Rapid Coastal Dune Migration into Temperate and Equatorial Forests: Optical Chronology of Imaged Upper Slipface Strata

Ilya V. Buynevich1, Albertas Bitinas2, Pedro Walfir M. Souza-Filho2, Donatas Pupienis3, Nils E. Asp4, Ronald J. Goble5 and Lauren E. Kerber1

1Department of Earth and Environmental Science
Temple University
Philadelphia, PA 19122, U.S.A.
coast@temple.edu

2Coastal research and Planning Institute
Klaipėda University
Klaipėda, LT 92294, Lithuania
albertas.bitinas@corpi.ku.lt

3Faculty of Natural Sciences
Vilnius University
Vilnius, LT 03101, Lithuania
donatas.pupienis@gf.vu.lt

4LARGECO/IECOS
Universidade Federal do Pará
Bragança, PA 68600-000, Brazil
nilsasp@ufpa.br

5Department of Geoscience
University of Nebraska
Lincoln, NE 68588, U.S.A.
rgoble@unlnotes.unl.edu

ABSTRACT

This study presents the first sets of optical dates that constrain dunefield evolution along a temperate, forested, microtidal barrier (Curonian Spit, southeast Baltic Sea, Lithuania) and a macrotidal equatorial mangrove coast (Pará State, northern Brazil). In both areas, high-resolution geophysical (georadar) images were used to map the subsurface architecture, relative chronology, and orientation of dune migration surfaces (slipfaces) and vertical accretion strata. Besides relative chronology of dune accretion, subsurface images reveal bounding (superimposition) surfaces indicative of distinct activity phases. A cross-barrier Preila transect on the Curonian Spit, served as the basis for establishing dune chronology in this historically active part of the Great Dune Ridge. Due to barrier width (>1 km) and dune height (>30 m), aeolian sand transfer, rather than overwash and breaching, has been the dominant process of landward migration for this barrier spit since mid-Holocene. OSL dating of the upper sections of buried slipfaces in shallow trenches revealed dune migration of more than 600 m between mid-1500s and late 1700s at the Preila site. These ages are consistent with historical records and the time of burial of a coastal village near the edge of a lagoon by 1797. In equatorial Brazil (Atalaia Beach), large reactivated parabolic dunes have been migrating over coastal roads and mangrove forests over at least the past 150 years. In geophysical images of a parabolic dune, numerous high-amplitude hyperbolic anomalies produced by buried trees contrast with steeply landward-dipping slipface reflections. Due to water table elevation, the lower older part of the dune sequence has been stabilized in the blowout area. Similarly, interdunal lake has partially arrested the migration of a transverse dune ridge, while the adjacent segment continues to advance onto a sparsely vegetated plain. Our preliminary data indicate that whereas the two regions differ markedly in their precipitation patterns, vegetation types, oceanographic setting, and land-use history, both experienced episodes of rapid (average: 1-2 m/year) migration of massive dunes (10-50 m high), which continues locally at the present time. Aside from their implications to coastal evolution, accurate reconstructions of dune dynamics on decadal to centennial time scales should be integrated into coastal development and management strategies.

ADDITIONAL INDEX WORDS: Parabolic dune, Bounding surfaces, OSL, GPR, Brazil, Lithuania

INTRODUCTION

At many coastal locations around the world, dunes of various sizes and morphologies have experienced phases of migration in historical times (past 500 years), traversing natural landforms and occasionally entombing entire settlements (Sherman and Nordstrom, 1994; Jimenez et al., 1999; Maia et al., 2005; Pedersen and Clemmensen, 2005; Buynevich et al., 2007a; Forman et al., 2008; Girardi and Davis, 2009; Povilanskas, 2009). With few exceptions, the information on the mode and chronology of dune activity is either limited to general historical accounts or must be reconstructed using a combination of geomorphological, sedimentological, and archaeological techniques. In addition to differences in the length of recorded history, the availability of such important signatures of dune stabilization as soil horizons and dendrochronological records may be limited by a variety of natural conditions. For example, numerous reconstructions of late Holocene and historical dune activity in western and northern Europe have been facilitated by the study of paleosols, ages of extant trees, and relatively long historical archives. In contrast, such databases are extremely limited or absent for most tropical coastal dunefields. Even where present, paleosol ages often bracket dune activity within a broad time interval. Optically-stimulated luminescence (OSL) dates provide direct measurement of the time elapsed since the burial of exposed aeolian strata.

Journal of Coastal Research, Special Issue 64, 2011
726
Field observations and measurements of coastal dunes were carried out during October (Brazil) and November (Lithuania) campaigns of 2008. Satellite image analysis was complemented by high-resolution ground-penetrating radar (GPR) images using a digital Geophysical Survey Systems Inc. SIR-2000 GPR system with 200 and 400 MHz monostatic antennas (for technical aspects of GPR and its use in coastal settings, see van Heteren et al., 1998; Jol and Bristow, 2003; Buynevich et al., 2009). GPR images were post-processed using RADAN 5.0 software. No topographic correction was applied to sections of profiles that had less than 0.3 m variation in elevation. Geophysical data were groundtruthed using shallow trenches (0.3-1.0 m) and hand augers. Grain size, sorting, organic content, and bulk mineralogy of surficial and subsurface samples were analyzed using standard sedimentological techniques. Optically-stimulated luminescence dates were obtained at the OSL Laboratory, University of Nebraska-Lincoln.

RESULTS

Curonian Spit, Lithuania

A cross-barrier geological transect at Preila served as the basis for establishing dune chronology in this historically active part of the Great Dune Ridge (Fig. 2C). In this wide (>1 km) and high (>40 m) part of the spit, massive aeolian sand transfer, rather than overwash and breaching, has been the dominant process of landward migration since mid-Holocene. GPR images were used to locate key bounding surfaces (superposition and reactivation surfaces) to guide the OSL sampling strategy (Fig. 2D). Three OSL ages are progressively younger in the eastward direction (downwind), as expected: 490±60, 410±60, and 370±50 years before present (present=AD 2009). These dates of the upper sections of buried slipfaces indicate that dune migration of more than 600 m took place between mid-1500s and late 1700s, with rapid advance between AD 1500 and 1630. These ages are consistent with historical records and the time of burial of a coastal village near the edge of a lagoon by the late 1700s.

Equatorial Brazil

At the Atalaia site, northern Brazil (Fig. 3A), two westward-migrating dunes were analyzed using aerial and satellite images, 400 MHz GPR records, and OSL ages of slipface strata. Dune 1 (L=700 m, W=270 m) has a well-developed parabolic shape, exhibits distinct trailing vegetation marks, and is advancing into a mangrove forest (Fig. 3B; Buynevich et al., 2010). The first set of OSL dates suggest recent migration of the dune (from 140±10 to 37±21 years before present; Figs. 3C and 3D). Based on imaged and OSL-dated paleo-dune surfaces, the time-averaged dune migration rate decreased from 1.6 to 1.1 m/yr, with a stabilization of the dune limb approximately 90 years ago. Based on the most recent changes in the position of the dune crest (using geo-referenced2008 ground surveys, 2001 vertical aerial photographs, and 2009 satellite images; Figs. 3B and 3C), Dune 1 continues to migrate at a rate of 1.0 m/yr. Approximately 2,000 m upwind of Dune 1, a rapidly evolving Dune 2 (L=500 m, W=150 m) is migrating into a low-relief residential area (Fig. 2D). Subsurface images indicate that this dune consists of four sedimentary packages (average thickness 4.0 m), which represent distinct phases of dune migration (Fig. 3E). The optical sample taken from the uppermost slipface strata upwind of a partially buried telephone pole gave a nearly modern age (0±34 years). Based on this information, this dune has migrated at an average rate of at least 1.6 m/yr, while accreting vertically at a rate of 0.3 m/yr (Fig. 3E).
Figure 2. Example of a historically active Karvaičiūnė dune north of Preila settlement, Curonian Spit, Lithuania: A) Location of the study area; B) a partially buried house along the lagoon shoreline (from Gudelis, 1998); C) Location of the master geophysical profile across the Karvaičiūnė dune; D) Section of a 200 MHz GPR profile across a recently stabilized dune near Preila (see Fig. 2C for location; PR-1 - hand auger. MSL – mean sea level).
Figure 3. Active parabolic dunes in coastal Pará, Brazil: A) Location of the study area (note the positions of Dunes 1 and 2; GoogleEarth™ image); B) 2001 vertical aerial photograph of Dune 1 showing well-developed vegetation marks between the limbs (arrow); C) 2009 GoogleEarth™ image of Dune 1 with superimposed 2001 outline. Locations of OSL dates (ATO) and median ages (numbers in parentheses) are shown; D) 2009 GoogleEarth™ image of Dune 2, with the location of GPR profile (scale as in Fig. 3C); E) GPR image of Dune 2 showing thicknesses (in meters) of individual aeolian accretionary packages. Note the partially buried telephone pole.
DISCUSSION
The OSL ages indicating a recent migration of the dune at Preila, Lithuania are consistent with historical data for this part of the spit (Gudelis, 1998; Povilanskas, 2009). This chronology contrasts with the nearly 6,000-year migration of the dune at Nagliq to the north (Buynevich et al., 2007b), but both sites show reactivation of aeolian processes during the little ice age. The two dunes at Atalaia, Brazil show activity over the past 150 years and were likely migrating prior to that. To the west of the Atalaia site, optical dates indicate that two main coastal dune ridges at Salinópolis (Praia do Maçarico; Fig. 3A) have partially infringed on dense interdunal wetlands and experienced a period of aggradation within the past 80-90 years. To the east, the seawardmost dune generations at Ajuruteua were established in the past 200 years and are backed by relic dunes associated with former shoreline positions dating back to late Holocene (1,000-2,500 years BP). Both recent and future migration patterns and rates of the dunes are affected by downwind topography (tidal channels, vegetation density and height, and intensity of development; Sherman and Nordstrom, 1994; Jimenez et al., 1999; Maia et al., 2005; Buynevich et al., 2007a; Forman et al., 2008; Girardi and Davis, 2009; Buynevich et al., 2010). Our study demonstrates that for a region with limited historical records, integrated morphological and subsurface datasets provide valuable information about the rapidly evolving coastal dunefields. Ongoing research is focusing on integrating the new OSL data with historical records and detailed analysis of reactivation surfaces in GPR records.

CONCLUSIONS
Our geological and chronological data indicate that whereas the two study regions differ markedly in their precipitation patterns, vegetation types, oceanographic setting, and land-use history, both experienced episodes of rapid (average: 1-2 m/year) migration of massive dunes (10-50 m high). This trend continues locally at the present time, although efforts to stabilize the dune with vegetation have been underway along the Curonian Spit for more than a century (Gudelis, 1998; Povilanskas, 2009). Aside from their implications to coastal evolution, accurate reconstructions of dune dynamics on decadal to centennial time scales should be integrated into coastal development and management strategies.

ACKNOWLEDGMENTS
This research was funded by the Ocean and Climate Change Institute of the Woods Hole Oceanographic Institution. We thank W. da Silva Leite, Jânio dos Santos, Aldona Damišytė, and Anton Symonovich for their assistance in the field. Comments by two anonymous reviewers greatly improved the manuscript.

LITERATURE CITED