First-Year Research in Earth Sciences: Dunes

Investigating a Natural Blowout: The Beginning of a Comparison Study

by Hans Leisman, Rachel Commons, Noah DenBleyker, Josh DeVries, Jake Mulder, Kyra Schofield, and Abby Voskuil

FYRES: Dunes Research Report #34
June 2019

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

Abstract

A pair of blowouts in the Kitchel-Lindquist-Hartger Dunes Preserve near Grand Haven, MI, provides a unique location for a comparison study of how blowouts change. Our study focused on the north blowout as a potential control site if management takes place on the south blowout. Our study objectives were to investigate blowout characteristics, measure wind and sand movement, and record vegetation patterns. Methods included GPS mapping, a stadia rod survey, wind measurements, erosion pins to track surface changes, and a vegetation survey. The 16-meter high blowout has an overall rounded "saucer" shape but a deep depression and steep slopes that are more typical of trough blowouts. We documented sand movement on the windward slopes of the blowout, which had other evidence of being the most active part of the dune such as the presence of pioneering species of vegetation and more open sand. In contrast, the slipface is significantly vegetated with many established groups of shrubs and even trees anchoring the slope. This suggests that although the windward slope still experiences sand movement and is active, the slipface of the blowout is stabilizing. To set up the blowout as a control site, we established reference locations to measure dune advance. We also recommend that managers remove some ineffective sand fences on the blowout's windward slope.

Introduction

It is rare that conditions exist in the natural world for an effective comparison study of similar landforms subject to different variables. In the Kitchel-Lindquist-Hartger Dunes Preserve, there is this opportunity. Two similar blowouts are located next to each other. One of these blowouts (the south blowout) is likely to undergo management activities to slow movement towards some human structures. The other blowout (the north blowout) is further away from human structures and is beginning processes of natural stabilization. The blowouts offer a unique opportunity to make comparisons between them as they develop differently in the future. Our work in fall 2018 focused on collecting baseline information and setting up future studies on the north blowout.

The objectives for this study were to 1) investigate blowout characteristics, 2) measure wind and sand movement patterns, and 3) record vegetation patterns.

Background

Blowouts form on pre-existing sand deposits when wind erosion creates depressions or hollows (Gares and Nordstrom 1995; Hesp 2002). Blowouts come in a variety of sizes and shapes, with two common shapes known as trough blowouts (depression is deep and elongated) and saucer blowouts (depression is shallow and more rounded like a saucer) (Trenhaile 1997). Blowout components include a deflation area where wind erodes the dune surface and a downwind deposit of sand called the depositional lobe (Figure 1). Although the depositional lobe

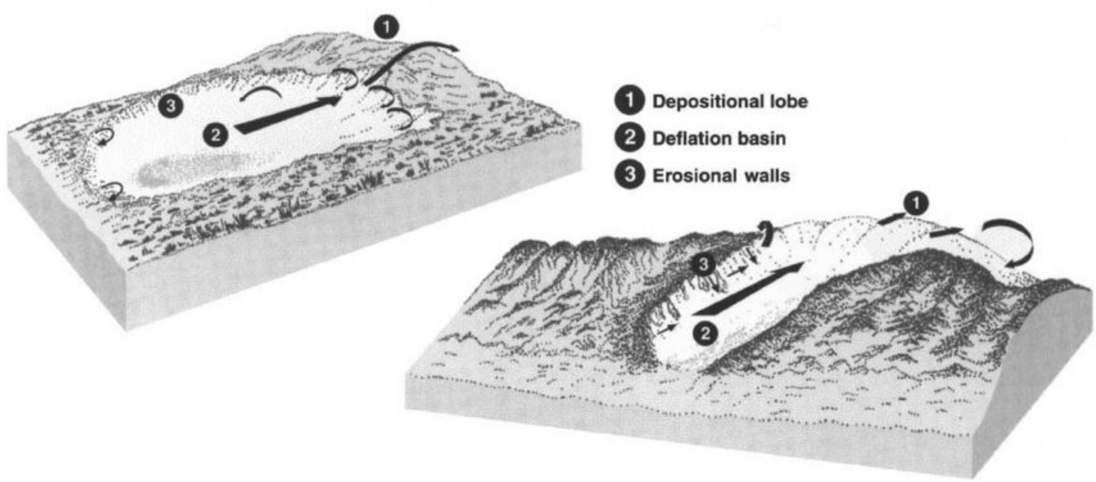


Figure 1. Illustration of a saucer and trough blowout showing shapes, components, and wind flow patterns (from Hesp 2002).

can be upslope from the deflation area where a blowout forms on a larger dune, many blowouts have the two areas separated by the dune crest, with sand moved by wind up the windward slope, over the crest, and deposited on the leeward slope. Because the deposited sand slides down the leeward slope under the influence of gravity, this slope is known as the slipface.

A blowout is started when something disturbs the vegetation on an existing dune, creating an opening in the vegetation that allows wind to erode the bare sand surface and transport the sand in the downwind direction (Gares 1992; Hesp 2002). Hesp's (2002) study of blowouts describes trampling of vegetation and vegetation die off (such as by drought or disease) as two main types of disturbances that create blowouts. Other possible disturbances come from weather (strong winds or wave erosion during storm events or fires started by lightning), animals (grazing), human activities (driving vehicles on the dunes or removing sand during construction), and natural dune processes (such as inputs of moving sand that bury vegetation).

Wind flow both affects the surface changes in the blowout and is itself influenced by the dune topography. Where winds are strong, sand is eroded and transported, but the sand is deposited where wind speed drops below a critical level. Because wind speeds increase as wind moves up a slope, the upper windward slope and crest tend to be the areas of greatest erosion. Deposition occurs where wind speeds decrease because of topography (the sheltered leeward slopes of the dune) or where vegetation slows down the wind. Topographic steering of the wind has been measured in deep or large trough blowouts, where winds may approach the blowout from different angles but are steered by blowout slopes to align more closely with the main direction of the blowout (Fraser *et al.* 1998; Hansen *et al.* 2009; Pease and Gares 2013). These studies also demonstrated that the wind flow separated from the slope as wind went over the crest, creating a stagnant (low wind) zone in the lee of the crest, followed by downwind reattachment of the wind to the dune slopes (Pease and Gares 2013).

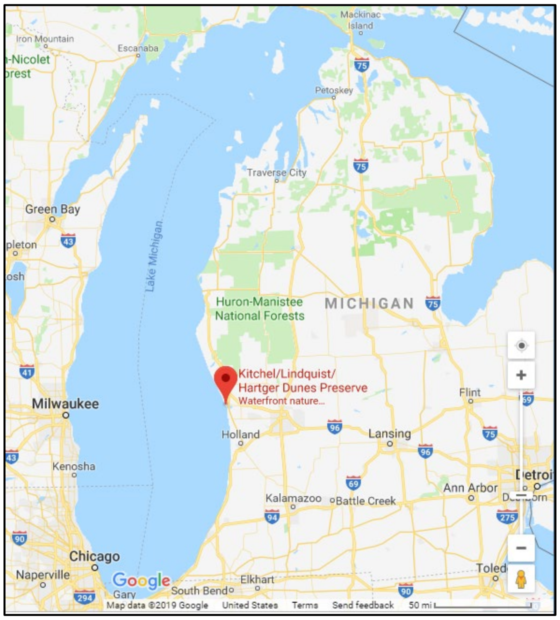
Interactions between wind, sand supply and vegetation affect the evolution of the blowout. Wind erosion can enlarge the deflation area, moving more sand to the depositional lobe, and generating or increasing dune advance at the bottom of the slipface. A deflation area may have a lower limit for wind erosion because the erosion reaches the groundwater surface or different sediments (Bauer and Sherman 1999). Vegetation also reduces the susceptibility of a surface to wind erosion, and the spread of vegetation in the deflation area can stabilize a blowout. Hugenholtz and Wolfe (2006) found that a limited sand supply leads to more vegetation on a dune surface, and more vegetation leads to sand deposition. The positive feedback between vegetation growth and sand deposition may end the cycle of blowout initiation, growth and healing (Bauer and Sherman 1999). Other influences may also be present and blowout life-spans can be short; Trenhaile (1997) reported that the rapid colonization and stabilization by algae resulted in many blowouts in the Netherlands not surviving more than five years.

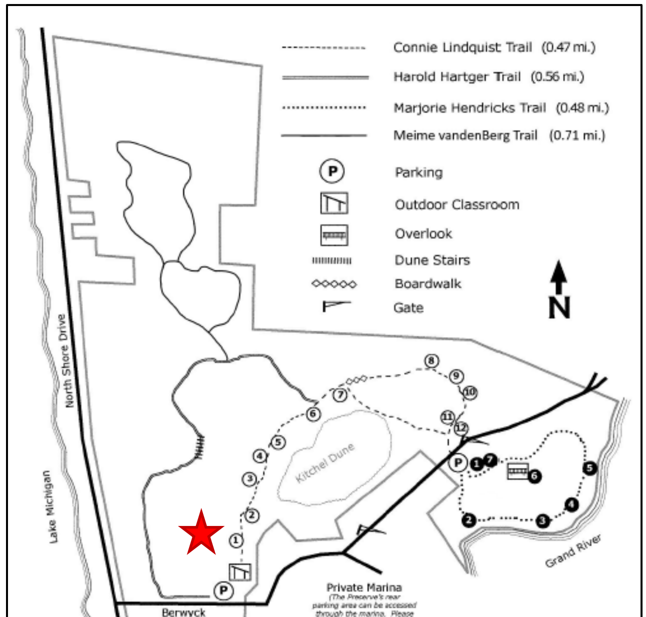
Vegetation is not only an essential player in blowout dynamics, but it serves as an indicator of surface stability or activity levels. Bare sand or very sparse vegetation are indicators of erosion or deposition in amounts large enough to inhibit vegetation growth. Pioneering species indicate that conditions are within the range that species adapted to particular conditions can survive. For example, *Ammophila breviligulata* (American beach grass or marram grass) needs some sand burial to thrive; it does well in sand deposition up to 60 cm/year but can survive up to about 100 cm of burial per year (Maun 1984). The threatened species *Cirsium pitcheri* (Pitcher's thistle) needs some sand disturbance to stimulate its growth, but its maximum tolerance is a one-time burial of 15 cm or 75% of its height (Maun *et al.* 1996). Early-succession species, including a variety of herbaceous vegetation and dune-building shrubs, are indicators that the dune surface is stable enough for the species to do well (Olson 1958). Apart from *Populus deltoides* (cottonwoods) and *Tilia Americana* (basswood) which can tolerate some sand burial, most trees are indicators of a greater amount of surface stability at that location (Olson 1958).

Some human interventions on dunes can replace or augment the natural role of vegetation in stabilizing dune surfaces. One common management strategy is to install sand fences, either for stabilization or to control human traffic or protect vegetation (Grafals-Soto and Nordstrom 2009). If a sand fence is intended to slow down wind speed and sand transport (either to reduce erosion or encourage deposition), then it is most effective if it is installed perpendicular to the direction of the sand-moving winds or in a zigzag pattern if sand is moving from different directions (Grafals-Soto 2012), has a porosity of 0.3-0.6 (Dong *et al.* 2006), and is one of multiple rows of fences (Grafals-Soto 2012). Fences installed to decrease human access are often placed across unmanaged paths or at the boundary of an area to be protected (Etienne *et al.* 2016). Depending on whether this placement coincides with effective characteristics for slowing down wind, these fences may or may not have the effect of producing sand deposition downwind from the fence. Etienne *et al.* (2016) noted damage to fences is a variable that likely reduces the effectiveness of the fences.

Study Area

Our research site is a blowout located in the Kitchel-Lindquist Hartger (KLH) Dunes Preserve (Figure 2), a 115-acre protected area with sand dunes and natural trails located north of Grand Haven, Michigan (Nature Org 2017).





Source: KLH Trail map from Nature Org (2017)

Figure 2. Location of Kitchel-Lindquist-Hartger Dunes Preserve and the study area location in the preserve (red star).

This study focused on the north blowout of a pair of two similar blowouts (Figure 3). Both blowouts are located east of row of beach-front houses and adjacent to the North Shore Marina. The blowouts share a ridge and are of similar size and shape. The south blowout was the focus of a concurrent study by Duimstra *et al*. (2019). The south blowout is closer to the education building in the KLH Dunes Preserve and therefore might be the focus of future management activities. Both blowouts were previously studied by Karsten *et al.* (2013).

Figure 3. North blowout (circled) and nearby south blowout.

The north blowout, which will be referred to as the “natural blowout” in this study, is further away from the parking lot and education building for KLH Dunes Preserve. The term natural blowout refers both to observed current conditions (Figure 4) and future recommendations for the dune.

Figure 4. View (from the blowout crest) looking down into the natural blowout. In the background (west of the blowout), houses and Lake Michigan are visible.

Several previous studies have included the north blowout or both blowouts. Karsten *et al.* (2013) investigated patterns of vegetation and sand transport on both blowouts. The study concluded that both blowouts were active, but the north blowout was less active, and it might be undergoing a period of stabilization (Karsten *et al.* 2013). VanEyl-Godin *et al.* (2014) installed dune pins in the north blowout to test the use of photographic measurements of dune surface changes. They concluded that surface change was patchy but there was net erosion in the deflation area of the blowout during their study (VanEyl-Godin *et al.* 2014).

Methods

During the fall of 2018, field data collection took place during three site visits: October 25, November 1, and November 8. Data collection focused on investigating blowout characteristics, measuring wind and sand movement, and recording vegetation patterns.

Investigating Blowout Characteristics

We investigated blowout topography by measuring the slope angles and dune elevation with a stadia rod survey along two transects (survey lines). This method measures distances and surface heights relative to a starting point so that the topography can be plotted along the transect. One transect went from the western edge of the blowout to the blowout crest, and the second transect went from a high point on the north arm to a high point on the south arm. Because the survey team adjusted the profile direction while surveying in order to capture more of the dune, the team is not confident about where the intersection of the two profiles is.

Dune characteristics such as the crest, wetland areas, sand fences, and overall shape were documented and mapped using Trimble Juno GPS units. We photographed blowout features and conditions to provide a baseline dataset for comparison with future studies investigating blowout changes.

Measuring Wind and Sand Movement

We obtained wind measurements from reference anemometers at four heights (0.5 m, 1 m, 2 m, and 4.55 m above the ground) and a wind vane located approximately 5 kilometers north of our study site in P.J. Hoffmaster State Park. Wind measurements were electronically collected every 15 seconds and averaged or totaled every 30 minutes and daily. We supplemented this data with handheld anemometer measurements taken in the KLH blowout.

We measured short-term surface changes with erosion pins. At five representative locations erosion pins were placed: two at locations on the crest, one west of the sand fence, one east of the sand fence, and one in the middle of the blowout. During the first site visit (October 25), the erosion pins were hammered into the dune and measured. In the next two weekly site visits, the pins were measured again. Measurements were taken from the top of the dune surface (sand) to the top of the erosion pin. We also deployed sand traps at several blowout locations while we were at the site to document short-term sand movement.

We made some estimates of longer-term surface changes using erosion pins which were present in the blowout when we started our study. We noted visible differences in burial at the pins, such as locations where much less of the pin was exposed above the ground compared to other areas. Upon consulting with KLH Managers, we learned that the pins were from a Hope College study that was no longer active. Therefore, we removed the pins from the dune and returned them to Hope College. Subsequently we learned that the pins were likely installed in the blowout in June 2013 (VanEyl-Godin *et al.* 2014).

To investigate dune advance, baseline reference points were established so that future studies can revisit the natural blowout and observe the rate of advance. For reference points, we looked for distinctive features which were likely to remain at the same location for a number of years, such as established trees, sign posts, corners of trails, etc. For each reference point, we recorded the distance from the edge of the dune, the compass direction of the distance measurement, and a description of the surrounding area. The edge of the dune was defined by the change in topography from the steeper-angled slipface to the more horizontal ground near the dune. We took photographs and mapped the reference points with GPS to supplement our written notes.

Recording Vegetation Patterns

We recorded vegetation patterns by measuring species types, heights, and health at sampling locations on the blowout. Our study used ten different quadrat throws to find the sampling locations. Starting from the leeward slope of the dune, the vegetation survey team walked a transect line across the dune and threw the 0.5 m by 0.5 m quadrat to randomly select a sampling location in each different vegetation community. Vegetation communities were identified by major changes in vegetation, such as shrubs vs. dune grasses vs. trees vs. open sand. For each 0.5x0.5 plot, the number of types of vegetation were counted, attempts were made to identify the different species, photographs were taken, percent coverage of vegetation was estimated, the height of the tallest plant was measured, and the health of the plants (percent healthy) was estimated.

We mapped the spatial patterns of vegetation communities on the blowout with GPS, with a focus on the dune grasses, trees, and shrub areas. For the vegetation and other collected GPS data, we downloaded the data using GPS Pathfinder Office. Before exporting the data to

ArcGIS, we used the software to increase data accuracy by applying a differential correction using a base station along the lakeshore. In ArcGIS we combined the data to produce maps, such as a map of vegetation patterns on the blowout.

Results

Blowout Characteristics

The blowout has traits of both saucer and trough blowouts (Figure 5). The shape of the deflation area is saucer-like, with length and width both in the 50-60 m range. The blowout depth is trough-like, with a relief of 15-18 meters between the lowest area of the blowout and its crest. The dune crestline mapped in Figure 5 is a visible boundary between the bare-sand deflation area and the vegetated outer slopes (and deposition areas) of the blowout. The lowest point of the blowout is a small depression that was visibly wetter than the surrounding dune during our site visits.

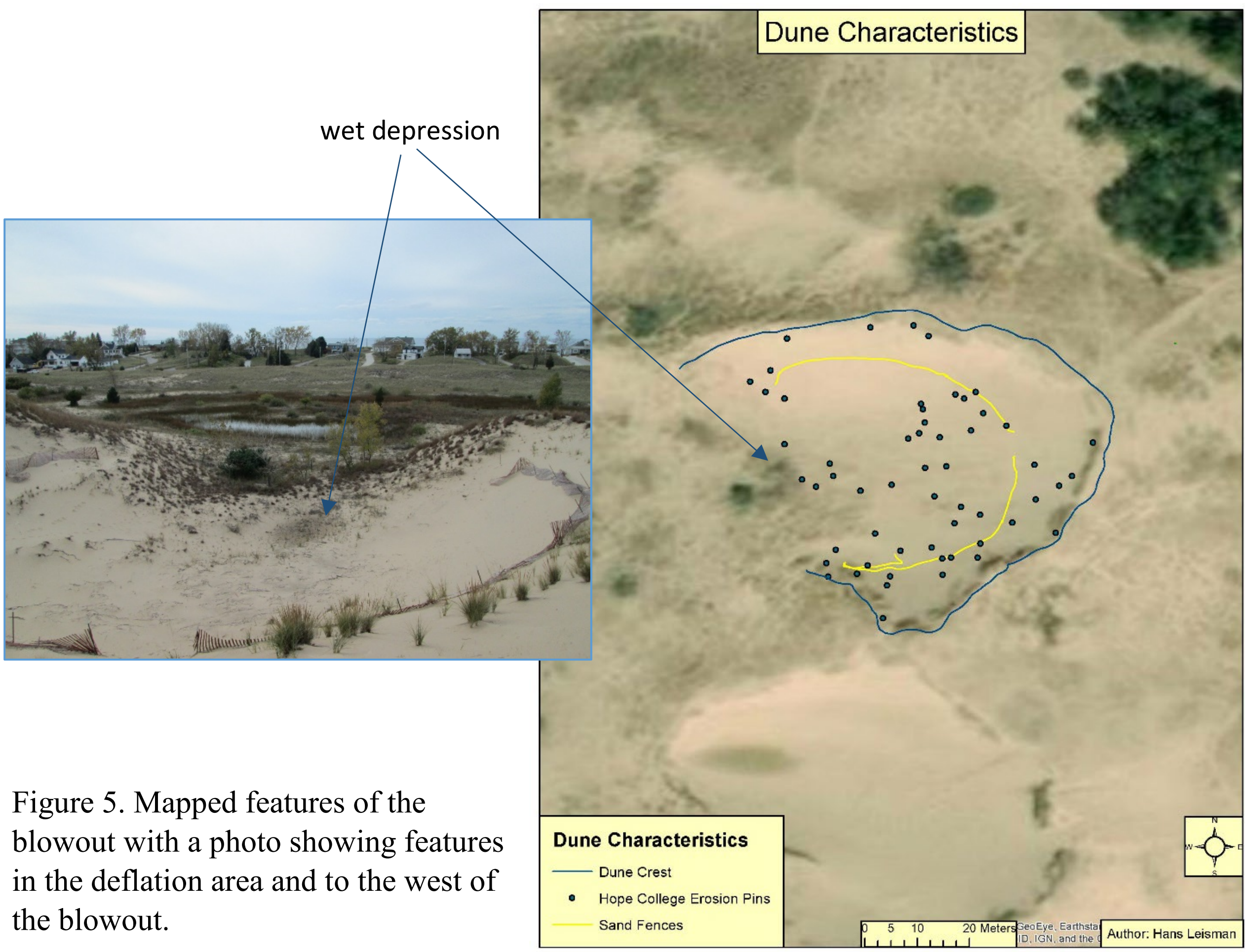


Figure 5. Mapped features of the blowout with a photo showing features in the deflation area and to the west of the blowout.

The survey profiles (Figures 6 and 7) show that the blowout height was 16 meters, and the arm-to arm length was approximately 60 meters. The wet depression is visible in Figure 7 as the low point in the profile at about 10 meters distance. Both profiles show the steep angles of the upper slopes in the deflation area.

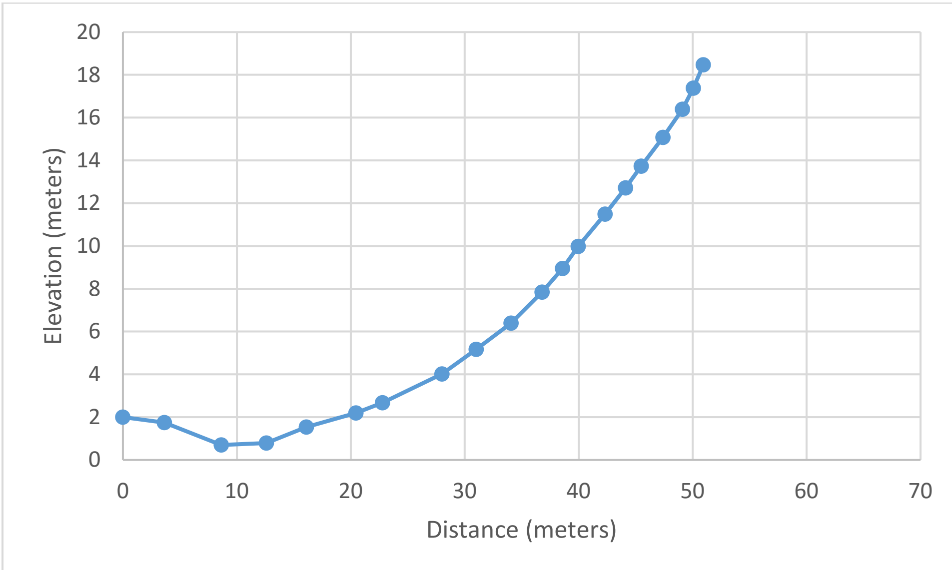


Figure 6. Profile from west to east in blowout deflation area.

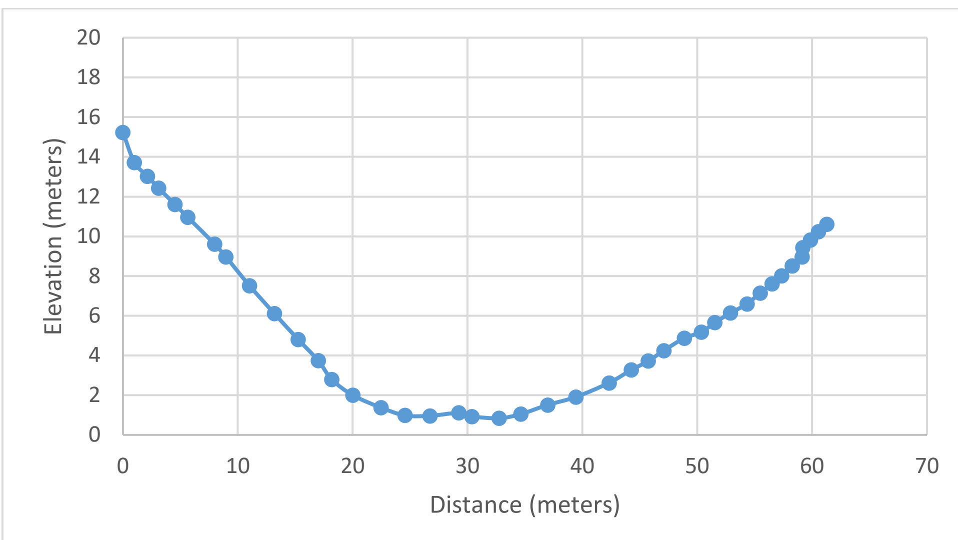


Figure 7. Profile from north to south across the blowout from arm to arm.

Human features recorded in the blowout included sand fences and erosion pins left behind by a previous study done by Hope College. The sand fences were on the upper slope of the deflation area and roughly paralleled the dune crest (see Figure 5 for mapped locations and photo view). The sand fence type was wood slat and wire with roughly 50% porosity; fences were attached to the dune by metal poles installed in the dune. We did not observe topographic changes near the sand fence that would indicate deposition (mounds of sand), and we did not measure such changes in our profiles. Sections of the sand fence were leaning over and/or had become detached from their anchoring poles (Figure 8).

Figure 8. Sand fence type and condition in the blowout

Wind and Sand Movement Patterns

Local wind data shows a small wind event in the first week between site visits and a stronger event in the second week (Figure 9). The substantial wind event took place from 11/05/2018 to 11/07/2018 and reached average wind speeds of nearly 10 m/s. Wind speeds during this time were more than double the previous wind speeds. Wind directions were variable over the two weeks, but during the November 5-7 event the winds were consistently from the west.

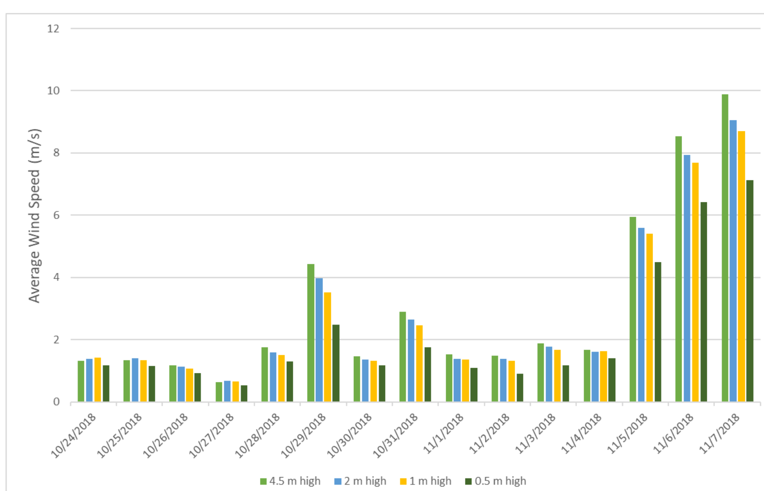


Figure 9. Wind speeds recorded at Hoffmaster sensors.

Measurements at erosion pins show deposition at all pins during the first week of measurements (October 25-November 1) with amounts ranging from 2-5 cm (Figure 10). During the second week of measurements (November 1-8), there was some erosion recorded in the middle of the deflation area and deposition up to 2.5 cm recorded at dune crest locations. Observations of the Hope College erosion pins indicated that there was deposition (erosion pins were buried deeper in the sand) on the crest, arms and leeward slopes of the dune. Pins in the middle of the deflation area had more pin visible, suggesting erosion.

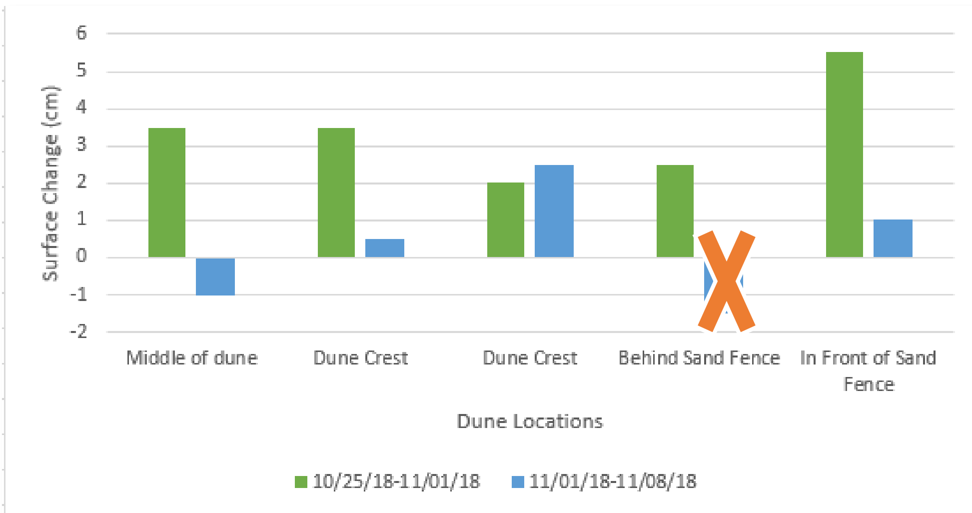


Figure 10. Surface changes recorded at erosion pins for the two weeks of the study. The X indicates results from a pin that appeared to be disturbed by human or animal during the study.

Four reference points were established for future measurements of dune advance (Table 1). Distances from the reference markers to the dune edge ranged from 4-12+ m. Appendix A has more information about the reference points, including GPS locations and photos.

Point	Marker	Distance from Dune (m)	Compass Direction from Dune (degrees, bearing)	Comments
A	Tree (pine)	3.98	220 (SW)	Part of a clump of trees; lots of pine cones on tree
B	Tree (pine?)	6.97	255 (SW)	Tree standing by itself in this area
C	Sign	6.31	274 (W)	Near managed trail; sign has image of person walking
D	Tree (fruit)	12.26	308 (NW)	Dark green tree with significant foliage; fruit similar to blueberry.

Table 1. Information for established reference points for measuring dune advance

Vegetation Patterns

The blowout has served several different vegetation communities, including bare sand, pioneering grasses, early succession species (grasses and shrubs), and some scattered trees (Figure 11). Inside the blowout, *Ammophilia breviligulata* (dune grass) roughly follows the sand fences, but overall this grass is very sparse on the windward slope (Figure 12). Dune grass was more dense on the leeward slope, arms, and area to the west of the blowout. More established vegetation including a variety of shrubs and multiple species of pine trees indicate that the leeward slope of the blowout is stabilizing naturally (Figure 13).

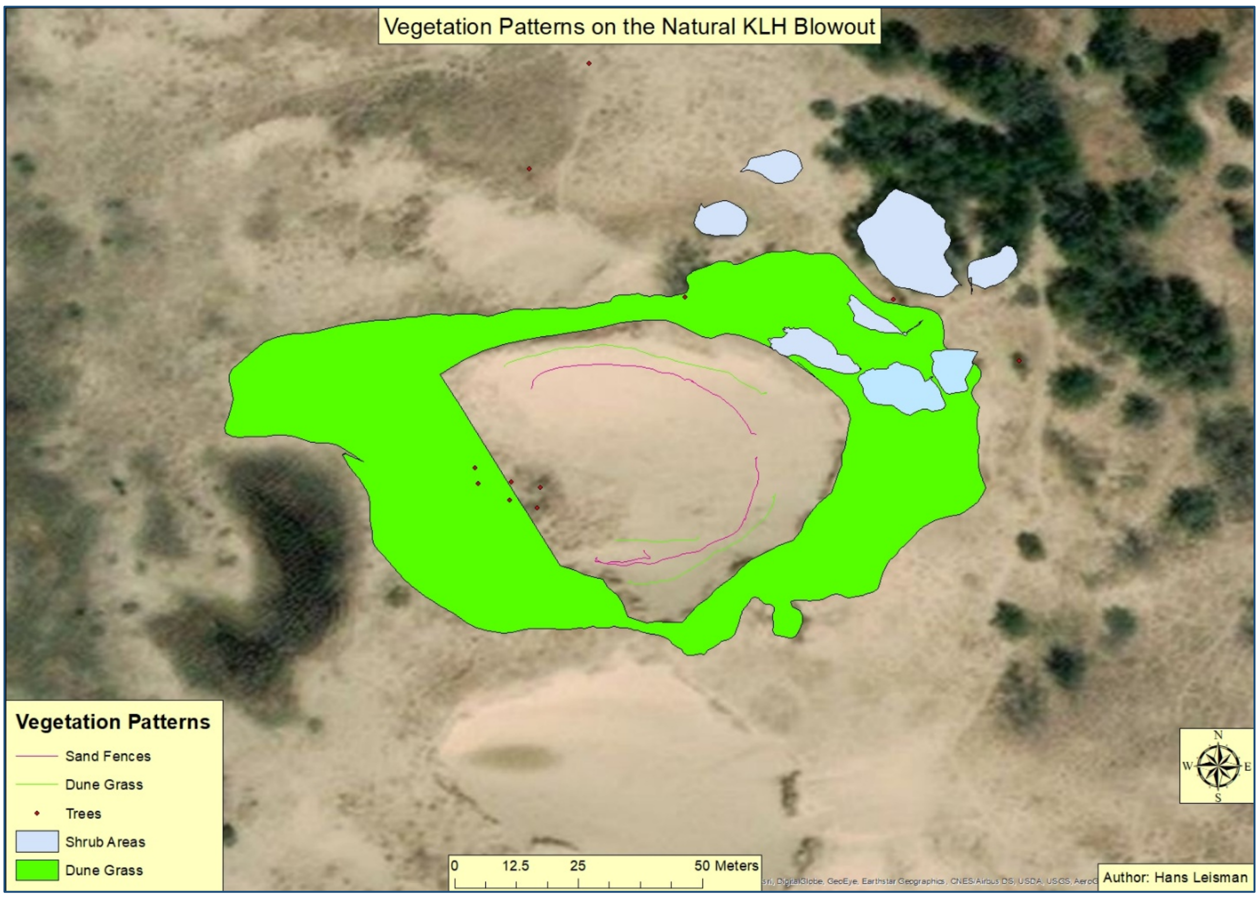


Figure 11. Patterns of vegetation mapped in the blowout

Figure 12. Much of the vegetation in the deflation area is close to the sand fences.

Figure 13. Slipface vegetation includes shrubs and trees.

Discussion

The measured characteristics suggest this blowout is a significant landform in Kitchel-Lindquist-Hartger Dunes Preserve. With a height of 16 meters, this blowout would be considered large in many other coastal areas (such as Atlantic and Gulf coast barrier islands), but in west Michigan it is dwarfed by the 45-80 meter-high parabolic dunes found in North Ottawa Dunes and Hoffmaster State Park. Therefore, we can best describe this dune as a medium-sized blowout. Blowout shape seems to be transitional between saucer and trough shaped, with the rounded footprint having saucer tendencies, but the deep depression and steep sides of the deflation area resembling a trough blowout. Both blowout size and shape suggest that it is likely doing some steering of winds when they reach the blowout.

In the deflation area, the sparsity of established vegetation and the surface changes measured at erosion pins indicate that the windward slopes of the blowout are still active. These short-term indicators are supported by the observations from the Hope College erosion pins: that there is erosion taking place in the deflation area and deposition on the outside arms and leeward slope of the blowout. The presence of a wet depression in the deflation area suggests that erosion has reached the groundwater surface (water table) here, which is likely to be a limiting factor to further wind erosion at this location. Because the groundwater surface varies in response to precipitation, temperatures and lake levels, this may not be a long-term limitation.

Although the deflation area shows signs of active erosion, the presence of established shrubs and trees on the leeward slope indicate a natural process of stabilization is underway for the deposition lobe of the blowout. Annual amounts of wind-blown sand moving over the blowout crest must be below the burial tolerance levels for these species or they would die. The *A. breviligulata* has been shown to tolerate burial amounts up to 1 meter per year (Maun 1984), but the other early- and mid-succession species on these slopes need more stable environments. We did not see many indicators of large amounts of deposition, such as mounds of fresh sand, so we estimate that the amount of deposition is much lower than 1 meter per year. Future measurements of dune edge position relative the reference markers established in this study will be able to show whether the dune is advancing and how fast. Repeating dune advance measurements, along with recording vegetation patterns in the deflation area of the blowout will allow some conclusions about whether the blowout is maintaining its current level of activity, is becoming more active, or is becoming more stable over time. Our current study does not provide enough information to draw those conclusions, but we note that any of those three scenarios is natural behavior for a blowout and does not need to be managed.

Of the human impacts recorded in our study, the sand fences present on the dune appear to be the most significant. The presence of vegetation near the sand fences on the upper windward slopes of the blowout indicates some success of this management action. However, in October-November 2018 the sand fences were in generally poor condition and did not appear to be affecting sand movement on the dune, as shown by the lack of sand deposits near the fences. Two reasonable options for dune managers would be 1) to replace them with more effective sand fences or 2) to remove them from the dune altogether. Based on observations that sand movement was not affected substantially by the sand fences and the vegetation indicators of stabilization on the leeward slope, we recommend taking out the sand fences. In addition to making the natural blowout more aesthetically pleasing, it will also allow the natural blowout to be a more interesting and natural control site for future studies of the adjacent dune.

One important but unpredictable consequence of removing the sand fences is the future of the grasses growing near the current fences. Because the grasses appear to have some spatial connection to the fences, we do not know whether they will continue to thrive on their own. In other management contexts, sand fences have been put in place while planted vegetation establishes itself and then the fences have been removed when the vegetation can continue thriving without the aid of the fence. Removing the sand fences will provide an interesting test of the effect on the vegetation. Based on other indicators of dune activity level, such as stabilization on the leeward slope, we expect the dune grass to continue to grow in the absence of sand fences.

We have several recommendations for future studies, some of which have already been suggested in the previous paragraphs. More detailed study of the vegetation patterns on the blowout, and particularly how different species relate to areas of dune activity or stabilization, would be valuable for this particular blowout and more generally for building knowledge of Michigan dunes. Both *A. breviligulata* (tolerating sand burial up to 100 cm) and *C. pitcheri* (tolerating sand burial up to 15 cm) have their relationships with sand movement identified by previous studies (Maun 1984; Maun *et al.* 1996). Their presence in or near this blowout may be helpful for assessing dune activity patterns. (We did not see *C. pitcheri* in our study area, but we did see some plants to the north of the blowout). Direct measurements of the advance rate of the blowout will be very valuable to understanding the blowout's activity level and trends. If the sand fences are removed, investigating whether there are any changes to the blowout will be valuable to dune managers along the lakeshore who might consider removing sand fences in some of their dune areas. If the nearby south blowout does undergo more intense management to slow down its advance towards the outdoor classroom, the north blowout will serve as a useful, natural comparison site to identify the impacts and effectiveness of the management activities.

Conclusions

The north (or natural) blowout in the pair of blowouts near the outdoor classroom in Kitchel-Lindquist-Hartger Dunes Preserve is a 16-meter high blowout with characteristics of saucer (the rounded footprint) and trough (the deep depression and steep slopes) blowouts. The windward slope is active, with evidence including bare sand surfaces, pioneering vegetation, and measured surface change. The leeward slopes have more evidence of stabilization, including the growth of shrubs and trees. Sand fences on the windward slope are visible evidence of human presence in the form of management, but the fence condition is poor and there is little current evidence that it is effective.

We established reference points for measuring blowout advance rates and we recommended taking out the sand fences. These actions, plus the additional questions generated by our study, provide a good foundation for future investigations of the blowout. If some new management actions are implemented on the nearby south blowout, then investigating the future changes to both blowouts will make a very interesting comparison of how similar blowouts with some different variables change over time. With or without the comparison study, the north blowout poses some intriguing questions about its possible trend towards natural stabilization that can only be answered by collecting future data and comparing it with past measurements.

Acknowledgements

We would like to thank Kitchel-Lindquist-Hartiger Dunes Preserve Board for giving us permission to investigate this very interesting blowout. We appreciate the direction and mentoring of Professor Deanna van Dijk. We are grateful to Calvin College and the Department of Geology, Geography, and Environmental Studies for providing equipment, training and logistical support. We also thank the Michigan Space Grant Consortium for funding which made this study possible.

Works Cited

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

Dong, Z., G. Qian, W. Luo, and H. Wang. 2006. "Threshold velocity for wind erosion: The effects of porous fences." *Environmental Geology* 51 (3): 471-75.

Duimstra, P., C. H. Anderson, K. C. Benedict, H. I. Box, K. VanDerAa, L. Vargas, and A. Volzer. 2019. "Considering management for a blowout in Kitchel-Lindquist-Hartgers Dunes Preserve." FYRES: Dunes Research Report #35. Grand Rapids (MI): Department of Geology, Geography and Environmental Studies, Calvin College. 16 p.

Etienne, K. A. Crevier, J. M. Davis, S. A. Praamsma, and A. A. Tauscheck. 2016. "Evaluating sand fence placement, purpose and efficacy on west Michigan dunes." FYRES: Dunes Research Report #20. Grand Rapids (MI): Department of Geology, Geography and Environmental Studies, Calvin College. 19 p.

Fraser, G. S., S. W. Bennett, G. A. Olyphant, N. Bauch, V. Ferguson, C. A. Gellasch, C. L. Millard, B. Mueller, P. O'Malley, J. N. Way, and M. C. Woodfield. 1998. "Windflow circulation patterns in a coastal dune blowout, south coast of Lake Michigan." *Journal of Coastal Research* 14 (2): 451-460.

Gares, P. A. 1992. "Topographic changes associated with coastal dune blowouts at Island Beach State Park, New Jersey." *Earth Surface Processes and Landforms* 17: 589-604.

Gares, P. A., and K. Nordstrom. 1995. "A cyclic model of foredune blowout evolution for a leeward coast: Island Beach, New Jersey." *Annals of the Association of American Geographers* 85 (1): 1-20.

Grafals-Soto, R. 2012. "Effects of sand fences on coastal dune vegetation distribution." *Geomorphology* 145: 45-55.

Grafals-Soto, R., and K. Nordstom. 2009. "Sand fences in the coastal zone: Intended and unintended effects." *Environmental Management* 44 (3): 420-429.

Hansen, E., S. DeVries-Zimmerman, and D. van Dijk. 2009. "Patterns of wind flow and aeolian deposition on a parabolic dune on the southeastern shore of Lake Michigan." *Geomorphology* 105: 147-157.

Hesp, P. 2002. "Foredunes and blowouts: Initiation, geomorphology and dynamics." *Geomorphology* 48: 245-268.

Hugenholtz, C. H., and S. A. Wolfe. 2006. "Morphodynamics and climate controls of two aeolian blowouts on the northern Great Plains, Canada." *Earth Surface Processes and Landforms* 31: 1540-1557.

Karsten, J., G. LePage, M. Messina, D. Shisler, and J. Smith. 2013. "Sand transport and vegetation in two Lake Michigan blowouts in Ottawa County, Michigan." FYRES: Dunes Research Report #8. Grand Rapids (MI): Department of Geology, Geography and Environmental Studies, Calvin College. 22 p.

Maun, M. A. 1984. "Colonizing ability of *Ammophila breviligulata* through vegetative regeneration." *Journal of Ecology* 72: 565-574.

Maun, M. A., H. Elberling, and A. D'Ulisse. 1996. "The effects of burial by sand on survival and growth of Pitcher's thistle *(Cirsium pitcheri)* along Lake Huron. *Journal of Coastal Conservation* 2 (1): 3-12.

Nature Org. 2017. "Kitchel-Lindquist-Hartger Dunes Preserve." Accessed on 12 June 2019. www.klhdunespreserve.org.

Olson, J. S. 1958. "Rates of succession and soil changes on southern Lake Michigan sand dunes." *Botanical Gazette* 119 (3): 125-170.

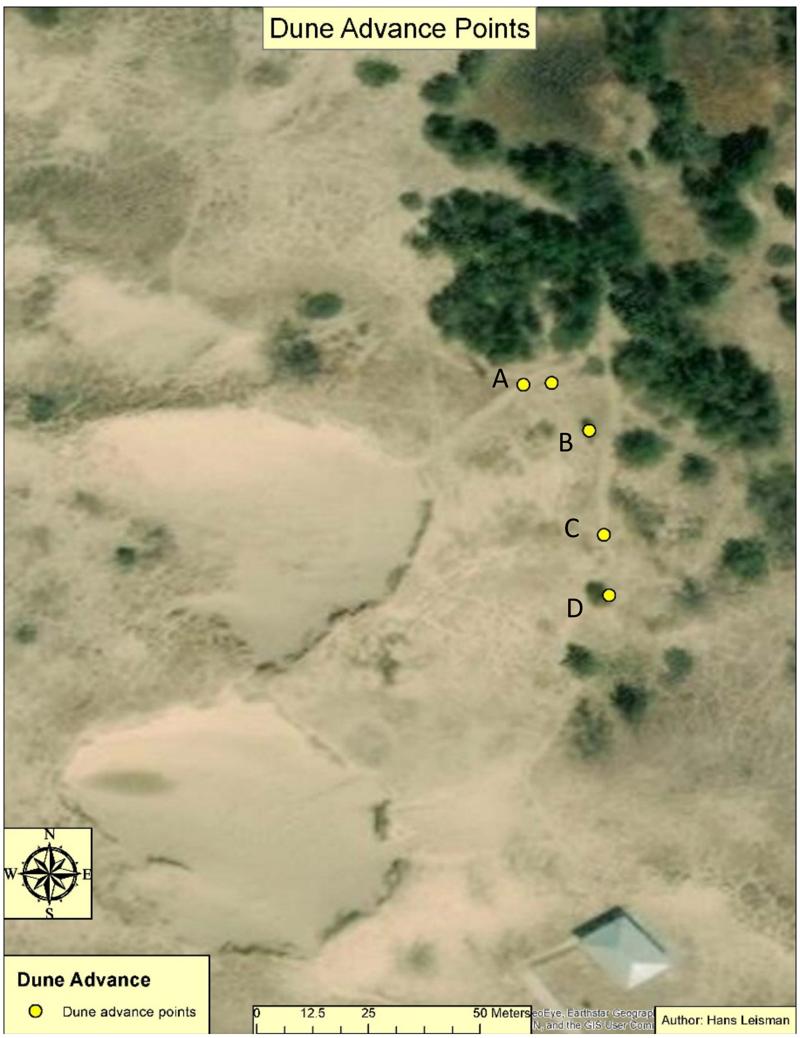
Pease, P. and P. Gares. 2013. "The influence of topography and approach angles on local deflections of airflow within a coastal blowout." *Earth Surface Processes and Landforms* 38: 1160-1169.

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

VanEyl-Godin, K., K. E. VanZytveld, J. Hunter, and B. E. Bodenbender. 2014. "Photographic measurement of sand movement in gigapixel panoramas reveals short term variability in geomorphologically similar Lake Michigan dunes." *Abstracts with Programs – Geological Society of America* 46 (6): 306.

Appendix A. Reference Points Established at the North KLH Blowout

Point	Marker	Distance from Dune (m)	Compass Direction from Dune (degrees, bearing)	Comments
A	Tree (pine)	3.98	220 (SW)	Part of a clump of trees; lots of pine cones on tree
B	Tree (pine?)	6.97	255 (SW)	Tree standing by itself in this area
C	Sign	6.31	274 (W)	Near managed trail; sign has image of person walking
D	Tree (fruit)	12.26	308 (NW)	Dark green tree with significant foliage; fruit similar to blueberry.



Map shows locations of reference points. (Extra point shown was considered as a reference point and then changed to a better location.) Photos of each point from two different angles are on the following pages.

Photos of Reference Point A – Pine Tree

Photos of Reference Point B – Tree

Photos of Reference Point C – Sign

Photos of Reference Point D – Tree