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Spatio-temporal changes (1956-2013) of coastal ecosystems in Southern Iberian Peninsula (Spain)

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Abstract. Spatial and temporal changes of coastal vegetation since the 1950s along the southern Iberian Peninsula coast (Andalusia, Spain), have been analysed. Three examples have been selected: one on the Atlantic coast (Punta Umbria, Huelva) and two in the Mediterranean: Marbella (Malaga) and Punta Entinas-Sabinar (Almeria). The three areas are currently included in the Andalusian Network of Protected Natural Areas (RENPA). Aerial photographs dated in the years 1956-57 have been used and compared with the most recent (2013) using photointerpretation techniques and GIS (geographic information system) software. Observations have been completed with phytosociological data and historical cartography (forest and vegetation maps) that allowed us to analyse and identify the different communities and their transformation over 60 years. The results show the changes and impacts linked to the anthropic actions in this territory. In recent decades, the reforestation and expansion of urbanized areas are the main cause of coastal ecosystem alteration, especially affecting the Marbella coast that has had its dune system considerably reduced.
Keywords: Coastal vegetation; landscape transformation; aerial photographs; Mediterranean basin.

Cambios espacio-temporales (1956-2013) de ecosistemas costeros en el sur de la Península Ibérica (España)

Resumen. Se analizan los cambios espaciales y temporales de la vegetación costera del sur de la Península Ibérica (Andalucía, España) en las últimas décadas. Se han seleccionado tres ejemplos: uno en la costa atlántica. (Punta Umbría, Huelva) y dos en la mediterránea: Cabopino, Marbella (Málaga) y Punta Entinas-Sabinar (Almería). Actualmente, una parte de estos territorios está incluida en la Red de Espacios Protegidos de Andalucía (RENPA). Se han utilizado fotografías aéreas de los años 1956-57 y comparado con las más recientes (2013), usando técnicas de fotointerpretación y GIS (sistema de información geográfica). Las observaciones se han completado con datos fitosociológicos y cartografía histórica (mapas de bosques y vegetación) que nos ha permitido analizar e identificar las diferentes comunidades y su transformación en los últimos 60 años. Los resultados muestran la variación experimentada en estas zonas y los diferentes impactos vinculados a las acciones antrópicas en el territorio. En las últimas décadas la reforestación y expansión de áreas urbanizadas han sido la causa principal de alteración de los ecosistemas costeros, que han afectado especialmente a la costa de Marbella que ha perdido de forma considerable el sistema dunar.
Palabras clave: Vegetación costera; transformación del paisaje; fotografía aérea; Cuenca.

1. Introduction

The southern Spanish coast (about 800 km) possesses dune and saltmarsh ecosystems which highlights their biological and landscape values. Psammophilous and halophilous plant communities are generally distributed in function with ecological gradients derived from the combined action of topographic, edaphic and physical factors. These gradients can be identified along transects that express the vegetation zonation whose result is a catenal expression of a set of neighbouring series and geopermaseries (Rivas-Martínez, 2007).

Disturbance of Mediterranean coastal ecosystems has significantly increased in recent decades because of human pressure (Acosta & *al*., 2000; Campos & *al*., 2004; Martínez & *al*. 2008; Malavasi & *al*., 2013; Bertachi & Lombardi, 2014; Gómez-Zotano, 2014; Sciandrello & *al*., 2015, 2017). Transformation of the Mediterranean coastal ecosystems were justified in its beginnings due to consideration as the unproductive and marginal spaces and therefore susceptible to alteration with alternative uses (Gómez-Zotano, 2014).

In Southern Spain, the main changes are due to several factors: in the western area (Huelva, Cadiz, Malaga) the reforestation of extensive zones with pines (*Pinus pinea*) at the beginning of the 20th century, to slow down the advance of dunes and in the last decades the urban growth due to the tourist pressure. In eastern coastal areas (Almeria), intensive crops in greenhouses and also urban development have affected coastal ecosystems. Another factor to consider is the increase of invasive alien species, many of them from gardens (Sanz Elorza & *al*., 2010; Lloret & *al.,* 2005; Asensi & *al*., 2016).

There is extensive bibliography on the southern Spanish coastal vegetation with the description of diverse

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communities and their floristic composition (Ceballos & Martín Bolaños, 1930; Ceballos & Vicioso, 1933; Rivas Martínez, 1966; Diez-Garretas & *al*., 1975, 2003; Rivas-Martínez & *al*., 1980; Alcaraz & *al*., 1989; Peinado & *al*., 1992; Asensi & Díez-Garretas 1993, 2017; Giménez Luque & *al*. 2003). Other more recent analyses take into account aspects such as the vulnerability, variability over time, global assessment of ecosystems or their biodiversity and the conservation degree (García Mora et *al*., 2000; Gómez Mercado & Giménez Luque, 2003; Asensi & Diez-Garretas, 2010; Muñoz Vallés & *al*., 2011; Martins & *al*., 2013; Asensi & *al*., 2014; Gómez-Zotano, 2014).

The aim of this study is to evaluate the changes experienced with the different anthropic activities and their causes in three zones of Southern Spain.

Study area

The study area is comprised of three zones, one in Punta Umbria (Huelva), another in Cabopino, Marbella (Málaga) and the third in Almeria: Punta Entinas-Sabinar (Figure 1).

The Iberian Peninsula southern coastal area has experienced a great alteration mainly due to the increase of tourism and residential areas, although the impact has been different depending on the area. Currently, part of these areas is included in the Andalusian Network of Protected Natural Areas (RENPA), two with the category of Paraje Natural (exceptional space with unique values of flora, fauna or geomorphology, which must be protected for conservation), such as Enebrales de Punta Umbria (Huelva) and Punta Entinas-Sabinar (Almeria), both since 1989. In 2003, a small area of Malaga coast, Dunas de Cabopino was protected with the figure of Natural Monument (space or element with singular formations of rarity or beauty that are object of special protection). The boundaries of these natural spaces are indicated, in the corresponding photographs, with dashed lines.

Enebrales de Punta Umbria with 169 hectares is situated in the southwest of the Huelva province. The dune system is extended along 3 km of the coastline and between 350 and 1400 m inland. This natural space is part of the Punta Umbria coastal arrow which has a triangular shape of about 9 km in length and 2 km in width, located on the right bank of the river mouths Tinto and Odiel.

Punta Entinas-Sabinar west of Almeria Bay is comprised of a coastal strip about 15 km long and 2 km wide and 1960 hectares, of which 785 are catalogued as Natural Reserve. It has a dune ecosystem and a series of ponds and saltmarshes of great interest as a refuge for numerous birds. It has been declared a Special Area of Conservation (Anon., 2017) due to its high ecological value with numerous habitats and species included in Directive 92/43 EEC, Annexes I and II.

Dunas de Cabopino is a small natural area (19.27 ha) in Marbella (Malaga) which represents the rest of an old dune front of about 18 km in length.

Both Enebrales de Punta Umbria and Dunas de Cabopino belong to the Andalusia and West Lusitania Coastal biogeographic province (Rivas-Martínez & *al*., 2017). Using climate data from the nearest thermopluviometric stations: Huelva and Marbella, the average temperature is 18ºC and annual rainfall is 465 mm and 659 mm, respectively, with a dry period in summer from June to September. According to the bioclimatic classification of Rivas-Martínez (2007), both have a Mediterranean pluviseasonal-oceanic bioclimate with thermomediterranean thermotype and dry ombrotype. Punta Entinas-Sabinar, on the other hand, is included in the Murcia-Almeria biogeographic province. Thermopluviometric data also show an average temperature of 18ºC, but the annual rainfall in the neighbouring town of Almeria registers 231 mm with a drought period from February to November. This zone has a Mediterranean xeric-oceanic bioclimate with thermomediterranean thermotype and semiarid ombrotype (Rivas-Martínez, 2007).

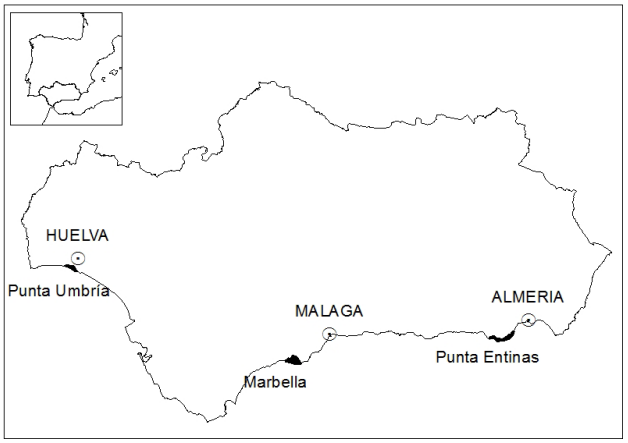


Figure 1. Study area.

Material and Methods

In order to evaluate the conservation degree and/or the reduction of psammophilous and halophilous communities in recent decades, panchromatic digital orthophoto of Andalusia 1956-1957 of 1 m resolution and digital orthophoto colour of Andalusia 2013, 0.5 m resolution was used, ETRS89/UTM zone 30N was used in both cases.

The comparative analysis has been carried out using a geographic information system (ArcGIS 9.3), photointerpreting the large units at an approximate scale of 1:10000. We have compared the data obtained with other historical data such as forest maps (Ceballos & Martín Bolaños, 1930; Ceballos & Vicioso 1933) as well as personal information from our own observations in the period from 1975 to the present. The habitats conservation state in chosen areas was verified by transects and phytosociological releves made during 2010-2015. We have also taken into account the evaluation carried out in the coastal habitats of southern Spain (Asensi & *al*., 2014), following the proposals of Bioret & *al*. (2011) on the intrinsic biological value of

the located habitats in each of the natural areas and the different types of threat (natural and anthropogenic).

Tables 1 and 2 express the phytosociological plant communities of the three zones (Rivas-Martínez & *al*., 2001, 2011), the habitat code (Annex I of CEE Directive 92/43, * indicates priority habitats) and location where they are present. The habitat code is accompanied by a bracketed number that reflects, in a simplified way, the ecological units: 1. Beach and the halo-nitrophilous communities; 2. Mobile dunes; 3. Semi-fixed dunes; 4. Stable dunes; 5. Urbanizations; 6. Saltmarsh plant communities.

Table 1. Dune plant communities.

Phytosociological syntaxon	Habitat code	Locality
Salsolo kali-Cakiletum maritimae Costa & Mansanet 1981 corr. Rivas-Martínez, Costa & Loidi 1992	1210 Annual vegetation of drift lines [1]	Cabopino Punta Entinas Punta Umbría
Eryngio maritimi-Sporoboletum arenarii (Arènes ex Géhu & Biondi 1994) Rivas-Martínez & Cantó 2002	2110 Embryonic shifting dunes [2]	Punta Entinas
Sporoboletum arenarii Rothmaler 1943	2110 Embryonic shifting dunes [2]	Cabopino
Cypero mucronati-Elytrigietum junceae Br.-Bl. 1933	2110 Embryonic shifting dunes [2]	Cabopino Punta Entinas
Euphorbio paraliae-Elytrigietum boreoatlanticae Tüxen in Br.-Bl. & Tüxen 1952	2110 Embryonic shifting dunes [2]	Punta Umbría
Loto cretici-Ammophiletum australis Rivas-Martínez 1965 corr. Rivas-Martínez et *al.* 2002	2120 Shifting dunes along the shoreline with *Ammophila arenaria* [2]	Cabopino Punta Entinas Punta Umbria
Artemisio crithmifoliae-Armerietum pungentis Rivas Goday & Rivas-Martínez 1959	2130*Fixed coastal dunes with herbaceous vegetation [3]	Punta Umbría
Loto cretici-Crucianelletum maritimae Alcaraz, T.E. Díaz, Rivas-Martínez & P. Sánchez 1989	2210 *Crucianellion maritimae* fixed beach dunes [3]	Cabopino Punta Entinas
Wahlenbergio nutabundae-Loeflingietum pentandrae Alcaraz et al. in Ferre, Díez Garretas & Asensi 1985	2230 *Malcolmietalia* dune grasslands [3]	Punta Entinas
Triplachno nitentis-Silenetum ramosissimae Peinado, Martinez Parras, Alcaraz, Garre & de la Cruz 1985	2230 *Malcolmietalia* dune grasslands [3]	Punta Entinas
Ononido variegatae-Linarietum pedunculatae Diez-Garretas in Izco, P. & J. Guitian 1988	2230 *Malcolmietalia* dune grasslands [3]	Cabopino
Malcolmio littoreae-Vulpietum alopecuroris Diez-Garretas, Hernández & Asensi 1975	2230 *Malcolmietalia* dune grasslands [3]	Cabopino
Triplachno nitentis-Vulpietum alopecuroris Peinado, Alcaraz & Martínez Parras 1992	2230 *Malcolmietalia* dune grasslands [3]	Punta Entinas
Osyrio quadripartitae-Juniperetum turbinatae Rivas-Martínez ex Rivas-Martínez et *al*. 1990	2250*Coastal dunes with *Juniperus* spp. [4]	Cabopino Punta Umbria
Rhamno oleoidis-Juniperetum macrocarpae Rivas-Martínez 1965	2250*Coastal dunes with *Juniperus* spp. [4]	Punta Umbria
Rhamno angustifolii-Juniperetum turbinatae Rivas-Martínez ex Freitag 1971 corr. Alcaraz et *al*. 1989	2250* Coastal dunes with *Juniperus* spp. [4]	Punta Entinas
Rubio longifoliae-Corematetum albi Rivas-Martínez *in* Rivas-Martínez, Costa, Castroviejo & E. Valdés 1980	2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs [4]	Punta Umbria
Halimio halimifolii-Stauracanthetum genistoidis Rivas-Martínez et *al.* 1980	2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs [4]	Punta Umbria
Teucrio belionis-Helianthemetum scopulorum Peinado et *al*. 1986	2260 *Cisto-Lavanduletalia* dune sclerophyllous scrubs [4]	Punta Entinas
Pycnocomono rutaefolii-Retametum monospermae Pérez Chiscano 1983	Not classified [4]	Punta Umbria
Dunes with *Pinus pinea*	2270*Wooded dunes with *Pinus pinea* and/or *P. pinaster* [4]	Cabopino Punta Umbria
Aro neglecti-Quercetum suberis Rivas-Martínez & Diez-Garretas 2011	9330 *Quercus suber* forests [4]	Cabopino

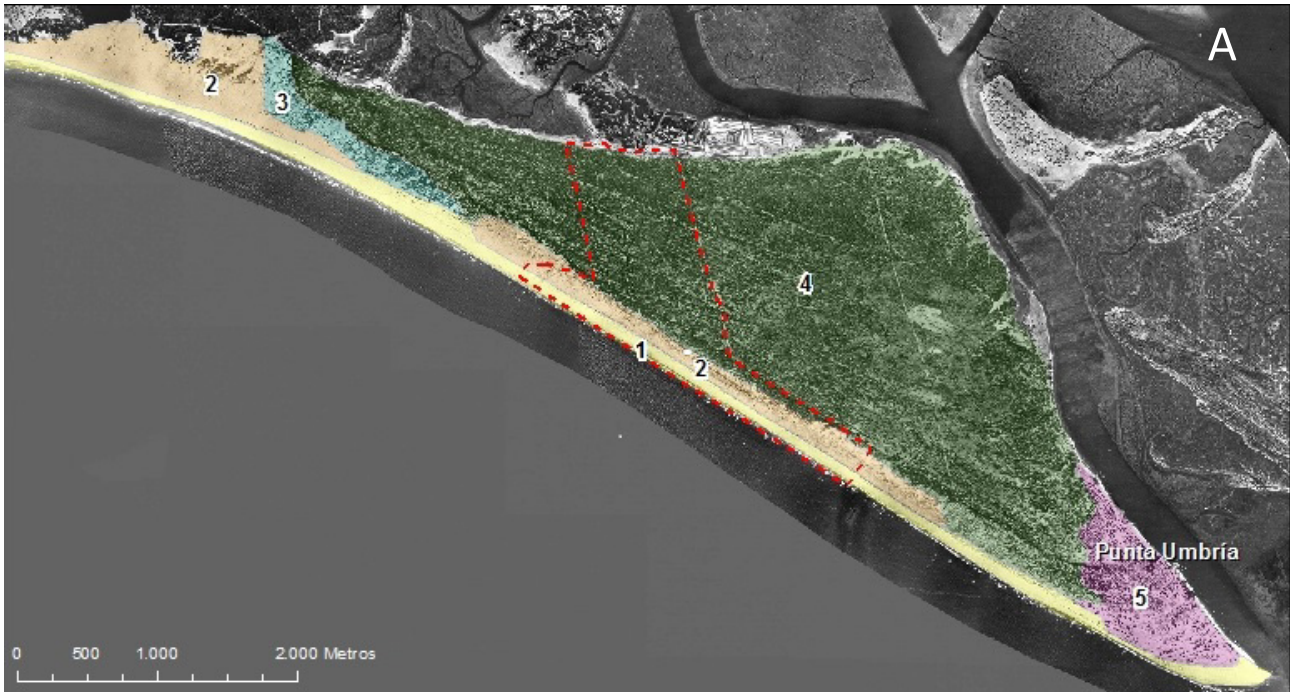
Table 2. Saltmarsh plant communities of Punta Entinas-Sabinar, Almería.

Phytosociological syntaxon	Habitat code
Suaedo spicatae-Salicornietum patulae Brullo & Furnari ex Géhu & Géhu-Franck 1984 corr. Alcaraz et *al*. 1998	1310 *Salicornia* and other annuals colonising mud and sand [6]
Parapholido incurvae-Frankenietum pulverulentae Rivas-Martínez ex Castroviejo & Porta 1976	1310 *Salicornia* and other annuals colonising mud and sand [6]
Elymo elongati-Juncetum maritimi Alcaraz, Garre, Peinado & Martínez Parras 1986	1410 Mediterranean salt meadows (*Juncetalia maritimi*) [6]
Frankenio corymbosae-Arthrocnemetum macrostachyi Rivas-Martínez et *al*. 1984	1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornieta fruticosi*) [6]
Sarcocornietum alpini Br.-Bl. 1933 corr. Rivas Martínez, Lousã, T. E. Díaz, Fernández González & J. C. Costa 1990	1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornieta fruticosi*) [6]
Limonio cossonianae-Sarcocornietum lagascae M.A. Alonso & De la Torre 2002 corr. Rufo et *al.* 2016	1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornieta fruticosi*) [6]
Frankenio corymbosae-Suaedetum verae Alonso & De la Torre 2002	1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornieta fruticosi*) [6]
Withanio frutescentis-Lycietum intricati Alcaraz et *al*. 1991	1430 Halo-nitrophilous scrubs (*Pegano-Salsoletea*) [6]
Limonietum angustibracteato-delicatuli Rivas-Martínez & Alcaraz in Alcaraz 1984	1510* Mediterranean salt steppes (*Limonietalia*) [6]
Inulo crithmoidis-Tamaricetum boveanae Izco, Fernández-González & A. Molina 1984	92D0 Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*) [6]

Results and discussion

The evolution of land use and its surface is shown after analysing both historical and current aerial photographs. Table 3 showed the area (ha) occupied by different types of vegetation and their variation in recent years. Data showed an increase in urbanized areas which give rise to a decrease of coastal communities. This loss of the coastal landscape is increasingly frequent in the Mediterranean and other European coastlines (Provoost & *al*., 2011; Tomaselli & *al*., 2012; Bertachi & Lombardi, 2014; Malavasi & *al*., 2013, 2016).

The modification of landscape can be seen in the Punta Umbria images (Figure 2) in which the mobile dunes surface has been decreased significantly. Precisely in this location the number of tourists, especially in summer, double or triple the number of residents.



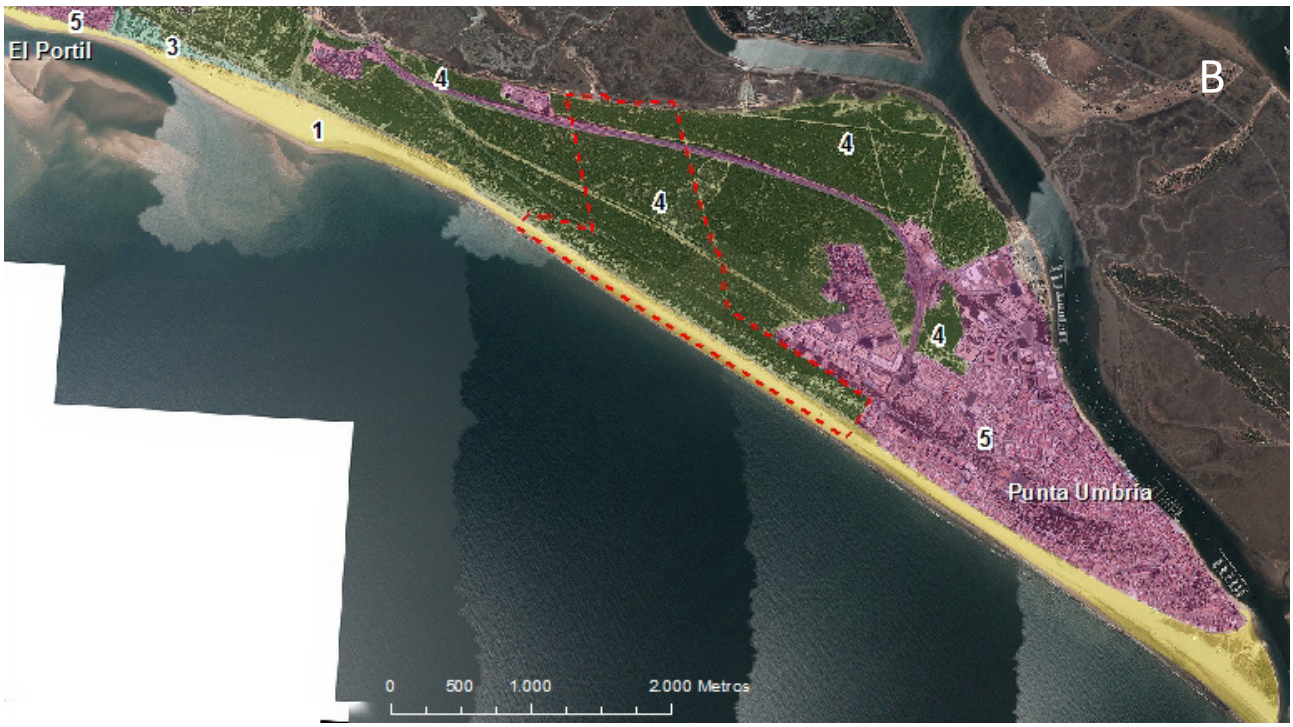


Figure 2. Vegetation map of Punta Umbria (Huelva) 1956 (A) and 2013 (B). The discontinuous red lines indicate the protected natural space. 1, Beach and the halo-nitrophilous communities; 2, Mobile dunes; 3, Semi-fixed dunes; 4, Stable dunes; 5, Urbanizations.

Table 3. Variation of plant communities surface (ha).

Punta Umbria (Huelva)	1956	2013
1. Beach + halonitrophilous communities	119,38	178,60
2. Mobile dunes	136,54	0,04
3. Semi-fixed dunes	34,27	12,32
4. Stable dunes	744,47	596,12
5. Urbanizations	70,69	392,69
Cabopino, Marbella (Malaga)	1956	2013
1. Beach + halonitrophilous communities	28,97	18,73
2. Mobile dunes	87,75	0,005
3. Semi-fixed dunes	38,89	22,13
4. Stable dunes	219,58	116,50
5. Urbanizations	0,00	850,00
Punta Entinas-Sabinar (Almeria)	1956	2013
1. Beach + halonitrophilous communities	146,10	134,41
2. Mobile dunes	51,96	81,79
3. Semi-fixed dunes	151,41	223,58
4 Stable dunes	381,06	345,11
5. Urbanizations	0,00	893,09
6. Salt-marsh communities	446,25	560,64

The best conserved area, in spite of its surface decrease, corresponds to the semi-fixed dunes (*Artemisio crithmifoliae-Armerietum pungentis*, habitat *2130) and the stable dunes that present extensive pine forests of *Pinus pinea* (habitat *2270), under which other habitats classified as priority for conservation are developed, such as coastal dunes with *Juniperus* (*Osyrio quadripartitae-Juniperetum turbinatae, Rhamno oleoidis-Juniperetum macrocarpae*). We can also highlight other plant communities that represent stages of replacement of these forests (*Pycnocomono rutaefolii-Retametum monospermae, Rubio longifoliae-Corematetum albi, Halimio halimifolii-Stauracanthetum genistoidis*). The construction of six wooden bridges crossing the dune system probably contributes to the conservation of the stable dunes, however this area has become very vulnerable because bridges are precisely behind the mobile dunes, allowing visitors to walk through the dunes to get to the beach (Muñoz Vallés & *al*., 2011).

The conservation state, according to the biological value is very high, compared to other dune ecosystems of Southern Spain (Asensi & *al*., 2014).

With regard to the Marbella coast, the image of 1956 (Figure 3A) shows a territory not affected by urbanizations. The dune system is well represented and the main ecological units are recognizable. This situation persisted in some areas of this coast in the 70s (Díez-Garretas & *al*., 1975). The most recent image (Figure 3B) and the verification with field transects shows the strong transformation mainly due to intense and rapid development of urbanized areas that currently occupy about 850 hectares. Marbella has experienced an accelerated growth with an economy based on the tourist offer destined to visitors and residents. The demographic growth has been very remarkable, in just over 50 years it has increased by more than 100%.

The surviving dune ecosystem (about 12ha, Cabopino) is represented mainly by semi-stable and stable dunes with much altered habitats and reduced diversity that facilitates the entry of more or less nitrophilous species (eg. *Sonchus* L., *Oxalis pes-caprae* L.) as well as the increase of subnitrophilous communities (*Malcolmio littoreae-Vulpietum alopecuroris*) or invasive exotic taxa,

such as *Acacia saligna* (Labill.) H.L. Wendl., *Arundo donax* L., *Arctotheca calendula* (L.) Levyns, *Carpobrotus edulis* (L.) N.E. Br., *Lantana camara* L., *Opuntia ficus-indica* (L.) Mill. (Sobrino et al., 2001; Asensi & *al*., 2016). The presence of these species which are planted frequently in the gardens of houses close to the beach facilitates their introduction into Mediterranean dune ecosystems and loss of diversity (Sobrino & *al*. 2002; Malavasi & *al*., 2013). The biological value of this space and its conservation state is low (Asensi & *al*., 2014).

Punta Entinas-Sabinar (Figure 4) presents a different evolution from the previous cases. Until the end of the 60s, this space was a socially and economically depressed area. The great development in the last decades of intensive agriculture has transformed the economy and landscape of this region (Campo de Dalias). A natural space with outstanding flora and bird values coexists next to more than 30,000 hectares of greenhouses.

The dune ecosystem has an extensive formation dominated by *Juniperus turbinata* and *Pistacia lentiscus* (*Rhamno angustifolii-Juniperetum turbinatae*) together with wide spaces occupied by chamaephytic communities (*Loto cretici-Crucianelletum maritimae, Teucrio belionis-Helianthemetum scopulori*). Next to them, therophytes grasslands in open areas or under the shadow of the *Juniperus* formations (*Triplachno nitentis-Silenetum ramosissimae, Wahlenbergio nutabundae-Loeflingietum pentandrae*) are developed. Several halophilous plant communities (Table 2) thrive in ponds and lagoons that were previously exploited as salt flats and are home for a remarkable avifauna.

Most psammophilous communities have experienced little change in their size while salt marsh areas have increased by over 100 hectares (Table 2, Figure 4). The insignificant urban areas in 1956 (Figure 4 A) have increased considerably at the extremes of the natural space with the development of tourist facilities (golf courses, marinas, tourist accommodation, etc.). The main threats of the Punta Entinas-Sabinar natural space are mainly due to the degradation of plastics from greenhouses and contamination by chemical agents. Natural ecosystems are at present well conserved and have high values in biological evaluation (Asensi & *al*., 2014).

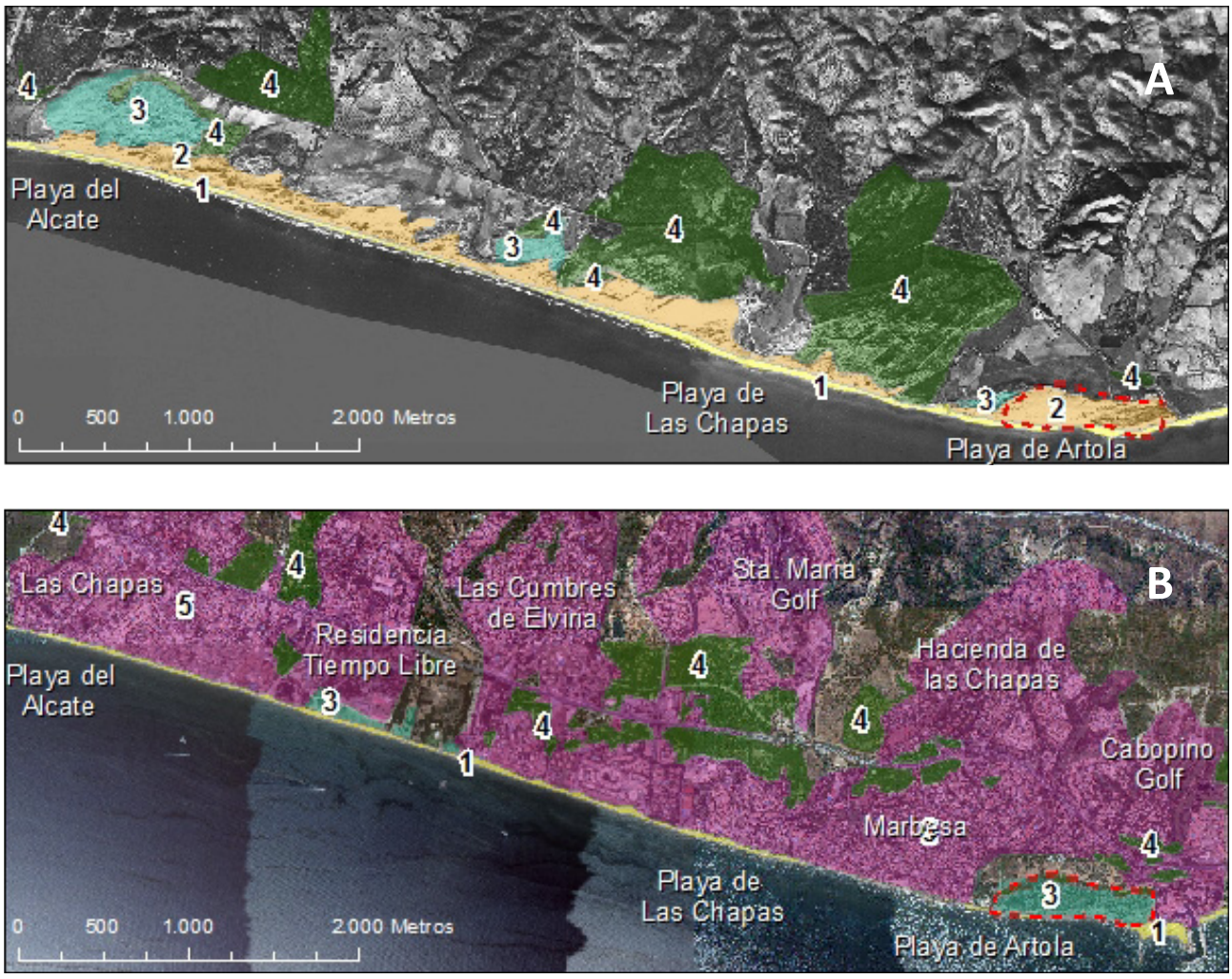


Figure 3. Vegetation map of Marbella (Málaga) 1956 (A) and 2013 (B). The discontinuous red lines indicate the protected natural space. 1, Beach and the halo-nitrophilous communities; 2, Mobile dunes; 3, Semi-fixed dunes; 4, Stable dunes; 5, Urbanizations.

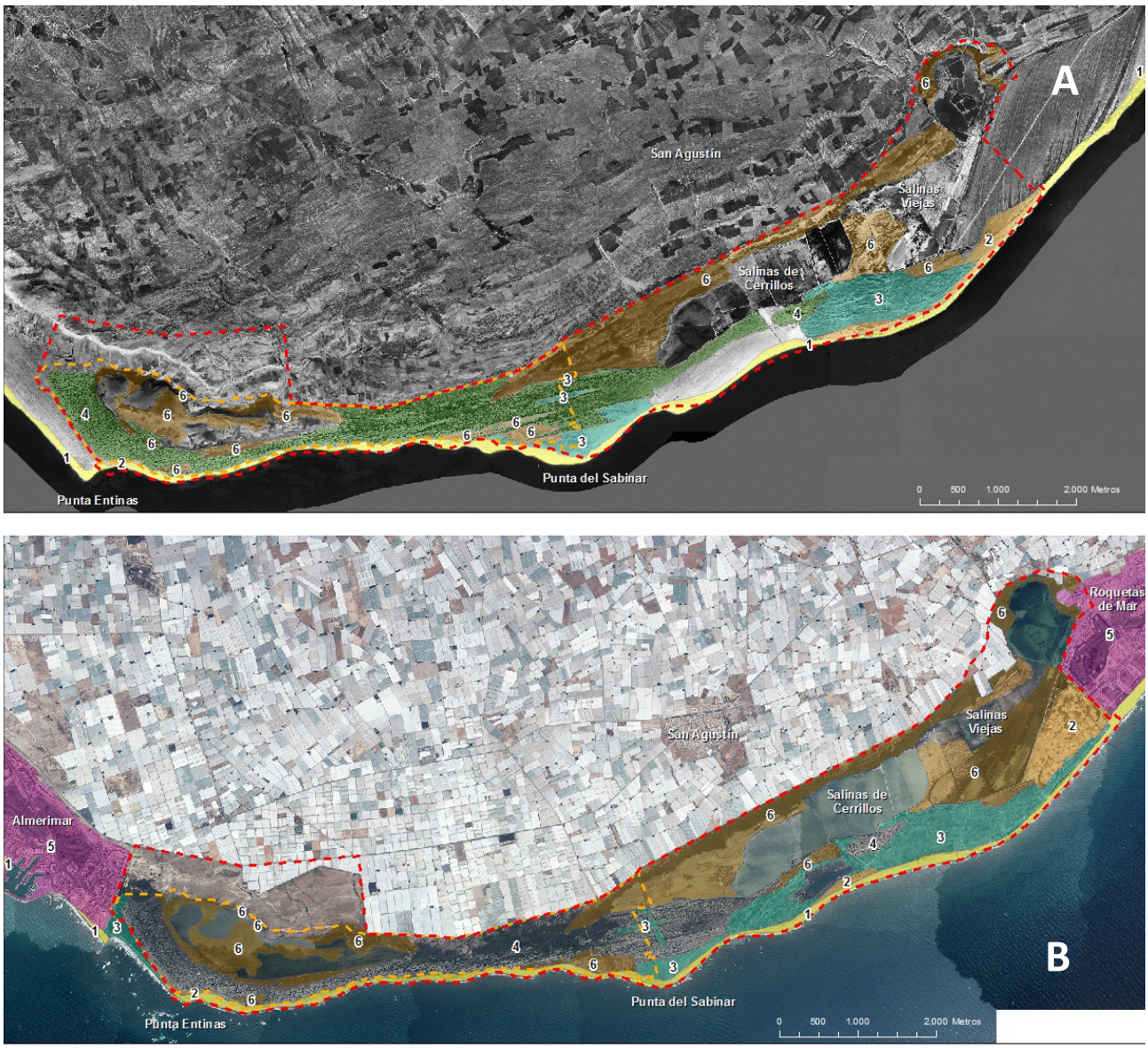


Figure 4. Vegetation map of Punta Entinas-Sabinar (Almeria) 1956 (A) and 2013 (B). The discontinuous red lines indicate the protected natural space, the yellow lines the natural reserve. 1, Beach and the halo-nitrophilous communities; 2, Mobile dunes; 3, Semi-fixed dunes; 4, Stable dunes; 5, Urbanizations; 6, Salt marsh communities.

Conclusion

The studied natural zones show differences in the last decades derived from human activities. Marbella dune ecosystem has been the most affected, mainly due to the urban pressure that has practically occupied the coastal zone, leaving only a small space that holds some dune plant communities. Similarly, it has been also the cause of the dune system decrease in Punta Umbria, urbanized areas have increased from around 70 hectares in 1956, to 400 now. However, this protected territory, right now exhibits the best example of *Juniperus macrocarpa* communities in southern Spain. Finally, the Punta Entinas-Sabinar is the best-preserved space despite the moderate urban development and the intensive crops in greenhouses.

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