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The European *Juniperus* habitat in the Sardinian coastal dunes: Implication for conservation

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ABSTRACT

In this study, we explore the influence of environmental and anthropogenic factors on the floristic variability of the “coastal dunes with *Juniperus* spp.” European habitat (code 2250*) in Sardinia. Two datasets were created: the first by inputting phytosociological relevés available in literature plus our own samplings; the second by including, for each relevé, environmental, floristic, and human-related factors. Differences in *Juniperus* habitat composition and the influence of the explanatory variables were analyzed by multivariate analysis, while GLM were used to test the effect of human disturbance and sampling period on several habitat parameters (plant richness, cover of endemic and alien taxa). The floristic composition differed among sites, being significantly influenced by all the variables analyzed except coastal type. Composition was governed mainly by a latitudinal gradient, linked to a climatic gradient, which varied from North to South. In addition, the floristic richness was positively influenced by low and medium levels of human disturbance. Similarly, the plant richness and cover of endemic taxa was positively related to medium level of human disturbance, while the cover of alien taxa was positively related to recent sampling. The analysis of our own floristic data together with those recorded from 1976 is useful to monitor floristic changes over decades and gives a better understanding of the “coastal dunes with *Juniperus* spp.” habitat to contribute to its conservation; therefore, management actions, such as eradication of alien taxa, should be implemented.

1. Introduction

Coastal dune ecosystems host high biodiversity, compared with other natural ecosystems, and show an extremely specialized flora and fauna (Carranza et al., 2008). This is because of the intricate interactions between abiotic and biotic factors in coastal dunes that cause a complex sea-to-inland environmental gradient (Carranza et al., 2008; Prisco et al., 2012; Fenu et al., 2013a; Angiolini et al., 2013). This gradient determines a gradual change in vegetation, and, as 17 coastal habitat types were listed in Annex I of the European Habitats Directive (92/43/EEC), this shows the high heterogeneity of all coastal dune habitats in Europe. However, the structure and composition of plant communities are not only affected by environmental factors such as the high sand mobility, the wind impact, the salt spray, and sand accretion (Maun, 2009), but also by anthropogenic factors, since human disturbance has increased greatly in the last two centuries in coastal systems (Nordstrom, 2000; Brown et al., 2008). The rapid increase in a wide range of human activities (urbanization, agriculture, forestry, industry, transport and tourism, etc.) has led to a progressive deterioration and biodiversity loss, causing fragmentation and a dramatic decline in the distribution and quality of dune habitats (Davenport and Davenport, 2006; Reger et al., 2007; Arianoutsou et al., 2012).

As such, many works have highlighted the effects of human disturbance on the plant diversity of coastal dunes in the Mediterranean region (e.g., van der Meulen and Salman, 1996; Acosta et al., 2006; Carboni et al., 2009; Attorre et al., 2013; Fenu et al., 2012, 2013a; Santoro et al., 2012; Ciccarelli, 2014). In Italy, the overall conservation status of coastal habitats is unsatisfactory for

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86.7% of the sites (Biondi and Zivkovic, 2014). In particular, Prisco et al. (2013) demonstrated that mobile and fixed dunes (including 2120, 2210, 2250 habitats), are projected to lose most of their distribution area in the near future. Certainly, the 'coastal dunes with *Juniperus* spp.' habitat (code 2250 in the Habitats Directive; *Juniperus* habitat, hereafter), which is the focus of this study, has a rather reduced size as a consequence of human pressure (Arianoutsou et al., 2012). This habitat comprises juniper scrubs or micro-forests, which represent the most mature stage of psammophilous succession on coastal sand dunes in a variety of situations (Biondi et al., 2009; Fenu et al., 2013a). It is characterized mainly by *Juniperus communis* L., in thermo-Atlantic coastal dunes of Central/Northern Europe, or *Juniperus macrocarpa* Sm. and *Juniperus phoenicea* L. var. *turbinata* (Guss.) Parl., in Southern Europe. It is widely distributed along the Mediterranean and Atlantic sandy coasts of Southern and Western Europe and secondly in Central and Northern Europe (European Commission, 2007; Biondi et al., 2009). Italy hosts the largest surface area of this habitat in Europe (including the 39% of the total) and approx. 5% of the European surface is located in Sardinia (Picchi, 2008). This priority habitat for conservation in the Mediterranean Basin is highly threatened by human related-factors (i.e. touristic settlements, urbanization) and alien plant species invasion as well as from other pressure such as coastal erosion, habitat fragmentation, forest fire and pollution (Paradis et al., 2004; Picchi, 2008; Attorre et al., 2013; Del Vecchio et al., 2013). *Juniperus* habitat shows critical constraints for the natural recovery (Pinna et al., 2014a, b), some studies have dealt with this habitat (e.g. Géhu et al., 1990; Paradis, 1991; Piazza and Paradis, 1998; Muñoz-Reinoso, 2004; Paradis et al., 2004; Díez-Garretas and Asensi, 2014), but the key to solving conservation problems are far from being understood.

Therefore, new studies are needed to increase the knowledge of this priority habitat and to provide tools for its conservation. This is the overall goal of the present study, and the specific aims are: (1) to explore the floristic variability of *Juniperus* habitat in Sardinia in relation to environmental and human variables, and (2) to evaluate spatio-temporal changes in key plant parameters by analyzing samples located in areas with several human disturbance levels and performed in different periods.

2. Materials and methods

2.1. Data collections

We combined the phytosociological relevés carried out on *Juniperus* habitat in Sardinia available in the literature, with our own unpublished relevés (see Appendix A), all of them made according to the Sigmatist School of Zurich-Montpellier (Rivas-Martínez, 2005). The spatial distribution of relevés is showed in Fig. 1. The taxonomic treatment of vascular flora was updated according to Conti et al. (2007; see a complete list of vascular plants in Appendix B), building a final floristic matrix of 154 relevés × 167 taxa. Then the Braun-Blanquet value of each taxon was transformed into the quantitative scale according to van der Maarel (1979) and Noest et al. (1989).

Subsequently, we created a second data matrix inputting for each relevé plant parameters as well as environmental and anthropogenic variables. Environmental factors included: geographic variables (latitude and longitude), coastal type (using two categories: sandy coast and rocky coast) and climatic variables (annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, annual precipitation and precipitation of the driest quarter) which were downloaded from the WorldClim database (version 1.4; http://www.worldclim.org; Hijmans et al., 2005). Human disturbance and sampling period were assigned as anthropogenic variables. In particular, three levels of human disturbance were established (low, medium and high), on the basis of data on arrivals, nights spent, and capacity of tourist accommodation in Sardinia during the tourist season (data from http://www.sardegnastatistiche.it/argomenti/turismo). Regarding sampling period, relevès were grouped in two categories: old sampling, including the relevés carried out before 1996 (n = 94), and recent sampling, for those subsequent to 2000 (n = 60), since the influx of tourism on the coasts of Sardinia has been increasing sharply from this date. Plant parameters included: plant cover, species number (richness), as well as number and cover of endemic and alien taxa. Specifically, for endemic and alien species we followed Bacchetta et al. (2012a,b) and Podda et al. (2011), respectively.

2.2. Data analysis

Firstly, we performed multivariate analyses by using the R vegan package (Oksanen et al., 2012). We tested changes in *Juniperus* habitat composition and the influence of the explanatory variables through ordinations and permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001) using the 'adonis' procedure (Oksanen et al., 2012). Subsequently, we used Non-Metric Multidimensional Scaling (NMDS) to visualize the relationship in our study area between plant species composition, sites and explanatory variables. In addition, we used a General Linear Model (GLM) to test the effect of human disturbance and sampling period on plant richness, as well as on cover of endemic and alien taxa. GLM were fitted specifying a Poisson error distribution and log as a link function. All statistical analyses were performed using the R statistical package (R Development Core Team, 2012).

3. Results

3.1. Factors influencing floristic composition

The total mean cover of the *Juniperus* habitat in Sardinia was 85.3% (habitat cover for each relevè was calculated by the sum of the cover of each species). The mean cover of the two *Juniperus* species was 53.32%. The most frequent taxa were *Pistacia lentiscus* (133 relevés; mean cover: 9.96%), *J. macrocarpa* (104 relevés; mean cover: 47.38%), *J. phoenicea* var. *turbinata* (100 relevés; mean cover: 37.91%), *Rubia peregrina* (95 relevés; mean cover: 1.70%) and *Phillyrea angustifolia* (88 relevés; mean cover: 4.49%).

Floristic composition differed among sites and was significantly influenced by almost all the evaluated variables, which explained 38.70% of the total variability (Table 1). Only coastal type factor (sandy or rocky coast) did not significantly influence floristic composition. In particular, the floristic composition was described mainly by geographic variables (longitude: $R^2 = 0.0525$; latitude: $R^2 = 0.1059$). Among climatic variables, the effect of the maximum temperatures ($R^2 = 0.0497$) was remarkable. Also the effects of human disturbance and sampling period were significant ($R^2 = 0.0237$ and $R^2 = 0.0372$, respectively).

Fig. 2 shows these patterns, where proximity among points means floristic similarity. Two main groups of relevés can be distinguished: on the right side of the graph (positive values of NMDS1) the relevés are related to *J. phoenicea* var. *turbinata*, while on the left side (negative values of NMDS1) the relevés are related to *J. macrocarpa.* The first group showed lower variability and included the relevés from La Maddalena and Nurra localities (Northern Sardinia), characterized mainly by the presence of taxa such as *Chamaerops humilis*, *Hypochaeris achyrophorus*, *Arbutus unedo*, *Carex flacca* subsp. *serrulata*, *Genista corsica*, *Myrtus*

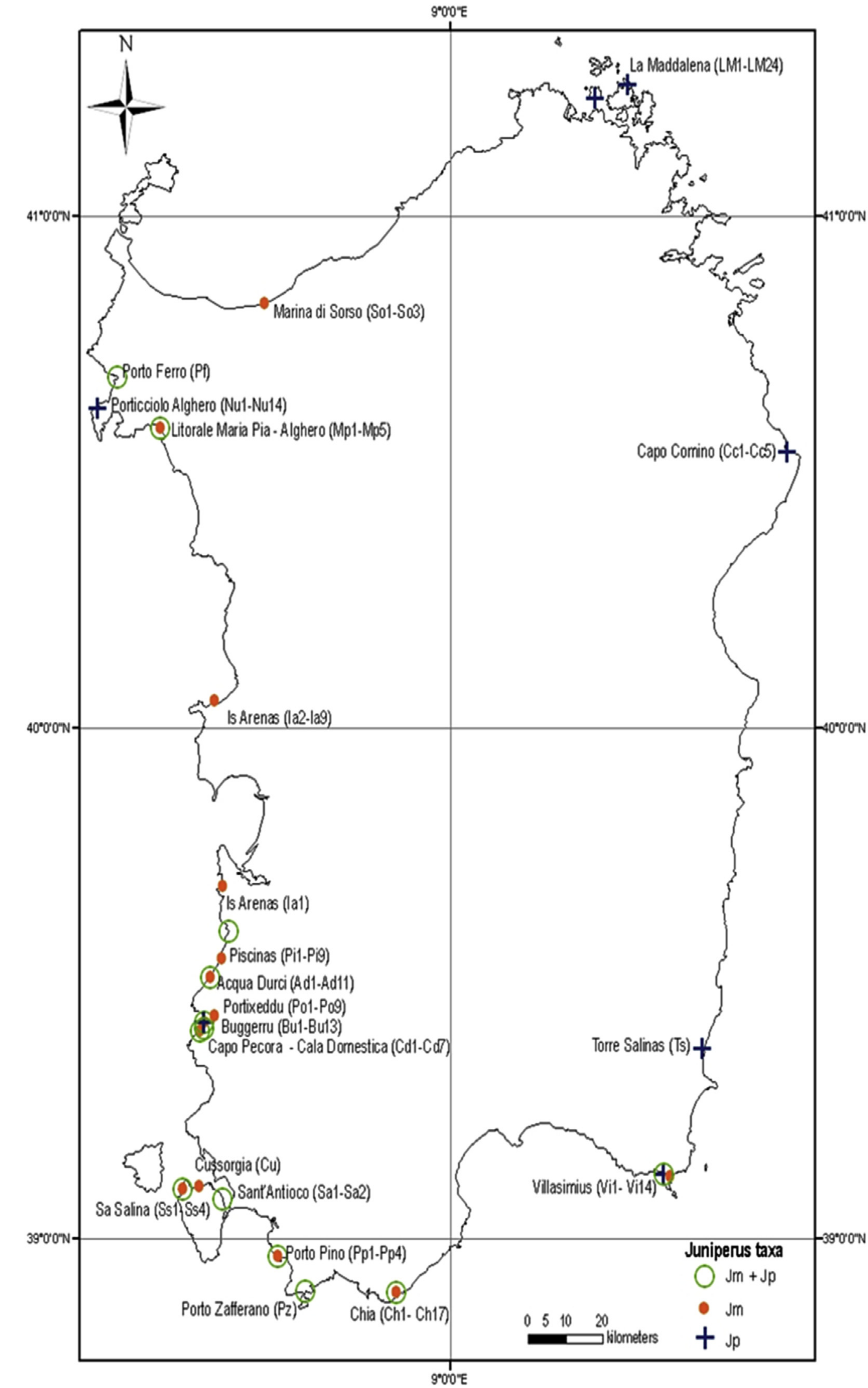

Fig. 1. Relevè sites showing symbols to distinguish the occurrence of *Juniperus*: habitat with *Juniperus macrocarpa* only (points), habitat with *Juniperus phoenicea* var. *turbinata* only (crosses), habitat with *Juniperus phoenicea* var. *turbinata* and *Juniperus macrocarpa* (circles). Abbreviations of relevè sites: **Ad**: Acqua Durci; **Bu**: Buggerru; **Cc**: Capo Comino; **Cd**: Tra Capo Pecora e Torre di Cala Domestica; **Ch**: Chia; **Cu**: Cussorgia; **Ia**: Is Arenas; **LM**: La Maddalena; **Mp**: Litorale Maria Pia – Alghero; **Nu**: Porticciolo Alghero; **Pf**: Porto Ferro; **Pi**: Piscinas; **Po**: Portixeddu; **Pp**: Porto Pino; **Pz**: Porto Zafferano; **Sa**: Sant'Antioco; **So**: Marina di Sorso; **Ss**: Sa salina; **Ts**: Torre salinas; **Vi**: Villasimius.

Table 1
PERMANOVA test results for factors influencing habitat composition. Df: degrees of freedom; X: longitude; Y: latitude; tma: annual mean temperature; tmax: maximum temperature of the warmest month; tmin: minimum temperature of the coldest month; pa: annual precipitation; pdq: precipitation of the driest quarter.

Variables	Df	Sums of squares	Mean squares	F. Model	R^2	Pr (>F)
X	1	2.030	2.0305	12.2224	0.0525	0.0010***
Y	1	4.098	4.0983	24.6700	0.1059	0.0010***
tma	1	1.331	1.3310	8.0121	0.0344	0.0010***
tmax	1	1.924	1.9240	11.5814	0.0497	0.0010***
tmin	1	1.167	1.1675	7.0276	0.0302	0.0010***
pa	1	1.170	1.1699	7.0420	0.0302	0.0010***
pdq	1	0.809	0.8091	4.8705	0.0209	0.0020**
Human disturbance	2	0.917	0.4585	2.7598	0.0237	0.0020**
Sampling period	1	1.438	1.4382	8.6570	0.0372	0.0010***
Coastal type	1	0.222	0.2225	1.3392	0.0057	0.1798 NS
Residuals	142	23.590	0.1661		0.6096	
Total	153	38.698			1.0000	

NS: not significant; **: 0.01 > p > 0.001; ***: p < 0.001.

communis, *Euphorbia characias*, as well as the relevés from Capo Comino and Maria Pia localities characterized by *Clematis cirrhosa*. The second group linked to *J. macrocarpa* showed greater variability, and included taxa such as *Polycarpon tetraphyllum*, *Cyperus capitatus*, *Crucianella maritima*, *Malcolmia ramosissima*, *Pancratium maritimum*, and *Scrophularia ramosissima*. Many of these species are characteristic of other vegetation assemblages (i.e. psammophylous habitats such as '*Crucianellion maritimae* fixed beach dunes' or '*Malcolmietalia* dune grasslands'). The second group was constituted mainly by the relevés made in Southern Sardinia (Chia, Villasimius, Piscinas, Buggerru, Portixeddu, and Cala Domestica).

The variables most correlated with NMDS1 were precipitation of the driest quarter and latitude (positively correlated), as well as maximum temperature of the warmest month and annual mean temperature (negatively correlated), while the variables most correlated with NMDS2 were longitude and annual precipitation (Figs. 2 and 3; Table 2). The length of the arrows (vectors) showed

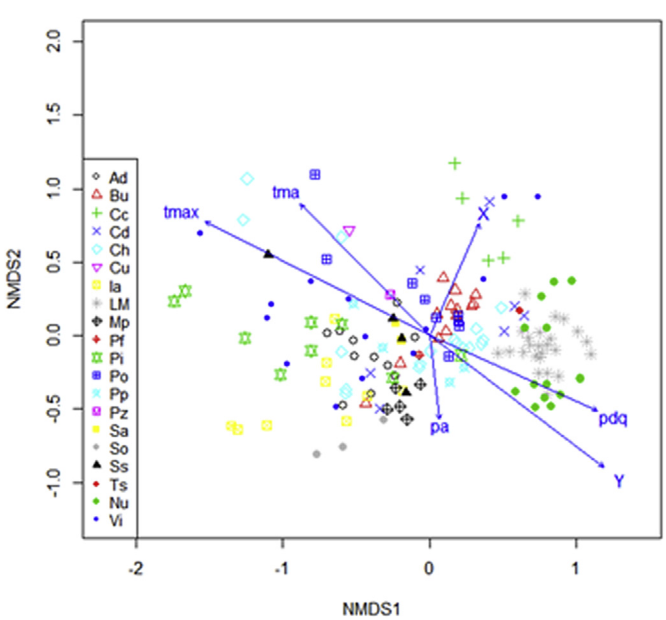

Fig. 2. Non-Metric Multidimensional Scaling (NMDS) ordination of the 154 relevés showing the distribution of the main site groups and vectors of the significant explanatory factors. Explanatory factors: X: longitude; Y: latitude; tma: annual mean temperature; tmax: maximum temperature of the warmest month; pa: annual precipitation; pdq: precipitation of the driest quarter. Different symbols represent different relevé sites. Only significant variables were projected onto the ordination diagram. For abbreviation, see Fig. 1.

the strength of the gradient, with arrows pointing in the direction of most rapid change in the variable (direction of the gradient).

3.2. Effects of human disturbance and sampling period on plant parameters

The total number of taxa per relevé ranged from 4 to 27. The relevés with the highest species richness were those from the localities of Sa Salina (Ss3 and Ss2; 27 and 26 taxa, respectively; for abbreviations see Fig. 1), Punta Cristallo, Porto Pino, and Sant'Antioco (Nu8, Pp4, Sa2; 25 taxa).

Of the 167 taxa recorded in this study, 14 were endemic. The richest site in endemic species was Acqua Durci (4 taxa), whereas the maximum cover in endemic species was found at La Maddalena (38.5%). Moreover, a total of 6 alien taxa was recorded, with the site richest in alien taxa being Marina di Sorso (2 taxa), where also the maximum cover (39.75%) was recorded.

Human disturbance significantly influenced species richness, while sampling period was not significant (Table 3). In particular, a significant positive effect of low and medium human disturbance on species richness was found. Also the effect of medium human disturbance and recent sampling on the cover of endemic taxa was found to be significantly positive. Finally, the effect of recent sampling on alien taxa cover also proved significantly positive (Table 3).

4. Discussion

4.1. Factors influencing floristic composition and plant parameters

The coastal *Juniperus* habitat showed considerable variability in floristic composition among sites in Sardinia. We found that the habitat had a dominant underlying gradient. Specifically, it was mainly a latitudinal gradient, implying, in turn, changes in climatic factors that have been also noted by other authors as drivers of dune-habitat composition (e.g., Miller et al., 2010). In particular, we found that the floristic composition varied gradually from North (where habitat is characterized by the dominance of *J. phoenicea* var. *turbinata* and the lack of *J. macrocarpa*) to South (where *J. macrocarpa* predominates), with the habitat being progressively more exposed to the extreme summer drought as latitude decreases (higher temperature and lower precipitations, especially of the driest quarter). This pattern differs from that observed nearby in Corsica, where the distribution of different *Juniperus* taxa does not seems related to latitude (Paradis, 1991) and other factors (i.e. ancient biogeography, geology) may have played a pivotal role in this process. Furthermore, a secondary longitudinal gradient may be interpreted, with precipitation increasing westwards, where

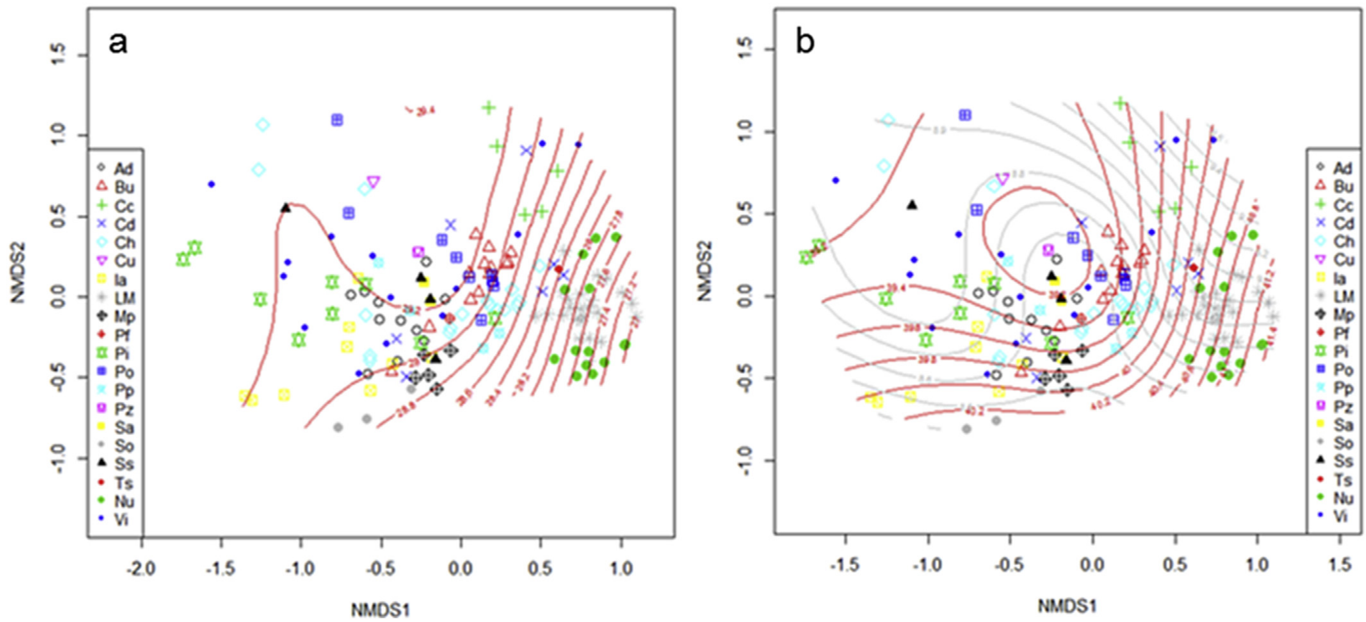

Fig. 3. Relevés in ordination space (1st and 2nd axes) overlaid on fitted surfaces (contour lines). a) Fitted climatic surface: Maximum temperature of the warmest month (red line); b) Fitted geographic surface: Latitude in red line and Longitude in gray line. Different symbols represent different relevé sites, for abbreviations and location see Fig. 1 (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 2
Vector results of explanatory factors fitted onto NMDS. P values based on 1000 permutations. Abbreviations of variables are given in Table 1.

Variables	NMDS1	NMDS2	R^2	Pr (>r)
X	0.4074	0.9133	0.1139	0.0010***
Y	0.7979	−0.6028	0.3591	0.0010***
tma	−0.7019	0.7122	0.2584	0.0010***
tmax	−0.8922	0.4517	0.4802	0.0010***
tmin	−0.2734	0.9619	0.0237	0.1548 NS
pa	0.1174	−0.9931	0.0539	0.0160*
pdq	0.9126	−0.4089	0.2546	0.0010***
Human disturbance	0.3375	0.9413	0.0163	0.2717 NS
Sampling period	−0.6660	−0.7459	0.0067	0.5794 NS

NS: not significant; *:0.05 > p > 0.01; ***: p < 0.001.

prevailing wet winds and Atlantic perturbations arrive, and aeolian coastal dune systems are generally deeper and better-structured than in the East. The variables evaluated explain changes in habitat composition, but other local environmental factors, such as dune morphology, topography, and soil nutrients, may also determine floristic variability (e.g. Frederiksen et al., 2006; Zuo et al., 2009; Fenu et al., 2013a; Angiolini et al., 2013).

Table 3
Generalized Linear Model (GLM) results examining the effect of human disturbance and sampling period on plant richness, as well as on cover of endemic and alien taxa.

	Estimate	Standard error	z value	Pr (>|z|)
Richness				
Intercept	2.3119	0.0436	53.053	<0.001***
Low disturbance	0.3189	0.0586	5.441	<0.001***
Medium disturbance	0.4365	0.0561	7.783	<0.001***
Recent sampling	−0.0331	0.0501	−0.659	0.51 NS
Endemic taxa cover				
Intercept	0.0123	0.1254	0.098	0.9220 NS
Low disturbance	0.0744	0.1889	0.394	0.6935 NS
Medium disturbance	0.8931	0.1447	6.172	<0.001***
Recent sampling	0.3596	0.1343	2.677	0.0074**
Alien taxa cover				
Intercept	−1.9694	0.4082	−4.824	<0.001***
Low disturbance	−18.0651	1439	−0.013	0.990 NS
Medium disturbance	−17.7868	1311	−0.014	0.989 NS
Recent sampling	1.8394	0.4410	4.171	<0.001***

NS: not significant; **: 0.01 > p > 0.001; ***: p < 0.001.

Floristic composition in *Juniperus* habitat was influenced also by human disturbance and sampling period, as we expected (e.g. Acosta et al., 2006; Santoro et al., 2012; Ciccarelli, 2014). Moreover, both factors significantly influenced plant-species richness, as well as the cover of endemic and alien taxa, which are key parameters to evaluate habitat quality. Our results highlight a general decrease in the number of species in areas with high levels of human disturbance, while low and medium human disturbance intensity determined an increase in the floristic richness, according to the previous studies on coastal vegetation (e.g. Kutiel et al., 1999; Kerbiriou et al., 2008; Santoro et al., 2012; Attorre et al., 2013; Ciccarelli, 2014). A similar effect to that described for floristic richness was found for endemics (both number and cover), which were positively related to a medium level of human disturbance. However, a negative effect of human disturbance on endemic species was found in some other habitats in Mediterranean coastal dunes (e.g. Kutiel et al., 1999; Santoro et al., 2012; Fenu et al., 2013b).

Our results show that in recent years the cover of alien species has increased significantly. This increment appears to be related to the recent increase in human pressure, as in other coastal areas (Carboni et al., 2010; Podda et al., 2011). Several studies have demonstrated that alien species, such as *Carpobrotus* spp., *Agave* spp. and *Acacia saligna* (Labill.) H.L. Wendl., are more competitive than native species in Mediterranean coastal dunes (e.g. Suehs et al., 2004; Vilà et al., 2006; Traveset et al., 2008; Meloni et al., 2015). In addition, the proliferation of alien species cover in the study area is due in part to the expansion of conifer afforestation during the last century in Mediterranean coastal areas for dune stabilization (Court-Picon et al., 2004; Del Vecchio et al., 2013), but afforestation competes with *Juniperus* habitat and eventually displaces it (Malavasi et al., 2013).

In conclusion, the analysis of our own floristic data together with those recorded throughout Sardinia from 1976 was valuable to monitor floristic changes over decades, considering that performing specific long-term studies is highly complex. Results obtained are relevant to better understand the *Juniperus* habitat, and the factors influencing it, and to contribute to its conservation. Thus, we did not find a decline in species richness or cover of endemic taxa to date, but we found an increase in the cover of alien taxa in recent years. Hence, in the near future, alien taxa could be detrimental to endemics and other native species in Mediterranean coastal dunes.

4.2. Implication for conservation

Our study highlights the urgent need to implement conservation actions for the Sardinian *Juniperus* habitat. Habitat restoration actions such as planting or sowing should take into account spatial changes in habitat composition, in close relation with climatic factors, with special attention to endemic taxa. In addition, implementation of actions to eradicate and hinder expansion of alien species must be priority.

Certainly, the *Juniperus* habitat is a highly threatened habitat in Europe and therefore several LIFE projects (financial instrument supporting environmental and nature-conservation projects throughout the European Union) have funded studies and actions to promote its conservation (Enebro, Duna, Junicoast and Providune). In particular, the 'Conservatoire du Littoral' in Corsica carried out several restoration and recovery projects in dune systems with *Juniperus* habitat, using laying fences, planting of marram grass, planting of *J. macrocarpa* and *J. phoenicea* var. *turbinata* and uprooting of aliens (Paradis et al., 2004). Moreover, some of the research results funded from Providune project have shown critical constraints for the recovery of *J. macrocarpa* habitat in critical stages of its life-cycle such as germination (Pinna et al., 2014a) or seedling recruitment (Pinna et al., 2014b).

In general, due to the high conservation value of the *Juniperus* habitat, we emphasize the need for more sustainable planning and recreational use of these areas. In particular, considering that the poorly regulated and dense networks of trails and tourist activities are primarily responsible for the habitat fragmentation, we propose to remove, or at least prevent, the growth of the most intrusive trail types and to encourage the relocation of tourism to less sensitive areas. Unfortunately, in highly tourist areas, it is not always possible to protect *Juniperus* habitat by fences to prevent people entering, so conservation actions should include people information and motivation to reduce frequentation impacts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ecss.2015.07.032.

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