Recent Changes of Ecosystem Surfaces and their Services Value in a Mediterranean Costal Protected Area: the Role of Wetlands

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Abstract
Coastal ecosystems provide key services, but human activities and natural phenomena such as coastal erosion can strongly affect them. These changes can induce severe ecological and economic damages. This study aims to evaluate temporal changes in a protected area (Regional Park of Maremma, Southern Tuscany, Italy) in terms of both ecological and economical damage associated with ecosystem services loss observed over the period 2001–2014. Studies were performed using remote sensing as well as field verification for more critical habitat types. Results show an overall reduction of the habitat in flooded areas. During the study period total Ecosystem Services Values (ESV) decreased by more than 13% and the major contributor to that changes is loss of wetlands (net reduction of about 4.3 M US$/y), not directly beach erosion. Although this study proposes a first order approximation in terms of ESVs of considered biomes, these values are set to increase in the near future as knowledge and technologies improve. Therefore, wetlands management plans are crucial in this context, and could have much more significant effects on ecosystem efficiency and resources for future generations than beach erosion prevention.

Introduction

Coastal ecosystems are a dynamic and complex mosaic of habitats of great ecological value that provide unique, low-redundancy services and offer a wide range of benefits both from the economic and ecological points of view, but at the same time many of these ecosystems have become degraded due to several factors (UNEP 2006). Among others ecosystems that provides key services there are beach and dunes (Malavasi et al. 2013; Drius et al. 2016) and wetlands. Wetlands play a very important role as constitute biodiversity hotspots, supporting the presence of a multiplicity of habitat niches and, consequently, species of the greatest ecological concern. Several studies have evidenced significant difficulty in defining and classifying specific habitat traits of wetlands (Tagliapietra and Volpi Ghirardini 2006; Pérez-Ruzafa et al. 2011). In fact, according to the "Convention on wetlands of international importance, particularly waterfowl habitat" (1971), wetlands are classified as "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of sea water the depth of which at low tide does not exceed six metres, and which constitute a resource of great economic, cultural, scientific and recreational value, the loss of which would be irreparable*". The ecological relevance of these habitats is due mainly to the presence of great biodiversity in both animal (fishes, amphibians, birds, invertebrates) and vegetal (aquatic macrophytes) species (Moyle and Leidy 1992). Worldwide, wetlands are the ecosystems most exploited by human activities, such as sport fishing, aquaculture, hunting, timber and reed cutting, food gathering, and recreational activities (Ferronato et al. 2000; Ramsar Convention Secretariat 2006). A significant share of fish production in the Mediterranean basin (10–30%) comes from aquaculture in wetlands (Petrella et al. 2005). Furthermore, wetlands ensure important ecosystem services such as gas regulation, climate regulation, water supply, nutrient recycling and waste treatment (Mitsch and Gosselink 2000). Ecosystem services are defined as the sum of goods and services that a specific biome could provide, and consist of flows of material, energy, and information forming natural capital stocks, which combine with manufactured and human capital services to produce human welfare (Costanza et al.

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1997;MA 2005). Ecosystem services can be classified, mapped, measured and valuated according to various criteria, as reported in the literature (Costanza et al. 1997, 2014; Kreuter et al. 2001; Landry and Liu 2009; de Groot et al. 2012). Costanza et al. (1997) initially highlighted the economic advantages of wetlands conservation so that the wetland category of land use has been associated with the highest unit value of ecosystem services (about 14,785 \$ ha^{-1} per year). The monetization approach to ecosystem services proposed by Costanza et al. (1997) should not be interpreted as an extreme simplification of a complex matter like ecosystem conservation, but rather as a means to allow us to construct a more complex and balanced picture of the assets that support human interdependence with the well-being of ecosystems (Costanza et al. 2014). In fact, expressing the value in monetary units must not lead to the privatization and trading of public services as commodities in private markets. Rather, it should be an instrument that supports conventional decision-making frameworks (de Groot et al. 2012). At large-scale levels, a wide range of socio-economic and environmental factors affect ecosystem services valuation, including employment and living conditions, income levels, population density and prices (Barrio and Loureiro 2010) and problems of identification buffer zones between different habitats (Di sabatino et al. 2013). As reported by Brander et al. (2011), these factors could be measured and controlled for in a complete and complex meta-data analyses on local measurements that would otherwise be time-consuming and expensive. Alternatively, the "benefit transfer" approach, based on environmental value transfer criterion, allows estimation of ESVs in a studied ecosystem using existing studies that best match the new context (Brouwer 2000). Environmental value transfer, as reported by Brouwer (2000), is the transposition of monetary environmental values estimates at one site (study site) through market-based or non-market-based economic valuation techniques to another site (policy site).

The Mediterranean region hosts only about 1–2% of the world's wetlands and the Mediterranean Wetlands Observatory reports that in the last 100 years about 50% of wetlands have been lost (MWO 2012). The most represented Mediterranean wetlands are temporary marshes and pools, lakes, reservoirs, rivers, deltas, and lagoons (MWO 2012). The last two environments, also known as transitional coastal ecosystems, are characterized in particular by the variable spatial and temporal commixture of fresh water and marine water (Petrella et al. 2005). These habitats have a physical-chemical gradient that drives and supports a multiplicity of ecological niches and thus makes them a "hotspot" of biodiversity (Ferronato et al. 2000). In these ecosystems, primary productivity is about 10 times greater than in marine ones, and could support high rates of fish growth and fish productivity (Petrella et al. 2005). Since the 1950's most wetland areas have been reclaimed for agricultural and sanitary purposes, and few flooded areas survive today. In Italy, wetlands were reclaimed to build industrial plants and power plants, with a consequent severe impact on coastal ecosystems. In addition, global warming represents a possible impact on wetlands due to rising seawater levels consequent seawater flooding (Stoch 2004, 2009) and coastal erosion (MWO 2012). Furthermore, preserving wetlands functions and services are considered among the priority of the Water Framework Directive and the management of water scarcity is recognized as a major future challenge especially in southern Europe (European Commission 2010).

The Regional Park of Maremma includes the estuary of the Ombrone River and several European Union Sites of Community Importance (SCI), Special Protected Areas (SPA) and Sites of Regional Importance (SRI) of particular ecological concern (Regione Toscana 2013). Despite of its importance, it is severely affected by coastal erosion with a progressive loss of beaches from 1883 to the present (Cipriani et al. 2013). The erosion process is particularly worrisome due to the area's ecological relevance as well as seasonal tourism-based economic interests. Numerous studies have been carried out to analyse erosion and historic and recent coastline evolution (Pranzini 1994a, b, 2001; Tarragoni et al. 2011, 2015; Cipriani et al. 2013). Fewer studies have focused on the consequences of these processes on aquatic habitats and, in particular, on the canals, coastal lagoons, salt marshes, flooded plans, and temporary ponds that are present in this area. The presence of these habitat types is particularly important for the conservation of wetlands in coastal ecosystems especially at large spatial scale.

The aim of this study is to evaluate the recent and decadal evolution of habitats in a highly dynamic coastal ecosystem of particular ecological and economical concern: Regional Park of Maremma (Southern Tuscany, Italy). In particular, in this study were performed: i) an retrospective analysis of habitat evolutions by satellite images elaborations, in line with the EU Biodiversity Strategy 2020 that planned strategies for ecosystem conservation entailing the assessment, mapping and valuation of all ecosystem services in Europe (European Commission 2011); ii) a detailed in situ screening of wetlands to evaluate recent changes due to natural and anthropic factors, and additionally, iii) we provide an estimation of the ecosystem services values related to the study area using benefit transfer approach. In this study, the temporal evolution of habitat surfaces and the economic value of ecosystem services associated were estimated since 2001 according to Costanza et al. (1997, 2014).

Materials and Methods

Study Area

The study area (Fig. 1) covers about 1600 ha lying within the Regional Park of Maremma (Tuscany, Italy) and includes three Sites of Community Importance (SCI) belonging to the Natura 2000 network. The three sites are recognized as well Sites of Regional Interest (SRI) from the Tuscany Regional Law n. 56/2000. In addition, the study area is included for a large part in the Ramsar Site "Padule della Trappola-Foce dell'Ombrone". The study area represents the most dynamic part of the Natural Park due to the presence of low-lying areas and the Ombrone River delta, and comprises some priority habitats and species (Regione Toscana 2013). The study area is characterized by a fairly uniform geomorphology featuring 17 beach ridges set more or less parallel to the coastline and delimited to the south-east by the Uccellina hills. The presence of dunes and inter-dune depressions lends a peculiar patchiness to the ecosystem, supporting great local biodiversity (Bazzichetto et al. 2016). Coastal ponds called "Chiaro Grande" and "Chiari del Porciatti" lie in the northern part of the Ombrone River delta in the Trappola area (Tarragoni et al. 2011, 2015) where the interdune distance is sufficient to contain perennial water ponds (Sgherri and Costantini 2004; Bellotti et al. 2004). Due to their depth, represent a more stable aquatic environment (mean depth about of 3.5 m, with the maximum depths of about 4.5 m; Tarragoni et al. 2011, 2015). These ponds are also characterized by patchiness, with small- and medium- scale zones, some marked by the presence of *Ruppia spp.,* others by Chlorophyceae, others by bare sediment bottoms and other covered with *Cerastoderma glaucum* shells or *Ficopomatus enigmaticus* tube aggregates. The littoral belt of them presents a dense growth of *Phragmites australis*. Closer to the river delta there are some temporary beach ponds with sandy bottoms and *Ruppia spp*. meadows. During rainy seasons, interdune areas are flooded, creating singular habitats with water a few centimetres deep. During summer droughts, these habitats dry up and became muddy, salty plains covered with halophile vegetation like *Salicornia* ("habitat 1310/annual and pioneer species such as *Salicornia* and other species typical of sandy and muddy zones" - Regione Toscana 2013). This habitat joins the halophile habitat featuring Chenopodiaceae ("habitat 1420/ Mediterranean and thermo-Atlantic prairies of halophyte as *Sarcocornietea fruticosi*" - Regione Toscana 2013), dominated by perennial *Sarcocornia* and *Arthrocnemum* taxa. One rare species, *Halocnemum strobilaceum,* is present only in the study area and one other area of Continental Italy (Regione Toscana 2013). Halophile habitats alternate in a mosaic pattern with "1410/Mediterranean salt meadows (*Juncetalia maritimi*)" (Regione Toscana 2013), with dense growth of *Juncus maritimus* and *J. acutus*. The Mediterranean brush is dominated by *Juniperusoxycedrus* ssp. *macrocarpa* and *J. phoenicea* ssp. *turbinata* which colonizes the northern coast of the Ombrone River delta. *Limonium etruscum* is an endemic local punctiform protected species established in the Southern part of the study area (Giovacchini and Stefanini 2008). It has recently been affected by significant coastal erosion and salinization of groundwater aquifers (Cipriani et al. 2013). The study area also includes some priority habitats according to 92/43/CEE (Council Directive 1992; Biondi et al. 2009): habitat 1150/Coastal lagoon, habitat 2250/Coastal dunes with *Juniperus spp*., and habitat 2270/Wooded dunes with forests of *Pinus pinea* and/ or *Pinus pinaster*) (Regione Toscana 2013; Giovacchini and Stefanini 2008). In the southern part of the Ombrone River delta, there is a human-managed area (Fig. 1, #3) where it was built an embankment and forced drainage of water through a pumping system to counter coastal erosion.

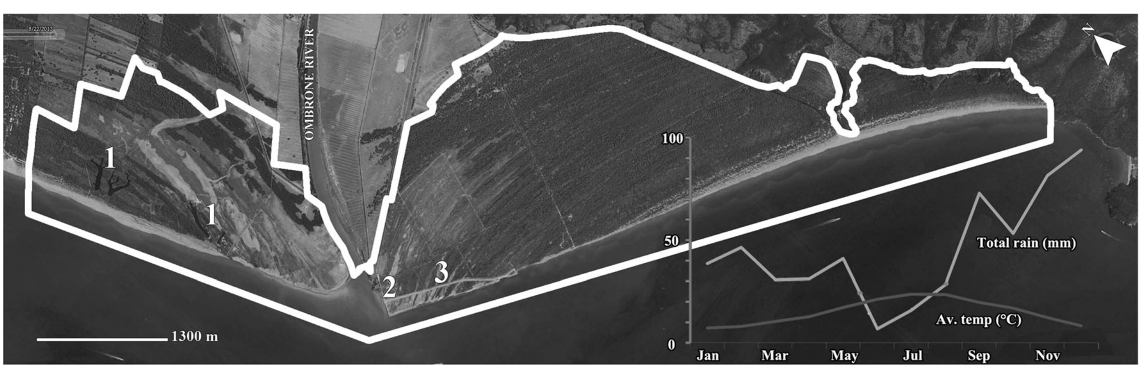


Fig. 1 Study area and thermopluviometric average trends. The study area is indicated with a white line. The diagram shows thermopluviometric average data (total rains and air temperatures) collected from 2001 to 2010 at meteorological station n. 103 - Alberese by ARSIA. Notes: 1 = Chiari; 2 = meteorological station; 3 = Human-managed area (Saline San Paolo)

Retrospective Analysis of Ecosystem Evolution

Satellite data are used to examine spatial and temporal trends in environmental studies (Specchiulli et al. 2008; Focardi et al. 2009). The availability of an historic data series allows evaluation of changes over time due to natural or human-induced factors. Google Earth® images of the study area were collected for the years 2001 (September), 2004 (September), and 2013 (August). Images referred to the end of the warmest season were selected to standardize the impact of rain and evaporation of wetland extensions. The warmest period (June – August) was selected by analysing historical series of meteorological data on total rain and air temperatures (ARSIA 2015) collected at meteorological station n. 103 – Alberese, placed inside the study area (Fig. 1, #2). This allowed us to standardize measured flooded surfaces as minimal and to assume that the areas flooded during the warmest period are in fact permanently flooded throughout the year. All the images were acquired at an altitude of 5500 m to get more detail on the ground. The identification of shoreline evolution has been obtained by superimposition of the three historical images (2001, 2004, and 2013) through the identification of fixed points and marking the line between water and sand. Ecological evaluation in term of habitat variations was based on quantification of the habitat areas as revealed in satellite images through photo interpretation. In situ surveys were performed to check and correct satellite-based interpretations. Habitats were classified using "Biomes" categories proposed by Costanza et al. (1997, 2014). We adopted this classification because it is globally recognized and because it makes less problematic to identify habitats within biomes. The use of more detailed classification of habitats could create more difficulties due to ecotones identification and classification. Biome's surfaces were outlined in different colours to isolate total surfaces and classes considered. ImageJ software (v1.50i, Wayne Rasband, National Institute of Health, USA) was used to evaluate the area of outlined surfaces. Categories identified were "Coastal" including area from the sea to the back dunes, "Forest" including principally pinewood, "Grass/rangelands" including meadows, pastures and the Salicornia and "Wetlands" including all flooded areas and canals. Urban areas (i.e. buildings and infrastructures) cover a negligible area and were not considered. For the analyses we divided Coastal category in "Beach and dunes" and "Sea" sub-categories, according with Wilson et al. (2005), to better detect the influence of coastal erosion in the first of them. Seasons not entail difference in the identification of forest and shrubland areas due to the dominance of evergreen woody species (mainly *Pinus pinaster* and *Pinus pinea* L.) while Mediterranean shrub land is a marginal component.

Dynamics Affecting Wetlands: Habitat Type Changes

We focused on coastal wetlands because these ecosystems contain key features for biodiversity conservation and at the same time are particularly vulnerable. The presence or the absence of water during the driest season is the key ecological factor in influencing flora and fauna associated (Bolduc and Afton 2004; Osland et al. 2011) and, as a consequence, in determining habitats of major ecological concern. Furthermore, Costanza et al. (2014) indicated wetlands as the biome with the highest unit value (193,843 2007$*ha^{-1} per year). In this study four years in situ observations period was considered (2011–2014), even if the study period is not enough to draw general conclusion, it is useful to get preliminary observation and to assess the actual situation. Wetlands were monitored in detail and temporary evolution of aquatic environments and large-scale dynamics was evaluated in 2011 and 2012 by direct survey at 102 sampling stations within the study area located in the northern (N; $n = 76$) and southern (S; $n = 26$) parts of the Ombrone River delta. Sampling stations were randomly selected in all flooded areas present in the driest season of 2011. In 2014, 32 sampling stations ($n = 14$ in N and $n = 18$ in S of the Ombrone River delta) were selected from the former 102. In each sampling station, water presence/absence, water depth and the habitat type were recorded. The habitat type was classified taking into account morphological features and the substrate type observed during direct surveys. On the whole, four different habitat types were considered for wetlands: Salt marshes (flooded plain with muddy bottom, without aquatic vegetation, water depth < 15 cm); Canals (artificial canals, various substrates with or without aquatic vegetation, variable water depth); Coastal lagoons and ponds (body of water with muddy substrate, presence of aquatic vegetation, water depth > 15 cm); Beach ponds (body of water located on the beach with sandy substrates, often with aquatic vegetation, water depth > 15 cm).

Economic Values of Ecosystem Services

Economic evaluation is a useful tool for weighing the complexity of ecosystem services because it produce data in a well-known form that may be used in decision making context, for example, for performing environmental analyses like retrospective analyses of the effects over time of local environmental management actions. Unit values (called below also coefficients) calculated by Costanza and colleagues and published in 2014, relative to 1997 and 2011 estimations, were used to assign a value to the areas previously identified. So, we followed "benefit transfer" technique (but see Plummer 2009 for the limits of this approach). This approach allows estimation of ESVs in a studied ecosystem using existing studies that best match the new context (Brouwer 2000). Costanza et al. (1997) is recognised as the most-cited study applying benefit transfer techniques to estimate ESVs. The absence of local studies on the Regional Park of Maremma precludes the utilization of matching local values. Furthermore, although there are some studies in the literature on coastal ecosystem values (see for example Barbier et al. 2011), they focus on coral reefs, or on other continents, so calculated values are not a good match for Mediterranean coastal areas. In addition, available studies for the Mediterranean area only quantify some ecosystem services (see for example Drius et al. (2016) concerning carbon sink and diversity sources services), often without estimating their economic value. In our opinion, the use of these studies could induce greater estimation errors than the use of Costanza's ESVs. The use of unit values calculated by Costanza et al. (1997, 2014) is justified by the fact that for every biome they cobbled together estimates from different areas and different socio-economics context and glean a mean value that we can use in replacement of more detailed studies. In particular, for Coastal area was used the coefficient related to the sub-category "Estuaries", for Forest area was used coefficient related to "Temperate/boreal" sub-category, Grass/rangelands coefficient for the same named area category and for Wetlands was used the coefficient relating to the sub-category Tidal marsh/Mangroves. An economic Value of Ecosystem Services (ESV) was associated with each class of biome (k) as per both 1997 ($ESV_o k$) and 2011 ($ESV_n k$) Costanza and colleagues estimations to take into account recent revaluations due to enhanced scientific knowledge and recent improvements in evaluation techniques regarding ecosystem services. $ESV_o k = \sum Sk \times C_o k$ where: $ESV_o k$ is the economic value of the ecosystem services for the k biome obtained through application of 1997 coefficient; $\sum Sk$ is the total surface of the k biome and $C_o k$ is the unit value (2007\$ ha^{-1}*per* year) of the k biome, while $ESV_n k = \sum Sk \times C_n k$ where: $ESV_n k$ is the economic value of the ecosystem service for the k biome obtained through application of 2011 coefficient, $\sum Sk$ is the total surface of the k biome and $C_n k$ is the 2011 unit value (2007\$ ha^{-1}*per* year) of the k biome. Values obtained were summed separately to calculate total ESV_o and ESV_n for the study area.

Results

Retrospective Analysis of Ecosystem Evolution

In Fig. 2 the temporal evolution of the study area in the period 2001–2013 is represented. As shown in the figure, the Ombrone River delta was subject to a significant erosion process during the study period, with the northern part

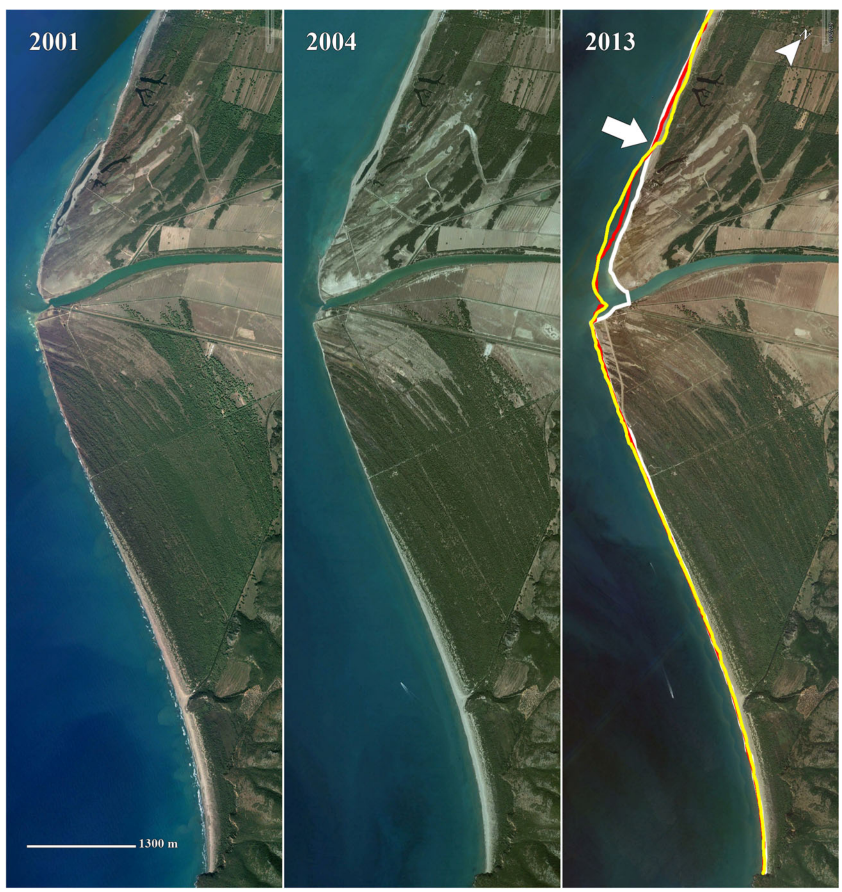


Fig. 2 Temporal evolution of the study area. Temporal evolution of the study area is reported by means of ortho-rectified satellite images (Google Earth®) within the study period 2001–2013. The evolution of the coastline is illustrated using different coloured lines in the 2013 image. Specifically, the yellow line represents the coastline in 2001, the red line represents the coastline in 2004, while the white line represents the coastline in 2013. The white arrow indicates an inversion of the erosion trend

particularly affected. Halfway up the coastline, an inverse trend of the sedimentation process can be seen. Consequently, a net increase in beach area from 2001 to 2013 is observed near the northern extremity of the study area. The southern wing of the Ombrone delta is more stable in terms of shore line shifts, and very limited fluctuations are observed. Temporal evolution of areas covered by each biome sensu Costanza et al. (1997) is shown in Figs. 3 and 4, while associated areas are reported in Table 1. The amount reported in Table 1 under Coastal category is the sum that included both Sea and Beach and dunes sub-category. Coastal area on the whole (light blue and pink in Fig. 3) increases of about 44 ha from 2001 to 2013. In spite of the increase of Coastal, the component Beach and dunes changed from 106.42 ha in 2001, to 100.56 ha in 2004 and 105.72 ha in 2013 with a net reduction of 0.7 ha during the study period. Concerning Forest, a notable decrease in covered surface is observed during the study period. This area, with a net loss of about 72 ha, appears to have been the most strongly affected. Wetlands were progressively reduced by about 22 ha during the study period (with a loss of 63% of wetlands area in 2001).

Dynamics Affecting Wetlands: Habitat Type Changes

Results obtained from the 2011, 2012 and 2014 in situ surveys are shown in Fig. 5a, b. In particular, Fig. 5a illustrates a comparison between 2011 and 2012, and Fig. 5b a comparison between 2012 and 2014. Because of in 2011 sampling stations were selected randomly but only in flooded areas, the percentage of dry stations for that year is 0%. In 2012, 17.65% of the total number of sampling stations throughout the entire study area were dry. In particular, in the southern part of the Ombrone River delta 53.85% of the total number of sampling stations had dried up in 2012, while in the northern part of the delta only 5.26% of sampling stations were dry that year. From 2012 to 2014 a further appreciable reduction in wetlands was recorded and no new flooded areas were formed. Of the 32 sampling sites used throughout the entire study period, 56.25% dried up between 2011 and 2014, more than 66% of sampling sites in S and more than 42% in N.

Concerning the total amount of lost wetlands, detailed analyses were carried out to evaluate the type of habitat lost (Fig. 6). Overall, salt marshes (T1) were reduced by 39.39%.

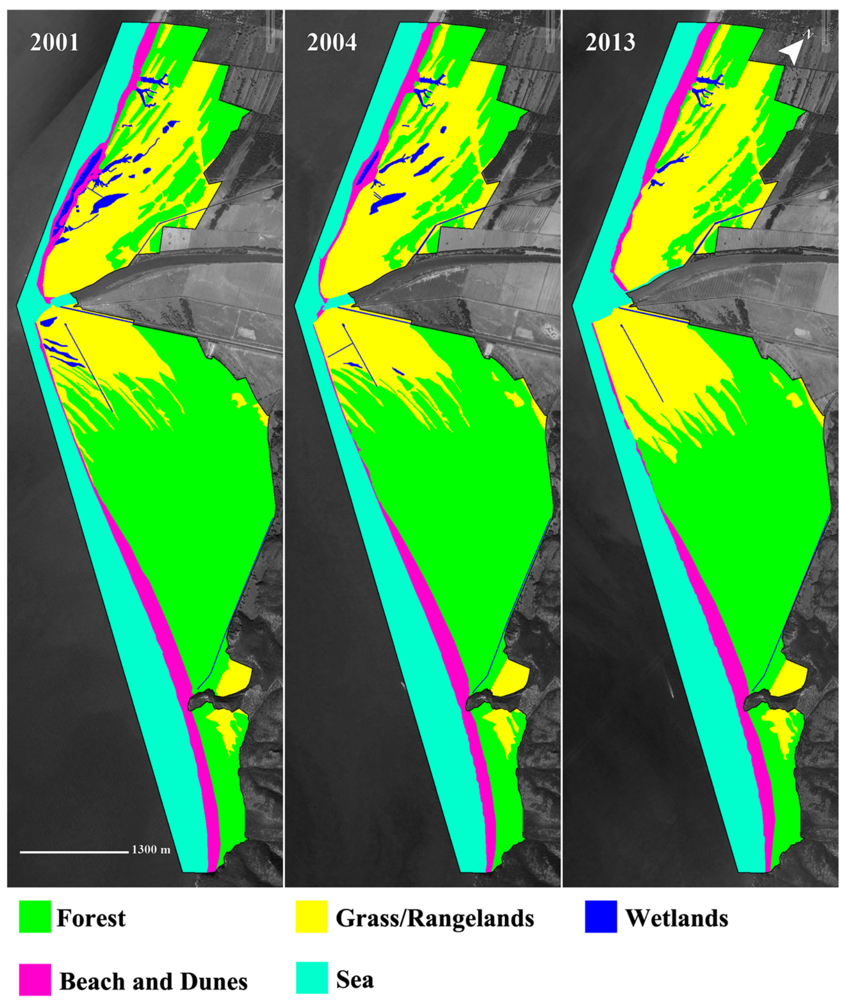
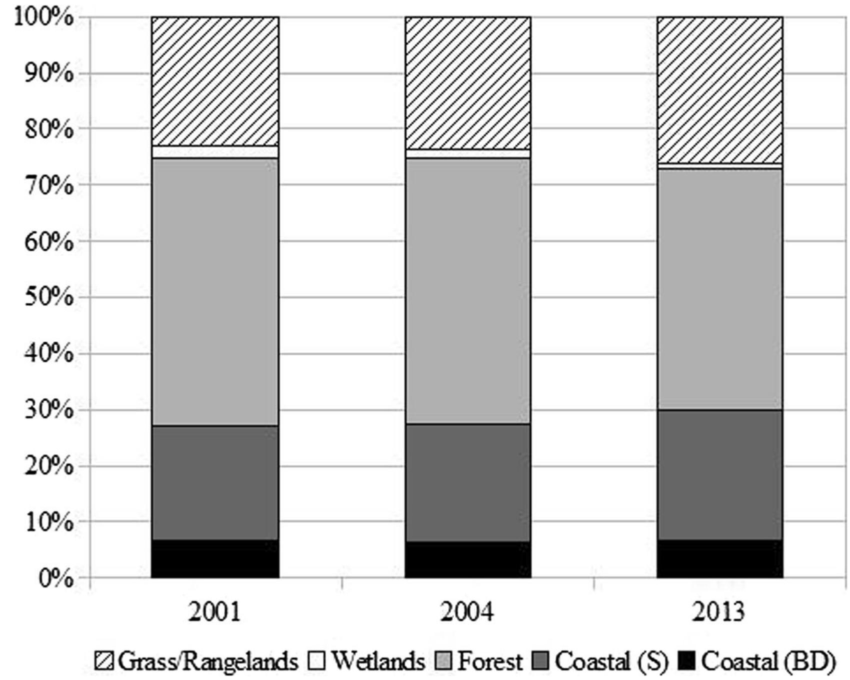


Fig. 3 Biome surface areas in studied area 2001–2013. In the study area, the temporal evolution of surfaces covered by different biomes sensu Costanza et al. 2014 is represented within the study period using different colours

Fig. 4 Percentage of different categories of area detected on the total surface. Coastal category is splitted in Sea (S) and Beach and dune (BD)



Loss of salt marshes was highest in the S area: 70.59% of sampling sites flooded in 2011 were completely dry in 2012. In contrast, only 6.25% in N (one of 16 sampling sites) of flooded sampling sites in 2011 were dry in 2012. Canals (T2) are subject to annual management efforts and are much more stable than other wetlands. Nevertheless, canals also showed a reduction in area, with a loss of 13.64% in sampling sites throughout the entire study area (22.22% in S and 7.69% in N). Coastal lagoons and ponds (T3) decreased by 4.44% (one of 43 sampling sites) in N in 2012 (no T3 habitat type was present in S area). Beach ponds (T4) showed a reduction of 25.00% (one of 4 sampling sites) in N from 2011 to 2012 (no T4 habitat was present in S during the study period). In sampling stations located near the sites of management efforts ($n = 32$), T1 habitat type showed a greater reduction, and 75.00% of sampling sites flooded in 2011 were dry in 2014. The same percentage decrease was recorded in S and N. T2 showed no further reduction in 2014, nor did T3: all sampling sites flooded in 2011 were still flooded in 2014. In 2014, all T4 habitat types recorded in 2011 and 2012 had disappeared from the study area, having dried up or become marine habitats.

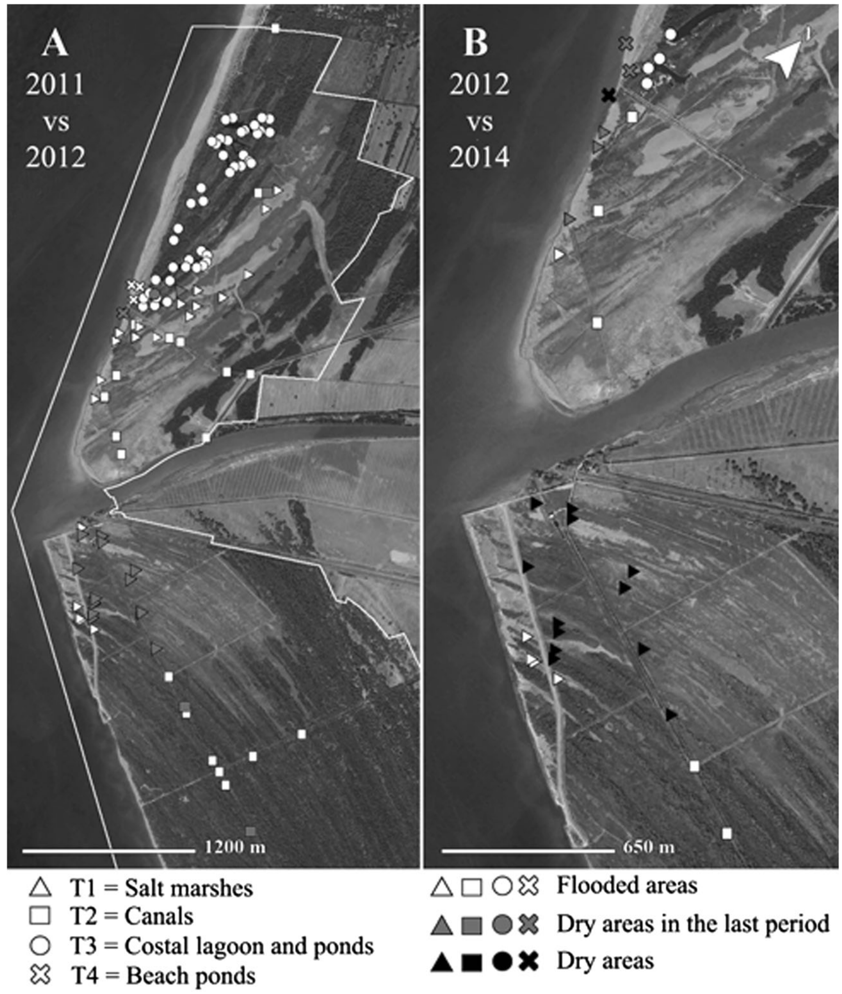
Table 1 Categories of area detected, relative surfaces and difference between 2013 and 2001

	Area (ha)			
	2001	2004	2013	Δ
Coastal	432.62	439.35	477.02	44.40
Beach and dunes	106.42	100.56	105.72	−0.70
Sea	326.20	338.80	371.30	45.10
Forest	762.10	755.97	690.07	−72.03
Grass/Rangelands	368.76	379.32	418.71	49.95
Wetlands	35.40	24.25	13.08	−22.32
Total	1598.89	1598.89	1598.89	

Economic Values of Ecosystem Services

Overall annual Values of Ecosystem Services (ESV) are reported in Table 2 for each considered year (2001, 2004 and 2013) and the contribution of single categories of habitat on the total value of ecosystem services are expressed in Fig. 7. The use of 2011 unit values produces ESV_n that are on average one and a half times bigger than ESV_o calculated using 1997 values, both expressed in 2007 US dollars. Also considering change in value from 2001 to 2013, ESV_n appplication highlights an overall decrease in value of the study area (−3060.59 $*10^3$ US$/yr), which is not evident when ESV_o is used (1077.37 $*10^3$ US$/yr). Using ESV_n, Coastal show a progressive increase in value during the study period of 1283.98 $*10^3$ US$/yr. With regard to the Forest category, ESV_n decreases of 225.96 $*10^3$ US$/y are almost completely offset by the increase in value of the Grass/Rangelands component (208.08 $*10^3$ US$/yr). The largest decrease in ESV_n regards Wetlands (−4326.08 $*10^3$ US$/y), and it is due to both loss of flooded areas (about 63% of the flooded areas that had been present in 2001) and the high per hectare value of this component. In 2001, Wetlands represented almost 2% of the total surface of the study area, but decreased by 1% between 2001 and 2013, producing a loss of ESV_n of 4326.58 10^3 US$/yr.

Fig. 5 Habitat type changes 2011–2014. The white line indicates the study area. Habitat type changes are represented comparing pairs of years, specifically, in (**a**), comparisons between 2011 and 2012 in 102 sampling stations, and in (**b**) comparisons between 2012 and 2014 in 32 stations. Notes: T1 = salt marshes; T2 = canals; T3 = coastal lagoon and ponds; T4 = beach ponds. White figures are flooded areas, black and grey ones are dry (the grey ones in the most recently analyzed period)



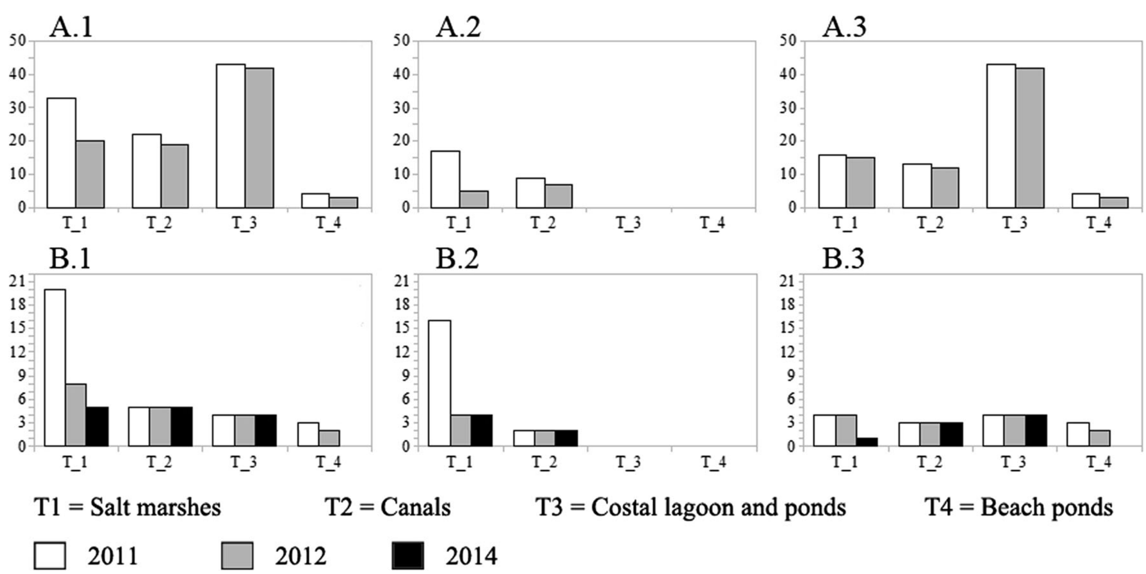


Fig. 6 Flooded sampling stations per habitat type. Notes: A 1–3 are in situ observations of wetlands in 2011–2012 in 102 sampling stations. A1 is the entire study area, A2 is the S part of the study area, and A3 is the N part of the study area. B 1–3 are in situ observations of wetlands in 2011, 2012 and 2014 in 32 sampling stations. B1 is the entire study area, B2 is the S part of the study area, and B3 is the N part of the study area. The axis represents the number of flooded wetlands for each habitat type. T1 = salt marshes; T2 = canals; T3 = coastal lagoon and ponds; T4 = beach ponds

Table 2 Unit values, ESVs calculated for the study area according to Costanza et al. (1997, 2014) during the study period 2001–2013

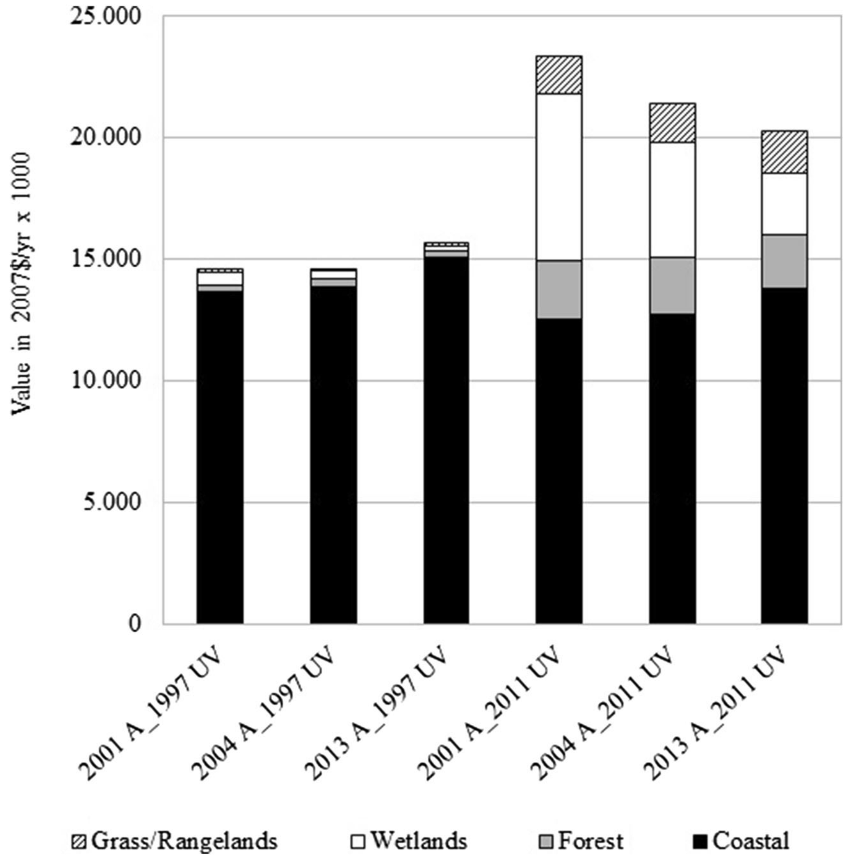
Biomes	Unit values 2007$/ha/yr		Ecosystem services values 2007$/yr. × 10^3					
	1997	2011	2001 area 1997 unit value	2001 area 2011 unit value	2004 area 1997 unit value	2004 area 2011 unit value	2013 area 1997 unit vale	2013 area 2011 unit value
Marine								
Coastal								
Estuaries	31.508,66	28.916,00	13.631,32	12.509,68	13.843,45	12.704,35	15.030,42	13.793,65
Terrestrial								
Forest								
Temperate/Boreal	417,35	3.137,00	318,06	2.390,71	315,50	2.371,48	288,00	2.164,75
Grass/Rangelands	320,58	4.165,92	118,22	1.536,24	121,60	1.580,21	134,23	1.744,32
Wetlands								
Tidal Marsh/Mangroves	13.786,34	193.843,00	488,06	6.862,31	334,31	4.700,58	180,38	2.536,22
		Total	14.555,65	23.298,94	14.614,86	21.356,62	15.633,03	20.238,95

Discussion

In Europe, rates of coastal erosion are on the rise; leading to rapid degradation and transformation of the habitats they support (Roebeling et al. 2013). Most coastal management actions performed in Mediterranean areas and in Italy in particular, involve beach conservation to counteract erosion processes (Ferretti et al. 2003; Bigongiari et al. 2015). The Ombrone River delta is subject to intense remodelling processes involving augmentation or, more frequently, retreats of the coastline in both the southern and northern wings. A recent research developed on coastal transformation occurring in the Mediterranean area analysed landscape changes and performed an exhaustive analysis on coastal transformation over the last sixty years in Italy including also habitats considered in this study focusing in particular coastal dunes (Malavasi et al. 2013). Results obtained in our study evidenced low total loss of beach and dunes habitat (−0.70 ha between 2001 and 2013). Nevertheless, the role of coastal dunes as carbon sink and diversity sources is of notable importance in coastal ecosystems (Drius et al. 2016).

The erosion phenomenon induces a significant loss for the ecological and economic value of the coastal area due directly to the decline of beaches, dunes (Malavasi et al. 2013; Drius et al. 2016) and wetlands habitat and indirectly to the closely related processes of salinization of groundwater and aquifers. Groundwater salinity varies naturally, increasing during the dry summer season and decreasing in rainy periods; the area affected by this phenomenon appears to be slowly expanding inland (Teobaldelli et al. 2004). Seawater input affects wetlands in the southern part of the Ombrone River delta, causing an increase in water salinity. Previous studies in the Regional Park of Maremma showed a compromised state of health of the pine forest, associated with decreased timber and seed production (Ciancio et al. 1986) and reduced pine needle length (Torta and De Capua 1993; Piussi and Torta 1994). In our study, the Forest category lost about 10% of its area (72 ha) between 2001 and 2013, due to the indirect effects of erosion processes rather than to soil reclamation for human activities, as the latter are prohibited in protected areas. In the study area, Forest is not made up of deciduous species or coppice, and the principal loss of Forest is due to the pinewoods drying. Some authors associate coastline erosion with seawater infiltration and the re-rising of salt water from the depths of the water table (Conese et al. 1989; Maracchi et al. 1996). A recent study of the pine tree forest in the study area showed that pine tree death is associated with a reduction in fresh water supplies (Teobaldelli et al. 2004). On the other hand, coastline erosion reduces Beach and dunes, and increasing pinewood exposure to sea spray, which has a significant impact on the trees (Raddi et al. 2009). Furthermore, the presence of surfactants in seawater is a synergic factor that may affect forest health along coasts (Raddi et al. 2009). In spite of

Fig. 7 **Total values of ecosystem services of the total area and relative contribute of each bioma.** Values are calculated for surfaces 2001, 2004, and 2013 (A) by application both 1997 and 2011 unit values (UV)



the great importance of beach and dunes conservation to preserve pinewood areas, a clear regression is occurring in the study area. At the same time Grass/Rangelands component increased by about 50 ha and this trend is associated with both Forest and Wetlands regression. The changeability or stability of wetland behaviour is determined by the presence of water during the warmest part of the year (Céréghino et al. 2008; MWO 2012). Comprehensive field data collected in this study also show that wetlands is the most heavily impacted biome, and that salt marshes and beach ponds are the most affected habitat types within wetlands. The loss of wetlands is principally related to the progressive loss of beach ponds located in the Northern part of the Ombrone River delta that completely vanished in 2014. Although wetlands actually contribute only about 13% to the total ESV_n of the study area, their importance should not be underestimated. In fact, Wetlands provide unique ecosystem services such as biodiversity conservation that are irreplaceable on the large scale at which observations are made in this study. At local scale of observation, the unit value of wetlands should be considered higher due to their scarcity than at global scale, and should in fact quickly jump to infinity as the category progressively disappears (Costanza et al. 1997). Loss of wetlands could bring about significant local ecological and economic damages. In fact, according to de Groot et al. (2012), coastal wetlands support a significant biodiversity, providing important ecosystem services such as provisioning (food and freshwater supply, raw materials etc.), regulating (climate regulation, waste treatments, water purification, erosion prevention etc.), habitat (lifecycles maintenance and conservation), and cultural (aesthetic, inspiration, recreation etc.) services.

To contend with the erosion processes, local administrations have planned and implemented several management actions, and a protective structure consisting of an embankment made of large boulders have been built. However, as the coastline retreated, it was demolished by seawater. Subsequently, between 2011 and 2012, a second dike was built, higher and stronger, parallel to the coastline and situated about 150 m from the shore, with the aim of halting erosive processes and preventing the entrance of salt water into the southern part of the Ombrone River delta during winter storms. An artificial water pumping station was also reactivated, and artificial canals were dredged to deal with soil salinization in salt marshes. Cipriani et al. (2013) estimated that if the rate of erosion remains constant, the coastline will reach the embankment in 15 years. A plan was developed to build 18 ditches, perpendicular to the embankment and located between its base and the shoreline, to reduce the rate of retrogradation by working as groins to further slow erosion (Cipriani et al. 2013). Highly dynamic ecosystems are subject to frequent geomorphological changes, and this is certainly the case of coastal estuaries and lagoons; numerous examples in the literature show how these systems alternate disruption and reconstruction periods over the long-term (Ruta et al. 2009). In order to preserve the geomorphological features of such a systems, civil society should invest a great deal of energy to counter entropy and to preserve the state of disequilibrium. Associated costs have a significant impact on local economies, and management plans should be made a priori to avoid depleting economic resources. Human actions aimed at preventing or mitigating natural phenomena are expensive and fail to prevent processes that occur on a wider scale or over a longer time period than the planned action can effectively impact. Rough ecosystem service evaluations are perfunctorily carried out during the planning phases of local environmental management actions, but usually only profit-making ecosystem services are considered without considering other key services. However, paradoxically, in some cases it may be better from an ecological and economic point of view to spend some resources to support or transfer productive activities suffering damages (i.e. tourism, aquaculture, fisheries etc.) rather than try to contain the natural evolution of such ecosystems. An additional problem is that local actions carried out at the spot where a natural phenomenon is observed will not be effective to reduce or prevent it; drivers of natural phenomenon often act on a smaller scale than affected municipalities, and decisions involving small-scale actions should involve work groups made up of stakeholders from different scale levels. For example, a reduction in sedimentary supply to a coastal area may be due to drivers acting on a river catch basin.

Ecosystem services valuation is a key process in evaluating loss or gain of ecosystem services, and could be strategic in *ante operam* cost/benefit analysis. To date, no cost/benefit analysis that includes economic comparison between resources that might be spent to prevent erosion in such dynamic areas and the potential benefits of its preservation has ever been carried out. This is partially due to a lack of knowledge and data on the economic values of ecosystem services provided by beaches and dunes within the Coastal biome. Furthermore, a better knowledge on the evolution of the study area should be obtained by the application of the transitional matrix approach that should be helpful to quantify point-by-point ecosystem transformations in this last decade, in order to have a much more detailed assessment on actual changes (Malavasi et al. 2013). This analysis should represent an improvement for further researches on the study area with the aim to develop a useful management tools.

Conclusions

The approach applied, based on satellite image analysis, and could represent a useful tool for carrying out long-term evaluations and monitoring management actions on large spatial scales. The use of monetary units clarifies and underscores the meaning of ecosystem loss or degradation for stakeholders. Results show a generalized reduction of flooded areas. The major contributor to the overall total change in ESV in the study area is loss of wetlands area rather than beach erosion, although the two factors are linked. Environmental management planning involving wetlands is crucial in this context, and could have a much more significant effect on ecosystem efficiency and resources for future generations than beach erosion prevention.

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Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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