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The impacts of land-use changes on the recovery of saltmarshes in Portugal

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ABSTRACT

Human-induced land-use changes have resulted in loss and degradation of intertidal environments worldwide. Saltmarsh ecosystem dynamics in Portugal are greatly influenced by historic uses and consequent habitat degradation. This study uses an original approach combining vegetation surveys and spatial analysis of historic maps and aerial photographs to assess the effects of land use changes on saltmarshes in two areas in the Algarve, southern Portugal. Historical maps from c. 1800 and aerial photographs from 1958 to 2010 were analyzed to map saltmarsh ecosystems and quantify land-use changes in the Alvor estuary and Arade River. Between c. 1800 and 2010 more than half of saltmarshes were lost due to dyke building and saltmarsh reclamation for agriculture. In mid-1960s, the abandonment of reclaimed agricultural areas resulted in the recolonization of saltmarsh vegetation, which developed physically separated from natural marshes. In the study area, these saltmarshes naturally evolved into two distinct typologies: (1) enclosed mixed marshes, formed by patches of brackish, freshwater and some invasive species developing due to saline intrusion in areas where dykes have not been breached; and (2) tidally-restored saltmarshes, formed in areas where dyke breaching allows incursion of tides and development of a vegetation structure similar to natural saltmarshes. In Europe, passive (without human intervention) and active (artificially planned) saltmarsh restoration are important mechanisms for voluntary or statutory re-creation of intertidal habitats. Improved understanding of the factors influencing the development of distinct saltmarsh typologies through passive ecosystem recovery can provide new insights to support decision-making concerning intertidal habitat restoration.

1. Introduction

Human-induced saltmarsh loss is widespread along the world's temperate coasts (Moreira, 1986, 1992; Gu et al., 2007; Currin et al., 2008). Many studies have assessed the causes and consequences of saltmarsh loss (Eliot et al., 1999; Miller et al., 2001; Wu et al., 2002; Cahoon et al., 2006; Marfai and King, 2008), including in Portugal (Moreira, 1986; Ferreira et al., 2008). Degradation and loss of saltmarshes have major implications to their capacity of delivering ecosystem services, including: sediment accumulation; nutrients cycling; filtering of contaminants; wildlife habitat; flood regulation and storm protection (Simas et al., 2001; Currin et al., 2008; Feagin et al., 2010; Gedan and Bertness, 2010; Kim et al., 2011). The extension, exposure and orientation of the saltmarsh in relation to the coast, and the vegetation cover and maturity level of the plant communities influence the capacity to provide ecosystem services.

Environmental changes driven by natural processes, such as sea-level rise, have greatly affected saltmarshes (Simas et al., 2001; Morris et al., 2002; Gedan and Bertness, 2010; Mensah and FitzGibbon, 2012). However, human occupation in coastal areas has affected saltmarhes natural dynamics (Reeve and Karunarathna, 2009). In Europe, since the Middle Age, artificial manipulation of these ecosystems often enhanced erosion rates and resulted in substantial transformations in saltmarsh composition, distribution and functions (Castillo et al., 2000; Mattheus et al., 2010; Gedan et al., 2011). These transformations increased saltmarshes vulnerability to environmental changes, reducing their natural adaptive capacity (French and Burningham, 2003; Gedan

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et al., 2009). The urban, touristic, industrial and agricultural uses along the Portuguese coast have severely prevented the chances of saltmarsh recovery (Moreira, 1992; Rolo, 2007).

Natural saltmarsh evolution and diversity have been widely studied (Moreira, 1987; Costa and Lousã, 1989; Leveuvre et al., 2000; Caçador et al., 2007; Deegan et al., 2012). More recently, studies have focused on vegetation cover and species richness in embanked areas (Kleyer et al., 2003; Robinson et al., 2004; Bonisa et al., 2005) and as a result of de-embankment (Garbutt and Wolters, 2008; Barkowski et al., 2009). Such studies describe the effects of human intervention on the characteristics and recovery of saltmarshes and are important to inform practices and policy concerning intertidal habitat creation (e.g. Habitat Directive objectives and/or to compensate for loss of protected areas) and their ability to deliver ecosystem services (Mossman et al., 2012; Spencer and Harvey, 2012). In southern Europe (e.g. Portugal, Spain and France), economic drivers led to the abandonment of agricultural practices in some areas, including coastal reclaimed land, creating opportunities for saltmarsh colonization (Boorman et al., 2002; Vélez-Martín et al., 2010).

This article assesses the effects of land use change on the evolution of secondary saltmarshes and describes the emerging distinct typologies using selected areas in the Algarve (Southern Portugal) as case study. A novel approach combining vegetation surveys and mapping of land-use changes based on analyses of historic maps and aerial photography is used here to assess how historic land uses (from 1800s to 2010) contribute to the development of different saltmarsh typologies. The article first identifies the effects of human activities on saltmarsh dynamics along the Alvor estuary and the Arade river mouth. Then results from spatial analysis of land use changes and vegetation surveys are used to identify the main typologies of recovered saltmarshes. The discussion focuses on the drivers influencing unmanaged saltmarsh recovery under a Mediterranean climate and highlights wider applications concerning the restoration of saltmarsh habitats. The article ends with a summary of the main conclusions concerning the effects of land-use changes on the typology and development of secondary saltmarshes.

2. Study area

The Alvor estuary (Ria de Alvor) and the marshes of the Arade river (and the tributary Ribeira de Boina) are located in the Portimão municipality (Algarve, southern Portugal, Fig. 1). The area has temperate Mediterranean climate, showing mean annual temperature around 17 °C (at Faro Airport, IGP, 2005) and annual mean precipitation at the coast between 400 mm and 500 mm, with the wet season occurring from October to April (Ribeiro, 1987). Alvor is a tidal lagoon dominated by sandy sediments of maritime origin set in a mesotidal environment with little freshwater input. The Arade River mouth is a drowned river valley subjected to tidal influence from the mouth to 13 km upstream.

Human occupation in the study area began in the Neolithic (2 000–1 600 BC). The Carthaginians and the Romans had introduced fish salting and salt exploitation as regular economic activities. In 715 BC the Arab occupation enhanced the economic importance of Portimão and Alvor, which were important seaports exporting products to the rest of the Arab empire (Vieira, 1911). The economic activities were based on activities undertaken at high marsh areas, including: fishing, bivalve gathering, sun-drying fish and fruit and extraction of salt in salt pans (Loureiro, 1909; Vieira, 1911).

The earthquake of 1755 and the associated major tsunami reconfigured the Portuguese coast (Dias, 2004). Records suggest that the tsunami wave entered 667 m inland in the area of Alvor altering the ebb delta morphology preventing tall ships to enter the estuary; saltmarshes were one of the most affected ecosystems (Loureiro, 1909). The tsunami resulted in a greater mobility of the Alvor estuary inlet, which threatened adjacent property and triggered the construction of dykes and embankments leading to saltmarsh reclamation (Pullam, 1988). The tsunami impact at the coast triggered a series of floods in the Arade River, in which the sea entered 14 m inland, causing siltation of the river mouth (Loureiro, 1909).

3. Materials and methods

Qualitative data sources were analyzed to understand the socio-economic and environmental factors influencing saltmarsh evolution in the study area. The main sources of qualitative information included: parish records of population surveys and land registry; the genealogy of Algarve's landlords and noble families, in order to access the land use changes and acquisitions; and port authorities' records about damage caused by the earthquake. Historical documents allowed the reconstruction of the human occupation and the economic activities that have taken place in marsh areas, including land reclamation.

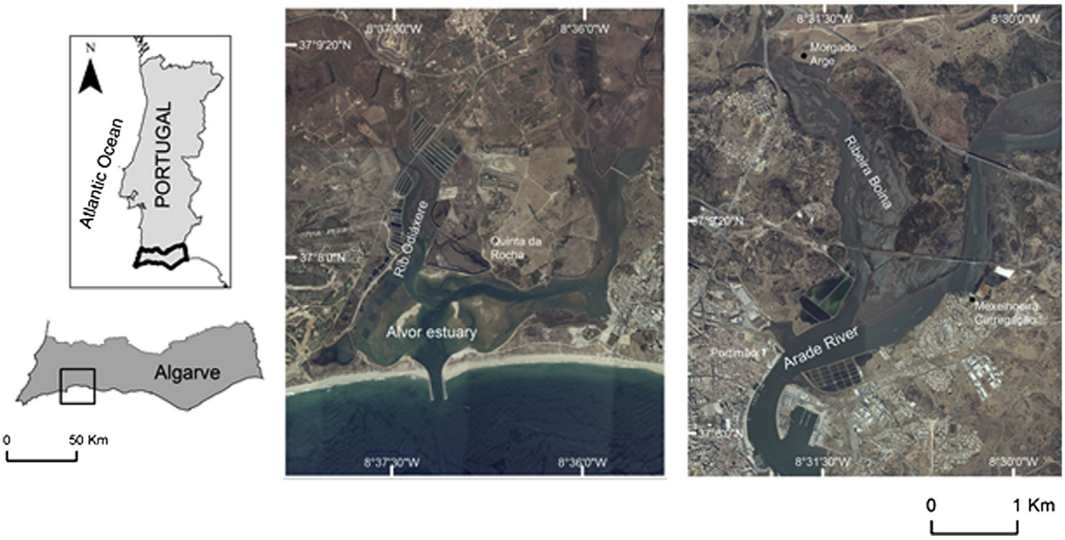

Fig. 1. The study area: Ria de Alvor and Arade River (Algarve, southern Portugal).

Table 1
Cartographic data sources used in this study.

Date	Chart type	Source	Information provided
1789–1800	Segundo Plano Hidrográfico do Rio de Villa Nova de Portimão	Baltazar de Azevedo Coutinho, Eng.°. Instituto Geográfico do Exército – IGEOe	High and low saltmarshes, mudflats, saltpans, agriculture
1884	Carta de Portugal 1:100 000, No.36 (Military Chart)	Direcção Geral dos Trabalhos Geodésicos do Reino,	Coastal configuration and saltmarshes position
1909	Planta da Bahia do Porto de Lagos	Loureiro, Adolfo (1904), *Os Portos Marítimos de Portugal*, vol.5 (1904–1909)	Coastal configuration and saltmarshes position
1922 1923 1930	Carta de Portugal 1:50 000, sheets 49D, 52ª; 49C (Land Use Chart)	Direcção Geral dos Trabalhos Geodésicos e Topográficos	Wetlands, saltmarshes and irrigation schemes
1950 1951	Carta Agricola e Florestal 1:25 000, sheets 594, 595, 603	Secretariado Geral da Agricultura	Agriculture uses, land occupation and transformation of saltmarshes
1967 1970	Carta de Portugal 1:100000, sheets 52, 49 (Hydrographic Chart)	Instituto Geográfico e Cadastral	Alterations in irrigation schemes, reservoirs, mudflats, marshes and salt pans.
1958 1972 1987	Aerial photos	Centro de Estudos Geográficos (1958) Instituto Geográfico Português (IGP)	Land cover
1995 2005 2010	Ortophotomaps	Instituto Geográfico Português (IGP)	Land cover

The methodology applied here is an original approach specifically designed for this study. A combination of vegetation surveys and spatial analysis of historic maps and aerial photography is used to assess the effects of land-use changes on saltmarsh typologies in the study areas. The methods of the spatial analysis and vegetation surveys are detailed below.

3.1. Spatial analysis

Historical cartography was essential in the spatial analysis of changes in saltmarsh boundaries and extent. Spatial analysis of historic data was possible only for the Arade River due to lack of data sources with adequate quality for the Alvor estuary. Although a map from 1909 shows the area of the Alvor, it does not show features that allow georeferencing. Sources of spatial information used in this study are listed in Table 1. The hydrography chart covering the area of the Arade river (named then Villa Nova de Portimão) dated from the period 1789-1800 is used here as a historic baseline for the photointerpretation and geoprocessing operations. The historic chart was georeferenced using ArcGIS 10 resulting in a root mean square error of 8.90 m. This historic chart allowed clear identification of land cover types (Fig. 2a), such as: high and low marshes (indicated on the original map by the common name of the dominant species); salt pans were easily identified by their shape, name, and location in the edge of the high marsh; other agriculture activities showing in the chart were not object of analysis. Geoprocessing analysis resulted in a land cover map and a table showing the extent of saltmarsh areas (Table 2).

Analysis of aerial photos and ortophotomaps were also used to map the human occupation in the study area. The Portuguese Cartographic Institute has obtained aerial photographs covering areas of the Portuguese coast at intervals of approximately ten years. Aerial photographs covering the study area were obtained in 1958, 1972 and 1987. All maps and photographs were georeferenced using the Portuguese national coordinate system ETRS_1989_Portugal_TM06. Spatial analysis in ArcGIS 10 was undertaken to estimate areas of saltmarsh accretion, erosion and stability. Validation of photo-interpretation was undertaken during fieldwork, conducted at the same dates of the vegetation surveys described below.

3.2. Vegetation data

Floristic surveys were conducted in the following dates: 15–18 October 2012 (Alvor); 7–10 February 2013 (Arade); 23–25 March 2013 and 20–26 April 2013 (Alvor and Arade). Floristic surveys

Fig. 2. a) Arade River and surroundings in c. 1800 (Baltazar de Azevedo Coutinho, Geographic Military Institute-IGEOe), b) saltmarshes of Arade River in c. 1800 over ortophotomap of 2010.

Table 2
Land-cover/land-use changes over 1958 to 2010 in Alvor and Arade.

Covered area (ha)												
Land cover	1958		1972		1987		1995		2005		2010	
	Alvor	Arade	Alvor	Arade	Alvor	Arade	Alvor	Arade	Alvor	Arade	Alvor	Arade
Saltpans (working)	39	34	48	38	43	40	30	36	30	12	29	12
Saltpans (abandoned)	0	0	0	0	24	0	44	0	25	22	36	4
Aquaculture	0	0	0	0	0	0	9	11	21	29	20	48
Saltmarsh early reclamation	44	120	0	0	0	0	0	0	0	0	0	0
Saltmarsh in process of reclamation	41	0	6	70	0	67	0	0	0	0	0	0
Salrmarsh (reclaimed)	84	120	161	70	45	67	24	13	55	27	47	49
Saltmarsh (natural)	182	196	73	129	69	111	55	109	65	85	72	118
Saltmarsh (dyked)	0	48	35	66	5	5	10	17	5	17	24	25
Saltmash (recovered)	0	0	0	0	0	0	1	24	1	1	16	14
Saltmash (eroded)	0	3	1	0	3	2	1	0	0	0	0	13
Dykeland	134	211	128	153	125	151	2	36	2	70	65	30
Dykeland (agriculture)	0	0	0	0	117	0	123	0	14	0	0	17
Dykeland (abandoned)	0	0	0	0	24	0	243	121	237	139	188	167

were conducted following the abundance/dominance scores method (Braun-Blanquet, 1979) by using sampling quadrats of 2 m^2 along selected transects. A total of 112 floristic surveys, amounting to 209 quadrats, were conducted in 15 randomly selected saltmarsh areas (Table 3). The botanical nomenclature followed the works of Castroviejo et al. (1986–2007), Franco (1971, 1984); Franco and Rocha Afonso (1994, 1998, 2003) and Rivas-Martínez (2005). The degree of presence (Braun-Blanquet, 1979) was calculated to evaluate the differences in species richness between saltmarsh areas (Table 4). The presence is estimated in percentages of a species and classified according to a chosen scale into a set of ‘classes of presence’. The classes were defined as follows (Costa et al., 2009): *r* (<6%); + (6–10%); *I* (11–20%); *II* (21–40%); *III* (41–60%); *IV* (61–80%); *V* (>81%).

4. Results

The analysis of land cover c. 1800 (Fig. 2a) indicates that wetlands have been progressively urbanized in the area of Portimão (Fig. 2b). Geoprocessing of historic maps revealed that saltmarshes occupied an area of 242 ha c. 1800. Analyses of aerial photography indicate that in 2010 the total area of saltmarshes was 118 ha. Therefore, 51% of saltmarshes in the Arade River mouth were lost between 1800 and 2010. Further analyses taking into account other areas along the Arade River indicate that in total 65% of the saltmarshes were lost between 1800 and 2010. Reclaimed areas along the river Arade correspond to excavated old marshes, filled with estuarine mud and protected from tidal influence, with the purpose to create land for agriculture. Estuarine muds, nutrient-rich, were used to fill the reclaimed saltmarsh and build dykes structures upstream the Boina and along the left shore of the Arade River (Vieira, 1911).

4.1. Land-use changes between 1958 and 2010

Land-use changes in the period 1958 to 2010 highlight major transformations in the wetlands (Fig. 3), especially concerning saltmarsh reclamation for diverse economic activities (Table 2) and natural ecosystem distribution and composition. Table 2 shows the distribution in area of the saltmarsh sub-types and land uses in the Alvor estuary and Arade River identified though geoprocessing and photointerpretation. Dykeland refers to areas enclosed by dykes and embankments, built to prevent tidal incursion.

One of the major land cover transformations was the saltpans abandonment. These complexes of salt production generally occupied large areas. The abandonment of the salt production occurred as the traditional method for food preservation became less important, decreasing significantly the commercialization and export of salt (Rau, 1951). As a result saltpans were transformed into aquaculture production units starting around the mid-1980s in the Alvor and in the early 2000s in the Arade. By 2010, about 59% of saltpans were abandoned in the Alvor estuary and 85% in Arade river.

In 1958 natural saltmarshes occupied a slightly larger area in Arade River (196 ha) than in the Alvor (182 ha), this relative proportion was maintained throughout the studied period. The Agriculture Development Plan was responsible for a 90% of the

Table 3
Floristic surveys places by stage of saltmarsh transformation, location description and coordinates.

Stage of saltmarsh transformation	River/Estuary	Name of the place (village or site)	Coordinates (WGS 84)
(1) Natural saltmarshes	Arade	Marine of *Mexelhoeira da Carregação*	N 37°08.910′ W 008°30.311′
(1) Natural saltmarshes		*Companheira* site	N 37°09.586′ W 008°31.376′
(1) Natural saltmarshes		Arade tributary: *Ribeira de Boina*	N 37°10.280′ W 008°31.861′
(3) Fragmented saltmarsh	Alvor	Right side of *Odiáxere* creek	N 37°07.991′ W 008°37.440′
(2) Early reclamation		West of the Alvor village	N 37°07.596′ W 008°35.871′
(4) Dyked saltmarshes	Arade	Dyked marshes at the left side of Arade River	N 37°09.272′ W 008°30.042′
(4) Dyked saltmarshes		*Morgado de Arge* (Boina creek)	N 37°10.335′ W 008°31.985′
(4) Dyked saltmarshes		*Companheira* dykedland	N 37°09.615′ W 008°31.372′
(4) Dyked saltmarshes	Alvor	*Quinta da Rocha*	N 37°08.056′ W 008°36.939′
(6) Eroded saltmarshes		Southwest Alvor estuary	N 37°07.325′ W 008°38.091′
(4) Dyked saltmarshes	Arade	*Companheira* inland	N 37°09.656′ W 008°31.382′
(5) Recovered saltmarshes		Upstream left side Arade	N 37°09.696′ W 008°29.992′
(5) Recovered saltmarshes	Alvor	Former agriculture dykeland upstream Alvor River	N 37°08.537′ W 008°35.841′
(5) Recovered saltmarshes		*Maria Pires*	N 37°08.607′ W 008°35.464′
(6) Eroded saltmarshes		Northeast *Quinta da Rocha*	N 37°08.185′ W 008°37.119′

Table 4
Degree of vegetation presence in each marsh typology according to the scale: r (<6%); + (6–10%); I (11–20%); II (21–40%); III (41–60%); IV (61–80%); V (>81%).

Species	Total surveys by saltmarsh typology	Habitat						
		Natural saltmarsh (46)			Tidally-restored saltmarsh (32)			Enclosed mixed marshes (34)
	No. Surveys in relation to tidal level	Low	Medium	High	Low	Medium	High	
		16	15	15	10	12	10	–
	Number of *taxa* present	10	17	27	9	14	14	35
Spartina maritima		III						
Scirpus maritimus var. *compactus*		I						r
Atriplex prostrata		+						I
Suaeda albescens		I	I	II				
Sarcocornia perennis		III	I		VI	VI		VI
Sarcocornia perennis sub. *alpini*		I	II		VI	VI	III	+
Sarcocornia fruticosa		I	III	II	I	III		I
Cistanche phelypaea		II	II	III		II	+	II
Halimione portulacoides		V	V	II	VI	V	VI	+
Puccinellia iberica			+	+	II	I	+	+
Puccinellia maritima			I	+	+			
Arthrocnemum macrostachyum			+	II		II	III	r
Suaeda vera			I	IV				
Spergularia media			I	I				
Limonium algarvense			I	II				r
Spergularia media			I	I				
Limonium lanceolatum			+	I		+		
Juncus maritimus			II		+	I		+
Limonium vulgare			+					
Limoniastrum monopetalum				III			II	
Inula crithmoides				II		I	III	+
Aster tripolium subs. *pannonicus*				I				r
Oxalis pes-caprae				I				I
Salsola vermiculata				I				III
Limonium diffusum				I				
Atriplex halimus				I				
Calendula arvensis				+				r
Carpobrotus edulis				+				r
Elymus farctus				+				r
Emex spinosa				+				+
Ferula tingitana				+			+	VI
Medicago polymorpha				+				r
Sonchus maritimus				+			+	
Frankenia laevis				+	r	II		I
Scirpus maritimus					+			r
Aster tripolium						II		
Scorpiurus vermiculatus						I	III	r
Elymus elongatus						+	I	
Artemisia maritima var *galica*							+	II
Juncus acutus							+	r
Salicornia ramosissima							+	II
Artemisia campestris subs *maritima*								r
Atriplex hastata								r
Cotula coronopifolia								VI
Hypochaeris radicata								I
Lotus creticus								+
Melilotus segetalis								r
Polypogon maritimus								II
Salsola sola								I
Sedum sediforme								II

saltmarsh reclamation in both areas. Despite the decrease on natural saltmarshes between 1958 and 1995, a slight increase was observed in the subsequent years (Fig. 3 middle). The recovery dynamics started to be noticed in 1995 with an average of 9 ha/year of new saltmarshes in the Alvor and 13 ha/year in the Arade during 1995–2010. There was a great overall loss of saltmarsh areas in the period 1958–2010 (61% in the Alvor and 40% in the Arade). However, the loss would have been even greater without the recovery of saltmarsh areas observed between 1995 and 2010, resulting in the creation of 18 ha of new saltmarshes in the Alvor and 39 ha in the Arade.

Along the Arade River 48 ha of saltmarshes were already dyked in 1958. In 1987 agriculture within dykelands grew the most causing a great decrease in saltmarsh extent within embanked land. Until 1987, the loss of dyked saltmarsh represented the total saltmarsh area that had been destroyed. Over the period 1958–2010, 47% of saltmarshes were dyked along the Arade River. Only 19% of saltmarshes were diked in the Alvor estuary reflecting a more effective process of reclamation in Alvor.

Saltmarshes dynamics is not independent of other environmental and anthropogenic factors. Most changes in saltmarsh are associated with small local activities or development. For instance, the 13 ha of eroded saltmarshes quantified between 1995 and 2010 in the Arade River was caused by the construction of a touristic marina. Between 1958 and 2010, there was a net saltmarsh loss of 73 ha in the Alvor estuary, resulting from 98 ha of eroded

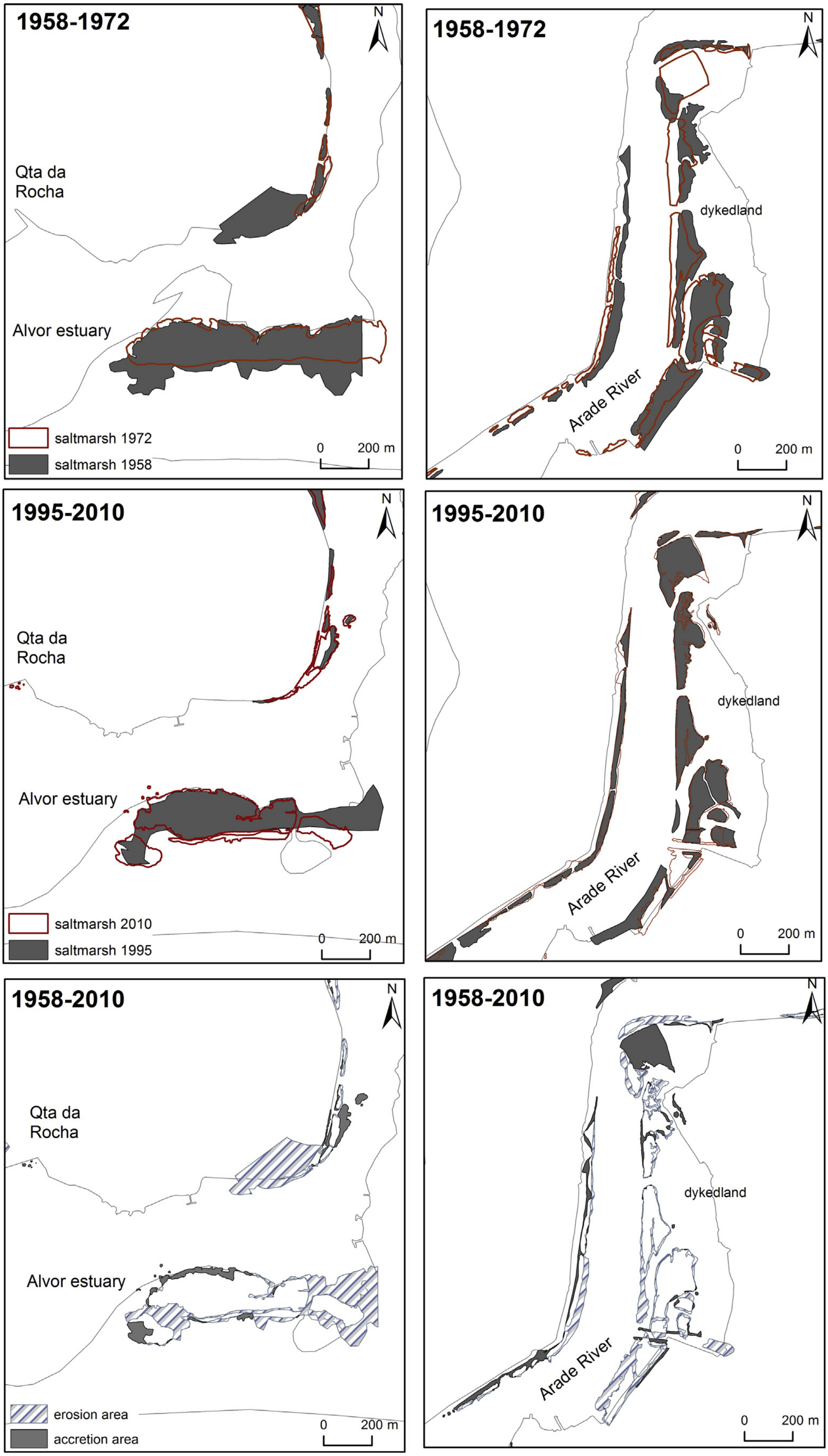

Fig. 3. Examples of saltmarsh changes in Alvor (left), years 1958–1972, 1995–2010 and the saltmarsh erosion and accretion areas in 1958–2010; and in Arade (right), years 1958–1972, 1995–2010 and the saltmarsh erosion and accretion areas in 1958–2010.

saltmarshes and 25 ha of restored saltmarshes. For the same period, the Arade River showed a net saltmarsh gain of 12 ha, resulting from 14 ha of eroded saltmarshes and 26 ha of restored saltmarshes.

4.2. Saltmarshes typologies

Land-use changes created a process of transformation in which natural marshes gave place to new sub-types (i.e. altered saltmarshes) and/or eventually were completely lost. Fig. 4 schematically represents the progressive transformation of saltmarshes caused by reclamation and restoration process, using as example an area along the left shore of Ribeira de Boina. Several marshes have disappeared through this process, at the same time that many other typologies emerged.

Based on photointerpretation of images dating from 1958, 1972, 1987, 1995, 2005 and 2010 and quarterly reports that accompanied the land reclamation process until 1987, six stages of transformation or saltmarsh sub-types were identified:

1. *natural saltmarshes:* all saltmarshes that were not dyked, destroyed or damaged;
2. *early reclamation*: the saltmarsh was dyked and started to fragment, usually observed in the period 1958–1972, when the Agriculture Development Plan was being implemented;
3. *fragmented saltmarsh:* at the final stages of the reclamation process, the saltmarsh is clearly fragmented and occupying a smaller area than in the *early reclamation* stage. The fragmented stage was observed until 1987; therefore, saltmarsh transformation from 'early reclamation' to 'fragmented' in the study area occurred in a time-frame of around 15 years.
4. *dyked saltmarshes:* saltmarshes are enclosed within embankments/dykes and completed isolated from tidal influence;
5. *recovered saltmarshes* corresponding to patches that were affected by land reclamation but were naturally recovering outside dyked areas; and
6. *eroded saltmarshes*, these refer to saltmarshes that were permanently lost.

In the study area, *dyked saltmarshes* naturally evolved into two distinct typologies based on their floristic structure: (1) *enclosed mixed marshes*, formed by patches of brackish, freshwater and some invasive species developing due to saline intrusion in areas where dykes have not been breached; and (2) *tidally-restored saltmarshes*, formed in areas where dyke breaching allows incursion of tides and development of a floristic structure similar to natural saltmarshes.

4.3. Floristic characterization of different saltmarshes

Table 3 lists the 15 locations where floristic surveys were conducted and indicates the dominant saltmarsh sub-type (or stage of transformation) present in each area. The surveys were conducted in randomly selected areas of 14.9 m^2.

The degree of presence calculated in each of the 112 floristic surveys is shown in Table 4 for *natural saltmarshes* and the two typologies of *diked saltmarshes* identified in this study (i.e. *tidally-restored* and *enclosed mixed*). Surveys allowed differentiating the floristic structure and composition of a natural saltmarsh from the other typologies. The floristic composition of a *natural saltmarsh* indicates low, medium and high marshes clearly structured in relation to the tidal levels. The floristic composition of *tidally-restored saltmarshes* varies depending on the elevation in relation to the tidal range. As the tidal flow is confined by the breach, the volume of tidal flow and the relative distance from the dike breach determines whether certain areas are subjected to inundation. *Scirpus maritimus, Halimione portulacoides* and *Sarcocornia perenis* appear near the dyke breach (low marsh); *Sarcocornia alpini, Sarcocornia fruticosa, Limonium algarvence* are present at the medium marsh; *Limonastrum monopetalium*, *Suaeda vera*, *Inula critmoides* (high marsh), occur near the paths or the upper dykes. *Enclosed mixed marshes* are not subjected to tidal inundation.

Table 4 indicates a loss of biodiversity at *tidally-restored saltmarshes* in comparison with *natural saltmarshes*, as can be seen by the reduction in the number of *taxa* and species observed in the surveys. *Natural saltmarshes* have higher number of *taxa* in all low, medium and high marsh areas (in relation to the tidal range) than *tidally-restored saltmarshes* (Table 4). In both typologies, low marshes show considerably lower number of *taxa* than medium and high marshes (Table 4). *Enclosed mixed marshes* show a distinguished composition and structure influenced by saltwater intrusion. These marshes are marked by the dominance of freshwater over brackish species (as freshwater input from rainfall is sufficient to last throughout the winter) and the presence of invasive (*Cotula coronopifolia, Carpobrotus edulis, Oxalis pes-caprae*) and terrestrial species (*Hypochaeris radicata, Polypogon maritimus, Lotus creticus, Sedum sediforme, Artemisia campestris* subs. *maritime).*

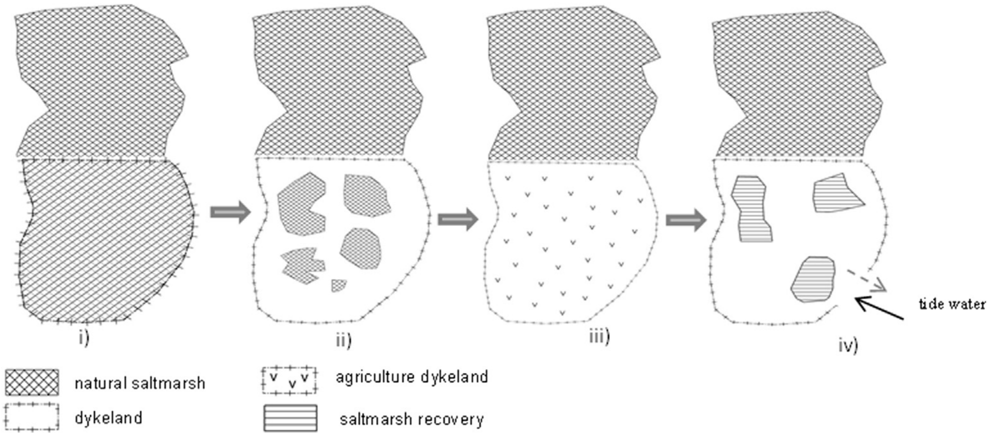

Fig. 4. Schematic diagram representing the evolution of the saltmarsh in dykelands: i) the dyke was built in a natural saltmarsh; ii) the saltmarsh started to defragment and progressively disappears; iii) after the drainage and the exsiccation, agricultural dykeland is ready to be at work; iv) dyke wall broke due to abandonment of the agriculture activity, the tide water comes in, providing a low energy environment, allowing the marsh to evolve: an ecosystem recovery takes place.

5. Discussion

Land-use changes commonly result in erosion and degradation of marshes (Bertness and Silliman, 2008). Natural saltmarshes are resilient to various disturbances in their ecology or ecosystems function (Roebeling et al., 2013) and they can respond positively to sea-level rise (Moreira, 1987). However, human occupation in coastal areas and the presence of hard engineering structures prevent inland migration of the saltmarsh ecosystems. Economic interests have been more important than the value or services offered by saltmarshes. Historically, coastal wetlands were seen as land available at low price with a privileged location.

The Alvor dykes were built in the early 17th century with the objective of supporting agricultural practices, e.g. by allowing freshwater farm irrigation from the Alvor tributaries to the Mexelhoeira Grande and Arão (Mariano, 2010). In Alvor, it was very common to artificially control tides along the tributary Ribeira de Odiáxere, in order to reclaim wetlands for agriculture. Two saltpans existed in Portimão; one at west of the urban center and the other in the north riverside, which progressively expanded towards Ribeira de Boina (Arade tributary).

Saltmarsh reclamation has occurred over a long period in the study area, but the greatest impacts arose by the implementation of the Portuguese Agriculture Development Plans (1953–1964), which targeted investments to stimulate economy. These Plans were implemented in two phases. The first phase (1953–1958) prioritized saltmarsh reclamation to create agricultural land through the construction of small embankments, clearing the original vegetation and irrigation with freshwater. These activities provided the leaching needed to avoid saltmarshes communities to grow. The second phase (1959–1964) focused on the exsiccation of dyked saltmarshes by trenching. Land reclamation in study area ceased mainly due to the failure of the Portuguese Agriculture Development Plans.

In many locations, the practices introduced by the Portuguese Agriculture Development Plans resulted in the destruction of marshlands beyond chances of restoration. Land reclamation for agricultural purposes was very successful on upstream saltmarshes, where freshwater streams feeding the Alvor estuary (i.e. Odiáxere, Arão, Penina) were able to reduced saltwater intrusion. Currently, marsh vegetation is not seen in these agricultural fields (agriculture dykeland). Recovery of saltmarshes are highly hindered in areas where the abandonment of commercial salt production has been replacement by aquaculture and in areas developed for urban-tourist uses (Gedan et al., 2009).

In other locations, the great exsiccation works had limited success in creating agricultural areas. In the Alvor estuary, the influence of saltwater intrusion allowed *enclosed mixed marshes* to develop inside the dykelands. An important factor for the emergence of *enclosed mixed marshes* is the Mediterranean climate dry conditions, which favor salt intrusion by capillarity, as observed in the areas of Maria Pires and Quinta da Rocha in the Alvor estuary. In the Arade River, the failure of agricultural dykelands is related to the degradation of the embankments or the destruction of floodgates, after economic practices (e.g. grazing, agriculture or salt production) were abandoned. In these areas, the natural breaching of abandoned embankments restored tidal flow into the dykelands providing opportunities for *tidally restored* saltmarsh communities to develop. The restoration of saltmarsh communities was favored especially in areas of high sedimentation rates.

Surveys show significant differences in floristic composition between the primary (*natural marsh*) and the *enclosed mixed marshes* that grow inside dykelands. *Enclosed mixed marshes* are formed by patches of brackish species (*Haliminone portulacoides*, *S. fruticosa*, *Arthrocnemun macrostachium*), within freshwater communities (*Puccinelia iberica*, *Juncus accutus*, *Scirpus compactus*) presenting some invasive species (*C. coronopifolia*, *C. edulis*, *Cistanche philipaea, O. pes-caprae* (e.g. observed at Maria Pires saltmarsh in the Alvor). Mossman et al. (2012) suggest that "*it is unlikely that restored marshes with very different vegetation will be functionally equivalent*" and discusses how floristic differences might affect different functions. Spencer and Harvey (2012) indicate that saltmarshes restored through active management (e.g. managed realignment) "*may be significantly impaired*" in their capacity to deliver "*ecosystem services including biodiversity, climate regulation and waste processing*".

Despite being impaired in their potential functionality when compared to natural saltmarshes, secondary saltmarshes (e.g. *tidally-restored* or *enclosed mixed marshes*) are still able to offer some ecosystem services. It is therefore required that further studies are able to quantify how functionally impaired restored saltmarshes might be and whether there are any ecosystem services they might not be able to provide. Nevertheless, especially for saltmarshes restored unmanaged, it might be more pertinent to compare their capacity to provide ecosystem services in relation to the land-use/land-cover type they have replaced (e.g. abandoned agricultural land), rather than their equivalence to natural habitats. For example, *enclosed mixed marshes* tend to be sheltered, providing conditions for birds and other animals to feed and refuge from predators; additionally, the saltmarshes enhance the ability to offer storm protection. These services are better provided by the restored saltmarshes than the previous land cover/use. Further understanding the evolution and functionality of restored saltmarshes and the ecosystem services they are able to provide is required to inform coastal managers on the benefits gained (and lost) from this unmanaged land use/cover change.

Regardless of the great land use transformations described here, *natural saltmarshes* continue to exist in both the Alvor and Arade study areas. Facing this great diversity of saltmarshes typologies, dealing with habitat management is truly a challenge. *Enclosed mixed marshes* and *tidally-restores saltmarshes* have different recovery rhythms mainly influenced by the previous land cover (economic activity) or by the stage of transformation at the time of abandonment. The saltmarshes typologies differentiation revealed extremely useful to categorize vegetation succession, which former studies fail to address. The analysis of the effects of past anthropogenic occupation revealed the resilience of saltmarshes and their ability to recover without artificial intervention.

6. Conclusion

Persistent human occupation and land-use changes in Portugal, rather than sea-level rise or other environmental changes, have caused the greatest impacts in coastal ecosystems in the last two centuries. This study quantified losses and gains in saltmarsh areas and identified typologies resulting from responses to land-use changes from 1800 to 2010 in the Arade River and Alvor estuary (Algarve, southern Portugal). A custom methodology involving a combination of spatial analysis (based on historic charts and aerial photographs) and vegetation surveys was used to quantify changes and identify saltmarsh typologies.

Land reclamation for agriculture was promoted by national policies in the 1950s and 1960s resulting in an overall loss of 763 ha (85%) of saltmarshes in the study area between 1958 and 2010. Six stages of transformation were identified associated with the response of natural saltmarshes to land reclamation. In the mid-1960s, economic drivers led to the abandonment of agricultural practices allowing saltmarsh recovery in reclaimed areas. Local particularities resulted in the (unmanaged) development of two distinguishable saltmarsh typologies: (1) *enclosed mixed marshes* formed by patches of brackish, freshwater and some invasive species developed due to saline intrusion in areas where dykes have not been breached; and (2) *tidally-restored saltmarshes* formed in areas where dyke breaching allowed incursion of tides and the development of a floristic structure similar to natural saltmarshes.

Over the 1958–2010 period, saltmarsh recovery in the Arade River is dominated by *tidally-restored saltmarshes*, while the Alvor estuary *enclosed mixed marshes* dominate. Identifying the different typologies of secondary saltmarshes helps inform management practices aiming to enhance environmental benefits. For example, it is necessary to identify and quantify the capacity of different typologies to deliver ecosystems services in order to inform management efforts targeting enhancement of specific ecosystem services (e.g. carbon sequestration, flood risk management etc.). In this regard, for example, studies focusing on sediment dynamics in areas of *tidally-restored saltmarshes* and saltwater intrusion affecting *enclosed mixed marshes* would contribute to further understand the processes involved in the restoration of ecological functions in the study area and elsewhere.

The methodology used in this study proved appropriate to assess the response of saltmarshes to land-use changes. The six transformation stages and the two typologies of secondary saltmarshes identified in this study are likely to be found in other areas of Mediterranean climate (e.g. in Portugal, Spain and France). This methodology can be easily applicable to other locations worldwide providing land-use changes have been recorded through time (e.g. in historic charts).

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