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Not just a sandy beach. The multi-service value of Mediterranean coastal dunes.

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Abstract

Coastal sand dunes are complex transitional systems hosting high levels of biodiversity and providing important benefits to society. In this paper we aimed to evaluate the multi-service nature of ecosystem services (ES) supply in the dunes of the Italian Adriatic coast within Natura 2000 (N2K) sites. We i) identified ES indicators and assessed the supply capacity (Climate regulation, Protection from wind and aerosol, Erosion regulation, Recreation and Tourism and Existence value of biodiversity) of natural dune ecosystems of European conservation concern; ii) upscaled this data to create an inventory of ES supply for all dune N2K sites in the study area; iii) explored the trade-offs among ES; and iv) summarized and spatially compared the overall multi-service value of the N2K sites.

The study provides a method for quantifying the role of N2K sites in supplying benefits for our society. We found that the multi-service capacity of coastal dunes is uneven within sites and within administrative regions. This variability is related to both ecological (e.g. distribution, ecological integrity, extent and conservation status of dune habitats) and administrative (e.g. local implementation of the Habitats Directive) characteristics of the analysed area. ES are not coupled as several sites with high values for one ES show very low values for others.

The results suggest that conservation actions should favour restoration of the natural dune zonation, since this underpins multi-service ES supply. The approach can distinguish regions with high ES values and regions where the paucity of protected areas represents a gap in ES supply, fact that offers an incentive to enhance the protection strategy but also suggests an urgent need to improve the N2K network by enlarging existent sites and including new ones.

Keywords:

Adriatic coast; conservation network; Ecosystem services assessment; Ecosystem services mapping; Habitats Directive; coastal dunes

1. Introduction

Coastal dunes are dynamic systems which provide essential benefits to society (Barbier et al., 2011; Everard et al., 2010; Jones et al., 2011; McLachlan and Brown, 2006; MA, 2005). They supply ecosystem services (ES) that can have a clearly recognized market value, such as groundwater stored in dunes (Van Dijk, 1989), or provide benefits such as water purification and coastal defence (French, 2001; Rhymes et al., 2015), which have value in the form of replacement costs. They also provide less tangible cultural services such as opportunities for recreation and tourism (Petrosillo et al., 2007; Doody et al., 2013). Some dune sites are highly visited for tourism, but dunes are also seen as wild spots and are valued as a place of escape and isolation and as a source of mental well-being (Doody, 1997; Houston, 1997; Everard et al., 2010). While these services are well recognised, there are other services provided by coastal dunes which are considered less frequently, such as the capacity to protect from wind and aerosols, and to regulate climate at local and global scales (Barbier et al., 2011; Jones et al., 2008; Drius et al., 2016). In addition, coastal dunes provide unique habitat assemblages due to a strong environmental sea-inland gradient, which supports a highly specialized flora and fauna sharing relatively few species with other terrestrial ecosystems (Acosta et al., 2009; Martínez et al., 2004). The unique dune plant diversity is not only valuable itself (so-called ES "Existence value of biodiversity" e.g. Drius et al., 2016; Stanisci et al., 2014), but it also underpins the other ES provided by dunes, both directly (e.g. Protection from wind and aerosol, Erosion regulation, and Recreation and Tourism; see Liquete et al., 2013; Martínez et al., 2007) and indirectly (e.g. Climate regulation; see Barbier et al., 2011; Drius et al., 2016; Jones et al., 2008).

Despite their high biodiversity value and numerous benefits, coastal sand dunes are among the most threatened habitats both globally (Schlacher et al., 2007; Defeo et al., 2007) and in the Mediterranean (Hesp and Martínez, 2007; Malavasi et al., 2016). Human activities in European littoral areas have been intensifying in the course of the 20th century (Cori, 1999); consequently, sand dunes across Europe had lost on average 25% of their extent by 1998, compared to 1900 (EUCC, 1998), with peaks of 80% area loss in some Mediterranean countries. In Italy, 86.7% of EU coastal habitats currently have an

unsatisfactory (bad or inadequate) conservation status, having suffered a drastic reduction in both extent and ecological quality, mainly due to urban expansion (Genovesi et al., 2014; Falcucci et al., 2007; Carranza et al., 2018; Romano and Zullo, 2014). Therefore, in order to preserve the last intact coastal landscapes from human-driven threats, they were included by the Italian government in an extended ecological network of sites of European importance, called Natura 2000 (N2K, here after), as determined by the Council Directive 92/43/EEC (EEC, 1992; Habitats Directive from now onwards).

N2K is the largest network of protected areas in the world (Sundseth and Creed, 2008; Trochet and Schmeller, 2013; Kati et al., 2014) and given that for each site there is a management plan able to assure the long-term survival of the policy habitats for which it was designated (EEC, 1992), the network should represent an excellent training ground to develop and test methodologies able to evaluate the ecosystem services (ES) of coastal dune ecosystems.

There is an urgent need to highlight the role of N2K sites in providing benefits for our society (Bastian, 2013). Such call is also reflected in the most recent international environmental policy: the European Biodiversity Strategy to 2020 requires Member States to halt the loss of biodiversity and the degradation of ES in the European Union by 2020, and, specifically in the coastal and marine domain, the Marine Strategy Framework Directive (MSFD) emphasizes the maintenance of healthy ecosystems as a prerequisite for providing ES (Directive 2008/56/EC of the European Parliament and of the Council, 2008). In answer to this call, a dedicated Mapping and Assessing Ecosystem Services group (Maes et al., 2013) has been recently set up. The assessment of ES helps bridge the conceptual gap between the natural and social sciences (i.e. between ecosystems and human preferences) by linking the state of ecosystems (i.e. their processes and functions) with human well-being and activities, even (or perhaps especially) when formal markets are incapable of doing so (MA, 2005; TEEB, 2010). This potential of the ES concept is important given that there is a tendency within decision-making to ignore social welfare changes that are not directly quantified through market-based measures, and that humanity's ultimate reliance is on well-functioning ecosystems (Brown et al., 2007; Boyd, 2008; Petrosillo et al., 2007).

Although the identification, quantification and mapping of ES have been recognized as critical component of effective conservation plans for protected areas (Maes et al., 2018), and the methodologies to obtain this information is steadily increasing (Bastian, 2013), a multilevel assessment of ES in a network of coastal dunes protected areas remains poorly explored (Drius et al., 2016). Previous studies have either conducted in-depth analysis of ES at a single site (Ford et al., 2012), or performed assessments of few services across multiple dune sites (Drius et al., 2016). Moreover, although the unique biodiversity of sand dunes has been largely investigated, few studies have explored if and how people perceive this value (Marzetti Dall'Aste Brandolini, 2006).

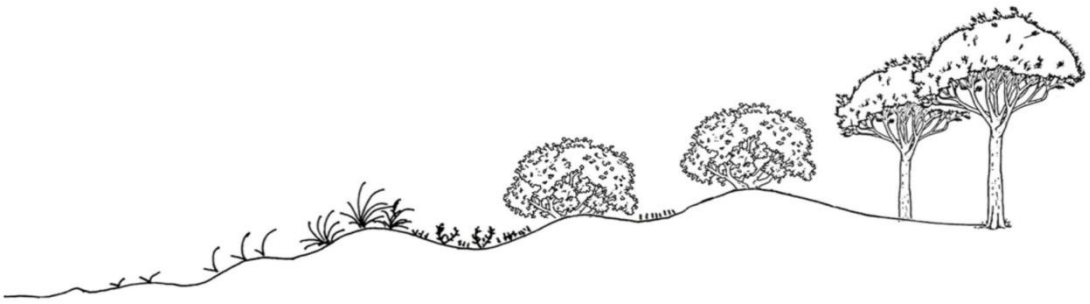
Therefore, in consideration of the above, and in line with the requirements of international environmental policy, the present work provides a method for quantifying the role of a network of protected areas in supplying our society with multiple benefits. Specifically we assess the multi-service value of ES supply of coastal dune habitats in the N2K (EEC, 1992) across the Italian Adriatic coast. First, we identified ES indicators for Climate regulation, Protection from wind and aerosol, Erosion regulation, Recreation and Tourism and Existence value of biodiversity and we assessed the supply capacity of each natural dune habitat of European conservation concern present in N2K sites. By supply, we mean the potential provision of ES, without considering where the beneficiaries are located (Wolff et al., 2015). Second, we up-scaled this data to create an inventory of ES supply for all dune N2K sites in the study area. Third, we explored the trade-offs among ES. Then, we summarized and compared the overall multi-service value of the N2K sites across the Italian Adriatic coast. We assume that the ES supply of the N2K sites is not uniform, but it varies through space according with dune morphology features, conservation status, land use and the specific strategy adopted by each administrative region when implementing the international environmental policy. Lastly, we used the findings to provide guidance to the current environmental protection strategy for coastal dunes in Italy.

2 MATERIALS AND METHODS

2.1. Coastal dune habitat types

In order to assess and map ES we adopted the standard classification scheme of habitat types used in the European Union (EU) Habitats Directive (EEC, 1992; 2013). Mapping dune habitats and in general linear landscapes can be difficult (Malavasi et al., 2018), but previous work has mapped coastal dunes in Italy (Acosta et al., 2005) solving most of the pitfalls raised when mapping the long, narrow strip following the coastline. In this way, standardized and recognizable EU habitats description and spatial data are available for Italian coasts, as well for the whole Europe (Janssen et al., 2016). This data set therefore offers the basis for quantifying and transferring ES values to other sandy coastal ecosystems across European countries hosting the same habitat types (Bastian, 2013; Drius et al., 2016). The EU dune habitat types have been already used in previous studies on ES assessment at landscape scale (e.g. Drius et al., 2016; Carranza et al., 2018).

In the present work we focused on four EU dune habitat types widespread across the Italian coast and representative of the Mediterranean vegetation zonation (Feola et al., 2011). Specifically we analysed Embryonic shifting dunes (EU code: 2110), Shifting dunes along the shoreline with *Ammophila arenaria*, also called white dunes (EU code: 2120), Coastal dunes with *Juniperus* spp. (EU code: 2250), Wooded dunes with *Pinus pinea* and/or *Pinus pinaster* (EU code: 2270) (Figure 1). These habitats are highly related with variations in substrate coherence (Santoro et al., 2011), wind action and environmental stress along the sea-inland gradient (Acosta et al., 2003; Frederiksen et al., 2006; Bazzichetto et al., 2016; Šilc et al., 2018, Figure 1). Two of them (fixed dunes and wooded dunes) are of priority conservation interest at European level and three of them (embryo dunes, mobile dunes and fixed dunes) are currently in poor conservation status in Italy (La Posta et al., 2008) and in Europe (European Commission, 2008), requiring specific conservation actions (Janssen et al., 2016).



Abbreviation	**Embryo dunes**	**Mobile dunes**	**Fixed dunes**	**Wooded dunes**
EU habitat type name	Embryonic shifting dunes	Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')	Coastal dunes with *Juniperus* spp.	Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*
EU habitat code	2110	2120	2250*	2270*
Habitat description	Formation of the first sandy drift with *Elymus farctus*	Seaward and semi-permanent cordons of dune systems dominated by *Ammophila arenaria*	Fixed dunes with pioneer maquis dominated by *Juniperus oxycedrus* subsp. *macrocarpa* and *Juniperus communis*	Backdunes with forest dominated by *Pinus halepensis* , *P. pinea* and *P. pinaster*

Figure 1: A schematic profile (Drius et al., 2016) describing the typical Mediterranean coastal dune vegetation zonation and the analysed EU habitat types (EEC, 1992) along with their codes, brief description and the abbreviations used in this manuscript (EU priority habitats are marked with an asterisk). A description of the habitats is presented in Appendix A.

2.2. Study area

The study was conducted in a wide network of conservation sites of the Italian Adriatic coast. We specifically analysed the coastal dune N2K network distributed across six administrative regions (Friuli-Venezia Giulia, Veneto, Emilia-Romagna, Marche, Abruzzo and Molise; Figure 1) covering ~74,000 ha, (~1% of the administrative regions) and including ~3,000 ha of sand dune habitats of European conservation concern (Appendix B). The distribution of the analysed habitats in the conservation sites is not homogeneous but varies across the different regions. Embryo and mobile dunes are widespread across all the Adriatic N2K network, while wooded dunes tend to be concentrated in the Po Plain (between Veneto and Emilia-Romagna), and are mainly related with pine afforestation established during the 19th century and before WW II for reclamation purposes and to protect crops (Curr et al., 2000; Malavasi et al., 2013; Carranza et al., 2018). Fixed dunes have a scarce distribution, with the most intact areas occurring in Molise (20 ha).

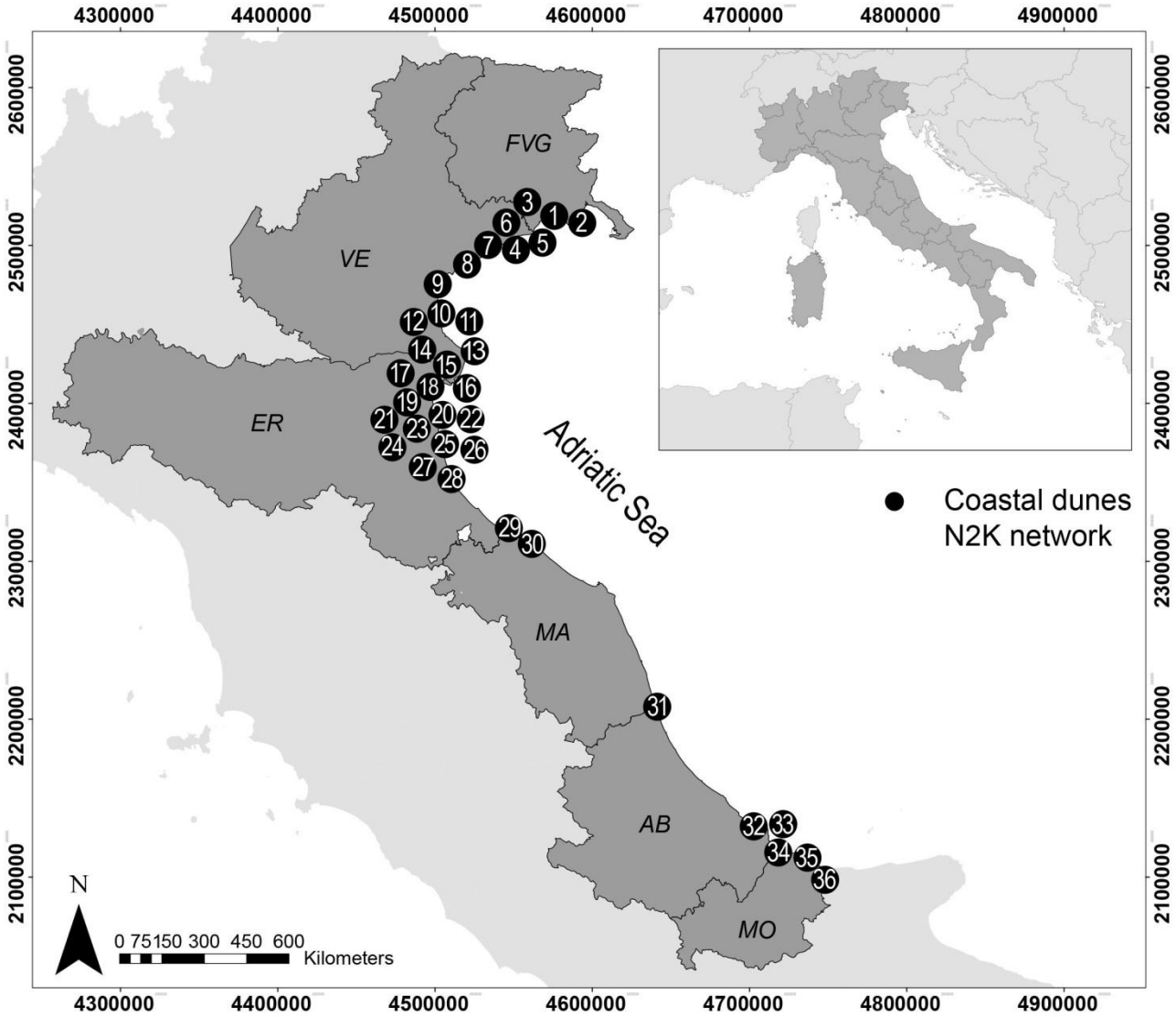


Figure 2. Study area reporting the distribution of the N2K sites along the Italian Adriatic coast (numbered black circles). For a complete name and code of each N2K site see Appendix B. Administrative regions: FVG - Friuli-Venezia Giulia, VE - Veneto, ER – Emilia Romagna, MA - Marche, AB - Abruzzo and MO - Molise. Coordinates are given in Datum: WGS 84, UTM 33N.

2.3. ES and indicators selection

The selection of the most relevant ES provided by Mediterranean coastal dunes was based on an assessment of the literature (e.g. Martínez et al., 2007; Barbier et al., 2011; Everard et al., 2011; Liquete et al., 2013, Beaumont et al., 2014; Stoll et al., 2015). Selection criteria included (i) relevance of the service to the specific type of coastal habitats present in the region, (ii) importance of dunes in providing

that service e.g. as scored in Everard et al. (2011), and (iii) climatic constraints in the Mediterranean region according to the CICES (Common International Classification of Ecosystem Services; Haines-Young et al., 2012) classification (Martínez et al., 2007; Barbier et al., 2011; Everard et al., 2011; Liquete et al., 2013; Beaumont et al., 2014; Stoll et al., 2015). As a result of this process we selected five ES: three regulating (Climate regulation, Wind and aerosol protection, Erosion regulation) and two cultural (Recreation and Tourism, Existence value of biodiversity) ES (Table 1). Then, we identified the ES indicators based on literature research and data availability (Table 1). For the selection of the indicators we followed the demand/supply approach adopted in Wolff et al. (2015). We focused on supply indicators only, since we aimed at highlighting the often neglected functional role coastal dunes play for society, without consideration of the direct beneficiaries. We populated each ES indicator with a combination of various spatial and non-spatial data sources according to the indicator requirements (Table 1). The methodologies used for multi-service value assessment of natural dune habitats and of N2K sites are described in the following paragraphs and schematically represented in Figure 3.

Table 1: Chosen ES selected in this study according to the scheme proposed by Wolff et al. (2015) along with the relative supply indicators, references and proxies.

ES ***Category*** and type	Supply Indicator	Reference	Indicator Proxy
Regulation and maintenance			
Climate regulation	Carbon stock in the soil (kg)	Drius et al., 2016; Jones et al., 2008.	kg of soil carbon stock per habitat and habitats extent
Protection from wind and aerosol	Wooded dunes presence and sea-inland vegetation zonation integrity	Liquete et al., 2013; Avis and Lubke, 1996; Gellini et al., 1983; Martínez et al., 2007.	n. of dune habitats (double score when wooded dunes are present)
Erosion regulation	Fore dune vegetation occurrence and integrity of the sea-inland vegetation zonation	Liquete et al., 2013; Drius et al., 2013; Barbier et al., 2011; Acosta et al., 2003.	n. of dune habitats (double score when embryo, mobile or fixed dunes are present)
Cultural			
Recreation and Tourism	People's perceived benefit towards a set of coastal natural features	Everard et al., 2010; Palombo et al., 2013.	stated preferences per habitat and habitats extent
Existence value of biodiversity	Number of focal species and habitat conservation status	Drius et al., 2016; Stanisci et al., 2014.	number of focal species per habitat and conservation status per habitat

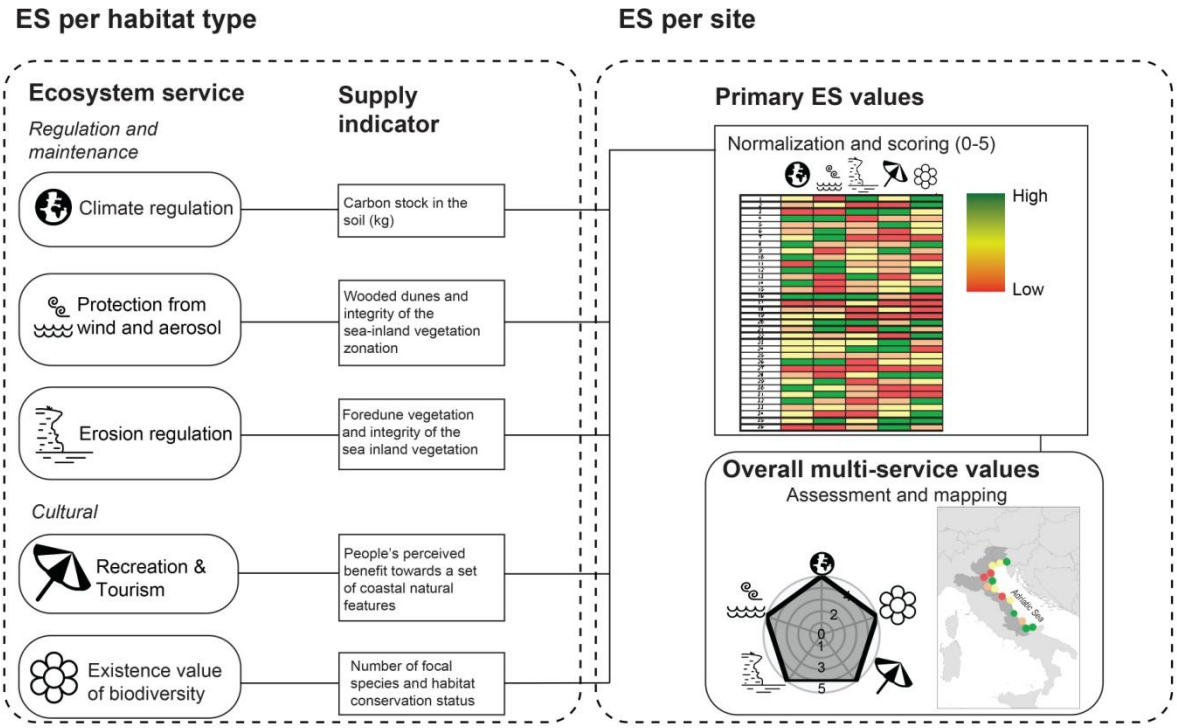


Figure 3: Flowchart synthesizing the proposed procedure for multi-service value assessment of natural dune habitats and of N2K Mediterranean conservation sites. Icons from *thenounproject.com*

2.3.1. Climate regulation

Coastal dunes being early successional ecosystems have high soil carbon accumulation rates (Jones et al., 2008; Olff et al., 1993), and due to their wide distribution they fulfil an important role in regulating greenhouse gas emissions in coastal areas (Everard et al., 2010). Carbon stock values for each EU habitat were derived from a field study aimed at building a pioneer inventory of soil carbon stocks in the Mediterranean dune systems (Drius et al., 2016). The average soil carbon stock per unit area (t ha^{-1}) was computed from carbon content, fresh soil weight, % moisture and the area of core samples (see for details Drius et al., 2016; carbon stock values for each habitat type are reported in Appendix C). To quantify the carbon stock values per N2K site, we multiplied the unitary soil carbon stock values (kg/ha) of dune habitats by their extent (ha) (Carranza et al., 2018) and then we summed them up within each site.

2.3.2. Protection from wind and aerosol

To assess Protection from wind and aerosol for each coastal tract, we focused on the presence of the four main natural dune habitats (those reported in Table 1) because there is evidence that the

occurrence of dune vegetation zonation works as a wind barrier (Liquete et al., 2013). Still, among dune ecosystems, wooded dunes provide greater attenuation or dissipation from wind and aerosol influence than the herbaceous habitats (Avis and Lubke, 1996; EEA, 2006). In fact, wooded dunes for their high level of standing biomass and leaf density represent an efficient filter for sea spray (Bonari et al., 2017). To evaluate the supply of Protection from wind and aerosol a score was assigned to each coastal habitat ("2" to wooded dunes and "1" to the herbaceous habitats). Then, to obtain the ES value at N2K level we summed up the scores according to the habitats occurring in each site. Consequently, the ES supply value (from 0 to 5) per site was computed as follows: 5= the site includes the main four dune habitat types; 4= the site includes three dune habitats and one of them is wooded dunes; 3= the site includes two dune habitats and one of them is wooded dunes, or the site includes three dune habitats, wooded dunes excluded; 2= the site includes two dune habitats and one of them is wooded dunes; 1= the site includes only one dune habitat other than wooded dunes; 0= the site includes no dune habitats.

2.3.3. Erosion regulation

The integrity of dune zonation is important to ensure dune ecosystem functioning (e.g. Drius et al., 2013) and in particular the presence of the embryonic, mobile and fore dunes plays an important role in protecting the inner coastal sectors (Acosta et al., 2003; Bazzichetto et al., 2016; Bini et al., 2002). Actually the vegetation root structure of dune habitats facing the sea provides sediment stabilization and soil retention functions that can control erosion processes (Barbier et al., 2011). On the other hand, along the Adriatic coast wooded dunes with ancient plantations of *Pinus* sp.pl. mainly occur in flat lands and, if embryonic, shifting and pioneer foredune were removed, they alone can offer low protection against coastal erosion caused by swells and storm tides (Bondesan et al., 1995; Rosskopf et al., 2017). Based on these considerations, to assess Erosion regulation supply per N2K site we took into account the presence of the four dune habitats, and in particular the presence of embryo, mobile and fixed dunes. First we assigned a score to each coastal habitat ("2" for the presence of at least one herbaceous habitat

and “1” for wooded dunes and the other dune habitats). Then, we summed up the scores (from 0 to 5) per N2K site according to the habitats occurring in each site, as follows: 5= the site includes the four dune habitat types; 4= the site includes the following three dune habitats: embryonic, mobile and fixed dunes; 3= the site includes at least two dune habitats among embryonic, mobile and fixed dunes; 2= the site includes at least one dune habitat among embryonic, mobile and fixed dunes; 1= the site includes wooded dunes only; 0= the site includes no dune habitats.

2.3.4. Recreation and tourism

To assess the cultural ES Recreation and tourism we considered people’s perception towards natural dune habitats by means of questionnaires distributed to beach users. The survey approach is a consolidated method to assess cultural services such as the recreational value of an ecosystem (e.g. Petrosillo et al., 2007; Hein et al., 2006). Questionnaires were administered to tourists and residents during summer seasons 2014, 2015 and 2017 in N2K sites along the Adriatic coastline. People interviewed once were not interviewed again. Profile questions were used to characterize interviewees’ profiles (gender, age, education level, place of residence and profession). Of the 10 questions (see Rinaldi et al., 2018), one specific question was designed to elicit users’ perception towards the natural features present in coastal sites. Specifically, we asked “How important do you consider the following natural features: Sandy beach, Sand dune vegetation, and Pine forest?” where natural features correspond to embryonic, mobile and wooded dunes respectively. The answers were structured into five categorical alternatives: “not important”, “scarcely important”, “important”, “very important”, “I don’t know”. Fixed dunes were included into wooded dunes, as it would have been difficult for interviewees to distinguish them.

A total of 591 interviews was conducted (see Rinaldi et al., 2018). The profile data showed that the interviewed public was quite heterogeneous with no dominant gender and coming from diverse proveniences (Appendix D). For a complete description of the respondents’ profile see Appendix D.

Based on respondents' perception towards the dune habitats the four possible alternative categorical answers were rated using a four-point Likert scale, from the most negative (score 0, "not important") to the most positive (score 4, "very important"). We considered the answer "I don't know" a missing value. For each habitat we assigned the score based on answer's frequency (mode). The habitats were then ranked from 0 (no ES supply) to 4 (maximum ES supply). More than 55% of the interviewees consider dune habitats very important (70.6%: Embryonic, 57.5%: Mobile, 55.2%: Wooded) (see for details Appendix E). Furthermore, for more than 80% of the interviewees, embryonic, mobile and wooded dune habitats are either important or very important, highlighting that natural coastal dunes provide very high Recreation and Tourism ES. In order to derive an ES value for each N2K site we multiplied the ES scores of each dune habitat derived from the interviews by their extent (ha) and then we summed up the obtained ES values within each site.

2.3.5. Existence value of biodiversity

The assessment of the cultural ES Existence value of biodiversity was based on the number of focal species and on the conservation status of the coastal dune habitat types. Vascular plant species and specifically focal species (diagnostic species, see Santoro et al., 2012a; Stanisci et al., 2014) are good indicators of overall biodiversity and of ecosystem functioning of coastal dune systems (Carboni et al., 2009). Since all the sites are part of the N2K network, the extent and the conservation status of the four selected dune habitats are available from official Natura 2000 Standard data forms (Genovesi et al., 2014; raw data is downloadable from the portal of the Italian Ministry of the Environment ftp://ftp.minambiente.it/PNM/Natura2000/TrasmissioneCE_dicembre2017/). The updated extents were derived from Drius et al. (2016). The conservation status of coastal dune habitats ranged from 3 (excellent conservation status) to 1 (poor conservation status).

The number of focal plant species for each habitat type was extracted from the Italian Interpretation Manual of the 92/43/EEC Directive habitats (Biondi et al., 2010) and restricted to the taxa present along

Italian Adriatic coast (Géhù and Biondi, 1996; Del Vecchio et al., 2016; Prisco et al., 2012; Stanisci et al., 2014). The number of focal species and the conservation status per habitat for each N2K site are reported in Appendix F.

To quantify the biodiversity values per N2K site, we multiplied the number of focal species of dune habitats by their conservation status and then we summed them up within each site.

2.4. Normalisation and scoring of primary ES indicators

One of the requirements for processing multiple indicators, within an ES aggregation framework, is that all are reduced to the same scale, with common units (Nardo et al., 2005). Therefore all primary (i.e. rough) ES indicator scores (Table 2) were normalised and re-scaled to an ordinal rank ranging from 0 (no ES supply) to 5 (maximum ES supply). The final rank is 1: very low, 2: low, 3: medium, 4: high, 5: very high (Figure 3), and 0 <ES< 5 for all the five analysed services. Two normalisation approaches were employed for this aggregation process according with the continuous or discrete nature of the ES indicator. The first is a normalisation with respect to the range of indicator values (that can include the maximum observed ES value), while the second is a normalisation with respect to the ecological functionality of coastal dune zonation (similar to a direct scoring procedure).

The first approach was used to normalize and re-scale the primary ES indicator values collected as continuous variables (i.e. Climate regulation, Recreation and Tourism, and Existence value of biodiversity; Appendix G). In order to maximise signal (Paracchini et al., 2011), in some cases the range within which each indicator value was normalized was restricted based on its distribution on the quintiles of the observed values (Burnaby, 1970; Carranza et al., 1998).

The second approach was used to normalize and re-scale the primary ES indicator values collected as discrete variables (i.e. Protection from wind and aerosol, Erosion regulation). The approach is intrinsic to the allocation criteria used to assign scores with respect to the ecological functionality of coastal dune zonation. The ES limit is intrinsic to the scaling procedure and the indicator is scaled with respect to the

ES limit *a priori*. Values are scaled from 0 (representing the absence of ecosystem functionality) to 5, according to the increasing functionality assured by the integrity of natural dune coastal zonation (Drius et al., 2013). In this approach, the indicator is scaled and scored according to units of equal ES, rather than equal intervals of indicator values. Such normalisation approach has the advantage that the scores are directly interpretable with respect to the ES supply.

2.5. Upscaling and mapping ES supply

After the normalisation and scoring of primary ES values (0 <ES< 5), we synthesized the multilevel ES supply of the N2K sites by means of spider plot analysis. First, for each site we built a spider plot whose axes represent the five ES (Climate regulation, Protection from wind and aerosol, Erosion regulation, Recreation and Tourism, Existence value of biodiversity). Then, we inserted the ranked values of the five ES in the spider plot, we linked them drawing a pentagon and we calculated its inner area (Figure 3, ggplot2 R library). Then, we re-scaled the measured spider plot areas from 0 (all the ES values are at their minimum possible value, i.e. no natural dune habitats, neither ES) to 1 (all the ES values are at their maximum possible value, i.e. 5 for all the analysed services). Then we reported such multilevel ES supply values for the N2K sites in a map (by means of ArcGIS 10.4) and we compared them across the Italian Adriatic coast.

3. RESULTS

3.1. ES supply primary values

ES supply varies across EU habitat types and along the Italian Adriatic N2K network (Table 2, Figure 4), according to the spatial distribution, ecological integrity, extent and conservation status of the coastal dune habitats. Illustrative maps of ES supply primary indicators at habitat level inside the N2K sites are reported in Figure 4.

Concerning Climate regulation, the analysis of dune habitats of the Adriatic coast evidenced good levels of soil carbon accumulation. The distribution of soil carbon stock varies substantially across the N2K sites (see carbon stock values per site and min - max measured values in Table 2), following the extent of wooded dunes. Carbon values are high in the sites where wooded dunes cover wide areas, even when this habitat occurs alone (e.g. Pineta di Classe ~14681.53 t) and are very low in sites with small patches of mobile dune habitats (e.g. Valle Cavanata e Banco Mula di Muggia ~0.640 t).

Protection from wind and aerosol ES supply varies across the N2K network, with several sites showing low values due to deficient levels of dune vegetation zonation integrity combined with the absence of wooded dunes. Such condition is widespread in the Italian Adriatic coast (see Protection from wind and aerosol ES values per site and min -max values in Table 2). In fact, the northern sites included in the Friuli-Venezia Giulia Region (e.g. Valle Cavanata e Banco Mula di Muggia; Laguna di Marano e Grado) and the central ones, like those in the Marche Region, comprise only small areas of embryonic dunes (e.g. Colle San Bartolo e litorale pesarese; Litorale della Baia del Re; Litorale di Porto d'Ascoli). On the other hand, a number of sites scattered along the investigated coastline (Veneto, Emilia Romagna and Molise) revealed high levels of Protection from wind and aerosol ES supply (e.g. Laguna di Caorle Foce Tagliamento; Ortazzo, Ortazzino, Foce del Torrente Bevano; Foce Saccione - Bonifica Ramitelli).

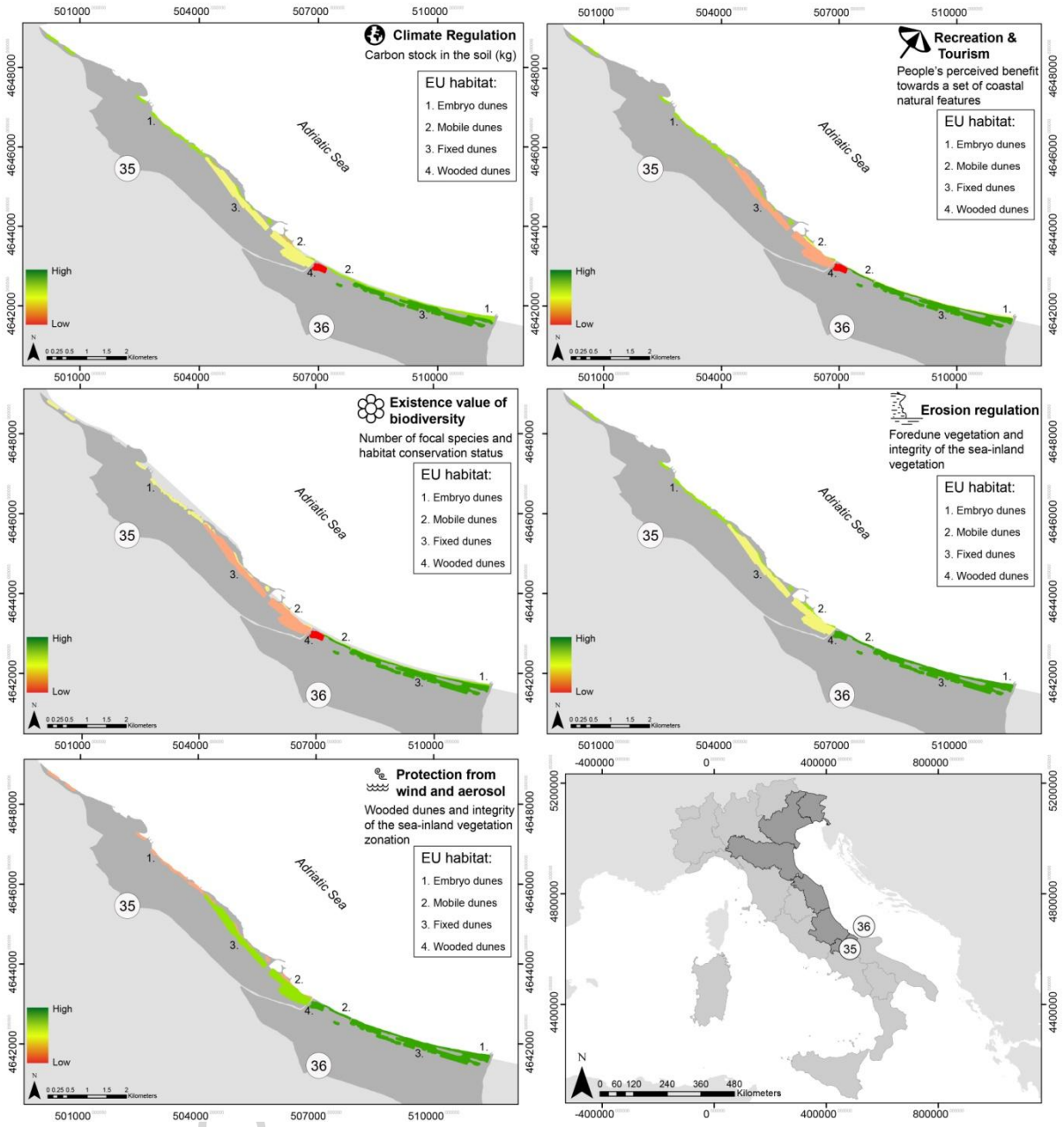


Figure 4: Illustrative maps of ES supply indicators at EU habitat level inside two N2K sites. The location of the sites in the N2K network area is also reported in the bottom right panel. 35: Foce Biferno - Litorale di Campomarino (IT7222216) 36: Foce Saccione - Bonifica Ramitelli (IT7222217). For the description of EU habitats refer to Appendix B. Coordinates are given in Datum: WGS 84, UTM 33N. Icons from *thenounproject.com*

Erosion regulation is not homogeneous across the N2K network, with various sites showing medium values (Table 2) due to intermediate levels of dune landscape integrity and the moderate presence of natural habitats facing the sea. The abundance of sites with medium ES values relates to a widespread

absence of fixed dunes vegetation, which fulfils an important role on stabilizing and consolidating the substrate (e.g. Laguna di Marano e Grado; Dune residue Bacucco; Dune di San Giuseppe; Marina di Vasto). Several sites revealed good levels of Protection from wind and aerosol (Laguna di Caorle foce Tagliamento; Pineta di Cervia; Foce Saccione - Bonifica Ramitelli), while the sites located in the central sectors of the Adriatic coast (Emilia Romagna region) show very low values..

High values of Recreation and Tourism characterize all the analysed dune habitats, but still this ES supply along the Italian Adriatic N2K coastal sites varies spatially (see primary indicator values of ES supply per site and min - max measured values in Table 2). This is due to the extent of the N2K sites. Specifically, protected dunes are large and continuous in the northern and central sectors, whereas they tend to occur in scattered small areas in central and southern ones. For instance, the northern sites “Delta del Po: tratto terminale e delta veneto” (in Veneto) and “Laguna di Marano e Grado” (in Friuli-Venezia Giulia) encompass together more than half of the total network, whereas only one site in the central and southern regions (Marche, Abruzzo and Molise regions) exceeds 1000 ha. We observed the highest value (~1894) on a site with a large extent of dune habitats (Pineta di Classe) and very low vales (~0.5) in a site with low cover of dune habitats (Bardello).

The dune habitat types differed in terms of focal species richness and their conservation status across the N2K sites is not uniform (Table 2). Very-high and high values of Existence value of biodiversity characterize only some sectors of the Adriatic coast (Emilia Romagna and Molise). Observed values in the Adriatic coast N2K network (Table 2) range from 10, observed in a Friulian site comprising only one habitat, whose conservation status is “poor” (Valle Cavanata e Banco Mula di Muggia) to the value 125, observed in sites comprising all the dune habitats, mostly characterized by an excellent conservation status (e.g. Pialasse Baiona, Risega e Pontazzo; Ortazzo, Ortazzino, Foce del Torrente Bevano).

Table 2: List of the coastal dune N2K sites ordered according to a North-South geographical sequence along with the primary indicator values of ES supply. For each site, the official name, the ordinal number (S) and the administrative region (R) are reported. For administrative regions abbreviations and site

distribution across the Adriatic coast refer to Figure 1. Colours represent levels of ES supply primary values ranging from red (low) to green (high). **C stock (t)**: tonnes of carbon stock in the soil. **Wooded dunes**: Coastal dune vegetation zonation weighted by the occurrence of wooded dunes. **Foredune vegetation:** Coastal dune vegetation zonation weighted by the presence of sparse psammophilous vegetation. **Perceived benefit**: people's perceived benefit towards coastal natural habitats weighted by habitat extent. **Focal species**: Number of focal species weighted by habitat conservation status.

		ES supply	*Climate regulation*	*Protection from wind and aerosol*	*Erosion regulation*	*Recreation and Tourism*	*Existence value of biodiversity*
			C stock (t)	**Wooded dunes**	**Foredune vegetation**	**Perceived benefit**	**Focal species**
S	**R**	**Natura 2000 site name**					
1	FVG	Laguna di Marano e Grado	288.06	2	3	373.04	20
2	FVG	Valle Cavanata e Banco Mula di Muggia	0.64	1	2	0.84	10
3	FVG	Pineta di Lignano	1582.27	3	2	198.4	39
4	VE	Laguna di Caorle foce Tagliamento	4664.04	5	5	651.8	59
5	VE	Foce Tagliamento	2205.1	4	3	303.72	59
6	VE	Valle Vecchia Zumelle Bibione	2503.84	5	5	372.44	59
7	VE	Laguna del Mort e Pinete di Eraclea	939.71	3	2	133.36	59
8	VE	Penisola del Cavallino: biotopi litoranei	1058.06	5	5	163.28	46
9	VE	Lido di Venezia: biotopi litoranei	1635.28	5	5	318.32	46
10	VE	Dune residue Bacucco	14.79	2	3	19.28	30
11	VE	Bosco Nordio	520.15	3	2	67	52
12	VE	Dune di Donada e Contarina	807.65	2	1	104.24	13
13	VE	Delta del Po: tratto terminale e delta veneto	4597.47	5	5	907.56	59
14	VE	Dune fossili Ariano Polesine	8.52	2	1	1.12	13
15	ER	Bosco della Mesola, Bosco Panfilia, Bosco di Santa Giustina, Valle Falce, La Goara	1411.69	2	1	182.2	39
16	ER	Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano	618.44	4	3	229.8	26
17	ER	Valle Bertuzzi, Valle Porticino-Cannevié	114.36	2	1	14.76	86
18	ER	Bosco di Volano	2523.82	4	3	342.44	66
19	ER	Dune di San Giuseppe	1.57	2	3	2.04	40
20	ER	Vene di Bellocchio, Sacca di Bellocchio, Foce del Fiume Reno, Pineta di Bellocchio	5415.03	4	3	862.96	40
21	ER	Bardello	2.79	2	1	0.36	26
22	ER	Pineta di Casalborsetti, Pineta Staggioni, Duna di Porto Corsini	5499.96	4	3	731.32	92
23	ER	Pialasse Baiona, Risega e Pontazzo	300.62	2	1	38.8	125
24	ER	Pineta di San Vitale, Bassa del Pirottolo	11807.64	2	1	1523.96	99

25	ER	Pialassa dei Piomboni, Pineta di Punta Marina	3670.74	4	3	488.92	66
26	ER	Ortazzo, Ortazzino, Foce del Torrente Bevano	6203.66	5	5	909.52	125
27	ER	Pineta di Classe	14681.53	2	1	1894.88	39
28	ER	Pineta di Cervia	3191.52	5	5	413.12	65
29	MA	Colle San Bartolo e litorale pesarese	20.25	2	3	25.8	52
30	MA	Litorale della Baia del Re	19.34	2	3	24.64	30
31	MA	Litorale di Porto d'Ascoli	21.25	2	2	27.04	10
32	AB	Punta Aderci - Punta della Penna	9.24	2	3	11.96	40
33	AB	Marina di Vasto	75.72	4	3	25.44	53
34	MO	Foce Trigno - Marina di Petacciato	1561.58	4	3	287.16	86
35	MO	Foce Biferno - Litorale di Campomarino	1386.1	4	3	214.6	56
36	MO	Foce Saccione - Bonifica Ramitelli	241.88	5	5	83.48	112
		max	14681.53	5	5	1894.88	125
		min	0.64	1	1	0.36	10

3.2. Multi-service ES supply maps

The multi-service capacity of coastal dunes along the N2K Adriatic coast expressed by the spider diagrams is uneven within sites and within administrative regions (Figure 5). Only Veneto and Emilia-Romagna comprise sites, in which the overall value of the ES offered by natural coastal dune habitats is very high (e.g. Laguna di Caorle foce Tagliamento-VE; Ortazzo, Ortazzino, Foce del Torrente Bevano-ER). However, sites characterized by well preserved and extensive dune habitats are not very common and ES are not necessarily coupled. Actually, several sites with medium overall ES supply excel on a few ES and have very low values on others (e.g. Pineta di San Vitale; Bassa del Pirottolo; Pineta di lasse; Foce Trigno - Marina di Petacciato). Sites with very low values of ES are distributed across the entire analysed coastline. In these sites dune habitats are scarcely distributed and in poor conservation status (e.g. Dune fossili Ariano Polesine; Bardello; Litorale della Baia del Re).

The multilevel ES supply also varies across administrative regions, with higher values observed in Emilia Romagna and Veneto, which include a vast extent of protected natural dunes (~19000 ha and ~780 ha, respectively) distributed in several sites (14 and 11, respectively) and thus assure a great amount of benefits for human wellbeing. On the other hand, the coastal dune N2K network of Marche and Abruzzo includes few sites (3 and 2, respectively) with very small patches of natural dune ecosystems (~19 ha and

~383 ha, respectively). It is interesting to note that Molise, despite its small extent, includes a N2K network covering approximately two thirds of its coastline and it comprises large patches of natural dunes (~2600 ha), thus offering substantial multi-service ES supply.

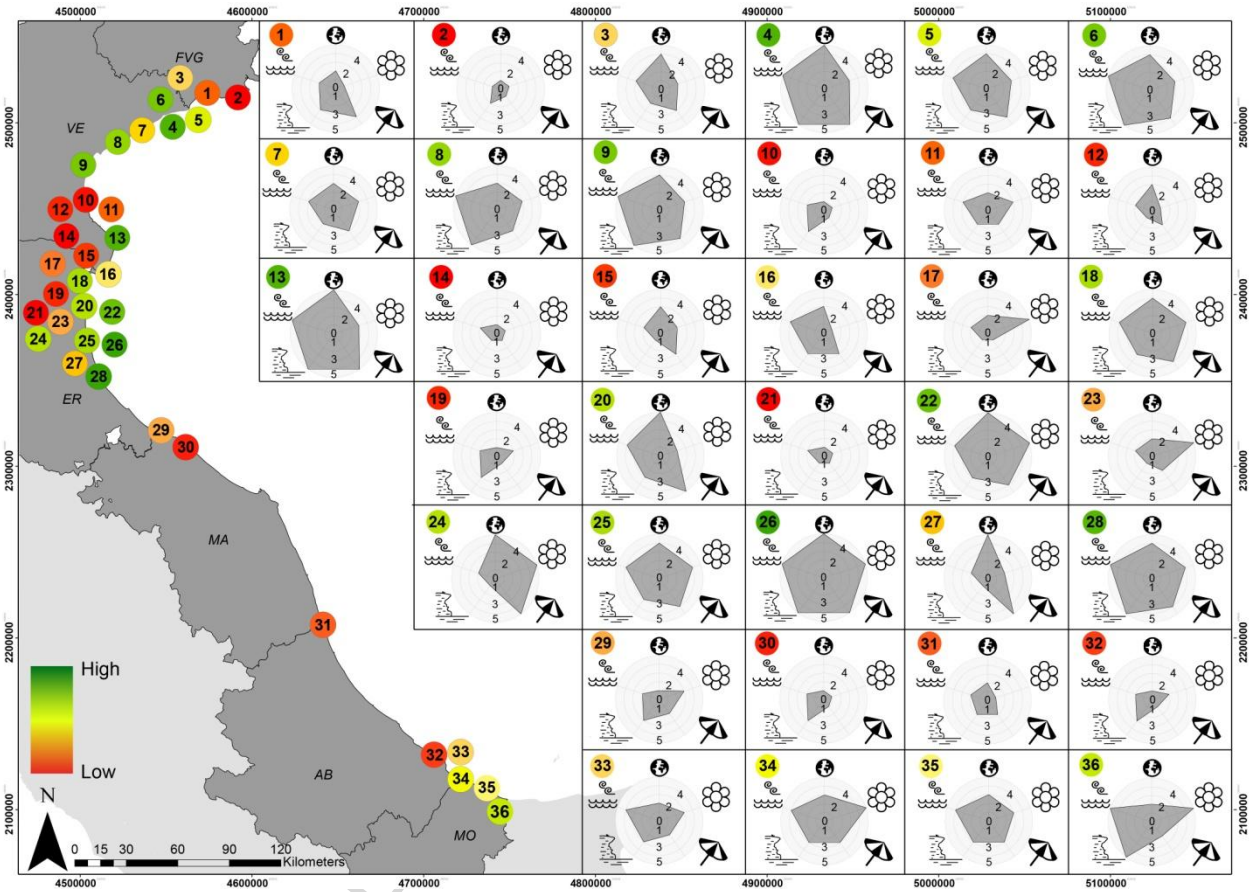


Figure 5. Multi-service value of the N2K sites in the Adriatic coast. Each site, represented by numbered circles, is coloured according with the quantity and quality of the ES offered by natural coastal dune habitats (ranging from red: low ES supply, to green: high ES supply). Spider diagrams of each N2K site are built using the ranked values for each ES, corresponding clockwise to: Climate regulation, Existence value of biodiversity, Recreation and Tourism, Erosion regulation and Protection from wind and aerosol. Wider is the grey area in the spider plot, higher is the multi-service value of the site. For the complete name and code of each site see Appendix B. For primary ES supply values per site refer to Table 2. Administrative regions abbreviations are described in Fig. 1. Coordinates are given in Datum: WGS 84, UTM 33N. Icons from *thenounproject.com*

4. DISCUSSION

In this research, we have evaluated the multi-service nature of ES supply in the Italian Adriatic N2K sites comprising natural coastal dunes, using a combination of measured and categorical supply indicators. Both the total ES supply and the individual ES contribution (Climate regulation, Protection from wind and aerosol, Erosion regulation, Recreation and Tourism, Existence value of biodiversity) vary along the Italian Adriatic N2K network, driven by the distribution of coastal dune habitats, their spatial extent, ecological integrity, conservation status and the administrative schemes. It is of interest that the sites with the highest ES scores are generally the sites with the highest number and extent of coastal dune habitats. Indeed, the integrity of the dune vegetation zonation is critical to deliver the greatest number and quality of services. Larger N2K sites more likely include multiple habitat zones. Therefore, our results confirm that diversity of habitats, but also their extent play a role in ES supply (Tscharntke et al., 2005; Lovell et al., 2010), and can also underpin multi-functionality of coastal habitats (Townsend et al., 2011).

The observed heterogeneity in ES supply across the administrative regions is partially related with the different approaches adopted by the local administrations for dealing with nature conservation issues, and specifically for the implementation of the Habitats Directive (Genovesi et al., 2014). Our results underline the role of regions (e.g. Emilia Romagna) with a forward-looking conservation policy, which have protected the residual natural coastal dunes, maintaining their multiple benefits for human wellbeing. By contrast, other regions (e.g. Marche and Abruzzo) did not protect all the residual natural coastal dunes and thus they should promote the enlargement of their N2K network and restore natural dune zonation, in order to recover their functionality and ES supply in the long term.

One of the major challenges in this study was to quantify the spatial variation in ES in complex ecosystem mosaics that are often subjected to several human pressures. Although ES can be often modelled by means of satellite data as a proxy or as a data source on which to base statistical upscaling (Bush et al., 2017), this works best on larger scales, or where there is clear differentiation between habitats (Adamo et al., 2016). Differentiation between coastal dry dune habitats remains challenging, particularly where they occur as narrow ecosystem mosaics (Bazzichetto et al., 2018; Higginbottom et al., 2018). Moreover,

quantification is an even greater challenge for cultural services and for under-studied regulating services (Schirpke et al., 2017). For these reasons and since the majority of services are poorly studied in this region, it was decided to use a scoring approach (Wolff et al., 2015). This has the advantage of being able to combine quantitative and categorical data into a harmonized assessment approach.

Building an aggregation framework for multi-service capacity assessment creates an inherent trade-off in trying to simplify a complex system. While our approach may introduce some limitations on fully characterizing variability within and among sites, we believe it represents the first attempt to systematically explore the multi-service value of Adriatic coastal dunes. Further work should focus on modelling coastal ES in more detail, based on direct measures for regulating services combined with the use of newly available satellite data and/or a range of ES models.

5. IMPLICATIONS FOR MANAGEMENT

There is a paradox that urban expansion provides increasing beneficiaries who will make use of the dune ES, but at the same time they represent perhaps the greatest pressure on the sustainable management of coastal systems (Mendoza-González et al., 2012; Carranza et al., 2018).

Some recent research papers revealed deleterious effects of urban expansion and land cover change on coastal dune landscapes in the Adriatic coast, ranging from reduction in the extent of coastal habitats (Malavasi et al., 2013), to a decline in biodiversity (Malavasi et al., 2018) and the services they provide (Carranza et al., 2018). Urban development also boosts the action of many other threats (e.g trampling pressure, alien invasions, and fire risk) on the remaining natural dunes, reducing their quality and compromising their ability to provide ES in the future, particularly the cultural and aesthetic services. Thus, developing strategies to manage this valuable coastal resource is essential. Recent investigation dealing both with regional coastal dune conservation (e.g. Doddy et al., 2013; Martínez et al., 2004) and local studies carried out in the Mediterranean can help identify adequate strategies dealing with dune ecosystems and their threats. To counter threats such as fires and urban expansion, regional and

national strategies for promoting prevention and legality are necessary. Instead, possible local measures to preserve embryo dunes across the Adriatic coast include avoiding beach levelling, promoting the manual cleaning of the seashore litter rather than mechanical beach cleaning (Poeta et al.,2015; De Francesco et al., 2018) and governing touristic movement. Experimental research in Central Italy on foredunes evidenced significant biodiversity recovery thanks to enclosures that preserved dune morphology (Santoro et al., 2012b; Prisco et al., 2016). Measures for preserving wooded dunes biodiversity might include selective clearing as a sustainable regeneration treatment for Mediterranean forests (Torras and Saura, 2008), and the recovery of a more complex structure in coastal pine forests to strengthen the role of wind protection and increase biodiversity (Fabbio et al., 2003; Bonari et al., 2017; Botero et al., 2018). Coastal dunes protection should recognise the inter-connectedness of dune successional habitats, and the supply of sand which maintains dunes in healthy condition, and should aim to protect dunes from further encroachment by development pressures (Barbier et al.,2011; Liquete et al., 2013). Maintaining natural dune zonation has been identified as critical in preserving the integrity and biodiversity value of dune systems, but is also essential to provide many regulating ecosystem services, such as coastal defence (van der Meulen et al., 2008; Berry et al., 2013).

There is evidence that the apparent economic gains promoted by new touristic structures will be eclipsed by long lasting ES losses (Mendoza-Gonzalez et al., 2012; Carranza et al., 2018). Therefore, coastal development projects should take into account the considerable non-market economic values intrinsic to natural ecosystems (Martín-López et al., 2011) especially in N2K sites. Site designations and condition for coastal dune N2K sites are dependent on their biodiversity and maintenance of ecological processes, functions and connectivity of dune habitats. However, site management and site use can also be influenced by recognition of the ES that dunes provide. As long as these are not in conflict with the ecological integrity of the site, there is scope for management to achieve ‘win-win’s for both biodiversity and ES, and their ecosystem service value can also be used as an argument to increase protection of these valuable sites.

6. CONCLUSIONS

This study conducted a multilevel assessment of the ES provided by highly diverse and fragile Mediterranean dune ecosystems, which are in need of further protection.

Our results help differentiate the contribution of each dune habitat to coastal ES supply. For instance, in those N2K sites where natural embryonic and mobile dunes are missing, due for example to the mechanical levelling of beaches, Erosion regulation and the recreational services are negatively affected as well. Similarly, where coastal wood dunes and fixed dunes are missing, then Protection from wind and aerosol, Climate regulation and Existence value of biodiversity are likely to decline.

The multi-service capacity of coastal dunes is uneven within sites and within administrative regions, because of both the ecological (e.g. distribution, ecological integrity, extent and conservation status of dune habitats) and administrative (e.g. local implementation of the Habitats Directive) assets of the analysed study area. The results distinguish regions with high ES values and regions where the low conservation of coastal dunes and the paucity of protected areas represent a gap in ES supply and in the regional strategy for the adaptation and mitigation of climate change effects. Our findings provide insights into a useful basis for nature conservation planning, monitoring and ES assessments, conforming to the reporting obligations established by the EU Habitats Directive, which can ultimately lead to better management of N2K sites.

The approach taken in this study can be adapted to fit a wide range of indicator types. Since the assessment is based on information, which is available across Europe, it has the potential for application to European coasts at scales ranging from continental to regional or local. Such unified information on multi-service capacity of coastal dunes should offer a comprehensive guide to policy makers and landscape managers in defining adequate conservation and management strategies able to enhance areas providing high levels of ES and to improve the network of protected sites in the regions where the ES provision is below its potential.

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Appendix A

Name, detailed description and relative EU code of the analysed coastal dune habitat types according to the EU Habitats Directive.

Embryonic shifting dunes (EU 2110)

Formations of the coast representing the first stages of dune construction, constituted by ripples or raised sand surfaces of the upper beach or by a seaward fringe of small embryonic dunes at the foot of the tall dunes. This habitat consists of pioneer communities, dominated by *Elymus farctus*, which represent the first stages of plant colonization and contain some therophytes belonging to annual vegetation of the drift line.

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

Taller mobile dunes forming the seaward cordons of dune systems, colonized by a perennial herb community dominated by the rhizomatous tussock grass *Ammophila arenaria* ssp. *australis*. This habitat is generally in sequential contact with the embryonic shifting dunes on the seaward side and with the fixed dunes with Cisto-Lavanduletalia dune sclerophyllous scrubs (habitat type 2260) and coastal dunes with *Juniperus* spp. (habitat type 2250*) on the landward side.

Coastal dunes with Juniperus spp. (EU 2250*)

This habitat type comprises juniper scrub on coastal stable sand dunes in a variety of situations. Junipers are coniferous plants, shrubs or small trees, native to Mediterranean coasts, growing into a pyramid shape, with branches growing from its base. In Northern Adriatic coast *Juniperus communis* is more common whereas in central and southern Adriatic sectors *Juniperus oxycedrus* subsp. *macrocarpa* is dominant. The habitat has often sequential contact with Cisto-Lavanduletalia dune sclerophyllous scrubs (habitat type 2260) and with wooded dunes with *Pinus pinea* and/or *Pinus pinaster* (habitat type 2270) on the landward side.

Wooded dunes with *Pinus pinea* and/or *Pinus* pinaster (EU 2270*)

Coastal dunes colonised by Mediterranean and Atlantic thermophilous pines (*Pinus halepensis*, *P. pinea*, *P. pinaster*), often corresponding to substitution facies of artificial origin or to climax formations of evergreen oak (*Quercus ilex*). On the Italian Adriatic coast, these are mostly plantations and are rarely natural formations, even if they host maquis and evergreen oak in the undergrowth. They generally occupy the inland stable sector of dune systems. Many stations are currently threatened by marine erosion.

Appendix B

List of the coastal dune N2K sites (S) distributed from north to south along the Adriatic coast comprising the analysed EU habitat types. For each site, identified by its official name and code according to Habitats Directive, the administrative region, the status, the total area, and the extent of the coastal dune EU habitat types included are reported. For administrative regions abbreviations, refer to Figure 1. Status acronyms: SCI: Site of Community Importance; SPA: Special Protection Area; SAC: Special Area of Conservation (updated to 2016). The geographic position and coordinates of each site (S) can be consulted in Figure 1.

S	Site code	Natura 2000 site name	Region	Status	Area (ha)	EU habitat type area (ha)			
						Embryo	Mobile	Fixed	Wooded
1	IT3320037	Laguna di Marano e Grado	FVG	SAC/SPA	16364	30	63.26		
2	IT3330006	Valle Cavanata e Banco Mula di Muggia	FVG	SAC/SPA	860		0.21		
3	IT3320038	Pineta di Lignano	FVG	SCI	118			10.94	49.6
4	IT3250033	Laguna di Caorle foce Tagliamento	VE	SCI	4386	7.35	6.61	0.78	148.99
5	IT3250040	Foce Tagliamento	VE	SPA	280	2.22	3.09		70.62
6	IT3250041	Valle Vecchia Zumelle Bibione	VE	SPA	2089	8.43	5.38	0.78	79.3
7	IT3250013	Laguna del Mort e Pinete di Eraclea	VE	SCI	214		3.35		29.99
8	IT3250003	Penisola del Cavallino: biotopi litoranei	VE	SCI/SPA	315	0.51	6.91	0.04	33.4
9	IT3250023	Lido di Venezia: biotopi litoranei	VE	SCI/SPA	166	8.3	21.48		49.8
10	IT3250034	Dune residue Bacucco	VE	SCI	13	0.36	4.46		
11	IT3250032	Bosco Nordio	VE	SCI/SPA	157			0.25	16.75
12	IT3270003	Dune di Donada e Contarina	VE	SCI	105				26.06
13	IT3270017	Delta del Po: tratto terminale e delta veneto	VE	SCI	25362	30.67	58.8	15.06	137.42
14	IT3270005	Dune fossili Ariano Polesine	VE	SCI	101				0.28
15	IT4060015	Bosco della Mesola, Bosco Panfilia, Bosco di Santa Giustina, Valle Falce, La Goara	ER	SCI/SPA	1563				45.55
16	IT4060005	Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano	ER	SCI/SPA	4872	28.94	12.75		15.76
17	IT4060004	Valle Bertuzzi, Valle Porticino-Cannevié	ER	SCI/SPA	2691				3.69
18	IT4060007	Bosco di Volano	ER	SCI/SPA	400	2.32	2.32		80.97
19	IT4060012	Dune di San Giuseppe	ER	SCI/SPA	73	0.15	0.36		
20	IT4060003	Vene di Bellocchio, Sacca di Bellocchio, Foce del Fiume Reno, Pineta di Bellocchio	ER	SCI/SPA	2244	22.7	22.88		170.16
21	IT4070002	Bardello	ER	SCI/SPA	100				0.09
22	IT4070005	Pineta di Casalborsetti, Pineta Staggioni, Duna di Porto Corsini	ER	SCI/SPA	578	5.29	0.68		176.86
23	IT4070004	Pialasse Baiona, Risega e Pontazzo	ER	SCI/SPA	1596				9.7
24	IT4070003	Pineta di San Vitale, Bassa del Pirottolo	ER	SCI/SPA	1222				380.99
25	IT4070006	Pialassa dei Piomboni, Pineta di Punta Marina	ER	SCI/SPA	464	2	2.21		118.02
26	IT4070009	Ortazzo, Ortazzino, Foce del Torrente Bevano	ER	SCI/SPA	1255	23.12	7.17	0.2	197.09
27	IT4070010	Pineta di Classe	ER	SCI/SPA	1082				473.72
28	IT4070008	Pineta di Cervia	ER	SCI	194	0.34	0.06	0.44	102.88
29	IT5310024	Colle San Bartolo e litorale pesarese	MA	SPA	4031	6.05	0.4		
30	IT5310007	Litorale della Baia del Re	MA	SCI	17	5.96	0.2		
31	IT5340001	Litorale di Porto d'Ascoli	MA	SCI/SPA	109	6.76			

32	IT7140108	Punta Aderci - Punta della Penna	AB	SCI	317	0.99	2		
33	IT7140109	Marina di Vasto	AB	SCI	57	1.25	3.1		2.01
34	IT7228221	Foce Trigno - Marina di Petacciato	MO	SCI	747	13.72	10.07		48
35	IT7222216	Foce Biferno - Litorale di Campomarino	MO	SCI	817	8.87	1.06		43.72
36	IT7222217	Foce Saccione - Bonifica Ramitelli	MO	SCI	870	8.43	9.13	20.59	3.31
				Totals	**75829**	**224.73**	**247.9**	**49.07**	**2514.73**

Appendix C

Estimated unitary soil organic carbon content of the selected EU sand dune habitat types present in the Adriatic Natura 2000 network. Values are reported as mean ± s.d. (see for details Drius et al., 2016)

EU habitat type	Soil C ($t\ ha^{-1}$)
Embryonic shifting dunes	3.14 ± 1.25
Shifting dunes along the shoreline with Ammophila arenaria ('white dunes')	3.06 ± 1.71
Coastal dunes with Juniperus spp.	4.12 ± 1.41
Wooded dunes with Pinus pinea and/or Pinus pinaster	30.99 ± 19.71

Appendix D

Respondents' profile in terms of gender, age, education, place of residence and job.

Social descriptors	%
Gender	
Male	48
Female	52
Education	
primary school	5
Secondary school	60
University	35
Place of residence	
local	60

other regions	40
Job	
Employed	50
Freelance	22
Retired	9
Student/housewife	17
Unemployed	2

Total number of respondents = 591.

Appendix E

Frequencies of the alternative categorical answers to the question concerning people's perception towards the natural features present in the coastal sites. N of answers and percentage (%) synthesize the response to the question "How important do you consider the following natural features (Embryonic, Mobile and Wooded dunes)? Possible answers were: "not important"; "scarcely important"; "important"; "very important"; "I don't know".

	Embryonic		Mobile		Wooded	
	N answers	%	N answers	%	N answers	%
Very important	417	70.6	340	57.5	326	55.2
Important	132	22.3	155	26.2	145	24.5
Scarcely important	26	4.4	55	9.3	60	10.2
Not important	6	1.0	31	5.2	48	8.1
I don't know	10	1.7	10	1.7	12	2.0

Total number of respondents = 591

Appendix F

List of the coastal dune N2K sites along with the number of focal species and the conservation status of the coastal dune habitat types used for assessing the ES Existence value of biodiversity. The number of focal plant species for each habitat was extracted from the Italian Interpretation Manual of the 92/43/EEC Directive habitats (Biondi et al., 2009) and restricted to the taxa present along Italian Adriatic coast (Géhu and Biondi, 1996; Del Vecchio et al., 2015; Prisco et al., 2012; Stanisci et al., 2014). The conservation status of the four selected dune habitats is available from the official Natura 2000 Standard data forms (Genovesi et al., 2014; raw data is downloadable from the portal of the Italian Ministry of the Environment ftp://ftp.minambiente.it/PNM/Natura2000/TrasmissioneCE_dicembre2017/)..

S	Site code	Natura 2000 site name	Conservation status				Number of focal species			
			Embryo	Mobile	Fixed	Wooded	Embryo	Mobile	Fixed	Wooded
1	IT3320037	Laguna di Marano e Grado	1	1			10	10		
2	IT3330006	Valle Cavanata e Banco Mula di Muggia		1				10		
3	IT3320038	Pineta di Lignano			2	2			13	13
4	IT3250033	Laguna di Caorle foce Tagliamento	1	1	1	2	10	10	13	13
5	IT3250040	Foce Tagliamento	1	1	1	2	10	10	13	13
6	IT3250041	Valle Vecchia Zumelle Bibione	1	1	1	2	10	10	13	13
7	IT3250013	Laguna del Mort e Pinete di Eraclea	1	1	1	2	10	10	13	13
8	IT3250003	Penisola del Cavallino: biotopi litoranei	1	1	1	1	10	10	13	13
9	IT3250023	Lido di Venezia: biotopi litoranei	1	1		2	10	10		13
10	IT3250034	Dune residue Bacucco	1	2			10	10		
11	IT3250032	Bosco Nordio			2	2			13	13
12	IT3270003	Dune di Donada e Contarina				1				13
13	IT3270017	Delta del Po: tratto terminale e delta veneto	1	1	2	1	10	10	13	13

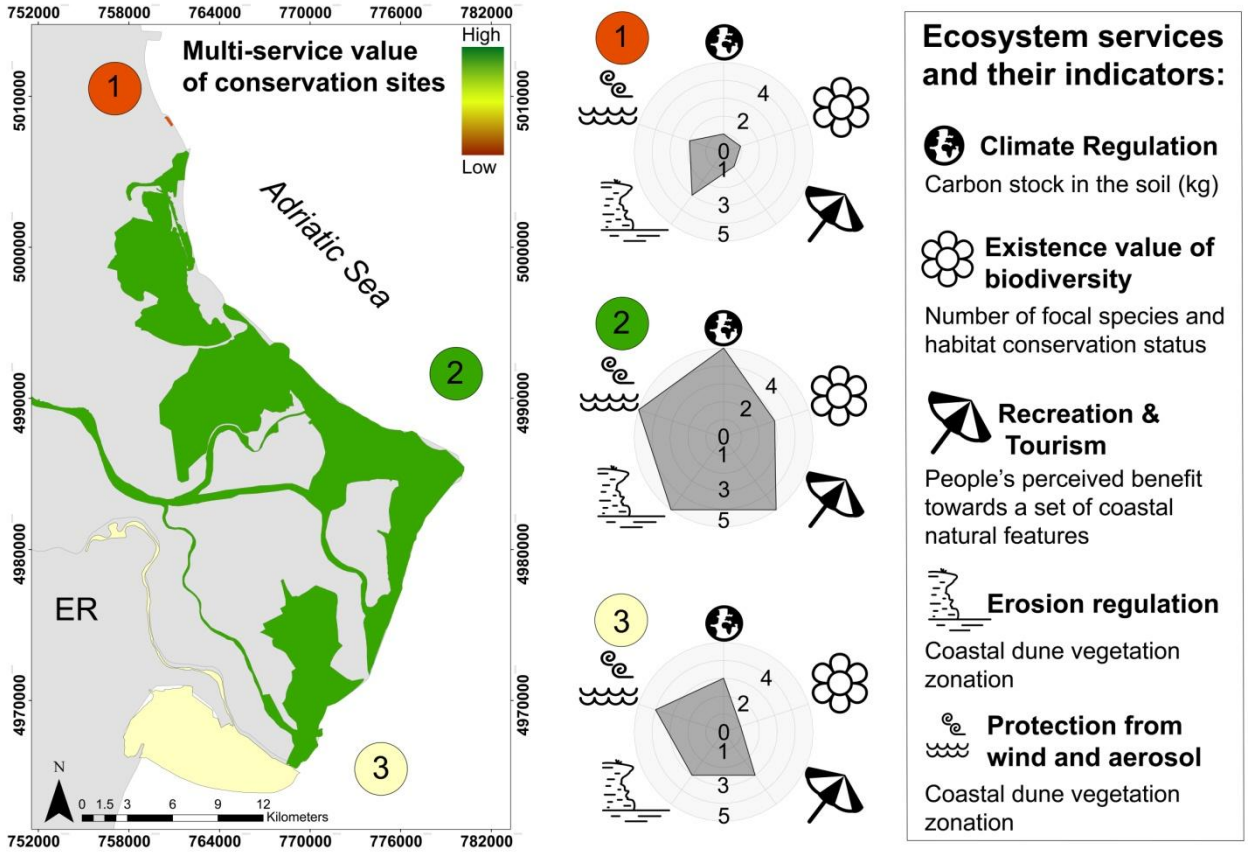
14	IT3270005	Dune fossili Ariano Polesine				1				13
15	IT4060015	Bosco della Mesola, Bosco Panfilia, Bosco di Santa Giustina, Valle Falce, La Goara				3				13
16	IT4060005	Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano	3	3		3	10	10		13
17	IT4060004	Valle Bertuzzi, Valle Porticino-Cannevié				2				13
18	IT4060007	Bosco di Volano	2	2		2	10	10		13
19	IT4060012	Dune di San Giuseppe	2	2			10	10		
20	IT4060003	Vene di Bellocchio, Sacca di Bellocchio, Foce del Fiume Reno, Pineta di Bellocchio	3	3		2	10	10		13
21	IT4070002	Bardello				2				13
22	IT4070005	Pineta di Casalborsetti, Pineta Staggioni, Duna di Porto Corsini	3	3	2	3	10	10	13	13
23	IT4070004	Pialasse Baiona, Risega e Pontazzo				3				13
24	IT4070003	Pineta di San Vitale, Bassa del Pirottolo				3				13
25	IT4070006	Pialassa dei Piomboni, Pineta di Punta Marina	2	2		2	10	10		13
26	IT4070009	Ortazzo, Ortazzino, Foce del Torrente Bevano	3	3	3	2	10	10	13	13
27	IT4070010	Pineta di Classe			2	3			13	13
28	IT4070008	Pineta di Cervia	2	2	2	2	10	10	13	13
29	IT5310024	Colle San Bartolo e litorale pesarese	2	2			10	10		
30	IT5310007	Litorale della Baia del Re	2	1			10	10		
31	IT5340001	Litorale di Porto d'Ascoli	1				10			
32	IT7140108	Punta Aderci - Punta della Penna	2	2			10	10		
33	IT7140109	Marina di Vasto	2	2		1	10	10		13
34	IT7228221	Foce Trigno - Marina di Petacciato	3	3		2	10	10		13
35	IT7222216	Foce Biferno - Litorale di Campomarino	2	1		2	10	10		13
36	IT7222217	Foce Saccione - Bonifica Ramitelli	3	3	2	2	10	10	13	13

Appendix G

List of the coastal dune N2K sites, ordered along a North-South gradient, and of the ranked values of ES supply ranging from 1 to 5 and coloured from red (low values) to green (high values). ES supply ranking values are: 1 - very low, 2 - low, 3 - medium, 4 - high, 5 - very high. S: site identification number, following Figure 1. **C stock** (t): Carbon stock in the soil**, Wooded dunes**: Coastal dune vegetation zonation weighted by the occurrence of wooded dunes, **Foredune vegetation:** Coastal dune vegetation zonation weighted by the presence of sparse psammophilous vegetation, **Perceived benefit**: people's perceived benefit towards coastal natural habitat weighted by habitat extent, **Focal species**: Number of focal species weighted habitat conservation status.

ES supply		*Clim. Reg.*	*Wind prot.*	*Eros. Reg.*	*Rec. Tour.*	*Biodiv.*
		C stock (t)	**Wooded dunes (dimensionless)**	**Fore dune vegetation (dimensionless)**	**Perceived benefit (dimensionless)**	**Focal species (dimensionless)**
S	Natura 2000 site name					
1	Laguna di Marano e Grado	2	2	3	4	1
2	Valle Cavanata e Banco Mula di Muggia	1	1	2	1	1
3	Pineta di Lignano	4	3	2	3	2
4	Laguna di Caorle foce Tagliamento	5	5	5	5	3
5	Foce Tagliamento	4	4	3	4	3
6	Valle Vecchia Zumelle Bibione	4	5	5	4	3
7	Laguna del Mort e Pinete di Eraclea	3	3	2	3	3
8	Penisola del Cavallino: biotopi litoranei	3	5	5	3	3
9	Lido di Venezia: biotopi litoranei	4	5	5	4	3
10	Dune residue Bacucco	1	2	3	1	1
11	Bosco Nordio	2	3	2	2	3
12	Dune di Donada e Contarina	3	2	1	2	1
13	Delta del Po: tratto terminale e delta veneto	5	5	5	5	3
14	Dune fossili Ariano Polesine	1	2	1	1	1
15	Bosco della Mesola, Bosco Panfilia, Bosco di Santa Giustina, Valle Falce, La Goara	3	2	1	3	2
16	Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano	3	4	3	3	1
17	Valle Bertuzzi, Valle Porticino-Cannevié	2	2	1	1	5
18	Bosco di Volano	4	4	3	4	4
19	Dune di San Giuseppe	1	2	3	1	2
20	Vene di Bellocchio, Sacca di Bellocchio, Foce del Fiume Reno, Pineta di Bellocchio	5	4	3	5	2

21	Bardello	1	2	1	1	1
22	Pineta di Casalborsetti, Pineta Staggioni, Duna di Porto Corsini	5	4	3	5	5
23	Pialasse Baiona, Risega e Pontazzo	2	2	1	2	5
24	Pineta di San Vitale, Bassa del Pirottolo	5	2	1	5	5
25	Pialassa dei Piomboni, Pineta di Punta Marina	4	4	3	4	4
26	Ortazzo, Ortazzino, Foce del Torrente Bevano	5	5	5	5	5
27	Pineta di Classe	5	2	1	5	2
28	Pineta di Cervia	4	5	5	4	4
29	Colle San Bartolo e litorale pesarese	1	2	3	2	3
30	Litorale della Baia del Re	1	2	3	1	1
31	Litorale di Porto d'Ascoli	2	2	2	2	1
32	Punta Aderci - Punta della Penna	1	2	3	1	2
33	Marina di Vasto	2	4	3	2	3
34	Foce Trigno - Marina di Petacciato	3	4	3	3	5
35	Foce Biferno - Litorale di Campomarino	3	4	3	3	3
36	Foce Saccione - Bonifica Ramitelli	2	5	5	2	5



Graphical abstract

Highlights

- We proposed ES supply indicators tailored for natural dune ecosystems
- We explored the role of coastal dune conservation sites in providing five ES
- ES indicators were normalized and synthesized in one multiservice ES value per site
- ES supply varies along the coast due to both extent and integrity of dune systems
- Management of integrity is crucial for maintaining optimum levels of ES supply