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How does dune morphology shape coastal EC habitats occurrence? A remote sensing approach using airborne LiDAR on the Mediterranean coast

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ABSTRACT

We examined the relationship between coastal habitats (sensu European Union Habitats Directive) and local dune morphology along a Mediterranean coastal dune system by integrating field collected vegetation data and remotely sensed imagery. Specifically, we described the morphological profile of each EC habitat based on the morphological variables that are most likely to affect their occurrence, including elevation, slope, curvature, northness, eastness and sea distance. In addition, we assessed the role and strength of each morphological variable in determining the occurrence of EC habitats.

We used 394 random vegetation plots representative of six EC habitats (Habitat 1210: "Annual vegetation of drift lines"; Habitat 2110: "Embryonic shifting dunes"; Habitat 2120: "Shifting dunes along the shoreline with *Ammophila arenaria*"; Habitat 2210 and 2230: "*Crucianellion maritimae* fixed beach dunes" and "*Malcolmietalia* dune grasslands"; Habitat 2250: "Coastal dunes with *Juniperus* spp."; Habitat 2260: "*Cisto-Lavanduletalia* dune sclerophyllous scrubs") found along the Tyrrhenian coast of central Italy. We derived each morphological variable from a DTM (Digital Terrain Model) obtained from 2-m resolution LiDAR (Light Detection And Range) images. The mean value of each variable was calculated at different spatial scales using buffer areas of increasing radius (2 m, 4 m, 8 m) around each vegetation plot. Mean morphological values for each EC habitat were compared using Kruskal-Wallis rank test. The role and strength of the relationship between habitat type and the morphological variables were assessed using Generalized Linear Models.

EC habitats occur differentially across dune morphology, and the role and strength of each morphological variable define habitat specificity. Dune elevation and sea distance were determined to be the key factors in shaping EC habitat occurrence along this section of the Mediterranean coast. Identification of the close relationship between habitat type and morphological variables deriving from airborne LiDAR imagery points to the high potential of such remote sensing tool for analyzing and monitoring the integrity of coastal dune ecosystems. As airborne LiDAR enables the rapid collection of extremely accurate topographic data over large areas, it also offers useful information for the management of these threatened and fragile ecosystems.

1. Introduction

Coastal dunes comprise nearly three-quarters of the world's shorelines (Bascom, 1980). They provide unique habitat assemblages due to a steep environmental sea-inland gradient, which supports a highly specialized and characteristic flora and fauna (Acosta et al., 2009; Martínez et al., 2004). In addition, coastal dunes offer numerous ecological services, such as filtration of large volumes of seawater, nutrient recycling, flood control and storm protection (Liquete et al., 2013; McLachlan and Brown, 2006). In recent years, however coastal dune ecosystems have been increasingly transformed by urban, industrial, agricultural and reforestation expansion, as well as shoreline and harbor development (Malavasi et al., 2016a, 2013; Schlacher et al., 2007; Sitzia

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et al., 2014). They represent prime locations for human recreation and support many coastal economies around the world (Schlacher et al., 2008). Consequently, coastal sandy ecosystems are currently one of the most threatened ecosystems in Europe, especially concerning biodiversity loss (EEA, 2008). The degradation of the littoral landscape is particularly striking on the Mediterranean coastline (Miccadei et al., 2011); most of the plant communities growing on coastal dunes lining the Mediterranean have been listed as EC Habitats in Annex I of the Habitats Directive (EEC, 1992; European Commission, 2013).

The remarkable speed of coastal dune degradation and biodiversity loss increases the urgency of identifying and implementing standard screening procedures that stress the benefits and drawbacks of different management scenarios (Defeo et al., 2009; Poeta et al., 2014). Scientifically sound instruments capable of describing and monitoring coastal dune ecosystems are crucial for determining conservation priorities aimed at maintaining coastal dune integrity and ecosystem services over time (Acosta et al., 2003b; Drius et al., 2013). Remotely sensed imagery is an effective tool for mapping and modeling natural and artificial environments and enhancing our understanding of ecosystem functioning (Lefsky et al., 2002). Moreover, remote sensing offers a cost–effective means for conducting recurrent observations over vast areas (Turner et al., 2003). The use of modern sensors to identify important areas of biodiversity, determine species distributions and model community responses to environmental and anthropogenic changes is of growing interest among ecologists and landscape planners (Mairota et al., 2015; Turner et al., 2003). Remote sensing is very useful for mapping the key environmental parameters and biophysical properties that shape the distribution and abundance of species across landscapes (Alexander et al., 2016; Turner et al., 2003).

Airborne LiDAR (Light Detection And Range) is particularly effective for collecting accurate elevation data over large areas, thus extending spatial analysis into the third dimension (z) and reducing the amount of time and expense required to collect field data (Jensen, 2007). The creation of topographical maps is currently the largest and fastest growing area of LiDAR application, along with its widespread use in commercial land surveys (Flood and Gutelius, 1997). More recently, airborne laser altimetry has been used to map coastal geomorphology, improving knowledge of many geomorphic processes; it has been used, for instance, for monitoring coastal erosion and accretion rates, sediment transport and budgets, and for flood hazard assessments (Brock and Purkis, 2009; Brock et al., 2004; Sallenger et al., 2007, 2003, 1999), as well as for analyzing ecological processes in coastal and estuarine habitats (Chust et al., 2008; Sallenger et al., 2007). Moreover, research carried out by Ward et al. (2013) has demonstrated the usefulness of LiDAR derived elevation data in analyzing the distribution of vegetation in areas characterized by micro-topographical relief, such as coastal dunes.

However, the utilization of LiDAR images for describing and monitoring the impacts of abiotic and biotic factors on extensive coastal dune systems requires further study. Indeed, in well-preserved dune ecosystems, the typical dune vegetation zonation is closely related to the morphological and sedimentological features of the dune system (Abuodha et al., 2003; Acosta et al., 2007), changing along an environmental gradient from the shoreline to the inland regions (Acosta et al., 2003a; Isermann, 2005; Lane et al., 2008; Sýkora et al., 2004). The relationships between plant communities and local dune morphology have been previously described by field research at local scales (Acosta et al., 2007; Kempeneers et al., 2009; Kim and Yu 2009; Ruocco et al., 2014; Ward et al., 2010; Woolard and Colby, 2002), but few studies have focused on large coastal areas or on the integration of recent and accurate topographic maps with field data.

The present study was undertaken to examine the relationship between coastal dune vegetation and local dune morphology in a broad strip of the Mediterranean coast by integrating field collected vegetation data and remotely sensed images. We analyze the occurrence of habitat types sensu 92/43/EEC Habitats Directive (EEC, 1992; European Commission, 2013) of conservation concern in relation with morphological variables (LiDAR derived) that more likely affect the presence of each habitat type, including the elevation, slope, curvature, northness, eastness and sea distance. In particular, we aim to (i) describe the morphological profile of each EC habitat, and (ii) assess the role and strength of each morphological variable in determining the occurrence of the EC habitats.

2. Materials and methods

2.1. Study area

The study was carried out on the Tyrrhenian coast of central Italy and focused on recent coastal dunes (Holocene) hosting a highly specialized native flora (Izzi et al., 2007) and plant communities that have been associated to different habitat types sensu 92/43/EEC Habitats Directive (EEC, 1992; Prisco et al., 2012). The area includes 9 study sites located along the coast of the Lazio region (Fig. 1), where recent dunes harbor remnant natural seashore vegetation (Malavasi et al., 2016b). Recent dunes occupy a narrow strip along the seashore (<500 m). The dunes are low (<10 m in height) and are relatively simple in structure. Beaches vary in width, from a few meters to approximately 40 m and are backed by a section of low embryo dunes, typically a single mobile dune ridge, dune slacks and, finally, a stabilized dune zone (Acosta et al., 2003a). Vegetation on the dune profile follows a compressed zonation along the sea-inland environmental gradient, from the pioneer communities of the upper beach to the woody communities (Mediterranean macchia and evergreen forests) of the inland fixed dunes (Acosta et al., 2007) (Fig. 2).

2.2. Vegetation

Vegetation plots were randomly collected on coastal dunes in spring (April–May) over the period 2006–2011; the plots covered most of the coastal EC habitat types that are present in central Italy (Acosta et al., 2007; Carranza et al., 2008; Prisco et al., 2012). The mean distance between neighboring plots was 66 m (lower quartile 40 m; upper quartile 107 m). The plots were 2 m × 2 m wide, dimensions determined to be adequate for describing coastal dune habitats (e.g., Acosta et al., 2007; Carboni et al., 2011). The complete list of vascular plant species and the relative percentage cover was reported. According with the interpretation manual of the EC habitats (Biondi et al., 2009), the 394 plots covered 6 EC habitat types (Table 1): '1210': Annual vegetation of the drift lines (n = 53); '2110': Embryonic shifting dunes (n = 54); '2120': Shifting dunes along the shoreline with *Ammophila arenaria* (n = 39); '2210' and '2230': *Crucianellion maritimae* fixed dunes and *Malcomietalia* dune grasslands (n = 96); '2250': Coastal dunes with *Juniperus* spp. (n = 42); and '2260': *Cisto-Lavanduletalia* dune sclerophyllous scrubs (n = 90) (for details regarding vegetation data and classification to EC habitat categories, see Carboni et al., 2011). As habitats '2210' and '2230' typically occur in a complex mosaic in the transition between mobile dunes and fixed dunes (Acosta et al., 2003a), we decided to combine them into a single category.

2.3. Morphological variables

Airborne LiDAR imagery were acquired in 2008 during the PST-A mission (Piano Straordinario di Telerilevamento Ambientale; Ministero dell'Ambiente e della Tutela del Territorio e del Mare). From