DOCTORAL SCHOOL IN BIOLOGY

Section: Biodiversity and Ecosystems Analysis

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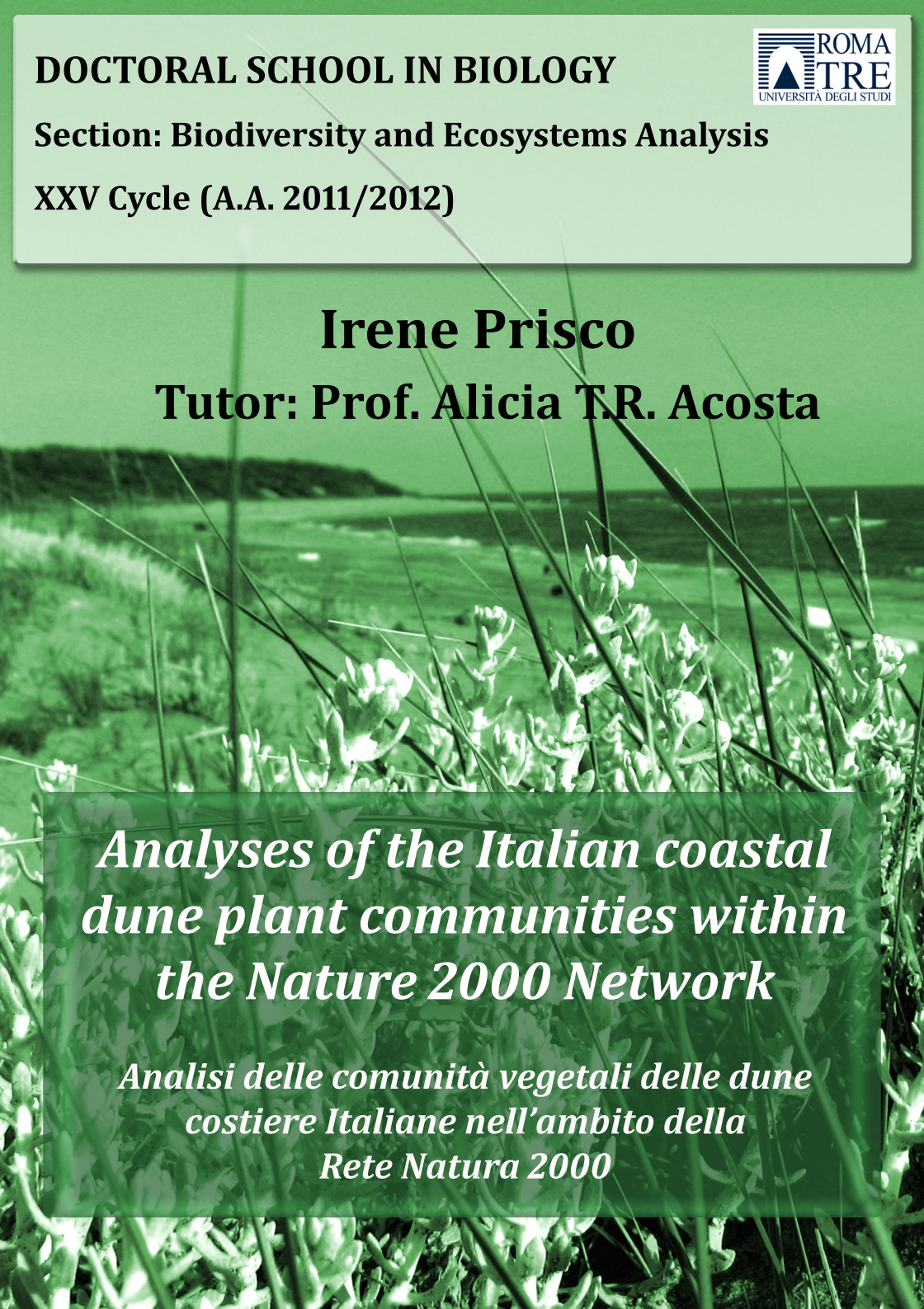

Analyses of the Italian coastal dune plant communities within the Nature 2000 Network

Analisi delle comunità vegetali delle dune costiere Italiane nell'ambito della Rete Natura 2000

ROMA TRE
UNIVERSITÀ DEGLI STUDI

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Abstract

By occupying a transition zone between terrestrial and marine ecosystems, coastal dunes are one of the most ecologically relevant ecosystems on earth. One of the main characteristics of coastal dunes is the spatial variability of the plant communities due to a strong environmental heterogeneity. This allows the coexistence of different plant communities in relatively small spaces and determines the typical sea-inland vegetation zonation. At present, dune environments are considered to be threatened worldwide. Coastal dune management and conservation have become critical issues, representing a priority for many European countries. In Italy coastal sand dunes and inland dunes are considered in a bad or unsuitable conservation state with relation to urbanization and other human pressures. Thus, dune habitats (as defined by the European Habitats Directive 92/43/EEC) require special attention and conservation actions, especially in the light of predicted global changes.

In this thesis I analysed the current knowledge of Italian dunes vegetation by setting up a national coastal database; I focused on dune habitats diversity and geographical distribution at the national level; I used this large amount of data to forecast future distribution of dune habitats under climate change scenarios and to evaluate the current and projected effectiveness of the protected areas network.

I conducted a detailed research on the Italian phytosociological information putting together different accessible sources regarding Italian coastal dunes vegetation. I also conducted a field campaign adding original phytosociological plots in areas with scarce vegetation information, in order to complete the national coastal database as far as possible. Phytosociological plots (relevés) were georeferenced and assigned to a habitat type following the guide-lines of the Interpretation Manuals of the Habitats Directive. I collected 2.806 relevés (both published and unpublished) distributed in 13 coastal habitats, and stored them using the database software Turboveg. The oldest plot in the database is dated 1967, whereas the newest is dated 2011, although most of the data comes from the 1980's till present. The most part of the relevés has a medium-high geographical accuracy and, to avoid small position errors, I transferred the relevés on a coastal UTM grid (10 km x 10 km) for further analysis.

Embryo dune, mobile dune and transition dune habitats had the highest number of records in the database, followed by beach and fixed dune

habitats. The *Crucianellion maritimae* fixed beach dunes and the *Malcomietalia* dune grasslands habitats were characterised by the highest number of species and phytosociological associations, most of them endemic of few regions (in particular Sardinia, Sicily, Calabria, Basilicata and Tuscany). Regarding dune habitats' geographical distribution, those close to the sea were widespread along the Italian sandy coasts, while fixed and inland dune habitats showed a more restricted spatial distribution. There is a wide variety of psammophilous plant communities along the Italian coasts linked to the variability of bioclimatic and phytogeographic features. A particularly high number of relevés and habitat types were found in central Italy and also the insular areas were characterised by high species richness and by endemic and rare associations. In addition, on the northern Adriatic coast there was a rare, priority habitat (Fixed coastal dunes with herbaceous vegetation – Grey dunes) with a high species richness and a restricted geographic distribution.

For the most representative dune habitats at national level I developed habitat distribution models to forecast the response of sandy dunes to climate change over the next 50 years. I took a community-level strategy by adopting two complementary modelling approaches: *indirect* (species-based) and *direct* (habitat-based). In the *indirect* approach I modelled individual plant species distributions as a function of the environmental predictors. Then, for each habitat, I used the predicted occurrences of its diagnostic species as explanatory variables in the models to predict habitat distribution both in the current projections and in the future scenarios. I compared this indirect approach with a straightforward *direct* one, using the current distribution of the habitat itself to model its present and future distribution based on the environmental predictors.

Using the R-based package BIOMOD, I performed all the projections combining in an ensemble forecast eight different and widely used niche-based modelling techniques. As explanatory variables I selected six non-correlated bioclimatic variables and three land use and morpho-sedimentological variables. I focused on two IPCC emission scenarios (A2 -high emissions- and B2 -intermediate emissions-) for the year 2050 in order to explore possible changes in an intermediate time range.

Predictive performance, as assessed by TSS (True Skill Statistic), was particularly good in the indirect models, while the evaluation of direct models revealed that this is a less reliable approach for coastal dune habitats. There were no significant differences between the two future

scenarios (A2 and B2) that showed pretty much the same percentage of increase/decrease of coastal habitats for the year 2050. The results showed that habitats closer to the sea (beach and embryo dune) could increase their geographical distribution in the near future even by more than 40%. On the contrary, mobile dune and fixed dunes habitats were projected to lose most of their current geographical distribution (more than 75%), while the transition dune habitat was projected to remain stable.

Finally, I performed a comprehensive gap analysis based on the modelled habitat distributions (current and future predictions of the indirect models) and the Italian conservation areas network, in order to evaluate its present and future efficacy. The current protected areas network was fairly effective in preserving coastal dune habitats as most of them were well represented in the protected areas. Only the priority fixed dune habitat with *Juniperus* spp. failed to reach the *conservation target* (minimum number of grid cells where each habitat occurred overlapping with protected areas), thus being, at present, less protected than other habitats. However, in the two future scenarios the distribution range reduction of mobile and fixed dune habitats due to climate change could lead to a decrease in the future efficacy of protected areas.

In conclusion, the information derived from the database gives an excellent account of the diversity of Italian coastal dune habitat types, and thereby it constitutes an important tool for nature conservation. As it is highly probable that human development and recreational activities along coasts will continue to be intense, an appropriate management of well-preserved dune systems, paired with the restoration of the more damaged ones, is urgently needed to guarantee their conservation for the future generations. Furthermore our results call for adaptive and flexible management of protected areas in face of habitat distribution shifts linked to predicted climate change.

Riassunto

Occupando la zona di transizione tra gli ecosistemi marini e quelli terrestri, le dune costiere rappresentano uno degli ambienti ecologicamente più rilevanti sulla terra. Una delle principali caratteristiche delle dune costiere è la variabilità spaziale delle comunità vegetali dovuta all'eterogeneità ambientale. Questo permette la coesistenza di differenti comunità vegetali in spazi relativamente ristretti e determina la tipica zonazione mare-terra della vegetazione. Attualmente gli ambienti dunali sono considerati minacciati in tutto il mondo. La conservazione e la gestione delle dune costiere sono diventati dei problemi critici e rappresentano una priorità per molti paesi europei. In Italia le dune sabbiose costiere ed interne sono un uno stato di conservazione cattivo o inadeguato a causa dell'urbanizzazione e di altre pressioni antropiche. Gli habitat dunali (come definiti dalla Direttiva Habitat 92/43/EEC) richiedono, pertanto, una particolare attenzione e misure di conservazione più efficaci, anche in vista dei possibili cambiamenti climatici globali.

In questa tesi ho analizzato l'attuale stato delle conoscenze riguardo la vegetazione delle dune costiere italiane compilando un database nazionale costiero; mi sono concentrata sulla diversità e la distribuzione geografica degli habitat dunali; ho usato questa grande quantità di dati per modellare la distribuzione futura degli habitat dunali in diversi scenari di cambiamento climatico e per valutare l'efficacia dell'attuale rete di aree protette italiane.

Ho condotto una ricerca dettagliata raccogliendo tutte le fonti bibliografiche accessibili di rilievi fitosociologici condotti in Italia sulle dune sabbiose costiere. Ho condotto inoltre un'attività di campo mirata ad aggiungere rilievi fitosociologici originali in aree con scarsa informazione vegetazionale, allo scopo di rendere il database nazionale costiero il più possibile completo. Ogni rilievo di vegetazione è stato georeferenziato e assegnato ad una categoria di habitat, seguendo le linee guida dei manuali di interpretazione della Direttiva Habitat. Usando il programma di database Turboveg, ho raccolto 2.806 rilievi (sia pubblicati che inediti) distribuiti in 13 habitat costieri. Il range temporale dei rilievi va dal 1967 al 2011, ma la maggior parte di essi sono datati dal 1980 ad oggi. La maggior parte dei rilievi è stata registrata, nelle fonti originali, con un'accuratezza geografica medio-alta. Tuttavia, per evitare piccoli errori di posizionamento, nelle analisi successive ho trasferito tutti i rilievi su una griglia UTM costiera di 10

km per lato. Gli habitat di duna embrionale, mobile e di transizione hanno il più alto numero di rilievi nel database, seguiti dagli habitat di spiaggia e duna fissa. Gli habitat di duna fissa (*Crucianellion maritimae*) e i pratelli effimeri dei *Malcolmietalia* sono caratterizzati dal più alto numero di specie e associazioni fitosociologiche, molte delle quali endemiche di poche regioni (in particolare Sardegna, Sicilia, Calabria, Basilicata e Toscana). Per quanto riguarda la distribuzione geografica degli habitat, quelli più vicini alla linea di costa sono molto diffusi lungo le coste italiane, mentre gli habitat di duna fissa e di duna interna mostrano una distribuzione più ristretta. Lungo le coste italiane c'è un'ampia varietà di comunità vegetali psammofile, legate alla variabilità bioclimatica e alle caratteristiche fitogeografiche della penisola. Un elevato numero di rilievi e tipologie di habitat si rinvengono nell'Italia centrale e sulle due isole maggiori, Sicilia e Sardegna, caratterizzate da un'elevata ricchezza di specie ed associazioni fitosociologiche rare ed endemiche. Inoltre, lungo le coste nord Adriatiche si trova un habitat prioritario raro (Dune costiere fisse a vegetazione erbacea – Dune grigie) con un'ampia ricchezza di specie e una ristretta distribuzione geografica.

Per gli habitat dunali più rappresentativi a livello nazionale ho sviluppato dei modelli di distribuzione per prevedere la risposta ai cambiamenti climatici degli habitat di dune sabbiose nei prossimi 50 anni. Ho comparato due approcci modellistici complementari a livello di comunità: uno *indiretto* basato sulle specie e uno più semplice e *diretto* basato sugli habitat. Nell'approccio *indiretto*, in una prima fase, ho modellato la distribuzione delle specie vegetali in funzione delle variabili ambientali. Poi, in una seconda fase, ho usato le presenze delle specie diagnostiche predette dai modelli come variabili esplicative (invece delle variabili ambientali) per predire la distribuzione di ciascun habitat nel presente e nel futuro. Ho comparato questo approccio indiretto con uno più semplice e *diretto*. Usando la distribuzione attuale di ciascun habitat ho modellato la sua distribuzione presente e futura sulla base delle variabili ambientali, come se l'habitat possedesse una nicchia ambientale e fosse una singola entità.

Usando il pacchetto BIOMOD del software R, ho eseguito tutte le proiezioni combinando in un *ensemble forecast* 8 tecniche modellistiche largamente usate in letteratura. Come variabili esplicative ho selezionato 6 variabili bioclimatiche non correlate e 3 variabili morfo-sedimentologiche e di uso del suolo. Le proiezioni sono state fatte per l'anno 2050 allo scopo di esplorare i possibili cambiamenti in un

intervallo di tempo intermedio e sono stati usati due scenari di emissioni, A2 (emissioni alte) e B2 (emissioni intermedie).

La performance predittiva, valutata dal TSS (True Skill Statistic), è risultata buona per i modelli indiretti, mentre la valutazione dei modelli diretti ha indicato che questo approccio è meno affidabile per gli habitat di dune costiere. Non è stata riscontrata una significativa differenza tra i due scenari di emissioni (A2 e B2) che mostrano simili percentuali di aumento/diminuzione degli habitat dunali per l'anno 2050. I risultati mostrano che gli habitat più vicini alla linea di costa (spiaggia, duna embrionale) potrebbero aumentare la loro distribuzione geografica nel prossimo futuro anche più del 40%. Al contrario, per gli habitat di duna mobile e fissa è prevista una perdita di più del 75% della loro attuale distribuzione geografica. Gli habitat di duna di transizione potrebbero invece rimanere stabili.

Infine, ho effettuato una dettagliata gap analisi basandomi sulla distribuzione degli habitat prevista dai modelli indiretti (presente e futura) e la rete di aree protette italiane, allo scopo di valutare la sua efficacia presente e futura. L'attuale rete di aree protette è abbastanza adeguata nel preservare gli habitat di dune costiere; la maggior parte di essi sono infatti ben rappresentati all'interno delle aree protette. Solamente l'habitat prioritario di dune costiere con *Juniperus* spp., nella sua distribuzione attuale, non raggiunge il *target di conservazione* (numero minimo di celle della griglia in cui l'habitat è presente che deve sovrapporsi con le aree protette), essendo attualmente meno protetto di altri habitat. Nei due scenari futuri la riduzione del range di distribuzione degli habitat di duna mobile e fissa dovuta ai cambiamenti climatici, porterà alla diminuzione dell'efficacia dell'attuale sistema di aree protette.

In conclusione, l'informazione contenuta in questo database dà un eccellente resoconto della diversità degli habitat di dune costiere in Italia e rappresenta un importante strumento di conservazione a livello comunitario. Data l'alta probabilità che le attività antropiche lungo le coste continueranno ad essere intense nei prossimi anni, c'è un urgente bisogno di un'appropriata gestione dei sistemi dunali ancora ben conservati e, parallelamente, del ripristino di quelli danneggiati, al fine di garantire la loro conservazione per le future generazioni. Questi risultati, inoltre, rappresentano un'indicazione per una gestione più flessibile e adattativa delle aree protette, che prenda in considerazione le variazioni nella distribuzione degli habitat costieri dovute al cambiamento climatico.

Papers published or prepared in the course of the PhD

Paper 1
Prisco I., Carboni M., Acosta A.T.R. (2012) *VegDunes - A coastal dune vegetation database for the analysis of Italian EU habitats.* In: Dengler J., Oldeland J., Jansen F., Chytrý M., Ewald J., Finckh M., Glöckler F., Lopez-Gonzalez G., Peet R.K., Schaminée J.H.J. (Eds.) Vegetation databases for the 21st Century. BIODIVERSITY & ECOLOGY 4: 191-200.

Paper 2
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Paper 3
Landucci F., Acosta A.T.R., Agrillo E., Attorre F., Biondi E., Cambria V.E., Chiarucci A., Del Vico E., De Sanctis M., Facioni L., Geri F., Gigante D., Guarino R., Landi S., Lucarini D., Panfili E., Pesaresi S., **Prisco I.**, Rosati L., Spada F., Venanzoni R. (2012) *VegItaly: The Italian collaborative project for a national vegetation database.* PLANT BIOSYSTEMS 146 (4): 756-763.

Paper 4
Gigante D., Acosta A.T.R., Agrillo E., Attorre F., Cambria V.E., Casavecchia S., Chiarucci A., Del Vico E., De Sanctis M., Facioni L., Geri F., Guarino R., Landi S., Landucci F., Lucarini D., Panfili E., Pesaresi S., **Prisco I.**, Rosati L., Spada F., Venanzoni R. (2012) *VegItaly: Technical features, critical points and some solutions.* PLANT SOCIOLOGY 49 (2): 71-79.

Paper 5
Santoro R., Jucker T., **Prisco I.**, Carboni M., Battisti C., Acosta A.T.R. (2012) *Effects of trampling limitation on coastal dune plant communities.* ENVIRONMENTAL MANAGEMENT 49: 534-542.

Paper 6

Acosta A.T.R., Jucker T., **Prisco I.**, Santoro R. (2012) *Passive recovery of Mediterranean coastal dunes following limitations to human trampling.* In: Martinez M.L., Gallego-Fernandez J.B., Hesp P.A. (Eds.) RESTORATION OF COASTAL DUNES. Elsevier, Netherlands. ISBN 978-3-642-33444-3. Cap. 12.

Paper 7

Prisco I., Carboni M., Acosta A.T.R. *The fate of threatened coastal dune habitats in Italy under climate change scenarios.* Plos One (under revision).

General Introduction

Cakile maritima

Coastal dune environments: major features, benefits and main threats

Coastal habitats represent the thin line where marine and terrestrial environments meet. Sandy beaches and dunes hold one of the most ecologically relevant ecosystems on earth and the dune vegetation, directly involved in creating the structure of coastal habitats, is the main architect.

The vegetation of coastal dune systems is shaped by a strong sea-inland environmental gradient. Soil characteristics, salt spray, wind intensity and sand burial are some of the natural stress factors that highly constrain the plant assemblage. The unique adaptations of plant species make the high biodiversity value of these ecosystems one of the most interesting features of the Mediterranean sandy shores (Brullo et al. 2001, Acosta et al. 2003, van der Maarel 2003, McLachlan and Brown 2006, Biondi 2007, Miller et al. 2010). One of the main characteristics of coastal dunes is the spatial variability of the plant communities due to environmental heterogeneity (Van der Maarel 1993, Acosta et al. 2000, Acosta et al. 2005). This allows the coexistence of different plant communities in relatively small spaces (Frederiksen et al. 2006) and determines the typical sea-inland vegetation zonation, ranging from the fore dunes close to the sea, to embryo dunes, mobile dunes, transition dunes, fixed dunes and finally inland dunes (Doing 1985, Sykes and Wilson 1991, Feola et al. 2011).

Many ecological, environmental and economic benefits are associated with well preserved coastal dune systems (Martínez and Psuty 2004). More than half of the world's population lives within 60 km of the shoreline (UNCED 1992) and dune habitats provide important ecosystem services to humans, such as coastal protection, erosion control, water catchment and purification, maintenance of wildlife, carbon sequestration, tourism, recreation, education and research (Carter 1990, Pye and Tsoar 1990, Barbier et al. 2011). However, at present, dune environments are considered to be threatened worldwide (Brown and McLachlan 2002).

Coastal environments are dynamic systems responding to sea level movements, subsidence effects, wave action and sediments transport (Douglas 1991). Most of the world's coastlines are in a state of erosion or retreat as a consequence of natural processes, but it usually remains unclear to what extent coastal erosion results from global warming, and to what extent it is associated with relative sea-level rise due to

subsidence or human drivers of land loss (Hansom 2001, Jackson et al. 2002, Burkett et al. 2005, Wolters et al. 2005). In addition, climate changes could directly affect plant species' life cycle (e.g. with rainfall reduction) or could modify inter-specific relationship (e.g. competition, host-parasites or mutualism). At a higher level of biodiversity, climate could also induce changes in vegetation communities modifying community structure and ecosystem functions (Sala et al. 2005, Lafferty 2009, Walther 2010, Yang and Rudolf 2010).

Coastal habitats are particularly sensitive to anthropogenic changes (Defeo et al. 2009). There is a wide number of human activities that can affect sandy shore habitats directly or indirectly and this pressure has dramatically increased in the last 50 years, especially in the Mediterranean (Curr et al. 2000). Urbanization, transport and tourism, pollution, trampling, introduction of alien species, agriculture, forestry, industry, etc., are all factors that have considerable negative impacts on sandy coastlines. The progressive fragmentation and deterioration of dune habitats have led to a dramatic loss of biodiversity and ecosystem functions (Brown and McLachlan 2002, Hansen et al. 2004, Reidsma et al. 2006, Reger et al. 2007, Carboni et al. 2011), in addiction to an increasing in biological invasions, to decline of water quality and to decrease of the coastal protection from flooding and storm events (Braatz et al. 2007, Cochard et al. 2008, Koch et al. 2009).

Conservation strategies and the use of vegetation databases

Coastal dune management and conservation have become critical issues, representing a priority for many European countries (Martínez et al. 2004, Schlacher et al. 2008). With the aim of facilitating and improving efforts and management strategies several coastal habitats were included in the European Directive 92/43/EEC, also known as the "Habitats Directive". This piece of legislation, together with the "Birds Directive" (79/409/EEC), requires each Member State of the European Union to establish a network of special areas for conservation throughout Europe, resulting in the Natura 2000 Network sites (Evans 2006, Mücher et al. 2009). This EU program is currently the most important legal tool for nature conservation in the European Union (Mücher et al. 2004, Wätzold and Schwerdtner 2005).

The last Report of the European Commission about the implementation of the Habitats Directive showed that coastal habitats are in a very bad conservation state throughout Europe (European

Commission 2008). Particularly, among all 130 habitats listed in the Annex I for Italy, "Coastal sand dunes and inland dunes" habitats are one of the few types that fall within the categories "unfavourable" or "bad" conservation state, and thus they are currently considered highly endangered (La Posta et al. 2008). Therefore, Italian dune habitats require special attention and conservation actions, so further developments in vegetation science should attempt to address these demands. In light of international policies for biodiversity conservation, vegetation databases represent useful sources of data not only for the analysis of spatial distribution and conservation state of habitats and species, but also for monitoring future environmental and global changes (Schaminée et al. 2011, Landucci et al. 2012).

In Europe, as well as in Italy, there is a long tradition of vegetation survey based on the classical phytosociological approach (Braun Blanquet 1964, Westhoff and van der Maarel 1973, Dierschke 1994, Dengler et al. 2008). Vegetation plot observations (relevés) constitute the primary descriptive data that contribute in many ways to a better understanding of vegetation and to the daily practice of nature management (Dengler et al. 2011). A huge amount of phytosociological relevés have been performed through years, although this information was often unpublished and the access thereto was extremely limited prior to the advent of electronic database technologies and digital communication tools (Mucina and van der Maarel 1989, Dengler et al. 2011).

In recent years, with the introduction and the widespread adoption of several database software, great advancements have been made in the field of vegetation science. The development of regional and national vegetation plot databases has been going beyond traditional descriptive approaches, stimulating their use in multiple applications in basic ecological and biogeographical research, as well as in applied studies addressing environmental and conservation issues (Dengler et al. 2011). At present, millions of vegetation plots have already been digitalised and managed in central databases. With the aim of facilitating the discover, the access and the use of vegetation data through increasing its visibility and availability worldwide, an on-line archive of metadata on existing databases was established: the Global Index of Vegetation-Plot Databases (www.givd.info). As of 23 November 2012, a total of 184 databases have been registered in GIVD, containing about 2.839.568 vegetation plots, that are regularly becoming registered and available (Jansen et al. 2012).

Schamineé et al. (2009) reported for Italy a total amount of 150.000 vegetation plots including published and unpublished relevés, with only about 20.000 computerised relevés (13% ca.). They also remarked the absence of an Italian national vegetation database. However, new efforts have been performed towards this scope recently (Gigante et al. 2012, Landucci et al. 2012). In the light of the considerable threats facing sandy shores, the compilation of a national vegetation plot database is particularly urgent for Italian coastal dune habitats.

The possible impact of future global changes

Notwithstanding many recent international conservation efforts, several habitats and species of community interest still fall outside national protected areas. Major socio-economic, environmental and climatic changes could be translated into changes in biodiversity. Coastal dunes habitats are highly endangered by the increase of human pressure, by the massive widespread coastal erosion and by the effects of ongoing global climate changes (Stanisci et al. 2004, Feagin et al. 2005, Harley et al. 2006). Climate change and associated increased sea level rise can affect coastal dunes especially when natural systems cannot shift landward because they are squeezed between the sea and the human structures behind, increasing the erosion rates (Martínez and Psuty 2004).

A particularly active field in recent researches concerns predicting the response of biodiversity to climate change and the most pressing issue is to quantitatively assess the future chances of biological diversity (Bellard et al. 2012). As the response of biocoenoses, as well as entire ecosystems, to rapid climate change are largely unclear, quantify the potential alterations in species and habitats' distribution is of great importance in nature conservation actions. In recent years, predictive geographical modelling gained importance as a tool for assessing the impact of accelerated climate and other human-induced changes in biodiversity in the past, present, and future at regional and global scales (Guisan and Zimmermann 2000, Guisan and Thuiller 2005, Alkemade et al. 2009). Model predictions of where, when and how future risks may affect species, biomes or ecosystems could assist in identifying the most appropriate conservation measures, in order to re-evaluate the current set of protected areas, their places, size, layout and design (Araújo et al. 2011, Bellard et al. 2012). A powerful approach to assess the effectiveness of protected areas in representing local and global

biodiversity and to indentify conservation priorities is the *gap analysis*, a method currently used at a variety of scales and focused on both individual species as well as on community or whole habitats (Scott et al. 1993, Jennings 2000). Comparing the distribution of any feature of conservation interest (vegetation alliance, habitat, or species) with that of protected areas, can be identified elements that need greater protection (Jennings 2000, Scott et al. 2001, Oldfield et al. 2004, Dietz and Czech 2005).

Effects of land use changes and sea level rise on coastal habitats are currently being considered in many predictive models (Feagin et al. 2005, Rounsevell et al. 2006, Chust et al. 2010), whereas the main results about the impact of climate change on coasts come particularly from polar coasts and tropical reefs (Nicholls et al. 2007). However, the most sensitive natural ecosystems in Europe are located, besides in the Arctic and mountain regions, in coastal zones of the Mediterranean Sea, where future climate is projected to become warmer and drier (Alcamo et al. 2007). Moreover, the Mediterranean basin is considered one of the "hottest hotspots" in the world (Shi et al. 2005) and at the same time is one of the most significantly altered (Myers et al. 2000, Maiorano et al. 2006).

In this context, vegetation databases can be particularly useful to identify species responses to environmental changes (Coudun and Gégout 2005, Schaminée et al. 2007) and to model spatial distributions of species (Coudun and Gégout 2007) and plant communities (Brzeziecki et al. 1993, Marage and Gégout 2009) in sandy coastal environments. As current concepts of nature protection are aimed at habitats in their entirety (Mücher et al. 2009), habitats as a whole are attracting more attention as focus of research on global change effects. Modeling biodiversity at the community level provides a synthesis of the ecological information resulting from a large number of species and it restores the biodiversity value in a collective form (Ferrier and Guisan 2006, Austin 1999). The community-level approach is therefore particularly valuable for directing national level conservation measures in response to European Union directives.

Aims

In synthesis, the current conservation state of costal dune habitats in Italy should be viewed with alarm if the protected areas network designed to preserve biodiversity fails to guarantee their effective

maintenance and/or proves to be ineffective in the near future under predicted global changes. On these bases, in this thesis I aim to achieve the following three major objectives:

1) The first aim is to build a national vegetation-plot database comprising phytosociological relevés of coastal dunes conducted in Italy in the last 40 years (**Chapter 1**, Appendix A). In particular, I aim to:
    a. Investigate the state of knowledge of Italian coastal dunes vegetation;
    b. Focus on critical areas with missing vegetation data in order to fill these gaps with new relevés;
    c. Collect relevant information linked to the vegetation-plots, such as habitat type, date of sampling, geographic coordinates, phytosociological association, etc., setting up a database in TURBOVEG format to facilitate future data exchange, both with Italian and other European vegetation databases.

2) The second aim is to analyse the coastal dune information gathered in the database (**Chapter 2**). In particular, I aim to:
    a. Describe Italian beach and dune habitats of European interest, focusing on the floristic and coenological information;
    b. Analyse the spatial distribution and the species richness of the different coastal dune habitats;
    c. Highlight major biodiversity hotspots at the national level.

3) The third aim is to predict future variations in coastal dunes under climate change scenarios and to evaluate the effectiveness of Italian protected areas network (**Chapter 3**). To achieve this aim, I plan to:
    a. Develop habitat distribution models comparing two complementary modelling approaches, an "indirect" species-based and a "direct" habitat-based one;
    b. Define the current geographical distribution of dune habitats and analyse how their distribution will be altered under the effects of two climate change scenarios;
    c. Carry out a thorough gap analysis with all Italian protected areas and the Natura 2000 sites in order to assess which dune habitats could become less protected as a consequence of distribution shifts due to climate changes.

Chapter 1

VegDunes - A coastal dune vegetation database for the analysis of Italian EU habitats

Eryngium maritimum

Long Database Report

VegDunes – a coastal dune vegetation database for the analysis of Italian EU habitats

Irene Prisco, Marta Carboni & Alicia Teresa Rosario Acosta

Abstract: In this paper we illustrate VegDunes (GIVD ID EU-IT-005), a vegetation database of Italian coastal dune EU habitats (sensu 92/43/EEC Habitats Directive). We explore general features of the data collected, in particular variation in plot size, time range of the relevés and geographical position accuracy. Then, we characterise and explore the spatial distribution of the different coastal dune habitats in the database, evidencing major biodiversity "hotspots" (areas with the highest number of habitats) at the national level. We collected previously published phytosociological information (2,666 phytosociological relevés) concerning Italian coastal dune vegetation (10 different EU habitats) that ranged from 1967 to 2011. Most relevés were recorded with a medium to high accuracy (from the exact GPS coordinates to a coastal length up to 5 km) and the plot size did not exceed 100 m². Habitats close to the sea-line were much more widespread along Italian coasts compared to more inland ones, possibly in relation with habitat loss caused by the intensification of human impact in back dune communities. Even though phytosociological databases are affected by preferential sampling issues, this kind of data is an important source of information for nature conservation, especially for threatened coastal environments. Overall, this information may be a powerful instrument for the future management of EU habitats from a conservation perspective.

Keywords: Coastal dune habitat; Habitats Directive; phytosociological database; psammophilous vegetation; UTM grid.

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Introduction

In Europe there is a long tradition of vegetation survey based on the classical phytosociological approach (Braun Blanquet 1964, Westhoff & van der Maarel 1973, Dierschke 1994, Dengler et al. 2008) which has proved to be a very useful methodological framework for local and regional overviews of vegetation types (Schaminée et al. 2009). In fact, the floristic-sociological approach makes it possible to describe and define characteristic vegetation groups in relatively small sample plots (usually between 1–100 m²) taking also environmental factors and biotic interactions into account (Botta-Dukát et al. 2007, Schaminée et al. 2007).

Millions of vegetation plots have been recorded for different purposes as well as a huge amount of metadata (Bekker et al. 2007). Nevertheless, the access to this massive but also scattered information was extremely limited prior to the advent of electronic database technologies and digital communication tools (Mucina & van der Maarel 1989, Dengler et al. 2011).

In Italy huge amounts of phytosociological relevés have been performed (estimated in 150,000 samples according to Schaminée et al. 2009), although this information is often unpublished and not yet widely available on digital archives. However, many efforts in this regard are currently being carried out (Venanzoni et al. 2012). The compilation of a national vegetation-plot database is particularly urgent for Italian coastal dune habitats. The second National Report about the implementation of the 92/43/EEC Directive (the so called "Habitats Directive"; EEC 1992) indicates that among all 130 habitats listed in the Annex I for Italy, coastal dunes are one of the few types that fall within the category "unfavourable conservation state" (European Commission 2008, La Posta et al. 2008; Fig. 1).

The critically poor conservation conditions make these habitats those with the highest risk level and requiring special management measures in the near future (La Posta et al. 2008). In fact, even though the great diversity of Italian coastal dune habitats is widely recognised (Biondi et al. 2009), they are highly endangered not only by the increase of human pressure on sandy littorals but also by massive coastal erosion coupled with missing space for natural coastal dynamics. Due to the combination of these factors dune habitats end up being compressed between the retreating coastline and the presence of human structures in the inland. Coupled with these phenomena are the effects of ongoing global climate change (Stanisci et al. 2004), which could cause alterations in the climate characteristics of the Mediterranean and changes in the sea-level, consequently affecting water resources, natural ecosystems (both terrestrial and marine), human activities (e.g. agriculture, recreation, tourism) and health (Giorgi & Lionello 2008). Overall, the most threatened habitats are embryonic shifting dunes (EU habitat 2110), shifting dunes along the shoreline with *Ammophila arenaria* (EU habitat 2120), coastal dunes with *Juniperus spp*. (EU priority habitat 2250*) and *Cisto-Lavanduletalia* dune sclerophyllous scrubs (EU habitat 2260) (European Commission 2008, La Posta et al. 2008).

On such a basis we built a vegetation database of Italian coastal dune EU habitats (sensu 92/43/EEC Habitats Directive;

In: Dengler, J., Oldeland, J., Jansen, F., Chytrý, M., Ewald, J., Finckh, M., Glöckler, F., Lopez-Gonzalez, G., Peet, R.K., Schaminée, J.H.J. (2012) [Eds.]: Vegetation databases for the 21st century. – Biodiversity & Ecology **4:** 191–200. DOI: 10.7809/b-e.00076.

EEC 1992), collecting previously published phytosociological information and georeferencing each relevé with a specified geographic accuracy level. Then we focused on the spatial distribution of the different coastal dune habitats based on the information available in the database. In this paper we aim to 1) increase the visibility of the database illustrating its main characteristics and its potential future uses, 2) highlighting likely biodiversity hotspots (areas with the highest number of habitats) for sandy coasts at the national level.

GIVD Database ID: EU-IT-005		**Last update:** 2012-07-08
VegDunes		
Scope: The database contains published and original phytosociological relevés of Italian coastal dunes. We considered only plant communities of Holocenic dunes. Each vegetation plot is associated to a habitat of Community interest (sensu "Habitats Directive" 92/43/EEC)		
Status: ongoing capture	**Period:** 1967-2011	
Database manager(s): Irene Prisco (iprisco@uniroma3.it)		
Owner: Laboratorio di Ecologia Vegetale, Dipartimento di Biologia Ambientale, Università Roma Tre, Rome, Italy		
Web address: [NA]		
Availability: according to a specific agreement	**Online upload:** [NA]	**Online search:** [NA]
Database format(s): Turboveg	**Export format(s):** Turboveg	
Publication: Prisco I., Acosta A.T.R., Ercole S. (2012) An overview of the Italian coastal dune EU habitats. Annali di Botanica 2: 39-48.		
Plot type(s): normal plots	**Plot-size range:** 0.2-500 m²	
Non-overlapping plots: 2,666	**Estimate of existing plots:** [NA]	**Completeness:** [NA]
Total plot observations: 2,666	**Number of sources:** 71	**Valid taxa:** [NA]
Countries: IT: 100.0%		
Forest: 0% — **Non-forest:** aquatic: 0%; semi-aquatic: 0%; arctic-alpine: 0%; natural: 100%; semi-natural: 0%; anthropogenic: 0%		
Guilds: all vascular plants: 100%		
Environmental data: altitude: 5%; slope aspect: 1%; slope inclination: 3%		
Performance measure(s): cover: 100%		
Geographic localisation: GPS coordinates (precision 25 m or less): 2%; point coordinates less precise than GPS, up to 1 km: 34%; small grid (not coarser than 10 km): 39%; political units or only on a coarser scale (>10 km): 26%		
Sampling periods: 1960-1969: 0.8%; 1970-1979: 24.8%; 1980-1989: 31.8%; 1990-1999: 22.1%; 2000-2009: 18.6%; 2010-2019: 1.9%		
Information as of 2012-07-19; further details and future updates available from http://www.givd.info/ID/EU-IT-005		

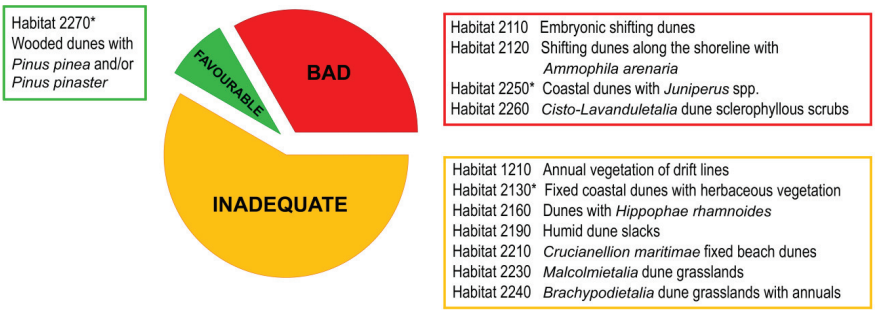

Fig. 1: Conservation state of "Coastal Sand Dunes" and "Inland Dunes" (La Posta et al. 2008). Dune habitats show a high percentage of inadequate (59%) and bad conservation state (33%). Only one habitat show a favourable conservation state. * = priority habitat.

Methods

Data collection

We conducted a detailed research of the Italian phytosociological information by collecting accessible sources regarding Italian coastal dune vegetation, including mainly published literature (Appendix) but also some original data. We considered only plant communities of recent (Holocenic) dunes: fore dune, mobile dune, transition dune, fixed and inland dune. Thus, only phytosociological associations regarding these communities were selected. Specifically, we lead our bibliographical research by consulting all available issues of Italian journals reporting phytosociological relevés from the 1980s (e.g. Annali di Botanica, Informatore Botanico Italiano, Giornale Botanico Italiano, Fitosociologia. See Appendix for the complete list) and screening for vegetation surveys of coastal dunes in Italy. Then we searched for specific bibliography for each habitat through dedicated references reported in two main sources: the Italian Interpretation Manual of the 92/43/EEC Directive habitats (http://vnr.unipg.it/habitat/index.jsp) and the List of Italian Syntaxonomic Literature (LISY) which stores all citations of syntaxa and related bibliographic references published since 1909 for the Italian territory (http://www.scienzadellavegetazione.it/siv/index.jsp). Finally, the search was integrated by directly inquiring many experts on these environments. The database is continuously updated based on information and literature sources made available to us.

After a first analysis of the collected information we identified areas with sandy coasts where no or very few relevés were available and conducted original phytosociological relevés in the spring of 2010 and 2011. In total we realized ca. 50 relevés distributed in the regions Lazio, Campania, Abruzzo, Molise and Puglia (all details in the database).

Database construction and structure

The database was built using the software Turboveg (Hennekens & Schaminée 2001). Although bryophytes and lichens are often abundant on the grey dune habitats in northern Europe (Houston 2008), no data about these species were available in the reference sources. We used as taxonomic reference list the species list of the *Flora d'Italia* (Pignatti 1982), the most commonly used in most of the relevés recorded. Cases of synonymy and taxonomical problems (see Jansen & Dengler 2010) were resolved by relying on Conti et al. (2005), which report an updated list of synonyms with reference to the *Flora d'Italia* (Pignatti 1982).

For each relevé we also registered all metadata available from the reference sources, in particular sampling year, plot size, geographical location and phytosociological association. For the phytosociological associations we reported the original nomenclature of the primary reference sources. Based on the phytosociological classification of vegetation types provided in the reference source, each relevé was assigned to an EU habitat type following the guide-lines of the Italian Interpretation Manual of the 92/43/EEC Directive habitats (Biondi et al. 2009) and the Interpretation Manual of European Union Habitats (European Commission 2007).

The geographical position of each relevé allowed us to infer the spatial distribution of habitats at national level. In this regard, we should note that the description of the local geographical position of relevés varied, according to the reference source, from the exact geographical coordinates measured by Global Positioning System (GPS) to a general toponymic name. We used this information to georeference the relevés in decimal degrees through Google Earth, taking care to also assign an accuracy level. To this end, we proposed a scale of geographic accuracy, ranging from the lowest level of accuracy (if the toponym referred to a coast with a length over 5 km), to a medium level (coast length between 3 and 5 km) and finally to the highest level of accuracy (relevés with GPS coordinates, river outlets and small beaches -less than 3 km-).

The database VegDunes is registered in the Global Index of Vegetation Database (GIVD, http://www.givd.info) with the code EU-IT-005. The GIVD is an on-line archive of metadata on vegetation databases whose primary goal is to facilitate the use of vegetation data through increasing its visibility and availability worldwide (Dengler et al. 2011).

Brief analysis of the information in VegDunes and spatial distribution of relevés and habitats

For comparison with other databases in GIVD, we briefly explored the variation in plot size, level of georeferentiation accuracy and time range of all relevés as of December 2011. We also characterised each EU habitat in terms of the number of relevés available, the plot size range, the most abundant species and the number of different phytosociological associations. To analyse the spatial distribution of Italian coastal EU habitats contained in VegDunes, the information associated with each relevé was transferred into a 10 km x 10 km UTM grid, which is the spatial resolution most commonly used in regional and national analyses (Hassall & Thompson 2010), using a GIS software (ESRI Inc. 2006). Grid squares are commonly used to analyse habitats and species distribution patterns because this simple method is applicable to any amount of data (Bombi et al. 2011). In fact, information on the habitat types and species listed in the Annexes of the Habitats Directive (EEC 1992) has been aggregated at European level and organised on the UTM grid (European Commission 2008). Thus, we first calculated the number of relevés in each 10 km x 10 km UTM grid square. Then, we produced grid distribution maps for each EU coastal dune habitat identified. Finally, with the aim of identifying diversity hotspots, we calculated the total number of EU habitats for each grid square.

Results

VegDunes – Database of Italian coastal dune vegetation

Overall, the coastal dune vegetation database includes 2,666 phytosociological relevés related to the Italian peninsula and islands, 2,618 being from published sources (Appendix) and 48 being original data. The oldest plot in the database is dated 1967, whereas the newest is dated 2011, although most of the data comes from the 1980s till present (75%; Fig. 2). Regarding the geographic accuracy of the database, it is worth noting that most relevés were recorded with a medium and high accuracy (74%) and only 26% had a coarser accuracy.

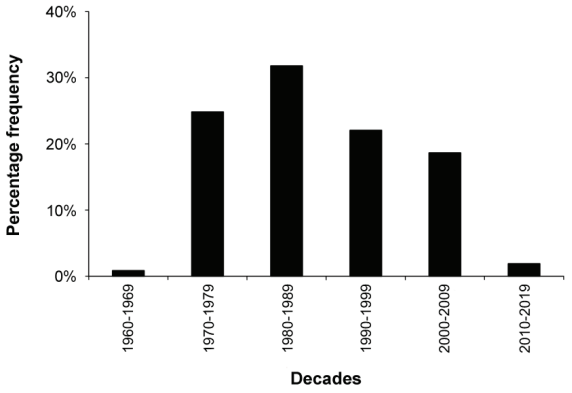

Fig. 2: Proportion of relevés recorded in each decade. We observed that most of relevés have been conducted since the 1980s to the present (75%), so we could affirm that the information in the database is relatively recent.

We noted that geographic accuracy increased slightly from the year 2000 up to the present (probably due to the recent widespread use of precision instruments as the GPS); however, relevés with a high geographic accuracy were available for the whole time range covered by the database. Sampling size varied from 1 to 300 m², but in most cases sampling plots were not larger than 100 m² (70%; Fig. 3). In particular, fore dune herbaceous vegetation (e.g. EU habitat 1210, 2110, 2120) was usually sampled in plots up to 100 m², whereas in fixed dune perennial vegetation (e.g. EU habitat 2250*, 9340) plots could reach up to 300 m². We observed that in recent years relevés have tended to be smaller (they do not exceed 100 m² after 2000).

Coastal dune EU habitats

Coastal dune relevés were distributed in 10 different EU habitats (Tab. 1). In the original sources 90 phytosociological associations have been described, however some of them probably include many synonyms, so the number of associations could be overestimated. Habitats concerning mobile dune and transition dune (EU habitat 2110, 2120, 2210) have the highest number of records, followed by fore dune and fixed dune habitats (EU habitat 1210, 2230, 2250*).

Regarding habitats' spatial distribution, we should note that fore dune, mobile dune and transition dune habitats (EU habitat 1210, 2110, 2120, 2210, 2230) were widespread but scattered along the Italian sandy coasts, while fixed and inland dune habitats (EU habitat 2130*, 2240, 2250*, 2260, 9340) showed a more restricted spatial distribution (Fig. 4). We should evidence that the EU priority habitat 2130* (grey dunes) is quite rare in Italy and localised only in the northern Adriatic Sea, but it is characterised by a relevant number of plant species (Tab. 1). This particular EU habitat corresponds to a Mediterranean sub-type of the more widely distributed "Atlantic 2130 habitat", extending from the Strait of Gibraltar to the North and the Baltic Sea (Houston 2008).

Even though relevés were widely distributed throughout the Italian coasts (Fig. 5a), the total number of habitats was higher in Central Italy (including both Tyrrhenian and Adriatic coasts) and in the major islands, Sicily and Sardinia. Furthermore, we identified some small localised hotspots along the North Adriatic and Ionic Sea (Fig. 5b).

Discussion

First of all, we should emphasize that this is the first attempt to produce an Italian database focused on coastal dune vegetation. A national database for botanical data is currently being assembled (VegItaly, Venanzoni et al. 2012): this is an ambitious project collecting not only vegetation plots, but also information about Italian flora, taxonomy and herbarium records (http://www.anarchive.it/anArchive/index.jsp). VegDunes instead concentrates exclusively on coastal sand dunes habitats, aiming to a detailed characterisation of the vegetation of these threatened environments. At the moment VegDunes already includes almost 3,000 records distributed in a limited number of vegetation types (10 EU habitats) most of them with a consistent number of samples. In particular, we found that those habitats close to the sea-line were much more widespread compared to more inland ones. One possible explanation is that inland dune habitats have been less preserved as they have been often transformed into areas suitable for agriculture activities or urban development. The intensification of human presence in back dune communities has led to the increase of water catchment, pine plantation and tourist activities (Acosta et al. 2000, 2006), with the consequent decrease of more inland coastal dune habitats.

Considering all habitats together, based on the information contained in VegDunes, we can identify areas of high biodiversity, which are likely to be the most important for conservation purposes. Specifically, we highlighted that central Italy and the major islands seem to have the highest concentration of coastal dune habitats. These "hotspots" are possibly related to particularly well-preserved coastal dune vegetation systems (Brullo et al. 2001). The inclusion of such areas in the national reserve network or in conservation programs can be of fundamental importance for the ability of protecting these habitats and all the organisms that they harbour on the long-term.

Several biases typically influence the patterns highlighted by means of large electronic vegetation databases. As these databases are compiled using numerous literature sources, phytosociological relevés are usually unevenly distributed over time and space, and in terms of authorship (Haveman & Janssen 2008). Most common sources of heterogeneity include: geographic positioning accuracy, plot size, sampling effort and the time range covered by all relevés in the database.

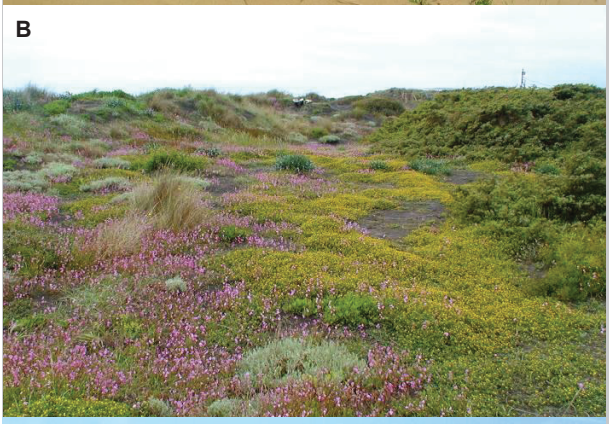

Plate: Vegetation types featured by the vegetation-plot database GIVD EU-IT-005:

A: Shifting dunes along the shoreline with *Ammophila arenaria* (EU habitat 2120) in Punta Aderci (Vasto, Abruzzo).

B: *Malcolmietalia* dune grasslands (EU habitat 2230) in Tarquinia (Rome, Lazio).

C: Coastal dunes with *Juniperus* spp. (EU priority habitat 2250*) at Circeo National Park (Latina, Lazio)

Table 1: Summary of the 10 coastal EU habitats (* = priority habitat) within the database. For each habitat was reported information regarding relevés, most frequent species and phytosociological associations. Species names were updated according to the recent checklist of the Italian Flora (Conti et al. 2005).

Habitat	Relevés		Species		Phytosociological associations	
	Tot n°	*% of Tot.*	*Tot n°*	*Most abundant (frequency > 40%)*	*Tot n°*	*Most frequent*
1210 Annual vegetation of drift lines	376	14.10%	123	*Cakile maritima, Salsola kali, Xanthium orientale*	10	*Salsolo kali-Cakiletum maritimae, Salsolo kali-Euphorbietum peplis, Cakiletum maritimae-Xanthietum italici*
2110 Embryonic shifting dunes	568	21.30%	168	*Elymus farctus, Eryngium maritimum, Echinophora spinosa, Cakile maritima, Medicago marina, Otanthus maritimus, Sporobolus virginicus, Pancratium maritimum*	9	*Elymetum farcti, Echinophoro spinosae-Elymetum farcti, Sporobolo arenarii-Elymetum farcti*
2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)	506	19.00%	241	*Ammophila arenaria, Eryngium maritimum, Echinophora spinosa, Elymus farctus, Euphorbia paralias*	6	*Ammophiletum arundinaceae, Echinophoro spinosae-Ammophiletum arundinaceae*
2130* Fixed coastal dunes with herbaceous vegetation (grey dunes)	21	0.80%	74	*Fumana procumbens, Oenothera biennis, Scabiosa argentea, Teucrium chamaedrys, Teucrium polium, Cyperus kalli, Silene vulgaris, Ammophila littoralis, Koeleria macrantha, Petrorhagia saxifraga, Stachys recta, Helianthemum jonium, Hypochoeris radicata, Tortula ruraliformis, Ambrosia maritima, Calystegia soldanella, Silene otites, Dactylis glomerata, Helichrysum italicum, Sanguisorba minor, Phleum arenarium*	1	*Tortulo-Scabiosetum*
2210 *Crucianellion maritimae* fixed beach dunes	462	17.30%	289	*Crucianella maritima, Pancratium maritimum, Helichrysum italicum, Lotus cytisoides*	19	*Crucianelletum maritimae, Centaureo sphaerocephalae-Ononidetum ramosissimae, Helichryso microphylli-Crucianelletum maritimae, Pycnocomo rutifolii-Crucianelletum maritimae*
2230 *Malcolmietalia* dune grasslands	333	12.50%	361	*Vulpia fasciculata, Lagurus ovatus, Silene colorata, Rumex bucephalophorus, Medicago litoralis*	20	*Vulpio-leopoldietum gussonei, Sileno coloratae-Vulpietum membranaceae, Sileno coloratae-Ononidetum variegatae, Glaucio flavi-Matthioletum tricuspidatae*
2240 *Brachypodietalia* dune grasslands with annuals	23	0.90%	109	*Rumex bucephalophorus, Lotus angustissimus, Coleostephus myconis, Tuberaria guttata*	3	*Euphorbio terracinae-Hyparrhenietum hirtae, Moenchio-Tuberarietum guttati, Psiluro-Crassuletum tillaeae*
2250* Coastal dunes with *Juniperus* spp.	238	8.90%	254	*Juniperus oxycedrus, Pistacia lentiscus, Rubia peregrina, Smilax aspera, Asparagus acutifolius, Phillyrea angustifolia, Juniperus phoenicea*	9	*Asparago acutifolii-Juniperetum macrocarpae, Pistacio lentisci-Juniperetum macrocarpae, Junipero-Quercetum calliprini, Phillyreo angustifoliae-Juniperetum turbinatae*
2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs	100	3.75%	225	*Rubia peregrina, Asparagus acutifolius, Pistacia lentiscus, Cistus salvifolius, Phillyrea latifolia, Sixalix atroporpurea, Smilax aspera*	9	*Phillyreo latifoliae-Ericetum scopariae, Loto-Thymetum capitati*
9340 *Quercus ilex* and *Quercus rotundifolia* forests	39	1.45%	92	*Smilax aspera, Quercus ilex, Pistacia lentiscus, Rubia peregrina, Asparagus acutifolius, Phillyrea angustifolia, Lonicera implexa, Clematis flammula, Arbutus unedo, Hedera helix, Myrtus communis, Phillyrea latifolia, Ruscus aculeatus*	4	*Phillyreo angustifoliae-Ericetum multiflorae, Quercetum ilicis, Pistacio lentisci-Rhamnetum alaterni*

Most relevés in the database are registered with a medium-high geographic accuracy. We show here that relevés with this accuracy level can easily be transferred into a 10 km x 10 km UTM grid. This procedure not only allows a clear presentation of their spatial distribution at national scale but can also contribute to avoid the influence of small position errors of relevés. As far as plot size is concerned, variation in dimensions is well-known in phytosociological surveys (Chytrý & Otýpková 2003). As van der Maarel (1975) pointed out, phytosociological relevés extension depend on the type of sampled vegetation. The largest plots (25–200 m²) are usually used for woodlands, scrubs or for species-poor or very open vegetation types, whereas for herbaceous and grasslands vegetation smaller plots are usually used (5–50 m²) (Westhoff & van der Maarel 1973, Dierschke 1994, Chytrý 2001). The plot size variations in our database reflect this general rule: smaller plots for fore dune and mobile dune and larger ones for woody vegetation on fixed dunes. Regarding sampling effort, results could be influenced by the different phytosociological traditions developed in the different regions, as some areas could have been traditionally more studied than others. Field researchers could also be hindered by time availability and budget (Kueper et al. 2006). In our case, visual inspection of the number of relevés per grid square shows that some squares have received greater sampling effort, but these are quite scattered throughout the peninsula and not concentrated in few specific regions. Besides, these more thoroughly sampled squares overlap only partially with the areas identified as diversity hotspots, suggesting that differences in sampling effort have limited influence on the distribution patterns highlighted. Despite the wide time range of the relevés we observed that most of them have been conducted since the 1980s to the present. Thus, the information is relatively recent and it probably reflects current knowledge concerning the Italian coastal dune vegetation. However, we are conscious that some habitats could have been overestimated in some areas due to a more recent habitat loss while others could have been underestimated.

The application of the phytosociological approach provides advantages and disadvantages, as pointed out by several authors (Botta-Dukák et al. 2007, Chiarucci 2007, Diekmann et al. 2007, Hédl 2007, Lájer 2007, Roleček et al. 2007, Michalcová et al. 2011). Subjective field selection, that characterises phytosociological relevés, is probably the best strategy for capturing diverse sites (local "hotspots") which are usually of a very small extent (Hédl 2007), in particular considering the localised habitats of coastal dunes. In this situation random sampling may miss some vegetation types. An often mentioned drawback of phytosociology is the difficulty (or even the impossibility) of not to under- or oversample some particular vegetation types (Hédl 2007). Moreover, preferential sampling may lead to biased results due to violation of statistical assumptions of randomness and independence of observations (Kershaw & Looney 1985, Chiarucci 2007, Lájer 2007). Therefore, the frequency and distribution of habitat types we report on the basis of the information stored in VegDunes should serve as a general indication rather than a precise account of the current distribution. The use of habitat distribution modelling can potentially help overcome these drawbacks in the future (Bittner et al. 2011).

In conclusion, the information derived from this database gives an excellent account of the diversity of Italian coastal dune habitat types, and thereby serves as an important tool for nature conservation. In particular, this information may be useful for the future management of EU habitats from a conservation perspective. In fact, large vegetation databases could be relevant for the effective implementation of the Natura 2000 Network (Shaminée et al. 2011). Information derived from this database could be overlapped with the Natura 2000 Network with the aim of identifying major gaps. By contrast, the identification of areas with the highest concentration of habitats may constitute the first step to proposing new protected areas in cases where such areas have not yet been demarcated.

Finally, the information contained in VegDune database could be used for several further scopes. For example, it could be combined with information on morpho-functional traits (e.g. SynBioSys Europe; Schaminée et al. 2007) or with abiotic data such as climatic, geomorphological or edaphic strata (Coudun & Gégout 2007) to highlight possible causes of present day distribution patterns. This information would also help to evaluate the response of coastal dune habitats to different global change scenarios (Ozinga et al. 2005) and to estimate future possible range shifts for long-term conservation efforts (Elith & Leathwick 2009, Seo et al. 2009).

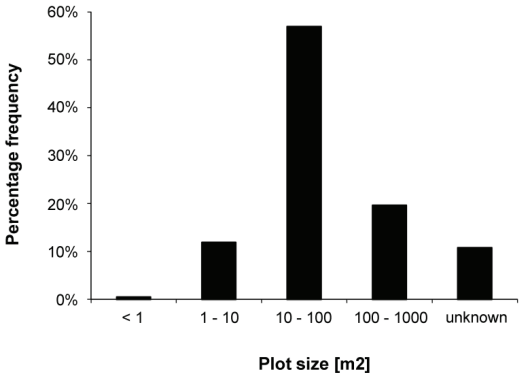

Fig. 3: Plot size distribution of the relevés in the database. In most cases sampling plots were not larger than 100 m² (70%). Larger plots were usually used for back and inland dunes habitats.

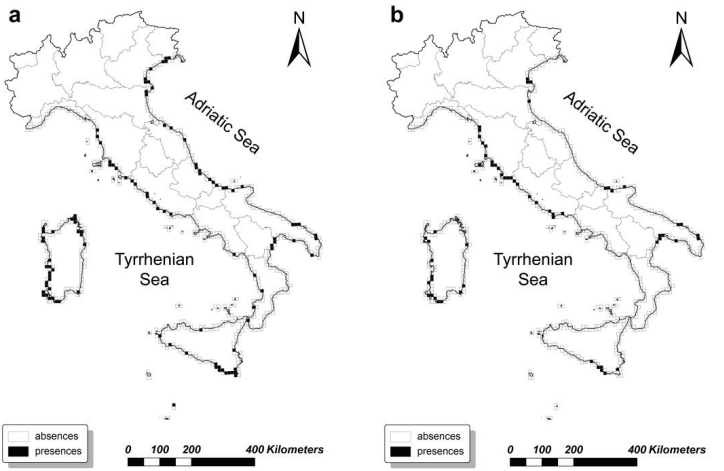

Fig. 4: Comparison between the geographical distribution of (a) a fore dune habitat 2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) and (b) a back dune habitat 2250* Coastal dunes with *Juniperus* spp.. We found that habitats close to the sea-line were much more widespread compared to more inland ones.

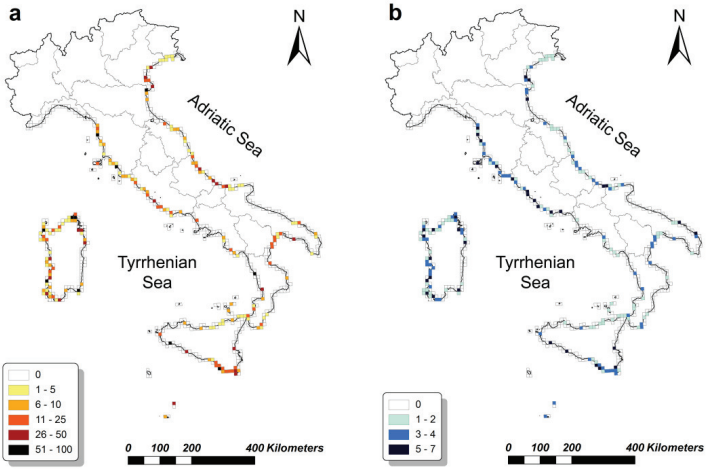

Fig. 5: (a) Total number of relevés and (b) number of EU habitats in each grid square (UTM grid 10 km x 10 km). Although relevés were widely distributed throughout the Italian coasts, we localised areas with high concentration of habitats, particularly in central Italy (including both Tyrrhenian and Adriatic coasts), in the two major islands (Sicily and Sardinia) and along the North Adriatic Sea.

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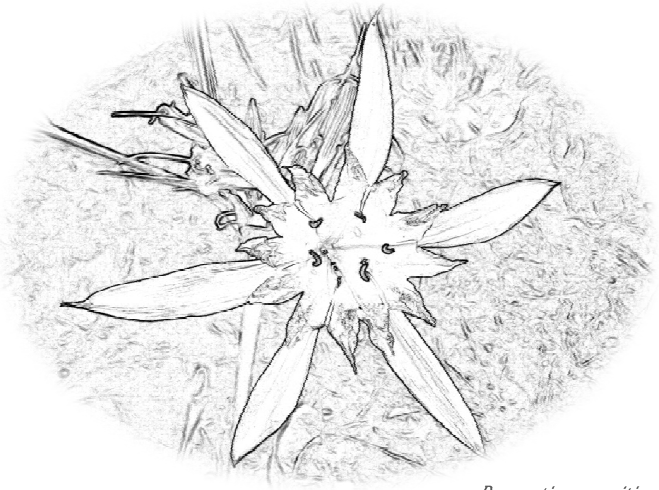
Chapter 2

An overview of the Italian coastal dune EU habitats



Pancratium maritimum

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AN OVERVIEW OF THE ITALIAN COASTAL DUNE EU HABITATS

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Running Head: Italian dune habitats

Abstract – In Europe, as in Italy, there is a long phytosociological tradition and a huge amount of vegetation plots has been performed. Considering the critical conservation status of coastal habitats, highlighted by the second Italian Report about the implementation of Habitats Directive (93/42/CEE), we aim to investigate the state of knowledge on Italian coastal dunes vegetation at national level. We built a national database recording 2666 phytosociological relevés concerning 10 dune habitats, most conducted from 1980 to present day. We conducted an explorative meta-analysis through DCA and we described Italian beach and dune EU habitats, focusing on the floristic and coenological information derived from published studies and from interpretation manuals of Habitats Directive. The DCA reflected the gradual turnover of the vegetation, ranging from upper beach habitats to fixed dune habitats. The most part of habitats are widespread throughout the Italian coasts and are represented by a consistent number of samples. Insular areas are characterized by a high number of species and phytosociological associations, often rare or endemic. However, the most part of EU dunes habitats has a bad or inadequate conservation status. This database could be useful for the monitoring and surveillance of EU habitats and species, as required by Habitats Directive.

Keywords: Coastal dune zonation, psammophilous vegetation, phytosociological relevés, Habitats Directive, dune habitats conservation, national database

Introduction

By occupying transition zones between terrestrial and marine ecosystems, coastal dunes hold one of the most ecologically relevant ecosystems on earth. The influence of the sea leads to a strong sea-inland environmental gradient related to gradual change in intensity of factors such as salt spray, wind intensity, sand burial, etc. (Miller et al., 2010). Consequently, the vegetation features of coastal dune systems are highly shaped by this gradient and plant communities are often arranged along a compressed sea-inland vegetation zonation (Doing, 1985; Feola et al., 2011). This complex arrangement of plant communities is one of the most interesting features of Mediterranean sandy shores and gives rise to high values of biodiversity in terms of habitat richness and species of interest (Brullo et al., 2001; Acosta et al., 2003; van der Maarel, 2003; Biondi, 2007). Many ecological, environmental and economic benefits are associated with well preserved coastal dune systems (Martínez & Psuty, 2004; Barbier et al., 2011). However, at present, dune environments are considered to be threatened worldwide (McLachlan & Brown, 2006). In Europe, it has been estimated about 70% of dune systems loss during last century, and this loss has been mainly related to urbanization and other human pressures (McLachlan & Brown, 2006). Moreover, biodiversity is highly endangered also in those dune systems still well preserved (van der Meulen & Udo de Haes, 1996; Cori, 1999). The loss of biodiversity and ecosystem functions in coastal dune vegetation may have contributed to the increase in biological invasions, to the decline of water quality and to the decrease of coastal protection from flooding and storm events (Braatz et al., 2007; Cochard et al., 2008, Koch et al., 2009). Nowadays, coastal dune conservation and restoration has become a priority for many European countries (Martínez

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& Psuty, 2004). In this sense, the Council Directive 92/43/EEC, also known as "Habitats Directive" (EEC, 1992), constitutes the most important legal instrument for biodiversity conservation at European level (Mücher et al., 2004; Wätzold & Schwerdtner, 2005).
The last Report of European Commission (Article 17 of Habitats Directive) concerning the implementation of the Directive in the period 2001-2006, showed that dune habitats have very bad conservation status throughout Europe (European Commission, 2008). In particular, the Italian Report highlighted the inadequate or bad conservation status of coastal dune habitats in Italy (La Posta et al., 2008). Currently, most of the EU dune habitats require special attention and conservation actions, so further developments in vegetation science should attempt to address these demands.
There is a long tradition of vegetation survey based on the classical phytosociological approach in Europe (Braun-Blanquet, 1928; Westhoff & van der Maarel, 1973). In Italy at least 150.000 phytosociological relevés have been performed according to Schaminée et al. (2009). On these bases, in this paper we investigate the state of knowledge on Italian coastal dunes vegetation at national level. In particular, through a meta-analysis, we describe Italian beach and dune habitats of European interest, focusing on the floristic and coenological information derived from published phytosociological studies.

Material and methods

We conducted a detailed bibliographic research on published studies regarding Italian costal dunes vegetation. In addition, some original data (Prisco et al., unpublished) were included in the dataset. We considered only phytosociological relevés regarding plant communities of Holocenic dunes (beach, fore dunes, mobile dunes, transition dunes, fixed dunes and inland dunes).
A database containing phytosociological relevés performed in the last 44 years was built. We used the software TURBOVEG (Hennekens, 1996) developed for storing, editing and selecting phytosociological relevés in virtually unlimited quantities (Hennekens & Schaminée, 2001). For species nomenclature we followed the "Checklist of the Italian vascular flora" (Conti et al., 2005).
Each relevé was paired with the corresponding EU habitat, following the guide lines of the "Italian Interpretation Manual of the 92/43/EEC Directive Habitats" (Biondi et al., 2009) and the "Interpretation Manual of European Union Habitats" (European Commission, 2007). Information about relevés localization (reported in the published articles) allowed us to infer the geographical position of each relevé. Then, using a GIS software (ESRI Inc., 2006), the relevés were georeferenced in order to depict their spatial pattern at national level and, consequently, the distribution pattern of dune habitats.
With the aim of conduct an explorative meta-analysis, the final matrix was analyzed using the software PC-ORD (McCune & Mefford, 2006) through Detrended Correspondence Analysis (DCA). DCA was chosen because it has been proved to be suitable when floristic gradients are relatively wide, i.e. a high turnover of species occurs (Jongman et al., 1987).
For each EU habitat we presented a brief description with the list of diagnostic species based on the European and Italian interpretation Manuals of the 92/43/EEC Habitats Directive (European Commission, 2007; Biondi et al., 2009). We also included the list of most frequent species in the dataset (frequency > 40%) and the complete list of phytosociological associations reported in the articles. We highlighted those phytosociological associations that are endemic or with a particular distribution pattern. In addition, for each habitat we reported the spatial distribution at national scale and their conservation status based on the last Italian Report on the implementation of the Habitats Directive (La Posta et al., 2008). According to these authors a *favourable* conservation status occurs when habitats can thrive without any change of management and strategies currently in place; an *inadequate* conservation status occurs when habitats require a change of management policies, but they are not at risk of extinction; finally, a *bad* conservation status occurs when habitats are in serious danger of extinction, at least locally (La Posta et al., 2008). Finally, for each habitat we included major threats.

Results

The database included 2.666 phytosociological relevés, 2.219 relevés performed in the Mediterranean region and 447 relevés in the Continental one (Fig. 1). Although the time span of the relevés ranged from 1967 to 2011, most of them were conducted after the 80s.
Relevés were performed in different plant communities distributed in 10 EU habitats (Fig. 2). The highest number of relevés were recorded in "Embryonic shifting dunes" (EU habitat 2110; 568 relevés), "Shifting dunes along the shoreline with *Ammophila arenaria*" (EU habitat 2120; 506 relevés) and "*Crucianellion maritimae* fixed beach dunes" (EU habitat 2210; 462 relevés), whereas the highest diversity of phytosociological associations was found in transition dunes habitats 2230 and 2210 ("*Malcolmietalia* dune grassland" -20 associations- and "*Crucianellion maritimae* fixed beach dunes" -17 associations-). For these last two habitats many endemic or very localized

phytosociological associations have been described, particularly in the major islands (Sardinia and Sicily).

Fig. 1. Geographical distribution of the 2.666 Italian phytosociological relevés. Continental and Mediterranean Bioclimatic Regions are evidenced (sensu Directive 92/43/EEC).Biotopes System codes.

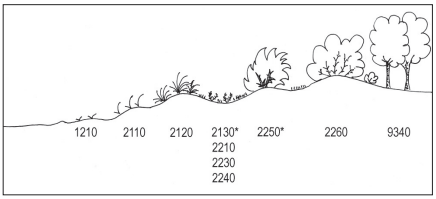

Fig. 2. Scheme of a typical coastal dune zonation evidencing EU habitats: 1210 Annual vegetation of drift lines; 2110 Embryonic shifting dunes; 2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes); 2130* Fixed coastal dunes with herbaceous vegetation; 2210 *Crucianellion maritimae* fixed beach dunes; 2230 *Malcolmietalia* dune grasslands; 2240 *Brachypodietalia* dune grasslands with annuals; 2250* Coastal dunes with *Juniperus* spp.; 2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs; 9340 *Quercus ilex* and *Quercus rotundifolia* forests.

The first DCA axis reflected the gradual turnover of the vegetation, ranging from upper beach habitats to the fixed dune habitats (Fig. 3). This axis could therefore be assumed to synthesize the sea-inland vegetation zonation along the dune profile, with lower scores indicating habitats closer to the beach and higher scores representing more sheltered habitats further from the sea. We can highlight a clear separation between beach, fore dune and transition dune habitats dominated by herbaceous species and back dune habitats with perennial vegetation. The second axis, instead, showed the variability of transition dune habitats.

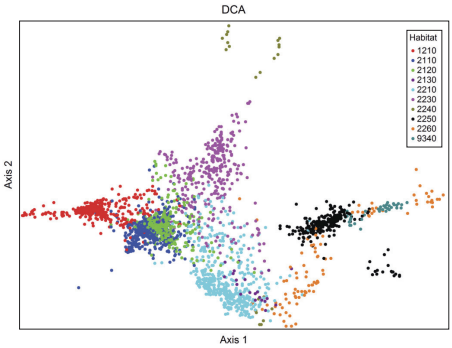

Fig. 3. Detrended Correspondence Analysis of the 2.666 phytosociological relevés. The first axis highlights the sea-inland vegetation zonation from fore dunes to inland dunes, while the second axis shows the variability of transition dune habitats (Total inertia = 70.1150; Axis 1 eigenvalue = 0.9221948385; Axis 2 eigenvalue = 0.7971464396).

Italian coastal dune EU habitats

EU Habitat 1210 Annual vegetation of drift lines

Major features: The habitat includes formations of herbaceous annual plants that start the dune building. It is found on beaches with sand and/or fine gravel near the shoreline, where the organic matter brought by the waves accumulates and decomposes, creating a substrate rich in sea salts and organic matter decomposition. The vegetation cover is generally very low (up to 5% of the total).
Diagnostic species: *Cakile maritima, Salsola kali, Chamaesyce peplis, Matthiola sinuata, Matthiola tricuspidata, Glaucium flavum.*
Most frequent species in the dataset: *Cakile maritima, Salsola kali, Xanthium orientale.*
Phytosociological associations (in order of abundance): *Salsolo kali-Cakiletum maritimae* Costa & Manzanet 1981, *Salsolo kali-Euphorbietum peplis* Pignatti 1952 (only in Sicily), *Atriplicetum hastato-tornabenii* O. Bòlos 1962 (only

in Sicily and Sardinia), *Cakiletum maritimae-Xanthietum italici* Pignatti 1953, *Raphano maritimi-Glaucietum flavi* Biondi, Brugiapaglia, Allegrezza, Ballelli 1989 (only in Marches), *Xanthio italici-Cenchretum incerti* Biondi, Brugiapaglia, Allegrezza, Ballelli 1989 (only in northern Adriatic Sea).

Geographical distribution and conservation status: The 1210 habitat is widespread throughout the Italian coasts (Fig. 4), but its conservation status is inadequate in both Mediterranean and Continental bioclimatic regions. This habitat is highly threatened by coastal erosion and by the mechanical cleaning of the beaches during the summer season.

EU Habitats	N° of relevés: Continental region	N° of relevés: Mediterranean Region	Habitat presence in the Italian Regions
1210 Annual vegetation of drift lines	97	279	
CONSERVATION STATUS	INADEQUATE	INADEQUATE	
2110 Embryonic shifting dunes	107	461	
CONSERVATION STATUS	BAD	BAD	
2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)	124	382	
CONSERVATION STATUS	BAD	BAD	
2130* Fixed coastal dunes with herbaceous vegetation (grey dunes)	21		
CONSERVATION STATUS	INADEQUATE		
2210 *Crucianellion maritimae* fixed beach dunes		462	
CONSERVATION STATUS		INADEQUATE	
2230 *Malcolmietalia* dune grasslands	72	261	
CONSERVATION STATUS	INADEQUATE	UNKNOWN	
2240 *Brachypodietalia* dune grasslands with annuals		23	
CONSERVATION STATUS	INADEQUATE	UNKNOWN	
2250* Coastal dunes with *Juniperus* spp.	19	219	
CONSERVATION STATUS	BAD	INADEQUATE	
2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs	7	93	
CONSERVATION STATUS	BAD	INADEQUATE	
9340 *Quercus ilex* and *Quercus rotundifolia* forests		39	
CONSERVATION STATUS	FAVOURABLE	FAVOURABLE	

Fig. 4. Conservation status of the different coastal dune habitats (according to La Posta et al., 2008). The number of relevés for each habitat is reported for the two bioclimatic regions (Mediterranean and Continental).

EU Habitat 2110 Embryonic shifting dunes

Major features: The habitat is characterized by psammophilous perennial plants (geophytes and hemicryptophytes) that give rise to the formation of the first sandy drift, called "embryo dune". These formations, dominated by *Elymus farctus*, represent the first stages of the plant colonization, that make it possible the spread of many other species, feeding the dune construction process.

Diagnostic species: *Elymus farctus, Sporobolus virginicus, Cyperus capitatus, Otanthus maritimus, Echinophora spinosa, Eryngium maritimum.*

Most frequent species in the dataset: *Elymus farctus, Eryngium maritimum, Echinophora spinosa, Cakile maritima, Medicago marina, Otanthus maritimus, Sporobolus virginicus, Pancratium maritimum.*

Phytosociological associations (in order of abundance): *Elymetum farcti* Br.-Bl. 1933, *Echinophoro spinosae-Elymetum farcti* Géhu 1987, *Sporobolo arenarii-Elymetum farcti* (Br.-Bl. 1933) Géhu, Rivas-Martinez, R. Tx. (1972) 1984, *Sileno corsicae-Elymetum farcti* Bartolo, Brullo, De Marco, Dinelli, Signorello, Spampinato 1992 (Sardinian-Corsican endemism), *Cypero capitati-Elymetum farcti* (Kühnholtz-Lordat 1923) Br.-Bl. 1933 (only in Sicily and Calabria), *Sporoboletum arenarii* (Arènes 1924) Géhu & Biondi 1994, *Inulo crithmoidis- Elymetum farcti* Géhu 1979 (only in Veneto), *Elymo farcti-Spartinetum junceae* Vagge & Biondi 1999 (only in Tuscany), *Pancratietum angustifolii* Brullo & Siracusa 1996 (endemic of the Linosa and Lampedusa islands, Sicily).

Geographical distribution and conservation status: The 2110 habitat is widespread throughout the Italian coasts (Fig. 4), but its conservation status is bad in both Mediterranean and Continental bioclimatic regions. This habitat is often fragmented due to different disturbances, mainly related to tourism and recreational activities.

EU Habitat 2120 Shifting dunes along the shoreline with* Ammophila arenaria *(white dunes)

Major features: The habitat identifies the more stabilized and inner coastal dunes colonized by *Ammophila arenaria*: these are defined as white dunes and they form the seaward cordons of dune systems of the coasts. This habitat represents a semi-permanent stage and the vegetation cover could reach 50-70% of the total.

Diagnostic species: *Ammophila arenaria*, *Echinophora spinosa*, *Anthemis maritima*, *Eryngium maritimum*, *Euphorbia paralias*, *Medicago marina*, *Cyperus capitatus.*

Most frequent species in the dataset: *Ammophila arenaria, Eryngium maritimum, Echinophora spinosa, Elymus farctus,*

Euphorbia paralias.

Phytosociological associations (in order of abundance): *Ammophiletum arenariae* Br.-Bl. (1921) 1933, *Echinophoro spinosae-Ammophiletum arenariae* (Br.-Bl. 1933) Géhu, Rivas-Martinez, R. Tx. 1972, *Medicagini marinae-Ammophiletum arenariae* Br.-Bl. 1921 corr. Prieto & Diaz 1991, *Sileno cosicae-Ammophiletum arenariae* Bartolo, Brullo, De Marco, Dinelli, Signorello, Spampinato 1992 (Sardinian-Corsican endemism).

Geographical distribution and conservation status: The 2120 habitat is widespread throughout the Italian coasts (Fig. 4), but its conservation status is bad in both Mediterranean and Continental bioclimatic regions. This habitat is strongly influenced by human trampling and by the mechanical levelling of sand dunes.

EU Habitat 2130* Fixed coastal dunes with herbaceous vegetation (grey dunes) [* priority Habitat]

Major features: This priority habitat is characterized by inland stable dune formations sheltered from salt winds, coastal erosion and sand burial. Fixed dunes are colonised by more or less closed perennial grasslands (hemicryptophytes and chamaephytes) associated with abundant carpets of lichens and mosses. The habitat is principally found along the Atlantic coasts from the Straits of Gibraltar to the North Sea coasts and the Baltic Sea. However, the sub-type "Ibero-Mediterranean grey dunes" is associated with the Adriatic coasts (Houston, 2008).

Diagnostic species: *Tortula ruraliformis, Cladonia convoluta, Cladonia rangiformis, Silene otites, Phleum arenarium.*

Most frequent species in the dataset: *Fumana procumbens, Oenothera biennis, Lomelosia argentea, Teucrium chamaedrys, Teucrium polium, Cyperus capitatus, Silene vulgaris, Ammophila arenaria, Koeleria cristata, Petrorhagia saxifraga, Stachys recta, Helianthemum jonium, Hypochaeris radicata, Tortula ruraliformis, Ambrosia maritima, Calystegia soldanella, Silene otites, Dactylis glomerata, Helichrysum italicum, Sanguisorba minor, Phleum arenarium.*

Phytosociological associations (in order of abundance): *Tortulo ruralis-Scabiosetum gramuntietum* (Pignatti 1953) Géhu & Biondi 1996 (only in Veneto), *Tortulo ruralis-Scabiosetum albae* Pignatti 1952 (only in Veneto and Emilia-Romagna).

Geographical distribution and conservation status: This priority habitat is distributed only along the North Adriatic Sea, in the Continental bioclimatic region (Fig. 4). Its conservation status is inadequate probably due to land use transformations mainly related to agriculture activities and urban development.

EU Habitat 2210* Crucianellion maritimae *fixed beach dunes

Major features: This habitat (distributed only in the Mediterranean biogeographic region) includes chamaephytic vegetation that develops on the inner slope of sand dunes with a more stable and compact substrate. In general, many phytosociological associations concerning this habitat are often endemic-vicariant: particularly rich in associations related to *Crucianellion maritimae* is Sardinia region.

Diagnostic species: *Crucianella maritima, Pancratium maritimum.*

Most frequent species in the dataset: *Crucianella maritima, Pancratium maritimum, Helichrysum italicum, Lotus cytisoides.*

Phytosociological associations (in order of abundance): *Crucianelletum maritimae* Br.-Bl. 1933, *Centaureo sphaerocephalae-Ononidetum ramosissimae* Br.-Bl. & Frei 1937 (endemic of Sicily), *Helichryso microphylli-Crucianelletum maritimae* Mossa 1992 (endemic of Sardinia), *Helichryso italici-Ephedretum distachyae* Géhu et al. 1987 (endemic of Sardinia), *Armerio pungentis-Scrophularietum ramosissimae* Valsecchi & Bagella 1991 (endemic of Sardinia), *Pycnocomo rutifolii-Crucianelletum maritimae* Géhu, Biondi, Géhu-Franck, Toffetani 1987, *Helichryso microphylli-Armerietum pungentis* Filigheddu & Valsecchi 1992 (endemic of Sardinia), *Artemisio variabilis-Ephedretum distachyae* Brullo, Giusso del Galdo, Siracusa, Spampinato 2001 (endemic of Calabria and Basilicata), *Scrophulario-Crucianelletum maritimae* Géhu & Costa 1984 (endemic of Sardinia), *Scrophulario ramosissimae-Helichrysetum microphylli* Valsecchi & Bagella 1991 (Sardinian-Corsican endemism), *Pycnocomo rutifolii-Seselietum tortuosi* Arrigoni 1990 (endemic of Tuscany), *Seselio maritimi-Helichrysetum microphylli* Brullo, Giusso del Galdo, Siracusa, Spampinato 2001 (endemic of Sardinia), *Astragalo massiliensis-Armerietum pungentis* Filigheddu & Valsecchi 1992 (endemic of Sardinia), *Crucianello-Armerietum pungentis* (Desole 1959) Zevaco 1969 (Sardinian-Corsican endemism), *Thymelaeo tartonrairae-Crucianelletum maritimae* Brullo, Giusso del Galdo, Siracusa, Spampinato 2001 (endemic of Sardinia), *Seselio maritimi-Crucianelletum maritimae* Brullo, Minissale, Siracusa 1998 (endemic of Sicily), *Verbasco phlomoidis-Seselietum maritimi* Brullo, Giusso del Galdo, Siracusa, Spampinato 2001 (endemic of Tyrrhenian coasts of Calabria).

Geographical distribution and conservation status: This habitat is widespread throughout Mediterranean bioclimatic region, however, its conservation status is inadequate (Fig. 4). Anthropic activities have led to important changes in the floristic composition, among them the enhancement in ruderal and exotic species.

EU Habitat 2230 **Malcolmietalia** ***dune grasslands***

Major features: The habitat is characterized by associations with many small annuals species and often abundant ephemeral spring bloom. It is located in the clearings of perennial vegetation and the plant species in these open spaces could reach a high coverage.
Diagnostic species: *Malcolmia ramosissima, Filago asterisciflora.*
Most frequent species in the dataset: *Vulpia fasciculata, Lagurus ovatus, Silene colorata, Rumex bucephalophorus, Medicago littoralis.*
Phytosociological associations (in order of abundance): *Vulpio fasciculatae-Leopoldietum gussonei* Brullo & Marcenò 1974 (endemic of Sicily), *Sileno coloratae-Vulpietum membranaceae* (Pignatti 1953) Géhu & Scoppola 1984, *Sileno coloratae-Ononidetum variegatae* Géhu et al. 1986, *Glaucio flavi-Matthioletum tricuspidatae* Blasi, Fascetti, Veri, Bruno 1983 (only in Campania), *Senecioni leucanthemifolii-Matthioletum tricuspidatae* Géhu & Biondi 1994 (Sardinian-Corsican endemism), *Ambrosio coronopifoliae-Lophochloetum pubescentis* Biondi, Brugiapaglia, Allegrezza, Ballelli 1989, *Onobrychido-Cerastietum gussonei* Brullo & Grillo 1985 (endemic of Sicily), *Loto-Ononidetum serratae* Brullo & Grillo 1985 (only on Linosa island; Sicily), *Scabiosetum rutifoliae* Brullo, Di Martino, Marcenò 1974 (endemic of Sicily), *Sileno nicaeensis-Chamaemeletum mixti* Brullo, De Santis, Furnari, Longhitano, Ronsisvalle 1988 (Sicilian-Sardinian endemism), *Malcolmio ramosissimae-Linarietum sardoe* Bartolo, Brullo, De Marco, Dinelli, Signorello, Spampinato 1992 (endemic of Sardinia), *Sileno nummicae-Malcomietum ramosissimae* Biondi & Bagella 2005 (only in Sardinia), *Maresio-Walenbergietum nutabundae* Brullo & Grillo 1985 (endemic of Aeolian islands, Sicily), *Vulpio fasciculatae-Hormuzakietum aggregatae* Brullo, Guarino, Ronsisvalle 2000 (endemic of Sicily), *Vulpio fasciculatae-Silenetum coloratae* Pignatti 1953 corr. Diez-Garretas & Asensi 2003 (only in Latium), *Anthemido-Centauretum conocephalae* Brullo & Grillo 1985 (Sicilian-Calabrian endemism), *Cutandio-Parapholidetum marginatae* Bartolo, Brullo, Minissale, Spampinato 1988 (endemic of Lampedusa island, Sicily), *Anthemido secundirameae-Desmazerietum siculae* Brullo 1985 (only in Sicily), *Corrigiolo telephifoliae-Corynephoretus articulatae* (Géhu, Biondi, Géhu-Franck, Toffetani 1987) Géhu & Biondi 1994 (Sardinian-Corsican endemism), *Sileno nicaeensis-Cutandietum maritimae* Géhu & Biondi 1994.
Geographical distribution and conservation status: This habitat is widespread throughout the Italian coasts (Fig. 4). Its conservation status is inadequate for the Continental bioclimatic region and it is unknown for the Mediterranean one. Floristic composition is often modified by presence of ruderal species, particularly in trampled areas.

EU Habitat 2240 **Brachypodietalia** ***dune grasslands with annuals***

Major features: This habitat includes dune formations of the habitat 6220 Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*. The vegetation is mostly open, rich in perennial grass species and annual psammophilous species, often in common with the habitat 2230 *Malcolmietalia* dune grasslands. The habitat is localized on the xeric side of the dunes and it develops on calcareous substrates.
Diagnostic species: *Trachynia distachya.*
Most frequent species in the dataset: *Rumex bucephalophorus, Lotus angustissimus, Coleostephus myconis, Tuberaria guttata.*
Phytosociological associations (in order of abundance): *Euphorbio terracinae-Hyparrhenietum hirtae* Brullo & Siracusa 1996, *Moenchio-Tuberarietum guttati* Lucchese & Pignatti 1987, *Psiluro-Crassuletum tillaeae* Lucchese & Pignatti 1990.
Geographical distribution and conservation status: Although relevés in the database include only the Latium region (Fig. 4), the 2240 habitat is distributed along the Italian coasts except in the northern Adriatic Sea (Biondi et al., 2009). The habitat conservation status is inadequate in the Continental bioclimatic region and it is unknown in the Mediterranean one. The habitat is preserved under conditions of moderate grazing and trampling, but changes of land use and overgrazing often led to loss of its ecological value.

EU Habitat 2250* Coastal dunes with **Juniperus** ***spp. [* priority Habitat]***

Major features: The habitat is characterized by shrub formations dominated by juniper (*Juniperus* spp.) localized on the fixed dunes. In the Mediterranean bioclimatic region *Juniperus oxycedrus* and *J. phoenicea* dominate on shrub vegetation; instead, in the Continental bioclimatic region rare formation with *Juniperus communis* are found.
Diagnostic species: *Juniperus oxycedrus, Juniperus phoenicea, Juniperus communis.*
Most frequent species in the dataset: *Juniperus oxycedrus, Pistacia lentiscus, Rubia peregrina, Smilax aspera, Asparagus acutifolius, Phillyrea angustifolia, Juniperus phoenicea.*
Phytosociological associations (in order of abundance): *Asparago acutifolii-Juniperetum macrocarpae* Géhu & Biondi 1994, *Pistacio lentisci-Juniperetum macrocarpae* Caneva, De Marco, Mossa 1981, *Junipero turbinatae-*

Quercetum calliprini Bartolo, Brullo, Marcenò 1982 (Sicilian-Sardinian endemism), *Phillyreo angustifoliae-Juniperetum turbinatae* Arrigoni, Nardi, Raffaelli 1985, *Ephedro fragilis-Juniperetum macrocarpae* Bartolo, Brullo, Marcenò 1982 (only in Sicily), *Junipero communis-Hyppophaetum fluviatilis* Géhu & Scoppola 1984 (only in Veneto), *Juniperetum macrocarpae-phoeniceae* Pedrotti & Cortini Pedrotti 1976, *Helianthemo sessiflori-Juniperetum macrocarpae* Brullo, Giusso del Galdo, Siracusa, Spampinato 2001 (endemic of Apulia), *Phillyreo latifoliae-Juniperetum phoeniceae* Arrigoni, Nardi, Raffaelli 1985 (endemic of Apulia), *Sparto juncei-Juniperetum macrocarpae* Vagge & Biondi 1999 (endemic of Tuscany).

Geographical distribution and conservation status: The geographical distribution of 2250* priority habitat is scattered along the Italian coasts (Fig. 4); its conservation status is bad in Continental bioclimatic region and it is inadequate in the Mediterranean one. Due to urban development in coastal areas, many fixed dunes habitats have been removed in the last 50 years. In particular, during summer these habitats have been subjected to intense recreational activities, as the trampling and the transit of off-road vehicles (Picchi, 2008).

EU Habitat 2260 Cisto-Lavanduletalia *dune sclerophyllous scrubs*

Major features: The habitat occupy the more inland and stabilized sand bars. Sclerophyllous and lauriphyllous scrubs are the dominant vegetation with high cover values. It also includes the replacement garrigues and the degraded stages of the wooded dunes. The habitat is widespread in places where the inland dunes have been well-conserved.

Diagnostic species: *Cistus laurifolius, Cistus monspeliensis, Cistus salvifolius, Erica multiflora, Halimium halimifolium, Rosmarinus officinalis, Cirsium creticum.*

Most frequent species in the dataset: *Rubia peregrina, Asparagus acutifolius, Pistacia lentiscus, Cistus salvifolius, Phillyrea latifolia, Sixalix atroporpurea, Smilax aspera.*

Phytosociological associations (in order of abundance): *Phillyreo latifoliae-Ericetum scopariae* Blasi, Stanisci, Filesi, Milanese, Perinelli, Riggio 2002 (only in Latium), *Loto-Thymetum capitati* Géhu, Biondi, Géhu-Franck, Marchiori 1984 (only in Apulia), *Erico multiflorae-Halimietum halimifolii* Taffetani & Biondi 1989, *Sparto juncei-Phillyretum angustifoliae* Vagge & Biondi 1999 (only in Tuscany), *Helianthemo jonii-Fumanetum thymifoliae* Taffetani & Biondi 1989, *Pistacio lentisci-Haliemietum halimifolii* Arrigoni 1996 (only in Sardinia), *Cisto eriocephali-Rosmarinetum officinalis* Biondi 1999, *Ephedro fragilis-Pistacietum lentisci* Biondi, Brugiapaglia, Farris, Filigheddu, Secchi 2004 (only in Sardinia), *Helichryso stoechadis-Cistetum eriocephali* Biondi 1999 (only in Tuscany).

Geographical distribution and conservation status: This habitat is mainly distributed in Mediterranean region (Fig. 4); its conservation status is bad in Continental bioclimatic region and inadequate in the Mediterranean one. It has often been replaced by artificial pine plantations.

EU Habitat 9340 Quercus ilex *and* Quercus rotundifolia *forests*

Major features: The habitat includes Meso-Mediterranean holm-oak forests where *Quercus ilex* dominates, often mixed with deciduous oaks. These forests could be found in a large variety of ecological and edaphic conditions (rocky, psammophilous or mesophilic) and they are widespread both in coastal and inland Apennine and pre-Alpine areas. The Mediterranean thermophilic oak woods are characterized by a dense tree layer and an undergrowth shrub-dominated evergreen sclerophyllous.

Diagnostic species: *Quercus ilex.*

Most frequent species in the dataset: *Smilax aspera, Quercus ilex, Pistacia lentiscus, Rubia peregrina, Asparagus acutifolius, Phillyrea angustifolia, Lonicera implexa, Clematis flammula, Arbutus unedo, Hedera helix, Myrtus communis, Phillyrea latifolia, Ruscus aculeatus.*

Phytosociological associations (in order of abundance): *Phillyreo angustifoliae-Ericetum multiflorae* Arrigoni, Nardi, Raffaelli 1985, *Asplenio-Quercetum ilicis* Rivas-Martínez 1974, *Viburno tini-Quercetum ilicis* (Br.-Bl. 1936) Rivas-Martínez 1975, *Pistacio lentisci-Rhamnetum alaterni* Bòlos 1970.

Geographical distribution and conservation status: The relevés in the dataset were performed only in Latium and Tuscany (Fig. 4). However, this habitat is widespread in many Italian regions (Biondi et al., 2009). The conservation status is favourable both in the Mediterranean and in the Continental regions. The habitat may be threatened by uncontrolled fires and by deforestation.

Discussion

Along the Italian coasts there is a wide variety of psammophilous plant communities, linked to the variability of bioclimatic and phytogeographic features. Moreover, the insular areas are characterized by high species richness and by endemic and rare associations. In addition, on the northern Adriatic coast there is a high concentration of associations with a restricted geographic distribution mainly

related to the Continental bioclimate (Brullo et al., 2001).
The dataset reasonably reflects the current knowledge of Italian coastal dunes vegetation. However, as the time span of relevés concerns more than 40 years, it is also probable that in some areas the presence of coastal habitats could have been overestimated. In fact, some communities may have disappeared due to a more recent habitat loss. In addition, it is also possible that in other areas habitats were underestimated because of the lack of published phytosociological studies.
The results of the meta-analysis showed that community patterns shift from annual beach communities to shrub-covered fixed dunes, probably associated with changes in the environmental characteristics along the sea-inland gradient. This pattern has already been observed in other coastal European sand dune ecosystems (Olff et al., 1993; Rosenzweig 1995; Sýkora et al., 2004; Isermann 2005; Forey et al. 2008; Acosta et al. 2009). In fact, moving inland, plant communities are progressively less exposed to the extreme conditions of the fore dunes and, gradually, less tolerant to salt spray, winds, and sand burial (Wiedemann & Pickart, 2004; Carboni et al., 2011). The vegetation zonation pointed out here is also coherent with previous studies on Italian sandy coasts at national scale (Géhu et al., 1984; Pignatti, 1993; Biondi, 1999; Brullo et al., 2001).
The boundaries between dune habitats are not sharp-cut as there is a gradual transition from one community to the other, so we can highlight a partial overlap of the dune habitats (Stanisci et al., 2004; Acosta et al., 2003). Nevertheless the perennial woody vegetation of fixed dunes habitats differ substantially from the upper beach, mobile dune and transition dune communities, separated in a well-defined group of relevés. We can also pinpoint a sub-group represented by the north Adriatic juniper association characterized by a particular species assemblage (Gamper et al., 2008).
We have highlighted that Italian coastal dunes and inland dunes are among the most threatened habitats at national level, mainly due to anthropic activities. As it is highly probable that human development and recreational activities along coasts will continue to be intense, an appropriate management of well-preserved dune systems, paired with the restoration of the more damaged ones, are urgently needed. The information derived from this database could be used for the monitoring and surveillance of EU habitats and species, as required by Habitats Directive (EEC, 1992), as well as for the "Natura 2000" ecological network management (Boillot et al., 1997). An adequate implementation of the Habitats Directive will help to guarantee that coastal dunes retain their major features, promoting their conservation for the future generations.

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Chapter 3

The fate of threatened coastal dune habitats in Italy under climate change scenarios

Crucianella maritima

The fate of threatened coastal dune habitats in Italy under climate change scenarios

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Abstract

Coastal dunes worldwide harbor threatened habitats characterized by high diversity in terms of plant communities. In Italy, recent assessments have highlighted the bad or unsuitable state of conservation of these habitats as defined by the EU Habitats Directive. The effects of predicted climate change could have dramatic consequences for coastal environments in the near future. An assessment of the efficacy of protection measures under climate change is thus a priority. Here, we have developed environmental envelope models for the most widespread dune habitats in Italy, following two complementary approaches: an "indirect" plant-species-based one and a simple "direct" one. We analyzed how habitat distribution will be altered under the effects of two climate change scenarios and evaluated if the current Italian protected areas network will be effective in the future after distribution shifts. While modeling dune habitats with the "direct" approach was not satisfactory, "indirect" models had a good predictive performance, highlighting the importance of using species' responses to climate change for modeling these habitats. The results showed that habitats closer to the sea may even increase their geographical distribution in the near future. The transition dune habitat is projected to remain stable, although mobile and fixed dune habitats are projected to lose most of their actual geographical distribution. A relevant proportion of current habitats' distribution is covered by protected areas, but the level of protection for mobile and fixed dune habitats will drop drastically under the examined climate change scenarios. Our results provide a useful indicator for setting management priorities and better addressing conservation efforts to preserve these threatened habitats in the future.

Introduction

Sandy beaches and dunes occur at all latitudes covering ca. 34% of the world's coastlines [1]. Being a narrow strip between marine and terrestrial ecosystems, coastal dunes are critical habitats characterized by high ecological and biological diversity in terms of their animal and plant communities. Plant communities on sand dunes worldwide show particular adaptations and are spatially arranged along the sea-inland environmental gradient resulting in a typical vegetation zonation, ranging from the fore dunes close to the sea, to embryo dunes, mobile dunes, transition dunes, fixed dunes and finally inland dunes [2, 3]. Moreover these habitats provide important ecosystem services to humans [4], such as coastal protection, erosion control, water catchment and purification, maintenance of wildlife, carbon sequestration, tourism, recreation, education and research [5, 6]. More than half of the world's population lives within 60 km of the shoreline [7] and the human pressure on coastal environments has dramatically increased in the last 50 years, especially in the Mediterranean [8]. The rapid increase of a wide range of human activities (urbanization, agriculture, forestry, industry, transport and tourism, etc.) has led to a progressive deterioration and loss of biodiversity, causing fragmentation and dramatic declines in the distribution and quality of dune habitats [9, 10, 11]. Coupled with direct anthropogenic impacts on beaches are the effects of predicted climate change, which could have dramatic, widespread and long-lasting consequences for coastal environments in the near future [12, 13, 14]. Thus, coastal dune management and conservation have become a critical issue, representing a priority for many European countries [15, 16].

Currently the Habitats Directive (92/43/EEC) is the most important legal instrument for biodiversity conservation at European level [17, 18]. It requires each Member State of the European Union to establish a network of special areas for conservation resulting in the Natura 2000 Network sites [19, 20]. In addition to a number of species requiring special protection (Annex II), the Directive also lists the habitats of community interest (Annex I), which should be at the center of national conservation efforts and adequately covered by the Natura 2000 Network. Recent assessments have highlighted the bad or unsuitable conservation state of "Coastal sand dunes and inland dunes" habitats included in this list, these being considered among the most endangered, especially in Italy [21]. Notwithstanding many recent international conservation efforts, many habitats and species of community interest

still fall outside national protected areas. At the national level the situation should be viewed with alarm if the protected areas network designed to preserve biodiversity fails to guarantee an effective maintenance of threatened habitats and/or proved to be ineffective in the near future under predicted climate change [9, 20, 22].

Alterations in climatic and land use conditions can lead to changes in species composition and community structure [23, 24] and wildlife conservation faces new and extreme challenges responding to accelerated dynamics of global change. In recent years, predictive geographical modeling gained importance as a tool for assessing the impact of accelerated climate and other environmental changes (e.g. land use) on the distribution of organisms, so as to address various issues in ecology, biogeography, evolution, conservation biology and climate change research [25, 26]. As current concepts of nature protection are aimed at habitats in their entirety [20], habitats as a whole are attracting more attention as focus of research on global change effects [27, 28, 29, 30, 31, 32, 33, 34]. Although modeling distributions of individual species has been the most popular strategy, species-level models are one of the many approaches to evaluate changes in biodiversity [25, 35, 36, 37]. The choice of modeling (community vs. species) varies depending on the type, quality and quantity of data and on the purpose of the study and the conservation aims [27]. Modeling biodiversity at the community level is not in contrast with the species-level approach; furthermore, it provides a synthesis of the ecological information resulting from a large number of species and it restores the biodiversity value in a collective form [27, 38]. The community-level approach is therefore particularly valuable for directing national level conservation measures in response to European Union directives.

In this study we plan to model the response of coastal sandy dune habitats to climate change over the next 50 years, focusing on the case of Italy, where coastal dunes require particular attention as highlighted by the latest Italian Report to the European Commission concerning the implementation of the Habitats Directive [21]. We take a community-level conservation strategy by adopting two complementary modeling approaches: an “indirect” species-based one and a simple “direct” one. In the “indirect” approach we model individual plant species distributions as function of environmental predictors, and then predict the distribution of the habitat itself based on species occurrences. We compare this “indirect” approach with a straightforward “direct” one, focusing on the habitat as a whole, hereby assuming unified responses

and distribution shifts. This could be a realistic approach for coastal dune habitats characterized by a few dominant/diagnostic species. Then, we use current and predicted distributions of dune habitats for future global change scenarios in a gap analysis with the Italian protected areas network in order to evaluate its effectiveness.

On such a basis, the specific aims of this study are:

1. To develop distribution models for dune habitats in Italy based on *a)* diagnostic species' responses to climate and *b)* following a direct holistic approach. Is direct modeling of habitat distributions a valid alternative to modeling single species distributions followed by habitat identification?
2. To define the current geographical distribution of dune habitats and analyze how their distribution will be altered under the effects of two climate change scenarios. Which habitats of the coastal zonation will be most at risk?
3. To evaluate the current and future efficacy of the Italian protected areas network. Are dune habitats currently adequately protected? As a consequence of distribution shifts due to climate changes, will the current protected areas network also be effective in future? Which habitats will become less protected?

Methods

Habitat distribution models were built for the most representative dune habitats using data from an existing database of coastal dunes vegetation. We modeled habitat and species environmental envelopes using a set of selected variables (climate, morpho-sedimentology and land use). In order to facilitate comparisons with other surveys at European level, we transferred and managed all data (habitat, species, environmental variables) and the geographical outputs of the models into a 10 km x 10 km UTM coastal grid, using a GIS software [39]. This resolution is the most commonly used in regional and national analyses [40]. In fact information on the habitat types and species listed in the Annexes of the Habitats Directive [41] has been aggregated at European level and organized on the same UTM grid [42].

Habitat and species data

We used information on the current distribution of the habitat types from the VegDunes database (EU-IT-005, www.givd.info) [43]. This national database contains phytosociological relevés conducted mostly in the last 30 years throughout Italian Holocenic dune communities, along the whole length of Italian sandy beaches (about 3300 Km) [44]. Each relevé was georeferenced and associated to a habitat type listed in the Annex I of the Habitats Directive [41]. The database covers the whole dune zonation, from beach and fore dune habitats to the inner ones. In this study we focus only on those dune habitats of community interest relevant at national level. These coastal habitats are the most widespread along the Italian coasts and have the highest number of records in the database, for a total of 2'483 relevés considered (90% of the VegDunes database). The habitat types selected include beach (Habitat 1210 Annual vegetation of drift lines, 376 relevés), embryo dune (Habitat 2110 Embryonic shifting dunes, 568 relevés), mobile dune (Habitat 2120 Shifting dunes along the shoreline with *Ammophila arenaria*, 506 relevés), transition dune (Habitat 2230 *Malcolmietalia* dune grasslands, 333 relevés) and fixed dune (Habitat 2210 *Crucianellion maritimae* fixed beach dunes, 462 relevés; priority Habitat 2250* Coastal dunes with *Juniperus* spp., 238 relevés). Endemic and/or highly localized habitats, and thus represented by a low number of relevés, were excluded from the analyses.

For each habitat type we drew up a list of diagnostic species by using the Italian and the European interpretation manual of the Habitats Directive [45, 46]. From the VegDunes database we selected and extracted presence/absence distribution of diagnostic species available with a high number of records (> 40 grid cells) (Fig. 1).

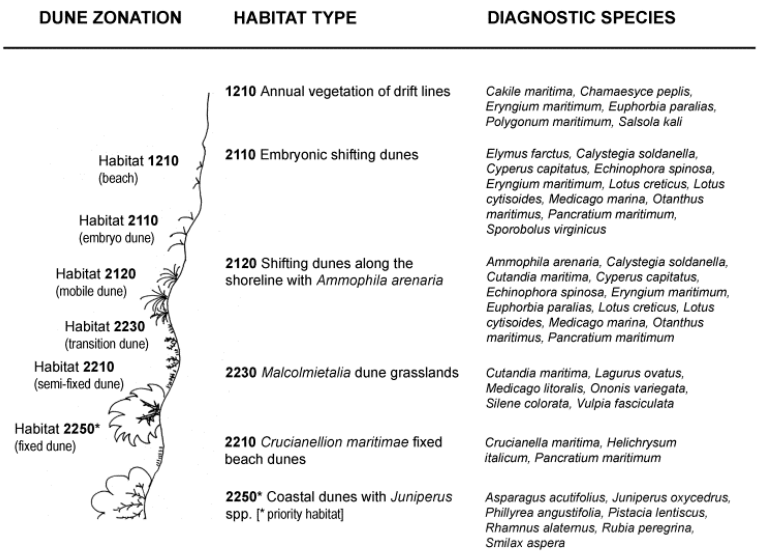

Fig. 1. Habitat types and diagnostic species. List of the habitat types considered with corresponding diagnostic plant species (as defined by Interpretation Manuals of Habitats Directive) used in the "indirect models".

Morpho-sedimentological and land use variables

In each grid square we calculated two variables related to the nature of sandy beaches and their fragmentation, the length of sandy shore and the number of beach fragments, using the Geographical European Coastal Erosion database [47] in a GIS environment. The morpho-sedimentological characteristics of each coastal segment in this database are identified by a specific code and nomenclature. We considered 4 "beach" classes: 1) small beaches (200 to 1000 m long) separated by rocky capes (<200m long), 2) extensive beaches (>1 km long) with strands of coarse sediment (gravel or pebbles), 3) extensive beaches (>1 km long) with strands of fine to coarse sand and 4) coastlines of soft non-cohesive sediments (barriers, spits, tombolos) [47]. In each grid square we obtained the "total length of sandy shore" by adding together the length of the 4 beach classes. The variable "number of beach fragments" was introduced in order to quantify the fragmentation degree of sandy beaches due to the presence of rocky, gravel and muddy beaches, estuaries and artificial shoreline (harbors, dikes, quays).

Finally, we considered in the models the urban area in each grid square as a proxy of human pressure, this as previously observed being the most frequent source of degradation, fragmentation and alteration of the current distribution of dune habitats [48]. We calculated the area of "Artificial surfaces" of the CORINE Land Cover 2000 map (first level, code 1) considering a 2 km buffer from the coastline to the inland. Although coastal habitats do not spread for more than 500 meters inland, the presence of human structures (cities, industrial areas, tourist facilities, etc.) up to 2 km can have direct and indirect effects on coastal habitats and diversity [48].

Climatic data

We used 19 bioclimatic variables that capture annual ranges, seasonality, and limiting factors useful for niche modeling available from WorldClim [49]. The WorldClim data are at ~1 km^2 spatial resolution (30 arc-seconds) and have been averaged over a 50-year time period from 1950 to 2000. In order to simulate the distribution of dune habitats under possible future climate conditions we used the output from the global circulation model HadCM3 (hccpr) being part of the IPCC 4th Assessment (http://www.ccafs-climate.org/). We focused on predictions for the year 2050 to explore changes in an intermediate time range. We used two different emission scenarios, A2 and B2 [32, 50]. The A2 scenario describes a very heterogeneous world, assuming a high population growth with an associated increase in emissions. The B2 scenario describes a world in which the emphasis is on environmental sustainability with a slower population growth and intermediate levels of anthropogenic emissions [51, 52, 53]. Because the WorldClim variables are derived from a common set of temperature and precipitation data, they can exhibit multicollinearity [49]. Hence, the VIF-approach (Variance Inflation Factor) [54] was used to select a subset of variables. We selected only six bioclimatic variables (more related to coastal habitats) that were not significantly inter-correlated (VIF < 10) and all the morpho-sedimentological and land use variables (Tab. 1).

Table 1. Variables used in the models. Type and source of the nine variables used in the modeling design. All the variables were calculated in each UTM coastal grid cell.

Variable name	Variable type	Reference
BIO2 Mean diurnal range (Mean of monthly: max temp-min temp)	Bioclimatic	http://www.worldclim.org
BIO8 Mean temperature of wettest quarter	Bioclimatic	http://www.worldclim.org
BIO9 Mean temperature of driest quarter	Bioclimatic	http://www.worldclim.org
BIO10 Mean temperature of warmest quarter	Bioclimatic	http://www.worldclim.org
BIO16 Precipitation of wettest quarter	Bioclimatic	http://www.worldclim.org
BIO17 Precipitation of driest quarter	Bioclimatic	http://www.worldclim.org
Urban area	Land use	CORINE Land Cover 2000
Length of sandy coast	Morpho-sedimentological	Lenôtre et al., 2004
Number of beach fragment	Morpho-sedimentological	Lenôtre et al., 2004

Modeling design

We compared two complementary modeling approaches: “indirect” and “direct”. In the “indirect” approach we modeled each habitat in terms of its diagnostic species, following the approach outlined in Bittner et al. [32]. First we modeled the climatic envelope for each species and projected the current and the future occurrence probabilities of the species based on their climatic envelopes. Second, for each habitat, we used the predicted occurrences of its diagnostic species as explanatory variables in the models (instead of climatic variables) to predict habitat distribution both in the current projections and in the future scenarios. In the simple “direct” approach we used the current distribution of the habitat itself and modeled its present and future distribution based on the environmental predictors as if it possessed an environmental niche as a single entity. This “direct” approach is generally considered highly simplistic, but in the case of coastal dune habitats it might be a more realistic assumption. In fact, sandy dune communities harbor an extremely specialized flora that includes a small number of species in common with the flora of other terrestrial ecosystems. Furthermore they are often dominated by one or very few characteristic species which usually do not overlap among different habitats [46].

We performed all the projections using eight different and widely used niche-based modeling techniques, within the R-based BIOMOD computational framework [55, 56] that allows combinations of several modeling techniques in an ensemble forecast resulting in a higher predictive power than when simply taking the average of all models, or using the best model [57, 58]. Here we combined the following models:

generalized linear models (GLM) [59], generalized boosting models (GBM) [60], generalized additive models (GAM) [61], multivariate adaptive regression splines (MARS) [62], random forest (RF) [63], artificial neural networks (ANN) [64], classification tree analysis (CTA) [65] and surface range envelope (SRE) [66]. Through a randomization procedure we estimated the importance of each variable for each model [56]. We used a random subset (80%) of the distribution data for fitting the models, and the remainder to evaluate the models. The number of model evaluation runs was set to three. We did not select pseudo-absences, as we are fairly confident that absences in the grid cells at this scale represent true absences for these ecosystems (fairly well studied in Italy). By averaging across evaluation runs and the eight models, the final performance of each model was estimated using TSS (True Skill Statistic). This is a simple method that corrects the overall accuracy of model predictions by the accuracy expected to occur by chance, accounts for commission and omission errors in one parameter and which is affected neither by prevalence (proportion of data representing presences) nor by the size of the validation set [67]. We applied a binary transformation on the projected occurrence probabilities per grid cell (presence/absence) based on the threshold that maximizes model accuracy using TSS. This threshold represents the optimum correct classification of both presences and absences within the evaluation data [67].

In the future projection of the models we kept the morpho-sedimentological and land use variables (length of sandy shore, number of beach fragments and urban area) constant, in order to evaluate the habitat distribution changes due to climate effects only. Our projections therefore represent conservative estimates of habitat distributional shifts.

Gap Analysis

Gap analysis is a method for identifying “gaps” in the conservation areas network based on the actual spatial distribution of habitats and species, in order to address successful management activities [68, 69]. We sought to identify if the considered dune habitats (the most relevant at national level) are sufficiently represented in the Italian conservation areas. Hence we established a “conservation target” defined as minimum number of grid cells where each habitat occurs that must overlap with protected areas. We established the conservation target following the guide-lines by Rodrigues et al. [69], assuming that each habitat should be represented in the protected areas network proportionally to its

distribution range. A sizeable representation target (a large percentage of the range) should be set for habitats with restricted distribution (e.g. 20%, 30%, 50% or 100% for very rare habitats), while for widespread ones the minimum percentage of conservation target (10% of their distribution) should be sufficient to guarantee the overlapping with protected areas. The issues of how much of habitat's distribution needs to be represented in protected areas and the arbitrary levels of conservation targets are still under discussion [70, 71], however we chose approaches for target setting widely used in conservation biology literature [68, 69, 72, 73, 74].

We considered all levels of Italian protected areas (National Parks, Regional Parks, Natural Parks, Natural Reserves, Protected Natural Areas, Natural Monuments, Natural Oasis) [75] and the protected Natura 2000 sites (Sites of Community Importance; Habitats Directive [41] - Special Protection Areas; Birds Directive [76]), obtained from the Italian Institute for Environmental Research and Protection (ISPRA, available at: http://www.pcn.minambiente.it/). We calculated the total protected area in each grid cell, considering a 500 meters buffer as the maximum spread of dune habitats towards inland. We established a threshold of 75% of total protected area within this buffer to consider each grid cell protected or not. Considering this threshold, approximately 20% of the total UTM coastal grid would be protected (similar to the total surface currently protected in Italy which is about 20%). For the habitat with the lowest number of presences in the UTM grid (2250* Coastal dunes with *Juniperus* spp.) we chose the arbitrary level of 30% as the conservation target: at least 30% of its distribution range should overlap with the protected areas network in order to guarantee the habitat's conservation. For the most widespread habitat (2230 *Malcolmietalia* dune grasslands) the conservation target was set at 10%. The intermediate values of conservation target for the other habitats were calculated by a simple linear regression.

Finally, the same approach was adopted to evaluate the future efficacy of the protected areas network, based on the predicted distribution of dune habitats in future scenarios.

Results

Predictive performance was good in the "indirect" models, with TSS values ranging from 0.68 to 0.81 (Tab. 2). By contrast, the evaluation of "direct" models gave TSS values ranging from 0.29 to 0.57, indicating that this is an unreliable approach for coastal dune habitats (see

Supporting Information for details). Hence, we report results only for "indirect" models in the following.

Table 2. Indirect models evaluation. Evaluation by TSS of "indirect models" (species-based) and important variables in the models.

Habitat	TSS mean	TSS min-max	Most important variables
1210 Annual vegetation of drift lines	0.68	0.56-0.84	Length of sandy coast; Mean temperature of warmest quarter
2110 Embryonic shifting dunes	0.72	0.58-0.81	Length of sandy coast; Precipitation of driest quarter
2120 Shifting dunes along the shoreline with *Ammophila arenaria*	0.81	0.62-0.91	Length of sandy coast; Mean temperature of warmest quarter
2210 *Crucianellion maritimae* fixed beach dunes	0.81	0.77-0.87	Length of sandy coast; Precipitation of driest quarter
2230 *Malcolmietalia* dune grasslands	0.68	0.54-0.78	Length of sandy coast
2250* Coastal dunes with *Juniperus* spp. (* priority habitat)	0.80	0.71-0.92	Length of sandy coast; Urban area; Mean diurnal range; Mean temperature of driest quarter

There were no significant differences between the two future scenarios (A2 and B2) that showed pretty much the same percentage of increase/decrease of coastal habitats for the year 2050 (Tab. 3). The predicted future geographical distribution of coastal dune habitats varied depending on the habitat type. The results showed that the habitats closer to the sea (1210, 2110) may increase their geographical distribution in the near future even by more than 40% (Fig. 2). On the contrary, mobile dune and fixed dunes habitats (2120, 2210, 2250*) are projected to lose most of their actual geographical distribution (Fig. 3), while the transition dune habitat 2230 is projected to remain stable (Tab. 3). The length of sandy coast was one of the most important variables in all models, followed by the mean temperature of the warmest quarter and the precipitation of the driest quarter (Tab. 2).

Table 3. Indirect models results. Results of the "indirect models" (species-based) for the year 2050: comparison of percentage changes in dune habitats distribution between the two future scenarios A2 and B2.

Habitat	Predicted changes Fut. A2	Predicted changes Fut. B2
1210 Annual vegetation of drift lines	+44.72%	+43.48%
2110 Embryonic shifting dunes	+48.08%	+40.38%
2120 Shifting dunes along the shoreline with *Ammophila arenaria*	-95.65%	-95.65%
2210 *Crucianellion maritimae* fixed beach dunes	-74.59%	-77.05%
2230 *Malcolmietalia* dune grasslands	+4.49%	+6.18%
2250* Coastal dunes with *Juniperus* spp. (* priority habitat)	-100.00%	-99.03%

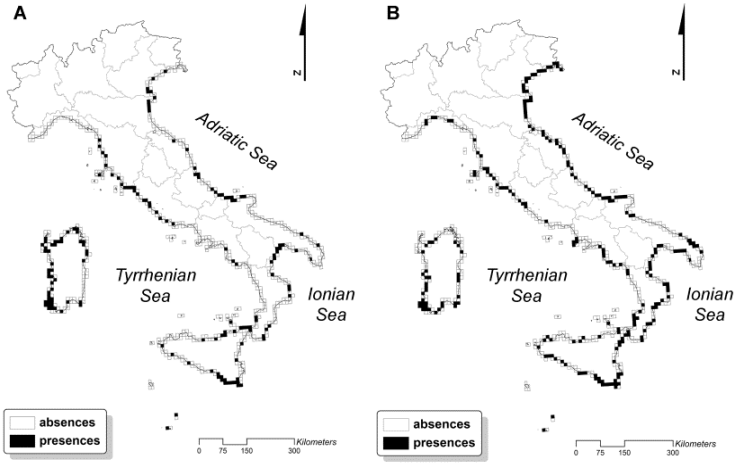

Fig. 2. Current and future distribution of embryo dune habitat. (A) Current and **(B)** future predicted distribution of one of the habitats close to the coast line: the geographic distribution of embryonic shifting dunes (Habitat 2110) is expected to increase in the near future by more than 40%. As the results of the two future scenarios were similar, only the A2 future scenario is shown (details in Tab. 3).

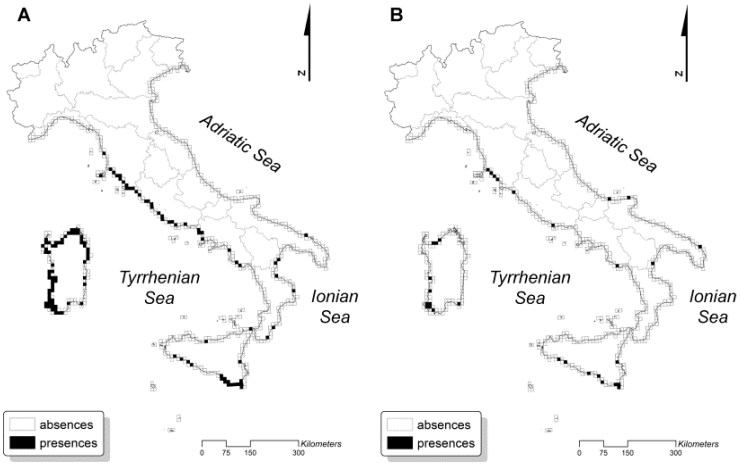

Fig. 3. Current and future distribution of fixed dune habitat. (A) Current and **(B)** future predicted distribution of one of the fixed dune habitats: the *Crucianellion maritimae* fixed beach dunes (Habitat 2210) are predicted to lose more than 70% of its current distribution in the near future. As the results of two future scenarios were similar, only the A2 future scenario is shown (details in Tab. 3).

Gap analysis highlighted a suitable achievement of the conservation target for almost all dune habitats in the present. A relevant proportion of current habitats distribution was covered by protected areas, especially for embryo dunes (2110) and transition dunes (2230) which exceeded almost two-fold the target (Fig. 4). Beach (1210) and mobile dunes (2120), for their part, achieved the conservation target (120% and 133% respectively), while fixed dunes (2210, 2250*) were at the limit of acceptability (101% and 90% respectively). In the two future scenarios we can observe that beach (1210), embryo dune (2110) and transition dune (2230) habitats will still be adequately protected. By contrast the mobile dune (2120) and fixed dune (2210, 2250*) habitats will not reach the conservation target (habitat 2120: 8-12%; habitat 2210: 25-29%; habitat 2250*: 0%), and their level of protection will drop drastically (Fig. 4). For mobile and fixed dune habitats, future predictions forecasted that there will be a large range reduction and that the protected areas network will become ineffective in the future scenario, as shown in Fig. 5.

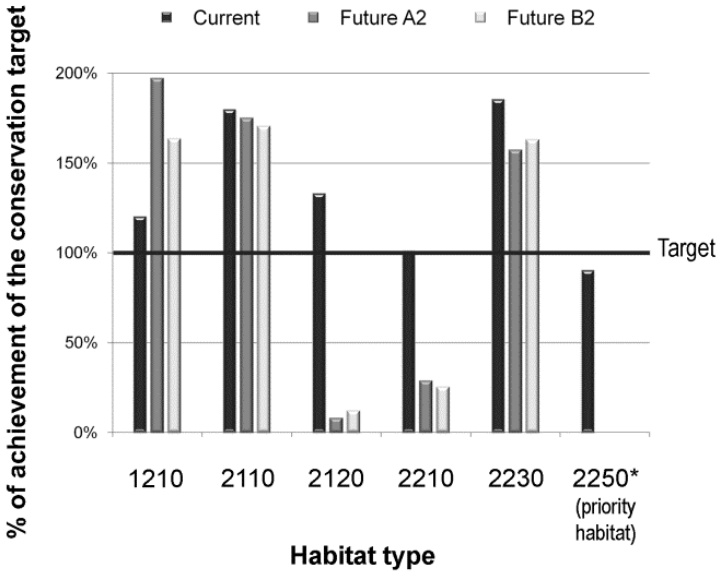

Fig. 4. Gap analysis results. Achievement of the conservation target for the selected dune habitats in the current and in the two future climate change scenarios (A2 and B2).

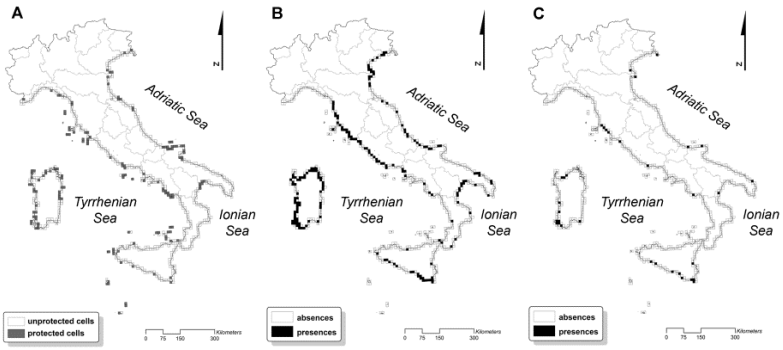

Fig. 5. Efficacy of the current protected areas network. Comparison between protected areas network and distribution of the three most threatened dune habitats (2120, 2210, 2250*). **(A)** Protected UTM grid cells; **(B)** UTM grid cells where at least one of the three threatened dune habitats currently occurs; **(C)** UTM grid cells with the predicted future distribution of the three dune habitats (A2 emission scenario).

Discussion

We built habitat distribution models for Italian coastal dune habitats comparing two approaches, "direct" and "indirect". We aimed to estimate the response of these threatened habitats to climate change in the near future and to evaluate if dune habitats in Italy are sufficiently represented in the Italian conservation areas, both in the present and in the predicted future distribution.

According to results of the "indirect" models, distribution of the coastal dune habitats closer to the sea will likely increase in the near future. The presence of all coastal dune habitats is strongly dependent on the good quality of sandy littorals, as highlighted by the importance of length of sandy shore in all models. This is particularly true for beach and embryo dune habitats, such as the annual vegetation of drift lines (Habitat 1210) and the embryonic shifting dunes (Habitat 2110), all being pioneer habitats well-adapted to the strong environmental conditions close to the sea and representing the first stages of the plant colonization [3]. These annual communities were less sensitive to climate change in our projections, probably because they are primarily dependent on the stability of the sea shore. This is not the case for the more inland coastal dune habitats. The *Malcolmietalia* dune grasslands (Habitat 2230) did not show any substantial change. This transition habitat is characterized by a mosaic of nitrophilous annual species with

ephemeral spring blooming [77], its response to climate change being complex and unpredictable. Mobile dunes and fixed dunes (Habitat 2120, 2210, 2250*), characterized by perennial or semi-perennial plant species and a more complex vegetation structure [77], are projected to lose most of their distribution area in the near future. Their floristic and coenological structure related to local climatic, morphologic and lithologic features make these habitats more sensitive to climate change effects [78, 79, 80].

The current protected areas network is fairly effective in preserving coastal dune habitats; most of them are well represented and meet the conservation target. Only the priority fixed dune habitat 2250* (Coastal dunes with *Juniperus* spp.), in its current distribution, fails to meet such a target, due to its being, at present, less protected than other habitats. It is well-known that over the last 50 years fixed and back dunes have been seriously disturbed by urban development, pine plantation and farming, these all causing coastal juniper woodland regression, especially in the Mediterranean [81, 82, 83]. However, in the two future scenarios distribution range reduction of mobile and fixed dune habitats due to climate change could lead to a decrease in the efficacy of existent protected areas. Valuable areas for conservation have already been identified in a previous study [43], pinpointing the high biodiversity value of dune habitats along the northern Adriatic Sea, the two coasts of central Italy and the two major islands, Sicily and Sardinia. A visual scrutiny of the coastal network of protected areas currently reveals some gaps along the Italian shoreline, especially along the Adriatic and Ionian coasts and in southern Sicily. These areas partially overlap with the major concentration of coastal dune habitats and should become priority sites for reserve system implementation. Recently other surveys have evaluated the efficacy of the Natura 2000 Network and protected areas in Italy, e.g. for the conservation of animal biodiversity [74] and from a landscape perspective [84]. These studies have already partially highlighted the need for expanding the current network of coastal conservation areas. Simple local management interventions have also been shown to be effective in limiting human disturbance and promote vegetation recovery [85] and can be implemented alongside large scale conservation efforts directed at improving the efficacy of the protected areas network at the national level.

Our results showed that “direct” models had a poor predictive performance. There are intrinsic problems associated with applying habitat models to multi-species assemblages [27]. Habitats are a

composition of different plant species that may react differently to changing conditions; their boundaries are not clear cut as there is a gradual transition from one community to another. Shifts or losses of whole habitats are slow events depending on species competition, soil type, dispersal ability, seed production and human impact [32, 86, 87, 88, 89, 90]. Although various authors have obtained valid results by modeling habitats directly [30, 32, 33, 34], in our case modeling dune habitats as single entities proved unsatisfactory. Some coastal dune habitats include a wide number of different phytosociological associations [91]. Different associations may each respond to climatic variation in their own way; in some cases the communities included under one habitat share only a moderate proportion of common species. This may cause excessive noise in the data, blurring the relationships between environmental and habitat distribution and leading to poor predictive performance of the models. For example the predictive performance of the direct model for the transition dune habitat 2230 (*Malcolmietalia* dune grasslands) is particularly low (see Supporting Information), being this habitat usually described in terms of a wide number of phytosociological associations [91]. Finally, another relevant issue is that all modeling approaches are limited by the quantity and quality of data. Being a spatially restricted habitats, coastal dunes cannot be described by a very large amount of data; this makes modeling efforts particularly challenging.

Contrary to the "direct" models, "indirect" models had a good predictive performance, highlighting the importance of using species' responses to climate change for modeling these particular habitats. Nevertheless, "indirect" approaches used to predict responses to climate changes of entire habitats have some strengths but also some weaknesses. Models require more time to be implemented; rare species that occur infrequently in the data may not yield accurate results and therefore contribute little to the subsequent community-level approach. Species and other biotic interactions still need to be improved and integrated into the early stages of the models. On the other hand, this community strategy takes into account the individual responses of each species to the environmental predictors and thus is a more realistic representation of community-level shifts.

While our approach is indeed a useful tool for conservation efforts and rapid biodiversity assessment, a number of caveats should be borne in mind. Firstly, it is worth to highlight that we did not consider the whole climatic niche of the dune species, but only their Italian distribution, as

is often the case in national level studies [92, 93, 94]. As a result the species' responses to climate change could be slightly biased. Secondly, future trends of coastal erosion and urban areas were not included in our analysis since we aimed to evaluate only climate change effects. Human impact on dune habitats depends on the future development of urban planning strategies along the coasts, even though human development and recreational activities along coasts have been on the increase since 1950. It is likely that the effects of climate change coupled with urban sprawl may lead to even worse future scenarios; thus our predicted changes in dune habitats distribution could actually be an underestimate. Furthermore, it is well known that coastal erosion can be caused by local as well as global factors (e.g. rise in sea level due to deglaciation, plate tectonic movements or subsidence effects, etc.) [95]. Although the Mediterranean Sea is among the European low tidal regions with high tectonic activity, the degree of coastal erosion resulting from the rise in sea level is uncertain [96, 97]. However, we should highlight that in recent years several efforts have been put in place to reduce human impact and coastal erosion: among them are shoreline defense and stabilization [98], development of new laws and institutions for managing coastal land, etc. Given the many uncertainties concerning the future effects of human impact and coastal erosion, our own modeling choices and results could offer an appropriate compromise for directing future conservation efforts.

Despite some limitations, our results show a clear and reliable future trend for dune habitats that could be useful for environmental management. A worst case scenario is that, without appropriate management, mobile and fixed dune habitats are expected to disappear as a response to changing climatic conditions alone. Our gap analysis highlights these habitats' vulnerability not only in the future projections, but also, in some cases, in the immediate present. The results of our habitat distribution models and gap analysis are a useful indicator for conservation and management priorities for Italian coastal habitats; as such they could lay the foundations for better addressing conservation efforts to preserve these threatened habitats in future.

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General Conclusions

Silene colorata

The aims of this thesis were to build a national database on coastal dunes vegetation, to describe Italian dune habitats identifying current major biodiversity hotspots and to analyse future distribution of dune habitats under climate change scenarios with a conservation purpose.

Current knowledge on coastal dune vegetation in Italy: VegDunes, the first national coastal database

VegDunes (www.givd.info/ID/EU-IT-005) is the first attempt to produce a national vegetation database focused exclusively on coastal sandy dunes habitats. Currently it contains more than 2.800 phytosociological relevés distributed in 13 habitats, most of them with a consistent number of samples evenly distributed along the Italian coasts. Although relevés were conducted in a wide time range (about 40 years), most of them (75%) were carried out since 1980.

VegDunes data reflect the current knowledge concerning Italian coastal dunes. However, it is likely that some habitats could have been overestimated in some areas due to a more recent habitat loss, while others could have been underestimated. Moreover, some Italian regions appear to have been more sampled than others, probably reflecting the different phytosociological traditions established in different regions, or because some areas have been traditionally more studied than others (Landucci et al. 2012). Most relevés in the database were registered with a medium-high geographic accuracy and their transfer into a 10 km x 10 km UTM grid has avoided small position errors. Although an often mentioned drawback of phytosociology is the difficulty of not to under- or oversample some particular vegetation types (Hédl 2007), the information stored in VegDunes should serve as a general indication rather than a precise account of the current distribution of dune habitats (Chapter 1). Despite the typical biases that affect large electronic databases based on phytosociological data, the information derived from this database gives a good account of the diversity of Italian coastal dune habitat types (Chapter 2).

One of the most interesting results is that habitats close to the sea are more widespread along Italian coasts, both in terms of number of samples and geographical distribution, compared to the more inland ones (Chapter 1). Over the last 50 years inland dune habitats have been less preserved as they were often transformed into agricultural or urban areas, pine plantations and tourism infrastructures (EEA 2006). All these transformations have caused a strong dune regression, and this

phenomenon has been particularly striking in the Mediterranean (Fiorentin 2006, Munoz-Reinoso 2007, Picchi 2008, Acosta et al. 2000, Acosta et al. 2006). Nevertheless, the information collected in the database allow to identify a wide variety of psammophilous plant communities, especially in central Italy and on the two major islands (Chapters 1 and 2). In fact, insular areas are characterised by high species richness and by endemic and rare associations. In addition, an endemic juniper association and the rare EU priority habitat 2130* (Fixed coastal dunes with herbaceous vegetation – Grey dunes) can be found on the northern Adriatic coast. This is a Mediterranean sub-type of the Atlantic dunes localised only in the northern Adriatic Sea and characterised by a relevant number of plant species (Chapter 2).

Further developments of vegetation databases

During the last years this PhD thesis contributed to the development of a unified Italian vegetation database (Appendices C, D). The project VegItaly started in 2010 and was proposed for the first time as a standard approach to collect and manage vegetation data at national scale (Venanzoni and Panfili 2010, Venanzoni et al. 2012; www.vegitaly.it). At present, a large number of data from different vegetation types are comprised in VegItaly, including coastal dune vegetation relevés from the VegDunes database. The working group is bringing together all the small databases scattered across Italy in one large collaborative project. Currently, VegItaly hosts 31.100 vegetation plots, whose large majority derives from published sources (Landucci et al. 2012, Appendix C). Thanks to a proper data standardization and to a user-friendly tool for importing, managing and exporting vegetation plots, VegItaly favours data exchange and integration with other national and European initiatives, such as the EVA project (European Vegetation Archive, Chytrý et al. 2012), for which VegItaly is the founding partner (Gigante et al. 2012, Appendix D). The convergence of such amount of data into a single national database represents an important milestone for Italian vegetation science and it might become one of the most important instruments for large-scale studies in plant ecology.

Italian coastal dunes habitats in the next future

Previous reports have highlighted that Italian coastal dunes are among the most threatened habitats at national level (La Posta et al. 2008) and that the effects of human activities are particularly heavy on inland dunes. Indeed, the distribution of the juniper priority habitat (2250*) is very discontinuous on the coasts of Italy, with large portions of habitat surviving mainly in protected areas (Picchi 2008). One of the major findings of the predictive models developed in this thesis (Chapter 3) is the confirmation of the critical state of inland dune habitats, both at present and for the next future. Habitats characterised by perennial or semi-perennial plant species and with a complex vegetation structure, such as mobile dunes and fixed dunes (Habitat 2120, 2210 and 2250*), come out as the most sensitive to climate change effects compared to the other dune habitats. As a consequence, the reduction of the distribution range related to climate change could lead to a definitive decrease in the efficacy of existent protected areas in the future. On the contrary, beach and embryo dune habitats (1210, 2110) with pioneer species, well-adapted to the strong environmental conditions close to the sea (Feola et al 2011), are predicted to even increase their distribution in the near future. The transition dunes habitat (2230), characterised by a mosaic of nitrophilous annual species with ephemeral spring blooming (Acosta et al. 2003), do not show any substantial change, being its response to climate change complex and unpredictable. In the models, the most important bioclimatic variables are the mean temperature of the warmest quarter and the precipitation of the driest quarter. As the future Mediterranean climate is predicted to become warmer and drier (Alcamo et al. 2007), distribution models developed in this thesis emphasize the vulnerability of mobile and fixed dunes habitats to climate change. On the other hand, the presence of sandy littorals in a good conservation state strongly conditions all coastal dune habitats, as highlighted by the importance of length of sandy shore in the current distribution. It is likely that urban sprawl and increasing coastal erosion will lead to even worse future scenarios, where also pioneer dune habitats would be at risk. Thus, considering only the effects of climate change, our predicted changes in dune habitats distribution are likely to be an underestimate.

Various authors have obtained valid results by modelling habitats directly (Riordan and Rundel 2009, Bittner et al. 2011, Hongjuan et al. 2011, Prober et al. 2012), but in our case such direct models have a poor predictive performance and consequently modelling dune habitats as

single entities has proved to be unsatisfactory (Chapter 3). The more adequate performance of indirect models highlight the importance of using species' responses to climate change for a more realistic representation of community-level shifts. Dune plant communities are characterised by high heterogeneity linked to the sea-inland environmental gradient. Although dune habitats are recognisable in the plant zonation, the boundaries between dune habitats are not sharp-cut as there is a gradual transition from one community to the other, thus single species or associations may each respond to climatic variation in their own way.

Conservation perspectives

In this thesis a high number of coastal dune habitats and valuable areas for conservation have been identified at the national level in Italy (Chapter 1 and 2). However, the coastal network of protected areas reveals some gaps along the Italian shoreline, especially along the Adriatic and Ionian coasts and in southern Sicily, where we propose that the current network of protected areas should be expanded (Chapter 3). In fact, other studies have already suggested the need for increasing the network of coastal conservation areas (Maiorano et al. 2006, D'Amen et al. 2011, Capotorti et al 2012).

Coastal dune ecosystems have undergone consistent transformations including urban expansion, agricultural and reforestation spread, and industrial and harbour development. In addition, they have become a prime site for human recreation, supporting many coastal economies around the world (Schlacher et al. 2008). The Mediterranean high environmental diversity is actually due to the integration of natural ecosystems and traditional human activities (Farina et al. 2003). In this situation, as there is a strong conflict between human activities and the conservation of dune habitats, the conservation actions should be planned in parallel with the preservation of traditional cultural landscape (Maiorano et al. 2006), developing coastal urban planning strategies efficiently integrated with the residential and tourism interests.

Coastal sandy ecosystems are currently pinpointed as highly threatened ecosystems, as well as being prone to biodiversity loss (La Posta et al. 2008, European Commission 2008). Thus, an appropriate management of well-preserved dune systems, paired with the restoration of the more damaged ones, is urgently needed. This thesis has partially highlighted the need for expanding the current network of coastal

conservation areas (Chapter 3). Simple local management interventions have also been shown to be effective in limiting human disturbance and promote vegetation recovery (Appendices E, F) and can be implemented alongside large scale conservation efforts directed at improving the efficacy of the protected areas network at the national level. Although gap analysis does not explicitly account for future threats, nor does it assess the long-term persistence of biodiversity in protected areas, it offers a simple, quantitative, and standardized method that can be incorporated in the assessments of the long-term changes in biodiversity distribution under climate change (Kujala et al. 2011).

The growing concerns over the loss of biodiversity in coastal ecosystems have spurred land managers to seek better ways of managing landscapes at a variety of spatial and temporal scales. Describing possible changes in habitat distribution is crucial for preserving biological diversity and developing strategies of sustainable ecosystem government. In fact, when developing conservation strategies, it is essential to better understand the mechanism by which species and ecosystems can be impacted by climate change. Improvements in ecological modelling must address the reduction of uncertainties and allow a forward-looking conservation planning.

In this thesis I have generated predictions about the vulnerability of coastal ecosystems to future climate changes which can help to design appropriate conservation policies (Chapter 3). From an applied research perspective, the integration of current and predicted habitat distribution patterns enhances the understanding and early detection of transformation patterns on coastal dunes. Such a combination will make it possible to identify the most effective strategies for sustainable management in order to prevent the high economic costs derived from the loss of the coastal dune habitats and the associated ecological services.

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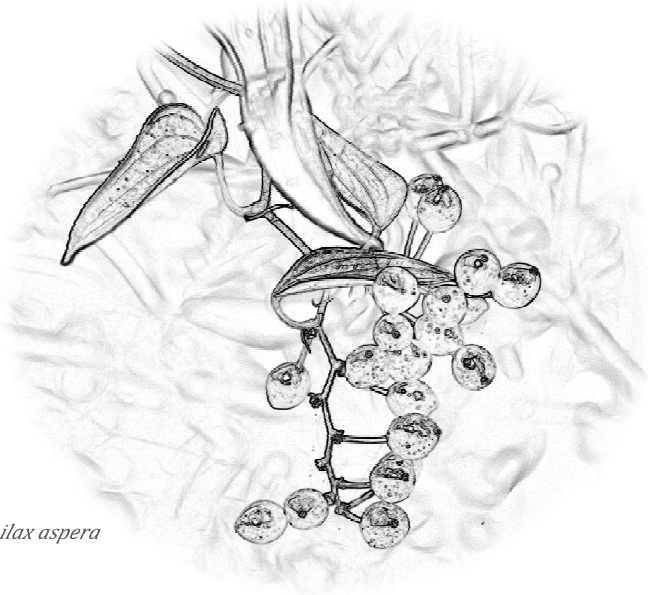

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