Geomorphology 236 (2015) 148–162

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Spatial–temporal evolution of aeolian blowout dunes at Cape Cod

Kimia C. Abhar [a], Ian J. Walker [a,*], Patrick A. Hesp [b], Paul A. Gares [c]

[a] Coastal Erosion and Dune Dynamics (CEDD) Laboratory, Department of Geography, University of Victoria, Canada
[b] School of the Environment, Flinders University, South Australia, Australia
[c] Department of Geography, Planning, and Environment, East Carolina University, United States

ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form 10 February 2015
Accepted 15 February 2015
Available online 25 February 2015

Keywords:
Aeolian
Blowout
Dune
GIS
Spatial–temporal analysis
Landscape evolution

ABSTRACT

This paper explores historical evolution of blowouts at Cape Cod National Seashore (CCNS), USA — a site that hosts one of the world's highest densities of active and stabilized blowouts. The Spatial–Temporal Analysis of Moving Polygons (STAMP) method is applied to a multi-decadal dataset of aerial photography and LiDAR to extract patterns of two-dimensional movement and morphometric changes in erosional deflation basins and depositional lobes. Blowout development in CCNS is characterized by several geometric (overlap) and movement (proximity) responses, including: i) generation and disappearance, ii) extension and contraction, iii) union or division, iv) clustering and v) divergence by stabilization. Other possible movement events include migration, amalgamation and proximal stabilization, but they were not observed in this study. Generation events were more frequent than disappearance events; the former were highest between 1985 and 1994, while the latter were highest between 2000 and 2005. High rates of areal change in erosional basins occurred between 1998 and 2000 ($+3932$ m^2 a^{-1}), the lowest rate ($+333$ m^2 a^{-1}) between 2005 and 2009, and the maximum rate ($+4589$ m^2 a^{-1}) between 2009 and 2011. Union events occurred mostly in recent years (2000–2012), while only one division was observed earlier (1985–1994). Net areal changes of lobes showed gradual growth from a period of contraction (-1119 m^2 a^{-1}) between 1998 and 2000 to rapid extension ($+2030$ m^2 a^{-1}) by 2010, which is roughly concurrent with rapid growth of erosional basins between 2005 and 2009. Blowouts extended radially in this multi-modal wind regime and, despite odd shapes initially, they became simpler in form (more circular) and larger over time. Net extension of erosional basins was toward ESE (109°) while depositional lobes extended SSE (147°). Lobes were aligned with the strongest (winter) sand drift vector although their magnitude of areal extension was only 33% that of the basins. These differences in extension responses likely result from more complex and evolving flow-form interactions inside erosional basins. Historical photographs and CCNS documents suggest that blowout evolution may be influenced by land-use changes, such as revegetation campaigns in 1985 that were followed by high blowout generation. High magnitude regional storm events (e.g., hurricanes) also play a role. The analytical framework presented provides a systematic means for two-dimensional geomorphic change detection and pattern analysis that can be applied to other landscapes.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Blowouts occur in both coastal and continental environments and from high to low latitudes, and they commonly occur as depressions, hollows, and troughs that form in pre-existing sand deposits by aeolian erosion (Carter et al., 1990; Hesp and Hyde, 1996; Byrne, 1997; Hesp and Pringle, 2001; Hesp, 2002; Hugenholtz and Wolfe, 2006). Blowouts are generally categorized by their morphology, which is variable and includes saucer, cup/bowl, or trough shaped forms. Saucer blowouts are semi-circular, shallow, dish-shaped depressions. Deeper cup- or bowl-shaped blowouts often evolve from saucer forms. Trough blowouts have steeper, longer erosional lateral walls, generally deeper deflation basins, and commonly more defined depositional lobes (Hesp, 2002). Although formed by erosion, blowouts also possess an associated depositional lobe and, thus, they are composed of both erosional and depositional features (Gares and Nordstrom, 1995). The development of blowouts is facilitated and limited by factors such as dominant wind speed and direction, sand inundation and burial, topography, vegetation cover and its variation through space and time, climatic variability, water and wave erosion, and land-use change by human activities (e.g., Gares and Nordstrom, 1995; Hesp, 2002; Smyth et al., 2012, 2013). However, the main driving force controlling blowout size, shape, and direction of expansion is the wind regime and resulting complex flow dynamics within blowouts that promote and maintain erosion (e.g., Landsberg, 1956; Cooper, 1958; Jungerius et al., 1981; Gares and Nordstrom, 1995; Hesp and Pringle, 2001; Hesp, 2002; Hesp and Walker, 2012, 2013; Smyth et al., 2012, 2013). Jungerius

---

* Corresponding author at: Dept. of Geography, University of Victoria, P.O. Box 3060, Station CSC, Victoria, British Columbia V8R3R4, Canada. Tel.: +1 250 721 7347; fax: +1 250 721 6216.
E-mail address: ijwalker@uvic.ca (I.J. Walker).

http://dx.doi.org/10.1016/j.geomorph.2015.02.015
0169-555X/© 2015 Elsevier B.V. All rights reserved.

et al. (1981) found that although sand erosion and deposition patterns in blowouts in De Blink, Netherlands were complex due to varying wind speeds and directions, blowouts commonly grew in length upwind against the prevailing wind.

Although blowouts are common aeolian features in desert and coastal dune landscapes, there are relatively few studies of their morphodynamics and development (Hesp and Hyde, 1996; Hesp, 2002, 2011; Hugenholtz and Wolfe, 2006; Smyth et al., 2013). Blowout development has been linked to changes in climate and human activity. However, without comprehensive knowledge and systematic methods to study their evolution, blowouts cannot be used as clear indicators for environmental change and efforts to conserve, restore, or manage such dunes within parks and protected areas will be less informed.

Increasingly, spatial–temporal patterns of change are being examined to monitor the geomorphic evolution of aeolian dunes (e.g., Woolard and Colby, 2002; Mitasova et al., 2005; Dech et al., 2005; Hugenholtz and Wolfe, 2005; Hugenholtz and Barchyn, 2010; Mathew et al., 2010; Hugenholtz et al., 2012; Eamer and Walker, 2013; Walker et al., 2013). The use of geographical information systems (GIS) to analyze remotely sensed data, such as aerial photography and LiDAR-derived digital elevation models (DEMs), allows analysis at larger spatial and temporal scales, which provides the opportunity to examine blowout morphodynamics (e.g., Dech et al., 2005) and longer-term evolution. Analysis of repeat DEMs, for example, allows multi-temporal investigation of two- and three-dimensional spatial patterns in blowouts, and associated volumetric changes, as they evolve. Until recently, methods were limited in their ability to represent and analyze spatial–temporal patterns and changes, as each GIS data layer was representative of a single temporal series and links between series were not explored. More recently, however, methods have been developed to specifically detect and quantify spatial–temporal changes in both raster (e.g., Wheaton et al., 2010) and polygonal datasets (e.g., Robertson et al., 2007).

The aims of this study are to obtain an improved understanding of blowout evolution and present a method for exploring their morphodynamics using accessible remotely sensed data and existing spatial–temporal analytical methods. This study identifies and analyzes change patterns in blowouts in CCNS using a spatial pattern detection and analysis method known as Spatial–Temporal Analysis of Moving Polygons (STAMP) developed by Robertson et al. (2007). Specifically, the objectives of this paper are to: (1) identify 30 erosional features in blowouts from digital orthophotography and LiDAR between 1985 and 2012 and 10 associated depositional lobes from more limited LiDAR data between 1998 and 2010 that have experienced notable geomorphic changes within the Provincelands region of CCNS, (2) modify and expand the STAMP method to include further geomorphologically-relevant categories and measures that describe observed changes in blowouts more effectively, and (3) analyze and interpret two-dimensional, spatial–temporal patterns within this population of blowouts to identify common geomorphic responses and improve our understanding of blowout evolution.

2. Study area

Cape Cod National Seashore (CCNS) is a protected area managed by the U.S. National Parks Service (NPS) that encompasses 176 km^2 of beach and upland landscapes on Cape Cod, Massachusetts, USA (Fig. 1). CCNS hosts one of the highest densities of saucer and bowl blowouts in the world. The outer cape region between Provincetown and Orleans was formed over 20,000 years ago by glacial melt-water deposits that drained westward from the South Channel Lobe into Glacial Lake Cape Cod (Zeigler et al., 1965). Following glacier retreat, the Provincelands hook spit formed approximately 6000 years ago from eroded glacial drift sediments and sandy marine deposits that traveled northward in littoral drift (Zeigler et al., 1965). Strong regional winds have further shaped the Provincelands area, resulting in the development of large parabolic dunes, foredunes, and blowouts on top of the former mid-Holocene deposits (Zeigler et al., 1965; Forman et al., 2008).

Since European settlement in the early 1700s, the Provincelands dunes have experienced phases of extreme climate variability and drought as well as significant anthropogenic changes in land cover (e.g., vegetation clearance, replanting, stabilization efforts) (Forman et al., 2008), including vegetation replanting campaigns in the 1980s. As observed by NPS staff (Burke, 2012), not all vegetation populations survived and some areas experienced vegetation die-back where areas of sand were exposed to wind erosion and blowout initiation. Interpretation of aerial photographs of the region indicates that the greatest generation of blowouts occurred between 1985 and 1994, which is hypothesized to relate to this revegetation campaign, as explored in this study.

Currently, vegetated areas of the landscape are dominated by American beach grass (*Ammophila breviligulata*), which is an effective agent in controlling the vertical accretion and horizontal movement of coastal dunes and blowouts (e.g., Maun, 1998; Maun and Perumal, 1999). Regional climatic variability and wind patterns are also dominant driving forces in the morphodynamics of dune systems in CCNS (Forman et al., 2008). The wind regime (Fig. 1) is seasonally bi-directional with dominant modes from the northwest and southwest.

The Provincelands dunefield is a prominent, geomorphically distinct region in the landscape of CCNS and covers approximately 35 km^2 (Fig. 2). As noted by Forman et al. (2008), there are at least eleven discrete parabolic dunes with distinct arms and depositional lobes in this landscape, and most of these are being reworked to varying degrees by contemporary blowout development. Blowout features in this region are diverse and vary in size and shape including: deep circular bowls and shallow saucers, elongated irregular troughs, and more complex, compound forms. This, combined with extensive historical aerial photography and recent LiDAR coverage in the region, allows for an excellent examination of spatial–temporal morphodynamics and decadal scale evolution of coastal blowouts. Within the Provincelands region, 30 erosional features and 10 depositional features within, or attached to, blowouts were identified from aerial photography for an analysis of their morphological evolution (see Fig. 2) as explained below.

3. Data and methods

3.1. Remotely sensed data sources and accuracy assessment

Orthorectified air photos and LiDAR data for the CCNS region were obtained from CCNS staff, the State of Massachusetts Office of Geographic Information (MassGIS) (Massachusetts Office of Geographic Information, 2013), and the National Oceanic and Atmospheric Administration online data access viewer (NOAA Coastal Services Center, 2013). In total, six years of orthophotography were used in this analysis (1985, 1994, 2007, 2009, 2011, 2012, Table 1), whereas the LiDAR data were more temporally limited (1998, 2000, 2007, 2010, Table 1). Both datasets were assessed for their post-processed quality and utility for identifying and assessing blowouts in CCNS by reviewing positional (horizontal) accuracy between years, as well as vertical accuracy of the LiDAR data (Table 1). When digitizing blowouts, both aerial photography and LiDAR datasets (as available) were used to ensure digitization accuracy.

In order to define uncertainty and accuracy issues for analyzing two-dimensional spatial data, a modified error and total uncertainty calculation was implemented for both LiDAR and orthophoto datasets that accounted for both positional and measurement uncertainty (e.g., Stojic et al., 1998; Moore, 2000; Fletcher et al., 2003; Mathew et al., 2010). Total uncertainty for respective LiDAR and orthophoto datasets was based on the sum of the horizontal accuracy and the onscreen delineation for each data set in individual years (Table 2). The horizontal accuracy is based on the position of a certain location

Download English Version:

https://daneshyari.com/en/article/4684257

Download Persian Version:

https://daneshyari.com/article/4684257

Daneshyari.com