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Sand incursion into temperate (Lithuania) and tropical (the Bahamas) maritime vegetation: Georadar visualization of target-rich aeolian lithosomes

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Interaction of windblown sand with maritime vegetation, either as dune migration or episodic grain transport is a common phenomenon along many sandy coasts. Vegetation introduces antecedent surface roughness, especially when scaled to the landform height, but its role may be concealed if overwhelmed by aeolian incursion and burial. Where field observations and cores lack detail for characterizing this complex process, ground-penetrating radar (GPR) offers continuous visualization of aeolian sequences. Along the Curonian Spit, Lithuania, dune reactivation phases resulted in massive invasion of siliciclastic sand triggered by natural perturbations and land clearance. Massive (>30 m high) dunes entombed mature pine, oak, and alder stands and this process is ongoing. Mid-frequency (200 MHz) georadar surveys reveal landward-dipping lateral accretion surfaces interrupted by high-amplitude point-source anomalies produced by recently buried trees. In tropical regions, dense vegetation and potential for rapid lithification of carbonate sand results in more complex internal structures. Along the windward coast of San Salvador Island, the Bahamas, a massive dune has buried several generations of maritime scrubland, resulting in highly chaotic reflection pattern and high target density. On a nearby Little Exuma Island, numerous reentrants in aeolianites promoted formation of blowouts and incursion of windblown sand 10–25 m into a silver thatch palm forest. High-frequency (800 MHz) GPR images resolve diffractions from trunks and roots buried by > 2 m of oolitic sand. Basal refection morphology helps differentiate the irregular dune/beachrock surface from a smooth palm-frond mat. Aside from detecting and mapping buried vegetation, geophysical images capture its effect on sediment accumulation. This has the potential for differentiating its effect from other discordant structures within dunes (clasts, dissolution voids, trunk molds, burrows, and cultural remains).

1. Introduction

Coastal sand dunes often interact with native vegetation at a variety of scales, resulting in a variety of morphotypes within the blowout-parabolic continuum. Whereas plants often play a key role in stabilizing dune limbs, the advance of the leading edge (slipface) of a parabolic dune may eventually encounter extensive and dense stands of forest or shrubbery (Hesp and Thom, 1990; Pye, 1993; Borówka, 1995; Seppälä, 1995; Claudino Sales and Paulvast, 2002; Hesp, 2002; Girardi and Davis, 2009; Buynevich et al., 2010). The

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ensuing interaction has implications not only for local aeolian dynamics, but also for regional interpretations of antecedent vs. external (e.g., climatic, hydrologic, anthropogenic) forcings (Wilson et al., 2001; Mann et al., 2002; Wiles et al., 2003; Clarke and Rendell, 2006; Halfen and Johnson, 2013; Yan and Baas, 2015). For coastal regions experiencing aeolian reactivation, burial of watercourses (Jimenez et al., 1999; Levin et al., 2009), man-made structures (Sherman and Nordstrom, 1994; Clemmensen et al., 2007; Buynevich, 2009), animals (Loope et al., 1998; Rick, 2002), and vegetation (Fillon, 1984; van der Meulen, 1990; Bakker et al., 1991; Clarke et al., 2002; Mann et al., 2002; Loope et al., 2004; Maia et al., 2005; Hart and Peterson, 2007; Forman et al., 2008; Girardi and Davis, 2009; Povilanskas et al., 2009; Buynevich et al., 2010) are topics in need of further research. In large unconsolidated Quaternary dunes these efforts are hampered by the difficulty of identifying and mapping buried targets.

One of the ways to overcome this challenge has been the increasing use of high-resolution geophysical imaging, such as ground-penetrating radar (GPR or georadar) that aids *in situ* visualization of buried objects. In this respect, decimeter-scale resolution of georadar is superior to other geophysical techniques and allows rapid collection of continuous subsurface records of aeolian sequences (Schenk et al., 1993; Clemmensen et al., 2001; Botha et al., 2003; van Dam et al., 2003; Havholm et al., 2004; Bristow et al., 2005; Pedersen and Clemmensen, 2005; Buynevich et al., 2007a; Bristow, 2009; Bristow et al., 2009; Buynevich et al., 2011). Georadar can be used not only to locate buried objects, but may also reveal the burial mode, such as grainfall deposition, sand sheet aggradation, or slipface migration (Bristow, 2009; Brothers et al., 2016).

The diagnostic response of the electromagnetic GPR signal to buried point-source objects is the high-amplitude bell-shaped diffraction hyperbola ("hyperbolic return"; Davis and Annan, 1989; Grasmueck and Weger, 2002; Girardi and Davis, 2009). Therefore buried trees (trunks, stumps, and roots), as well as smaller woody vegetation can be distinguished from the background sediment by this characteristic signal return (van Heteren et al., 1998; Doolittle and Butnor, 2009; Buynevich et al., 2010). Well-sorted aeolian sands are particularly suitable for such studies (Barton and Montagu, 2004). Hyperbolic diffractions in basal parts of aeolian sequences may be generated by cobbles and boulders from the underlying glacial deposits, by man-made structures, or by interference with power lines (van Heteren et al., 1998; Mann et al., 2002; Wiles et al., 2003; Pedersen and Clemmensen, 2005; Buynevich et al., 2007b). Within the aeolian lithosomes, bioturbation structures (open and filled burrows) and cultural remains will also serve as point-source reflections (White and Curran, 1988; Curran and White, 1991; Rick, 2002; Buynevich et al., 2014). In tropical carbonate settings, there is an additional aspect of rapid lithification that may result in preservation of molds of various parts of plants or formation of voids that may or may not be related to decayed vegetation (Harris et al., 1995; Lundberg and Taggart, 1995; Kraus and Hasiotis, 2006; Curran et al., 2008; Hearty and Olson, 2011). In order to examine the subsurface signal parameters of buried plants, this study focuses on temperate and tropical sites that exhibit ongoing interaction between windblown sand and vegetation (Fig. 1). The purpose of this paper is to characterize partially or fully buried vegetation in high-resolution GPR records.

2. Study areas

Three study sites demonstrate active processes of aeolian sand incursion into maritime vegetation stands. As an example of a temperate biotope, we use actively migrating sections of the Great Dune Ridge (max. height ~70 m) at the Naglių Nature Reserve, Lithuania (Fig. 1a). This site is situated 20–30 m above mean sea-level on the eastern flank of the Curonian Spit (UNESCO World Heritage Site), a ~100-km-long barrier spit stretching in a SW-NE orientation along the southeast Baltic Sea coast. Since at least the mid-Holocene, several aeolian phases have been recognized, all driven by the prevailing westerly winds (Gudelis and

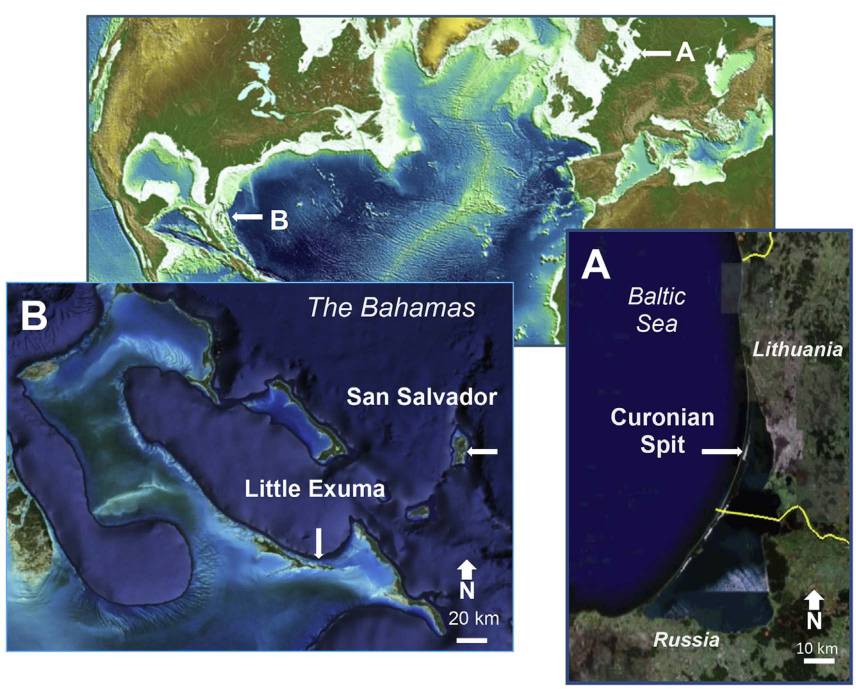

Fig. 1. Locations of the study sites: A – Great Dune Ridge, Curonian Spit, Lithuania. B – San Salvador and Little Exuma Islands, the Bahamas.