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Short communication

Assessing land take and its effects on dune carbon pools. An insight into the Mediterranean coastline

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ABSTRACT

In the Mediterranean sandy coasts urban growth largely occurs to sustain sea-side tourism, causing a severe loss of natural coastal dune habitats and the related ecosystem services. During the last half-century coastal dunes integrity has been widely altered by land use change; however, procedures and study cases assessing how in particular their carbon storage and sequestration capacity are affected by land take over this period are still scarce.

To fill such knowledge gap, we investigated to which extent urban growth has altered soil carbon sink in a representative sector of the Mediterranean dune system, from 1954 to 2006.

Specifically, we propose a procedure that combining experimental data of soil carbon stocks and multi-temporal cover maps allows assessing C stock variation over time. Based on field data we quantified soil carbon storage provided by the main dune habitat types of the Adriatic coast (Beach with Pioneer annual Vegetation, Herbaceous Dune Vegetation and Mediterranean Macchia). Using detailed multi-temporal land cover maps (1954, 1986 and 2006) we quantified the fraction of natural dune habitats replaced by urban areas over time, by means of transition matrices. Then, by combining carbon stocks values with the results of transition matrices, we estimated the C stock loss for natural dunes due to land take.

Results show that natural dune habitats have an important role as soil carbon sinks and land take has depleted them with different rates, causing a total net loss of 117 t of soil C in the first time step and a total net loss of 70 t of soil C in the second time step (~40% of soil C stock in the last 53 years).

Our work underlines the fragility of natural coastal dunes, which during the last decades have become a privileged destination for touristic and recreational activities, thus been progressively replaced by artificial areas, with a direct impact on their carbon storage capacity and the other precious services they provide.

By combining ecosystem services measurements with multi-temporal mapping techniques, we enhanced our understanding of transformation processes on coastal dunes, offering as well new insights for dune management.

1. Introduction

Coastal dunes are dynamic systems ruled by a steep environmental sea-inland gradient, which host unique habitat mosaics, with a greatly specialized fauna and flora (Acosta et al., 2009). These systems comprise approximately the 20% of the world's coasts (Davidson-Arnott, 2010) and are crucial for human health, guaranteeing fundamental services (Millennium Ecosystem Assessment, 2005) with significant socio-economic impacts (Everard et al., 2010; Millennium Ecosystem Assessment, 2005). The most relevant services are coastal defense, groundwater storage and water purification (Rhymes et al., 2015), tourism, recreation and mental well-being (Doody, 1997). Coastal dunes, being assemblages of early successional ecosystems, may also play a function in the global carbon budget (Mcleod et al., 2011). Although researchers have dedicated significant efforts in quantifying the role of several terrestrial ecosystems as carbon pools for climate regulation (Bloom et al., 2016), the contribution of coastal dune habitats in carbon cycling processes is scarcely known (Beaumont et al., 2014; Jones et al., 2008).

Despite the numerous benefits provided by coastal dunes, they are

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among the most threatened ecosystems worldwide (Schlacher et al., 2007). In Europe in fact urban expansion, intensive agriculture and reforestation spread and industrial and harbor sprawl along the coasts developed with a striking rate during the 20th century (Couch et al., 2007). Specifically in Italy, almost 85% of natural coastal habitats have suffered a drastic reduction in both extent and ecological quality, mainly due to these human pressures (Falcucci et al., 2007).

The conversion of natural areas into settlements and artificial surfaces seriously damages coastal dune integrity and related ecological functions (Ciccarelli et al., 2017), it alters environmental quality (Drius et al., 2013) and it affects the provision of ecosystem services (EEA, 2006). Previous studies have been performed focusing on the effects of coastal dune degradation and transformation on their capacity to supply ecosystem services, in particular recreational value and touristic services (Mendoza-Gonzalez et al., 2012). However, considering the increasingly extensive coastal dune habitat loss, their role in regulating and removing CO_2 emissions from the atmosphere has been also compromised and thus deserves to be taken into consideration (Everard et al., 2010). The impact of urbanization on soil carbon sinks is expressed mainly through the decrease in the vegetation cover and the deterioration of natural ecosystems (Hutyra et al., 2011). Additionally, the conversion of natural habitats into urban areas causes an initial loss in the carbon stock and a permanent reduction in the soil carbon uptake potential (Hutyra et al., 2011).

So far, the capacity of carbon storage of dune habitats has been explored in the Atlantic coastal dune ecosystems, where changes in the carbon sequestration service have been projected under different scenarios of coastal alteration (Beaumont et al., 2014). In the Mediterranean coasts, the contribution of dune habitats to soil carbon pool needs further research (Drius et al., 2016) and the specific effect of urban expansion on carbon nutrient cycling and on climate regulation has not been explored yet.

On this basis, the present work sets out to quantify how in the last 53 years land use conversion in favor of urban areas has affected the carbon storage capacity of Mediterranean coastal dune ecosystems. Specifically we propose a procedure that combining experimental data of soil carbon stocks and multi-temporal cover maps allows to assess C stock variation over time.

2. Materials and methods

2.1. Study area

The study was carried out in a representative zone that stretches for 30 km along of the Adriatic coast in Central Italy (Molise Region; Appendix A), characterized by a typical vegetation zonation, that ranges from pioneer annual plant communities on the upper beach to the Mediterranean Macchia on the landward fixed dunes (Acosta et al., 2003, Appendix A). Several potential hazards threaten coastal ecosystems on the whole Adriatic coast, mainly due to an intense and rapid urbanization process (Romano and Zullo, 2014; Malavasi et al., 2016). Nonetheless, coastal dunes of the analyzed area still host many EU habitat types (Council Directive 92/43/EEC) (Stanisci et al., 2014) and species of European concern (Foresta et al., 2016). Most of this coast is included in the Natura 2000 network and in the European Long Term Ecological Research monitoring system (Drius et al., 2013), thus representing an excellent training ground to develop methodologies for assessing the effects of land take on coastal dune ecosystems.

2.2 Carbon stock analysis

To perform our analysis, C stock values for each natural dune cover category were derived from samples collected in the field during a pioneer inventory of soil carbon stocks for Mediterranean dune systems (Drius et al., 2016). 70 samples were collected in the main natural dune psammophilous vegetation (Beach with Pioneer annual Vegetation, Herbaceous Dune Vegetation and Mediterranean Macchia, see Appendix A). For each soil sample, a 15 cm-deep core with 5 cm diameter was collected and treated in laboratory following standard procedures (e.g. Jones et al., 2008). Percentage C was measured by combustion on a Carlo Erba CSN analyzer, after acidification with 1 M HCl to gradually remove carbonates. The average soil carbon stock per unit area (t ha^{-1}) at the sample depth (C_{MM}, C_{PBV} and C_{HDV}) was computed from C content, fresh soil weight, % moisture and the area of core samples.

2.3. Multi-temporal land cover maps

To perform a multi-temporal analysis we produced fine scale (1:5000) land cover maps covering the last 50 years (years 1954, 1986 and 2006), derived from video interpretation of panchromatic digital aerial ortho-photographs with a 1 m resolution. Since the dune ridges in the Italian peninsula are quite narrow, we analyzed a 500 m wide strip starting from the coastline towards inland. The legend complies with Corine Land Cover (CLC) expanded to a fourth level of detail for natural and semi-natural areas (Acosta et al., 2005). We identified and mapped ten land cover typologies (Appendix B) and three different categories of natural dune cover types (Acosta et al., 2005), which include 6 EU habitat types *sensu* Habitats Directive, Annex I (Appendix B). The three natural dune cover types are: BPV: *Beach with Pioneer annual Vegetation* (3.3.1.1.), corresponding to annual vegetation growing close to the drift line and embryonic dunes; HDV: *Herbaceaous Dune Vegetation* (3.3.1.2.), corresponding to partially vegetated and densely vegetated dune grasslands; and MM: *Mediterranean Macchia* (3.2.3.1.), corresponding to the woody dune vegetation growing on fixed dunes.

2.4. Land take and soil carbon loss

After describing the cover of coastal dune categories (BPV: Beach with Pioneer Annual Vegetation; HDV: Herbaceous Dune Vegetation; MM: Mediterranean Macchia) and of urban areas over time, we quantified urban development (urbDev) into natural dune habitats by transition matrices. By comparing the CLC maps relative to the year 1954 with 1986, and 1986 with 2006, we calculated the area (ha) of change in each land cover category occurred for two time intervals, called T1 and T2 respectively (Turner and Ruscher 1988). As our objective was to quantify land take by urban development into natural habitats (urbDev $-_{H}$), we considered only the transitions from natural dune cover types to artificial land (urbDev $-_{BPV}$; urbDev $-_{HDV}$; urbDev $-_{MM}$).

Here we propose to assess alteration in C storage capacity due to land take based on the C stock values estimated for each natural dune category and its cover loss due to the transition from natural to artificial surfaces through time. We adopted for this exercise the conservative approach proposed by the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), which assume that artificial areas do not contribute to C storage. Thus, the net loss of soil C stock (t) per natural category due to land take was computed as follows:

$$C_{loss\ (H)} = urbDev\ -_{H}{}^{*}\ C_{H}$$

where $C_{loss(H)}$ is the net loss of soil C for the natural dune category h (being h = BPV, HDV, MM), urbDev $-_{H}$ is the extent (ha) of the category h which has been converted into artificial land in the analyzed time steps (from T1 (1954) to T2 (1986) and from T2 to T3 (2006)); and C_H is the unitary carbon stock of the natural category h (t ha^{-1}).

3. Results

The unitary carbon soil stock in coastal dune natural habitats follows a gradient that increases from the seashore to inland. In fact, while Beach with Pioneer annual Vegetation and Herbaceous Dune Vegetation showed similar unitary soil carbon values (3.14 t ha^{-1} and 3.06 t ha^{-1} respectively), the highest value was obtained for the inner