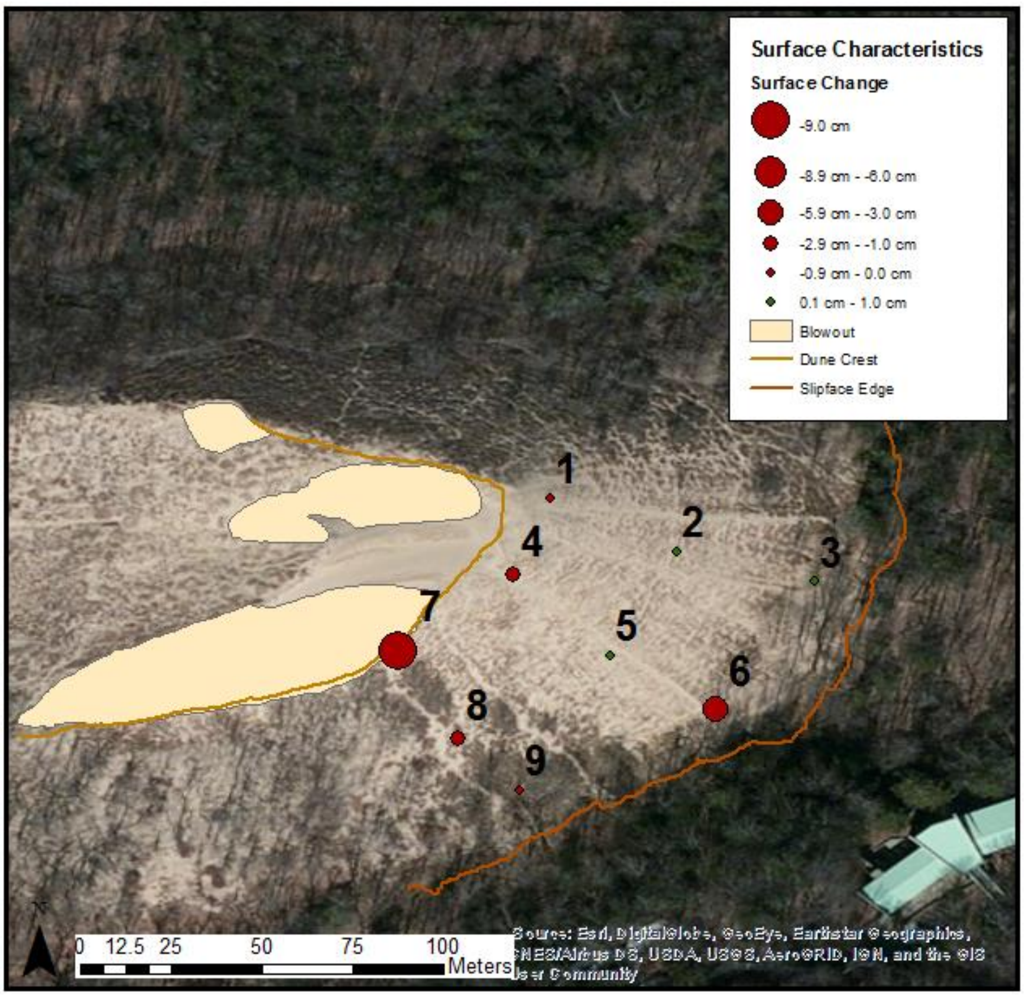

Figure 9. Erosion and deposition on the slipface of Mt. Baldy from October 27 to November 10, 2016. Green dots indicate deposition, while red dots indicate varying amounts of erosion.

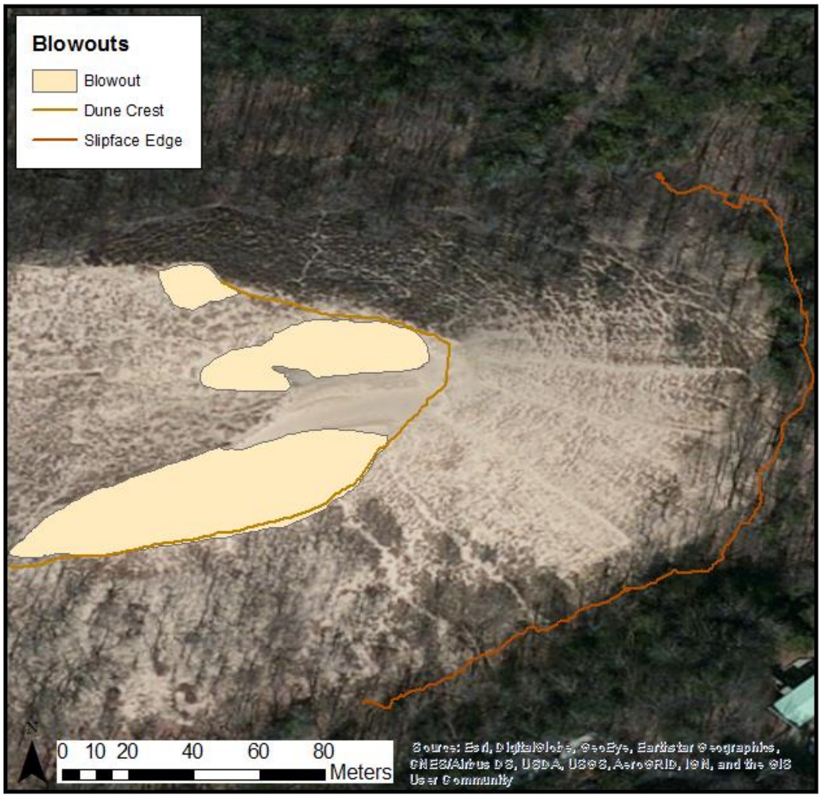

Figure 10. Blowouts on the crest of Mt Baldy (mapped on November 3 2016).

Three blowouts were mapped on the crest (Figure 10). These blowouts all have borders that touch the crest at some point. Two of these three blowouts are trough-shaped. Blowout areas (calculated in ArcMap) are 158 m^2, 708 m^2, and 1,731 m^2 respectively, from north to south.

Multiple unmanaged trails from the top of the slipface to the bottom were observed (Figure 11). On November 10, 2016, a group of runners was observed using one of these trails.

Figure 11. A trail on the slipface of Mt. Baldy. This trail is used but unmanaged.

Vegetation Characteristics

Two distinct areas of vegetation were observed on the slipface of Mt. Baldy, an upper grassy area and a lower wooded area (Figure 12). In the grassy area, the density of ground plant cover increased further down the slope. The species richness of the vegetation also slightly increased down the slope, away from the crest (Figure 13). The lower wooded area is an area of forest that has been partially buried by Mt. Baldy's advance. In these woods, the ground plant cover and species richness was much lower than in the grassy area (Appendix B). The wooded area makes up 29% of the slipface area (Figure 14).

Figure 12. The two types of vegetation areas on the slipface. The surface of the wooded area is pictured in the foreground of the photograph. The grassy area is pictured in the background. A distinct separation between the two areas can be seen.

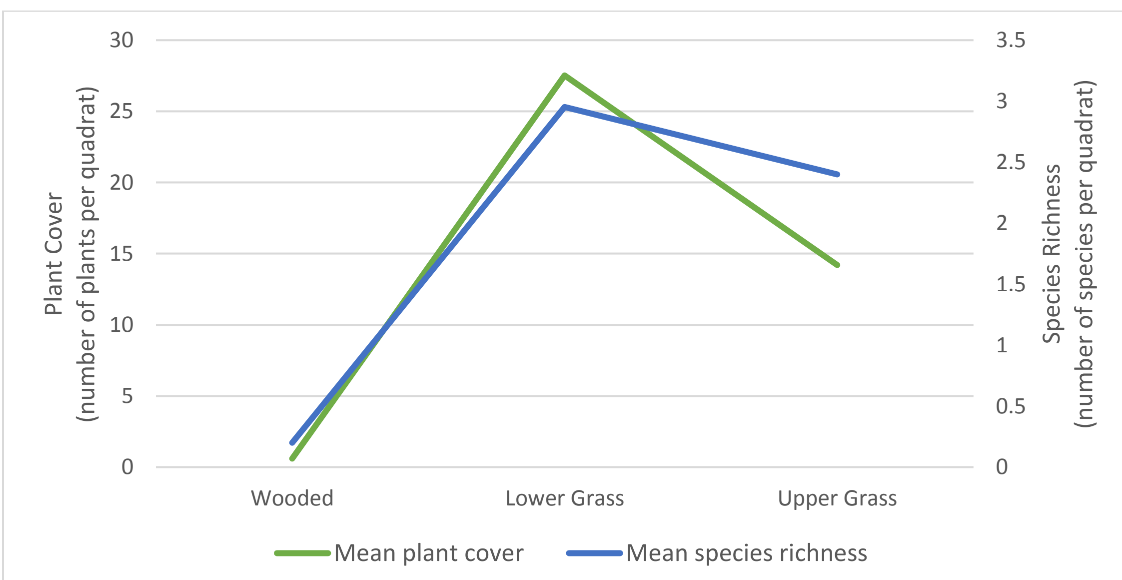

Figure 13. Plant cover and species richness in each area of vegetation.

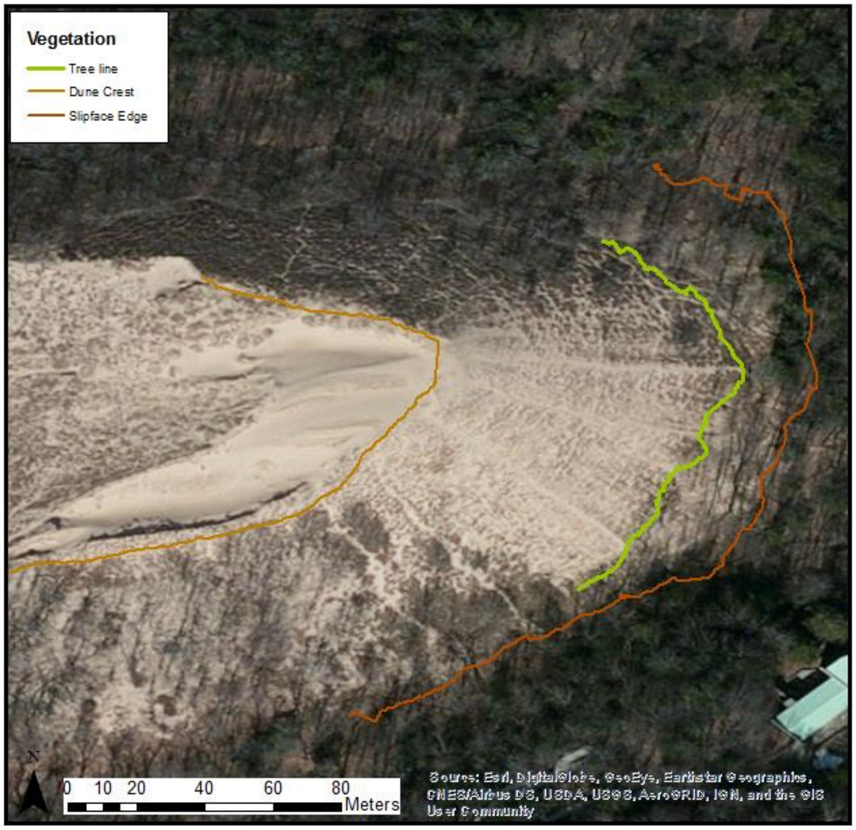

Figure 14. Mapped wooded area and grassy area across the slipface of Mt. Baldy.

Advance and Characteristics Relationships

The proportions of wooded dune to slipface distance at each post were compared to the rates of advance measured at these posts in 2014-15. The proportions were also compared to rates in 2015-16, but only at sites that did not show regression. The sample size is small, but visual inspection suggests that there is a relationship between greater rates of advance and greater proportions of wooded slipface in 2016 (Figure 15).

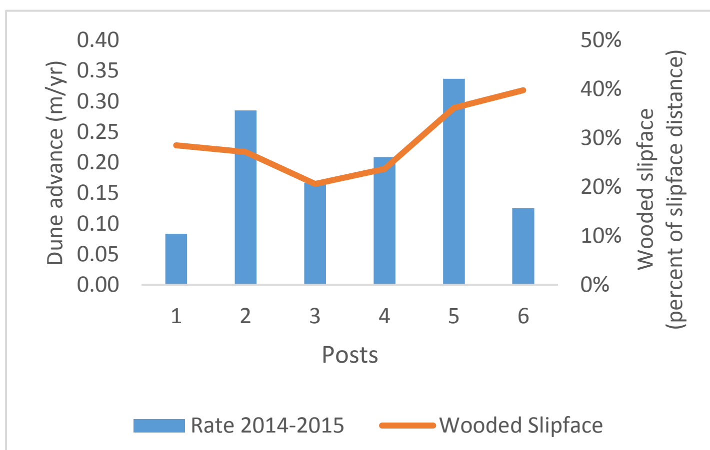

Figure 15. Comparison of the advance of Mt. Baldy and the percentage of wooded slipface at selected locations. The rates are from the years 2014 to 2015, and the measured proportions are from 2016.

DISCUSSION

Dune Advance

Our study results agree with advance rates calculated by Belford *et al.* (2014) using remote sensing of the bare sand edge. Despite the different methods of these studies, both found slow and variable rates of advance in Mt. Baldy's recent past. Regression of the bare sand edge was also observed by Belford *et al*. (2014), but this may be because the bare sand edge advanced into the wooded area at the foot of Mt. Baldy.

Despite its proximity to the Visitor Center of Hoffmaster State Park, Mt. Baldy will not be a threat to the building in the near future. Mt. Baldy's rates of advance are low, and the advance that we did see indicated an advance trend to the northeast, not the southeast where the Visitor Center is located relative to the dune.

The regression calculated at some monitoring posts was unexpected and could have several possible explanations. The regression seen at Post 5 is attributed to a log that fell over the edge of the slipface. This log would have fallen between the two years of measurement. After it fell, water and wind eroded the edge of the slipface, and new sand from the slipface could not replace the eroded sand because it was blocked by the log. The regression measured at other posts remains unexplained, other than by the error that could have been introduced into the study by using different dates from each year to calculate advance rates.

Surface Characteristics

Sand does not seem to be accumulating or eroding in large amounts during the fall season, as the surface of Mt. Baldy's slipface did not experience much change from October 27 to November 10, 2016. Across the slipface, measurements of erosion and deposition showed that little of either type of change was occurring. There seemed to be a slight pattern in that most sites that experienced change below the significance threshold experienced either erosion or deposition for both weeks of measurement. However, since these were not considered to be significant surface changes, this noticed pattern does not have strong support. Hansen *et al*. (2009) found that on an active dune, sand was deposited on the slipface in the fall and winter. Mt. Baldy did not experience significant deposition in this time period in the fall, meaning that it only accumulates sand on the slipface during other times in the fall and winter or it is becoming less active.

The slope angles on Mt. Baldy's slipface promote sand movement towards the bottom of the slipface, and the change at these sites indicate that the slipface, where it is changing, is becoming less steep. Most of the slope angles measured across the slipface of Mt. Baldy were near the angle of repose. Werner's model predicts that a slipface at the angle of repose will cause sand to move to the bottom of the slope (Pelletier *et al*. 2009). The slow advance rates measured on Mt. Baldy seem to indicate that this is not happening. One reason for this may be the vegetation on the slipface, which would trap sand as it moves down the slope. However, measurements taken at our erosion pins show no significant deposition on the slipface. Slope angles on the slipface only experienced negative change, which means that the sites measured on the slipface either experienced no change or became less steep.

The blowouts at the crest of Mt. Baldy do seem to be contributing to the small amount of advance that was observed. The general direction of the observed advance was to the northeast, and the axes of the two largest blowouts on the crest are parallel to this (Figure 16). This shows that sand may be funneled through the two largest blowouts to the northeast, contributing to advance in this direction.

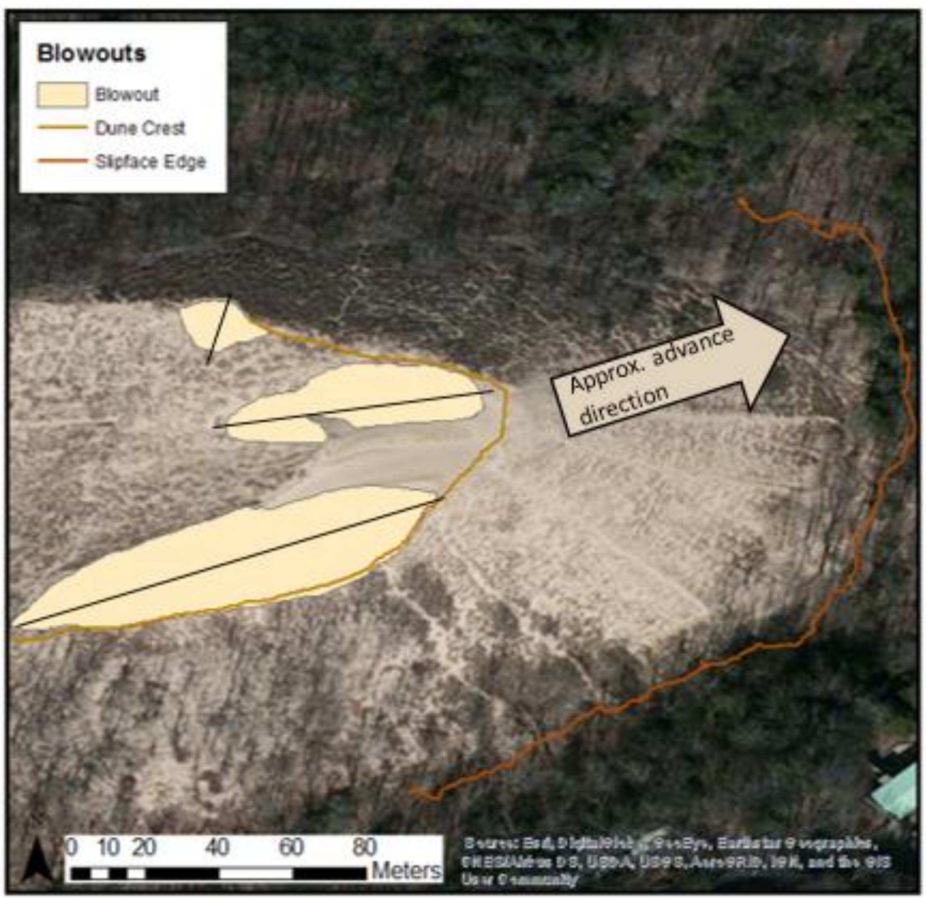

Figure 16. Blowouts on the crest of Mt. Baldy with their axes indicated.

While unmanaged trails normally lead to increased advance rates by loosening sand, the various unmanaged trails down the slipface do not seem to indicate that this is the case on Mt. Baldy. The two trails that were mapped head east and southeast, opposite the direction of the highest advance rates. However, aerial imagery indicates that there may be one more trail heading to the northeast, where the higher advance rates were measured. The several trails of Mt. Baldy's slipface lead in different directions that experience different amounts of advance. The relationship of unmanaged trails to dune advance on Mt. Baldy remains a question that could be studied in the future.

Vegetation Characteristics

The zones of vegetation observed on Mt. Baldy were similar to the zones described by Dech and Maun (2005). Grasses that thrive with sand burial were found near the crest and a more diverse community of shrubs and grasses was found further from the crest in a more stable area of the slipface. This community of grasses and shrubs was more dense and diverse than the grasses growing on and near the crest of the dune.

Ground plants on the slipface do not seem to thrive in wooded areas, even if those areas are on the slipface. There was very little ground cover in the forested area of the slipface. This indicates that ground plants that normally thrive in the environment of a dune slipface are either unable to thrive in a forested area or have not yet spread to the forested area but have the possibility of doing so in the future. Belford *et al*. (2014) began recording decreased and variable movement of the bare sand edge of Mt. Baldy's slipface as early as 1996, which could be when the slipface began to advance into the forested area behind the dune. If 1996 is indeed the year that the forested area of this slipface began its formation, this would give the ground plants of the slipface 20 years to spread into the forested area. Since this has not happened, we conclude that the ground plants of the slipface do not thrive in the forested area.

Some of the trees on the slipface of Mt. Baldy may be at high risk of mortality. Since the slipface may have advanced into the forest as early as 1996, some of the trees in the forested area of the slipface have experienced sand burial for 20 years. Trees may experience several meters of sand burial for as long as 20 years before mortality (Dech and Maun 2005). If trees on Mt. Baldy's slipface have experienced several meters of sand burial since 1996, they will have a high mortality risk.

Advance and Characteristics Relationships

The proportion of wooded slipface area seems to be an indicator of localized advance patterns on Mt. Baldy. More wooded slipface area indicates that rates of advance are higher in that location. Higher rates of advance cause the edge of the slipface to travel further into the forest near Mt. Baldy in some areas than lower rates of advance in other areas. For Mt. Baldy, both higher rates of advance and greater proportions of slipface area were found in the northeast area of the slipface.

A measurement of the edge of the slipface may be valuable for remote spatial analysis of dunes. Measurements of dune advance often rely on aerial imagery, especially long-term studies. These studies use the bare sand edge to estimate the advance of dunes. However, the trees present on the slipface of Mt. Baldy obscure the bare sand edge, so the true edge of the slipface cannot be seen in recent aerial imagery. Despite this challenge, obtaining the edge of slipface measurement could be valuable in these studies because it allows the proportions of wooded slipface area to be calculated. These measurements can be used to identify sections of a dune that may be advancing faster than other sections.

CONCLUSIONS

Based on direct measurements, the advance of Mt. Baldy has been slow and variable over the past two years, with advance rates of 0-0.34 meters per year and regression noted at some locations. Blowouts on the crest contribute to this advance, but the contribution from unmanaged trails remains unknown. Communities of vegetation have higher density and greater species richness further from the crest in more stable areas, while grasses that require sand burial have lower density and species richness at the crest in the active area of the slipface. A greater proportion of wooded slipface area indicates higher local rates of advance, making an edge of slipface measurement potentially valuable for spatial analysis studies of dune advance. Future studies could explore whether this pattern is observed on other dunes and whether the advance rates of different dunes can be compared using these measurements.

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Appendix A. Dates and information for monitoring post data collection

Date of measurement	Data collector	Comments
10/13/2014	Joel Bulthuis	Estimated date from researcher
12/29/2014	Deanna van Dijk	
4/23/2015	Deanna van Dijk	
9/3/2015	Deanna van Dijk and assistant	Post 2 went missing between 4/23/15 and 9/3/15.
12/24/2015	Deanna van Dijk and assistant	
4/15/2016	Deanna van Dijk	Several trees used in place of Post 2.
9/1/2016	Deanna van Dijk and assistant	
10/27/2016	Araceli Eikenberry and Taylor Grasman	One tree used in place of Post 2 (used 10/27/16 - 11/10/16).
11/3/2016	Araceli Eikenberry and Taylor Grasman	
11/10/2016	Jamie Atkinson and Taylor Grasman	Two additional trees were used, one between Posts 2 and 3, and one between Posts 3 and 4.

Appendix B. Vegetation data from quadrats

Quadrat	Number of plants	Number of species	Ground conditions/Species present	Distance to nearest tree (m)
Forest				
1	0	0	100% leaf litter	0.19
2	0	0	100% leaf litter	1.55
3	0	0	100% leaf litter	0.09
4	0	0	100% leaf litter	0.26
5	0	0	leaf litter, small sand mound	2.21
6	4	1	some bare sand (~1/8), baby trees, leaf litter	1.41
7	0	0	shady, ~65% bare sand, leaf litter	0.3
8	2	1	50/50 leaf litter/bare sand, two small shrubs	4.31
9	0	0	100% leaf litter	2.21
10	0	0	9% bare sand, fallen branch with mushroom	0.12
Lower Grass				
A	18	2	reeds, grass	
B	2	1	Reeds	
C	15	3	reeds, grass, leaf	
D	85	4	reeds, weeds, grass, colorful plant	
E	30	3	grass, reed, weeds	
F	35	3	grass, new grass, reed	
G	50	5	reed, weed, blue/green plant, grass, colorful grass	
H	8	1	Reeds	
I	16	2	grass, reeds	
J	30	3	weeds, reeds, grass	
K	36	4	pitcher's thistle, purple grass, weeds, reeds	
L	36	3	purple grass, grass, reeds	
M	33	4	Pitcher's thistle, weeds, reeds, grass	
N	25	3	grass, reeds, orange grass	
O	20	3	grass, purple grass, blue green plant	
P	27	4	reeds, weeds, purple grass, grass	
Q	8	3	weeds, grass, reeds	
R	30	3	grass, reeds, weeds	
S	32	4	purple grass, reeds, weeds, grass	
T	18	2	baby trees, reeds	
U	24	2	grass, reeds	
Upper Grass				
U1	19	2		
U2	12	4		
U3	14	3		
U4	22	6		
U5	19	4		
UA	14	1	grass	
UB	7	1	grass	
UC	12	1	grass	
UD	12	1	grass	
UE	11	1	grass	