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Is vegetation an indicator for evaluating the impact of tourism on the conservation status of Mediterranean coastal dunes?

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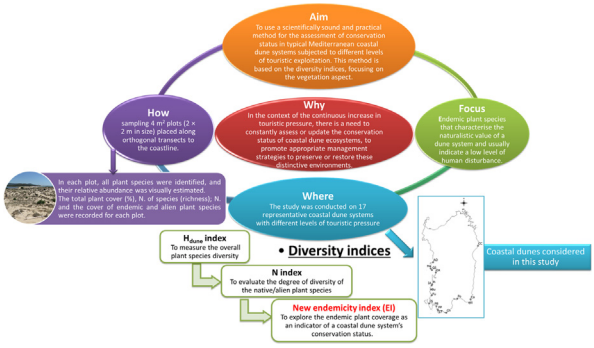
HIGHLIGHTS

- The new EI index supports the evaluation of coastal dunes' conservation status.
- We applied H_{dune}, E_{dune} and N indices in the Sardinian dune systems.
- Plant richness and coverage were recorded in 446 plots placed in 17 coastal dunes.
- A medium human disturbance was positively related to the plant richness and cover.
- Diversity indices are a support for a conservation strategy compatible with tourism.

GRAPHICAL ABSTRACT



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ABSTRACT

Mediterranean coastal dunes are threatened by several factors; particularly, tourism causes modifications to the vegetation and the disappearance of endemic species. Understanding the dunes' conservation status is crucial for preserving these vulnerable environments through appropriate management strategies.

This study was conducted on 17 Sardinian coastal dunes, with different levels of touristic pressure. We focused on endemic plant species and developed a new endemicity index (EI).

Our study aimed: 1) to assess the conservation status by applying the diversity indices; 2) to verify if the study sites would reveal a general pattern based on different degrees of human disturbance and 3) to test the effectiveness of the EI index.

Four m^2 plots (2×2 m) were placed along orthogonal transects to the coastline (446 plots in total), in which all plant species were identified, and their relative abundance was estimated.

We found significant differences among the sites for H_{dune} and EI values but no statistically significant differences in the N values. The EI showed the high naturalistic value of Sardinian coastal dunes and allowed us to distinguish the sites with higher anthropic pressure.

We found significant differences in the indices among the degrees of human disturbance in the coastal systems. The H_{dune} values were positively related to a medium level of human disturbance, and the EI allowed us to distinguish the sites with varying levels of human disturbance, although it differentiated better those with the highest anthropic pressure. A medium level of human disturbance was positively related to the plant richness and cover, and human trampling could be tolerated by psammophilous vascular plants.

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Results showed a satisfactory conservation status of Sardinian dune systems and highlighted diversity indices as valuable support for implementing a conservation strategy, compatible with the tourism purposes and the integrated management of the Mediterranean coastal dune systems.

1. Introduction

Occupying transition zones between terrestrial and marine ecosystems, the coastal dune ecosystem constitutes one of the most dynamic and patchy landscapes on earth (e.g. Carranza et al., 2008; Carboni et al., 2009; Fenu et al., 2013a; Malavasi et al., 2018). For this reason, coastal dunes are environments with great ecological diversity, associated with complex interactions between abiotic and biotic factors, which give rise to a complex sea-to-inland environmental gradient (Carranza et al., 2008; Fenu et al., 2013a). Accordingly, coastal dunes' vegetation is typically arranged in distinct zones along the coast-inland gradient, which are influenced by several abiotic factors, including wind, waves, tide, soil salinity, sand grain size, scarcity of water, geomorphological dynamics, as well as soil organic matter (e.g. Fenu et al., 2012, 2013a; Angiolini et al., 2013; Ciccarelli, 2014). Moreover, coastal dunes host highly specialised vascular flora, with a wide range of adaptations and responses to a large scale of environmental stresses typical of these environments (Maun, 2009). Common adaptations to these stresses are salt resistance and osmotic adaptation, positive growth response to burial, marine storms resistance, leaf roll, root adaptations, photosynthesis rate, salt bladders, nitrogen fixation, the variation of the life cycle and flowering times, seed dispersal and germination strategies (Maun, 2009; Fenu et al., 2013a). This specialised flora also include several endemic plants that locally enhance the ecological diversity of coastal dune (e.g. Acosta et al., 2009; Ciccarelli, 2014; Pinna et al., 2015a, 2015b).

Currently, coastal dunes are prone to massive biodiversity loss, associated with heavy habitat degradation or simplification, besides being among the most threatened ecosystems worldwide (e.g. Nordstrom, 2000; Brown and McLachlan, 2002; Malavasi et al., 2016). Usually, these environments naturally cope with stresses; however, recent threats driven by both the increase in direct anthropic disturbances (Nordstrom, 2000; Brown et al., 2008) and natural processes, such as shoreline erosion (Anderson et al., 2015) and climate changes (Prisco et al., 2013), seriously impact these ecosystems. Particularly, among anthropogenic disturbances, factors such as pollution, effects of global warming, mechanical beach cleaning, transit of off-road vehicles, coastal forest fire, construction of hydraulic and harbour infrastructures, land use transformations mainly related to agriculture activities, urban development and industrial areas (e.g. refineries) as well as afforestation activities, have strongly shaped the coastal dunes over time (e.g. Cuttelod et al., 2008; Santoro et al., 2012; Prisco et al., 2013; Ciccarelli, 2014; Pinna et al., 2015a; Marignani et al., 2017; Del Vecchio et al., 2019).

Anthropogenic pressures related to recreational activities deserve special attention since they can lead to the habitat fragmentation and, as a consequence, the disappearance of plant species and communities (van der Maarel, 2003; Fenu et al., 2013b; Del Vecchio et al., 2017; Abdelaal et al., 2018). These human-related processes, among which biological invasion, lead to important changes in coastal dunes' floristic composition and plant communities' structure (e.g. Carboni et al., 2010; Del Vecchio et al., 2013; Pinna et al., 2015b). Specifically, eutrophication of soil and water, due to human pressure on coastal dunes, reduces the nitrogen stress, creating simplified ecosystems with a lower diversity caused by changes in the competitive conditions imposed by nutrients (e.g. Nielsen et al., 2011). Along the Mediterranean coasts, among others anthropogenic factors, tourism (and the related activities) especially affects the coastal dunes (e.g. Davenport and Davenport, 2006; Ciccarelli, 2014; Fenu et al., 2015; Malavasi et al., 2016). Particularly, tourism represents an important activity that offers substantial economic benefits for many countries (Propín-Frejomil and Sánchez Crispín, 2007). Since 1995, tourism has grown by almost 75% in the Mediterranean coasts (EEA-UNEP/MAP Action Plan, 2014), and projections show an expected continuing increase in the number of tourists, which could reach 637 million by 2025 (UNEP/MAP -PLAN BLEU, 2012). However, the rapid development of tourism activities (construction of high rise buildings, and development of residential areas, resorts, marinas and recreation parks, etc.) is often associated with severe environmental degradation due to dune reshaping or flattening (Nordstrom, 2008), beach cleaning, vehicle driving and trampling. Several modifications of the coastal dune ecosystems that are related to these activities include the alteration of dune morphology or the spread of alien species that cause damage to the vegetation (e.g. Kerbiriou et al., 2008; Santoro et al., 2012; Nordstrom and Jackson, 2013; Šilc et al., 2017; Abdelaal et al., 2018). They also promote changes in plant communities, the modification of the local species composition and the disappearance of native species with great ecological value, such as endemic and keystone plant species (e.g. Kerbiriou et al., 2008; Santoro et al., 2012; Fenu et al., 2013b).

In the context of the continuous increase in touristic pressure, there is a need to constantly assess or update the conservation status of coastal dune ecosystems in order to promote appropriate management strategies to preserve or restore these distinctive environments. To achieve this goal, numerous indicators, indices and protocols have been suggested, focused on floristic patterns, diagnostic species, plant communities' structures, diversity indices, the landscape cover, characteristic plant communities, the vulnerability index, marine effects, and human impacts (e.g. Grunewald and Schubert, 2007; Carboni et al., 2009; Fenu et al., 2013b; Ciccarelli, 2014; Ciccarelli et al., 2017; Malavasi et al., 2018).

The Shannon diversity index (Shannon and Weaver, 1949), commonly used to characterise species diversity in a community, was frequently applied in ecological studies regarding vegetation analysis (i.e. Carboni et al., 2009). More recently, Grunewald and Schubert (2007) developed the H_{dune} index, based on the Shannon diversity index, which allows making distinctions among sites and the levels of anthropogenic impacts on extreme habitats, such as coastal dunes, whose natural stressful conditions determine the presence of few adapted plants with high coverage (Grunewald and Schubert, 2007). Specifically, the H_{dune} index uses the abundance of species (as cover percentage) in relation to a constant sampling area, and in contrast to the H index, it permits detecting changes in both plant species richness and total vegetation cover (Grunewald and Schubert, 2007).

To evaluate the conservation status of Mediterranean coastal dune ecosystems subjected to different levels of touristic exploitation, we analysed the most representative coastal dune systems in Sardinia by using the H_{dune} index. We also focused on endemic vascular plants that characterise the naturalistic value of a dune system and usually indicate a low level of human disturbance. Accordingly, we developed a new index, following the same approach of the Naturalness index (Grunewald and Schubert, 2007), where the relative abundance of endemic species was a proxy of the coastal dune systems' conservation status. Our study's specific aims were: 1) to assess the conservation status of the selected dune systems of Sardinia; 2) to verify if the study sites would reveal to a general pattern based on different degrees of human disturbance; and 3) to test the effectiveness of a new index (called

Endemicity Index) based on the endemic plant coverage as valuable support for evaluating these ecosystems' conservation status.

2. Materials and methods

2.1. Study areas and data sampling

Next to Sicily, Sardinia is the second largest island in the Mediterranean Basin, with a surface area of ca. 24,089 km^2, including approximately 300 satellite islands and islets. The island has a coastal length of 1896 km (>20% of Italian coasts), of which 24% comprise low, sandy and pebbly shores (Atzeni et al., 2000). Sardinia is one of the most important tourist sites in the Mediterranean Basin. Similar to many other Mediterranean islands, in recent decades, tourist activities have also grown rapidly in lowland plains and coastal areas. Considering, 3,097,366 arrivals, with 49% comprising foreign tourists in 2017 (data from http://www.sardegnastatistiche.it/documenti/), seasonal (summertime) and local (coastal) tourism is one of the most important economic sectors in Sardinia (Pungetti et al., 2008), which confirms the island's status as a popular tourist destination, especially its coastal areas.

This study was conducted on 17 representative coastal dune systems (Fig. 1), characterised by different levels of touristic pressure. The sites included the island's most important, complex and well-preserved dune systems, particularly those located along the western coast, where the largest and most developed systems are concentrated. On the study sites, the plant communities followed the typical sea-inland zonation related to an ecological gradient, starting from the annual vegetation of the strandline zone of the beach to the shrubby or the forest communities on the stabilised dunes (Fenu et al., 2012, 2013a).

The study sites were climatically, geologically, sedimentologically and floristically homogeneous allowing us to perform a robust comparison among sites; only coastal morphologies and plant communities appeared heterogeneous, mostly due to local ecological conditions. Geologically these areas mainly consisted of Quaternary deposits, particularly Holocene sandstones and aeolian sands. These latter presented different morphologies, dunes fairly uniform, as well as longitudinal, parabolic and transversal dunes (Di Gregorio et al., 2000). Foredune systems extended from a minimum of 0.04 km to a maximum of ca. 5 km inland, and had variable heights, from 2 to 80–90 m. Grain size ranging between 0.25 and 0.5 mm felt within medium sands (Di Gregorio et al., 2000; Fenu et al., 2012). All sites showed similar climatic patterns, typically Mediterranean with comparable annual trends of temperature and precipitation.

The study was carried out by sampling 4 m^2 plots (2 × 2 m), a size comparable with several studies carried out in these Mediterranean ecosystems during the last decade (e.g. Carboni et al., 2011; Fenu et al., 2012, 2013a; Pinna et al., 2015b; Ciccarelli et al., 2017). Plots were placed along transects, orthogonal to the coastline, starting from the first vegetated area (characterised by pioneer plants) to the backdune area (limit of the wooded formations), where recreational activities had major impact (Fig. 1). Length and number of transects depended on morphology and width of dunes systems (see Appendix A for details).

Along these transects, plots spaced 10 m from each other were placed. Twenty-five plots per coastal site were *a priori* established as the minimum number. Accordingly, during the field surveys, an adequate number of transects, as detailed above, were placed until the minimum threshold was reached (overall 83 transects). In total, 446 plots were thus considered in the studied areas. In each plot, all vascular plant species were identified and a floristic inventory was prepared;

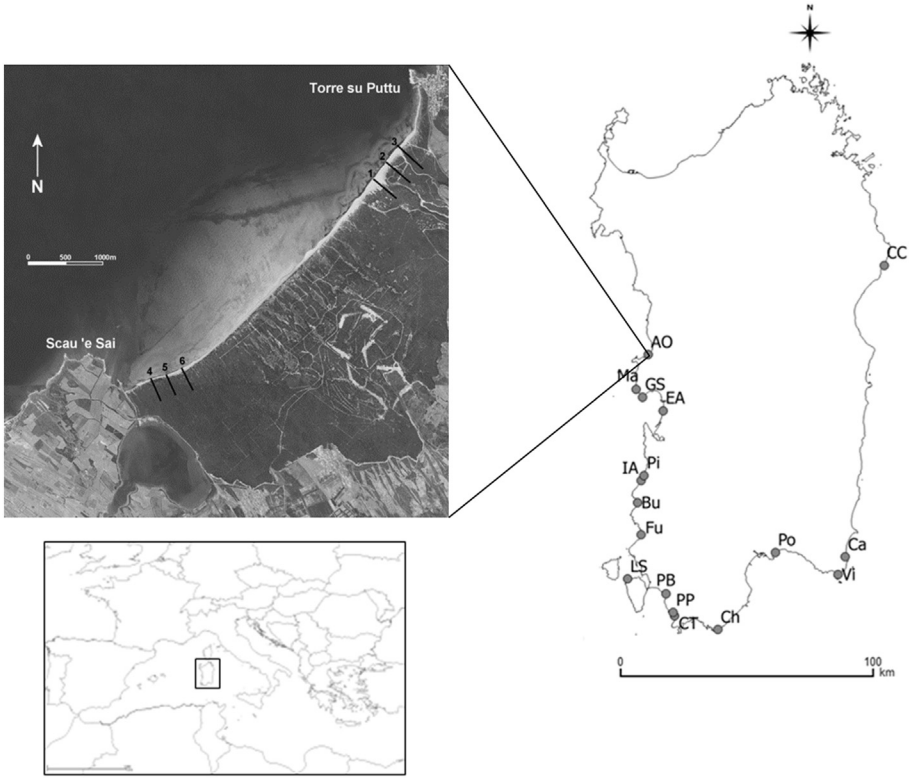

Fig. 1. Coastal dunes considered in this study. AO: Is Arenas of Oristano; Bu: Buggerru; Ca: Cala Sinzias; CC: Capo Comino; Ch: Chia; CT: Capo Teulada; EA: S'Ena Arrubia; Fu: Funtanamare; GS: S. Giovanni Sinis; IA: Is Arenas of Arbus; LS: Le Saline; Ma: Maimoni; PB: Porto Botte; Pi: Piscinas; PP: Porto Pino; Po: Poetto; Vi: Villasimius. In the box, a representative example of the transects placement: the case of Is Arenas of Oristano.

the total plant cover (%), the number of species (richness), the relative cover percentage per species as well as the number and the cover of endemic and alien plant species were recorded for each plot. The taxonomic treatment followed Bartolucci et al. (2018) for the native vascular flora; a specific focus on endemic plants was based on Fenu et al. (2014) while alien species followed Galasso et al. (2018). For endemic species the IUCN conservation status was obtained from a recent comprehensive study carried out at Italian level (Orsenigo et al., 2018).

The human disturbance level (grouped in three levels: low, medium and high) was calculated following the Human effect (HE) considered in a previous analysis (Ciccarelli et al., 2017), *ad hoc* updated. The considered parameters were the same described by Ciccarelli et al. (2017), except for three variables ("Trampling by animals", "Relative cover (%) of agriculture in the system (200 m inland from the foredune)" and "Grazing on the active system"), which were discarded since not directly related to our study purpose. Class of vulnerability of each variable, ranged from 0 (absence of human effects) to 4 (very high human effects), was calculated for each coastal dune (Appendix Table B1). The average of the 13 partial variables yielded the total HE per study site. HE ranging between 0 and 1, and as the index increases, the effects of human disturbance on a dune system increases. Finally, we grouped the selected sites into the three degrees of human disturbance, according to the following HE values: Low (0–0.50), Medium (0.50–0.75) and High (0.75–1; Appendix Table B1).

2.2. Diversity indices and statistical analyses

To measure the overall plant species diversity per site, the H_{dune} index (Grunewald and Schubert, 2007) was calculated following the formula:

$$H_{dune} = -\Sigma P_i \times \ln P_i$$

where P_i = % cover of the i^{th} plant species.

Usually, the H_{dune} value increases as the diversity in the community increases.

From the H_{dune} value it is possible to obtain the $H_{dune\text{-}max}$, which is the combination of the total cover and the number of plant species. Calculated by following the formula, H_{dune} will reach the maximum value ($H_{dune\text{-}max}$) if all species are equally abundant (Grunewald and Schubert, 2007).

$$H_{dune-max} = s \times [(\Sigma P_i)/s] \times \ln [(\Sigma P_i)/s]$$

where s = number of plant species.

The N index was calculated to evaluate the degree of diversity of the native/alien plant species at the site level, taking into account the percentage cover of the alien plants along each plot (Grunewald and Schubert, 2007):

$$N = H_{dune} \text{ (without alien plant species)}/H_{dune}$$

The N index ranges from 0 to 1, where 0 indicates that the plant diversity is composed exclusively of alien species, and 1 denotes the absence of alien plant species in the plant community (Grunewald and Schubert, 2007).

To explore the endemic plant coverage as an indicator of a coastal dune system's conservation status, a new Endemicity Index (EI) was developed, following the same theoretical approach of the N index. Consequently, the EI index was calculated according to the following formula:

$$EI = H_{dune} \text{ (considering only the endemic plant species)}/H_{dune}$$

The EI could provide a proxy of the coastal dune system's conservation status. It ranges from 0 to 1, where 0 represents the null coverage of endemic plant species in the coastal dune, and 1 indicates that the plant cover is composed exclusively of endemic species. Therefore, the increase in the EI value corresponds to a greater conservation status of a coastal dune system.

The diversity indices values of each plot were calculated by following the same methodology of Grunewald and Schubert (2007). Kruskal-Wallis one-way analysis of variance on ranks test, followed by all pairwise multiple comparison tests, was applied to evaluate the significant differences in the indices among all sites. As the degree of human disturbance was expected to affect the diversity indices, we also performed the same tests to evaluate the significant differences in the indices among the degrees of human disturbance.

All statistical analyses were performed using the Statistica 8.0 software (Statsoft, USA).

3. Results

In total, 173 vascular plant species were recorded on the 446 plots sampled. All sites showed a predominance of the plant species that were typical of the coastal dunes (54% of total plant species; the complete floristic inventory is reported in Appendix A). Of the total plant species recorded, 15 (8.1%) were endemics, and 5 were aliens (2.9%). Specifically, the most frequent endemic plant species were: *Lotus cytisoides* L. *subsp. conradiae* Gamisans present in 129 plots (0.29%), followed by *Silene succulenta* Forssk. subsp. *corsica* (DC.) Nyman present in 52 plots (0.12%). All endemic plants were insular endemics, most of them were restricted to Sardinia (53.34%) or to Sardinia and Corsica (20.00%). Only three endemics were threatened (CR and VU categories *sensu* IUCN), while the largest percentage presented no conservation problems (40.00%). It is interesting to note that several endemics (four species) were not assessed yet and their conservation status was unknown (33.32%; see Appendix A for details).

The most frequent alien plant species were: *Carpobrotus acinaciformis* (L.) L.Bolus present in 25 plots (0.06%), followed by *Arundo donax* L. and *Acacia saligna* (Labill.) H.L.Wendl. found in five and four plots, respectively. Porto Botte was the dune system with the highest floristic richness (PB; 66 plant species), while Capo Teulada had the lowest richness (CT; 13 plant species, Appendix Table B3). The richest sites in term of endemic species were Is Arenas of Arbus and Maimoni (IA and Ma; with eight and seven plant species, respectively), whereas the lowest ones were Buggerru (Bu), Poetto (Po), and CT (each with only one endemic plant species); however, at least one endemic plant species was found on each site. Additionally, the site with the highest number of alien plant species (three) was S′ Ena Arrubia (EA; Table B1).

Table 1
Mean values (± standard error) of H_{dune}, N and EI indices for each coastal dunes considered in this study. AO: Is Arenas (Or); Bu: Buggerru; Ca: Cala Sinzias; CC: Capo Comino; Ch: Chia; CT: Capo Teulada; EA: S'Ena Arrubia; Fu: Funtanamare; GS: S. Giovanni Sinis; IA: Is Arenas; LS: Le Saline; Ma: Maimoni; PB: Porto Botte; Pi: Piscinas; PP: Porto Pino; Po: Poetto; Vi: Villasimius.

Sites	H_{dune}	N	EI
Bu	0.302 ± 0.08	0.983 ± 0.01	0.010 ± 0.0010
Ca	0.795 ± 0.07	1	0.255 ± 0.035
CC	0.825 ± 0.07	1	0.020 ± 0.011
CT	0.234 ± 0,06	1	0.037 ± 0.035
Ch	0.683 ± 0.09	1	0.098 ± 0.022
Fu	0.629 ± 0.05	0.988 ± 0.01	0.156 ± 0.050
IA	0.625 ± 0.08	1	0.305 ± 0.052
AO	0.954 ± 0.06	0.999 ± 0.343 e^{-3}	0.065 ± 0.028
LS	0.638 ± 0.09	0.932 ± 0.03	0.111 ± 0.037
Ma	0.903 ± 0.09	0.999 ± 0.204 e^{-3}	0.064 ± 0.015
Pi	0.272 ± 0.05	1	0.244 ± 0.067
Po	0.416 ± 0.04	0.933 ± 0.05	0.0008 ± 0.0008
PB	0.727 ± 0.08	1	0.064 ± 0.025
PP	0.662 ± 0.08	1	0.060 ± 0.017
GS	1.146 ± 0.09	0.961 ± 0.02	0.069 ± 0.014
EA	0.893 ± 0.09	0.932 ± 0.02	0.043 ± 0.014
Vi	0.628 ± 0.07	1	0.158 ± 0.029

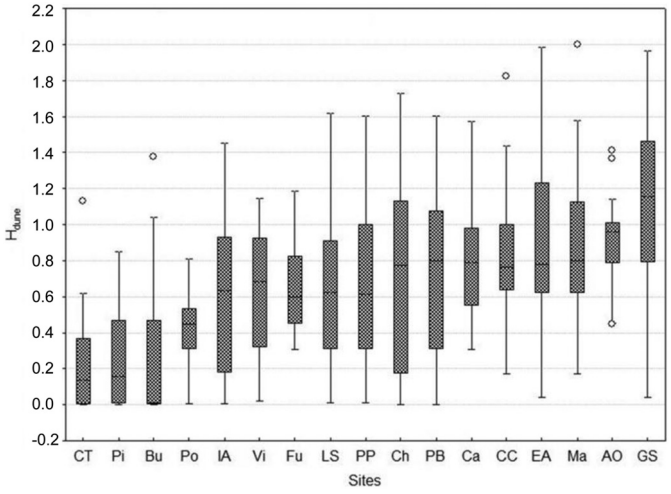

Fig. 2. Pattern of H_{dune} among coastal sites, the outliers are plotted with circles. For the abbreviations see Fig. 1.

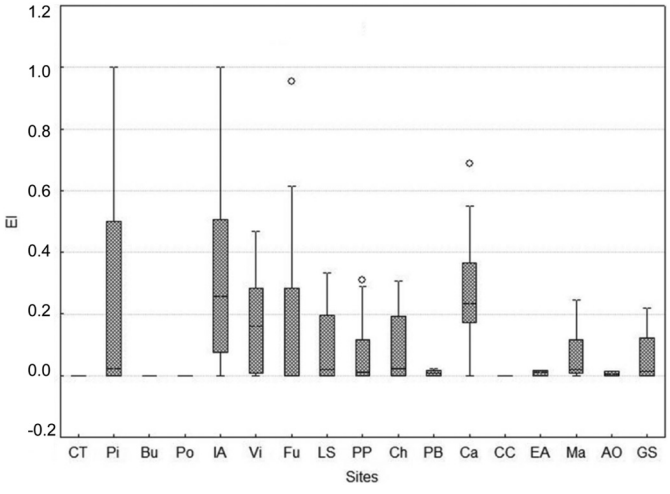

Fig. 3. Pattern of EI among sites, the outliers are plotted with circles. For the abbreviations see Fig. 1.

The results of the diversity indices calculated for each site are summarized in Table 1. The highest mean value of the H_{dune} index was recorded in San Giovanni (GS; 1.15 ± 0.09; Table 1, Fig. 2), whereas the lowest one was in CT (0.23 ± 0.06; Table 1, Fig. 2). The Kruskal-Wallis One-way Analysis of Variance on Ranks test showed significant differences in sites for H_{dune} values among the sites ($H_{(16,\ N=446)} = 139.8486$; $p < 0.05$; Table 2).

High values of the N index ($N > 0.9$) were obtained on all sites. Nine sites (53% of the total) registered the maximum value of naturalness ($N = 1$) while the lowest one was recorded in EA ($N = 0.93 \pm 0.02$; Table 1). No statistically significant differences in the N values were found among the sites (Kruskal-Wallis One-way Analysis of Variance on Ranks test: $H_{(16,\ N=434)} = 80.2974$; $p > 0.05$).

The EI values varied from the highest mean value recorded in IA (0.30 ± 0.05) to the lowest one noted in Po (0.0008 ± 0.0008; Table 1; Fig. 3); the Kruskal-Wallis One-way Analysis of Variance on Ranks test indicated statistically significant differences in the EI values among the sites ($H_{(16,\ N=434)} = 130.5858$; $p < 0.01$; Table 3).

Significant differences in the indices among the degrees of human disturbance were found. In particular, the highest H_{dune} values were recorded on the sites with a medium degree of human disturbance, while the lowest ones were noted on the sites with a low degree of human disturbance (0.79 ± 0.07 and 0.58 ± 0.05, respectively). The Kruskal-Wallis One-way Analysis of Variance on Ranks test indicated that these differences were statistically significant ($H_{(2,\ N=446)} = 14.083$; $p < 0.001$) between low and medium and between medium and high degrees of human disturbance (Fig. 4). Similarly, the Kruskal-Wallis One-way Analysis of Variance on Ranks test showed significant differences in the N values ($H_{(2,\ N=434)} = 33.424$; $p < 0.001$) between low and medium degrees of human disturbance. The highest EI values were recorded on the sites with a low degree of human disturbance (0.12 ± 0.009), and the lowest ones were noted on the sites with a medium level of human disturbance (0.07 ± 0.006). In this case, Kruskal-Wallis One-way Analysis of Variance on Ranks test highlighted significant differences ($H_{(2,\ N=434)} = 8.459$; $p < 0.05$) between the sites with medium and high degrees of human disturbance (Fig. 5).

4. Discussion

Over the last decades, tourism and all related activities have grown fast along the Mediterranean coasts, including the Sardinian dune systems, which are among the most visited tourist sites (data from http://www.sardegnastatistiche.it/documenti/; Pungetti et al., 2008). This rapid rate of growth has caused an increase in human-related impacts on plant populations and communities (e.g. Davenport and Davenport, 2006; Carboni et al., 2010; Santoro et al., 2012; Fenu et al.,

Table 2
Results of Kruskal-Wallis one-way analysis of variance on Ranks test for H_{dune} among sites.

Sites	CT	Pi	Bu	Po	IA	Vi	Fu	LS	PP	Ch	PB	Ca	CC	EA	Ma	AO	GS
CT		NS	NS	NS	>0.05	>0.05	>0.05	>0.05	>0.05	>0.01	>0.001	>0.001	>0.001	>0.001	>0.001	>0.001	>0.001
Pi			NS	NS	NS	NS	NS	NS	NS	NS	>0.01	>0.01	>0.001	>0.001	>0.001	>0.001	>0.001
Bu				NS	NS	NS	NS	NS	NS	NS	>0.05	>0.01	>0.001	>0.001	>0.001	>0.001	>0.001
Po					NS	NS	NS	NS	NS	NS	NS	NS	NS	>0.05	>0.05	>0.01	>0.001
IA						NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	>0.05
Vi							NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fu								NS	NS	NS	NS	NS	NS	NS	NS	NS	>0.05
LS									NS	NS	NS	NS	NS	NS	NS	NS	>0.05
PP										NS	NS	NS	NS	NS	NS	NS	NS
Ch											NS	NS	NS	NS	NS	NS	NS
PB												NS	NS	NS	NS	NS	NS
Ca													NS	NS	NS	NS	NS
CC														NS	NS	NS	NS
EA															NS	NS	NS
Ma																NS	NS
AO																	NS
GS																	

NS: not significant ($p > 0.05$).

Table 3
Results of Kruskal-Wallis one-way analysis of variance on Ranks test for EI among sites.

Sites	CT	Pi	Bu	Po	IA	Vi	Fu	LS	PP	Ch	PB	Ca	CC	EA	Ma	AO	GS
CT		>0.01	NS	NS	>0.001	>0.01	NS	NS	NS	NS	NS	>0.001	NS	NS	NS	NS	NS
Pi			>0.01	>0.01	NS	NS	NS	NS	NS	NS	NS	NS	>0.05	NS	NS	NS	NS
Bu				NS	>0.001	>0.001	NS	NS	NS	NS	NS	>0.001	NS	NS	>0.05	NS	NS
Po					>0.001	>0.001	NS	>0.05	NS	NS	NS	>0.001	NS	NS	>0.01	NS	NS
IA						NS	NS	NS	NS	NS	NS	NS	>0.001	NS	NS	>0.05	NS
Vi							NS	NS	NS	NS	NS	NS	>0.01	NS	NS	NS	NS
Fu								NS	NS	NS	NS	>0.05	NS	NS	NS	NS	NS
LS									NS	NS	NS	NS	NS	NS	NS	NS	NS
PP										NS	NS	NS	NS	NS	NS	NS	NS
Ch											NS	NS	NS	NS	NS	NS	NS
PB												>0.01	NS	NS	NS	NS	NS
Ca													>0.001	>0.05	NS	>0.01	NS
CC														NS	NS	NS	NS
EA															NS	NS	NS
Ma																NS	NS
AO																	NS
GS																	

NS: not significant ($p > 0.05$).

2013b; Ciccarelli, 2014; Pinna et al., 2015b), as well as the disappearance of native species with substantial ecological value, such as endemic and keystone plant species. Therefore, understanding the coastal dune systems' conservation status is crucial to preserve these extremely vulnerable environments through appropriate management strategies. We applied the diversity indices to assess the conservation status of the most vast and representative coastal dune systems of Sardinia, as well as the effects of different degrees of human disturbance related to the number of tourist visits.

The H_{dune} values in Sardinian coastal sites were influenced by human disturbance, as previously observed on oceanic dunes (Grunewald and Schubert, 2007). These results contradicted those of the study on the oceanic beaches by Pérez-Maqueo et al. (2017), which showed non-significant differences in the H_{dune} values among different locations and levels of tourism activity. In our study, the site with the highest H_{dune} value (GS), appeared quite distinct from the other sites in terms of the positive effects of decreased human trampling on this dune system, due to the building of wooden walking paths ten years ago. In contrast, the sites with the lowest H_{dune} values (CT, Pi, Bu) seemed to be affected more by geomorphological dynamics than by the human disturbance, except for Po, one of the most frequented beaches in Sardinia (Ciccarelli et al., 2017; Marignani et al., 2017). Indeed, although large portions of these sites were difficult to access, they were morphologically complex, large and well-developed dune systems characterised by a low number and coverage of plant species. Furthermore, the H_{dune} values of the Sardinian coastal systems were positively related to a medium level of human disturbance. Previous studies on coastal vegetation consistently highlighted that low and medium intensities of human disturbance, especially due to beach tourism and trampling, determined an increase in floristic richness (e.g. Kerbiriou et al., 2008; Santoro et al., 2012; Ciccarelli, 2014).

The Sardinian coastal dunes showed a general high value of naturalness according to the N index. The small variability of the N values among the sites indicated a low incidence of alien plants. This result is even more interesting, considering that if on one hand, the alien species invasion is one of the main threats to dune systems (EEA, 2012), on the other hand, in Sardinia the alien plant species coverage has increased significantly over the last decades (Pinna et al., 2015a). In particular, the presence of the most frequent alien species (*Carpobrotus acinaciformis* and *Acacia saligna*) is probably due to the strong tourist

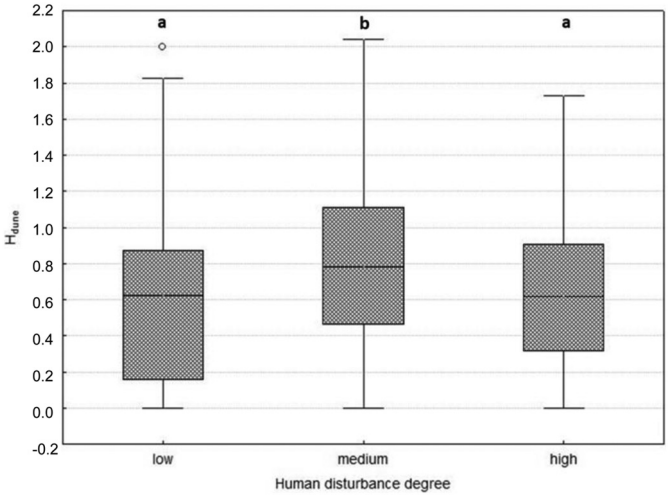

Fig. 4. Pattern of H_{dune} values among human disturbance degrees (low, medium, high). Bars with the different letter indicate the values with statistically significant differences among human disturbance degrees and the outliers are plotted with circles ($p < 0.05$ by the Kruskal-Wallis One-way Analysis of Variance on Ranks test).

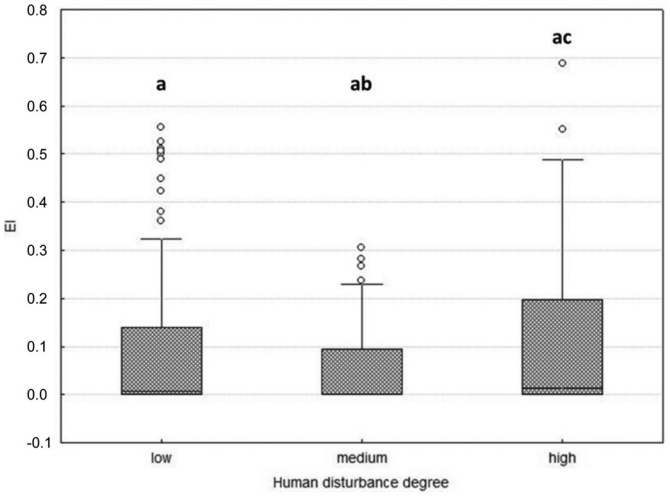

Fig. 5. Pattern of EI values among human disturbance degrees (low, medium, high). Bars with the different letter indicate the values with statistically significant differences among human disturbance degrees and the outliers are plotted with circles. ($p < 0.05$ by the Kruskal-Wallis One-way Analysis of Variance on Ranks test).

appeal of the study sites, the occurrence of such species as ornamental plants in the nearby resorts, and partly to the expansion of conifer afforestation during the previous century that led to the dune stabilisation in the Mediterranean coastal areas (e.g. Court-Picon et al., 2004; Del Vecchio et al., 2013). Nonetheless, our results do not support this evidence and N index seems a useless tool for assessing the human impact on coastal dunes, as reported by previous studies (e. g. Ciccarelli, 2014; Pinna et al., 2015b).

All study sites hosted endemic plant species, whose richness and coverage emphasised the high naturalistic value of Sardinian coastal dunes. The conservation status categories of the endemic assemblage typical of Sardinia coastal dunes highlighted that these plants were generally well-conserved and showed populations locally abundant. However, a significant percentage of these endemics was characterised by narrow distribution and small population size due to a wide spectrum of natural and human-related variables and its conservation was a priority for mangers.

To assess the conservation status of the Sardinian coastal dunes, a new specific index, based on the endemic plant coverage, was developed and applied. The EI showed significant differences among the selected sites. Moreover, the presence of endemic species in the dune systems would usually indicate a low level of human exploitation (Fenu et al., 2012). However, the coastal sites with the highest level of endemicity (IA, Pi and Ca) were characterised by a medium-low floristic richness, whereas the lowest EI value recorded in Po site, besides its low floristic richness, appeared strongly related to its severe touristic exploitation. This beach is indeed highly frequented by Cagliari's inhabitants throughout the year and additionally by tourists in the summer (Ciccarelli et al., 2017; Marignani et al., 2017). In fact, human trampling is one of the most relevant threats affecting the endemic species in Sardinia, particularly its coastal dunes (e.g. Fenu et al., 2013b, 2015, 2017). Along with other human-related disturbances linked to the Sardinian coasts as tourist attraction, trampling has a crucial detrimental impact on the sand dunes in the whole Mediterranean Basin (e.g. Ciccarelli, 2014). The EI results seem to confirm that trampling poses one of the most critical threats to the Mediterranean coastal systems, as well as allow to distinguish the sites with higher anthropogenic pressure among those that have lower EI values (as well as less richness and coverage of endemic species). On the contrary, the sites with the highest EI values are IA and Pi (despite their low number of species and total coverage) due to their geomorphology and position (long flat beaches in front of parabolic dune systems developing inland), they are quite isolated and hardly accessible.

The results of the diversity indices highlighted that in the coastal sites, a medium level of human disturbance was positively related to plant richness and cover, being a validation of the intermediate disturbance hypothesis (IDH). The intermediate disturbance hypothesis (Connell, 1978) is one of the most interesting concepts that predicts the community diversity response to a disturbance (Miller et al., 2011; Kershaw and Mallik, 2013; Huston, 2014). This hypothesis proposes that the relationship between species richness/diversity and disturbance is hump-shaped such that intermediate levels of disturbance maintain the highest biological diversity in plant and animal communities (Catford et al., 2012). It states that diversity is high when disturbances occur at an intermediate frequency or with an intermediate intensity based on the tension between competitively superior species and species that can rapidly colonize following a disturbance (Shea et al., 2004). Although the pattern is widely observed, the mechanisms underlying IDH reflect the complex interplay between life-history, biotic interactions and historical disturbance regimes that will be particular to anyone ecosystem (Catford et al., 2012). Our results highlighted that in these coastal sites with different human disturbance degree, the intermediate disturbance hypothesis seemed confirmed by the positive correlation between plant richness and cover and the medium level of human disturbance. Similar results were also obtained in a previous study carried out in the *Juniperus* spp. Mediterranean microforest along the Sardinian coastal dunes (Pinna et al., 2015a).

As a general rule, coastal plants are usually pioneer species that have adapted to natural stress and human disturbance (Santoro et al., 2012). Among the human disturbance factors, trampling was positively correlated to plant species diversity, especially for some psammophilous plant communities, dominated by the therophytes and rhizomatous species as *Elymus farctus, Sporobolus pungens* and *Ammophila arenaria* (Ciccarelli, 2014). Conversely, the lowest disturbance level was related to the low number (and coverage) of plant species due to the peculiar geomorphological characteristics of coastal sites, besides their having large portions that would be difficult to access.

4.1. Conservation implications

The results of this study indicated the Sardinian coastal dunes' satisfactory conservation status and high degree of naturalness despite the high touristic significance of the island. Specific attention should be taken for the endemic insular plants and for plant species with a special conservation interest, that increase the conservation value of these coastal dunes. These plants should be carefully considered when planning and managing these areas for recreational purposes.

Our study indicated that a medium degree of human disturbance also caused an increase in the coastal sites' floristic richness and coverage; such achievement showed that a science-based and regulated human access could be tolerated by the psammophilous plant species and communities. In this frame, it is relevant to promote a planned regulation of touristic activities based on local scale requirements. In particular, the touristic activities should be organized by mitigating or preventing the effects of human impacts in sensitive dune habitats, limiting the effect of unregulated human trampling that causes the opening of a complex path network. In this way, the use of light and removable structures, such as wooden walkways and light fences, can help to reduce the human impacts and to direct tourists to less sensitive areas.

The use of diversity indices was a quick and valuable, but not unique, support for evaluating the conservation status of the sandy coastal dunes in the Mediterranean Basin and detecting the anthropogenic pressures. In this paper, the new EI index was presented and applied for the first time to a large number of representative coastal dunes at the Mediterranean level. The EI index contributed, together with the other indices, to distinguishing the sites with varying levels of human disturbance, although it differentiated better those with the highest anthropic pressure. As a rapid tool, this index can be used by managers as a proxy to identify more sensitive coastal dunes and used to perform a rapid evaluation (monitoring) of these areas subjected to a touristic activities. Further studies are needed to develop this index and make it more sensitive to local conditions. Hence, the findings of this study highlighted that the EI index, as well as the applied diversity indices, does useful tools for implementing an adequate management and conservation strategy, compatible with touristic purposes both at the local and the Mediterranean levels.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.04.120.

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