

Inventory and conservation assessment for the management of coastal dunes, Veneto coasts, Italy

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Abstract Management of coastal dunes on developed coasts could effectively take advantage of comprehensive and multitemporal georeferenced data collection, which offers the possibility to relate dune data with the natural and cultural characteristics of the beach and hinterland. The recent implementation of a coastal management geodatabase for the Veneto region provides the opportunity for improving knowledge on coastal dunes on developed littoral as well as a basis for appropriate future coastal planning in the study area. The geodatabase gathers data concerning different physical, evolutionary and human aspects of the coastal zone, with a special focus on coastal dunes. Established foredunes, human-altered dunes and relict dunes are irregularly distributed along 59 km, 38% of the entire coastal length. Their distribution and characteristics are the result of favourable natural conditions as well as long-lasting tourism exploitation (evaluated through an index of Land Use Pressure) and fragmentary and diversified uses of beaches (evaluated through an index of Tourism Pressure on the beach). At the same time, beach/dune nourishment intervention allowed the presence of artificial or sand fenced dunes along 17 km of coast. High dune elevation up to 8–10 m is promoted by the onshore exposition of the beach to dominant wind (from ENE), by stable-to-slowly negative sedimentary budget or by the re-activation of high relict foredunes in the case of shoreline retreat associated with strong negative budget. Present sedimentary budget (evaluated through the code ASPE – Accretion, Stable, Precarious, Erosive) is the tool used for dividing coasts in sedimentary

compartments or cells. Past and present sedimentary budget and different human responses to erosive cases (hard and soft interventions) give the foredunes different means to form, grow, survive and evolve over time. The assessment of Human Impact and Active Management Practices on the dunes allows a first evaluation of the Management Effectiveness, which shows strong shortcomings for 81% of the dunes. The great variability of beach usage, human impact and management practises on the different dune stretches highlight the lack of effective and systematic management actions being correctly scheduled and performed.

Keywords Coastal dunes · Geodatabase · Coastal management · Sediment budget

Introduction

Coastal dunes play a key role in the context of coastal management. They represent sites with high geo- and biodiversity values and provide benefits to natural and human-altered coastal systems as sources of sediment supply, protection against storms and saltwater intrusion, and a location for recreation and tourism. Conversely, human actions can modify the morphology (shape, topography and dimension), vegetation and evolution of coastal dunes, or frequently, even eliminate them (Carter 1989; Nordstrom 2000).

Dune conservation and resilience are affected by natural factors such as beach morphodynamics, sedimentary budget (Psuty 1988, 1989; Hesp 2011), wind and wave climates (Short and Hesp 1982; Hesp 1989, 2011), but also by human-controlled constraints such as beach usage (tourism pressure), the presence of coastal defences, sand fence placement and vegetation planting (Psuty 1989; Sanjaume and Pardo 1992; Nordstrom 2000). Land use in the hinterland

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can influence the fate of coastal dunes: urbanisation can directly destroy the dunes or promote the construction of hard coastal defences (Nordstrom 2000; Tzatzanis et al. 2003; Heslenfeld et al. 2004).

Combining dune conservation and recreational beach use for tourism is an enduring challenge for managers on developed coasts. This implies an integrate programme of zoning, with access control, provision of alternative facilities, visitor information and education (Carter 1989). Typical tools for access control and trampling limitation are elevated walkovers, protective fences and signage (Carter 1989; McKann et al. 2001).

Where dunes have been eroded or destroyed by human action, beach nourishment can represent an opportunity for landform rebuilding and habitat restoration (Gómez-Pina et al. 2002, Matias et al. 2005; Nordstrom 2008; Bezzi et al. 2009). The typical approach is the direct supply of sand to reshape a new dune or fencing in order to trap the sand transported onshore by wind action over the newly enlarged beach. The success of this type of intervention depends on physical and ecological processes as well as on management policies (Nordstrom 2008). Governments at the national/regional level usually fund these projects, with minimal maintenance costs and without any plans for monitoring or ongoing maintenance (Townend and Fleming 1991). Local authorities and managers of the tourism facilities are often the most important stakeholders in the post-intervention management of beaches and the dune system, and locally based programmes or guidelines are often lacking (Nordstrom 2008).

For all these reasons, the management of coastal dunes on developed coasts requires an in-depth knowledge about processes (Psuty 1989), comprehensive and multitemporal data collection on their characteristics and also the possibility to correlate dune data with the natural and cultural characteristics of the beach and hinterland (Tzatzanis et al. 2003).

The Veneto Region has a mandate for the coastal management of 169 km of sandy beaches in North-East Italy (Fig. 1), and it thus promoted the ‘Construction and Implementation of a Geodatabase for the Management of the Coastal Area of the Veneto Region’ (GCV) between the mouths of the Adige and Tagliamento rivers (95 km) (Fontolan et al. 2015) within the SHAPE (Shaping an Holistic Approach to Protect the Adriatic Environment between coast and sea) project, IPA (Instrument for the Pre-Accession Assistance) Adriatic Cross-Border Cooperation Programme. This activity is referred to as preparatory to the drafting of the ‘Integrated Coastal Zone Management Plan of the Veneto’. At the same time, the regional authority promoted a similar study for the southern part of the region from the Adige to Po di Goro rivers (74 km). The two geodatabases have the same structure and approach, and so they can be used as a unique tool for coastal planning and future adaptation to climate change and sea level rise.

The aim of this paper is to illustrate an updated and comprehensive overview of the coastal dunes of the Veneto region based on data and information contained in the geodatabase. The results of analysis will highlight the strengths and weaknesses of the current state of the dunes for the future development of guidelines for correct management.

Study area

The Veneto region (northern Italy) contains 169 km of sandy beaches resulting from alluvial plain coasts that evolved during the Holocene in lagoons, barrier beaches, fluvial deltas and spits (Fig. 1). From the geomorphological point of view, several physiographic units can be identified along the littoral. They are limited by discontinuities due to the presence of river mouths or tidal inlets. The tidal regime is microtidal, with a mean spring tidal range of 1.0 m and a neap tidal range of 0.2 m. The annual-averaged significant wave height from 1958 to 1999 is 0.27 m (Martucci et al. 2010); the mean annual wave energy over the same period is 15.61 m²s² (Fontolan et al. 2007). Beaches have favourable conditions for the formation of coastal dunes due to the available grain size (fine sand) and the onshore wind regime (Bezzi and Fontolan 2003). The dominant wind is Bora, a katabatic wind blowing from ENE that can reach gust velocities over 100 km/h (Fig. 1).

According to the dominance of the Bora wind from ENE and the subordinate Scirocco wind from SE, the wave regime is typically bimodal. Along the whole northern coastal sector from the Tagliamento river to the Lido inlet, longshore transport is directed to the SW, increasing progressively from ca. 38,700 m³/y to 99,100 m³/y (Ruol et al. 2016). The Venice littorals (Lido and Pellestrina) are convergence sites, with quite null net longshore sediment transport. The southern sector features two main divergent points, corresponding to the apexes of the Adige and Po deltas. Longshore transport is directed northward along Sottomarina and Isola Verde, and southward along the Rosolina littoral, with rates of 24,700 m³/y, 49,900 m³/y and 82,100 m³/y, respectively. From Po di Pila to Albarella island, the longshore transport is directed northward, with decreasing rates from 220,500 m³/y to 77,100 m³/y; from Po di Pila to Po di Goro, the longshore transport is opposite, with decreasing rates from 340,800 m³/y to 139,300 m³/y (Ruol et al. 2016).

Coastal evolution has been strongly influenced since Roman times by human intervention in order to stabilise coastal environments (Zunica 1971, Day et al. 2005). Since the 1950s, the coasts have been subject to rapid and intense urban development due to tourist interest. Many dunes were destroyed, and the coastal area was strongly urbanised. Only a few coastal stretches survived this destructive human

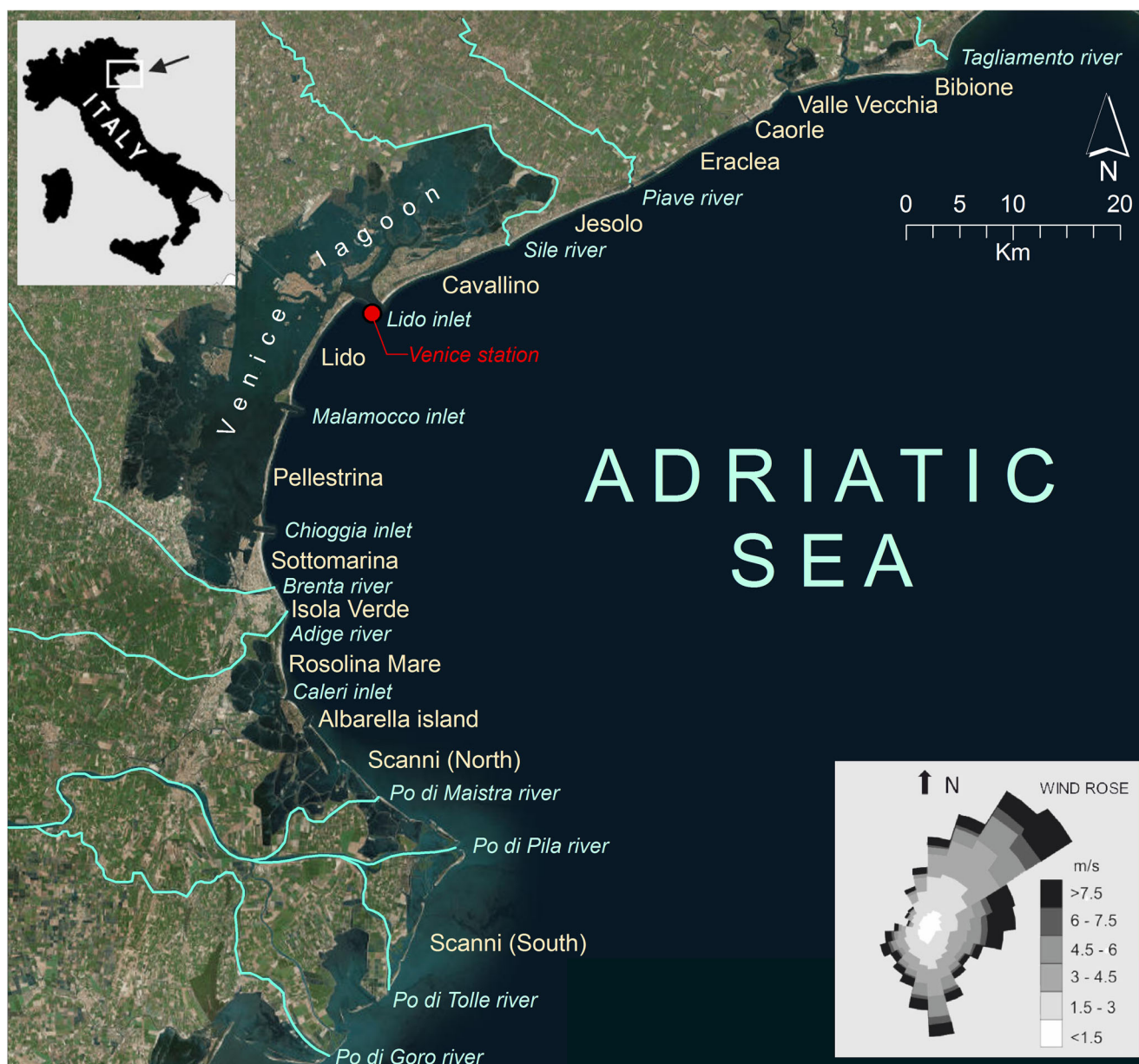


Fig. 1 Location of the study area. Wind data refers to the period 1973–2002 (elaboration from data by APAT, now ISPRA: www.mareografico.it) for Venice station

development (Bezzi and Fontolan 2003), for instance, along the Venetian Po river delta.

Sedimentary sources for beach and dune accretion come from the rivers whose solid load has been intercepted by dams, and which has been reducing drastically as a consequence of the intensive use of water for irrigation as well as gravel and sand mining along the river bed (Zunica 1971). According to Antonioli et al. (2017) the northern Adriatic coastal strip is the Italian area at the greatest risk of flooding due to the relative sea level rise scenario by 2100. During the 1960s and 1970s, the strong erosive processes involving beaches were addressed by the construction of coastal hard defences (revetments, sea-walls, groynes). Since 1995, beach nourishment

projects have been carried out to maintain and restore the coast using sand borrowed from the sea floor (Fontolan 2004).

From a management point of view, the coast of the Veneto region can be divided into three stretches (Fig. 1). The northern stretch, between the mouth of Tagliamento and Piave rivers, is under the jurisdiction of the Veneto Region, Soil Defence Dept. Here the coastal management is fragmented, coastal interventions are often promoted by municipalities, and beach monitoring (i.e. through topo-bathymetric surveys) is not updated or is quite sparse.

The central stretch, between the mouths of the Piave and Adige rivers, was for a long time and is still under the jurisdiction of the Magistrato alle Acque di Venezia - Consorzio

Venezia Nuova (MAV-CVN), a concessionaire of the Italian Ministry of Infrastructure and Transport for the implementation of measures to safeguard Venice and its lagoon. Since the 1990s, MAV-CVN has carried out a series of beach nourishment interventions and protection, and it has dealt with monitoring surveys. For this reason, a dense network of topo-bathymetric sections, repeated at different time scales until 2010, covers these coasts (with the exception of the Lido of Venice). They represent a valuable dataset, although not always easily accessible or used sufficiently for scientific purposes.

The southern coastal stretch is under the jurisdiction of the Reclamation Consortium Delta Po Adige, supervised by Veneto Region, Soil Defence Dept. The Consortium's fundamental aim is land reclamation activities, but it also focuses, on a regional grant, on coastal defence measures such as beach nourishment and hard defences.

Previous works on the Veneto coastal dunes are limited to a general inventory at a large scale between the Adige and Tagliamento rivers (Bezzi and Fontolan 2003) or to specific cases of natural growth at Ca' Roman (Bezzi et al. 2005) and dune formation linked to nourished beaches (Bezzi et al. 2009; Nordstrom et al. 2009).

Materials and methods

The geographic information system

Coastal dunes and their descriptive and quantitative variables presented and discussed in this paper are represented by feature classes and related attributes in the Coastal Geodatabase of Veneto (GVC) (Fontolan et al. 2014) and the Coastal Geodatabase of Po Delta (CGPD). The approach and prototype for the geodatabase construction (Fontolan et al. 2015) has been inspired by the SICELL method (Management System for the Littoral Cells) proposed by the Emilia-Romagna Region (Regione Emilia-Romagna 2011). According to the SICELL approach, the coastal area is divided into sedimentary cells or compartments, based on sediment budget characteristics, in order to evaluate their states, and thus to establish criteria for sediment management and possible solutions for deficit areas.

The SICELL method has been improved (Fontolan et al. 2015) based on the experience of the Coastal Storm Risk Assessment of the Veneto coasts (Fontolan et al. 2011 and references therein), which was developed in collaboration with the Civil Protection Department of the Province of Venice.

In the geodatabase, spatial data and their attributes (descriptive and quantitative parameters) are organised

by grouping them in three main categories: 1) Beach State (beach width, shoreface slope, sedimentology, tourism pressure) and connection with the hinterland (land-use pressure); 2) Evolutionary Dynamics (recent and past shoreline evolution, recent and past beach and upper shoreface sediment budget, artificial beach nourishment); 3) Coastal Defences (hard and soft protections and coastal dunes).

Coastal dunes are geographical entities included in the category Coastal Defences and are represented by a polyline drawn in correspondence to the dune crests, which were identified on the basis of high-resolution Lidar data (2013). Twenty descriptive and quantitative parameters are associated as numerical or textual attributes (Table 1). The data sources are the Lidar survey and associated orthophotos (year 2013), specific field surveys (year 2015) and technical reports on beach monitoring and nourishment interventions (mainly provided by Veneto Region).

The data were structured to allow analysis at the level of a single Coastal Dune (with reference to its geographic entity) and in relation to other geographical entities: Sedimentary Cells, Hinterland and Hard Coastal Defences (Fig. 2).

Table 1 Parameters describing the dunes of the Veneto coast

Parameter	Attributes (numeric, alphanumeric)
Dune type	Established Foredunes, Relict Foredunes, Human-Altered Dunes
Dune origin	Natural, Artificial, Induced by fences
Dune position	Primary (shore facing), Secondary
Dune elevation	Crest elevation (m above mean sea level)
Azimuth	Orientation (degree)
Blowout	Absent, Scarce, Present, Abundant
Erosive scarps	Absent, Scarce, Present, Abundant
Incipient foredunes	Absent, Scarce, Present, Abundant
Access way to the beach	Absent, Present, Abundant
Flattened areas	Absent, Present, Abundant
Pathways	Absent, Present, Abundant
Structures	Absent, Present, Abundant
Anomalous vegetation	Absent, Present, Abundant
Straightening of the dune seaside	Absent, Present, Abundant
Human impact	Low, Moderate, High, Very High
Sand fences	Absent, Present, Abundant
Protective fences	Absent, Present, Abundant
Protected beach access ways and/or elevated walkways	Absent, Present, Abundant
Signage	Absent, Present, Abundant
Active management practices	Absent, Moderate, High

The ASPE code and pressure indices

The geodatabase also contains some important indices: the ASPE Code, the Land Use Pressure and the Tourism Pressure, as better specified below.

Following the improved SICELL approach (Fontolan et al. 2015), different sedimentary cells were identified along the coastal zone according to the values of the latest (mostly referring to the last decade) sediment budget, as characterised by homogeneous erosional/depositional style and classified assigning a specific textual code (ASPE: Accretion, Stable, Precarious, Erosion). Accretion (A) and Erosion (E) are the end members and refer to sedimentary accumulation or deficits greater than $5 \text{ m}^3/\text{my}$ or lower than $-5 \text{ m}^3/\text{my}$, respectively; Stable (S) and Precarious (P) refer to cells with a sedimentary rate between -5 and $+5 \text{ m}^3/\text{my}$, whereas (P) means a stable budget altered by beach nourishment interventions carried out during the reference period. An identification code links each cell to the above-listed variables (categories 1, 2, 3).

A survey on land use was conducted based on Corine Land Cover (CLC) data and classification (<http://land.copernicus.eu/pan-european/corine-land-cover>). The CLC categories were grouped and weighted according to their anthropisation grade (an integer value on a scale between 1 = neutral and 4 = maximum). Four buffer zones were identified: 100 m, 300 m, 600 m and 1200 m from the backshore line, subdivided in polygons so as to correspond to the coastal cells. For each hinterland buffer zone an index of Land Use Pressure has been calculated, using the sum of the products of the percentages of surfaces of different values. Each polygon is categorised by a numerical value within the continuous range 100–400, corresponding to a maximum naturalness/minimum

anthropisation and maximum anthropisation/minimum naturalness, respectively. Low, Medium, High and Very High land use pressure values correspond to the classes 100–150, 150–250, 250–350, 350–400.

The direct pressure of tourism on the beaches has been evaluated with the Tourism Pressure indicator (Fontolan et al. 2011) on the basis of the number of tourists – over 24 million presences (overnight stays) in total – irregularly distributed on the littoral, according to the characteristics of the hinterland and the beach. Each specific beach is further classified through an index of Beach Touristic Use (BTU: 6 classes from min = 0 to max = 1). In fact, the distribution of natural or urbanised areas, tourist accommodations, private concessions of beaches for recreational use and ease of access to the beaches determine the different grades of touristic attendance. The BTU index was then normalised for the extent of the beach, thus obtaining the Tourism Pressure index, which was classified into four categories: Low (< 0.5 presences/ m^2y), Medium ($0.5\text{--}1.5$ presences/ m^2y), High ($1.5\text{--}4$ presences/ m^2y), Very High (> 4 presences/ m^2y).

Results and discussion

Distribution of coastal dunes

Coastal dunes are distributed along 59 km of the Veneto coastline (Fig. 3). According to the classification of Psuty (1988) and Hesp (2002, 2011) they are largely identifiable as foredunes.

An *established foredune*, sensu Hesp (2011), is the first (primary) sand ridge on the backshore, in close contact with the beach and characterised by an active feedback mechanism

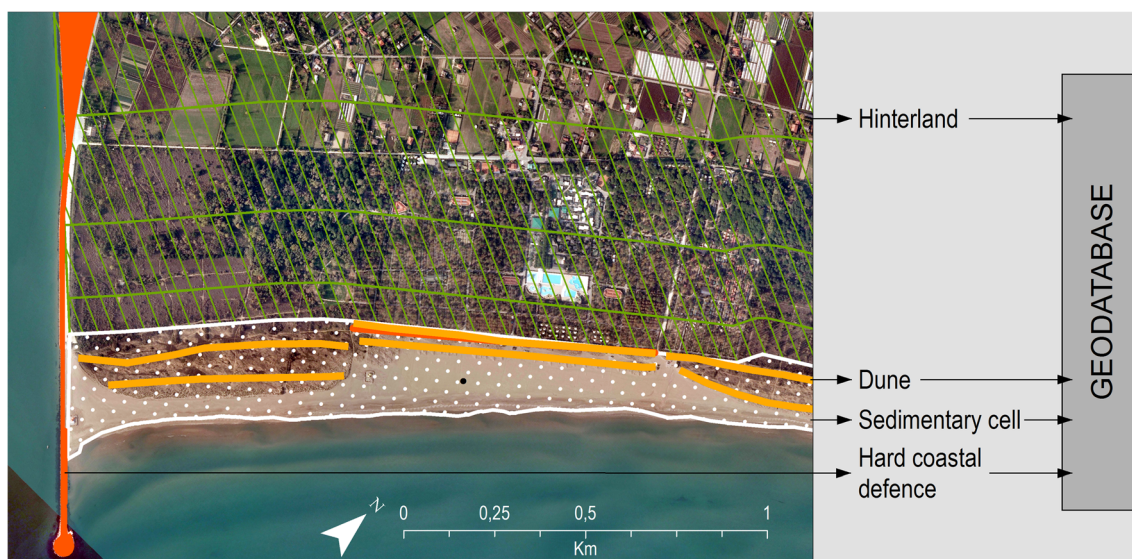


Fig. 2 Geographical entities in the geodatabase

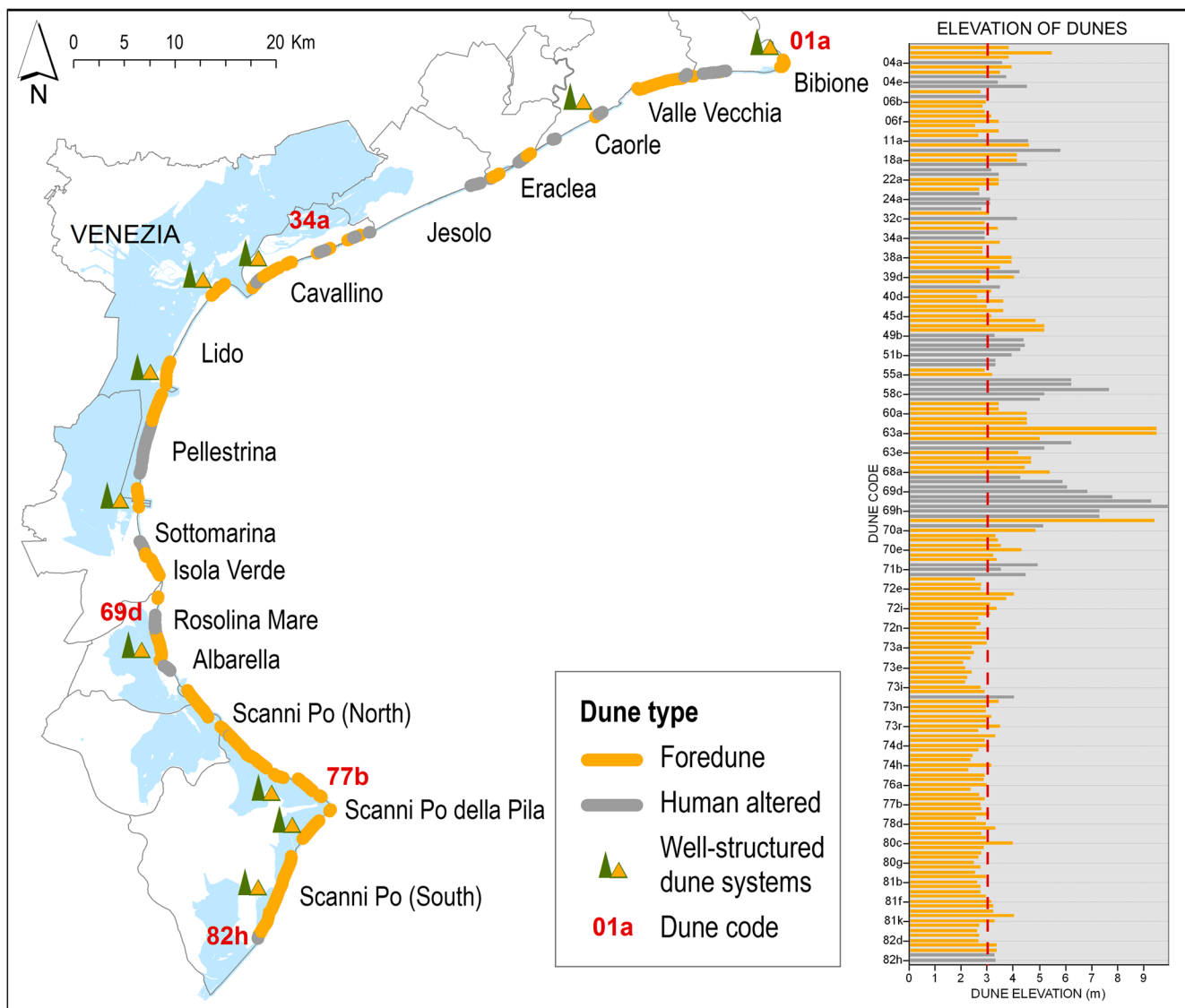


Fig. 3 Distribution of the dune types and elevations in the study area. Well-structured dune systems - mostly included in SACs according to the Natura 2000 European Directive - refer to the presence of a complete beach–dune gradient, given by incipient foredunes, foredunes and relict dunes

of sediment exchange with it. Typical characteristics of the established foredunes recognisable in the study area are as follows: crests parallel to the shoreline, in situ accretion or erosion, partial stabilisation and accretion by vegetation (Bezzi and Fontolan 2003, Bezzi et al. 2005), active aeolian erosion and/or deposition and the presence of discontinuous cover of psammophylus native species such as *Ammophila arenaria*, *Cakile maritima*, *Agropyron junceum*, *Eringium maritimum* and *Calystegia soldanella*. The morphology is variable, ranging from barchanoid crests originated by the coalescence of shadow dunes (nebhka) (Fig. 4a) to more transverse forms in those areas affected by a longshore wind orientation (Bezzi and Fontolan 2003). The seaward face of the dunes may be marked by the presence of *incipient foredunes* (Fig. 4b), which we have identified in the geodatabase with an

attribute of abundance. Incipient foredunes are present along 24 km of coastline only.

Human activities have affected the dunes in different ways, resulting in different grades of modified morphologies. In fact, tourist exploitation of the beach determines the occupation of spaces; beach raking results in an anomalous flattened profile, beach access determines gaps in the dune ridges, the construction of hard defences limits the aeolian transport and beach dune sediment exchange and the planting of exotic or anomalous vegetal species fixes the foredune. We defined *human-altered dunes* as those foredunes lacking natural features due to human actions: straightening, grading one or both dune sides or totally fixed by planted vegetation (Fig. 4d). The total length of human-altered dunes is 14 km.

Fig. 4 Photographs of different dune types: established foredune originated by the coalescence of shadow dunes (a), incipient foredunes (b) and relict dunes (c) on the beach / dune system of Ca'Roman (southern part of Pellestrina); human altered dunes (d) on the beach of Sottomarina



Finally, *relict foredunes* are present along 31 km of coast. They represent a mature stage of development of the foredune in a prograding system, occupying a secondary position (Psuty 1989; Hesp 2011) at the back of the primary form. Normally, relict dunes are smooth, with the sand surface covered by vegetation, and due to the inactive position, there is no evidence of aeolian erosion or deposition (Fig. 4c).

A pristine, complete beach-dune gradient composed of beach, incipient foredune, established foredune and one or more alignments of relict dunes (foredune plains sensu Hesp 2011) still survives along 19 km of the coastline. Due to their natural status, these dune systems are frequently protected as Special Areas of Conservation (SACs), according to the Natura 2000 European Directive.

In some cases, re-activated relict dunes may be included in the category of established foredunes, namely the relict dunes presently facing the beach due to destruction of pre-existing foredunes by shoreline retreat and/or by beach widening for tourism purposes. Re-activation is defined by the presence of erosive or depositional morphologies and vegetation in patches, resulting from a mixing between species typical of the foredunes and shrubs.

Dune elevations vary from 2.08 m and 9.95 m depending on the geographical position (Fig. 3). As already stated by Bezzi and Fontolan (2003), the orientation of the beach with respect to the dominant wind direction (Bora) has a direct influence on the aeolian fetch affecting sand transport, and therefore on the dimensions of coastal dunes, as well as on the morphological characteristics of the dune-beach system.

Conversely, the presence of an extended alignment of narrow barrier islands (mostly less than 200 m wide) all along the Po delta limits dune elevations even with effective exposure to the Bora wind (as along the Scanni north sector). This is due to the morphodynamics of barrier islands, as they have an intrinsic characteristic of rapidly changing their morphology, and foredunes can be quite vulnerable to storm surges and wave attacks, especially along sections that are at lower elevations or are discontinuous (Prietas and Fagherazzi 2010).

As a result, Fig. 5 reinforces the above concepts; beaches aligned parallel or strongly oblique to the dominant wind and all the deltaic barrier islands feature the lowest dune elevations (around or lower than 3–4 m). Maximum dune elevation (up to 8–10 m) is reached when the dominant winds (from ENE, and subordinately from the East) blow orthogonal to the shoreline.

Dunes were also classified according to their origin: *natural*, *induced by sand fences* and *artificial*. Since 1995, nourishment interventions have been carried out to maintain and restore the Veneto beaches. Works included dune construction by bulldozers (artificial dunes) and sand fence placement on the beaches in order to promote the deposition of wind-blown sand (induced by fence dunes). These interventions have allowed the formation of dunes along 17 km of coastline.

More than 50% of artificial dunes (4.2 km in total) are located in Cavallino, where protective artificial dunes were constructed using offshore mined sand and were subsequently planted with *Ammophila arenaria* (Fig. 6a). These dunes show anomalous monotonous morphologies determined by construction parameters. The

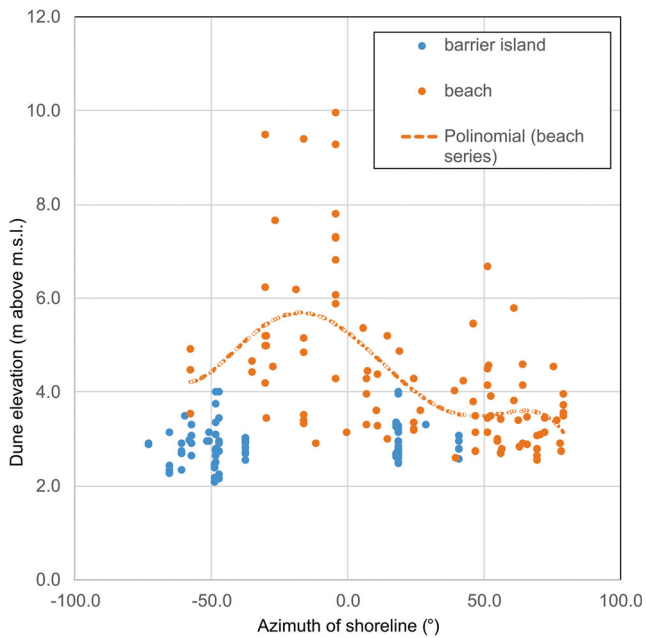


Fig. 5 Relationship between the orientation of the shoreline and dune elevation. Alluvial beaches are distinguished by narrow deltaic barrier islands, located along the perimeter of the Po delta, since the latter have their specific morphodynamics. Interpolation is given by a 5th order polynomial curve

placement of sand fences on the seaside has concentrated the deposition of sand in a fixed position, and the artificial dune has become an inactive environment with consequent *Ammophila arenaria* deterioration. Sand fences promoted the formation of a new foredune and the spontaneous growth of *Ammophila arenaria* in a more seaward position (Nordstrom et al. 2009) (Fig. 6b). In the same way, the use of sand fences has been demonstrated to be effective in most cases, for example, along Pellestrina (Bezzi et al. 2009). The characteristics of the induced dunes are often similar to those of the natural ones: elevation values are in compliance with the geographical distribution discussed above and native species are present, although the morphology is more straightened and the flanks steeper. Bad or ineffective results were obtained where the beach orientation was not favourable for

sediment transport across the beach, thus limiting the sediment availability, or where fences were positioned incorrectly (for example, too close to the shoreline).

Land use pressure

Specific attention was paid to the assessment of land use behind the backshore (hinterland) in order to highlight the potential pressure on each sedimentary cell, depending on the level of anthropisation of the territory. The basic idea is that a more human-developed coastal strip (with urban, industrial and touristic areas) represents a limiting factor for the formation and conservation of coastal dunes (Nordstrom 2000).

According to this analysis, coastal buffer with a higher level of anthropisation is the first 100-m-wide coastal buffer zone. The resulting data on the evaluation of Land Use Pressure on this buffer zone (Fig. 7) show that established foredunes are mainly located along coasts with low anthropisation (33 km), but also with medium (10 km), high (13 km) and very high anthropisation (2.5 km). Accordingly, the development of incipient foredunes and the conservation of relict dunes are also enhanced by low anthropisation, along 12 and 18 km of coastlines, respectively. Most parts of the tracts with dunes included in the zones with low or medium anthropisation are also protected as SACs. The most important is the area of the Po delta. A high degree of anthropisation of the coastal hinterland implies that the coastal system has a low degree of freedom and poses serious problems for the future, especially in view of rising sea levels.

Coastal dune and beach sedimentary budget

According to the main scope of the geodatabase, i.e. sedimentary management, the different sedimentary cells have been identified by the more recent sediment budget of the beach-upper shoreface system. Sediment budget – represented as a mean annual volume change per linear unit of shoreline (m^3/my) – refers to the period 2000–2010 for the littoral between the Tagliamento and the Adige rivers, and

Fig. 6 Photographs of dunes of different origin along the Cavallino beach: (a) artificial dunes constructed using offshore mined sand with anomalous monotonous morphology, (b) dune induced by sand fences on the seaside of the artificial dune; sand deposition and spontaneous growth of *Ammophila arenaria* are clearly seen

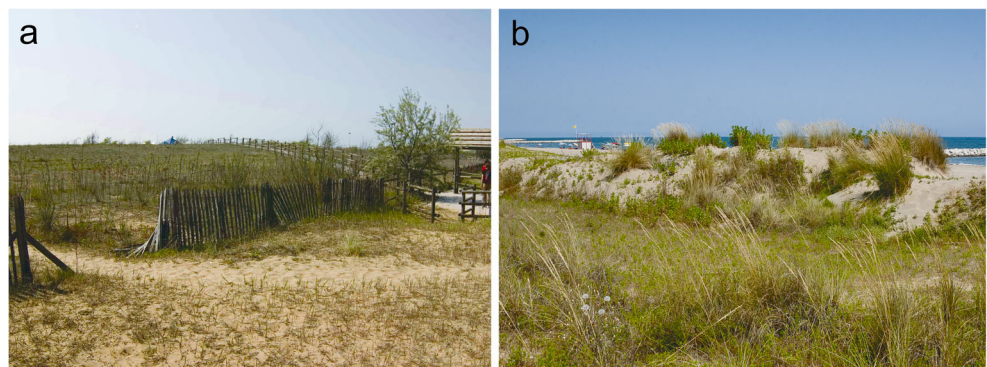
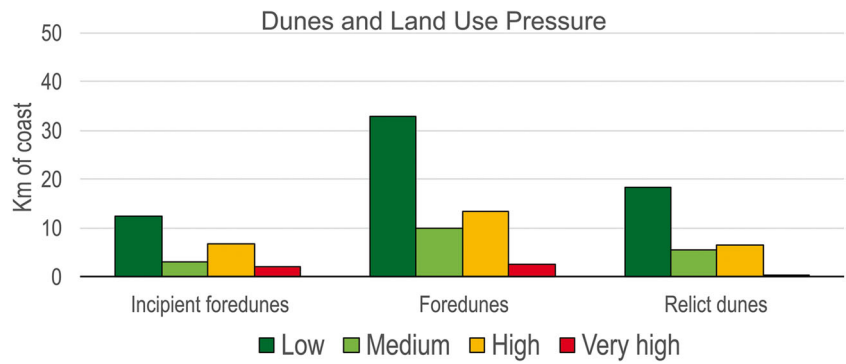


Fig. 7 Relationship between the presence of the aeolian morphologies (incipient foredunes, established foredunes and relict dunes) and the different grade of Land Use Pressure within the first 100-m-wide buffer coastal zone



to the period 2008–2014 for the coasts between the Adige and the Po di Goro rivers.

The geographical distribution of the foredunes classified according to the ASPE code is represented in Fig. 8, where the histogram cells are grouped in physiographic units.

The dunes are mainly located in costal cells with an accretionary trend (code A) greater than 5 m³/my (27 km = 45%). These data include 5.4 km of beaches either involved in recent beach nourishments (e.g. Cavallino and Jesolo in 2010) or still

under the effects of past interventions (e.g. Pellestrina and Cavallino) that included dune construction or sand fence placement (as described above). In the remnant sites (21.6 km), a natural positive budget promoted dune development and maintenance (southern part of Rosolina Mare, southern part of Lido island, southern part of Pellestrina, western part of Valle Vecchia). In Lido and Ca' Roman (Pellestrina) the accretionary processes occurred on the updrift side of jettied tidal inlets, where the longshore sand supply has been

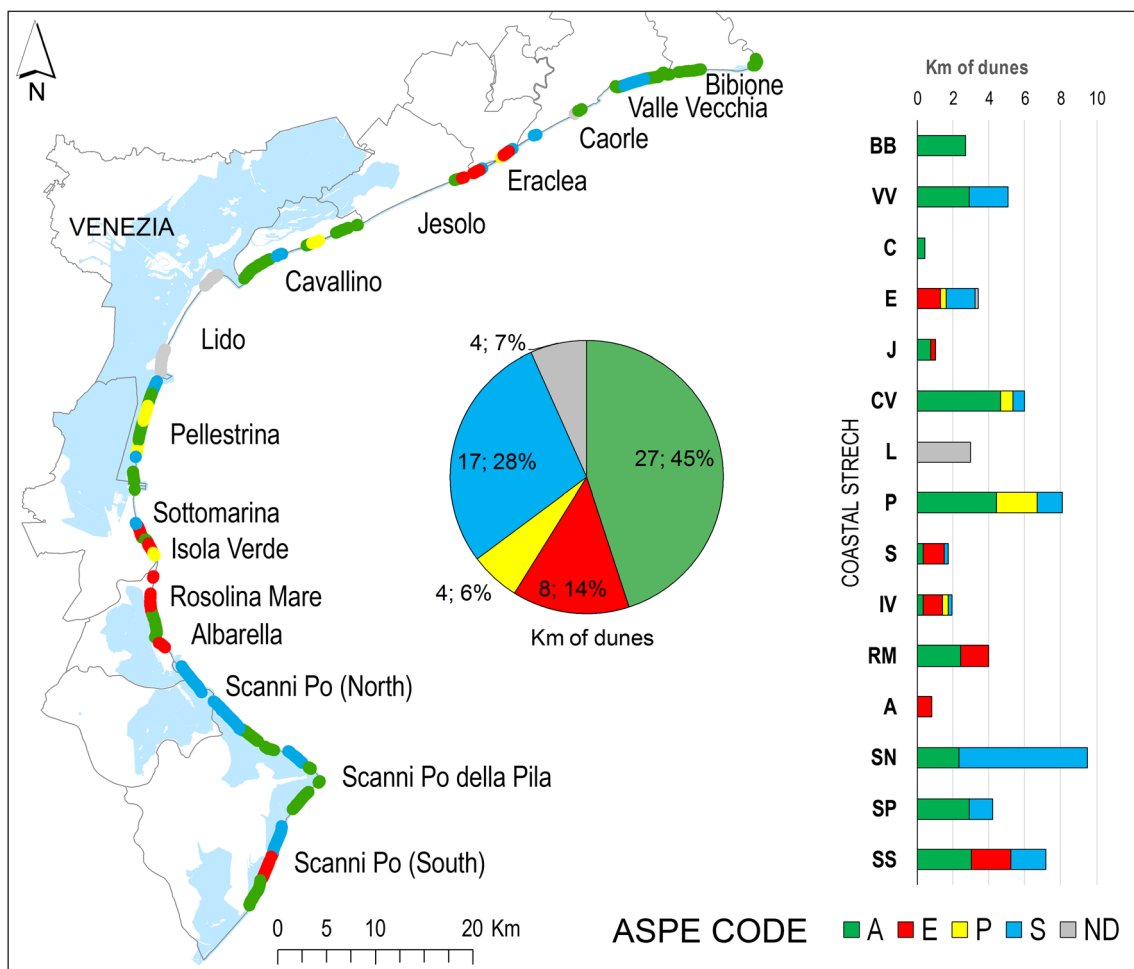


Fig. 8 Distribution of the beach sedimentary budget according to the ASPE code (Accretion, Stable, Precarious, Erosive). N.D. = Not Determined. In the histogram on the right, kilometres of foredunes are presented grouped according to the physiographic units

intercepted, and the consequent shoreline progradation has allowed the rapid formation of a foredune plain (Fig. 9a). These sites, although indirectly associated with human intervention, offer a good opportunity for geo- and biodiversity development and conservation. They are also functioning as open-air laboratories for improving knowledge about coastal dunes and identifying and quantifying aeolian processes at the local scale, which is useful for proper management of the neighbouring dune areas (Bezzi et al. 2005, 2009). In a more general sense, a positive sediment budget will offer a good perspective for future conservation of landforms and habitat and planning of a correct coexistence between dunes and recreational beach use (Bezzi et al. 2008).

The coastal stretch with dunes and a sedimentary budget evaluated as stable (code S) is 17.2 km, corresponding to 29% of the total coastline. In sites with prevalent natural dynamics such as Valle Vecchia, the foredunes are small (mean elevation 2.5 m), the orientation is longshore with respect to the dominant wind and the historical budget was slowly negative (Fig. 9b). In many areas with past chronically negative sedimentary budgets, the shorelines have been stabilised by hard defences (low-crested seawall), which prevents the natural exchange of sediment between the dunes and beaches, thus transforming foredunes into passive forms, comparable to the relict dunes (Bezzi et al. 2009). In some sites (i.e. Cavallino, Pellestrina and Isola Verde), a stable balance is maintained thanks to prior beach nourishment. Finally, some parts of Scanni North, Scanni South and Scanni del Po di Pila show recent stable trends and small dunes (average elevation = 2.9 m)

resulting from the morphodynamics typical of barrier islands along a deltaic coastline, strongly influenced and transformed by the direct terrigenous supply and wave attack.

Negative budgets lower than $-5 \text{ m}^3/\text{my}$ (code E) characterise 8 km (14%) of the coastlines, of which 4 km (6.8%) are characterised by sedimentary losses greater than $20 \text{ m}^3/\text{my}$. The presence of coastal dunes in tracts with erosive budgets is not typical along the Veneto coasts because, in the past, erosion involved the beach and the dunes together, causing their destruction and subsequent replacement with hard engineering defences. Nowadays, the presence of foredunes is limited to places where erosion has been managed with the interventions of beach nourishment and dune construction through fencing (Isola Verde, Sottomarina). A negative balance can cause the shoreline to retreat and re-activate the aeolian beach–dune feedback with the relict dunes, as observed in Sottomarina; these are high dunes (elevation between 5 and 7.7 m) that feature evident signs of erosion due to wind and storm scarping in addition to direct human interference (Fig. 9c).

Finally, the attempt to replenish beaches with a significant volume of sand that covered the already mentioned low-crested seawall, as along the Eraclea littoral, failed. There, the remnant foredunes are currently disconnected from the beach due to the effect of the hard defence, a 5-m-long rooted concrete sheet-piling, elevated 1 m above mean sea level. The beach has become a perched beach, moisture-laden most of the time, due to the scarce drainage constrained by the rooted impermeable structure, which prevents sand transport toward the dune (Fig. 9d).

Fig. 9 Different dune types associated with different ASPE context: (a) accretionary beach of Ca'Roman (Pellestrina) with the rapid formation of a foredune plain, (b) small foredunes along the littoral of Valle Vecchia, featured by a longshore orientation and a slowly negative historical budget (c) re-activate relict dunes along the beach of Sottomarina associated to negative sediment budget and shoreline retreat, (d) established foredunes disconnected from the beach due to the effect of the hard defence. The low-crested seawall is a 5-m-long rooted concrete sheet-piling, that limits the drainage from the perched beach, moisture-laden most of the time, thus preventing sand transport toward the dune



If we exclude dunes of the Po delta barrier islands, which are constrained by their specific morphodynamics, as well as a few outliers, dune elevation shows an overall inverse correlation with the beach-upper shoreface sediment budget (Fig. 10), although some of the highest dunes in strongly erosional contexts are re-activated relict dunes. The box inside Fig. 10 highlights that a negative sediment budget pertains to beaches with a limited shoreline retreat (on average between 0 and -3 m/y). Thus, the relationship between dune elevation and beach sediment budget is likely to be related to the more effective aeolian transfer for stable and slightly erosional beaches, which reduces their volume when transferring sand on the established foredunes, according to the conceptual model of dune development proposed by Psuty (1988).

Tourism pressure

In Italy, most beaches are managed as private properties in concession from the State, and managers implement different types of activities to enhance recreational use. Beaches or dunes are graded in order to improve space to accommodate visitors and recreational facilities, creating platforms and walkways, and the beaches are also cleaned through daily raking with mechanised equipment, facilitating beach access.

For this reason, the indicator Tourism Pressure implies some important consequences in relation to the beach state. Beaches with high or very high tourism pressure (Fig. 11) are usually flattened through frequent raking by mechanical equipment and occupied by recreational facilities (humbrellas, cabanas). The resulting topographic profile is anomalous, the bulk density of sand is modified, a significant amount of sand is removed with the wrack and the growth and germination of pioneer species is impeded. The lack of development of natural vegetation also

increases the vulnerability of the beach to wind erosion. As a consequence, the capacity of the beach to dissipate wave energy and its ecological value is reduced (Nordstrom 2000). The typical morphological indicator of this process is the lack of incipient foredunes on the backshore. As shown in the histogram in Fig. 11, the presence of incipient foredunes is negligible in beaches with very high tourism pressure, while it is more consistent in beaches with low tourism pressure.

Human impact and coastal dune management

Dunes in human-altered areas differ from each other depending on the way they are managed. Human impact, if not limited or correctly managed, could promote the alteration of morphologies, vegetation and beach–dune sedimentary feedback.

An inventory of human impacts on the studied dunes highlights different actions made both in natural areas and in areas with intensive beach exploitation, as follows:

- access way to the beach: 25 km of dunes are interrupted by gaps, often made by beach managers to facilitate access to the beach; alternatively, they may be the result of continuous trampling;
- flattened areas: 12 km of dunes are affected by grading of part of their extensions in order to provide new, flattened recreational spaces or to build facilities;
- pathways on the dunes: pedestrian trampling damaged vegetation and caused the formation of pathways along 24 km of dunes;
- structures placed on the beach: 17 km of dune are affected by the presence of coastal defences, buildings or other recreational facilities on the backshore. They may

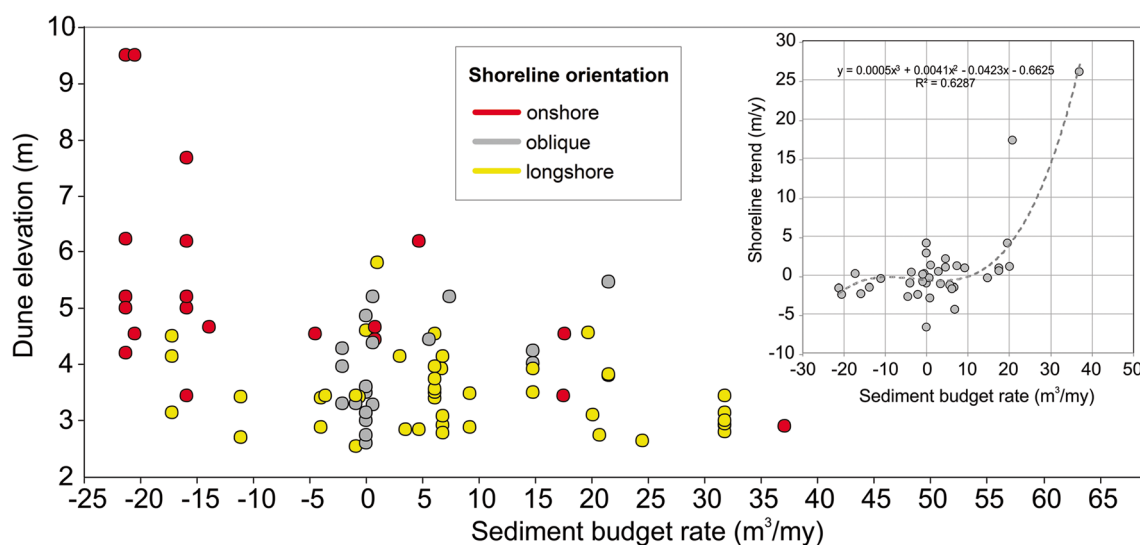


Fig. 10 Relationship between the sediment budget rate (referred to the beach and upper shoreface) and dune elevation. Beaches are distinguished according to their exposition to the dominant wind from

ENE. The inserted graph reports the correlation between the sediment budget and shoreline trend. Interpolation is given by a 3rd order polynomial curve

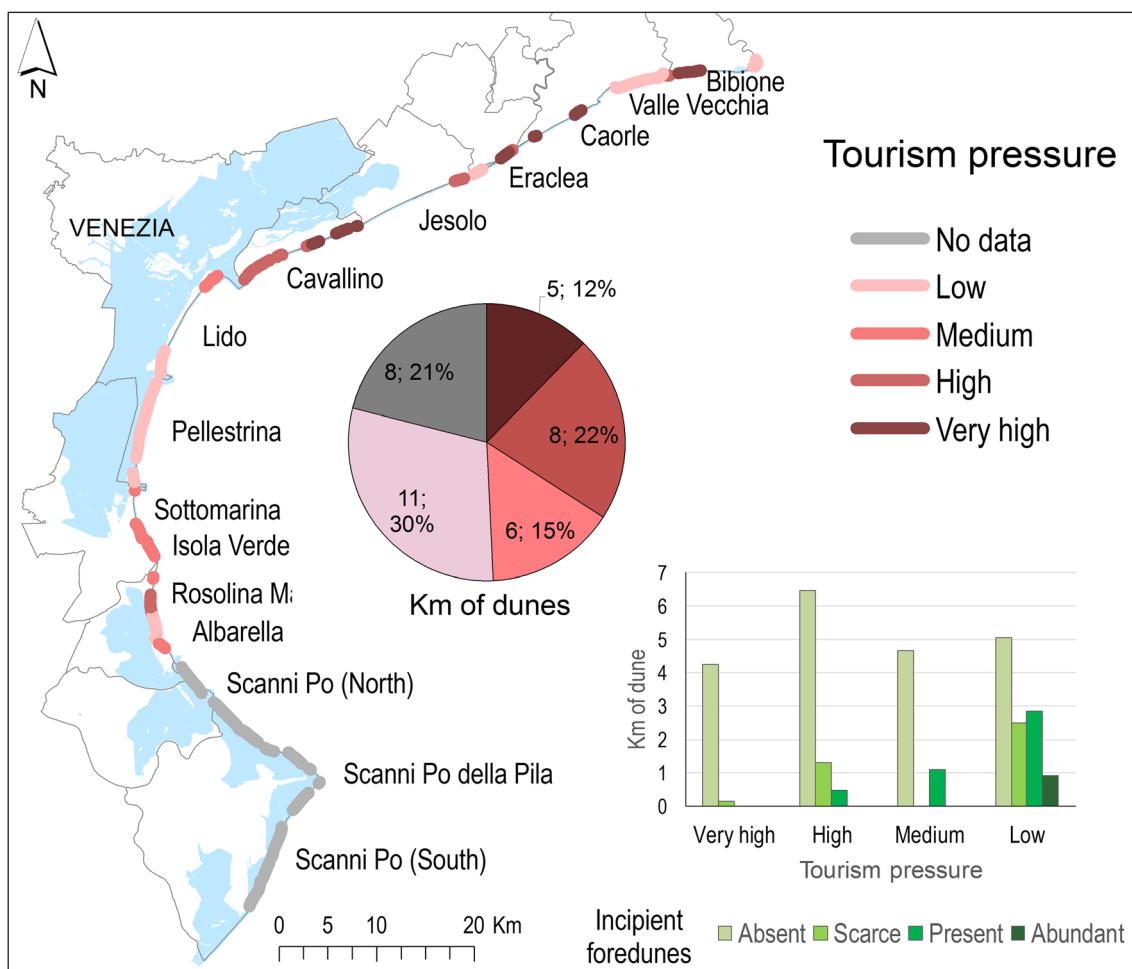


Fig. 11 Geographical distribution of costal dunes associated with different grades of Tourism Pressure. Histogram shows the presence/abundance of incipient foredunes associated with this index

represent an obstacle to the aeolian transport between the sediment source (the beach) and sink (the dune);

- anomalous vegetation: several inappropriate species were planted by managers along 26 km of dunes with the aim to improve aesthetic value, sand deposition or to stabilise the dunes;
- straightening of the dune: the seaside of 17 km of dunes is artificially straightened. Causes are routine beach raking or beach grading with the aim to improve space to accommodate visitors and recreational facilities.

We also considered those actions that reflect active management practices on the dunes, aimed to protect them or to promote their growth:

- sand fences: these structures are currently placed on 3 km of dunes, with the purpose to promote sand-trapping on the lee side of the dunes;
- protective fences: they are placed on the seaside of 9 km of dunes, aimed to limit visitor access and trampling, thus preserving vegetation;

- protected beach access ways and/or elevated walkways: fenced or elevated access ways make it possible to cross the dune fields to avoid disturbance along 13 km of littorals;
- signage: signage is only used on 7 km of beach–dune system to inform the community about undesirable behaviour (especially regarding access to the dune area) or on dune values. Although such information is crucial for sharing the meaning of the restoration projects, interventions and conservation practices, the messages and designs are often unclear and have poor informative contents; sign maintenance is also often lacking.

To contribute to furnishing guidelines for coastal dune management for the Veneto coast, a simple indicator called Management Effectiveness was developed. This indicator is the result of the combination of the different weights assigned to the variable Human Impact (from min = 0 to max = 12), with the attributes Low, Moderate and High, and the variable Active Management Practices, with the attributes Absent,

Table 2 Assessment of Management Effectiveness based on the combination of human impact and active management practices

Human Impact	Active Management Practices	Management Effectiveness
Low	Absent / Scarce	To Improve
Low	Moderate	Effective
Low	High	Effective
Medium	Absent / Scarce	Ineffective
Medium	Moderate	To Improve
Medium	High	Effective
High	Absent / Scarce	Ineffective
High	Moderate	Ineffective
High	High	To Improve

Scarce, Moderate and High (from min = 0 to max = 8) (Table 2). The resulting evaluation is as follows:

- Ineffective management: in these cases (11.6 km, 31% of dune length), the management is completely neglected or the active management practices are unsuitable to limit human impact, which results moderate or high.
- Management to improve: this category (18.4 km, 50% of dune length) includes different situations. Some dunes in areas with low human impact show signs of incipient deterioration, which would require a better and more precise management practice. Conversely, there are cases where bad management resulted in ineffective defence of the dunes and moderate to high human impact.



Fig. 12 Example of fragmentation of dune types and characteristics inside the same ASPE cell (Cavallino). See text for the explanation of the Human Impact and Management (Effectiveness) indices

Fig. 13 Evidence of the variability of beach uses and management along a short stretch of the Lido littoral. Here foredunes have been destroyed (fragmented) for tourism purposes



- c) Effective management: this concerns those cases (7 km, 19% of dune length) where the management practices are sufficient and effective for defending the dunes from human impact, which is thus low to moderate.

Our inventory on human impact and management practices highlights the great variability of these features along the same physiographic unit, but also at the scale of a single sedimentary cell. This is because of different fragmentary uses of the beaches and different management mandates. In 43% of the sedimentary cells, dunes with different characteristics coexist, proving that human constraints are more important than the natural ones. As an example, Fig. 12 reports on the Cavallino beach cell. Fig. 13 shows the iconic case of dune fragmentation due to an uncorrected beach use along the Lido littoral.

Beaches of variable extent are given in concession to private companies that have the mandate of management, without any specific rule for the dunes. As a consequence, dunes are a sort of no man's land, as they are involved in interventions or are protected only occasionally, and they are rarely restored or maintained in a timely manner. In the worst cases, the dunes are completely abandoned to deterioration, or even deliberately damaged to increase beach space for umbrellas or used as a source of sediment for occasional beach replenishments. Walkways and fences are damaged or partially destroyed due to the lack of maintenance; moreover, signage is often ineffective due to a lack of informative content, or they become illegible due to wear or acts of vandalism.

Beaches without concessions along partially urbanised littoral feature dunes that survive and grow because of the lack of beach flattening from raking and recreational structures. Conversely, the lack of control and the large amount of marine litter released after sea storms promote illicit practices such as

abusive camping and dumping. As a consequence, the image of dunes and natural areas is damaged, as they are seen as dirty and unsafe places.

Finally, the natural areas recognised as SACs also have management issues. Although the management of SACs is entrusted to reliable and well-known organisations involved in environmental protection, interventions are often carried out without suitable scientific knowledge and are thus doomed to failure or even have detrimental effects (e.g. planting using species inappropriate for conservation of the ecological succession, dune reconstruction using inappropriate sediment, use of fences in areas with limited or scarce aeolian transport).

Conclusions

The Veneto region represents an appropriate study case for improving knowledge on coastal dunes in developed areas. In fact, favourable natural conditions for dune development and strong constraints due to long-term but fragmentary tourism exploitation act simultaneously.

The recent implementation of a Coastal Management Geodatabase for this region provides an opportunity to examine the distribution and state of coastal dunes and to evaluate different management approaches, with the aim to furnish a basis for appropriate future coastal planning.

The elevations and characteristics of the foredunes in the study area are influenced by the natural dynamics of the coastlines (orientation of the beach with respect to the dominant wind, the sediment budget of the beach, limited sand exchange along narrow deltaic barrier islands). The present dune distribution is strongly limited by human factors such as land use pressure of the hinterland and tourism pressure on the

beach, and indirectly by past and recent sedimentary budgets. Chronically negative sedimentary budgets have caused two different human responses over time with opposite consequences on dune distribution: the construction of hard defences on one hand, and the soft engineering intervention of beach nourishment with dune construction and sand fence placement on the other. Consequently, the amount of coastal dunes resulting from interventions is currently significant (29% of the total coasts with dunes), and these dunes represent an opportunity for enhancing bio- and geodiversity. At the same time, due to various beach sedimentary budget contexts, foredunes are a critical issue for near-future conservation.

The assessment of a simple indicator such as Management Effectiveness related to the dunes represents the first attempt in this region to achieve updated knowledge on the beach/dune human impact and management practices. Although this indicator could be improved, the first results highlight one of the more critical aspects of the Veneto dunes: the lack of effective, systematic, correctly scheduled and performed management actions.

Accordingly, the SICELL method, even though it has been demonstrated to be a good tool for coastal sediment management, seems to be of limited application for dune management because of the great variability in effective beach use, human impact and management on the different dunes stretches. From this perspective, authorities and stakeholders should improve the scale of work and refer to the details of the GCV to develop future strategies. Taking into account that the principal challenge for this region is the coexistence between dune conservation and tourism exploitation, future management guidelines must be specific and suitable for dunes. Practices for beach/dune use should tend to be homogeneous and involve the different stakeholders.

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