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The role of Italian coastal dunes as carbon sinks and diversity sources. A multi-service perspective

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ABSTRACT

Coastal dunes support biodiverse habitats of conservation interest and provide other essential but often overlooked benefits to society, such as carbon sequestration, thanks to their high soil carbon accumulation rates. The recently established coastal dune Natura 2000 network in the Italian Adriatic coast aims at protecting dune habitats diversity, yet its capacity to provide other ecosystem services, and the potential trade-offs with biodiversity provision have so far not been evaluated. In this paper we conduct this analysis for a key ecosystem service: carbon storage and sequestration. We i) quantify soil carbon stocks and sequestration within four coastal dune EU habitat types along the Adriatic Natura 2000 network; ii) upscale these data to create an inventory of carbon stocks for all dune Natura 2000 sites in the study area; iii) collate biodiversity data of the selected EU habitat types using plant diversity measures as surrogates of coastal dune biodiversity and iv) explore the trade-offs between carbon storage and biodiversity value for the selected habitats. Italian Adriatic coastal dune Natura 2000 sites sequester 4998 t of CO_2e per year, with the majority in wooded dunes. Wooded dunes showed significantly higher soil carbon density than the other dune habitats, and had a much greater area, but they were characterized by lower species richness. By contrast, the endangered fixed dunes, which survive in few residual patches along the study area, showed the highest plant diversity for both total species richness and dune focal species, but had a much lower carbon density and extent. Although further analyses of additional services would be desirable for a more comprehensive assessment, these findings suggest that conservation actions should favor restoration of the natural dune zonation, since it guarantees both dune species diversity and carbon storage. The carbon stocks and EU habitat type extents produced in this study constitute the first systematic inventory for dune systems in the Mediterranean.

1. Introduction

Coastal dunes are dynamic systems which provide essential benefits to society, some of which have a considerable socio-economic impact (Everard, Jones, & Watts, 2010; Jones et al., 2011; McLachlan & Brown, 2006, p. 357; MA, 2005). These systems play a major role for recreation and tourism, being highly valued as a place of escape and isolation and as a source of mental well-being (Doody, 1997; Houston, 1997; Nordstrom, 2000). In addition, they provide unique habitat assemblages due to a strong environmental sea-inland gradient, which supports a highly specialized flora and fauna sharing relatively few species with other terrestrial ecosystems (Acosta, Carranza, & Izzi, 2009; Martínez, Psuty, & Lubke, 2004). While services such as coastal defence, groundwater storage and water purification are clearly recognized and integrated into the coastal management of many sites (French, 2001; Rhymes et al. 2015; Van Dijk, 1989), rather less is known about supporting ecosystem services such as nutrient cycling, soil formation and climate regulation (Barbier et al., 2011; Jones, Sowerby, Williams, & Jones, 2008). Being an early successional ecosystem, coastal dunes have a high soil carbon accumulation rate

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(Jones et al., 2008; Olff, Huisamn, & Van Tooren, 1993; Rohani et al., 2014), a feature in common with other coastal environments (Sevink, 1991). There is increasing interest in the role of "blue carbon" in climate regulation (Donato et al. 2011, 2012; Mcleod et al., 2011; Nellemann, Corcoran, Duarte, & Vald, 2009), and sequestration by marine and coastal ecosystems has been globally quantified as ca. 2 Gt C yr^{-1} (Chmura, Anisfeld, Cahoon, & Lynch, 2003). Yet, the specific role of carbon storage in dune habitats has been little explored to date, except in the UK, where both annual CO_2 sequestered and the stock of carbon in vegetation and soil were estimated for the whole country and changes in value of the carbon sequestration service were projected under different scenarios of coastal change alteration (Beaumont, Jones, Garbutt, Hansom, & Toberman, 2014). While carbon accumulation rates are very high, the gross contribution of dune habitats to climate regulation is relatively small due to their low area. However, in the context of widespread coastal habitat loss and land-use change at fine scale, and within a wider context of habitat management for multiple benefits, their role in regulating greenhouse gas emissions is worth taking into consideration (Everard et al., 2010).

Despite the high biodiversity value and numerous benefits provided by coastal dunes, this ecosystem is among the most threatened both globally (Schlacher et al., 2007) and in the Mediterranean (Rossi et al., 2013). Human activities in European littoral areas have been intensifying in the course of the 20th century (Cori, 1999); consequently, sand dunes across Europe had lost on average 25% of their extent by 1998, compared to 1900 (EUCC, 1998), with peaks of 80% area loss in some Mediterranean countries. In order to prevent these and other endangered habitats from further degradation, European Member States adopted the Council Directive 92/43/EEC (Habitats Directive from now onwards), which lists the habitats of European interest (EU habitat types) and establishes across Europe an extended network of sites of ecological importance, called Natura 2000.

In Italy, 86.7% of EU coastal habitats currently have an unsatisfactory (bad or inadequate) conservation status, having suffered a drastic reduction in both extent and ecological quality, mainly due to urban sprawl (Genovesi et al., 2014). Of the Italian 3000 km coastline, the Northern and Central Adriatic sector is probably the most developed and industrialized (with more than 70% of its seaside urbanized), hosting several international tourist resorts and important port cities, as well as an intense transportation network (Highway A14, State Road No 16 and railway line) which have destroyed the natural coastline in many points (Romano & Zullo, 2014). Therefore, in order to preserve the last intact coastal landscapes in this area, there is a need to study in more detail the role of Adriatic Natura 2000 sites both for biodiversity protection and their capacity to provide additional ecosystem services and, in particular, the interplay between those potentially conflicting functions. In this study we focus on two coastal services: biodiversity protection and carbon storage and sequestration. We selected carbon storage first because a consistent approach to measure and assess carbon storage service in coastal dunes is still lacking (Laffoley & Grimsditch, 2009; Beaumont et al., 2014); and secondly, because of the potential for conflicts with biodiversity provision, since carbon storage requires stabilised systems while much of the unique dune biodiversity relies on natural dune dynamics.

Thus, the aims of this work were i) to quantify soil carbon storage and sequestration provided by a set of coastal dune EU habitat types within Natura 2000 network along the Northern and Central Adriatic Sea; ii) to compare their relative contribution and to create the first inventory of carbon stocks for the Adriatic Natura 2000 sites; iii) to characterise coastal dune biodiversity value, using various metrics of plant species richness as a proxy; iv) lastly, to explore the trade-offs between carbon storage and biodiversity value for the selected habitats and to discuss their relative value in a multi-service perspective.

2. Materials and methods

2.1. Selection of EU coastal dune habitat types

For data collection and upscaling we adopted the EU habitat types classification, as it entails spatial data at sufficient detail to distinguish between habitats but at an appropriate spatial scale and consistency required for upscaling. The use of more detailed classifications of dune habitats creates difficulties because dunes usually occur as long, narrow strips following the coastline but they are mapped at a coarse resolution, which makes it problematic to define fine variation in plant communities (Acosta, Carranza, & Izzi, 2005; Lucas, Shanmungam, & Barnsley, 2002). Secondly, EU habitat types are standardized and recognizable across all EU Member States, allowing transferability of these data to other studies across Europe with the same habitat types. Both factors are important considerations for upscaling of results. Moreover, all EU habitat types present in Italy have been matched to national phytosociological types (Biondi et al., 2009), allowing cross-reference with Italian vegetation classifications, and EU dune habitat types in particular have been already adopted in previous studies (Berardo, Carranza, Frate, Stanisci, & Loy, 2015; Malavasi, Santoro, Cutini, Acosta, & Carranza, 2014; Stanisci et al., 2014).

Four of the 11 EU coastal dune habitat types (Biondi et al., 2009; Carranza, Acosta, Stanisci, Pirone, & Ciaschetti, 2008) found in Italy were characterized in this work: 2110 "Embryonic shifting dunes", 2120 "Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')", 2250* "Coastal dunes with *Juniperus* spp.", 2270* "Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*" (Table 1). These habitat types were selected for four main reasons: first, they represent the most common Mediterranean vegetation zonation, shaped by a harsh sea-inland gradient chiefly determined by variations in substrate and wind action (Acosta, Blasi, Carranza, Ricotta, & Stanisci, 2003; Frederiksen, Kollmann, Vestergaard, & Bruun, 2006, Fig. 1); secondly, they are present along the entire Adriatic Natura 2000 network; third, two of them (fixed dunes and wooded dunes) are priority habitats for conservation at European level; lastly, three of them (embryo dunes, mobile dunes and fixed dunes) currently are in poor conservation status in Italy (La Posta, Duprè, & Bianchi, 2008) and Europe (European Commission, 2008), requiring urgent protection efforts.

2.2. Distribution of the selected EU habitat types along the Adriatic Natura 2000 network

The Northern and Central Adriatic coastal dune Natura 2000 network is included in six administrative regions (from north to south): Friuli-Venezia Giulia, Veneto, Emilia-Romagna, Marche, Abruzzo and Molise (Fig. 2). The network in this study area extends for 74014 ha, which is roughly 1% of the administrative regions total surface. The four EU sand dune habitat types occupy nearly 3000 ha of the network (Table 2). Emilia-Romagna hosts overall the largest extent of the selected EU sand dunes, with nearly 1800 ha occupied by wooded dunes alone, some of which have historical value for the local population (Table 2). Veneto's coastal Natura 2000 network hosts a valuable portion of mobile dunes and includes nearly 450 ha of wooded dunes. Fixed dunes are present in scattered stations along Friuli-Venezia Giulia and Veneto, disappear in Central Italy and then occur again in the southern sector of Molise. Across Marche and Abruzzo Natura 2000 network, there is relatively little