A Volumetric Analysis of Coastal Dune Blowout Morphology Change, Pinery Provincial Park

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Abstract

A coastal dune trough blowout was studied in Pinery Provincial Park between 1999-2001. The park and the dunes are located on Lake Huron's western shoreline, where the sediment budget is rapidly increasing due to recent drops in Great Lake water levels allowing for a greater amount of exposed sand. This increased sediment supply may provide a catalyst for increased foredune development and increased volumes of sand transported through the blowout. Primarily, three research objectives were pursued throughout this study. Field research objectives included erosion pin measurement to monitor and verify morphological change through the throat of the blowout and aeolian sediment trap volume measurements to establish transport into and out of the blowout. Three-dimensional maps were utilized to calculate volumetric change between different study seasons. The greatest morphological change noted through these research objectives was rapid sediment deposition on the lakeward side of the foredune.

Introduction

Coastal dunes are found above high water marks of sandy beaches and can occur on ocean, estuary and lake shorelines (Carter *et al.*, 1990). Dune formation is a function of sediment grain characteristics and supply, the beach profile, and the wind regime. Several areas of dunes can be found around Great Lakes shorelines. Davidson (1991) identified 20 different sand dune locations along Ontario's shorelines, all of which are in different stages of maturity and erosion, due primarily to human influences.

The study site, within Pinery Provincial Park, is located on Lake Huron's eastern shore (Figure 1). Lake Huron water levels fluctuate over different temporal scales. Water levels have been declining over the past three years due to a combination of lower precipitation, higher air temperatures, and increased evapotranspiration in the Great Lakes basin (GLERL, 2000). The decreased lake level has allowed an opportunity to make a comparative analysis between data collected in 1995 (Byrne, 1997), when Lake Huron was at a relative high level, and during 1999 and 2000 when the Lake Huron was at a relative low. The more recent study occurs during a period of low lake levels, therefore having a much larger beach surface area, and ultimately a much larger sediment supply available to enter the dune system.

Figure 1. Location of Pinery Provincial Park.

Byrne (1997) studied the seasonal variations of sediment transport through a blowout in a secondary dune ridge. Blowouts are saucer-, cup-, or trough-shaped depressions or hollows formed by wind erosion on a pre-existing sand deposit (Hesp and Hyde, 1996).

Pinery Provincial Park dunes are part of a nature reserve section of the park (OMNR, 1986). The dunes are subject to intense recreational traffic which cause many erosional features, usually initiated by human trampling (Bowles, 1980). The park management plan has changed such that most of the park is now protected zones, in which park users are banned from moving freely off park road and trail networks. Part of the park's mandate is to conduct dune preservation research and use this research to make informed management decisions to protect the dunes and the overlying Oak-Savannah ecosystem. The research conducted on sediment transport, and transport during different time periods, will help managers to plan dune stabilization strategies.

Study Site

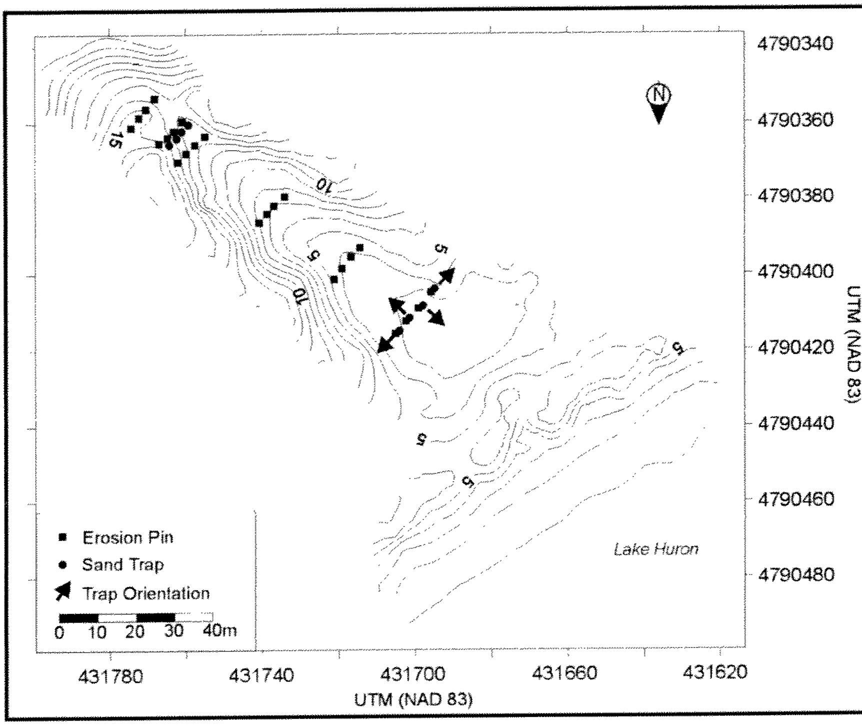
The field studies were conducted on the sand dunes along Lake Huron behind the foredune ridge. The study site is a small trough blowout located in the wilderness area of Pinery Provincial Park (Byrne, 1997). The 250 m long 90 - 75 m wide dune is a complex, digitate dune (Pye and Tsoar, 1990). The axis of the blowout (northwest to southeast) is normal to the foredune ridge and shoreline of Lake Huron. Winds are strongest form the north, west and south, while easterly winds are relatively weak. Park climate is characterized by warm summers and cold winters, with rapid changes in conditions with the passing of mid-latitude depressions. Precipitation is spread evenly throughout the year with slight peaks in February and March (Fisher *et al.*, 1987; Byrne, 1997). Snowfall usually begins in late November and ends at the beginning of April. The mean frost-free period is 150-160 days, with a 205 day growing season (Fisher *et al.,* 1987). The dominant vegetation in the foredune and along the crest of the trough blowout is *Ammophila breviligulata*, with occasional clumps of *Calamovilfa longifolia*. Both plants are perennial dune forming grasses, and are effective in trapping sand, and both possess pronounced abilities to elongate upwards in response to sand accumulation (Maun, 1984, 1985).

Methods

To quantify a relative amount of sediment movement through the trough blowout, measurements of sand flux were obtained using vertical cylindrical traps developed by Leatherman (1978) and enlarged by Rosen (1979). The traps were placed in two arrays of four traps; traps one through four were lined up in the lower opening of the blowout and traps five through eight were lined up in the throat at the crest of the blowout as seen in Figure 2. The open direction of the traps, which were lined up in four cardinal directions relative to the blowout's orientation, are as follows; southwest (1,5), northwest (2,6), northeast (3,7), and southeast (4,8). This arrangement was used to replicate Byrne's (1997) study. Sand traps were emptied approximately every ten days, three times per month. High lake level data were collected from August 1994 through August 1995. Low lake level data were collected June 1999 through August 2000.

Erosion pin data were collected to identify areas of erosion and deposition within the trough blowout. The erosion pins were 5mm round steel rods, approximately 2m in length. During each site visit, every pin was measured from the top of the pin to the sand surface (Byrne 1997; Jungerius and van der Meulen, 1989). The low lake level period study used the initial three arrays, but three more arrays were added early in the second study towards the upper portion and leeward side of the crest of the blowout. The first, or lowermost, array of pins were located approximately 15cm away from sand traps one through four. The second through fourth array of pins was located approximately 25 m up the blowout. Pins were spaced evenly across the width of the blowout within each array. The fifth pin array was in line with sand traps five through eight. The sixth array of pins was located just landwards of the crest of the blowout.

Figure 2. This topographic map shows the location of sand traps and erosion pins within the trough blowout. Traps 1- 4 are are located at the mouth of the blowout (middle of the map), and traps 5 - 8 are located at the crest (bottom right corner). Erosion pins 1 - 4 are adjacent to the lower traps (1 - 4) and are numbered sequentially landward through the blowout.

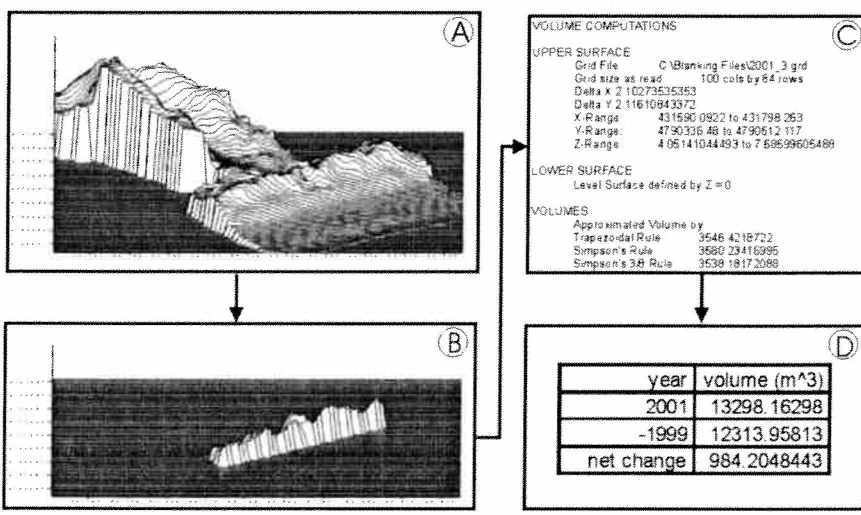


The site was mapped using a Leica Model T1600 Total Station in summer 1999 and a Leica Model SR530 Dual Frequency Geodetic Real-time receiver GPS Station during summer 2000. The data sets were formatted to UTM coordinates and verified for accuracy between data sets by comparing two control points and a back sight. The x,y,z, coordinates were entered into Surfer mapping software. Surfer interpolated (using Kriging gridding) all points between the collected coordinates to create a smooth surface for creating contour and wireframe maps. The end result of the interpolation process created a grid file. This grid file designated every data point to have an x, y, and z (or latitude, longitude, and elevation) coordinate. Using grid files, the three-dimensional maps were created.

To ensure that similar boundaries are used on both the 1999 and 2000 maps, blanking files were created. Blanking files are user chosen areas within a grid file. The user creates a polygon shape based on chosen grid points, and then the user can choose to include everything within, or outside, of that grid box. All other values become zero. For this study, blanking files were designated based on personal observations of areas of erosion and deposition, and were delineated at breaks of slope in the sand dunes.

From the beach moving landward, the study site was broken into 11 sections, or blanked files in which areas outside of the blanked region were assigned a zero value, for volumetric analysis. Volumes were calculated for each of the 11 sections for both the 1999 map and the 2000 map. The volume from the 1999 section was then subtracted from the volume of the exact same section of the 2000 mapping data. Positive values from subtracting the two maps indicates an overall increase in sediment in the section, or an area of deposition. Negative values indicate overall erosion in the area (Figure 3).

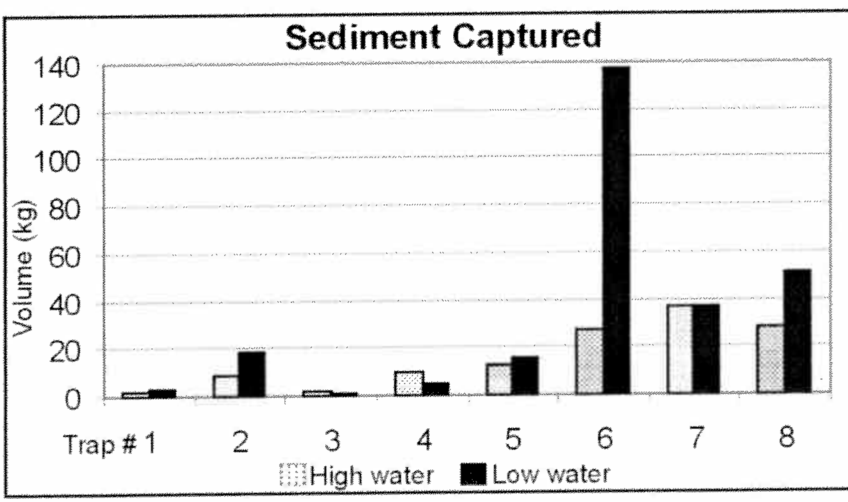
Figure 3. This is an example of the process for calculating volume change between data sets. The first step is to create a three-dimensional grid based on surveyed points (diagram A). A volume is calculated for identically defined areas on both maps (diagram B). All areas outside the region are assigned a value of 0. Diagram C displays a portion of the output file created by Surfer that includes volume calculations for the designated area. The final step is to the subtract 1999 map volume from the corresponding 2001 map volume (diagram D). Positive values indicate net deposition, negative values indicate net erosion.



Results

The upper four sediment traps (5-8) captured significantly more sand than the lower traps (1-4) as seen in Figure 4 during both the low and high water period studies (Byrne, 1997; Byrne and Bitton, 2002). Trap 2, the lakeward facing lower trap, captured the most sediment (16.2 kgs) of the lower traps indicating a definite net migration of sediment landward from the beach. Similarly, trap 6, the lakeward facing upper trap, captured the most sediment (137.3 kgs) moving landward in the upper array. This indicates a net landward migration of the dune blowout. The large amount of sediment moving in the upper compared to the lower traps indicates that most of the erosional activity is occurring through the blowout. As well, due to the increased sediment moving through the blowout during low lake levels, we can infer that the increased sediment budget (increased beach surface area) has allowed more sand to be readily available for transport through the dune system.

Figure 4. Sand transport variations between the high water period (1994/95) and the low water period (1999/2000) for all eight sediment traps. Low water period has substantially more sediment captured. This is especially marked in the upper traps (5 - 8).



The erosion pin record indicates a net erosion through the throat of the blowout. The first two groups of pins indicate the least amount of erosion through the two study periods, although it is a very small decrease in elevation (~less than 5 cm). The third pin row exhibits increasing erosion, especially along the north eastern side of the blowout throat. The fourth row of pins show the most erosion (~40 cm average), with the greatest decrease in elevation at all four pins in the row. The next two rows of pins, situated at the crest and brink of the blowout throat display areas of great erosion along the southwestern edge (30 cm decrease in elevation), and the initiation of dune building toward the northeast (10 – 20 cm deposition). From the erosion pin data we can conclude that the most erosion is occurring through the throat of the blowout, especially further up-slope from the base of the blowout, and that deposition is beginning landward of the crest in the northeast direction.

Volumes for each of the 11 subsections were calculated by averaging the volumes from the Surfer output file. The Surfer output file contained volumes based on 3 surface fitting interpolation methods: Trapezoidal Rule, Simpson's Rule, and Simpson's 3/8 Rule. All three rules approximate definite integrals to create an upper dimension for calculating volumes. Trapezoidal rule calculates using a straight line within each subinterval, while Simpson's and Simpson's 3/8 rules calculates to a quadratic and a fifth power respectively. These averaged volumes were next used to subtract the 1999 volume calculation from the 2000 calculation (Figure 5). These results give an absolute value of volume change (Table 1). Table 1 also lists a volume relative to the total volume of sand for that subsection, giving a relative amount of volume change.

Figure 5. The sections were divided based on breaks of slope within the study area. Negative volume change values indicate areas of erosion; positive indicate deposition. (See Table 1 for values). Each section represents the volume change relative to the total volume of that area; increased concentration of dots indicates erosion, darker shading indicates increased deposition.

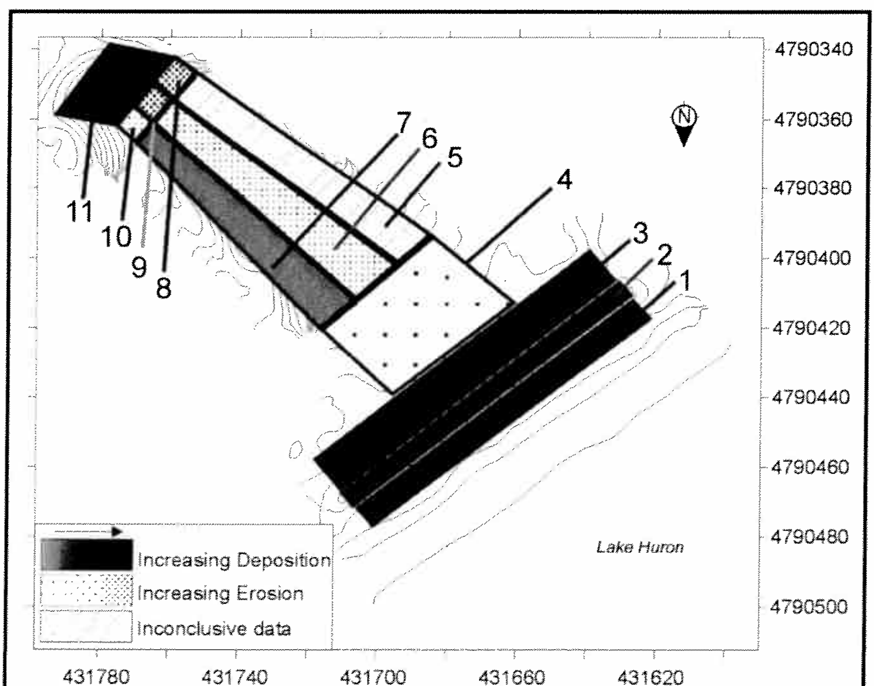


Table 1. Absolute and relative amount of volume change by subsection.

	Volume Change	Relative Volume Change
1	964.5	72.5
2	84.6	23.9
3	1210.0	152.1
4	-268.8	-0.7
5*	1768.9	168.4
6	-254.9	-40.9
7	29.0	5.7
8	-108.2	-130.6
9	-196.0	-199.3
10	-19.1	-15.4
11	119.3	18.7

During the 1999 surveying, large hummocks were not mapped due to a lack of time and technology using the total station. During the 2001 survey it was felt that these hummocks were important to monitor, and therefore were included in the survey data. The change in surveying protocol included the mapping of large amounts of sediment that were eliminated from the 1999 survey of section 5, and therefore section 5 data is inconclusive. Sections 1, 2, 3, 7, and 11 all display areas of deposition, while the remaining areas exhibit net erosion. The greatest relative deposition occurs in the foredune area, especially on the landward side. The landward side of the blowout also shows a large amount of deposition. The volumetric results indicate the greatest erosion occurring through the throat of the blowout as well as at the crest of the blowout.

Discussion

Combining the erosion pin and volumetric data, we can conclude that there is definite erosion occurring through the throat and the crest of the blowout. Since the blowout first formed, this process has likely happened continually. During low lake levels, it is possible that more sediment has moved through the blowout, depositing on the leeward side of the dune, and hence migrating into the more heavily vegetated zone. Sand trap evidence supports this. Both the upper and lower traps indicate sediment moving predominantly landward. Additionally, during the low lake level study period, far more sediment moved through the blowout than during the high lake level period.

The large amounts of sediment being captured on both the landward and lakeward side of the foredune demonstrate a significant growth in the foredune which may lead to a new stable ridge. Therefore, a new natural coastal defence system is being created by natural processes which can protect the landward ecosystem from storm waves and potential lake level rises.

This information is relevant to park managers in understanding the dynamics of blowouts as erosional landforms. As the lake water levels lower, more sediment will be available for transport through the dune system. Vegetation can be used to stabilize this transporting sand, and therefore stabilize the dunes, as well as promote dune growth. Park managers should seize this opportunity to increase the wilderness zone lakeward to include the areas of new vegetation and dune growth. By reducing human traffic over newly formed dune ridges, vegetation will have a greater chance to survive through different environmental conditions. Park managers can use periods of low lake levels to try to stabilize areas of erosion, such as blowouts, by planting vegetation, such as *Ammophila breviligulata,* that thrive in continual deposition of sediment.

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