First-Year Research in Earth Sciences: Dunes

Interactions Between Sequential Blowouts, Their Features, and Sand Transport

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Abstract

Sand transport shapes blowout characteristics and, in turn, blowout characteristics control wind and sand transport patterns. To better understand blowout interactions we studied three neighboring blowouts on a large parabolic dune in Hoffmaster State Park. Blowout characteristics were measured with field observation, stadia rod surveys, GPS, and aerial photos. Wind speed and direction were measured with anemometers on the foredune and at the entrance and crest of the largest blowout. At the crest of each blowout, sand transport was measured with sand traps. Results revealed a sequence of blowouts comprised of a saucer blowout, a grassy depression, a second saucer blowout, and a large trough blowout. Each blowout contained a mostly bare deflation area surrounded by small shrubs and grasses. Each blowout in the sequence increased in height and had its central axis shifted more towards the south. There was a greater amount of sand transport on the trough blowout than at either of the saucer blowouts. These results should spur future investigations of the dynamics of connected blowouts.

Introduction

Wind is one of the key factors in the formation and shaping of blowouts. Previous studies have shown that blowouts affect the patterns of entering wind flows (Fraser *et al.* 1998). Despite the focus on the interaction between wind and blowouts, there has been little research on these factors within *sequences of blowouts*. Even the few studies that provide information on multiple blowouts (Mir-Gual *et al.* 2012) rarely focus on the interactions between the blowouts. Our study sought to better understand how blowout characteristics and wind interact in the context of a series of connected blowouts.

Our objectives for this study were to:

1. Measure the features of three connected blowouts.
2. Track wind movement and sediment transport through the blowouts.
3. Compare the wind and sand transport patterns with the blowout characteristics.

Study Area

The research took place on the southwestern coast of the lower peninsula of Michigan (Figure 1a). Specifically, our research site was located in P.J Hoffmaster State Park (Figure 1b) which is in the southern part of Muskegon County and the northern section of Ottawa County. We focused on a series of three connected blowouts inside a large parabolic dune located at the southern end of the park (Figure 2).

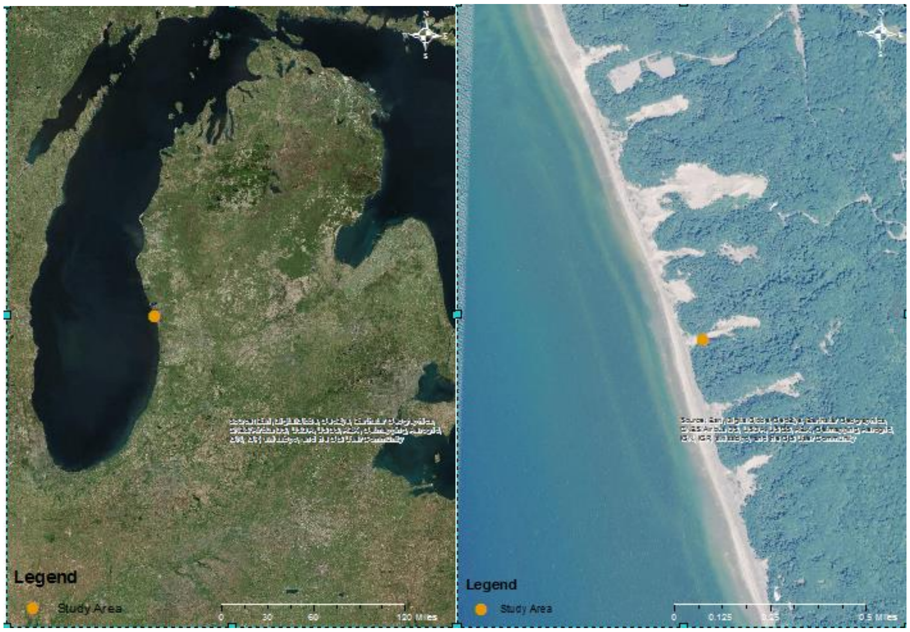

Figure 1. Location of study in a) Michigan and b) Hoffmaster State Park. (Images source: ESRI.)

Figure 2. Blowouts of the study. (Image source: VanHorn *et al.* 2016.)

Background

Dunes have long been vital to the wellbeing of communities that reside in coastal areas. Coastal research has recognized this importance and studies such as “The Dutch Foredunes: Inventory and Classification Areas” (Arens and Wiersma 1994), “A coastal dune vulnerability classification. A case study of the SW Iberian Peninsula” (García-Mora *et al.* 2001) and presentations such as “Grazing Domestic Livestock in Dutch Coastal Dunes: Experiments, Experiences, and Perspectives” (Van Dijk 1992) represent efforts to better understand the coastal dunes.

One aspect that has been studied intensely is the activation and subsequent movement of dunes. Dune movement is largely driven by sand transport (Hugenholtz and Wolfe 2006) which is in turn driven by wind patterns. Migration is a natural part of a dune’s life cycle but can sometimes be destructive to coastal property. As such, dune movements are the concern of park managers who must balance the concerns of the community with maintaining the natural environment.

Blowouts are part of active coastal dune environments. A blowout is a “depression or hollow formed by wind erosion on a preexisting sand deposit” (Hesp 2002) and it is a sign that the dune is active. A blowout can be characterized as either a saucer or a trough blowout. A saucer blowout is round and wide, while a trough blowout is long, deep, and narrow (Hesp and Pringle 2001). The deflation area of a blowout is a hollowed-out area where much of the sediment has been removed by the wind. This is often framed by a downwind deposition lobe, an elevated structure made up of sediment deposited by the wind (Hesp 2002).

Blowouts have several effects on the wind patterns. First they have been found to alter the velocity of entering wind streams. When wind initially enters the deflation area of a blowout it slows down, and wind speeds up as it exits the blowout (Hugenholtz and Wolfe 2006). In addition to altering wind velocity, blowouts have been shown to change the direction of wind flow (Fraser *et al.* 1998). Researchers have found that wind is steered when it enters a blowout (Hugenholtz and Wolfe 2009). Wind patterns are often directed within blowouts by several factors including localized low pressure and funneling caused by blowout erosional walls (Hesp and Pringle 2001). The amount of steering performed by the blowout is dependent on “the angle of incidence between the approach wind and the long-axis of the blowout” (Hugenholtz and Wolfe 2009: 919)

Wind patterns also have an effect on the features of the blowouts that they pass through. Wind speed and direction have been found to be a determinant of the length, width, size, and shape of blowouts (Bruno *et al.* 2002).

While numerous studies have focused on the relationship between wind and blowout formation, less effort has been dedicated to the interaction between wind patterns and blowout features in a sequence of blowouts. Most papers on blowouts are limited to looking at factors inside a single blowout (Pease and Gares 2013). On the other hand, papers that deal with multiple blowouts tend to focus on aspects other than their possible interaction with each other (Mir-Gual *et al.* 2012).

Methods

In Fall 2015, we focused field measurements on three connected blowouts to compare the features and wind patterns of each blowout. We observed the blowouts characteristics and carried out measurements of their features along with wind and sand transport patterns.

We measured the characteristics of each blowout by tracing its perimeter with handheld GPS units. The shape of each blowout was determined by these GPS measurements as was the width of each deflation area. One of the characteristics we were trying to determine was whether each blowout was saucer-shaped or trough-shaped. The length and height of each blowout's deflation area was determined by stadia rod transect measurements. The slope of each deflation area was determined by dividing its height by its length. Vegetation density was determined by visual observation as well as by aerial photography obtained from the Michigan Dune Inventory (gis.calvin.edu/mdi; VanHorn *et al.* 2016). Likewise, other features, such as the presence and location of paths, were determined by visual observation.

Sand transport was measured at each blowout by the use of sand traps on November 12, 2015. Each sand trap was placed near the landward side of the crest of the blowout. The team used sand traps at three blowout crests and took measurements over two intervals. The first interval lasted thirty minutes and the second lasted fifteen minutes. The collected sand samples were then taken back to the lab where they were dried and weighed. Sand transport patterns were noted by visual observations.

We collected samples for grain size analysis from three different points on the dune system. The samples were then taken back to the lab where they were dried and weighed. Each dried sample was then sorted using dry sieving. The results were then analyzed using the graphical methods of Folk (1980).

Wind patterns were measured with handheld and electronic anemometers. The hand-held anemometers were employed at both the entrance and crest of the largest blowout. Wind speeds were recorded every five minutes. We also used an anemometer on the foredune that acted as a reference point (Figure 3). We used a wind vane at the foredune site to ascertain the wind direction. The foredune instruments were recording at thirty-minute intervals.

Figure 3. Location of the foredune anemometer relative to the main study site.

Results

Blowout Characteristics

The three blowouts in our study (Figure 4) were a saucer blowout (S1) followed by a thinner saucer blowout (S2) and a trough blowout (T1). These blowouts were framed by the beach to the west, forest to the north and south, and the rest of the dune system to the east.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4. Blowout deflation and deposition areas at the study site.

The first blowout (S1) was distinguished by having the steepest slope (0.279 m/m) and being the closest to the lake of the three blowouts (Figure 5). To the west of the blowout was a foredune and a short grassy plain that led into the blowout. This blowout was saucer-shaped with sparse vegetation in the deflation area and scattered but dense vegetation in some spots on the perimeter. East of this first blowout was a grassy depression that continued to the west edge of the second blowout.

Figure 5. Researchers climb Saucer 1 (S1). (View is from the west at the blowout entrance.)

The second blowout (S2) was also saucer-shaped but narrower and more elongated than the first blowout (Figure 6). S2 had the shortest width (5.2 m), the shortest depositional lobe (3.5 m), the smallest area (77 m^2), and the gentlest slope of the three blowouts (0.236 m/m). The vegetation on this blowout was very sparse on the deflation area but retained roughly the same amount of vegetation on the perimeter as S1. The vegetation thinned on the northern perimeter of S2 but this was due to the encroachment of the third and final blowout.

Figure 6. Saucer 2 (S2) as viewed from the crest of S1. The furthest visible researcher is just below the crest of S2.

The third blowout (T1) was the largest by far (2070m^2) and was trough shaped unlike the other two blowouts (Figure 7). T1 was both the tallest (27.3 m) and farthest up the dune system of the three blowouts. The vegetation was sparse on the deflation area of the trough blowout and more prevalent on its perimeter and deposition area. To the east of T1 the dune continued with several other blowouts that were not part of this study.

Figure 7. The trough blowout (T1) as viewed from the crest of S2. The top of the large parabolic dune is visible in the background (above the crest of T1).

The blowout crests increased in height above the lake with distance from the lake (Figure 8). Each consecutive blowout's deflation area axis rotated further to the south with the trough blowout being oriented the furthest south (Table 1). The blowouts also became narrower as one progressed through the dune system. The trough blowout was larger in every measurable category than either of the saucer blowouts.

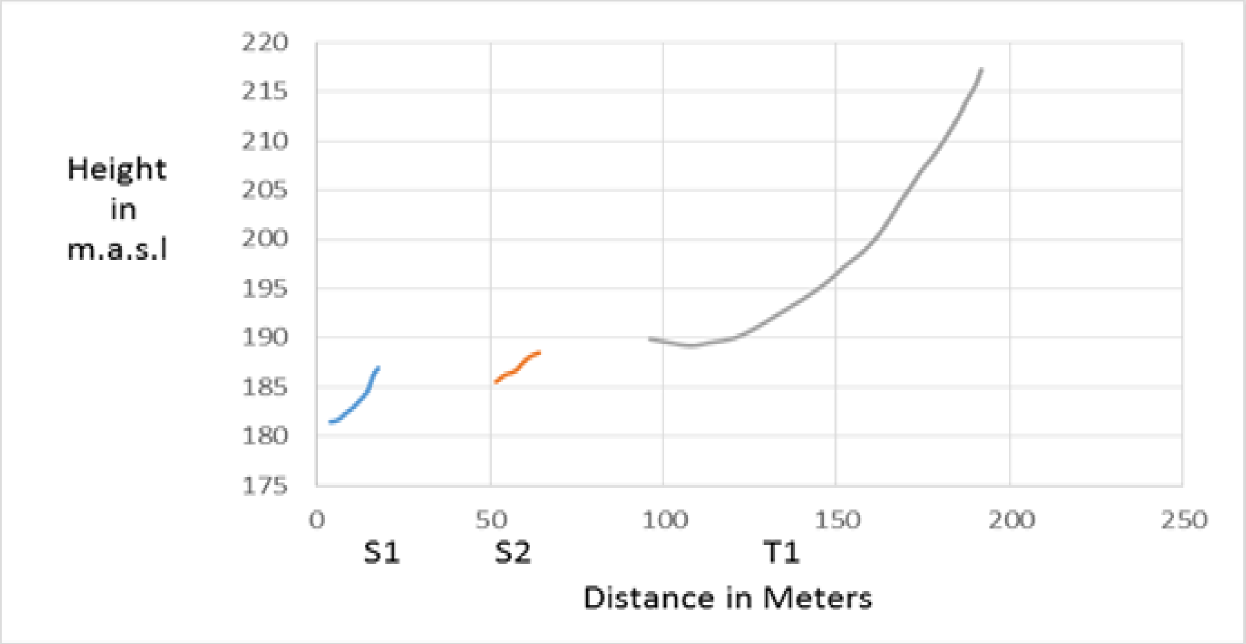

Figure 8. Profiles of blowout deflation areas (graphed from stadia rod measurements) show the relative heights of the blowouts.

Blowout	**Slope* (m/m)**	**Shape**	**Width (m)**	**Length (m)**	**Area (m^2)**	**Height (m)**	**Vegetation***	**Orientation* (degrees)**
Saucer 1 (S1)	0.279	Saucer	7.0	17.7	124	4.94	Sparse	54 (NE)
Saucer 2 (S2)	0.236	Saucer	5.2	14.8	77	3.5	Very sparse	58 (NE)
Trough 1 (T1)	0.267	Trough	20.3	102.0	2070	27.3	Sparse	78 (NE)

Table 1. Blowout characteristics.
*Indicates where characteristics are described for deflation area only.

Wind Patterns

Wind speed measurements on November 5 were taken from 4:05 pm to 4:35 pm (Figure 9). The wind speeds were between 2.4 m/s and 3.7 m/s on the foredune and 0.5 m/s and 2.3 m/s on the trough. Wind was blowing from the south during the measuring period. On November 12 wind speeds were much higher than the speeds recorded on November 5 (Figure 10). This was due to the storm conditions in the area for which several advisories were issued (Steffen 2015). Wind speeds were between 8.7 m/s and 14 m/s at the top of the trough blowout, 7.4 m/s and 8.8 m/s bottom of the trough blowout, and 7.98 m/s and 9.57 m/s at the foredune. The wind was blowing from the northwest during the measurement period.

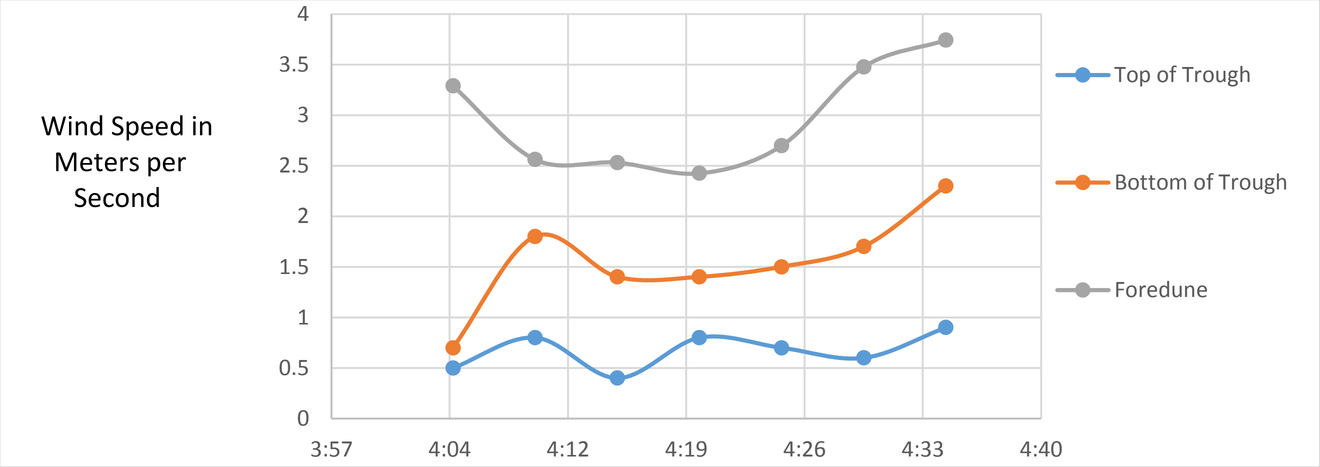

Figure 9. November 5 wind measurements.

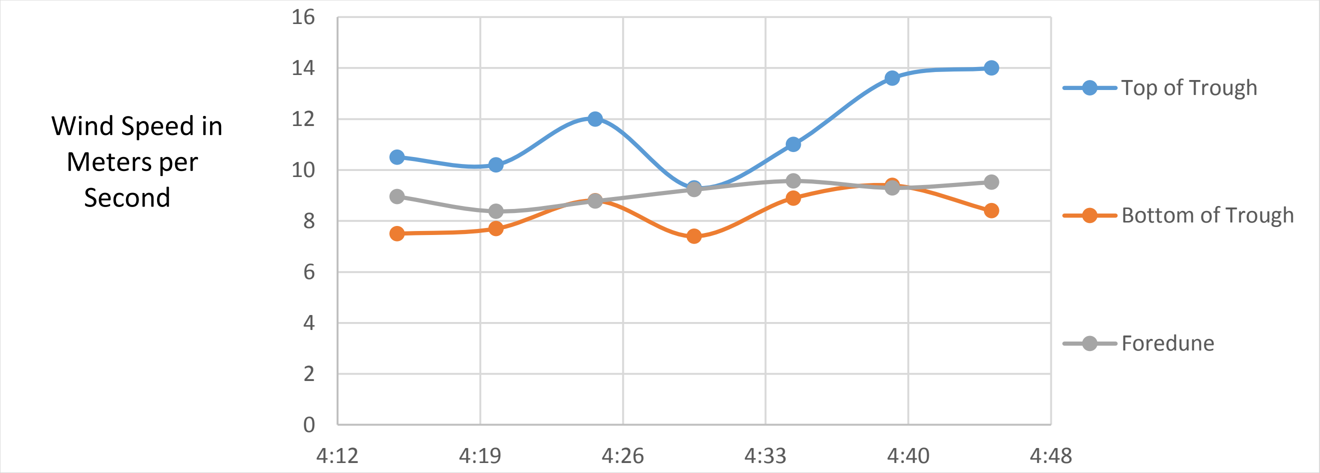

Figure 10. November 12 wind measurements.

Sand Transport

The sand trap at the first saucer blowout (S1) collected the least amount of sand of the three blowouts in the first measurement period. However, this sand trap saw an increase in sand transport during the second time period that gave it the second-most sand trapped during that time period. The second saucer blowout's (S2) trap collected the second-most sand during the first measurement. Unfortunately, it is difficult to say whether the second blowout also saw an increase in sand transport during the second measuring period as the sand trap collapsed part way through the measuring period. The trough blowout (T1) sand trap had the largest amount of sand collected for both the first and second collection period. Like S1, T1 saw an increase in sand transport during the second period.

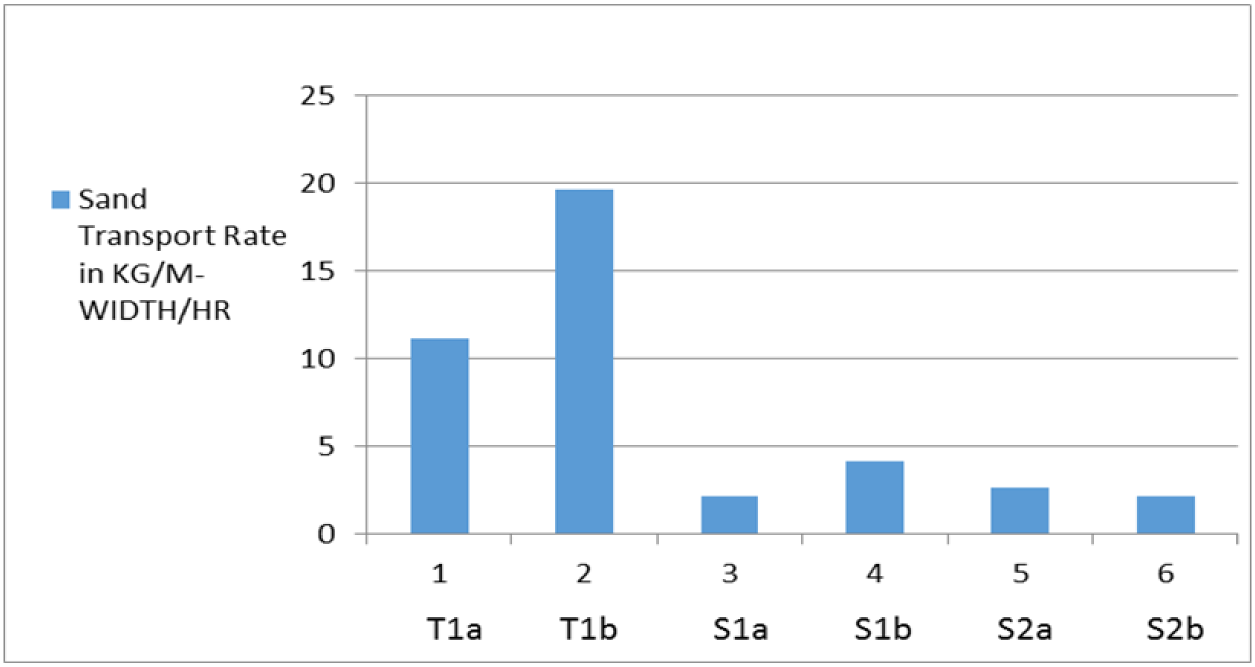

Figure 11. Graph of sand trapped at each blowout where a represents first measurement and b represents the second. S2b is an incomplete measurement as the sand trap collapsed.

Grain Size Analysis

Grain-size analysis shows small variations in grain-size characteristics (Table 2; Figure 11). Sand at the crest of S2 (sample 190) was well sorted, was strongly coarse-skewed, had a mean grain size of 0.27 mm, and had mesokurtic kurtosis. Sand at the bottom of the trough blowout (sample 189), was very well sorted, had near symmetrical skewness, had a mean grain size of 0.28 mm, and had leptokurtic kurtosis. Sand at the crest of the trough blowout (sample 188) was well sorted, had a coarse skewness, had a mean grain size of 0.27 mm, and had a mesokurtic kurtosis.

Sample	Location	Sorting	Skewness (Phi)	Mean Grain Size (mm)	Kurtosis
188	Top of T1	Well sorted	Coarse	0.27	Mesokurtic
189	Bottom of T1	Very well sorted	Near Symmetrical	0.28	Leptokurtic
190	Crest of S2	Well sorted	Strongly Coarse	0.27	Mesokurtic

Table 2. Grain-size characteristics for three blowout locations.

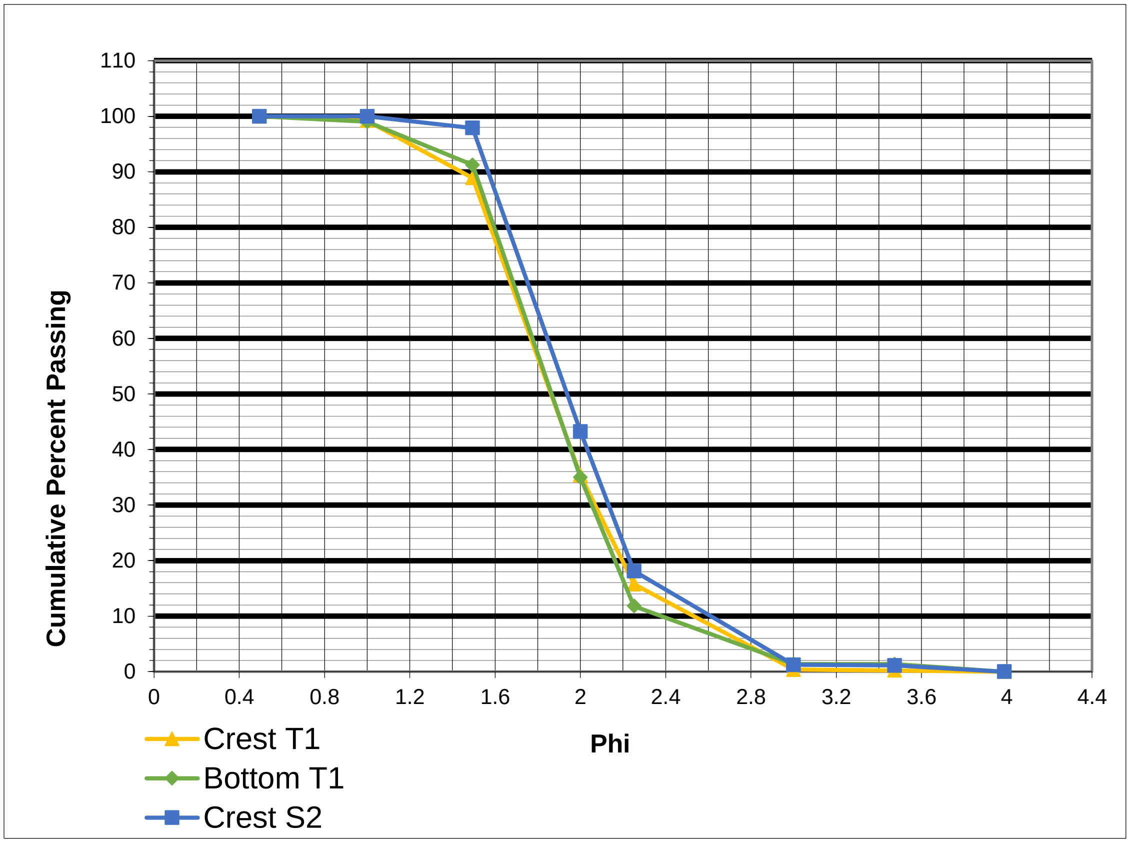

Figure 12. Grain-size curves for three blowout locations.

Discussion

Our findings corroborate results from previous studies (Hesp and Pringle 2001) indicating that wind speed slows as it enters the deflation area of a blowout and speeds up as it exits the deflation area. In our study area the effects of the wind patterns and blowout features intensified the further one went up into the system. The increasing wind speed due to the consecutive blowouts could be a driving factor behind this phenomenon. This would also account for the increase in sand trapped on each consecutive blowout in the dune system.

Another factor driving the increase in wind patterns was the differing shapes and sizes of the blowouts. The lower overall height and the greater width of S1 could account for it seeing less sand transport than S2. Likewise, T1 had by far the most sand transport likely due to its greater area, length, and narrow shape. Greater length of a blowout deflation area also corresponded with increased width but not increased height of the blowout. In addition, the increased height could help steer wind from the west into the blowout.

There seems to be a correlation between increased height, decreased width, and increased length of a blowouts deflation area and the amount of sand trapped on that blowout. The increased area provides more sediment and therefore possibly leads to more sand transport.

The width of the deflation area could be a factor in increased sand transport with narrower deflation areas being better at funneling the wind. This is supported by the increased sand transport at the blowouts with narrower deposition areas. This could be tested by comparing wide and narrow deflation areas that were outside a sequence of blowouts.

Measurements of sand transport were taken during a period of high winds. As such, our findings are more typical of storm conditions rather than normal conditions. Most periods with calmer winds would not have seen the amount of sand transport we observed. However, as storm conditions can account for a significant amount of an area’s sand transport, these results should not be discounted (Sallenger 2000).

Conclusions

The trough blowout was significantly larger than the two saucer blowouts and saw much more sand transport. The blowouts topographical features changed in accordance with how far they were in the dune system. Wind speeds were higher at the crest of the blowout than at the foredune or the bottom of the dune. Further research will be helpful in understanding how blowouts interact with one another and affect the movement of coastal dunes.

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