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Hard times for Italian coastal dunes: insights from a diachronic analysis based on random plots

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Abstract Multi-year temporal studies are invaluable tools for monitoring changes in biodiversity through time. However, their applications in coastal ecosystems are still scarce. We investigated temporal trends in coastal dunes analyzing a set of 858 randomly-sampled georeferenced relevés performed between 2002 and 2015 along Central Italy's sandy coastlines. Specifically, we explored changes in species richness and cover of targeted sandy habitats, we investigated trends in the cover of selected psammophilous native species and we assessed patterns of invasion by means of regression techniques. We observed a significant decrease in species richness and cover of the dune grasslands habitat. The species-level analysis confirmed a negative trend for two characteristic species of dune grasslands, *Cutandia maritima* and *Medicago littoralis*, while revealing a similar decline for *Crucianella maritima* and for *Ammophila arenaria* subsp. *australis*, key species of mobile dunes. The most striking trends emerged analyzing patterns in the cover of an invasive alien species, *Carpobrotus* sp., which showed a concerning increase in shifting dunes. In conclusion, our analyses reveal concerning changes involving dune grasslands, and at the same time hint at "early warnings" of degradation processes traceable in shifting dunes.

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Introduction

Although occupying a relatively small portion of the earth's surface, coastal dunes feature high ecological diversity, hosting a striking number of habitats considered to be relevant to international conservation goals (Janssen et al. 2016) along a well-described zonation running perpendicular to the coastline (Van der Maarel 2003; Acosta et al. 2009; Miller et al. 2010; Isermann 2011; Fenu et al. 2013; Ciccarelli 2015; Bazzichetto et al. 2016). Nevertheless, they appear to be threatened worldwide mainly due to coastal erosion (Feagin et al. 2005), urbanization, (Malavasi et al. 2013), pollution (Poeta et al. 2014, 2016) and other related human pressures. It has been estimated that, during the previous century, European dune systems reduced their cover of about 70% (McLachlan and Brown, 2006; Buffa et al. 2012). Additionally, a number of studies already reported on the vulnerability of coastal dune communities to biological invasions (Bruno et al. 2004; Vilà et al. 2006; Carboni et al. 2010; Del Vecchio et al. 2015a). In particular, it has been observed that in Mediterranean ecosystems species belonging to the genus *Carpobrotus* manifested an invasive behaviour (D'Antonio et al. 1993; Vilà et al. 2006; Traveset et al. 2008; Jucker et al. 2013; Novoa et al. 2013).

At present, it is known that habitat loss, land-use change and invasive species are causing a steady acceleration in the global rate of species extinction (Vellend et al. 2013), and there is growing consensus about biodiversity loss affecting ecosystem functioning, ecosystem services and generally, threatening human well-being (Díaz et al. 2006; Cardinale et al. 2012). In this context, diachronic studies are considered to be powerful tools for monitoring changes in biodiversity, exploring the causes beyond those changes and assessing the conservation status of particular habitats (Pignatti and Pignatti 2014; Del Vecchio et al. 2015b; Gigante et al. 2016; Prisco et al. 2016a). However, although recent years have witnessed a growing interest in the field of diachronic studies, such approaches appear to be still applied rather scarcely to highly dynamic ecosystems such as coastal dunes.

In Italy, multi-temporal analyses in coastal environments have been carried out at a landscape scale, mostly making use of remote sensing data (Drius et al. 2013; Bertacchi and Lombardi 2014; Malavasi et al. 2016). On the other hand, community-based approaches have been adopted within restoration projects (Landi et al. 2012), short-term monitoring and re-visitation studies conducted in relatively small study areas (Del Vecchio et al. 2015b; Prisco et al. 2016b). However, all these studies are either conducted at a local scale or focus on relatively short time-spans (but see Landi et al. 2012). In this context, to gain further understanding of temporal dynamics and to efficiently evaluate conservation measures, long-term monitoring studies performed at regional scale are urgently needed. A relevant contribution in this sense can be found in Prisco et al. (2016a) who detected consistent temporal changes in the vegetation cover of sandy coastal habitats and of selected species through the analysis of an extensive collection of phytosociological data. Nevertheless, caution is necessary when extracting temporal trends from vegetation databases since temporal analyses unfortunately fall outside the purposes for which phytosociological surveys were originally designed (Michalcová et al. 2011). This being said, potential sources of bias deriving from phytosociological data such as preferential sampling, uneven sampling intensity and different plot sizes (Jandt et al. 2011), can all be avoided making use of random standardized plots.

Diachronic studies might also act as a valuable resource when assessing temporal trends in plant invasion. In fact, evaluating invasion levels of different habitats over time can provide a better understanding of invasion dynamics as well as deliver useful insights about risk levels faced by different plant communities in the long term (Medvecká et al. 2014; Del Vecchio et al. 2015a). Given the high dynamism characterizing these endangered environments, such information appears to be particularly significant in coastal dune systems. Nevertheless, except for a study conducted by Del Vecchio et al. (2015a, b), to our knowledge no specific effort has been dedicated to assessing temporal dynamics of invasion in coastal ecosystems until now.

Thus, the use of a diachronic approach providing a comprehensive understanding of both plant communities and invasion dynamics, can ultimately contribute to the achievement of conservation goals in coastal ecosystems. On this basis, this paper aims to investigate temporal trends in relatively recent Holocenic dunes of central Italy, by means of both a habitat- and a species-approach, through the use of a random georeferenced vegetation database consisting of data gathered between 2002 and 2015. In particular, we intend to (i) analyze changes in plant species richness and cover of the main sandy habitats (sensu Habitats Directive 92/43/CEE and EUNIS classification), (ii) identify trends in the cover of selected native target species, (iii) evaluate tendencies in the richness of alien taxa and in the cover of one of the most abundant exotic plants in coastal dune environments, *Carpobrotus* spp.

Materials and methods

Study area

In this study, we focused on sandy coastal ecosystems of Central Italy. In particular, sampling activities were carried out in sandy beaches located in 5 Italian administrative regions (Lazio, Campania, Abruzzo, Molise and Puglia). Throughout the study area, vegetation was recorded across the whole coastal zonation, thus including upper beach, embryo dunes, shifting dunes, dune grasslands, wooded dunes and Mediterranean forests.

Habitats and species data

The analyses performed within the present study were conducted using standardized randomly-sampled georeferenced relevés stored in the "RanVegDunes" database (Sperandii et al. 2017). This database includes georeferenced floristic relevés, each sampled once between 2002 and 2015 in different spatial locations along Central Italy's sandy coastlines. It should be pointed out that relevés were not performed every year, but are only available for 10 years between 2002 and 2015. Vegetation data collected in the field were stored in Turboveg (Hennekens and Schaminée 2001) where, along with the list of recorded species and their relative abundances, additional information were entered for each plot such as geographical coordinates, a Habitat code assigned using the Interpretation Manual of the 92/43/EEC Habitats Directive (Biondi et al. 2009) and a level 3-EUNIS code (attributed according to a correspondence table developed by the Italian National

Institute for Environmental Protection and Research, ISPRA—http://www.isprambiente.gov.it/files/biodiversita/Tabella_Corrispondenze_181213.xls).

From "RanVegDunes" we extracted a set of 858 standardized, 4 m^2 relevés (hereafter, plots), available for ten years included in the previously mentioned 2002–2015 time-span, and referring to herbaceous and shrub formations. Selected plots were distributed across four EUNIS types (Table 1): B1.1—Sand beach drift lines, B1.3—Shifting coastal dunes, B1.4—Coastal stable dune grassland and B1.6—Coastal dune scrub. We chose to adopt level 3-EUNIS categories as reference units for conducting analyses at the community level as this system represents the standard classification for European habitats, and at the same time, by adopting a commonly accepted nomenclature, allows easier comparisons of the results between European countries (Medvecká et al. 2014). It is worth noting that some plots could not be assigned to a specific EUNIS type and were therefore labeled as "NOT CLASSIFIABLE" (hereafter, NC). NC plots included two different groups: (i) plots particularly rich in alien species ($\geq$ 20% of alien cover, tagged as "invaded") and (ii) plots performed in highly disturbed sites (tagged as "disturbed"), whose ascription to a single EUNIS type turned out to be unfeasible due to their hosting assemblages of species belonging to a mosaic of different habitats.

Table 1 EUNIS type, EU habitat category, description of the community and target species selected for this study

EUNIS type	EU habitat (ex Annex I 92/43/EEC)	Habitat description	Target species
B1.1 Sand beach drift lines	1210 Annual vegetation of drift line (upper beach)	Pioneer annual formations characterizing the strandline zone of the beach	*Cakile maritima* subsp. *maritima, Salsola kali*
B1.3 Shifting coastal dunes	2110 Embryonic shifting dunes (embryo dune) 2120 Shifting dunes along the shoreline with *Ammophila arenaria* (mobile dune)	Pioneer, perennial community of the low embryo-dunes dominated by *E. farctus* Seaward and semi-permanent cordons of dune systems dominated by *Ammophila arenaria* subsp. *australis*	*Elymus farctus* subsp. *farctus, Anthemis maritima*, *Medicago marina*, *Sporobolus virginicus*, *Cyperus capitatus* *Ammophila arenaria* subsp. *australis*, *Echinophora spinosa*, *Anthemis maritima*, *Medicago marina*
B1.4 Coastal stable dune grassland	2210 *Crucianellion maritimae* fixed beach dunes 2230 *Malcolmietalia* dune grasslands	Chamaephytic community of the inland side of fixed dunes dominated by *Crucianella maritima* Annual, species-rich community colonized by small terophytes in dry, interdunal depressions of the coast	*Crucianella maritima* *Cutandia maritima, Medicago littoralis*, *Lotus cytisoides*, *Ononis variegata*, *Vulpia fasciculata*
B1.6 Coastal dune scrub	2250 Coastal dunes with *Juniperus* spp. (juniper scrub) 2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs	Shrub formations dominated by juniper on the fixed dunes Shrub formations dominated by sclerophyllous species	*Juniperus oxycedrus* subsp. *macrocarpa* *Pistacia lentiscus*, *Phillyrea angustifolia*

To explore temporal trends in the cover of single species we selected 17 species among those regarded as diagnostic in each considered Annex I EU habitat, provided they were adequately represented in our database (see Supplementary material for details). Diagnostic species are considered to be playing a crucial role in supporting both the structuring and functioning of their reference habitat, and we identified them following Biondi et al. (2009). Concerning alien species, we decided to focus on *Carpobrotus acinaciformis* and *Carpobrotus edulis*, clonal South African succulents originally introduced as ornamentals and for preventing erosion (Castro-Díez et al. 2016), widely naturalized not only in Italian coasts (Carranza et al. 2010; Jucker et al. 2013) but also in other coastal habitats around the world (D'Antonio et al. 1993; Traveset et al. 2008; Vilà et al. 2006). Because of unresolved issues in the taxonomy of the species, in the present study they will be considered as a single taxon, namely *Carpobrotus* sp.. Plant nomenclature follows Conti et al. (2005).

Statistical analysis

Trends in species richness and cover over time, along with temporal patterns of invasion, were investigated by means of regression techniques (linear models and generalized linear models, but see next paragraphs for detailed explanations) chosen according to a number of response variables. In each of the models, EUNIS type was included as interaction term with sampling year in order to accommodate for patterns of species richness and vegetation cover characterizing different habitats of the coastal zonation. However, level 3-EUNIS types often include more than one vegetation unit, i.e. phytosociological syntaxa corresponding to Annex I EU Habitats (see Table 1). In order to assess which of the underlying psammophilous community was actually driving the change, new models including EU Habitat (see Table 1) as interaction term were fitted in case of statistically significant trends being detected at EUNIS level. Slope parameters (β values) were extracted from each model and used as a means to quantify temporal changes in target communities and species. All models were fitted in R (package: stats; R Core Team 2016). Overdispersion was calculated for each Poisson generalized linear model performing a dispersion test (package: AER; R Core Team 2016).

Model assumptions were evaluated by visually inspecting residual plots, which come as standard output of the models, and by checking for normality, homoscedasticity, and independence. Overall, model fit was assessed by means of an AIC-based approach. In particular, AIC values of each model (or QAIC in case of Quasi-Poisson models) were compared with those extracted from their corresponding intercept-only models, with the model showing the lowest AIC being the best (Burnham and Anderson 2003). Finally, correlograms were used to evaluate any remaining spatial dependencies among the residuals from the various models (R package ''spdep'').

Habitat changes in richness and cover

Species richness was calculated for each plot as the total number of species recorded. Generalized linear models (GLMs) following a Poisson distribution and a log-link function ("glm" function; R Core Team 2016) were fitted, using species richness as response variable and sampling year as predictor. In case of overdispersion being detected, models were corrected using a quasi-Poisson error distribution.

Cover values were computed for each plot summing up the percentage cover of each species present in the plot. Note that, since this value can exceed 100% ground cover, we resolved to rescale cover values between 0 and 1 dividing each cover value by the maximum for each species. Then, on rescaled cover values we applied a logit-transformation to normalize model residuals. Linear models ("lm" function; R Core Team 2016) were then fitted using rescaled cover values as response variable and sampling year as predictor.

Cover changes of native target species

Temporal changes in the cover of native target species were explored using a subset of 754 relevés (excluding NC plots). For each species we rescaled cover values over the years between 0 and 1. Then, in order to investigate if and how their abundance changed over time, for each target species we fitted linear models ("lm" function; R Core Team 2016) using rescaled logit-transformed cover values as response variable and sampling year as predictor.

Temporal patterns of invasion

We investigated temporal patterns of invasion examining changes both in the richness of alien species and in the cover of the most abundant exotic species in our database, *Carpobrotus* sp.. After identifying alien species according to Celesti-Grapow et al. (2009), alien species richness (calculated as the total number of alien taxa) and *Carpobrotus* sp. cover values were computed for each plot. Then, following the same approach we described above, we applied generalized linear models ("glm" function; R Core Team 2016) to alien species richness and linear models ("lm" function; R Core Team 2016) to *Carpobrotus* cover values.

Finally, it should be noted that as "NC" relevés consisted of both "invaded" and generically "disturbed" plots, temporal trends of invasion were further explored within this category. In particular new models where "plot status" (i.e. disturbed or invaded) was included as interaction term were ran on "NC relevés" for both alien species richness and *Carpobrotus* sp. cover.

Results

Habitat changes in richness and cover

Between 2002 and 2015, a significant decrease in species richness could be identified in EUNIS type B1.4 only, while no relevant trend could be otherwise detected (Table 2; Fig. 1a). As EUNIS type B1.4 includes plots belonging to EU Habitat 2210 (*Crucianellion maritimae* fixed beach dunes) and EU Habitat 2230 (*Malcolmietalia* dune grassland), a second GLM was run only on EUNIS B1.4 plots. The use of EU Habitat as a covariate allowed us to identify EU Habitat 2230 as being responsible for the decreasing trend observed at EUNIS level (estimate: -0.028 ± 0.010; p: 0.006; Fig. 1b).

Temporal trends in habitat cover highlighted no significant change except for EUNIS type B1.4 (Table 3; Fig. 2a). As in the previous case, in order to find out to which community was actually driving the trend, we fitted a second linear model (only selecting

Table 2 Changes in the richness of selected EUNIS types over time

GLM quasipoisson (eunis/anno -1)	Trend	Estimate	SE	*p* value
eunisB1.1:year	↑	0.032	0.017	0.064
eunisB1.3:year	↓	− 0.006	0.007	0.379
eunisB1.4:year	↓	− 0.024	0.009	**0.008**
eunisB1.6:year	↑	0.018	0.010	0.063
NC:year	↓	− 0.002	0.014	0.863

Statistically significant changes are reported in bold

NC not classifiable plots

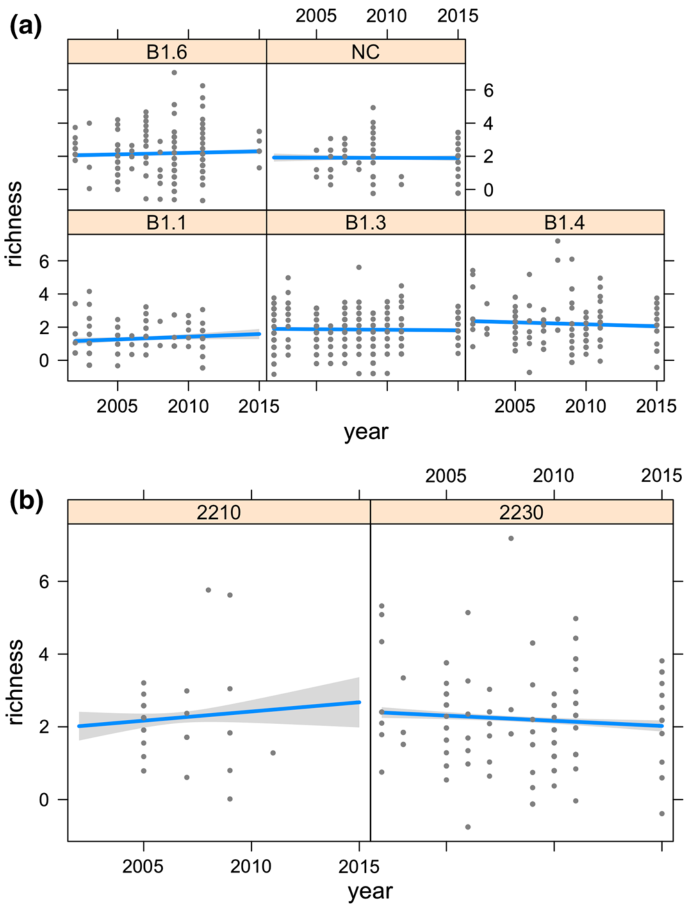

Fig. 1 Changes in the richness of EUNIS types over time (**a**) and in the two EU habitats included in EUNIS type B1.4 (**b**)

Table 3 Changes in the cover of selected EUNIS types over time

LM (eunis/year − 1)	Trend	Estimate	SE	*p* value
eunisB1.1: year	↑	0.004	0.020	0.841
eunisB1.3: year	↑	0.004	0.011	0.722
eunisB1.4: year	↓	− 0.067	0.016	**< 0.001**
eunisB1.6: year	↑	0.008	0.017	0.64
NC: year	↓	− 0.021	0.021	0.312

Statistically significant changes are reported in bold

NC not classifiable plots

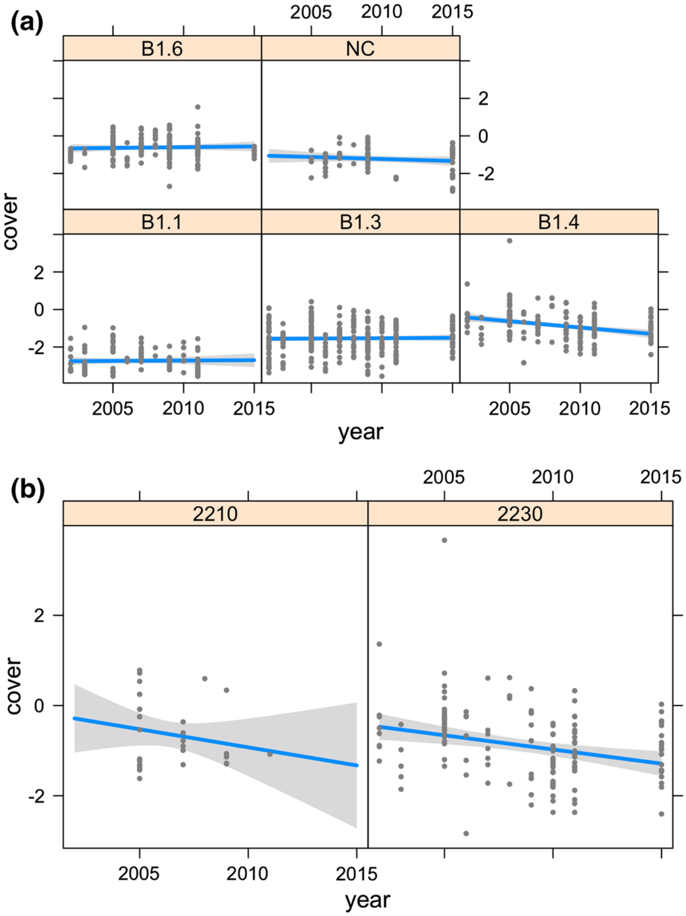

Fig. 2 Cover changes in EUNIS types over time (**a**) and in the two EU habitats included in EUNIS type B1.4 (**b**)

EUNIS B1.4 plots) including EU Habitat as interaction term. This second model indicated *Malcolmietalia* dune grasslands as driving the previously detected negative trend (estimate: − 0.0673 ± 0.019; p: 0.001; Fig. 2b).

Table 4 Changes in the cover of target species over time (only significant trends are showed)

Species name	Annex I EU habitat	Level 3—EUNIS type	Estimate	Trend	*p* value
Ammophila arenaria subsp. *australis*	2120	B1.3	− 0.068	↓	< 0.001
Anthemis maritima	2110, 2120	B1.3	0.038	↑	0.041
Medicago marina	2110, 2120	B1.3	− 0.028	↓	0.015
Crucianella maritima	2210	B1.4	− 0.126	↓	< 0.001
Lotus cytisoides	2110, 2120	B1.3	0.053	↑	< 0.001
Vulpia fasciculata	2230	B1.4	0.066	↑	< 0.001
Cutandia maritima	2230	B1.4	− 0.099	↓	< 0.001
Medicago littoralis	2230	B1.4	− 0.073	↓	< 0.001
Juniperus oxycedrus subsp. *macrocarpa*	2250	B1.6	− 0.083	↓	< 0.001

Cover changes of native target species

During the time-span considered, 9 out of the 17 selected species showed a significant change in their cover (Table 4, Supplementary material 1). In particular, 6 out of 9 species featured a negative trend, the greatest loss being encountered by *Crucianella maritima*, an endangered chamaephyte characterizing transition dunes. A similar pattern could be detected for *Ammophila arenaria* subsp. *australis*, key species of mobile dunes, for *Medicago marina* and for therophytes belonging to dune grassland habitats such as *Cutandia maritima* and *Medicago littoralis*. A marked decline over time was also observed for *Juniperus oxycedrus* ssp. *macrocarpa*, an evergreen shrub which dominates the landscape of wooded dunes, while no peculiar change could be noticed among the species characterizing the upper beach (*Cakile maritima*, *Salsola kali*). As for species featuring a positive trend, *Lotus cytisoides* and *Anthemis maritima* are perennial forbs of shifting coastal dunes habitats, while *Vulpia fasciculata* is an annual herb growing in dune grasslands.

Temporal patterns of invasion

During the time-span considered, alien species showed a significant decrease only in NC plots (estimate: -0.198 ± 0.041; p: 0.000). Another GLM built up using "plot status" as covariate suggested "disturbed" plots as driving the negative trend (Table 5).

Table 5 Temporal changes in the richness of alien species, according to "plot status" (disturbed –DIST-, or invaded –INV-)

GLM poisson (status/year − 1)	Trend	Estimate	SE	*p* value
Statusdist: year	↓	− 0.219	0.052	**< 0.001**
Statusinv: year	↓	− 0.059	0.108	0.582

Statistically significant changes are reported in bold

Table 6 Temporal changes in the cover of *Carpobrotus* sp., according to EUNIS type

LM (eunis/year − 1)	Trend	Estimate	SE	*p* value
eunisB1.1: year	↑	0.000	0.019	1.000
eunisB1.3: year	↑	0.051	0.010	**< 0.001**
eunisB1.4: year	↑	0.004	0.015	0.776
eunisB1.6: year	↑	0.014	0.017	0.401
NC: year	↓	− 0.359	0.020	**< 0.001**

Statistically significant changes are reported in bold

NC not classifiable plots

Table 7 Temporal changes in the cover of *Carpobrotus* sp. according to “plot status” (disturbed –DIST-, or invaded –INV-) in NC (not classifiable) plots

LM (status/year − 1)	trend	Estimate	SE	*p* value
Statusdist: year	↓	− 0.210	0.033	**< 0.001**
Statusinv: year	↑	0.381	0.113	**0.001**

Statistically significant changes are reported in bold

The analysis of changes in the abundance of *Carpobrotus* sp. over time produced two significant results (Table 6). In particular, its cover underwent a positive change in shifting coastal dunes (EUNIS type B1.3), while encountering a decline in “NC” category. Finally, running a second model including “plot status” as interaction term resulted in two significant patterns: a decreasing trend in highly “disturbed” plots, and an increasing one in “invaded” plots (Table 7).

Correlograms highlighted limited spatial autocorrelation in the residuals of the models, but only when considering first lag neighbors (data not shown). Nevertheless, it is worth noting that AIC values of intercept–only models were always found to be consistently higher than those computed on the corresponding full models, therefore indicating predictor terms to explain significant variation in response variables.

Discussion

Habitat changes in richness and cover

As highlighted by the models, between 2002 and 2015 EUNIS B1.4 type suffered negative changes in both species richness and cover. A further exploration of this trend allowed us to specifically identify dune grasslands (EU Habitat 2230) as driving the decreasing pattern, in line with observations made by Prisco et al. (2016a) and with those of Janssen et al. (2016), who recently classified it as the most “endangered” among coastal dune habitats. This raises fresh concerns about the fate of one of the Mediterranean most biodiverse habitats, its hosting several species of insects, nesting birds and rabbits, along with a number of endemic and highly specialized taxa (McLachlan and Brown 2006; Fattorini et al. 2012).

Cover changes in native target species

Consistent with our findings at the habitat scale, the species-level analysis showed a decline in two diagnostic species of dune grasslands, *Cutandia maritima* and *Medicago littoralis*. A similar trend was encountered by *Ammophila arenaria* subsp. *australis*, key species of shifting dune habitats. Even though no significant change over time could be detected in the habitat where this species is considered to be diagnostic (EUNIS type B1.3), the decrease in the cover of this perennial grass appears somehow connected with the positive trends recorded by the perennial forbs *Lotus cytisoides* and *Anthemis maritima*, both often indicated as being capable of forming replacement communities in degraded shifting dunes (Géhu and Biondi 1994; Acosta et al. 2007), and with the increase in the cover of the invasive *Carpobrotus* sp. (see next paragraph). Similarly, the sharp decrease encountered by *Crucianella maritima*, a perennial entity dominating stable dune grasslands, can be related to the widespread presence of species such as *Ononis variegata* and *Pycnocomon rutifolium*, which become abundant in *Crucianella* communities affected by disturbance (Géhu and Biondi 1994). Finally, a marked decline over time could be also observed in the cover of *Juniperus oxycedrus* ssp. *macrocarpa*. Even though not supported by a parallel loss in the corresponding EUNIS type, this tendency should not be underestimated given that in recent decades fixed dunes belonging to EU habitat 2250 have undergone a serious contraction due to anthropogenic disturbance (Malavasi et al. 2013; Genovesi et al. 2014). Increasing temporal patterns observed by Prisco et al. (2016a) in the cover of both EU Habitat 2250 and *Juniperus oxycedrus* ssp. *macrocarpa* seem to contradict our results, though ascribed by the authors to the positive role of Natura 2000 Network. However, the expansion of artificial and agricultural surfaces linked to human activities (Salvati et al. 2014; Sytnik and Stecchi 2015), together with a predicted reduction of this habitat under climate change scenarios (Prisco et al. 2013; Seabloom et al. 2013), could make this habitat vulnerable to land degradation in the near future, also within protected areas (Tsiafouli et al. 2013; Kallimanis et al. 2014; Salvati et al. 2014; Pinna et al. 2015).

Temporal patterns of invasion

Our analyses provide strong evidence that in “NC” plots the number of alien species has declined over the years. Such a finding appears even more surprising when taking into consideration the fact that the decrease actually took place in highly “disturbed” plots. Indeed, though a number of studies have already reported on high levels of anthropogenic disturbance in coastal environments, our results suggest that, besides affecting native communities, such conditions might also impact upon alien species, as shown by the declining pattern observed for *Carpobrotus* sp. in highly “disturbed” plots. Nevertheless, however positive, the decrease of *Carpobrotus* sp. in such plots is strongly counterbalanced by its significant growth in shifting dunes, coastal dune vegetation’s most characteristic habitat (EUNIS B1.3). Here, the increasing trend recorded by *Carpobrotus* sp., mirrored by a complementary decrease in the cover of *Ammophila arenaria* subsp. *australis*, appears to be particularly worrying since, despite the already documented presence of *Carpobrotus* in shifting dunes, invasion processes hitherto headed by this exotic plant have mainly affected dune grasslands and *Crucianella*-dominated communities.

Conclusions

In the present study, we have set out to unravel temporal trends in selected psammophilous communities through the use of a diachronic approach entirely based on random, standardized and unpreferentially collected data.

Our analyses revealed changes at a habitat level and raise concerns over the fate of dune grasslands, which during the considered period experienced a significant decline in both species richness and cover. However, it should be noted that as Mediterranean dune grasslands are mainly composed of annual therophytes, changes in their dynamics can be traced in the course of a few years, while the detection of similar trends in perennial communities might require longer-term observations. This being said, individual species might predict community trends through changes in their cover, with negative patterns serving as “early warnings” about the fate of the whole habitat. This could be the case in shifting dunes, where no statistically significant change was observed at habitat level, whereas a negative pattern was identified in the cover of key species *Ammophila arenaria* subsp. *australis*. Nevertheless, the most striking results emerged from the analysis of temporal patterns in the cover of *Carpobrotus* sp, which underwent a decrease in disturbed plots while, on the other hand, displaying a significant growth in shifting dunes.

Diachronic analyses in coastal dune ecosystems are both useful and highly versatile. As well as expanding current knowledge on temporal dynamics, they can contribute significantly to the development of conservation activities and of species-dedicated measures. In particular, our results highlight that priority should be given to the implementation of recovery processes in dune grasslands, while monitoring activities of invasion levels should mainly focus on well-preserved habitats experiencing recent alien invasion, such as shifting dunes.

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