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The role of natural vegetation in the analysis of the spatio-temporal changes of coastal dune system: a case study in Sicily

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Abstract The coastal dunes of the Mediterranean area are among the most vulnerable and seriously threatened ecosystems due to human activities. Habitat fragmentation is generally considered as one of the most influential factors in biodiversity loss. In this paper, we investigated the temporal and spatial changes in the floristic composition and abundance in sand dunes along a coastal strip of Sicily (Italy). Six transects perpendicular to the coastal line were selected in southern Sicily. For each transect, the floristic composition and cover of the species were determined using standard relevé methods. A total of 186 plots were collected. The plots data was analyzed using classification (UPGMA, Chord coefficient) and ordination methods (Detrended Correspondence Analysis). A total of 14 plant communities with specific floristic composition were established, belonging mainly to six habitats. To evaluate the reduction of the habitats of the complex dune system in the last 70 years, aerial photos from 1938 to 2007 have been used and elaborated with ArcGis 10.3. The cartographic analysis shows a radical transformation of the Macconi dune system with a reduction of the dune habitats. In particular, the results show a strong reduction/loss of habitats (2250, 2210 and 2120 EU code) as well as a strong alteration of the ecological succession of the psammophilous vegetation. Moreover, floristic richness and diversity index showed an increased trend from the coastal line towards inner dunal zone.

Keywords Coastal dunes · Psammophilous vegetation · Habitat reduction · Conservation status · Plant diversity · Mediterranean territory · Sicily

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Introduction

Habitat reduction/fragmentation is generally considered as one of the most influential factors in biodiversity loss (Sala et al. 2000). The coastal dunes of the Mediterranean area are among the most vulnerable and seriously threatened ecosystems due to human activities (Malavasi et al. 2013, 2014). Dune habitats, which were of little agricultural interest, were largely ignored during the first half of the last century; but then a systematic alteration of these environments began, particularly from the 60s onwards, due to urbanization, industrialization and recreational activities and, in the territory under consideration, intensive agricultural activities such as the construction of plastic-covered greenhouses. Several studies indicate that in the last few decades, human needs has led quickly to dune destruction, fragmentation and alteration in consequence of the high economic growth rates, land-use intensification, which resulted in loss of natural habitat, and the invasion of alien species (Falcucci et al. 2007; Tomaselli et al. 2012). Human disturbance has also had an effect on the structure, composition and functions of the plant communities, which are sensitive indicators of the state of these environments, revealing also the naturalness degree (Costa et al. 2011; De Luca et al. 2011; Acosta et al. 2005, 2009; Minissale and Sciandrello 2013). Under natural conditions, the psammophilous plant communities are normally strongly influenced by physical and microtopographic characteristics. They are arranged along ecological gradients, which develop from the shoreline to inland areas and perpendicular to the coastline, following a well-definite zonation (Acosta et al. 2003, 2007). There are several approaches used to describe the pattern changes due to the different levels of human pressure on the plant communities of coastal dunes in the transition from natural landscapes to urban areas (Kutiel et al. 2004; Faggi and Dadon 2011). Some approaches, such as the phytosociological analysis, emphasizes the existence of significant changes in plant species composition and plant cover (García-Mora et al. 2001; Tzatzanis et al. 2003; Levin and Ben Dor 2004), while others focus on the quantification of change by using indexes, as species richness and diversity (Grunewald and Schubert 2007). Taking into account the above considerations, this work sets out to analyze the temporal and spatial changes in the composition and structure of the plant communities as a result of agricultural and industrial development and related human activities, as well as define an analysis model for coastal landscapes before beginning targeted, environmental restoration actions with native vegetation.

The present study is a part of the LIFE-Leopoldia project (LIFE11 NAT/IT/000232). In particular, the project proposes the restoration of degraded coastal dunes, as well as the increase of *Leopoldia gussonei* populations in its natural environment as a target species at risk of extinction.

In summary, the objectives of this research were therefore to:

1. Analyze the structure and floristic composition of the psammophilous plant communities;
2. Analyze the ecological succession of the coastal dune vegetation;
3. Assess the conservation status of the dunes;
4. Analyze the spatiotemporal changes of the coastal dune system and assess the loss/reduction of the habitats over the last 70 years.

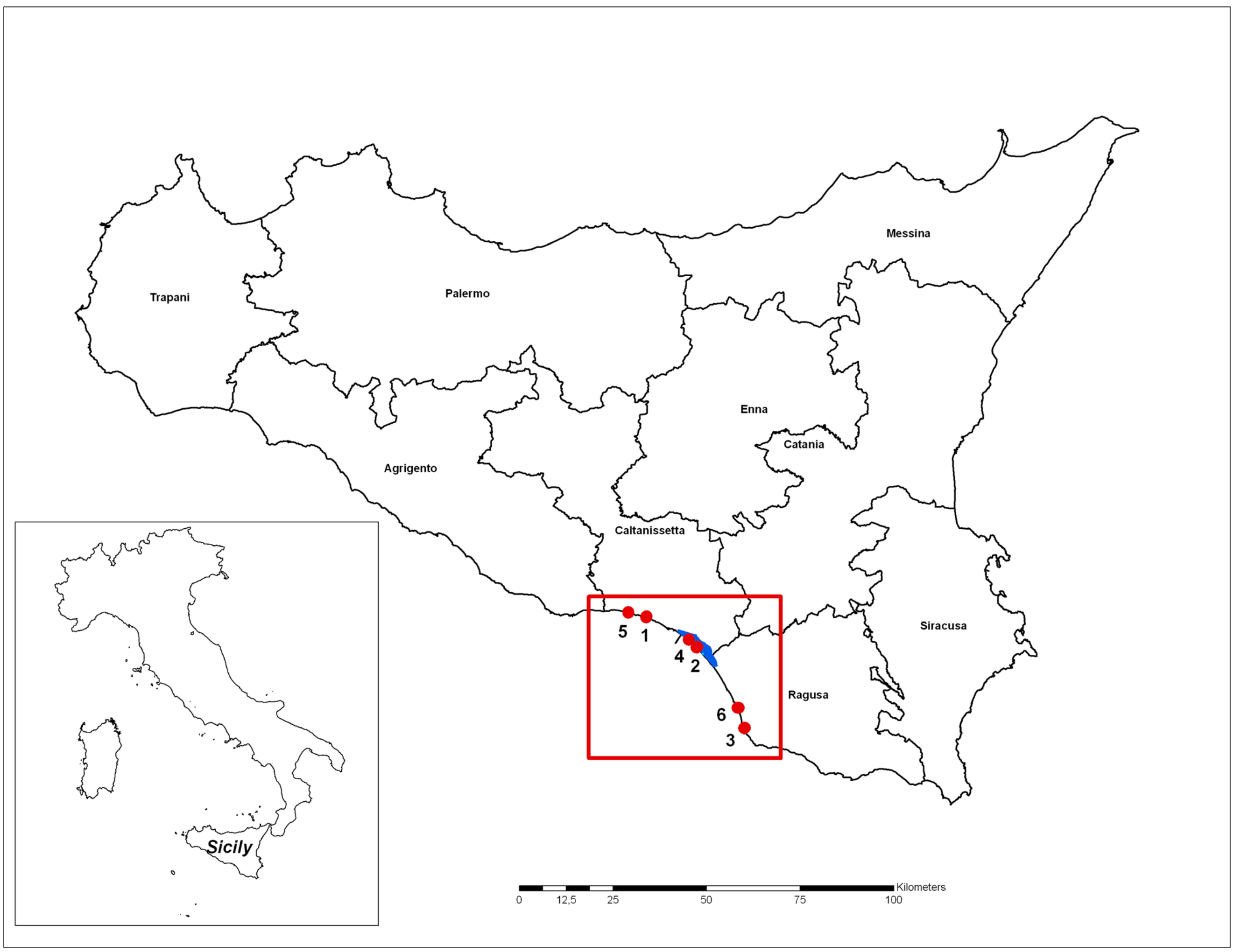

Fig. 1 Study area in red square (*red dots-the transects*, *blue-the mapped area*)

Table 1 Plots of the psammophilous plant communities

Distribution	Life form	N.	Plant communities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
			Plots number	9	3	15	3	10	22	5	31	50	13	6	3	2	16
			Coverage (%)	52,2	71,6	68,3	53,3	82	52,3	33,3	89,7	88	75	93,3	47	50	70
			Vegetation height (cm)	45,5	41,3	35,3	23,3	39,5	36,8	73,3	186	168	200	225	15	10	33,8
			No. species	7,56	15,7	7,47	7,33	6,6	5,45	3,67	11,7	10,3	6,77	7,67	11	15,5	12,1
			Simpson_1-D	0,81	0,92	0,82	0,81	0,78	0,71	0,67	0,88	0,86	0,77	0,77	0,89	0,92	0,89
			Shannon_H	1,85	2,67	1,85	1,82	1,71	1,46	1,21	2,32	2,14	1,7	1,76	2,29	2,64	2,38
			Evenness_e^H/S	0,93	0,94	0,88	0,85	0,84	0,92	0,94	0,88	0,88	0,88	0,84	0,93	0,91	0,9
Distribution	Life form	N.	Equitability_J	0,96	0,98	0,93	0,92	0,91	0,94	0,95	0,95	0,94	0,93	0,9	0,97	0,96	0,96
Med.	H scap	1	*Centaurea sphaerocephala* L.	33,3	100	53,3	0	0	36,4	0	100	92	100	50	50	20	100
Med.	NP caesp	2	*Ephedra fragilis* Desf.	0	0	0	0	0	0	0	93,5	100	69,2	100	0	40	12,5
Med.	NP	3	*Asparagus acutifolius* L.	0	0	0	0	0	0	0	83,9	66	84,6	33,3	0	0	37,5
Med.	T scap	4	*Lagurus ovatus* L.	0	33,3	0	0	0	9,09	0	54,8	56	53,8	33,3	50	40	100
Med.-Iran.-Tur.	NP	5	*Lycium intricatum* Boiss.	0	0	0	33,3	0	9,09	0	71	82	30,8	100	0	20	6,25
Med.	Ch frut	6	*Euphorbia terracina* L.	16,7	100	0	0	0	0	0	77,4	48	0	33,3	0	40	81,3
End. cam.-pach.	P caesp	7	*Retama raetam* (Forssk.) Webb & Berth. subsp. *gussonei* (Webb) Greuter in Greuter & Raus	0	66,7	0	0	0	4,55	0	100	38	38,5	0	0	0	56,3
Med.	NP	8	*Asparagus horridus* L.	0	0	13,3	0	0	0	0	71	60	0	100	0	20	25
Med.	T scap	9	*Anisantha rigida* (Roth) Hyl.	0	66,7	0	0	0	27,3	0	32,3	38	0	33,3	0	40	100
O Med.	H bien	10	*Daucus carota* L. subsp. *maritimus* (Lam.) Batt. in Batt. & Trab.	0	0	0	0	0	9,09	0	83,9	24	30,8	0	0	0	50
Med.	T scap	11	*Ononis variegata* L.	16,7	100	86,7	66,7	100	22,7	0	3,23	2	23,1	0	50	40	31,3
Med.-Atl.	G rhiz	12	*Eryngium maritimum* L.	75	100	100	66,7	40	54,5	100	0	0	0	0	0	0	6,25
Med.	T scap	13	*Cakile maritima* Scop.	41,7	66,7	46,7	33,3	0	72,7	0	0	24	0	33,3	0	40	6,25
Med.	G rhiz	14	*Elytrigia juncea* (L.) Nevski	50	0	13,3	33,3	50	100	100	0	10	0	33,3	0	0	0
Med.	T scap	15	*Silene colorata* Poir.	0	100	0	0	0	0	0	25,8	16	30,8	16,7	50	40	100
S Med.	H scap	16	*Silene nicaeensis* All. var. *perennis* Maire	50	100	66,7	66,7	100	4,55	33,3	0	8	0	0	0	0	50
Med.	T scap	17	*Cutandia maritima* (L.) Barbey	66,7	100	46,7	100	100	36,4	0	0	6	0	0	0	0	6,25
Med.	T scap	18	*Erodium laciniatum* (Cav.) Willd.	0	66,7	0	66,7	0	0	0	41,9	0	38,5	0	50	40	100
Nat.	P scap	19	*Acacia saligna* (Labill.) H.L. Wendl.	0	0	0	0	0	0	0	9,68	36	100	0	0	0	0
Med.	T scap	20	*Pseudorlaya pumila* (L.) Grande	0	100	0	33,3	0	13,6	0	0	36	0	33,3	0	40	6,25
Med.	G rhiz	21	*Cyperus capitatus* Vandel.	8,33	66,7	100	0	30	18,2	0	0	0	0	33,3	0	0	12,5
Med.	H scap	22	*Echinophora spinosa* L.	33,3	100	100	66,7	40	0	33,3	0	0	0	0	0	0	0
S Med.	Ch frut	23	*Launaea fragilis* (Asso) Pau	58,3	100	20	33,3	90	9,09	0	3,23	2	0	0	0	0	12,5
Med.	Ch frut	24	*Prasium majus* L.	0	0	0	0	0	0	0	22,6	40	0	0	0	0	0
Med.	T scap	25	*Rumex bucephalophorus* L.	0	0	0	0	0	0	0	51,6	18	0	0	0	0	12,5
Med.	T scap	26	*Cutandia divaricata* (Desf.) Asch. ex Barbey	0	0	0	0	0	0	0	12,9	12	0	0	0	0	87,5

Table 1 (continued)

			Plant communities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
O Med.	Ch suffr	27	*Rhodalsine geniculata* (Poir.) F. N. Williams	0	0	0	0	0	0	0	38,7	24	0	0	0	0	0
Med.	H caesp	28	*Ononis hispanica* L. subsp. *ramosissima* (Desf.) Förther & Podlech	0	0	0	0	0	0	0	16,1	8	0	0	0	0	81,3
Med.-Atl.	Ch frut	29	*Euphorbia paralias* L.	16,7	0	0	0	0	0	0	9,68	12	38,5	0	50	0	12,5
Med.	H scap	30	*Lobularia maritima* (L.) Desv.	0	0	0	0	0	0	0	41,9	8	0	0	0	0	18,8
Nat.	Ch suffr	31	*Carpobrotus edulis* (L.) N. E. Br.	0	0	0	33,3	0	13,6	0	0	24	0	0	0	0	12,5
Med.	Ch suffr	32	*Achillea maritima* (L.) Ehrend. & Y. - P. Guo	8,33	0	13,3	33,3	100	9,09	0	0	0	0	0	0	0	0
O Med.	H scap	33	*Echium sabulicolum* Pomel	0	0	0	0	0	0	0	0	12	7,69	0	50	40	18,8
Med.	P caesp	34	*Juniperus oxycedrus* L. subsp. *macrocarpa* (Sm.) Ball	0	0	0	0	0	0	0	9,68	10	0	100	0	0	0
Med.	P lian	35	*Rubia peregrina* L.	0	0	0	0	0	0	0	9,68	20	0	0	0	0	0
Med.	H bien	36	*Scolymus hispanicus* L.	0	0	20	0	0	18,2	0	6,45	4	0	0	0	0	12,5
S Med.	T scap	37	*Hormuzakia aggregata* (Lehm.) Guşul.	0	0	0	0	0	0	0	12,9	6	0	0	0	0	25
End. cam.-pach.	T scap	38	*Torilis nemoralis* (Brullo) Brullo & Giusso	0	0	0	0	0	0	0	3,23	20	0	0	0	0	0
O Med.	H ros	39	*Plantago macrorhiza* Poir.	8,33	0	66,7	0	0	0	0	0	0	0	0	0	0	0
Med.	Ch suffr	40	*Crucianella maritima* L.	0	100	0	0	0	13,6	0	0	2	0	0	50	0	0
Med.-Atl.	H caesp	41	*Piptatherum miliaceum* (L.) Coss.	0	0	0	0	0	0	0	3,23	18	0	0	0	0	0
Circumbor.	T scap	42	*Salsola kali* L. subsp. *tragus* (L.) Nyman	25	0	0	33,3	0	13,6	0	0	2	0	0	33,3	0	0
O Med.	P caesp	43	*Tamarix gallica* L.	0	0	0	0	0	0	0	6,45	12	0	33,3	0	0	0
Med.	T caesp	44	*Vulpia fasciculata* (Forssk.) Fritsch	0	0	0	0	0	0	0	0	0	30,8	0	50	0	18,8
Med.	H caesp	45	*Ammophila arenaria* (L.) Link subsp. *arundinacea* H. Lindb	25	0	0	33,3	10	0	100	0	0	0	0	0	0	0
Med.	T scap	46	*Centranthus calcitrapa* (L.) Dufr.	0	0	0	0	0	0	0	0	12	0	0	0	40	0
Med.	G bulb	47	*Pancratium maritimum* L.	16,7	0	0	0	0	4,55	0	0	8	0	0	0	0	6,25
Med.	Ch suffr	48	*Lotus commutatus* Guss.	0	0	0	0	0	27,3	0	0	0	0	0	0	0	0
O Med.	Ch suffr	49	*Phagnalon saxatile* (L.) Cass.	0	0	0	0	0	0	0	19,4	0	0	0	0	0	0
Med.	P caesp	50	*Pistacia lentiscus* L.	0	0	0	0	0	13,6	0	6,45	2	0	0	0	0	0
Med.-Iran.-Tur.	T scap	51	*Senecio glaucus* L. subsp. *coronopifolius* (Maire) C. Alexander	0	0	0	0	0	0	0	9,68	0	0	0	50	0	0
Subcosmop.	G rhiz	52	*Arundo donax* L.	0	0	0	0	0	0	0	9,68	2	0	0	0	0	0
Med.	T scap	53	*Maresia nana* (DC.) Batt.	0	66,7	0	0	0	0	0	0	0	0	0	0	40	0
Med.-Atl.	Ch rept	54	*Medicago marina* L.	16,7	0	0	0	0	4,55	0	0	2	0	0	0	0	0
Nat.	H caesp	55	*Saccharum spontaneum* L. subsp. *aegyptiacum* (Willd.) Hack.	0	0	0	0	0	0	0	9,68	0	0	0	0	0	6,25
C Med.	H bien	56	*Seseli tortuosum* L. subsp. *maritimum* (Guss.) Brullo et al.	0	0	0	0	0	0	0	12,9	0	0	0	0	0	0
SO-Med.	T scap	57	*Brassica souliei* (Batt.) Batt. subsp. *amplexicaulis* (Desf.) Greuter & Burdet	0	0	0	0	0	0	0	0	4	0	0	0	0	0

Table 1 (continued)

			Plant communities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
O Med.	T scap	58	*Coronilla repanda* (Poir.) Guss.	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Med.	T scap	59	*Ononis diffusa* Ten.	0	33,3	0	0	0	0	0	3,23	0	0	0	0	0	0
Med.	T scap	60	*Polycarpon tetraphyllum* subsp. *diphyllum* (Cav.) O. Bolòs & Font Quer	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Nat.	NP	61	*Rumex lunaria* L.	0	0	0	0	0	0	0	0	4	0	0	0	0	0
S Med.	NP caesp	62	*Salsola oppositifolia* Desf.	0	0	0	0	0	0	0	0	4	0	0	0	0	0
End. cam.-pach.	G bulb	63	*Leopoldia gussonei* Parl.	0	0	0	0	0	0	0	6,45	0	0	0	0	0	0

1. *Eryngium maritimum* and *Launaea fragilis*, 2. *Crucianella maritima*, 3. *Eryngium maritimum* and *Cyperus capitatus*, 4. *Cutandia maritima* and *Ononis variegata*, 5. *Achillea maritima* and *Silene nicaeensis* var. *perennis*, 6. *Elytrigia juncea*, 7. *Ammophila arenaria*, 8. *Retama raetam* subsp. *gussonei*, 9. *Ephedra fragilis*, 10. *Acacia saligna*, 11. *Juniperus macrocarpa*, 12. *Erodium laciniatum*, 13. *Pseudorlaya pumila*, 14. *Ononis hispanica* subsp. *ramosissima*

Material and methods

Study area

The coastal dunes areas of southern Sicily (Fig. 1), locally called "Macconi", were chosen as the representative areas for this study because although strongly transformed, they are still rich in biodiversity. The area is an extensive complex of dunes about 62 km from Licata (Agrigento) to Punta Braccetto (Ragusa) along the Gulf of Gela. Due to their remarkable naturalistic value, these dune systems are subject to various conservation measures, such as a Natural Reserve, a Site of Community Importance (SCI)-Habitat Directive (43/92/EEC), and a Special Protection Area (SPA)-Birds Directive (2009/147/EC). They are also an Important Bird Areas (IBA)-the Ramsar Convention (1979), and an Important Plant Areas (IPA)-Blasi et al. (2010).

According to a recent phytogeographic subdivision of Sicily (Brullo et al. 2011), this area belongs to the Camarino-Pachinense district included in the southern Sicilian subsector together with the Hyblaean district.

The climate is typically Mediterranean. Using climatic data from the neighboring thermo-pluviometric station of Gela (which is located within the study area) the mean annual temperature is 18 °C, while the mean annual precipitation, concentrated over the autumn and winter seasons, is 400 mm. Following the bioclimatic classification proposed by Rivas-Martìnez et al. (2004), the study area is referred to as the Mediterranean pluviseasonal oceanic bioclimate, with low thermomediterranean thermotypes and semiarid ombrotypes (Brullo et al. 1996).

Sampling

In order to analyze the ecological succession and the floristic composition of plant communities, 6 transects of vegetation were made perpendicularly to the coastal shoreline (falling within the Natura 2000 sites ITA050001 Biviere e Macconi di Gela; ITA050011 Torre Manfria; ITA080003 Vallata del F. Ippari; ITA080004 Punta Braccetto, Contrada Cammarana). Vegetation data was sampled during spring 2013 and autumn 2014. Each transect was investigated in detail through 4×4 m contiguous plots in which floristic data were recorded for a total length variable taking account of the inward extension of the dune. The floristic composition and cover of species was determined in each plot by using the standard method of relevés (Westhoff and Van der Maarel 1978). Transect length varied from 100 to 200 m depending on the plant community sequence encountered. Nomenclatural and taxonomical aspects referred to Giardina et al. (2007), Raimondo and Spadaro (2009); syntaxa followed Rivas-Martínez et al. (2001, 2002) and Brullo et al. (2002).

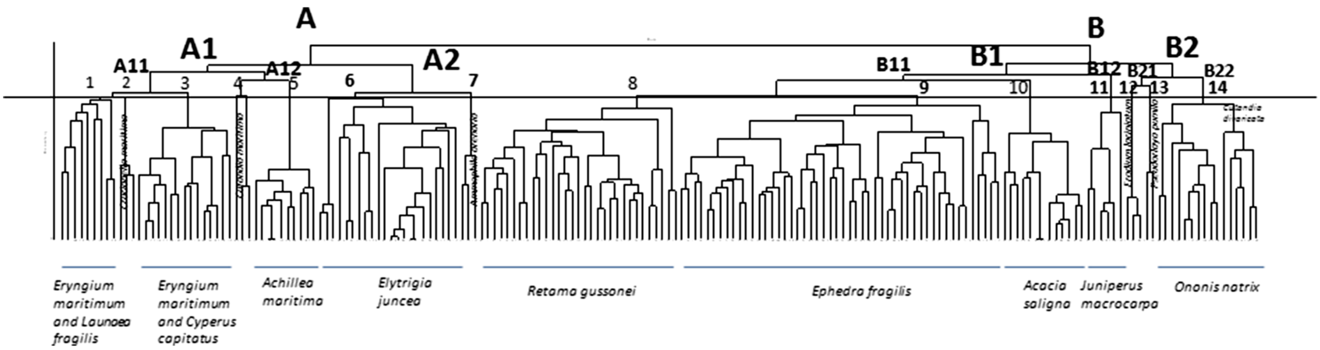

Fig. 2 Cluster analysis

On the whole, 186 plots (×63 species) were performed through multivariate analysis using the SYN-TAX 2000 software (Podani 2001). A hierarchic classification method (UPGMA) was performed. Dissimilarity of the relevés was measured using the Chord coefficient. The ordination of the data-sets were performed using the PC-ORD 4.34 software. Detrended Correspondence Analysis (DCA) (Hill and Gauch 1980) was used to establish spatial patterns in the scattergram and to generate hypotheses on the vegetation/environment relationships. Two indices were chosen to estimate diversity of the plant communities identified by cluster analysis: (1) species richness of each vegetation cluster (SR), calculated as the average of number species per plots, and (2) Shannon-Wiener's Index of diversity (H). This index takes into account the degree of equitability (J) of the species distribution (De Luca et al. 2011; Mahdavi et al. 2013). To evaluate the conservation status and reduction of the habitats of the complex dune system in the last 70 years, aerial photos taken in 1938, 2000, 2007 and IGM maps drawn in 1867, 1897, 1950 have been used as comparison and were elaborated with ArcGis 10.3.

Results

Overall, 63 species of vascular plants have been recorded on coastal dunes of the study area. Most species belong to Mediterranean elements (60 %), with the dominant life forms being therophytes (33 %), hemicryptophytes (21 %), chamaephytes (17 %), while the nanophanerophytes (10 %) and geophytes show low values (9 %).

The results of cluster analysis show two main groups of plots which match a clear topographic separation of the plant communities (Table 1, Fig. 2). The first group (A) contains the herbaceous psammophilous plant communities of the embryonic-white dunes and retrodunes (*Ammophiletea*, *Alkanno-Maresion nanae*); while the second one (B) groups the communities of the inner dunes with two subclusters: the first is characterized by shrubs plant communities (*Juniperion turbinatae*, *Periplocion angustifoliae*) and the second with the structurally altered plant communities (*Ononidion ramosissimae*, *Laguro-Vulpion fasciculatae*). The cluster analysis allows a total of 14 plant communities with specific floristic composition to be recognized, each one with a dominant species (Table 1). The first seven communities belong to group A, the second seven ones are included in B group.

All of these are attributable mainly to six habitats recognized and protected by European Directives (ECC 43/92) in the context of "Natura 2000" European Union network (Table 2): 2110 Embryonic shifting dunes; 2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes); 2210 *Crucianellion maritimae* fixed beach dunes; 2230 *Malcolmietalia* dune grasslands; 5330 Thermo-Mediterranean and pre-desert scrub; 2250* Coastal dunes with *Juniperus* spp.

Table 2 Plant communities (according to Fig. 2 and Table 1) and number of plots for each transect

Locality (No.)	Plant community (No.) Name of locality	1 Plot Qty.	2 Plot Qty	3 Plot Qty	4 Plot Qty	5 Plot Qty	6 Plot Qty	7 Plot Qty	8 Plot Qty	9 Plot Qty	10 Plot Qty	11 Plot Qty	12 Plot Qty	13 Plot Qty	14 Plot Qty	Total Plots Total Qty
1	Poggio Arena	2	3	0	0	0	0	0	19	12	0	0	0	0	0	36
2	Macconi Gela (ex forest nursery)	0	0	0	0	0	6	0	5	16	13	0	3	0	2	45
3	Cammarana (forest nursery)	1	0	0	0	0	9	0	0	12	0	2	0	2	0	26
4	Macconi Gela (Santa Lucia)	0	0	0	1	0	7	0	4	4	0	0	0	0	2	18
5	Piano Marina (Butera)	4	0	0	0	0	0	0	3	6	0	0	0	0	12	25
6	Foce Ippari (Scoglitti)	2	0	15	2	10	0	3	0	0	0	4	0	0	0	36
		9	3	15	3	10	22	3	31	50	13	6	3	2	16	186

The results obtained by DCA show a marked correspondence with cluster analysis (Fig. 3). The highest data dispersion is obtained with axes 1 and 2. The plants communities of the inner dunes, mainly represented by shrubs are spread on the left part of axis 1, while the plant communities of the embryonic/white dunes are spread on the right part of the same axis. Axis 2 shows a scattering of the communities, mainly in relation to species richness with the richest communities in the lower part of the axis.

The values of species richness and diversity index (Table 1) indicate that the plant communities in the embryonic/white dunes (primary sand dunes) (cluster A1, A2) have a low diversity with an average species richness of 6.7 and an average Shannon-Wiener diversity index of 1.68 (J=0.94). Both values increase in the inner dunes (cluster B1) with an average of 9.9 species and a Shannon-Wiener diversity index of 2.07 (J=0.93). Inner dunal areas subjected to human disturbance (cluster B2) show a high diversity with an average species richness of 12.4 and an average Shannon-Wiener diversity index of 2.40 (J=0.96).

Another level of interpretation of the territory is the cartographic analysis (Fig. 4), comparing the historical stereophoto (1938) and current aerial photos (2007). In the photo-interpretation of the oldest aerial photos, it was not possible to finely distinguish the 14 above-mentioned communities which must be grouped in broader categories such as the afore-mentioned European habitats. The comparison of the two periods highlights that the anthropogenic transformations and the almost complete occupation of the dunes by greenhouses and industrial settlements has caused the disappearance of a large part of the dune system due to leveling and removal of sand and also due to a marked coastal erosion. At the same time there has been a drastic change of land use shifting from natural to agricultural (Table 3). The surviving dunes are almost exclusively represented by flattened, inner dunes, which sometimes have mobile or embryonal forms on the outside foot of the inner dune. In particular, the results show a strong reduction/loss of the *Juniperus macrocarpa* community (*Ephedro-Juniperetum macrocarpae* - 2250) which decreased dramatically from 263 ha in 1938 to only 1 ha in 2007. Note that the second category (*Retama raetam* community - 5330) surveyed only in 2007 (33 ha), were also present in photographs from 1938 but it was not distinguishable from the vegetation characterized by juniper with which it is closely connected since it represents a less mature stage of dune vegetation succession. Moreover, the habitats of the mobile dunes (*Ammophiletalia* - 2110, 2120) and of the more stable dunes (*Crucianelletalia maritimae* - 2210) suffered a

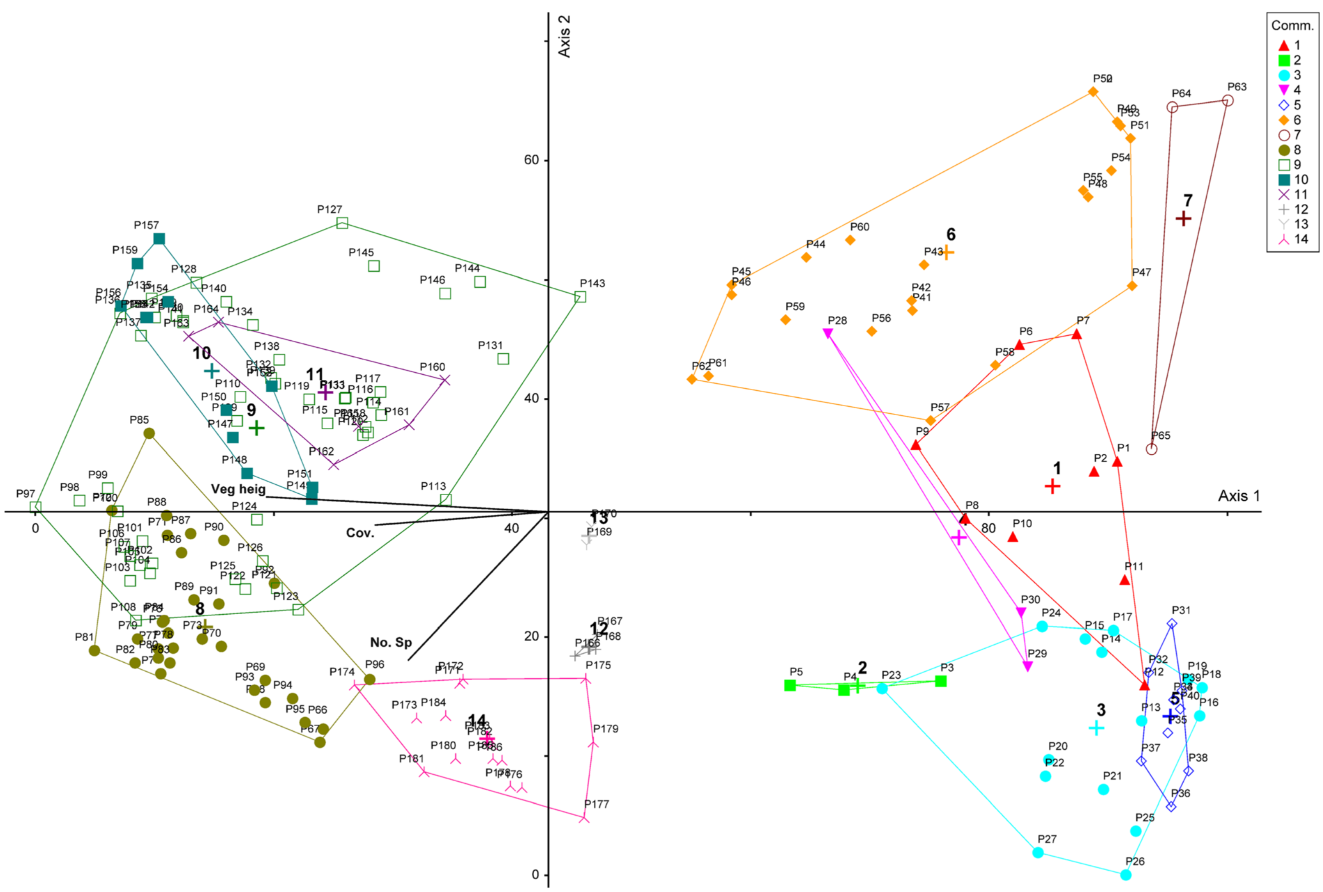

Fig. 3 Ordination scatter diagram (DCA). Plant communities according to Fig. 2

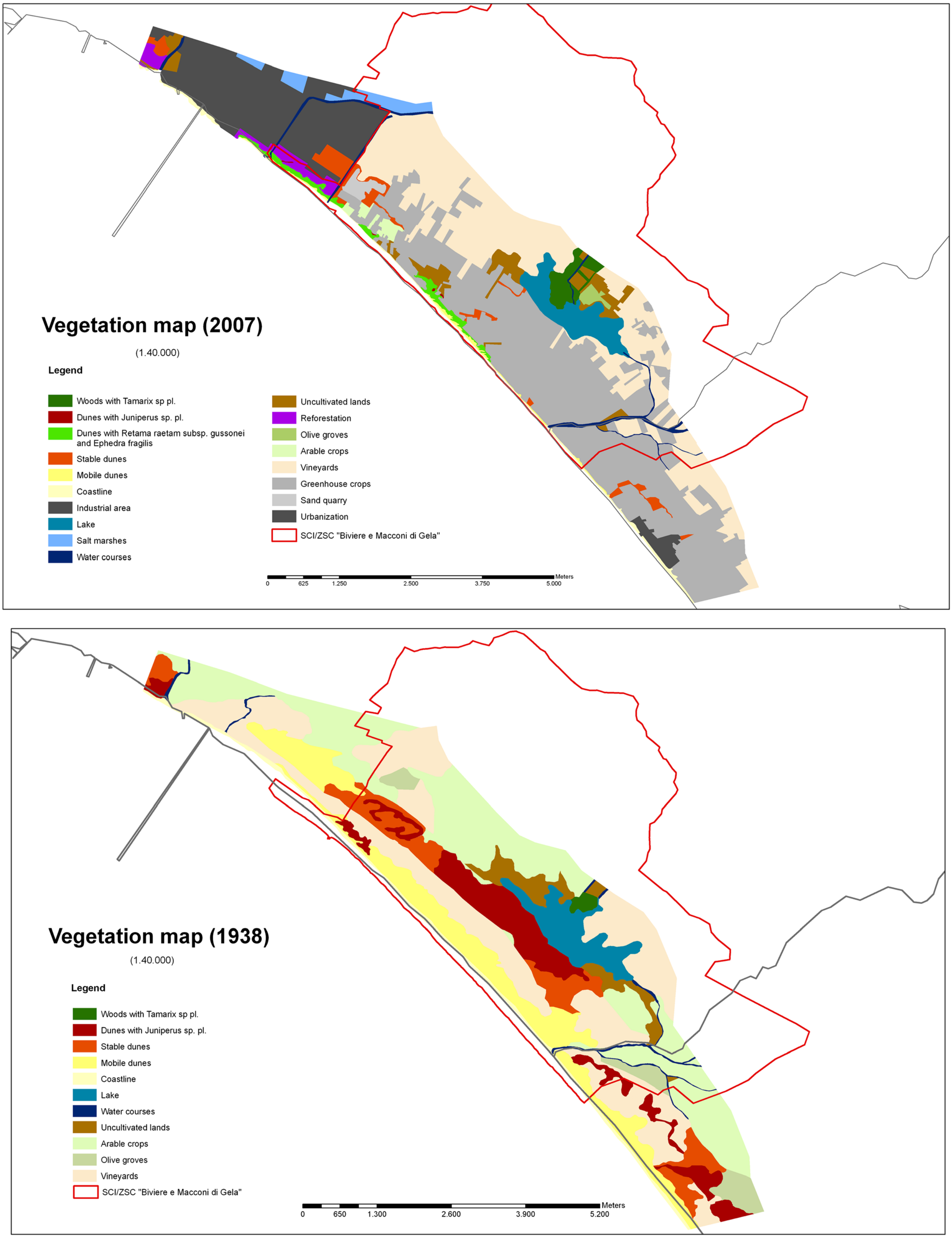

Fig. 4 Comparing the vegetation map (1938) and current vegetation map (2007)

Table 3 Surfaces comparison deduced from the historical stereophoto (1938) and current aerial photos (2007)

	1938	%	2007	%
Dunes with *Juniperus* sp. pl.	267,2	9,5	1,0	0,0
Dunes with *Retama raetam* subsp. *gussonei* and *Ephedra fragilis*	0,0	0,0	33,3	1,2
Mobile dunes (*Ammophiletalia*)	362,0	12,9	12,5	0,5
Stable dunes (*Crucianelletalia maritimae*)	200,1	7,2	67,9	2,5
Water courses (*Phragmito-Magnocaricetea*)	29,7	1,1	49,6	1,8
Woods with *Tamarix* sp pl. (*Nerio-Tamaricetea*)	12,6	0,5	40,3	1,5
Lake (*Potametea*, *Phragmito-Magnocaricetea*)	132,6	4,7	100,9	3,6
Coastline (*Cakiletea maritimae*)	65,0	2,3	31,3	1,1
Salt marshes (*Sarcocornietea fruticosae*)	0,0	0,0	47,7	1,7
Uncultivated lands	98,6	3,5	96,2	3,5
Arable crops	739,0	26,4	18,4	0,7
Olive groves	82,5	3,0	10,9	0,4
Vineyards	808,6	28,9	705,2	25,5
Sand quarry	0,0	0,0	17,7	0,6
Industrial area	0,0	0,0	419,6	15,2
Reforestation	0,0	0,0	41,3	1,5
Greenhouse crops	0,0	0,0	1041,7	37,6
Urbanization	0,0	0,0	33,7	1,2
Tot.	2797,92		2769,28	

drastic reduction from 532 to 80 ha in total during the same years. Agricultural transformations were very important factors and affected the dune systems because of the massive installation of plastic greenhouses, covering a surface of 1041 ha in 2007, the widest land-use typology of the studied territory; other crops such as olive groves and vineyards remain stable over time although vineyards in particular have shifted from the coast to occupy areas previously used for arable crops. These latter ones (arable crops) suffered a significant decrease, in part because of industrial installations, such as refineries and related activities affecting about 400 ha of land. Another peculiarity of 2007 worth mentioning was the reappearance of wetlands that were not previously appreciable as a result of past efficient drainage systems for the protection of now lapsed agricultural activities. It is also important to note that the retreat of the coast, highlighted by a loss of surface, is estimated at about 28 ha along 10 km of coastline.

Discussion

Psammophilous plant communities, ecological succession and conservation status

The comparison among psammophilous plant communities, as defined by statistical analysis (cluster analysis and DCA), and current phytosociological literature data on coastal dunes in Italy (Géhu et al. 1984; Brullo et al. 2001) generally allows the attribution of these communities to a more or less well-defined syntaxa, with a useful specific floristic composition in order to understand the naturalness degree and the position in the vegetation series of each plant communities (Table 4).

In dunes that are more or less stable and consolidated, the most relevant vegetation (in terms of natural integrity) is the community with *Juniperus macrocarpa* but it occurs only in a limited number of plots (6) as it has been destroyed from most of the area under consideration due to human activities in the twentieth century. In fact, the most widespread plant community in the study area (50 plots) is a maquis characterized by *Ephedra fragilis* which can be considered an altered aspect of *Juniperus macrocarpa* community which, if it is reduced to a few isolated individuals and in the absence of targeted interventions of restoration, has a rather limited possibility of re-expansion (Ortiz et al. 1998). Another widespread shrubby community is the one dominated by *Retama raetam* subsp. *gussonei* (31 plots), which represents a connection stage in the vegetation series of the herbaceous and chamaephytic vegetation to woody shrubs such as juniper. It has an excellent capacity for colonization of more stable coastal dunes but is slightly covered by vegetation. The recorded 13 plots with *Acacia saligna* are placed in the context of the communities just mentioned, representing a strong alteration caused by reforestation activities carried out some decades ago with this specie which, in these environments, tends to become spontaneous and moderately invasive. In the same environment of stable dunes, destruction of woody vegetation or at least the opening of large clearings, ease the settlement of annual grasslands characterized by psammophilous species, such as *Erodium laciniatum* (3 plots) or *Pseudorlaya pumila* community (2 plots), especially if the soil is subject to trampling and

Table 4 Nomenclatural comparison among plant communities and habitats

N.	Plant community dominant species	Habitat of annex I of CEE Directive (93/42)	Phytosociolgical sintaxon
1	*Eryngium maritimum* and *Launaea fragilis*	2110 Embryonic shifting dunes	Altered *Cypero mucronati-Elytrigietum junceae* Kühnholtz-Lordat ex Br.-Bl. 1933
2	*Crucianella maritima*	2210 *Crucianellion maritimae* fixed beach dunes	*Seselio-Crucianelletum maritimae* Brullo et al. 1998
3	*Eryngium maritimum* and *Cyperus capitatus*	2110 Embryonic shifting dunes	Altered *Cypero mucronati-Elytrigietum junceae* Kühnholtz-Lordat ex Br.-Bl. 1933
4	*Cutandia maritima* and *Ononis variegata*	2230 *Malcolmietalia* dune grasslands	*Sileno coloratae-Ononidetum variegatae* Gèhu & Gèhu-Franck 1986 subass. *cutandietosum maritimae* Minissale and Sciandrello 2015
5	*Achillea maritima* and *Silene nicaensis var. perennis*	2110 Embryonic shifting dunes	Altered *Cypero mucronati-Elytrigietum junceae* (Kühnholtz-Lordat 1923) Br.-Bl. 1933
6	*Elytrigia juncea*	2110 Embryonic shifting dunes	*Cypero mucronati-Elytrigietum junceae* Kühnholtz-Lordat ex Br.-Bl. 1933
7	*Ammophila arenaria*	2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)	*Medicagini marinae-Ammophiletum australis* Br.-Bl. 1921
8	*Retama raetam* subsp. *gussonei*	5330 Thermo-Mediterranean and pre-desert scrub	*Asparago horridi-Retametum gussonei* Brullo et al. 2001 *corr.*
9	*Ephedra fragilis*	5330 Thermo-Mediterranean and pre-desert scrub/ 2250* Coastal dunes with *Juniperus* spp.	Altered *Ephedro fragilis-Juniperetum macrocarpae* Bartolo et al. 1982
10	*Acacia saligna*	Not classified	Altered *Asparago horridi-Retametum gussonei* Brullo et al. 2001 corr.
11	*Juniperus macrocarpa*	2250* Coastal dunes with *Juniperus* spp.	*Ephedro fragilis-Juniperetum macrocarpae* Bartolo et al. 1982
12	*Erodium laciniatum*	2230 *Malcolmietalia* dune grasslands	*Vulpio fasciculatae-Leopoldietum gussonei* subass. *cutandietosum divaricatae* (Brullo and Scelsi 1998) Minissale and Sciandrello 2015
13	*Pseudorlaya pumila*	2230 *Malcolmietalia* dune grasslands	*Vulpio fasciculatae-Leopoldietum gussonei* subass. *hormuzakietosum* (Brullo et al. 2002) Minissale and Sciandrello 2015
14	*Ononis hispanica subsp. ramosissima*	2210 *Crucianellion maritimae* fixed beach dunes	*Centaureo-Ononidetum ramosissimae* Br.-Bl. & Frei in Frei 1937

earthmoving activities. On more stable soils but where the disturbance was earlier but greater (eg. agriculture, including greenhouse cultivation), the chamaephytic community with *Ononis hispanica* subsp. *ramosissima* grows; this case quite frequently occurred in 16 plots.

An overview of the embryonic dune shows the prevalence of the typical herbaceous vegetation with *Elytrigia juncea* (22 plots); including several variants, such as *Eryngium maritimum-Launaea fragilis* community (9 plots), *Eryngium maritimum-Cyperus capitatus* community (15 plots) and *Achillea maritima* community (10 plots), indicating a discrete disturbance of this environment. The plant communities of mobile dunes that currently have limited diffusion are the A*mmophila australis* community (5 plots); and the *Crucianella maritima* community (3 plots): this is because they are highly sensitive to human disturbance. Moreover, it is possible to sometimes find annual plant communities linked to regression processes of dune vegetation, such as the sabulicolous ephemeral plant communities belonging to *Cutandietalia maritimae* order (Minissale and Sciandrello 2015) (8 plots).

On the whole, our results show a strong alteration of the ecological succession of the psammophilous vegetation. In fact, in the study area is almost impossible to identify the regular succession of plant communities as can be seen in other parts of the Mediterranean's sandy shores (Géhu et al. 1984; Acosta et al. 2007; Fenu et al. 2012). The analysis of transects has highlighted the reduced diffusion of pioneer communities, linked to the embryonic shifting dunes, which were recorded in only 65 plots out of a total of 186. This is related to the strong coastal erosion along many sites of the Gulf of Gela (Anfuso et al. 2013), which has narrowed the embryonic dunes belt. At the same time on the more stable dunes, a strong, prolonged disturbance over the years has led to the almost total disappearance of the more mature, but less resilient woody vegetation with *Juniperus macrocarpa*, being replaced by the pioneer *Retama raetam* subsp. *gussonei* woody vegetation; and worse again, if the disturbance was more intense or prolonged, by the chamaephytic vegetation with *Ononis hispanica* subsp. *ramosissima* being favoured. Another distortion that has altered the normal succession was the introduction of *Acacia saligna* which now occupies potential sites for communities with juniper or white broom. According to Minissale and Sciandrello (2015), the floristic richness and diversity index showed an increased trend from the coastal line towards the inner zone. In this specific case, the environmental factors determining a low floristic richness along the primary dune are mainly the nature of the substrate, strong wind and the retreat of the coastline. These disrupting factors favour the development of a few psammophilous species with high ecological plasticity and adapted to the continuous sand movement of the embryonic dune system. By contrast, in inland areas, characterized by rather stable sandy soils, the various forms of disturbance connected to the presence of man is the main factor that favours a high floristic richness, and therefore the development of therophytic or chamaephytic communities rich in species with large resilience capacity.

Overall, the analysis performed on the collected data, summarized in Table 1, supports the conclusion that the territory in question has not yet suffered a net loss of species, but rather a more or less marked decline of populations of the most sensitive taxa to human disturbance as *Juniperus macrocarpa*, *Crucianella maritimae*, etc.; moreover the natural floristic poverty and reduced diversity of the communities of this very selective environment, decreases with the disturbance that facilitates the entry of native, more or less nitrophilous, species or exotic taxa, deliberately introduced, which may become invasive; in these cases the diversity increases, but regarding trivial species. Furthermore, the degradation phenomena lead to a simplification of the structure manifested, in the early stages, by a lower ground cover in the altered woody communities and, later, by the transition to the communities characterized structurally by chamaephytes and therophytes that expand on the internal dunes.

Fig. 5 Macconi di Gela (**ab**. retreat of the coastline; **c**. dunes with residues of agricultural plastic; **d**. greenhouse cultivation; **e**. relicts of natural vegetation; **f**. relicts of *Juniperus macrocarpa*; **gh**. last patches of white sand dunes)

Spatiotemporal changes of coastal dune system

Provoost et al. (2011), Bertacchi and Lombardi (2013), give some examples on how human pressure has drastically altered coastal dune landscapes in north Europe and north Mediterranean coasts, with negative consequences on the structure and function of plant communities (Tomaselli et al. 2012). The study case of the Gulf of Gela's sandy coast is a very representative example of how, in a few decades, it was possible to destroy one of the largest dune systems of the southern Mediterranean basin with direct effects on the specialized plant communities of these environments. Comparison of aerial photos taken almost 70 years ago show a dramatic change with permanent loss of land in the industrial settlements and almost complete leveling of the dunes due to the greenhouse crops (Fig. 5). Of particular importance is the loss of *Juniperus macrocarpa* wood on the coast and *Juniperus turbinata* stands which had been found on coastal, but more internally positioned, dunes as attested by Lopriore (1900), and today are present only in a few refuge areas in the territory (Minissale and Sciandrello 2013). In aerial photos from 1938, it seems possible to see, at least in part, near the Biviere Gela several shrubs of *Juniperus sp. pl.*, which today has almost completely disappeared (Fig. 6).

Beginning with the building of the ENI oil refinery in the 50s and 60s and then, in the 70s, the greenhouse crops, which grew without any regulations until the 90s, profoundly changed the spatial assets and altered the fragile ecological balance of the dune environments. The area suffered a radical historical-cultural change, switching from local agriculture mainly made up of vineyards, olive and almond groves in harmony with the Sicilian coastal landscape, to an invasive agriculture method capable of destroying, in a single day, extended dune surfaces by the use of bulldozers (Russo et al. 2009, 2011). Moreover, several rare plants species have declined dramatically in abundance and in some areas, are entirely lost (Gussone 1843, 1844, 1845; Lopriore 1900; Brullo and Giusso del Galdo 2006). In addition, another problem for the biodiversity conservation of the area, linked to landscape transformation, was the invasion of some alien species favoured by man such as *Acacia saligna*, *Carpobrotus edulis* and especially *Saccharum spontaneum* subsp. *aegyptiacum* which, in some cases, covers extensive areas and replaces the native psammophilous vegetation.

But it is important to point out that the surviving dune system still represents a "refuge" for psammophilous plant species (Brullo et al. 2013), which form a mosaic of well-defined plant communities in some cases trivialized by

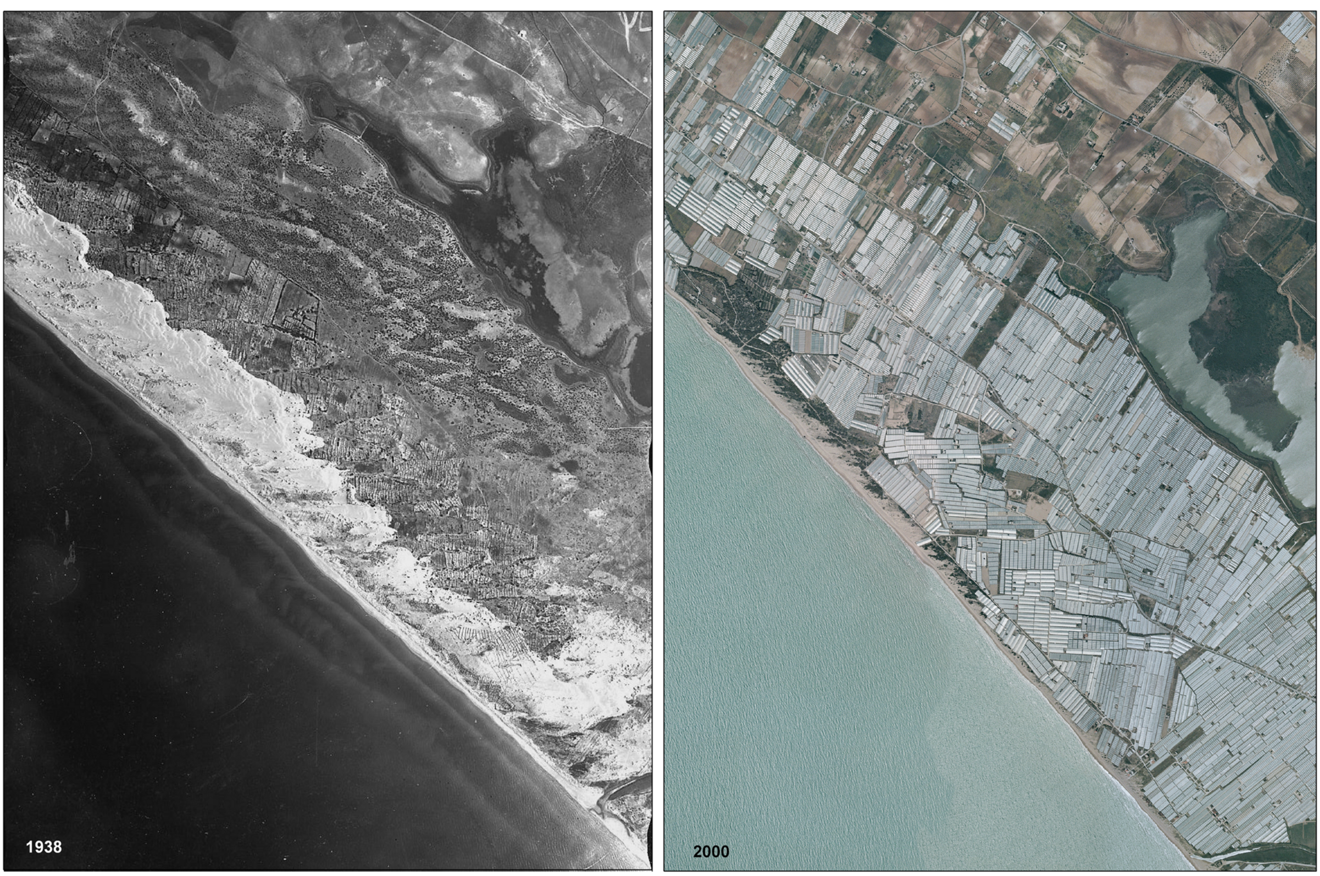

Fig. 6 Aerial photos of 1938 and 2000 (Biviere area with several shrubs of *Juniperus sp. pl.* today completely disappeared)

invasive species or indicating human disturbance, but with some biodiversity jewels, such as the narrow endemic *Leopoldia gussonei* (Vandepitte et al. 2013), which need careful protection measures and actions of environmental restoration. It is also important to note that the lakes and ponds behind the dunes are larger than in the past and this has opposed the loss of biodiversity of these environments, where, previously unknown species were recently recorded in the site (Brullo and Sciandrello 2006; Sciandrello 2007).

On the whole the previous analysis of the plant community, while allowing to recognize different vegetation types and their spatial and dynamic relationships, just partially can highlight the serious alterations of the dune systems of the area investigated. Only with the subsequent analysis spatiotemporal, the dramatic loss of dune habitats more vulnerable and the radical transformation of the landscape, is incisively highlighted.

In conclusion, our plant landscape analysis may be useful in developing management strategies for the coastal dune areas. This has been partly implemented in the study area with the Leopoldia-Life project which included several actions aimed at preserving and restoring the coastal natural habitats. These are, for example, the eradication and control of invasive species; dune protection from wind erosion with soft structures, such as wattles; and the reinforcement, with plantation in situ, of some psammophilous species numerically weakened or at risk of extinction. The project, still ongoing, represents the first serious attempt to reverse the apparently irreversible environmental degradation in progress on the south Sicilian coast.

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