Changing landscapes: habitat monitoring and land transformation in a long-time used Mediterranean coastal wetland

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Abstract Zone Umide della Capitanata, located in the northeastern part of the Apulia Region, is one of the most extensive coastal wetlands of the Italian peninsula and one of the largest components of the Mediterranean wetland system. Despite its high ecological importance, this site has been undergoing a variety of pressures intensified in recent decades. This study analyzes and evaluates the changes occurred in this area between 2010 and 2020. Land cover and habitat maps were performed by photointerpretation and on-site surveys, and classified according to the FAO-LCCS and EUNIS taxonomies, respectively. To focus on local dynamics, four subset areas were analyzed separately. A set of landscape metrics was computed to analyze the landscape structure. The anthropogenic pressures affecting the study area were described through the Driving Forces-Pressures-State-Impact-Response (DPSIR) conceptual framework. Numerous changes were identified, deriving from both finest thematic redefinition and anthropogenic pressures. Both class conversions and class modifications were identified and quantified by means of transition matrices. Most of the observed conversions were borne by classes belonging to saltmarshes and to coastal dune systems. In particular, landscape configuration of coastal dune classes was well highlighted by a set of specific landscape metrics. Agriculture practices and changes in water flow pattern turned out to be the main driving forces exerting pressures on these natural systems. Significant differences were found between the four subsets under analysis, thus indicating that different management strategies lead to different levels of conservation.

Keywords Habitat monitoring · Eunis · LCCS · Landscape changes · Landscape metrics · Coastal wetlands

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Introduction

Coastal environments have a fundamental role in keeping and enhancing a wide range of ecosystem services, such as improvement in water quality, equilibration of the water cycle, carbon sequestration, natural habitat for migratory birds, recreation (Maltby and Acreman 2011; Mehvar et al. 2018). Coastal

wetlands and sandy dune systems are characterized by high biological diversity, which includes several habitats of European Community interest, as well as plant and animal species listed in the Annexes to 92/43/EEC Habitat Directive (HD). These environments are also characterized by a great fragility due to different threat factors. Land claim, agricultural intensification, hydrological modifications, urbanization, coastal erosion, and introduction of alien species are the main drivers of change (Davy et al. 2009; Janssen et al. 2016). In addition, climate changes, such as increase in temperatures and/or decrease in precipitation during the spring and summer seasons (Giorgi and Bi 2005), and sea level rise (Janssen et al. 2016), may affect coastal plant communities and habitats, determining changes in their distribution and extension. In the Mediterranean region, coastal wetlands and dune systems have progressively undergone increasing pressures, with resulting habitat degradation, loss and fragmentation (Perennou et al. 2012; Bazzichetto et al. 2020; Margiotta et al. 2020; Rodríguez-Santalla and Navarro 2021). Moreover, complex, diverse and highly fragmented landscape patterns have been determined by a variety of historical land uses in whole the Mediterranean (Naveh 1990; Ruiz and Sanz-Sanchez 2020).

In this scenario, constant and consistent monitoring procedures, as well as awareness of the ongoing socio-economic dynamics, are fundamental to implement effective management policies and conservation strategies. Assessing changes in landscape ecological elements through land-cover and habitat monitoring over long time periods is essential to: (a) understand the drivers of the temporal changes; (b) make provisions for future trends; (c) design appropriate conservation policies (Fahrig 2003; Fisher and Lindenmayer 2007; Bunce et al. 2008; Lengyel et al. 2008; Nagendra et al. 2014).

The representation of the detected changes, that may occur in terms of both conversion and modification, is a crucial step and is closely depending on the Land Cover (LC) or habitat taxonomy used, that is to say, to its structure, semantics and especially to its level of thematic resolution (Jansen and Di Gregorio 2002; Bajocco et al. 2012; Tomaselli et al. 2016, 2021).

Quantifying the landscape's spatial structure provides an understanding of the underlying impact on ecological processes and of the effects that changing patterns have on ecosystem services provision (Turner et al. 2007). In this framework, Landscape Metrics (LM) are an essential tool to analyze and evaluate landscape mosaics and spatial arrangement of the landscape structure (Turner et al. 2001; Uuemaa et al. 2013). The application of LM in coastal areas can be relevant because these landscapes are prone to rapid transformations, due to numerous anthropogenic activities, with natural areas converted into other land uses or in other natural types, and vice-versa. Many analyses have been carried out to identify core sets of metrics for the assessment of landscape heterogeneity and the relationships with anthropogenic activities (Botequilha-Leitão and Ahren 2002; Nagendra et al. 2004; Schindler et al. 2008; Plexida et al. 2014). The analysis of a landscape pattern includes two main aspects: (a) composition, relating to the abundance and variety of patch types in the landscape; (b) configuration, relating to spatial arrangement and context of the patches (Riitters et al. 1995).

The definition of appropriate conservation policies requires a precise understanding of the driving forces and pressures influencing the environment. The Driver-Pressure-State-Impact-Response (DPSIR) model, developed by the European Environment Agency (EEA 1995) as a casual framework for describing the interactions between society and environment, has been widely used as analytical approach for determining pressures and impacts especially in coastal environments. DPSIR model is considered as an additional tool for policy makers concerning environmental resources management (Lozoya et al. 2011; Gari et al. 2015; Bruno et al. 2020).

In this paper, we focused on Capitanata (FG), one of the largest components of the Mediterranean wetland system that has historically been subject to various types of land use and that, despite its high ecological importance, has been undergoing a variety of pressures, which have intensified in recent decades and particularly in recent years.

The aim of this work is to detect, analyze, and evaluate the changes occurred in the study area between 2010 and 2020, in order to: (a) identify the main changes occurred over this time-frame, in a landscape that has been undergoing rapid transformations; (b) evaluate the effectiveness of selected landscape metrics in analyzing the landscape changes; (c) correlate driving forces, pressures and threats to the identified changes.

Materials and methods

Study area

The site "Zone Umide della Capitanata e Paludi presso il Golfo di Manfredonia" [Site of Community Importance (SCI) IT9110005; Special Protection Area (SPA) IT9110038], is located in the north-eastern part of the Apulia Region (SE Italy). It includes three protected areas: the State Natural Reserves "Palude Frattarolo" and "Saline di Margherita di Savoia", and the Oasis "Lago Salso", enclosed in the Gargano National Park (Fig. 1). This site, extended more than 14.000 ha, is one of the most extensive wetlands of the Italian peninsula and one of the largest components of the Mediterranean wetland system, classified as Ramsar site and Important Bird Area (IBA 230 M).

The Capitanata's landscape consists of a system of lagoons, with brackish to salt water (depending on the specific water regime), fresh water wetlands, swamps and ponds, surrounded by cultivated field and farmlands. The agricultural landscape is characterized by intensive horticultural crop fields, locally called "arenili", widely extended along the coast and mainly used to cultivate onions, potatoes and carrots; towards the inland, by graminoid crops, in some case interspersed with tree crops (olive groves, vineyards, orchards).

The long-term exploitation of the site, mainly for agricultural purposes, has led to a progressive reduction and fragmentation of the original natural habitats. The natural vegetation is mostly represented by halophytic shrub, annual pioneer communities, reed thickets, and rush and sedges communities, typical of salt marshes. Along the sandy coast, fragments of dune vegetation are still present, although strongly reduced and altered due to anthropic activities and coastal erosion (Tomaselli and Sciandrello 2017). According to the erosion risk map of Apulian coasts (Bruno et al. 2020), the Capitanata falls within low (northern part) to high (southern part) erosion risk level.

Despite the whole of these negative processes, the study area still represents an important site for avifauna, especially water bird species, which find nesting sites or rest areas during the annual migrations.

In consideration of the important conservation value of these coastal wetlands and their delicate and fragile ecological equilibrium, two Life+Nature and Biodiversity projects have been carried on in the last years: "Sipontine Wetlands"—Conservation actions of habitats in the coastal wetlands of SCI "Zone Umide della Capitanata" (www.lifezoneumide.it), and "Conservation Activities for Priority Avifauna in the Lago Salso Oasis" (www.lifelagosalso.it).

LC and habitat mapping

LC and habitat mapping in 2020 were performed by means of photointerpretation and on-site surveys, and compared to an analogous set of maps referring to 2010. The thematic maps were produced in Arc-Gis 10.2 by digitizing color orthophotos, produced between 2019 and 2020 within the POR-PUGLIA project COHECO (www.coheco.it), in three different months (February, June and October). The same criteria of a previous mapping carried out in 2010 were followed, taking care of spatial co-registration between the two maps, with appropriate corrections and modifications, in order to avoid mismatching problems or errors in the estimation of changes. First, natural and semi-natural landscape elements were described as vegetation types defined on the base of phytosociological units, according to the Zurich-Montpellier method (Braun-Blanquet 1964). We adopted a representation scale 1:5000, which allowed representing the studied landscapes with a 2 m resolution. Next, vegetation units were reclassified in habitat types and subsequently in LC classes. Habitat mapping was performed using the EUropean Nature Information System (EUNIS) (Davies et al. 2004) classification scheme (levels III and IV), which is considered an effective standardizing tool for habitat classification in the European Union (EU) (Ichter et al. 2014). LC classes were defined on the base of the FAO-Land Cover Classification System (LCCS) taxonomy (Di Gregorio and Jansen 2005) whose potentialities in mapping Mediterranean coastal wetlands have been explored in previous papers. Indeed, by comparing the effectiveness of different LC and habitat taxonomies in monitoring coastal wetlands emerged that, for long-term habitat monitoring and change detection, the coupling EUNIS and LCCS is highly recommended (Adamo et al. 2014, 2016; Tomaselli et al. 2013, 2016, 2021; Gavish et al. 2018). The output maps were validated by in-field campaigns carried out in 2020 and 2021. Information on vegetation composition and structure, as well as
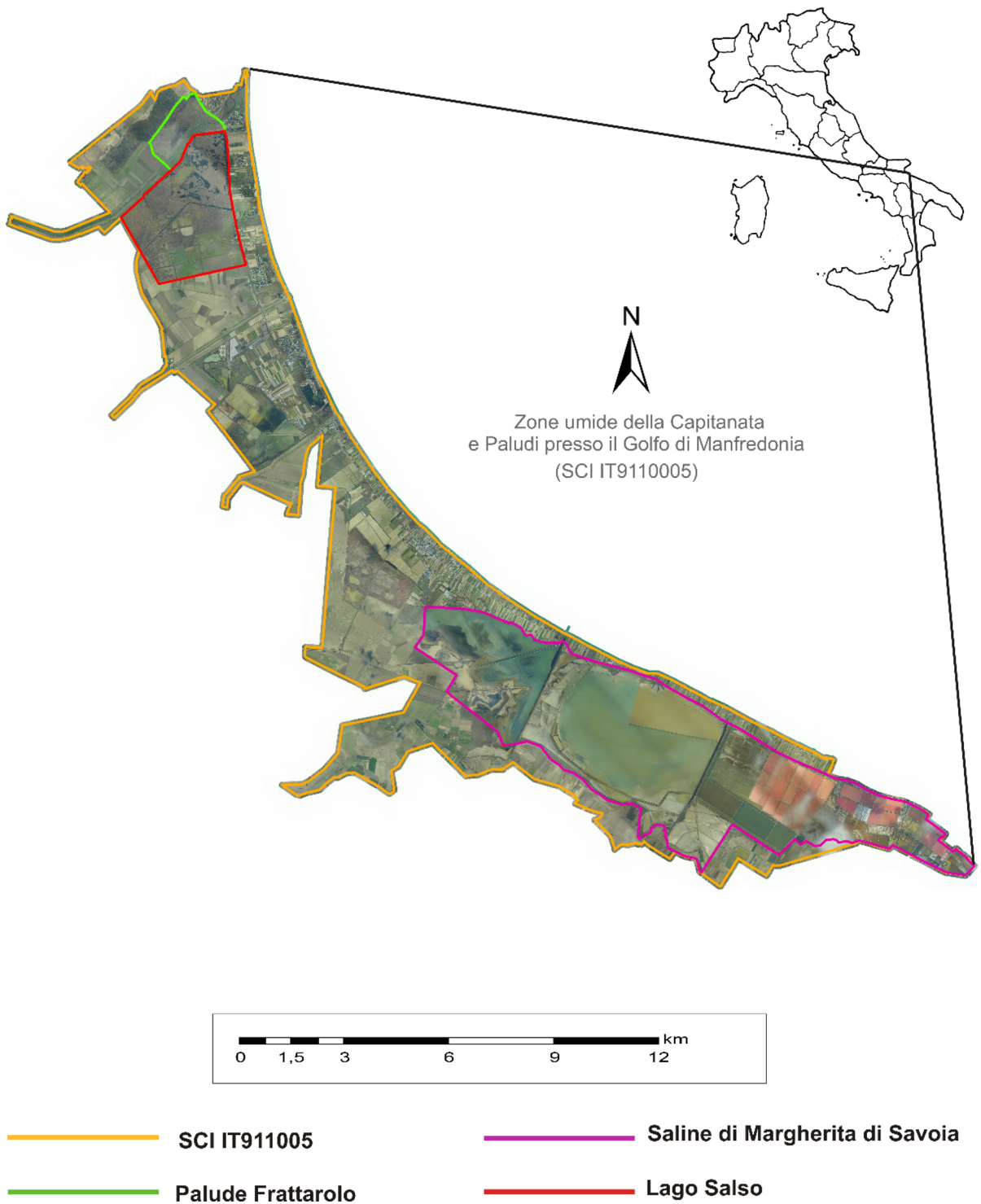
Fig. 1 Geographical location of the SCI "Zone Umide della Capitanata e Paludi presso il Golfo di Manfredonia"

agricultural practices or land use, was gathered, geocoded by GPS and integrated into a GIS geo-database for an accurate and detailed definition of some types.

Changes

Magnitude of Changes (MCs) in class area occurred between 2010 and 2020 for each habitat class was calculated by using the following formula (Abbas 2013; Abbas et al. 2018):

$$MC_i = CA_i(T2) - CA_i(T1),$$

where i is the habitat class considered and, for the case under study, $T1$ and $T2$ correspond to 2010 and 2020, respectively. CA represents the Class Area recorded for each class.

To describe the conversion size of habitat types in different periods, the transition matrix approach was used (Tomaselli et al. 2021). The transition matrix indicates the amount of different habitat types that remain unchanged and change in the study period. Based on the transition matrix, the following parameters were calculated for each habitat type: (1) the percentage of the 2010 habitat area that experienced a change (losses); (2) the percentage of the 2020 habitat area that resulted from a change (gains). For example, the gains or losses of habitat type i stand for the other habitat types having changed into i or habitat type i having been converted into other habitat types, respectively.

In order to compare in a more detailed way the changes occurred in some specific areas of the study site, we chose to analyze the transformations within "Palude Frattarolo" (PF), "Saline di Margherita di Savoia" (SMS), and in the "Lago Salso" wetland (LS), because subject to rapid transformations (PF and LS), and in order to compare the ongoing dynamics in protected areas with different management type (Fig. 1). To analyze the effects of the hydrogeological process of subsidence (Caldara et al. 2013), we added also the coastal area between Cervaro and Carapelle rivers, called "Ippocampo" (I) (Fig. 2).

Landscape metrics

Basing on an analysis of the literature on monitoring programs in Mediterranean coastal ecosystems, among the most widely used and effective in
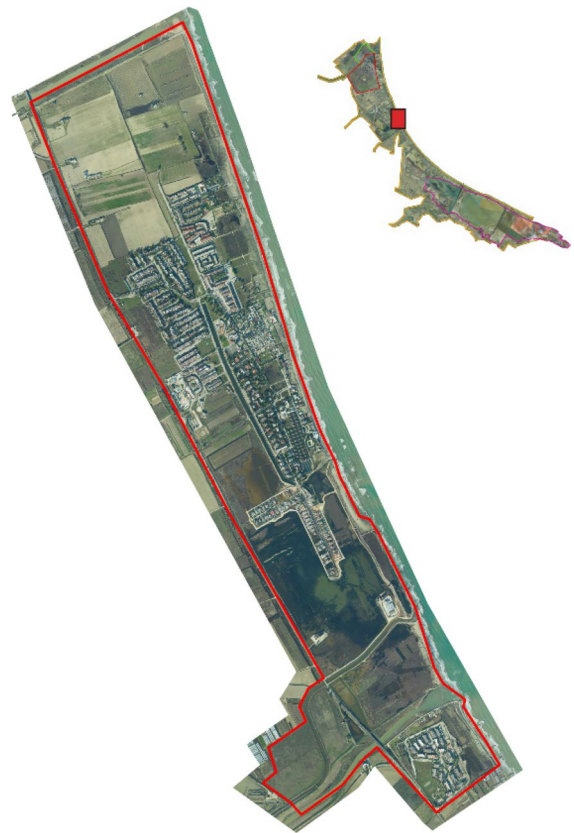

Fig. 2 Geographical location of the "Ippocampo" study site

detecting changes in spatial pattern, and in assessing ecological and functional features (Pascual-Aguilar et al. 2015; Almeida et al. 2016; Belda-Carrasco et al. 2019; Li et al. 2019), we selected the following set of LM (in Online resource 1 the table with definitions): Class Area (CA), Mean Patch Size (MPS), Largest Patch Index (LPI), Edge Density (ED), Patch Density (PD), Landscape Division Index (DIVISION), Effective Mesh Size (MESH), Shape Index (SHAPE).

MPS, LPI and MESH result to be good metrics for assessing the patchiness of landscapes, SHAPE and ED for evaluating landscape complexity, defining habitat network and functional features (Almeida et al. 2016). These LM were implemented using the LecoS-Land cover statistics plugin (https://plugins.qgis.org/plugins/LecoS/) of the open-source Geographic Information System (GIS) software QGIS (https://www.qgis.org/it/site/).

In coastal landscapes, the assessment (measurement) of the "elongatedness" of patches, especially
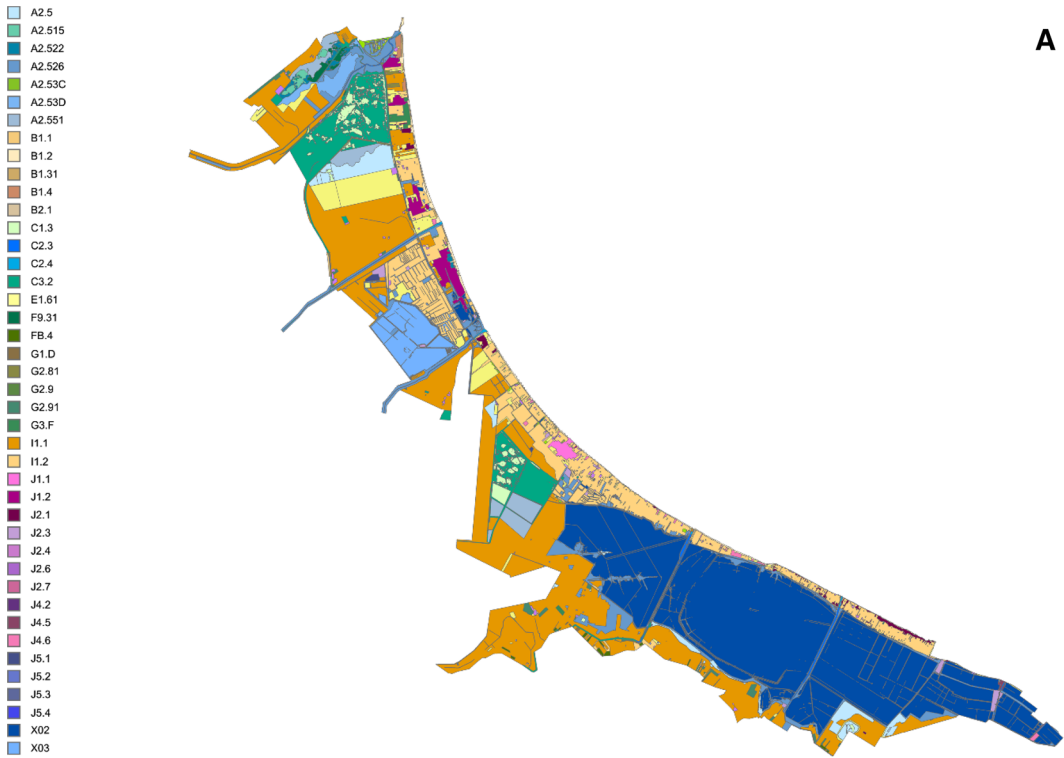
for dune systems, is a crucial issue to detect the integrity of these environments (Botequilha-Leitão and Ahren 2002; Tomaselli et al. 2012). Here we introduced a new metric, extracted by using eCognition Developer 8.9, the Mean Length/Width (MLW) (https://docs.ecognition.com/). For the evaluation of the adjacency between dune systems habitats, useful to evaluate in what measure the standard zonation has been altered, we introduced the "Mean Rel. Border to" (MRBT) https://docs.ecognition.com/).

Pressures and driving factors

In order to describe the anthropogenic pressures affecting the study area in an organic scheme, we resorted to the DPSIR conceptual framework (Gabrielsen and Bosch 2003). Within this frame, "driving forces" (causes) generate "pressures" on the environment, modifying its "state" (physical, chemical, and biological), leading to "impacts" on ecosystems (structure and function) and eventually to "responses" (policy). To relativize the main categories, we referred to the Unified Classifications of Direct Threats and Conservation Measures Actions (IUCN-CMP 2012a) for "drivers of changes", and to IUCN-CMP Classification of Stresses (IUCN-CMP 2012b) and to Nagendra et al. (2014) for "broad impact (stress) category". "Broad impact category", "specific type of impact" and "short description of the impact" refer to changes observed in the period of observation; "direct threat" (proximate pressure) and "underlying factors" (drivers of change) have been identified based on in field observations, and/or through interviews. In this latter respect, representatives of local authorities or management bodies, as well as members of the local communities (e.g., farmers, stakeholders, etc.) were interviewed using a semi-structured interview approach, covering issues related to: the implementation of conservation/restoration strategies (e.g., LIFE projects); water management and water supply systems; cultivation systems and agricultural practices (included crop rotation and irrigation); fire frequency.

Results

Habitat and LC maps of the whole site

Figure 3 shows the output EUNIS maps obtained in 2010 and in 2020. LCCS maps are in Online resource 2. The complete list of habitat types, in relation to LC classes, are reported in Online resource 3.

A high degree of landscape heterogeneity characterizes the site, due to both an effective natural diversity of the biotope and a variety of land uses. In the following sections, further considerations on landscape composition and on the degree of fragmentation of the site are provided.

Landscape composition

The overall landscape composition of the area in 2020 results as following. Cultivated areas (Croplands) are the predominant type in the whole site, covering the 39% of the SCI, with arable lands (I1.1—intensive unmixed crops and I1.2—mixed crops of market gardens and horticulture) making up the most part (38%). The class I1.1 is mainly distributed landwards while I1.2 extends along the sandy coast, the so-called "arenili". The next dominant landscape type, which covers about 37% of the whole area, is represented by natural and artificial water bodies (Table 1), with water from fresh to salty, and including the intricate system of canals and pools used to drain the cultivated areas. The coastal lagoons are highly present with the dominant class X02 (31%), principally represented by the salines of Margherita di Savoia.

As regards the natural vegetation, the most extensive and representative types are the helophytic communities (9.2%), in which the class C3.2 prevails with 6.5%, and halophytic shrubs and annual herbaceous communities of saline to hypersaline environments (7.4%) in which the most relevant class is A2.526 with 6.1% (Table 2).

Although the coastline of the site is over 30 km long, the classes of the sandy coast system (classes of group B are shown in Online resource 4), including both vegetated and not vegetated areas, cover only the 0.70% of the whole area.

This general outcome does not differ much from the 2010, but this is true only if considering coarse categories. If going into detailed description of single classes, numerous changes can be described.

Table 1 Eunis description of natural and artificial water bodies in the study area with relative cover percentage in 2020

	Eunis code	Cover (%)	Description
Natural water bodies	C1.3	1.87	Permanent eutrophic lakes, ponds and pools
	C2.3	0.52	Permanent non-tidal, smooth-flowing water courses
	C2.4	0.08	Tidal rivers, upstream from the estuary
	X02	30.99	Saline coastal lagoons
	X03	3.27	Brackish coastal lagoons
	Total	36.73	
Artificial water bodies	J5.1	0.30	Highly artificial saline standing waters
	J5.2	0.07	Highly artificial saline and brackish running waters
	J5.3	0.02	Highly artificial non-saline standing waters
	J5.4	0.01	Highly artificial non-saline running waters
	Total	0.4	

Table 2 Eunis description of helophytic and halophytic communities in the study area with relative cover percentage in 2020

|	EUNIS CODE	Cover (%)	Description
Helophytic communities	A2.522	0.92	Mediterranean [*Juncus maritimus*] and [*Juncus acutus*] saltmarshes
	A2.525	1.35	Mediterranean *Juncus subulatus* beds
	A2.53C	0.33	Saline beds of *Phragmites australis*
	A2.53D	0.11	Geolittoral wetlands and meadows: saline and brackish reed, rush and sedge stands
	C3.2	6.54	Water-fringing reedbeds and tall helophytes other than canes
	Total	9.25	
Halophytic communities	A2.516	0.47	*Suaeda vera* saltmarsh driftlines
	A2.526	6.12	Mediterranean saltmarsh scrubs
	A2.551	0.78	[*Salicornia*], [*Suaeda*] and [*Salsola*] pioneer saltmarshes
	Total	7.37	

Changes

Changes observed over the period 2010–2020 in the study area are of two types: (a) conversion from one class to another (inter-class changes); (b) modifications within a specific class (intra-class changes). In the case of class conversion, they may be: (a) real changes; (b) conversions due to a change in thematic resolutions (from broad to more detailed classes).

Inter-class changes (class conversion)

Habitat maps from 2010 and 2020 were analyzed to obtain the habitat Transition Matrix (TM). The analysis of the TM (Fig. 4) revealed an overall percentage of areal changes equal to 3.99% (about 564 ha).

The Magnitude of Change (MC) in class area (ha) along with gains and losses (%) occurred during 2010–2020 are reported in Table 3.

The first evident change is that two classes, included in the map 2010, were completely converted: A2.5 (Coastal saltmarshes and saline reedbeds) and J2.7 (Rural construction and demolition sites). The change of J2.7 is due to the correction of a misleading labelling, whereas, in the case of A2.5 it is partly due to a thematic redefinition of the mapping product and partly to a real change. In particular, the class A2.5 represents a very coarse habitat class that, in 2010, was used to include, in some cases, both the perennial and the annual halophilous vegetation of saltmarshes. In the 2020 map, an increasing thematic resolution has been applied and class A2.5 has been replaced with the more detailed classes A2.526 (Mediterranean
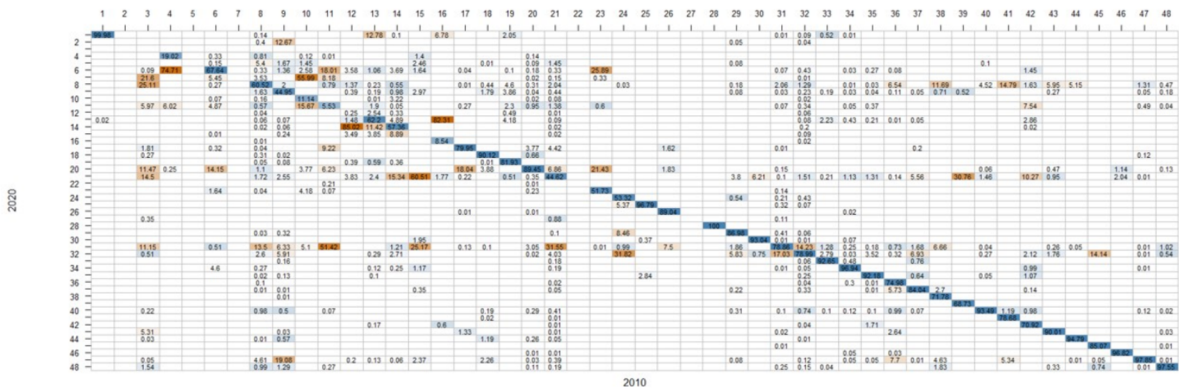
Fig. 4 Eunis habitat class transition matrix from 2010 to 2020

EUNIS Class	Numeric Label	EUNIS Class	Numeric Label	EUNIS Class	Numeric Label	EUNIS Class	Numeric Label	EUNIS Class	Numeric Label	EUNIS Class	Numeric Label	EUNIS Class	Numeric Label
OUT	1	A2.526	8	B1.4	15	F5.514	22	G2.91	29	J2.3	36	J5.1	43
A2.1	2	A2.53C	9	B2.1	16	F9.31	23	G3.F	30	J2.4	37	J5.2	44
A2.5	3	A2.53D	10	C1.3	17	FB.4	24	I1.1	31	J2.6	38	J5.3	45
A2.515	4	A2.551	11	C2.3	18	G1.D	25	I1.2	32	J2.7	39	J5.4	46
A2.516	5	B1.1	12	C2.4	19	G2.81	26	J1.1	33	J4.2	40	X02	47
A2.522	6	B1.2	13	C3.2	20	G2.83	27	J1.2	34	J4.5	41	X03	48
A2.525	7	B1.31	14	E1.61	21	G2.9	28	J2.1	35	J4.6	42		

saltmarsh scrubs) and A2.551 ([*Salicornia*], [*Suaeda*] and [*Salsola*] pioneer saltmarshes). Hence, this direct type of conversion is due to a simple thematic redefinition. Instead, in the case of conversions of A2.5 in A2.522 (Mediterranean [*Juncus maritimus*] and [*Juncus acutus*] saltmarshes) and A2.525 (Mediterranean *Juncus subulatus* beds), there is a real change. Five new classes have been introduced in the map 2020: A2.1 (Littoral coarse sediment), A2.516 (*Suaeda vera* saltmarsh driftlines), A2.525, F5.514 (Lentisc brush), G2.83 (Other evergreen broadleaved tree plantation). In particular, A2.516, F5.514, G2.83 arises mostly from a higher level of thematic redefinition, A2.525 partly from thematic redefinition of the class A2.53D (Geolittoral wetlands and meadows: saline and brackish reed, rush and sedge stands) (56%) and partly from real changes (A2.5 21.6%, A2.551 8.2%), while A2.1 from real changes.

Most of the observed conversions is borne by classes belonging to the Eunis high level categories A (marine habitats, directly or indirectly connected to the marine waters, included saltmarshes and constructed marine saline habitats), and B (coastal habitats, including coastal dunes and beaches) (Davies et al. 2004).

Group A—there is an overall reduction of this group throughout the whole area (Table 3). In terms of change in surface area, gains and losses (Fig. 4, Table 3), the most striking changes within this group are presented below:

– As mentioned above, the class A2.5 is entirely replaced by other classes. In part, it converted into the more detailed classes A2.526 (25.1%) and A2.551 (6%) consequently to thematic redefinition. The most significant conversions of A2.5 due to real changes are into the classes A2.525 (21.6%) and I1.1 (11.1%), in the second case with the loss of natural habitat.

– The class A2.522, on one hand, increments its surface of 85.2 ha, with gains of 72%, due to the conversion from F9.31 ([*Nerium oleander*], [*Vitex agnus-castus*] and [*Tamarix*] galleries) (25.89%), A2.551 (18.01%) and the classes of

Table 3 MCs, gains and losses occurred during 2010–2020 for each Eunis habitat class

Habitat	Gains (%)	Losses (%)	MC (2010–2020) (ha)	Habitat	Gains (%)	Losses (%)	MC (2010–2020) (ha)
A2.1	100	–	9.59	G2.81	0.81	10.96	− 2.15
A2.5	–	100	− 277.36	G2.83	100	–	10.25
A2.515	63.17	80.98	− 14.66	G2.9	0	0	0.00
A2.516	100	–	65.89	G2.91	24.05	13.02	9.68
A2.522	72.04	32.36	85.21	G3.F	3.24	6.96	− 1.72
A2.525	100	–	190.65	I1.1	20.05	21.01	176.36
A2.526	29.76	39.48	− 137.13	I1.2	39.95	21.01	419.94
A2.53C	62.71	55.05	8.36	J1.1	8.04	7.35	0.27
A2.53D	20.06	88.86	− 96.36	J1.2	5.59	3.06	3.82
A2.551	87.08	94.47	− 147.30	J2.1	7.74	7.82	− 0.03
B1.1	99.92	99.75	2.82	J2.3	5.22	25.02	− 10.94
B1.2	24.96	37.80	− 13.95	J2.4	15.43	15.96	− 0.34
B1.31	54.44	42.64	5.04	J2.6	0.25	28.22	− 0.57
B1.4	100	100	− 9.56	J2.7	0	31.27	− 0.23
B2.1	76.90	91.46	− 1.44	J4.2	68.31	6.51	35.14
C1.3	33.84	20.05	40.52	J4.5	1.37	21.32	− 0.99
C2.3	20.58	9.88	8.65	J4.6	9.67	29.08	− 4.58
C2.4	15.75	18.07	− 0.32	J5.1	71.08	9.99	32.20
C3.2	17.68	10.55	− 15.43	J5.2	39.70	5.21	3.75
E1.61	31.90	55.38	− 323.56	J5.3	12.73	14.93	− 0.06
F5.514	100	–	0.62	J5.4	8.89	3.18	0.11
F9.31	42.04	48.27	− 1.08	X02	1.47	2.15	− 30.12
FB.4	58.30	46.68	5.17	X03	6.40	2.45	18.67
G1.D	88.55	3.21	13.65				

the sandy coast system B1.1, B1.2, B1.31 and B1.4 (about 10%). On the other hand, A2.522 shows losses of 32% in the conversion towards the classes C3.2 (14.1%), A2.525 (5.4%), A2.551 (4.9%) e J.1.2—Residential buildings of villages and urban peripheries (4.6%).

– A2.526 undergoes a quite relevant reduction (MC = − 137.13 ha) and multiple conversions in numerous other classes with 39.5% of losses. The most significant are in arable lands (16.1%) [I1.1 (13.5%); I1.2 (2.6%)], X02 (4.6%) and A2.525 (3.5%), corresponding to real changes, and in A2.516 (5.4%) because of a better thematic resolution.

– The class A2.53D is affected by losses of 89%, with more than half of the original surface converted in A2.525 (56%), in A2.551 (15.7%), in I1.1 (5.1%) and in F9.31 (4.2%); most of these transformations are borne by the area "Palude

Frattarolo", whose dynamics will be further discussed.

– A2.551 shows a drastic reduction of the habitat present in 2010 (MC = − 147 ha), consequently to the conversion into the following classes: I1.1 (51.4%), in A2.522 (18.0%), in A2.525 (8.2%), C1.3 (9.2%) and C3.2 (6.2%).

– A2.515 (*Elymus repens* saltmarsh driftlines) reduces its surface with losses of 81%, changing into A2.522 (74.7%) and in A2.551 (6.0%).

Group B—the whole group, corresponding to the sand coast system, shows deep transformations due to processes of coastal erosion, in some traits, and accretion in other traits, resulting in a general reshaping of the coastline. In particular:

– The class B1.1 (Sand beach driftlines) shows a drastic transformation with gains and losses

of about 100%, in fact the areas covered by this habitat in 2020 have quite completely changed (residual 0.25%), with the 85% converted in B1.31 (Embryonic shifting dunes).

– B1.2 (Sand beaches above the driftline) undergoes losses of about 38%, with conversions into B1.31 (11.42%), B1.4 [Coastal stable dune grassland (grey dunes)] (3.8%), B1.1 (2.5%), and in "unknown" (12.8%).

– B1.31 has an overall increment of about 5 ha on the entire area, but the conserved surface undergoes a general rearrangement, with multiple conversions into various other classes, in particular in E1.61 (15.3%), B1.4 (8.9%), B1.2 (4.9%) and A2.522 (3.7%).

– B1.4 is interested by a general reduction (MC = 9.5 ha) and drastic transformations: the area covered by this class in 2010 appears entirely converted, mostly in E1.61 (60.5%) and I1.1 (25.2%) while, along the seaside, there are scattered new areas of B1.4 deriving from the conversion of B1.31, B1.2 and B1.1.

Analyzing the TM (Fig. 4) and Table 3, other significant changes are:

Class E1.61 reduces its surface (MC = − 199 ha) with the conversion into arable lands (I1.1 31.55%; I1.2 4.03%).

There is the significant increase of I1.2 (MC = 420 ha), from conversion of FB.4 (vineyards) (31.8%), I1.1 (17.0%) and E1.61 (4.0%). Moreover, different natural areas appear converted in I1.1, especially salt marshes A2.551 (51.4%), A2.5 (29.6%), A2.526 (16.1%), sandy coast system (29.4%) and helophyte communities (17.3%), with loss in natural environments. In addition, the woody crops show an overall increase, but to a minor extent.

As regards all other classes belonging to groups G, I, J and X, they do not indicate major transitions, only small oscillations, mainly between cultivated typologies or other land use types.

Intra-class changes (class modification)

LCCS allowed, within the same Eunis class, discriminating the presence of different vegetation types, or describing changes in terms of vegetation structure (i.e., cover, height, stratification), or vegetation dynamics. In particular:

– Within the class E1.61 (Mediterranean subnitrophilous grass communities), in 2010 the LCCS class A12/A2A10B4XXE5-B12E7 (Annual medium tall herbaceous vegetation) describes annual herbaceous communities that in 2020 become mixed (with annual and perennial species) indicated by the class A12/A2A10B4XXE5-B12 (Medium tall herbaceous vegetation).

– Within the class A2.53D (Geolittoral wetlands and meadows: saline and brackish reed, rush and sedge stands), on the base of the classifier "water seasonality", it is possible the distinction of vegetation with *Tripidium ravennae* (L.) H. Scholz, A24/A2A6A12B4C3E5-B11E6 (Perennial closed tall grasslands on waterlogged soil), from vegetation with *Bolboschoenus maritimus* (L.) Palla, A24/A2A6A12B4C2E5-B11E6 (Perennial closed tall grasslands on temporarily flooded land), improving the thematic resolution.

– Within the class A2.526 (Mediterranean saltmarsh scrubs), it is possible to define closed communities (A24/A1A4A12B3C2D3-B10—Aphyllous closed dwarf shrubs on temporarily flooded land) from the open ones (A24/A1A4A13B3C2D3-B10—Aphyllous open dwarf shrubs on temporarily flooded land).

LCCS allows describing the invasion of helophytes in the *Tamarix* community (A12/A1A4A11B3-A12B14—Open ((70–60)—40%) Medium to High Shrubs), using stratification classifiers (A12/A1A4A11B3F2F4F7G4-A12B9F8G11—Open ((70–60)—40%) Medium to High Shrub land with closed medium to tall herbaceous vegetation).

Data subset results

The analyses of the four data subsets corresponding to "Palude Frattarolo" (PF), "Lago Salso" (LS), "Ippocampo" (I) and "Saline di Margherita di Savoia" (SMS) lead to the following results. The Eunis maps of the four areas are shown in Online resource 5. The MC, gains and losses in class area occurred during 2010–2020 are reported in Online resource 6.

From the observation of the TMs (Online resource 7), the total change percentages of habitat surfaces are: PF 31.9%, LS 19.0%, I 9.4% and SMS 1.6%. The principal and more interesting results are discussed hereafter.

At PF numerous important changes have been observed. Perennial saltmarshes (class A2.526) turn out to have a drastic reduction (MC = − 88 ha), with losses of 98%. Part of this reduction (45.6%) is due to a thematic redefinition in A2.516. The remaining part (52.4%), as well as the 49% of the *Juncus acutus* L. communities (class A2.522), converts into less halophilous *Juncus subulatus* Forrsk. beds (class A2.525 with 48.7%) (Fig. 5), *Phragmites australis* reedbeds (class C3.2 with 35.7%) (Fig. 6), and *Elymus repens* (L.) Gould vegetation (class A2.515 with 5.7%). *Bolboschoenus maritimus* vegetation (class A2.53D) undergoes a drastic reduction (losses of 51%), replaced principally by *Juncus subulatus* communities (73.0%) (Fig. 5). These processes are mainly ascribable to hydrologic modifications implying changes in water regime and salinity, originating from both water extraction in surrounding agricultural areas and some management practices (in 2015, within the activities of the Life+ "*Sipontine wetlands*", some drainage canals were dug, with effects on water regime that have yet to be further investigated).

Tamarix vegetation (F9.31) increases its surface (MC = 4.5 ha), but shows two different dynamics, with gains of 61% and losses of 48%: in the northern part of the site, it is replaced by *Phragmites australis*

(Cav.) Trin. ex Steud. vegetation (45.5%) while, southwards, it expands.

At LS there is the conversion of a large extent of annual halophilous vegetation (A2.5 and A2.551) in A2.525 (about 80%) and in fallow land (E1.61) (29.7%) (Fig. 7).

The increase of C1.3 water bodies (MC = 61 ha) is due to two factors: the natural phenomenon of subsidence that have involved some areas of Capitanata during the last two decades (Caldara et al. 2013), and the interventions carried out with the Life+ project "Conservation Activities for Priority Avifauna in the Lago Salso Oasis". Specifically, the Life actions consisted in the opening of ponds in the reedbeds and the creation of a 90-ha basin, in the southern part of the Oasis, with variable water levels (Fig. 8). The significant expansion of *Juncus subulatus* vegetation ((MC = 89.7 ha) is strictly linked to the subsidence.

In the site I a general decrease of saltmarshes (A2.526, MC = − 25.3 ha, with losses of 53.5%) has been observed, due, on one hand, to the conversion in arable lands and (Fig. 9), and on the other hand, to the transformation in coastal lagoons (19.4%).

This latter is due to the effects of the subsidence, a trend widely generalized in the site that is causing also an increment of coastal lagoons (X02 with gains of 30.7%; X03 with gains of 67.5%) (Fig. 10),

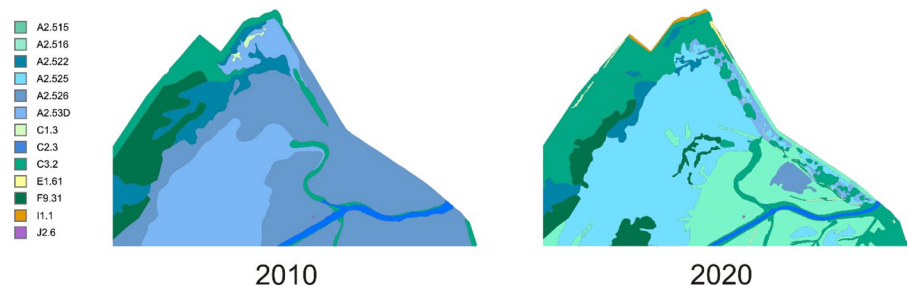**Fig. 5** Conversion of A2.526 and A2.53D in A2.525 at PF site

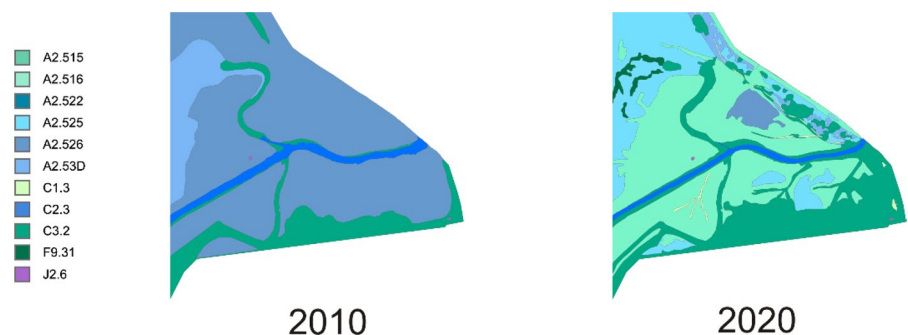

Fig. 6 Conversion of A2.526 in C3.2 at PF site

Fig. 7 Conversion of annual halophilous vegetation (A2.5 and A2.551) in A2.525 and E1.61 at LS site
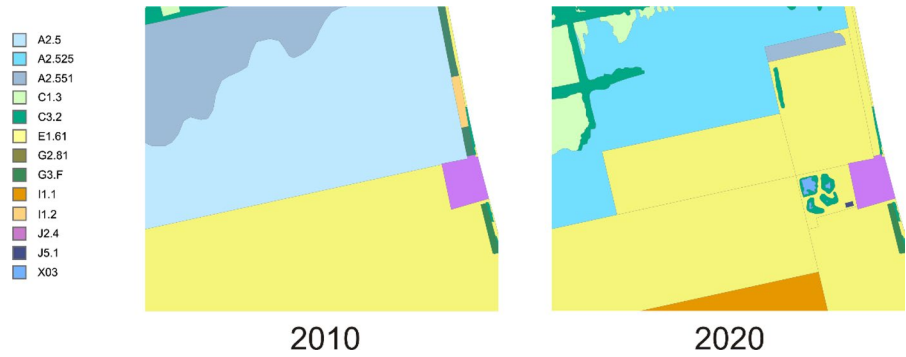

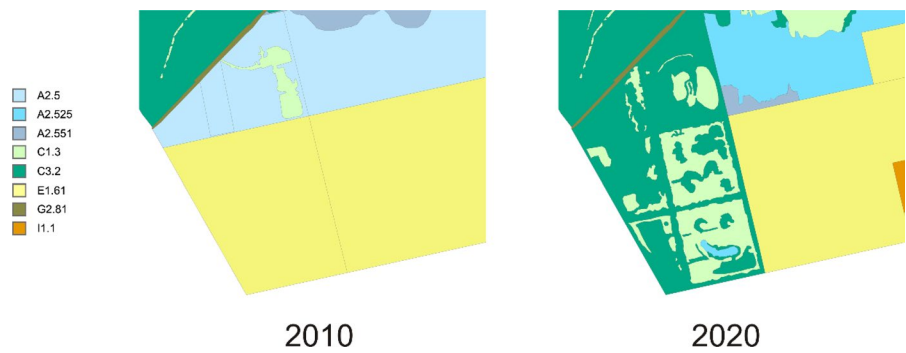|	
☐	A2.5
☐	A2.525
☐	A2.551
☐	C1.3
☐	C3.2
☐	E1.61
☐	G2.81
☐	G3.F
☐	I1.1
☐	I1.2
☐	J2.4
☐	J5.1
☐	X03

2010   2020

Fig. 8 Increase of C1.3 at LS site

☐	A2.5
☐	A2.525
☐	A2.551
☐	C1.3
☐	C3.2
☐	E1.61
☐	G2.81
☐	I1.1

2010   2020

Fig. 9 Conversion of A2.526 in arable lands at I site

☐	A2.526
☐	A2.53C
☐	A2.53D
☐	B1.1
☐	B1.2
☐	B1.31
☐	B1.4
☐	E1.61
☐	I1.1
☐	I1.2
☐	J2.3
☐	J2.4
☐	J2.6
☐	J4.6
☐	J5.2
☐	X02
☐	X03

2010   2020
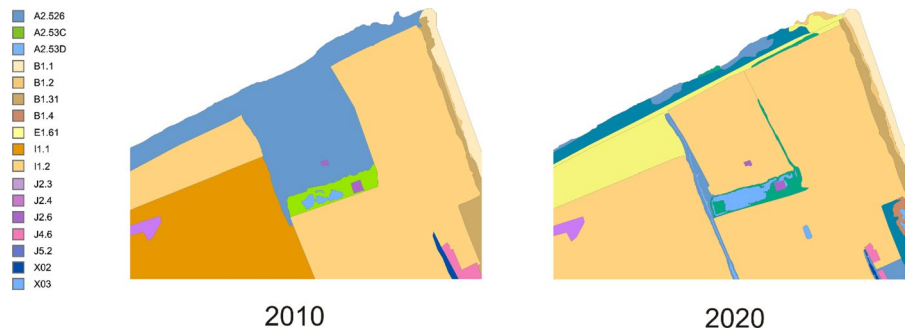
the conversion of the classes of sandy coast system (16.3%) and arable or fallow lands in saltmarshes (Fig. 11), and the transformation of fallow lands in *Suaeda vera* J.F. Gmel. vegetation (class A2.516 with 37.5%).

The site SMS presents a percentage of change smaller than the general one. In detail, the changes are due to thematic redefinition or occur at the border of the site, where there is the contact with croplands.

Changes through landscape metrics

CA data relative to all habitat classes are summarized in Fig. 12, data about Eunis classes of group A and B in Fig. 13; data have been partially discussed in Landscape general composition.

Some classes with significant reduction in CA (A2.551; A2.53D; B1.4) show an important reduction in MPS (Fig. 14A), and this happens because CA reduction is accompanied by a fragmentation

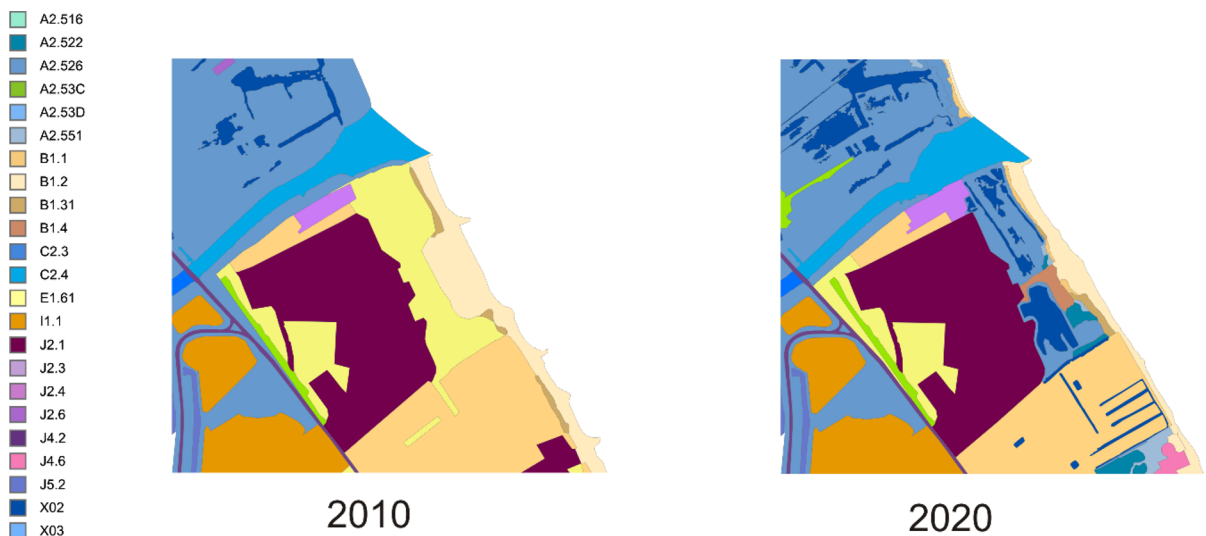**Fig. 10** Conversion of A2.526 in X02 at I site

Fig. 11 Conversion of classes of group B and arable and fallow lands in A2.526 at I site

in fairly homogeneous patches of smaller area. LPI (Fig. 14B) is higher in those classes that have a clear dominance in the landscape (e.g., X02, I1.1, I1.2, C3.2, A2.526, X03); the reduction of LPI in X03 and in I1.1, without particular variations in CA, reflects a more uniform distribution of the class. Both PD and ED (Online resource 8) have the highest values in A2.526 and X02, which are the habitat types most evenly distributed throughout the

landscape, with high complexity and good level of connectivity. The high complexity of habitat A2.526 results also in SHAPE values (Online resource 8). DIVISION (Online resource 8) and MESH are both aggregation indices and are perfectly, negatively correlated. The highest MESH values result for X02 and I1.1 that are the classes dominating the landscape, quite homogeneous and low fragmented;
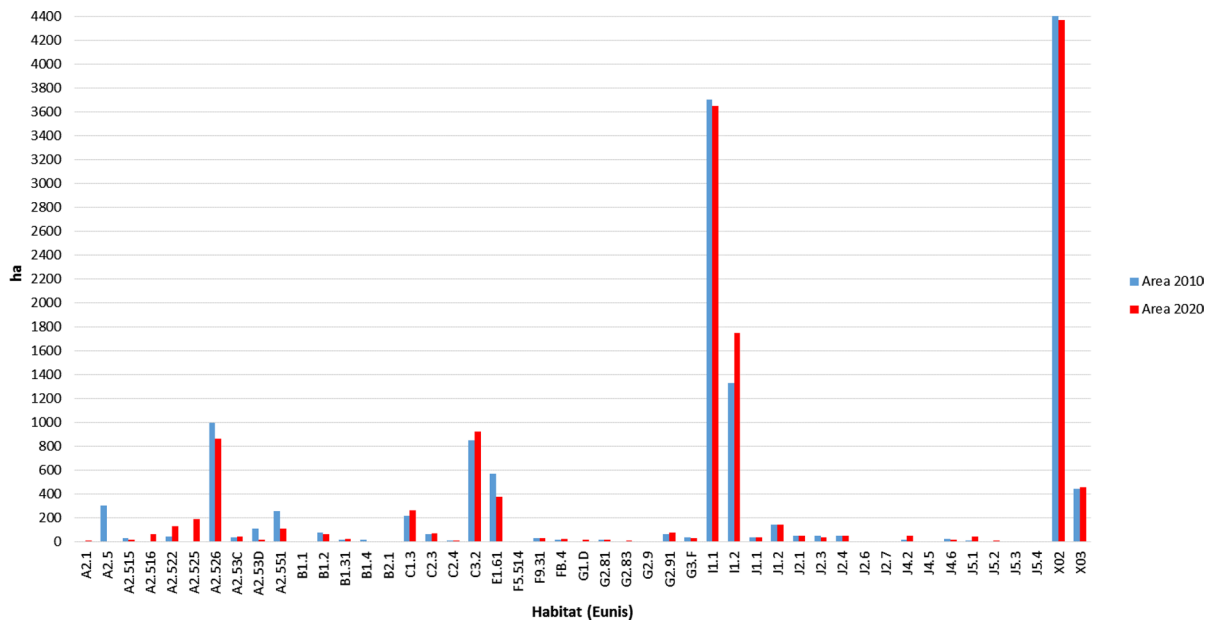
Fig. 12 Barplot comparing CA in 2010 (blue) and 2020 (red)

the decreasing of MESH values from 2010 to 2020 reflects a certain uneven distribution (Fig. 14C).

MLW is a measure of elongatedness of a patch; in the case of the sand dune systems (habitat types B1.1, B1.2, B1.31and B1.4) it is a proxy of the integrity of the vegetation strips forming this environment, and indicative of their level of fragmentation. The most striking outcome is for class B1.31 (Fig. 15), shifting from 2.8 to 10.4; this is in accordance with CA that has an important increment. No particular change is recorded for class B1.1, while for class B1.2 the MLW decreases from 13.5 to 6.3, indicating, along with a significative reduction, a fragmentation process, mainly due to coastal erosion.

MRBT is a measure to quantify the length of the edges in contact between two adjacent classes and indicative for the standard zonation. In the case of class B1.31 (Fig. 16A), an adjacency with B1.1 is expected, but the value is low in 2010 and becomes much lower in 2020, while it increases the contact with B1.2. As regards class B1.4 (Fig. 16B), a contact with B1.31 is expected, but no adjacency is recorded, neither in 2010 nor in 2020, while it borders on class B1.2 for a large part. This output indicates a deep alteration of the standard zonation, even worst in 2020.

Impacts

In Table 4 the impacts observed on natural and semi-natural classes during the period of observation, limited to those with highest impact (e.g., in terms of % of surface area affected), have been reported. Most of the observed impacts (14 out of 20) fall within the broad impact category "Land cover/habitat conversion" (1.1 Ecosystem Conversion); a minor portion has been classified as "Land cover/habitat modification" (1.2 Ecosystem Degradation and/or 2.3 Indirect Species Effect) and as "Habitat fragmentation and change in landscape connectivity" (1.3 Indirect Ecosystem Effects). Actually, this last category concerns a higher number of habitat types, but here we reported those that have been affected by fragmentation and change in landscape connectivity to such an extent that processes and functions may result to be altered. This is the case of the habitat types of the coastal dune systems, which resulted more or less all affected by this process along the entire length of the coastline. Among the "underlying factors", "Agriculture" (Agricultural practices intensification) seems to be the main driver of change, along with "Water Management/Use" (Changing water flow patterns from their natural range of variation; Abstraction of ground water) and "Other Ecosystem Modifications"

Fig. 13 Barplots comparing CA in 2010 (blue) and 2020 (red) for the Eunis habitat classes of groups A and B
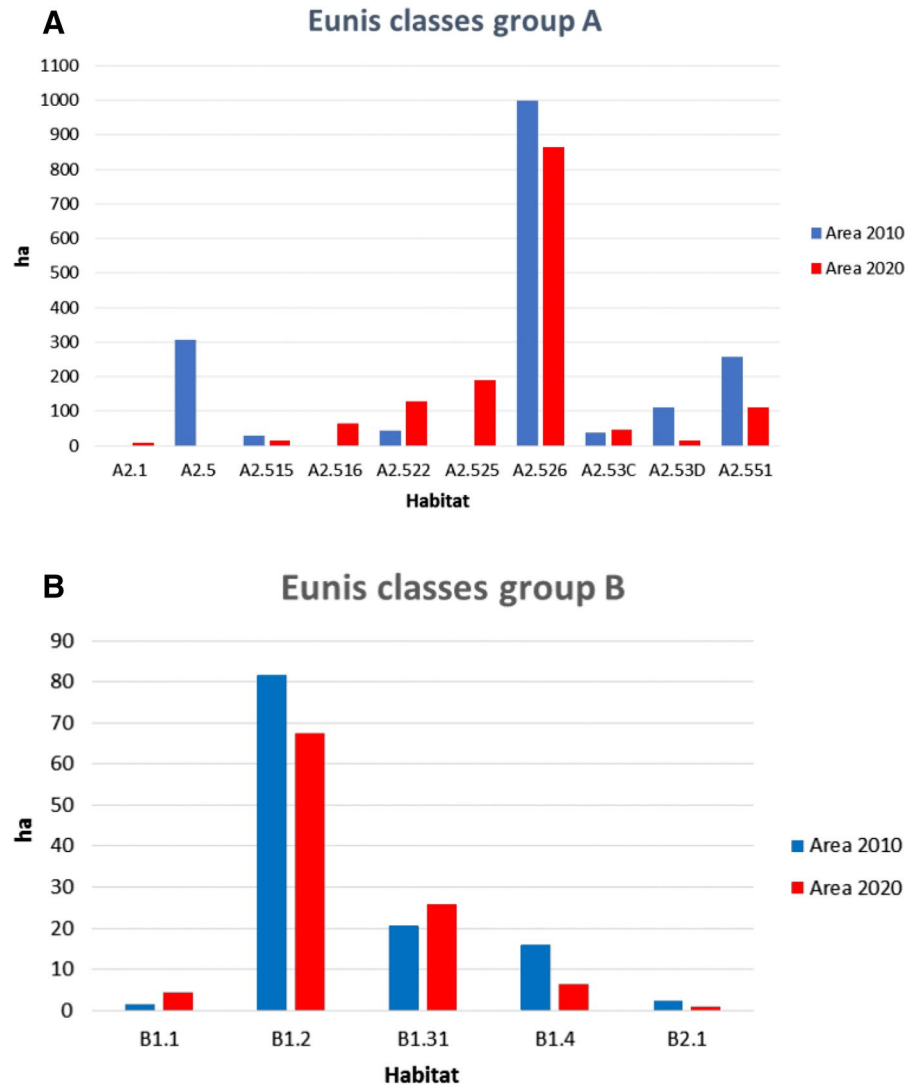
(Change in land management). The environments worst affected by impacts are salt marshes and coastal dune systems.

Discussions and conclusions

During the period of observation, a wide range of changes has been detected, in part due to an improving in thematic resolution, but in a large extent, attributable to anthropogenic pressures. Most of the observed conversions is borne by classes belonging to the Eunis high-level categories A and B, corresponding to saltmarshes and to coastal dune systems

respectively, which are the main types of natural ecosystems in the site.

In the case of salt marshes, the main pressures turned out to be intensification and expansion of agricultural areas, changes in land management, and modifications of the hydrological regime. In this last case, the underlying factors lead back to agricultural activities (e.g., uptake of surface and groundwater), land use conversions, but also to direct interventions to the natural environments. Subsidence, that plays a key role in some areas, may be largely linked back to water caption, driven by agricultural intensification. Similar processes, consisting of temporal changes in vegetation components, and related to water management practices, have been also observed in other
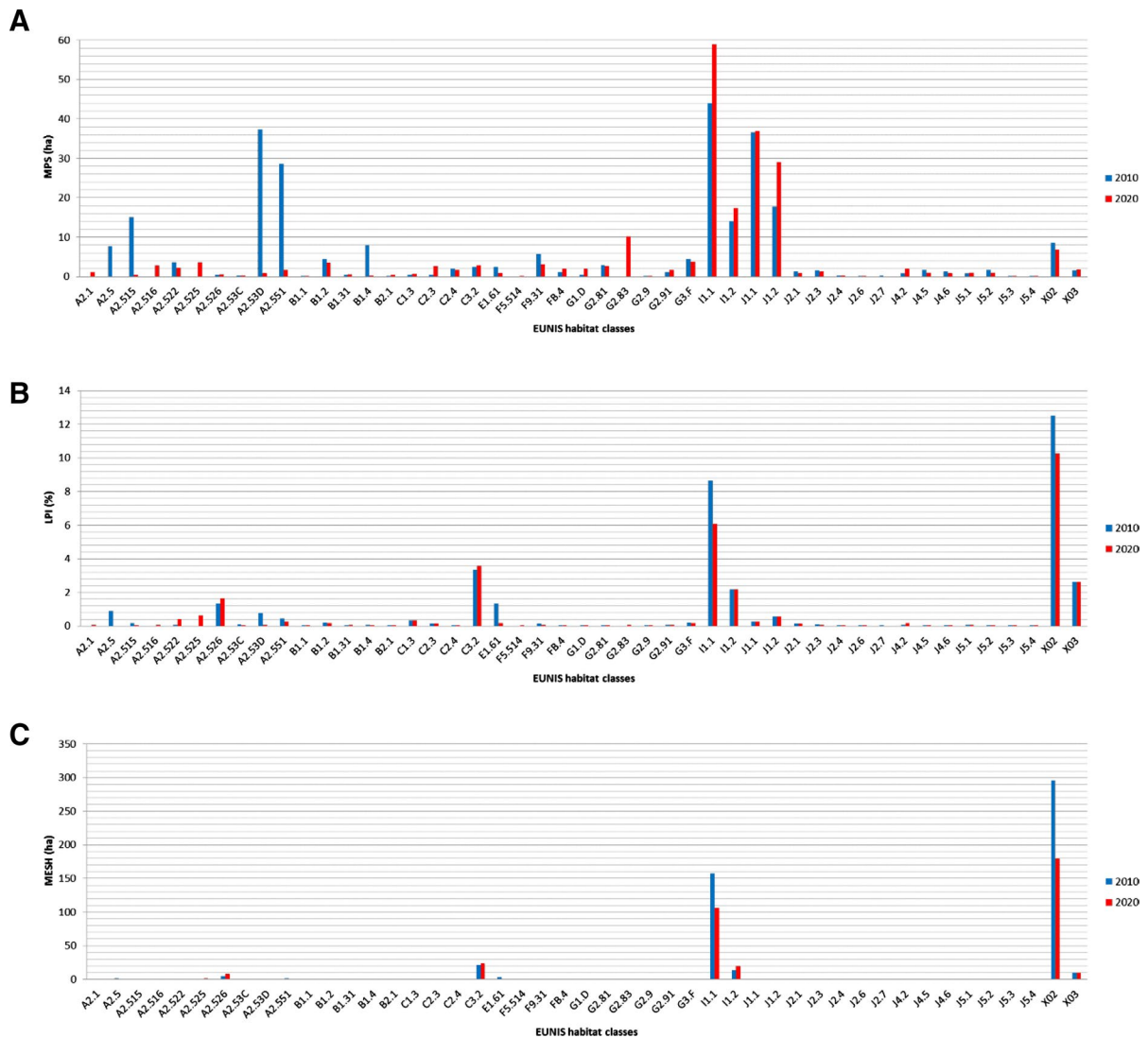
Fig. 14 Barplots comparing MPS (**A**), LPI (**B**) and MESH (**C**) in 2010 (blue) and 2020 (red)

coastal wetlands throughout the Mediterranean (Melendez-Pastor et al. 2010; Maneas et al. 2019). In particular, agriculture has been identified as the economic sector with the highest impact on wetlands, both directly (land reclamation) and indirectly (water management practices) (MedWet Secretariat 2016).

In the case of the sand dune system, this ecosystem is long-time severely compromised, subject to severe pressures by both land (intensive agriculture, touristic facilities) and sea (coastal erosion). Some dune habitats have been lost long ago (e.g., *Ammophila arenaria* communities—Eunis B1.31

white dunes, *Juniperus macrocarpa* communities—Eunis B1.631 Dune prickly juniper thickets), while others, especially those corresponding to the first zones of the standard zonation, result severely altered in distribution pattern, structure and functions. During the period of observation, a rapid dynamic of the coastline and of the related habitat types has been observed, with processes of erosion and accretion and often with rearrangement of the natural vegetation. Among the drivers producing such processes, both natural (the reduction of sediment flow from the Ofanto river), and

Fig. 15 Barplot comparing MLW values in 2010 (blue) and 2020 (red) for the Eunis habitat classes of group B
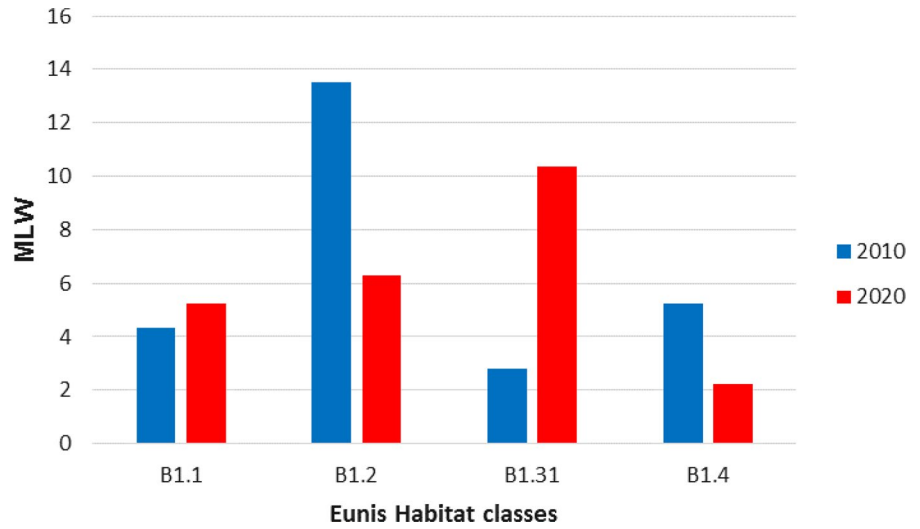

Fig. 16 Barplots comparing MRBT values in 2010 (blue) and 2020 (red) for the Eunis habitat classes B1.31 (**A**) and B1.4 (**B**)
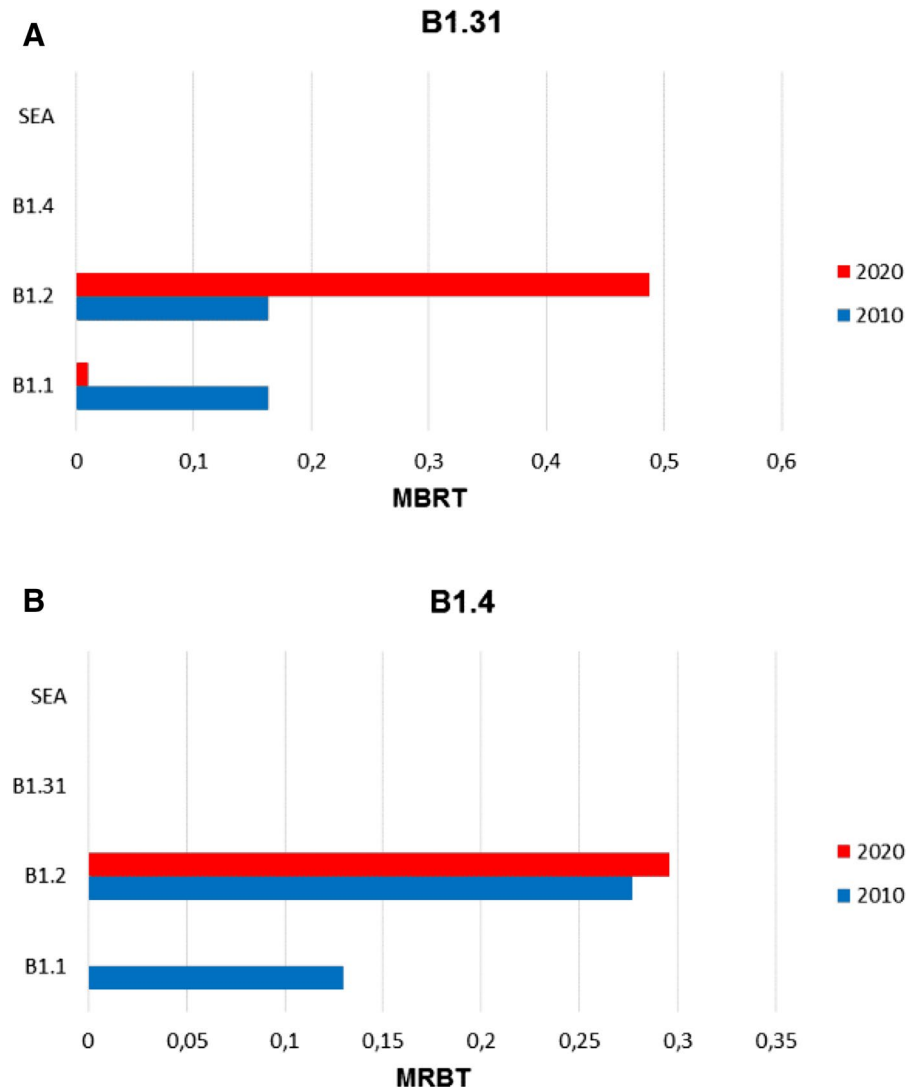
Table 4 List of the impacts affecting natural and semi-natural habitat types in the study area

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Dune vegetation (spatial pattern)	WA	1.3 Indirect Ecosystem Effects Habitat fragmentation and change in landscape connectivity	Habitat loss/fragmentation/change in spatial pattern	Coastal erosion and accretion processes have been determining deep transformation in the coast profile and in the spatial pattern of coastal dune habitat types, with changes in CA (class area), patch size, number, and shape	Structural changes in the hydrodynamic conditions	7. Natural system modifications	B1.1, B1.2, B1.31, B1.4
Dune vegetation (plant community type)	WA	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of driftline vegetation to Thinopyron junceum (L.) Á. Löve communities/Change in species composition	Annual halo-nitrophilous vegetation of driftlines results to be converted in Thinopyron junceum communities (shifting dunes) in a significant extent, throughout the area	Construction of artificial barriers between cultivated fields and beach	2. Agriculture 2.1.2 Small-holder farming	B1.1 to B1.31
Salt marshes (plant community type; land use)	WA	1.1 Ecosystem Conversion 1.3 Indirect Ecosystem Effects Land cover/habitat conversion Habitat fragmentation and change in landscape connectivity	Conversion of annual halophytic glasswort communities to arable lands	Annual glasswort (i.e. Salicornia patula Duval-Jouve) communities located in marginal areas are converted in cultivated areas	Agricultural practices intensification	2. Agriculture 2.1.2 Small-holder farming	A2.551 to I1.1

Table 4 (continued)

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Salt marshes (plant community type; land use)	WA	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of perennial glasswort communities to arable lands	Perennial glasswort (i.e. *Salicornia perennis* Mill., *Arthrocaulon macrostachyum* (Moric.) Piirainen & G. Kadereit) communities located in marginal areas convert in cultivated areas	Agricultural practices intensification	2. Agriculture 2.1.2 Small-holder farming	A2.526 to I1.1 and I1.2
Arable/managed lands (plant community type; land use)	WA	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of fallow and set-aside lands to arable lands	Wide areas used as fallow and/or set-aside lands have undergone a land-use change in arable lands; this process is observed throughout the whole area, both in inland areas and along the coast	Agricultural practices intensification	2. Agriculture 2.1.2 Small-holder farming	E1.61 to I1.1 and I1.2
Salt marshes (plant community type)	PF	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of perennial glasswort communities to helophytic vegetation (reedbeds expansion)	Perennial glasswort (i.e. *Salicornia perennis*, *Suaeda vera*) communities have undergone a progressive invasion and conversion to *Phragmites australis* or to *Juncus subulatus* communities	Change in water quality (salinity)	7.2 Dams & Water Management/Use Changing water flow patterns from their natural range of variation	A2.526 to A2.525 and C3.2

Table 4 (continued)

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Salt marshes (plant community type)	PF	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of spiny rush communities to other helophytic vegetation (reedbeds expansion)	Spiny rush (*Juncus acutus*) communities have undergone a progressive invasion and conversion to *Phragmites australis* communities or to *Juncus subulatus* communities	Change in water quality (salinity)	7.2 Dams & Water Management/Use Changing water flow patterns from their natural range of variation	A2.522 to C3.2 and A2.525
Salt marshes (plant community type)	PF	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of saltmarsh bulrush communities to other helophytic vegetation	Saltmarsh bulrush (*Bolboschoenus maritimus*) communities have undergone a progressive invasion and conversion to *Juncus subulatus* communities and, to a minor extent, to *Phragmites australis*	Change in water quality (salinity)	7.2 Dams & Water Management/Use Changing water flow patterns from their natural range of variation	A2.53D to A2.525 and C3.2
Woody vegetation (plant community type)	PF	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of Saltcedar (*Tamarix gallica* L.) communities to reedbeds	Part of Saltcedar (*Tamarix gallica*) communities have been replaced by reedbeds (*Phragmites australis*)	Fire	7.1.1 Increase in Fire Frequency/Intensity	F9.31 to C3.2
Woody vegetation (plant community type; land use)	PF	1.1 Ecosystem Conversion Land cover/habitat conversion Land use change	Conversion of cultivated areas in saltcedar (*Tamarix gallica*) communities	Part of cultivated areas have been abandoned and then progressively colonized by *Tamarix gallica*	Abandonment of managed lands	7.3 Other Ecosystem Modifications	I1.1 to F9.31

Table 4 (continued)

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Woody vegetation (spatial pattern)	PF	1.3 Indirect Ecosystem Effects Habitat fragmentation and change in landscape connectivity	Habitat fragmentation and change in spatial pattern of salt cedar communities	Salt cedar (*Tamarix gallica*) communities have undergone a change of spatial pattern (concurrent expansion and reduction)	Change in water/fire regime Change in land management	7.3 Other Ecosystem Modifications	F9.31
Salt marshes (plant community type)	PF*	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of halophytic annual glasswort communities in Spiny rush (*Juncus acutus*) communities	This conversion results from expansion and tightening of *Juncus acutus* communities in an area subject to buffalo grazing	Change in land management	7.3 Other Ecosystem Modifications	A2.551 to A2.53C
Water bodies (plant community type; land use)	LS	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of various types of natural and seminatural vegetation in waterbodies	Class C1.3 has an important increment in area because of specific interventions for birdlife (LIFE project) but also for a progressive subsidence of this area	Change in land management	7.3 Other ecosystem modifications	A.5, A2.551, C3.2 to C1.3
Salt marshes (plant community type; land use)	LS	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of various types of natural vegetation to *Juncus subulatus* communities	Large area covered by natural and semi-natural vegetation converts to *Juncus subulatus* communities as a result of a progressive flooding of this area	Change in land management Subsidence (lowering of the water table)	7.3 Other ecosystem modifications 7.2.7 Abstraction of ground water (agricultural use)	A.5, A2.551 to A2.525

Table 4 (continued)

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Salt marshes (plant community type)	I	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of perennial glasswort communities to coastal lagoons	Perennial glasswort (i.e. *Salicornia perennis, Arthrocaulon macrostachyum, Suaeda vera*) communities have been undergoing a progressive submersion by marine waters	Subsidence (lowering of the water table)	7.2.7 Abstraction of ground water (agricultural use)	A2.526 to X02
Arable lands/fallow lands (plant community type; land use)	I	1.1 Ecosystem Conversion Land cover/habitat conversion	Conversion of arable lands to perennial glasswort communities	Arable and fallow lands have been abandoned due to a progressive soil salinization and, consequently, colonized by perennial glasswort (i.e. *Salicornia perennis, Arthrocaulon macrostachyum, Suaeda vera*)	Change in salt regime in water Change in land management	7.2.7 Abstraction of ground water (agricultural use) 7.3 Other ecosystem modifications	E1.61 to A2.516 and A2.526
Arable lands/fallow lands (plant community structure, species composition)	WA	1.2 Ecosystem Degradation 2.3 Indirect Species Effect Changes in plant community structure Land cover/habitat modification	Change in species composition	Herbaceous annual vegetation of fallow and or set-aside lands, abandoned for long time, change species composition with the progressive emergence of perennials (from annual to "mixed")	Change in land management (abandonment of managed lands)	7.3 Other ecosystem modifications	EUNIS E1.61 LCCS A12/ A2A10B4XXE5-B12E7 to LCCS A12/ A2A10B4XXE5-B12E7

Table 4 (continued)

State (biodiversity target)	Site	Broad impact (stress) category (IUCN-CMP 2012b; Nagendra et al. 2015)	Specific type of impact	Short description of the impact	Direct threat (proximate pressure)	Underlying factors (drivers of change) (IUCN-CMP 2012a)	Habitat and LC types
Salt marshes (plant community structure, species composition)	PF	1.2 Ecosystem Degradation 2.3 Indirect Species Effect Land cover/habitat modification	Change in species composition	The underbrush of saltcedar (*Tamarix gallica*) communities has shown a progressive tightening with the emergence of helophytes	Change in water quality (salinity)	7.2 Dams & Water management/use changing water flow patterns from their natural range of variation	EUNIS F9.31 LCCS A12/ A1A4A11B3-A12B14 to LCCS A12/ A1A4A11B-3F2F4F7G4-A12B9F8G11
Salt marshes (plant community structure)	I	2.3 Indirect Species Effect Changes in plant community structure Land cover/habitat modification	Change in vegetation cover	Perennial glasswort (i.e. *Salicornia perennis*, *Arthrocaulon macrostachyum*, *Suaeda vera*) communities have progressively replaced cultivated areas and undergone a progressive tightening of their cover, especially in areas subject to subsidence and soil salinization	Change in salt regime in water Change in land management	7.2.7 Abstraction of ground water (agricultural use) 7.3 Other ecosystem modifications	EUNIS A2.526 LCCS A24/ A1A4A13B3C2D3-B10 to LCCS A24/ A1A4A12B3C2D3-B10

anthropogenic causes (the realization of infrastructures, such as the Margherita di Savoia harbor and the groynes along the coastline in the southern part of the study area) have been identified, especially in terms of accelerating erosion rates (Caldara et al. 2008). This is in accordance with what observed in many other coastal areas in the Mediterranean, where decrease in sedimentary contribution, sea level rise, and subsidence, are the main driving factors of coastal retreat (Rodríguez-Santalla and Navarro 2021).

The Mediterranean basin represents one of the most responsive region (primary hot spot) to climate change caused by human activities (Giorgi 2006). The principal threats that affect the Adriatic portion of the basin are increase in temperatures, decrease of precipitation during the spring and summer seasons, sea level rise. These factors may affect in different ways coastal plant communities. Nevertheless, in the case of our analysis and considering the 10-year timespan, the anthropogenic direct factors act at a faster rate in the determination of changes in land cover of coastal habitats.

As regards landscape composition and configuration, landscape metrics indicate a reduction in landscape complexity and a more even distribution and higher patchiness for some habitat types of group A. The outcomes for habitat types of group B indicate a deep alteration in the standard zonation of the whole stretch of sandy coast, and this alteration has become even more severe in 2020. MLW and MRBT turned out to be very effective metrics to assess the integrity of habitat types of group B (Coastal dune systems) and of their standard zonation. In the case of class B1.31, the significant increment of CA along with MLW indicates a positive trend with the re-establishment of this habitat along large stretches of coastline; the creation of some artificial barriers built at the edges between cultivated fields ("arenili") and the beach, has determined the accumulation of sand with following colonization by the typical vegetation of the shifting dunes (e.g., *Thinopyrum junceum*). It is worth noting that the re-establishment of this habitat is supported by human intervention, although the purpose was aimed at the protection of cultivated fields. MRBT may be very useful in evaluating the integrity of the standard zonation, as it gives a concrete measure of the contact between the different vegetation belts.

The separate analysis of the sub-set areas revealed the way in which different management strategies and practices may affect landscape composition and nature conservation. In particular, in the protected areas PF and LS there are the most significant total change percentages, much higher than the percentage of the whole study area. These are the areas where human interventions and changes in management, mostly involving agriculture practices and water flow patterns, have significantly affected the natural systems in the last decade; specifically, it is the case of water extraction in surrounding agricultural areas, and also of some management practices provided in restoration programs (e.g., creation of drainage channels that have negatively impacted on the hydric balance of the wetland area).

A system that has been undergoing such rapid transformations requires well-targeted policies and effective interventions. Coastal zones are very sensitive and dynamic systems, whose management planning requires in-depth knowledge of the natural dynamics as well as a full understanding of the social, economic, and political context (Damiani et al. 2002). With a view to identifying appropriate management and conservation measures, the Integrated Coastal Zone Management (ICZM) is a strategic reference point. ICZM is a widely accepted approach for sustainable management of the coastal environment and consists of the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental goals (McKenna et al. 2008; Dronkers 2022).

From the observed trends for both drivers/pressures and impacts obtained from the DPSIR analysis, and according to the key principles of the ICZM, some alternative recommendations could be provided:

1. Creation of buffer zones (limited to sensitive areas, such as those in spatial contact to agricultural areas subject to intensive exploitation), may contribute to mitigate the effects of agriculture on water quality and regime; in order to prevent conflicts with stakeholders, regulated and controlled uses can be allowed in these areas, as well as in adjacent areas—buffer zones could also be considered as effective means to mitigate the effects of sea level rising and coastal erosion; 2. Higher control and management of surrounding activities; 3. Promotion of pro-environmental activities that could have a lower environmental impact on the overall

system quality, such as eco sustainable activities, organic farming and, above all, proper management of water resources. In relation to the latter, crucial point, among the ICZM specific objectives, "Limitation of soil subsidence" ("Enhancing sustainability and ecosystem services") is included, with the actions provided: (a) regulations for groundwater extraction and drainage; (b) groundwater management and alternative water supply (incl. recharge of aquifers). Moreover, within the specific object "Land-use" ("Economic development"), the actions provided are: (a) ban on urban development in sensitive zones; (b) coastal zone water management plan and implementation (Clark 1997; Fujita et al. 2013; Dronkers 2022).

In order to achieve a comprehensive and effective management plan, this framework should be implemented at different (both local and national) administrative levels, and an effective coordination is needed among various organizations.

Data availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary information (online resources).

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article. The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval Not applicable.

References

Abbas I (2013) An assessment of land use/land cover changes in a section of Niger Delta, Nigeria. Front Sci 2(6):137–143. https://doi.org/10.5923/j.fs.20120206.02

Abbas I, Bello O, Abdullahi H (2018) Mapping and analyzing the land use—land cover of Nigeria between 2001 and 2009. MOJ Ecol Environ Sci 3(3):197–205. https://doi.org/10.15406/mojes.2018.03.00087

Adamo M, Tarantino C, Kosmidou V, Petrou Z, Manakos I, Lucas RM, Tomaselli V, Mucher CA, Blonda P (2014) Expert knowledge for translating land cover/use maps to General Habitat Categories (GHC). Landsc Ecol 29:1045–1067. https://doi.org/10.1007/s10980-014-0028-9

Adamo M, Tarantino C, Tomaselli V, Veronico G, Nagendra H, Blonda P (2016) Habitat mapping of coastal wetlands using expert knowledge and Earth observation data. J Appl Ecol 53:1521–1532. https://doi.org/10.1111/1365-2664.12695

Almeida D, Rocha J, Neto C, Arsénio P (2016) Landscape metrics applied to formerly reclaimed saltmarshes: a tool to evaluate ecosystem services? Estuar Coast Shelf Sci 181:100–113. https://doi.org/10.1016/j.ecss.2016.08.020

Bajocco S, De Angelis A, Perini L, Ferrara A, Salvati L (2012) The impact of land use/land cover changes on land degradation dynamics: a Mediterranean case study. Environ Manag 49(5):980–989. https://doi.org/10.1007/s00267-012-9831-8

Bazzichetto M, Sperandii MG, Malavasi M, Carranza ML, Acosta ATR (2020) Disentangling the effect of coastal erosion and accretion on plant communities of Mediterranean dune ecosystems. Estuar Coast Shelf Sci 241:106758. https://doi.org/10.1016/j.ecss.2020.106758

Belda-Carrasco R, Iranzo-García E, Pascual-Aguilar JA (2019) Landscape dynamics in Mediterranean coastal areas: Castelló de la Plana in the last hundred years. Landsc Online 9:1–15. https://doi.org/10.3097/LO.201969

Botequilha-Leitão A, Ahern J (2002) Applying landscape ecological concepts and metrics in sustainable land planning. Landsc Urban Plan 59:65–93. https://doi.org/10.1016/S0169-2046(02)00005-1

Braun-Blanquet J (1964) Pflanzensoziologie. Grundzüge der Vegetationskunde, 3. Aufl. Springer Verlag, Wien, New York

Bruno MF, Saponieri A, Molfetta MG, Damiani L (2020) The DPSIR approach for coastal risk assessment under climate change at regional scale: the Case of Apulian coast (Italy). J Mar Sci Eng 8:531. https://doi.org/10.3390/jmse8070531

Bunce RGH, Metzger MJ, Jongman RHG, Brandt J, de Blust G, Elena-Rossello R, Groom GB, Halada L, Hofer G, Howard DC, Kovář P, Mücher CA, Padoa Schioppa E, Paelinx D, Palo A, Perez Soba M, Ramos IL, Roche P, Skanes H, Wrbka T (2008) A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. Landsc Ecol 23:11–25. https://doi.org/10.1007/s10980-007-9173-8

Caldara M, Capolongo D, Pennetta L, Simone O (2008) Negative results of an ineffective and uncoordinated coastal management in the Gulf of Manfredonia (Puglia, southern Italy). In: Proceedings of the II international symposium "Mediterranean coastal monitoring: problems and measurement techniques", Naples 4–6 June 2008, pp 57–65

Caldara M, Capolongo D, Triggiani M, Refice A (2013) La subsidenza delle piane costiere pugliesi. Geologia dell'Ambiente Sup 2(2013):30–36

Clark JR (1997) Coastal zone management for the new century. Ocean Coast Manag 37(2):191–216

Damiani L, Petrillo A, Ranieri G (2002) Management of coastal area in Apulia region. Landscapes of water, history, innovation and sustainable design, vol I. Uniongrafica Corcelli Editrice, Bari, pp 71–80

Davies CE, Moss D, Hill MO (2004) EUNIS habitat classification revised 2004. Report to: European environment agency-European topic centre on nature protection and biodiversity, pp 127–143

Davy AJ, Bakker P, Figueroa ME (2009) Human modification of European salt marshes. In: Sillyman BR, Grosholz ED, Bertness MD (eds) Human impacts on salt marshes: a global perspective. University of California press, Berkeley, pp 311–3350

Di Gregorio A, Jansen LJM (2005) Land Cover Classification System (LCCS): classification concepts and user manual. Food and Agriculture Organization of the United Nations, Rome

Dronkers J (2022) Integrated Coastal Zone Management (ICZM). Available from http://www.coastalwiki.org/wiki/Integrated_Coastal_Zone_Management_(ICZM). Accessed 23 June 2022

EEA (1995) Europe's Environment: the Dobris Assessment. European Environmental Agency, Copenhagen, 8 pp.

Fahrig L (2003) Effects of habitat fragmentation on biodiversity. Annu Rev Ecol Evol Syst 34:487–515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Fisher J, Lindenmayer DB (2007) Landscape modification and habitat fragmentation: a synthesis. Glob Ecol Biogeogr 16:265–280. https://doi.org/10.1111/j.1466-8238.2007.00287.x

Fujita R, Lynham J, Micheli F, Feinberg PG, Bourillón L, Sáenz-Arroyo A, Markham AC (2013) Ecomarkets for conservation and sustainable development in the coastal zone. Biol Rev 88:273–286. https://doi.org/10.1111/j.1469-185X.2012.00251.x

Gabrielsen P, Bosch P (2003) Environmental indicators: typology and use in reporting. European Environment Agency, internal working paper

Gari SR, Newton A, Icely JD (2015) A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean Coast Manag 103:63–77. https://doi.org/10.1016/J.OCECOAMAN.2014.11.013

Gavish Y, O'Connell J, Marsh CJ, Tarantino C, Blonda P, Tomaselli V, Kunin WE (2018) Comparing the performance of flat and hierarchical habitat/land-cover classification models in a NATURA 2000 site. ISPRS J Photogramm Remote Sens 136:1–12. https://doi.org/10.1016/j.isprsjprs.2017.12.002

Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33:L08707. https://doi.org/10.1029/2006GL025734

Giorgi F, Bi X (2005) Updated regional precipitation and temperature changes for the 21st century from ensembles of recent AOGCM simulations. Geophys Res Lett 32:L21715. https://doi.org/10.1029/2005GL024288

Ichter J, Evans D, Richard D (2014) Terrestrial habitat mapping in Europe: an overview. European Environmental Agency, Luxembourg

IUCN-CMP (2012a) Unified classification of direct threats (version 3.2). Downloaded from https://www.iucnredlist.org/resources/threat-classification-scheme. Accessed 25 Feb 2022

IUCN-CMP (2012b) Unified classification of stresses (version 1.1). Downloaded from https://www.iucnredlist.org/resources/stresses-classification-scheme. Accessed 25 Feb 2022

Jansen LJM, Di Gregorio A (2002) Parametric land cover and land-use classifications as tools for environmental change detection. Agric Ecosyst Environ 91:89–100. https://doi.org/10.1016/S0167-8809(01)00243-2

Janssen JAM, Rodwell JS, Criado MG, Gubbay S, Haynes T, Nieto A, Sanders N, Landucci F, Loidi J, Ssymank A, Tahvanainen T, Valderrabano M, Acosta A, Aronsson M, Arts G, Attorre F, Bergmeier E, Bijlsma RJ, Bioret F, Biţă-Nicolae C, Biurrun I, Calix M, Capelo J, Čarni A, Chytrý M, Dengler J, Dimopoulos P, Essl F, Gardfell H, Gigante D, Giusso del Galdo G, Hájek M, Jansen F, Jansen J, Kapfer J, Mickolajczak A, Molina JA, Molnár Z, Paternoster D, Piernik A, Poulin B, Renaux B, Schaminée JHJ, Šumberová K, Toivonen H, Tonteri T, Tsiripidis I, Tzonev R, Valachovič M (2016) European red list of habitats. Part 2. Terrestrial and freshwater habitats. Publications Office of the European Union, Luxembourg. https://doi.org/10.2779/091372

Lengyel S, Kobler S, Kutnar L, Framstad E, Henry PY, Babij V, Gruber B, Schmeller D, Henle K (2008) A review and a framework for the integration of biodiversity monitoring at the habitat level. Biodivers Conserv 17:3341–3356. https://doi.org/10.1007/s10531-008-9359-7

Li Z, Feng Y, Dessay N, Delaitre E, Gurgel H, Gong P (2019) Continuous monitoring of the spatio-temporal patterns of surface water in response to land use and land cover types in a Mediterranean Lagoon Complex. Remote Sens 11:1425. https://doi.org/10.3390/rs11121425

Lozoya JP, Sardà R, Jiménez JA (2011) A methodological framework for multi-hazard risk assessment in beaches. Environ Sci Policy 14(6):685–696. https://doi.org/10.1016/j.envsci.2011.05.002

Maltby E, Acreman MC (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrol Sci J 56(8):1341–1359. https://doi.org/10.1080/02626667.2011.631014

Maneas G, Makopoulou E, Bousbouras D, Berg H, Manzoni S (2019) Anthropogenic changes in a Mediterranean coastal wetland during the last century—the Case of Gialova Lagoon, Messinia, Greece. Water 11:350. https://doi.org/10.3390/w11020350

Margiotta B, Colaprico G, Urbano M, Veronico G, Tommasi F, Tomaselli V (2020) Halophile wheatgrass *Thinopyrum elongatum* (Host) D.R. Dewey (Poaceae) in three Apulian coastal wetlands: vegetation survey and genetic diversity. Plant Biosyst 156(1):1–15. https://doi.org/10.1080/11263504.2020.1829732

McKenna J, Cooper A, O'Hagan AM (2008) Managing by principle: a critical analysis of the European principles of Integrated Coastal Zone Management (ICZM). Mar Policy 32(6):941–955. https://doi.org/10.1016/j.marpol.2008.02.005

MedWet Secretariat (2016) Wetlands for sustainable development in the Mediterranean region. A framework for action 2016–2030. Mediterranean Wetlands Committee (MedWet/Com)

Mehvar S, Filatova T, Dastgheib A, Ruyter De, van Steveninck E, Ranasinghe R (2018) Quantifying economic value of coastal ecosystem services: a review. J Mar Sci Eng 6:5. https://doi.org/10.3390/jmse6010005

Melendez-Pastor I, Navarro-Pedreño J, Gómez I, Koch M (2010) Detecting drought induced environmental changes in a Mediterranean wetland by remote sensing. Appl Geogr 30(2):254–262. https://doi.org/10.1016/j.apgeog.2009.05.006

Nagendra H, Munroe DK, Southworth J (2004) From pattern to process: landscape fragmentation and the analysis of land use/land cover change. Agric Ecosyst Environ 101(2–3):111–115. https://doi.org/10.1016/j.agee.2003.09.003

Nagendra H, Mairota P, Marangi C, Lucas R, Dimopoulos P, Honrado JP, Niphadkar M, Mücher CA, Tomaselli V, Panitsa M, Tarantino C, Manakos I, Blonda P (2015) Satellite Earth observation data to identify anthropogenic pressures in selected protected areas. Int J Appl Earth Obs Geoinf 37:124–132. https://doi.org/10.1016/j.jag.2014.10.010

Naveh Z (1990) Ancient man's impact on the Mediterranean landscape in Israel—ecological and evolutionary perspectives. In: Bottema S, Entjes-Nieborg G, van Zeist W (eds) Man's role in shaping of the Eastern Mediterranean landscape. Balkema, Rotterdam, pp 43–50

Pascual-Aguilar J, Andreu V, Gimeno-García E, Picó Y (2015) Current anthropogenic pressures on agro-ecological protected coastal wetlands. Sci Total Environ 503–504:190–199. https://doi.org/10.1016/j.scitotenv.2014.07.007

Perennou C, Beltrame C, Guelmami A, Tomas Vives P, Caessteker P (2012) Existing areas and past changes of wetland extent in the Mediterranean region: an overview. Ecol Mediterr 38:53–66. https://doi.org/10.3406/ecmed.2012.1316

Plexida SG, Sfougaris AI, Ispikoudis IP, Papanastasis VP (2014) Selecting landscape metrics as indicators of spatial heterogeneity—a comparison among Greek landscapes.

Int J Appl Earth Obs Geoinf 26:26–35. https://doi.org/10.1016/j.jag.2013.05.001

Riitters KH, O'Neill RV, Hunsaker CT, Wickham JD, Yankee DH, Timmins SP, Jones KB, Jackson BL (1995) A factor analysis of landscape pattern and structure metrics. Landsc Ecol 1:29–36. https://doi.org/10.1007/BF00158551

Rodríguez-Santalla I, Navarro N (2021) Main threats in Mediterranean coastal wetlands. The Ebro delta case. J Mar Sci Eng 9(11):1190. https://doi.org/10.3390/jmse9111190

Ruiz I, Sanz-Sanchez MJ (2020) Effects of historical land-use change in the Mediterranean environment. Sci Total Environ 732(1):139315. https://doi.org/10.1016/j.scitotenv.2020.139315

Schindler S, Poirazidis K, Wrbka T (2008) Towards a core set of landscape metrics for biodiversity assessments: a case study from Dadia National Park, Greece. Ecol Ind 8:502–514. https://doi.org/10.1016/j.ecolind.2007.06.001

Tomaselli V, Sciandrello S (2017) Contribution to the knowledge of the coastal vegetation of the SIC IT9110005 "Zone Umide della Capitanata" (Apulia, Italy). Plant Biosyst 151(4):673–694. https://doi.org/10.1080/11263504.2016.1200689

Tomaselli V, Tenerelli P, Sciandrello S (2012) Mapping and quantifying habitat fragmentation in small coastal areas: a case study of three protected wetlands in Apulia (Italy). Environ Monit Assess 184(2):693–713. https://doi.org/10.1007/s10661-011-1995-9

Tomaselli V, Dimopoulos P, Marangi C, Kallimanis AS, Adamo M, Tarantino C, Panitsa M, Terzi M, Veronico G, Lovergine F, Nagendra H, Lucas R, Mairota P, Mücher CA, Blonda P (2013) Translating land cover/land use classifications to habitat taxonomies for landscape monitoring: a Mediterranean assessment. Landsc Ecol 28(5):905–930. https://doi.org/10.1007/s10980-013-9863-3

Tomaselli V, Veronico G, Sciandrello S, Blonda P (2016) How does the selection of landscape classification schemes affect the spatial pattern of natural landscapes? An assessment on a coastal wetland site in southern Italy. Environ Monit Assess 188(6):1–15. https://doi.org/10.1007/s10661-016-5352-x

Tomaselli V, Veronico G, Adamo M (2021) Monitoring and recording changes in natural landscapes: a case study from two coastal wetlands in SE Italy. Land 10(1):50. https://doi.org/10.3390/land10010050

Turner MG, Gardner RH, O'Neil RV (2001) Landscape ecology in theory and practice: pattern and process. Springer, New York

Turner BL, Lambin EF, Reenberg A (2007) Land change science special feature: the emergence of land change science for global environmental change and sustainability. Proc Natl Acad Sci USA 104:20666–20671. https://doi.org/10.1073/pnas.0704119104

Uuemaa E, Mander U, Marja R (2013) Trends in the use of landscape spatial metrics as landscape indicators: a review. Ecol Indic 28:100–106. https://doi.org/10.1016/j.ecolind.2012.07.018