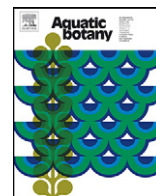




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Seagrasses in Portugal: A most endangered marine habitat

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ABSTRACT

Numerous reports of seagrass decline around the world indicate that seagrass habitats are undergoing a global crisis with important consequences for coastal biodiversity, environmental status and economy, reflecting their vulnerable and overlooked status within many conservation agendas.

This paper describes the results of the first extensive survey of this habitat in Portugal. It shows the present cover distribution and declining trends of seagrasses on the Portuguese coast (1980–2010), identifies environmental and conservation issues, and discusses challenges for long-term survival.

Seagrass populations of the Portuguese coast are also facing an unprecedented decline in distribution, matching the general trends described for most world seagrasses. The results of this investigation show a dramatic decrease of seagrass cover in Portugal in the last 20 years. This decrease followed different trends for the three species present on this coast. *Zostera noltii*, having disappeared from some systems by almost 75%, is still the most abundant species, present in 10 of the 18 sites assessed. *Zostera marina* is presently the most endangered seagrass species in Portugal, as it disappeared from six of eight historical locations and faces extinction from the Portuguese territory if measures are not taken to assure the protection of the last regions left with populations. *Cymodocea nodosa* has a geographic distribution range limited to the southern/southwestern coasts, and its current conservation status is uncertain, although there is evidence for the recent occurrence of several population bottlenecks.

Management questions are discussed and actions to improve habitat conservation are suggested.

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1. Introduction

Seagrass meadows are declining around the world at an unprecedented rate, suggesting a global crisis, yet most of the references are from a few highly developed countries (Orth et al., 2006; Duarte et al., 2009). Indeed, along extensive coastlines, there is no published information on seagrass distribution patterns and historical trends are unknown (Duarte et al., 2008). Reported losses (29% of the maximum area measured; Waycott et al., 2009), probably represent a small fraction of those that have occurred, many losses remain unreported, and real losses may never be known because most will disappear without ever having been reported to have occurred (Duarte et al., 2008). Striking seagrass losses have been documented in North America, Europe and Australia (Orth et al., 2006; Waycott et al., 2009). Major gaps in knowledge of seagrass cover and distribution exist for West Africa (Duarte et al., 2008; Cunha and Araújo, 2009), northeast South America, the northwest Pacific and the tropical Indo-Pacific (from East Africa to Hawaii) where seagrasses are widespread and abundant (Waycott et al., 2009).

In southern Europe and the Mediterranean, with some localized exceptions for *Posidonia oceanica*, information on seagrass distribution and abundance trends are scarce. Portugal, although entirely on the Atlantic coast, forms a biogeographic admixture zone where Atlantic species at their southernmost distributional limits encounter Mediterranean and African species that extend northwards. Furthermore, signatures of past climatic events, possibly interacting with local adaptation traits for these seagrass species with contrasting environmental affinities, have resulted in a unique population genetic constellation of the seagrasses along the Portuguese coast (Olsen et al., 2004; Coyer et al., 2004; Diekmann et al., 2005; Alberto et al., 2008).

The Portuguese coast is the northern limit in the Atlantic for *Cymodocea nodosa* (Ucria) Ascherson, and it is presently the southern distributional limit for *Zostera marina* Linnaeus 1753 (Cabaço and Santos, 2010; Bull et al., 2010). It is also the center of the distributional range for *Zostera noltii* Hornemann 1832, a mostly intertidal species ranging from Mauritania (Cunha and Araújo, 2009), to the southern fjords of Norway (den Hartog, 1970). Among all four native seagrass species of Europe (*sensu stricto*) only the Mediterranean endemic *P. oceanica* (Linnaeus) Delile is not present in Portugal, making this coastline particularly unique in terms of European seagrass biodiversity. Two other more typically brackish aquatic plant species are present on the Portuguese coastal ecosystems, *Ruppia maritima* and *Ruppia cirrhosa*. They are present in

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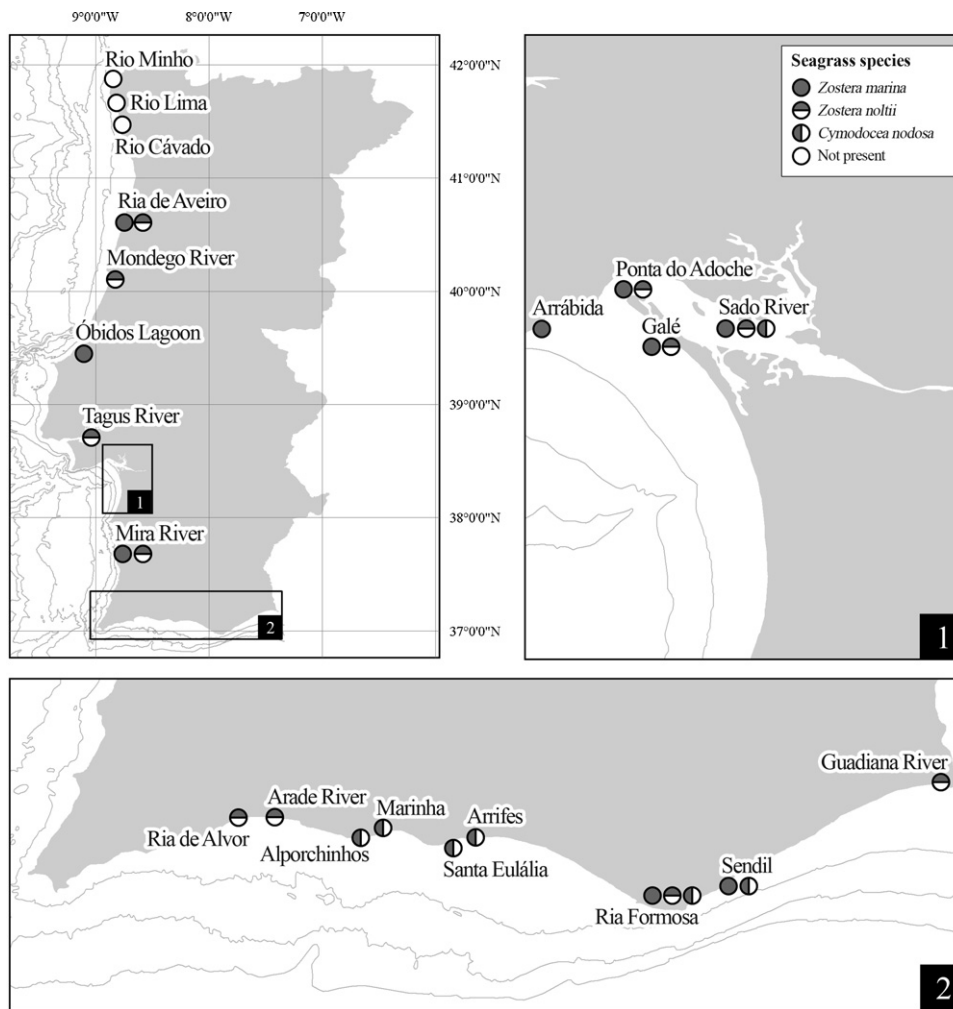


Fig. 1. Seagrass distribution in the Portuguese coast, depicting the 21 sites visited and information on seagrass presence/absence, and species present.

coastal lagoons with higher influence of freshwater and, although they were not target species in this study, their distribution is briefly reported for some sites, particularly where they mix in with the 3 seagrass species.

This paper depicts the first full assessment of the distribution, cover and conservation status of the Portuguese seagrasses. We report decreases in seagrass cover or even total disappearance along the Portuguese coast and highlight the need to evaluate past versus current distribution and ascertain the conservation status of Portuguese seagrasses.

2. Materials and methods

2.1. Study site

The Portuguese west coast extends for ca. 800 km along a straight North-South orientation, whereas the south coast, extends for ca. 200 km West–East (Fig. 1). Estuaries along this coastline vary significantly in geomorphologic and hydrologic features. While the Tagus and the Sado rivers estuaries have the broadest areas (ranges 320–180 km²), the Mondego, Mira, Arade and Guadiana rivers are channel-like (ranges 20–5 km²). Ria de Aveiro, Ria de Alvor and Ria Formosa are shallow coastal barrier islands lagoon systems (ranges 6–91 km²). Annual river flow is markedly different, with the Tagus estuary presenting mean values above 250 m³ s⁻¹, and the Mira and the Ria Formosa discharging on average below 5 m³ s⁻¹

(Vinagre et al., 2010). Salinity varies seasonally from a mean of 21.2 (9.3–31.8) in Mondego river, to 36.9 (35.0–39.0) in Sado river (Vinagre et al., 2010). The two coasts are subject to different climate and storm regimes, with the northern coast subjected to more intense westerly and northern winds. Both are very exposed to southern storms, which can be frequent and very intense in certain times of the year. Because of different current exposure and latitude water temperature ranges are very wide between the study sites with lowest means of 14 °C in the Arrábida coast in winter, to highest means of 27 °C in Ria Formosa and Guadiana river in summer (Vinagre et al., 2010).

2.2. Distribution and cover assessment techniques

The current distributional patterns of seagrasses in Portugal were assessed from 2007 to 2010 during the LIFE Biomares project (LIFE 06 NAT/P/192) that aimed at restoration of a seagrass meadow in the Marine Park Luiz Saldanha, on the Arrábida coast (Cunha et al., 2009, in press). Sites surveyed were selected because they had either previous written or oral records of present or past seagrass presence, or because seagrass-like cover areas were identified in aerial photos or Google Earth® images.

The methods used for seagrass cover assessment are described in detail in Cunha et al. (2009). Different approaches were used because the sites varied in their availability of prior information and in access to the field sites. For intertidal and shallow subtidal field sites with clear water conditions and inaccessible by boat,

mapping and distribution assessment was made by walking along the shore line, and by free diving (snorkeling), accurately registering GPS points and creating tracks around the seagrass patches, that were transferred to the project GIS. Deep water or low visibility subtidal sites were visually evaluated by means of scuba diving, placing the GPS unit to float on the water's surface, in a housing attached to a buoy, vertically positioned over the scuba diver. For large open sites with clear water, long distance boat/canoe transects were made, using a crystal glass tube to visually groundtruth underwater field features. Patches were delineated by GPS and transferred to the GIS. Intense field prospection and "bare foot mapping" were used to explore new areas. Intertidal and subtidal areas were surveyed for all regions except for Ria Formosa, where data from intertidal zone was available from a previous study (Guimarães, 2007; Guimarães et al., in press). Estimated seagrass area per region was calculated for each species with the help of a GIS. Moreover, seagrass habitat maps were generated for each studied region to visually evaluate the most diverse localities in terms of seagrass species, number and area of seagrass meadows. This information is digitally available in the project GIS.

2.3. Historical distribution assessment

During the field work several fishermen or clam and bait collectors were informally interviewed about the past existence of seagrass meadows. This method known as "bare foot mapping", was very useful because it was possible to obtain interesting information that do not have a formal record. Most people interviewed were familiar about the existence of seagrass, its present and historical distribution as well as their importance as support of fisheries. Furthermore, a lot of information about past seagrass distribution was obtained from fellow biologists, that had in some period of their lives, worked or studied these systems. Historical distribution records were also retrieved from scientific seagrass literature when existent, but mostly from "grey" literature. "Grey" literature used in this study comprised documents about seagrasses for the general public, field campaign reports from students or governmental institutes, and master's and doctoral theses that were never published in peer reviewed journals, but that could be obtained directly from the authors or from institution's libraries. Most scientific references were identified via searches of electronic library databases (Aquatic Sciences and Web of Science), and personal communications with national and international seagrass researchers were obtained directly by asking/emailing fellow researchers from the research centers in Portugal and Spain.

3. Results and discussion

3.1. Summary of seagrass distribution and abundance in Portugal

Presently, there are seagrasses in 18 of the 21 sites visited during this study (Fig. 1). The most widely distributed seagrass on the Portuguese coast is *Z. noltii* (15.74 km²) which occurs in 10 of the 18 sites with seagrasses in the estuaries of Mondego, Tagus, Sado, Mira, Arade and Guadiana rivers, and in Ria de Aveiro, Ria de Alvor and Ria Formosa coastal lagoons. In some locations such as in Ria de Aveiro (Canal de Ovar), Sado estuary, Mira estuary and Ria Formosa it is still possible to observe extensive meadows. It is interesting to note that *Z. noltii* is not present in the Óbidos Lagoon neither in the Costa da Galé sites, where *Z. marina* forms extensive meadows, whereas in other similar and adjacent areas the two species occur together.

Z. marina appears to be the most endangered seagrass species on the Portuguese coast, taking into account its historical patterns. From the eight sites where this plant was once abundant, only

two had *Z. marina* populations in 2010, with a total coverage of 0.075 km². The populations at these two sites (Lagoa de Óbidos and Ria Formosa) are subject to continued use of bivalve hand trawling and intense boat mooring, in addition to recent channel dredging and the opening of inlets (in Ria Formosa). The future of this species in Portugal is therefore, at the moment, uncertain. Furthermore, restoration attempts with this species on the Arrábida coast were not successful, particularly due to winter storms and fish grazing (Cunha et al., in press). As for *C. nodosa*, there are 3 main populations identified, with an acreage of approximately 1.09 km². Nevertheless, it is hard to acknowledge the cover distribution trends as this species was often confused with *Z. marina*, and was never referred to in documents prior to 1992. Still, due to its limited distribution and low clonal diversity with a unique genetic background, it is a species of special concern and action should be taken to avoid its local disappearance.

From the 21 sites visited, the three that did not have seagrasses (Fig. 1) were the Northern estuaries of the Minho, Lima and Cávado rivers, for which there are no previous records of seagrass presence. Further north, on the coast of Spain, only 200 km away from Ria de Aveiro, there are populations of *Z. marina* and *Z. noltii*, and so a distributional gap occurs here.

From the 18 sites where seagrasses were presently recorded, 14 had previous records. Five other sites identified in this work had never been cited before for the presence of seagrasses. Scientific information about seagrass distribution, ecology and biology in Portugal is recent, and historical information is mostly available in grey literature. Presently, 100 publications about seagrasses of the Portuguese coast were identified, but these include grey literature, public outreach articles and scientific papers. Worldwide, publications on seagrasses started in 1960 but only in the 1990s, scientists responded to the need for more information on seagrass ecology that resulted in a 100-fold increase in the annual number of papers published, which represented a sustained publication growth rate of 12.8% per year (Orth et al., 2006). In Portugal, it was also during the 1990s that scientific publications picked up, and during the last 10 years the publications increased 11-fold, with 55 published papers, representing a 9.9% increase during that period. Despite all this effort on seagrass research in Portugal, the causes for seagrass disappearance are still not totally understood. Some causes are particularly well understood, as the case of *Z. noltii* in Mondego (Ferreira et al., 2007; Lillebø et al., 2007; Baeta et al., 2009) and the evident impact of mechanical removal of seagrasses for human activities such as bivalve culturing, bivalve harvesting, boat mooring, or channel dredging.

3.2. Patterns of seagrass distribution and abundance of *Z. noltii*

3.2.1. Current distribution in Ria de Aveiro

In Ria de Aveiro coastal lagoon, the most northern site where *Z. noltii* is found, an area estimated as 0.43 km² was mapped in 2010, in the Canal de Ovar (north channel) and an area of 0.13 km² was mapped in the Costa Nova channel (Table 1). All meadows mapped were seagrass beds with very dense stands. It is possible that the acreage in the northern part of the lagoon is underestimated in this study, because it was not possible to visit some remote and secondary channel areas difficult to access.

3.2.2. Historical cover in Ria de Aveiro

Z. noltii used to cover up to 8 km² in 1984 (Silva et al., 2004), but by 2004 it had fallen to 3 km² (Silva et al., 2009). Erosion over the last decades caused deepening of major channels (Silva and Duck, 2001; Silva et al., 2004, 2009), and the combined action of increasing water current, loss of fine sediments and nutrients, and decline in intertidal area contributed to seagrass decrease (Silva et al., 2009). Until 1960, a large part of the area had a dense coverage

Table 1
Location and cover distribution (area in km² and m²) of seagrass species in the Portuguese coast from 2007 to 2010 (n.p.: not present; very rare: <10 shoots were found in the area).

Sites	Date survey	<i>Zostera marina</i>	<i>Zostera noltii</i>	<i>Cymodocea nodosa</i>	Latitude	Longitude
Ria de Aveiro (Mira channel)	2008	10 patches (<2 m)	0.130 km ²	n.p.	40°36'31.47"N	8°44'40.34"W
Ria de Aveiro (Ovar channel)	2010	n.p.	0.431 km ²	n.p.	40°43'33.69"N	8°41'09.64"W
Mondego river	2009	n.p.	0.044 km ²	n.p.	40°07'47.63"N	8°50'52.69"W
Óbidos Lagoon	2010	0.0105 km ²	n.p.	n.p.	40°07'47.63"N	8°50'52.69"W
Tagus river	2009	n.p.	0.21 km ²	n.p.	38°43'57.94"N	9°0'46.87"W
Arrábida	2007	n.p.	n.p.	n.p.	38°28'36.21"N	8°58'48.62"W
Sado river	2007	n.p.	0.29 km ²	0.022 km ²	38°27'46.47"N	8°51'32.85"W
Ponta do Adoche	2009	0.0121 km ²	Not-measured	n.p.	38°29'32.27"N	8°54'31.03"W
	2010	Very rare	Very rare	n.p.		
Costa da Galé	2009	0.0013 km ²	n.p.	n.p.	38°29'2.37"N	8°54'22.00"W
	2010	Very rare	Very rare	n.p.		
Mira river	2009	400 m ²	Not-measured	n.p.	37°43'21.15"N	8°46'29.50"W
	2010	Very rare	0.075 km ²	n.p.		
Ria de Alvor	2009	n.p.	0.01 km ²	n.p.	37°07'42.20"N	8°36'22.19"W
Arade river	2009	n.p.	0.004 km ²	n.p.	37°10'0.99"N	8°29'33.17"W
Alporchinhos Beach	2009	n.p.	n.p.	<100 m ²	37°05'21.53"N	8°24'46.66"W
Marinha Beach	2009	n.p.	n.p.	800 m ²	37°05'21.47"N	8°24'46.68"W
Santa Eulália Beach	2009	n.p.	n.p.	0.15 km ²	37°05'06.19"N	8°13'1.62"W
Arrifes Beach	2009	n.p.	n.p.	1000 m ²	37°04'33.87"N	8°16'33.96"W
Ria Formosa	2007	0.05 km ²	14.49 km ² ^a	0.913 km ²	37°00'0.67"N	7°49'56.48"W
Sendil	2007	50.3 m ²	n.p.	508.4 m ²	37°00'58.67"N	7°47'35.50"W
Guadiana river	2009	n.p.	0.054 km ²	n.p.	37°12'20.10"N	7°24'53.84"W

^a Both intertidal and subtidal populations from Guimarães (2007) and Cunha et al. (2009).

of SAV, including *Potamogeton pectinatus*, *R. cirrhosa*, *Z. noltii* and *Z. marina*. The historical descriptions about the amount of seagrasses and other aquatic vegetation that used to cover Ria de Aveiro are quite impressive. Viana de Lemos (1933), Taborda de Morais (1937), and Silva et al. (1974a,b) described the aquatic vegetation cover of Ria de Aveiro as luxuriant, but also acknowledged the alarming decrease of seagrasses observed in some areas. Ria de Aveiro was known by the traditional activity of collecting “molição” a mixture of aquatic plants that included mostly *Z. marina* and *Z. noltii*, which was used as fertilizer and supported important agricultural activity in the fields in the vicinity of the lagoon. In 1955 there were 800 boats (“moliceiros”) operating, which in turn collected more than 100,000 tons of aquatic vegetation per year (Silva et al., 2004). The decrease in seagrass and other SAV area within Ria de Aveiro over the past five decades is well described in Silva and Duck (2001) and Silva et al. (2004, 2009), which explain the effects of the construction of the inlet piers (Barra Nova), the dredging associated with the engineering works that channelized and deepened the water channel, increased water currents, promoting the transport and redistribution of sandy sediments. Furthermore, increased siltation, turbidity, and nutrients washing, which are associated with faster tidal flows, changed the physical forcing in the system leading to the disappearance of subtidal meadows of aquatic vegetation. *Z. noltii* is now restricted to some intertidal flats that are usually less exposed to tidal currents relative to adjacent areas (Silva et al., 2009).

3.2.3. Current distribution in Mondego river

Another site in the north of Portugal where *Z. noltii* had a dramatic decrease in cover area was the Mondego estuary. The estuary, 7 km in length, consists of two different arms separated by an alluvium-formed island (Murraceira Island; Martins et al., 2005). In the southern arm there is a *Z. noltii* meadow, that presently extends up to 4.4 m² (Table 1).

3.2.4. Historical distribution

Z. noltii used to be present in an upper and a lower reach, having disappeared from the upper reaches without trace more than 20

years ago. The meadow in the lower reach, identified as the richest area in the system with regard to macrofaunal abundance and biodiversity (Lillebø et al., 1999; Pardal et al., 2000, 2004; Cardoso et al., 2004a,b; Dolbeth et al., 2003), had almost disappeared by 1997 (Pardal et al., 2004; Ferreira et al., 2007). The main cause for this decrease was the interruption of the upstream communication between the two arms of the estuary in the early 1990s, which increased water residence time and nutrient concentrations. These became major driving forces for seasonal *Ulva* spp. blooms and a concomitant severe reduction of the area occupied by *Z. noltii* beds from approximately 150,000 m² in 1986 to 200 m² (Cardoso et al., 2005; Pardal et al., 2004; Martins et al., 2005). A recovery plan promoted by Coimbra University and implemented by the Water Management Authority, which manage the freshwater inputs to the system, resulted in a decrease in nutrient loading and *Ulva* spp. blooms and increased water transparency (Ferreira et al., 2007; Lillebø et al., 2007; Baeta et al., 2009). Further physical protection of the remaining few shoots and rhizomes, and seagrass transplantation resulted in increased *Z. noltii* abundance since 1998 (Neto, 2004; Pardal et al., 2004; Martins et al., 2005; Baeta et al., 2009). Despite this recent management success, the main threat to this population, the increased eutrophication of the system, is still on, caused by important inputs of nutrients from agricultural and urban origin (Pardal et al., 2000; Lillebø et al., 2004, 2005; Baeta et al., 2009). The combination of nutrient surplus with the natural variation in other factors (e.g. low hydrodynamics, high salinity) causes, in some periods, significant growth of green algae, mainly *Ulva* spp. (Martins et al., 2001) and the non-indigenous *Asparagopsis armata* (Cunha, pers. obs.). Another anthropogenic source of disturbance is the intensive macro invertebrate harvesting for fishing bait still observed nowadays (Cunha, pers. obs.).

3.2.5. Current distribution in the Tagus river

A meadow of *Z. noltii*, of at least 0.21 km² was identified in the lower reach of the Tagus river estuary (Salinas de Alcochete) in 2008 (Fig. 1 and Table 1). The meadow expands throughout an intertidal platform that has been growing since the construction of the

Vasco da Gama bridge, that appears to have created a sediment accumulation zone there (João Carlos Farinha, pers. commun.).

3.2.6. Historical distribution

Images from Google Earth, show that in 2002 this *Z. noltii* meadow was already present. Despite being one of the most studied estuaries in Portugal, there are no previous seagrass references for this estuary. Nevertheless, there is an historical reference from 1868 to “the threat that the collection of marine plants that protected the natural oyster banks posed to the sustainability of the oyster culture” (Baldaque da Silva, 1893), which we suspect that might be a reference to *Z. noltii*, because oysters are still found within *Z. noltii* banks, in other natural areas. An intertidal patch of *Z. noltii* was observed in this estuary, in Ponta dos Corvos (Alfeite, sapal de Corroios) in 1989 (E. Serrão, pers. obs.). The main threat to seagrasses observed in the recently mapped meadow, was clam (“lamejinha”) harvesting with a “fork” that is widely used in the area.

3.2.7. Current distribution in Sado river

The Sado estuary has extensive *Z. noltii* meadows in the intertidal flats and lower subtidal areas, estimated to cover 0.29 km² (Table 1; Cunha et al., 2009). Near the river mouth at Ponta do Adoche, a belt of *Z. noltii* at a depth of 3 m, surrounded the *Z. marina* bed that existed until November 2009. All the above ground canopy and great part of the rhizomes disappeared during the winter storms of 2009/2010 and by September 2010 only very slight recovering had occurred.

3.2.8. Historical distribution

Historical records for this site, including aerial photographs, are very limited. The region used to support one of the richest oyster productions of the Portuguese coast, which disappeared in the 1980s (Leal, 1984). It is very likely that seagrass meadows also covered larger areas before the development of the commercial port, paper mill industry and ship construction plants, because channel dredging, salt marsh occupation and organic and inorganic pollution affected intensively the estuary (Caeiro et al., 2005). Furthermore, the Sado river supports the most active rice fields in Portugal, which release a vast amount of fertilizers and pesticides in the estuary (Vale et al., 1993).

3.2.9. Current distribution in Mira river

Z. noltii population from the Mira estuary had disappeared almost completely in January 2007, after a major flood event in November 2006 which left behind a muddy area, full of dead rhizomes and very sparse *Z. noltii* shoots (Adão, Cunha, pers. obs.; Cunha et al., 2009). The population rebound in the summer of 2008, and in 2009, *Z. noltii* was present up to 4.5 km from the river mouth and had a total cover of 0.075 km², most of it at the southern margin (Table 1). It was noteworthy that the patches were very high on the river margin, next to the *Spartina* marshes, a possible response to increased water turbidity associated with heavy river sediment load.

3.2.10. Historical distribution

The *Z. noltii* habitat of the Mira river estuary has been studied since 1984 (Andrade, 1986). The roughly estimated cover area for the 2 species (*Z. noltii* and *Z. marina*) at that time was, approximately, 0.8 km². Subsequent studies focused on the associated fauna (Almeida, 1988; Costa et al., 1994; Ferreira, 1994; Adão, 2003) and not specifically on the seagrass population ecology or distribution. The *Z. noltii* population biomass varies seasonally with maxima in spring and summer, under higher temperature and light conditions (Ferreira, 1994; Adão, 2003). Before the 2007 population bottleneck, a continuous meadow of *Z. noltii* in the lower reach had one

of the highest genotypic (i.e., clonal) diversities in southwest Iberia (Diekmann et al., 2005), meaning that each sampled plant had its origin in a distinct seed, instead of predominant clonal propagation so common in seagrasses. This might be related with the frequency of disturbance by flooding events that carry vast amounts of sediment from a poor managed watershed (fires, forestry operations, intensive agriculture) periodically killing most vegetative shoots. It is possible that population resilience here is dependent on the germination of seeds that are buried in the sediment and germinate in the summer, after major flooding events. Clam and fish bait collection (Adão, 2003; Cunha, pers. obs., 2007–2009) and blooms of the non-indigenous red alga *A. armata* (Cunha, pers. obs., 2007–2009) are also potential threats to these populations.

3.2.11. Current distribution in Ria de Alvor

Ria de Alvor is a small estuarine system with an area of 14.5 km², formed by two rivers on the southern coast of Portugal. It is delimited by two barrier peninsulas and connected to the sea by a single inlet. In 2009 the *Z. noltii* cover was approximately 5000 m², and consisted of several fragmented patches at the upper intertidal level, near the salt marsh zone, and a central mudflat with very few shoots. In September 2010, these patches had almost disappeared, covered by a layer of sediment, apparently originated by the dredging of a new channel.

3.2.12. Historical distribution

Duarte and Mendonça (1988) and Antunes and Cunha (1988) were the first to report that the seagrasses and seaweeds of the area were important for the eggs and juveniles of commercial fish. In the eighties Santos and Salgado (1988) mapped and estimated the biomass of seagrasses and seaweeds of this system. They used aerial photos from April 1986, and refer, that the seagrass distribution looked stable compared with aerial photos from 1973. They identified seven *Z. noltii* meadows with a total cover of 19,600 m² and estimated the biomass in 27.2 tons (wet weight). This same area was reassessed using aerial photography in December 1991, just before intensive dredging and construction operations (fish harbor, nautical recreation area and two piers), and the same 7 meadows were identified and measured with a total cover of 15,880 m² and total biomass of 14.6 tons (wet weight) (Cunha, 1991). In 2009, all seven patches had disappeared, the *Z. noltii* cover was reduced by almost 75% and its biomass was negligible. The main threats identified in this area are habitat loss (channel dredging and aquaculture practices), eutrophication (nutrients washed off from agriculture fields and golf courses), and intensive collection of bivalves and bait.

3.2.13. Current distribution in Arade river

In 2009, the *Z. noltii* beds of Arade river estuary had 3 patches in a total of 4000 m² (Table 1).

3.2.14. Historical distribution

In 2004, a submerged aquatic vegetation (SAV) assessment estimated that 18,000 m² of *Z. noltii* meadows extended along the river margins, with other aquatic vegetation such as *R. maritima* and *Fucus vesiculosus* (Santos et al., 2004). Within 5 years, the *Z. noltii* cover was reduced by almost 78% and *F. vesiculosus* and *R. maritima* have completely disappeared. The Arade estuary has become increasingly impacted since a river dam was built in the sixties decreasing freshwater flow and increasing sediment. Large areas of saltmarsh and mudflats of the estuary are now occupied by fish aquaculture, and a fish harbor and a commercial port, that destroyed large seagrass beds that can be assumed as having been *Z. noltii*. Some minor clam and bait collection is still conducted in the river margins and over the remnant seagrass patches.

3.2.15. Current distribution in Ria Formosa

Guimarães (2007) mapped the intertidal *Z. noltii* meadows in Ria Formosa, which is the largest population in Portugal (13.04 km²) and occupies 45% of the intertidal area of the lagoon. From those, at least 3.95 km² that were *Z. noltii* beds are now occupied by clam farms, although this acreage is underestimated (Guimarães et al., in press). There is also subtidal *Z. noltii* in Ria Formosa, estimated to be 5.51 km² (Cunha et al., 2009), but because it also mixes with *Z. marina* patches it is possible that the acreage is higher.

3.2.16. Historical distribution

The first references to the presence of seagrasses (*Z. noltii*) in Ria Formosa (Olhão, Fuseta, Tavira) are from Baldaque da Silva (1893), and later by Rocha Peixoto (1903), that described the use of seagrasses for fertilizer. Later studies of seagrasses from Ria Formosa focused on light absorption (Enríquez et al., 1992), macrobenthic secondary production (Sprung, 1994), and vegetation descriptions (Costa et al., 1996). Since then, research on *Z. noltii* in Ria Formosa has grown exponentially, focusing on the biology and ecology (Cabaço, 2007; Cabaço et al., 2007, 2009; Alexandre et al., 2006; Santos et al., 2004), physiology (Alexandre, 2004; Peralta et al., 2005; Machás et al., 2003, 2006; Massa et al., 2009; Silva and Santos, 2003; Silva et al., 2005), genetics (Diekmann et al., 2005) and anthropogenic effects (Cabaço et al., 2007, 2008; Alexandre et al., 2005). Tidal delta migration and inlet opening can cause sharp reductions in mixed seagrass beds in this system, as described for a large seagrass patch (0.51 km²) including *Z. noltii* (Cunha et al., 2005; Cunha and Santos, 2009). Because there were no previous seagrass cover assessments it is not possible to estimate the historical losses or gains in Ria Formosa. Many areas that used to have *Z. noltii* beds are now occupied by clam farms (Guimarães et al., in press), harbors, industries and coastal constructions, or dredged to open and maintain navigation channels, such as the opening of a new inlet in Fuseta island and channel dredging (May 2011, Cunha pers. obs.) that are destroying vast areas of this species. Other major impacts on *Z. noltii* beds in Ria Formosa are bait and clam seed collection that are done by digging in *Z. noltii* beds and the frequent propeller scarring and anchoring that are widespread on the mudflats of the lagoon.

3.2.17. Current distribution in Guadiana river

The Guadiana river estuary, which sets the border with Spain, has a narrow (2–3 m) *Z. noltii* meadow that extends along the Portuguese margin of the river for 2 km (Fig. 1 and Table 1). *Z. noltii* beds are also present on the Spanish border of the Guadiana river, but were not included in this study. Information on the presence of *Z. noltii* in the Guadiana is limited to incidental reports by Lousã (1986) and Bettencourt and Ramos (2003) with no cover data. We expect that this seagrass had a wider distribution and cover prior to the extensive waterfront development that started in the 1960s.

3.3. Patterns of seagrass distribution and abundance of *Z. marina*

3.3.1. Current distribution in Óbidos and Ria Formosa

Z. marina was found only in the Óbidos Lagoon and in Ria Formosa (Fig. 1 and Table 1), having recently disappeared from several other sites during this study. Two areas in the Óbidos Lagoon have *Z. marina*, a shallow area behind a sand bar (Ponta do Arinho) with 36 single patches (1–2 m diameter), and a second large meadow, in the center of the lagoon (depth 4–6 m). In Ria Formosa, the seagrass population of the Fuseta channel was represented by 11 small patches (0.5–2.5 m diameter), growing on the channel margin at a low depth (2 m) in May 2010. This population is highly menaced by the recent opening (January 2011) of a new inlet in

the Fuseta island. The Culatra channel population is the largest, with 5 meadows identified along the channel margins and 2 others in mudflats and shallow channels.

During this study we observed the disappearance of six *Z. marina* populations. Considered extinct from Ria de Aveiro (Silva et al., 2004), *Z. marina* was identified and geo-referenced during the Biomares field campaign in 2009, that found one patch of *Z. marina* in the Ovar channel and 10 very small patches (about 1–2 m in diameter) in a mud flat in front of the Costa Nova do Prado. Later, in May 2010 (after the stormy winter of 2009/2010), those patches had disappeared. In Portinho da Arrábida, the remnant seagrass meadow that was last seen in October 2006 had disappeared by January 2007 and has not been found in subsequent surveys (2008–2011). In the Tróia peninsula, the Ponta do Adoche and Costa da Galé meadows, mapped and monitored in 2009, were not observed in April 2010 after strong southern storms affected the area in the winter 2009/2010, and the populations of Rio Mira were not observed in 2007 (a small patch with 7 shoots, appeared again in 2009). In Ria Formosa, from the 10 patches studied by Billingham et al. (2003), only four were found in May 2010.

3.3.2. Historical distribution

It is hard to have a precise idea of the historical distribution of *Z. marina* on the Portuguese coast, given the lack of information. Nevertheless, some historical records exist for the Ria de Aveiro, such as Viana de Lemos (1933) who described the distribution of submerged aquatic vegetation in Ria de Aveiro, referring to the once extensive meadows of *Z. marina*, and reporting their decrease. In a later publication, Taborda de Morais (1937) states that *Z. marina* disappeared from Ria de Aveiro because of the wasting disease (the only reference to the presence of this disease in Portugal). Póvoa do Reis in 1974, identified the presence of *Z. marina* in more than 30 locations in the Mira channel and Nova Costa do Prado, both in the south area of Ria de Aveiro (Silva et al., 1974a,b). In his hand-drawn map, another species identified as *Zostera intermedia* P. Póvoa, was also referenced for 9 locations mixed with *Z. marina*.

The Arrábida coast, which used to have luxuriant *Z. marina* beds (Palminha, 1958; L. Cancela da Fonseca; M. Guerra; E. Gonçalves, pers. commun., 2010) showed a decreasing trend since the eighties (Palmeirim et al., 1977; Azeiteiro, 1997). Silva (2004), based on aerial photo analyses, described in detail the decrease in cover of *Z. marina* in the bay Portinho da Arrábida. The oldest photos available (1946), show the existence of a 10 ha continuous meadow. Subsequent photos show an increase in fragmentation due to intensive clam collection by scuba diving, industrial clam trawling and free anchoring that led to the almost disappearance of seagrasses. The last major patch had about 60 m² in 2004 when, only 4 clones were found in a sample of 33 shoots, and was last recorded in 2006 (Diekmann et al., unpublished). By January 2007, the condition of this seagrass habitat had deteriorated significantly, consisting of only dead rhizomes colonized by the invasive red alga *A. armata*. This patch therefore disappeared in the 2006/2007 winter and was not observed in August 2011.

Ponta do Adoche and Costa da Galé are two areas on the outer coast of Tróia peninsula that had *Z. marina* meadows mapped and monitored during this study. Genetic data revealed that both meadows were genetically diverse and resulted almost entirely from massive seed-based recruitment, a pattern that contrasts with the highly clonal neighboring Sado and Arrábida populations (Diekmann et al., unpublished). Ponta do Adoche has been monitored by Andrade (2006, 2007) and Andrade and Ferreira (2011) for the Environmental Impact Assessment Studies of the Tróia Resort Marina. These studies showed that *Z. marina* had a seasonal growth pattern correlated with solar irradiance, and maximum summer cover of 10,839 m², coincident with our 2009 quantification (Table 1). This represents an increase, since Google Earth images from the

Table 2

Major habitat loss factors, threats identified in the seagrass ecosystem of the Portuguese coast and management needs for improving conservation status.

Factors	Threats	Management needs
Meadow destruction	Construction of marinas, ports, other coastal construction; channel dredging; beach filling, bivalve (clam and oyster) culturing	Environment policy enforcement; public and coastal management institutions awareness
Meadow fragmentation	Free mooring; boat propeller scarring; clam and bait hand collection; industrial clam trawling and with hand trawlers	Permanent buoys; better channel signalization; public information with boat license; policy law enforcement; banning of clam trawling from seagrass habitats; creation of management plan for clam/bait collection areas, public awareness programs; implementation of clam hatcheries and bait farms with progressive abandonment of collection of this species from the wild
Habitat sedimentation	Dredging operations, inlet opening Bad watershed soil practices Winter storms	Improvement of water drainage practices (agriculture and natural barriers) Better practices in dredging activities – observer on board Environment policy enforcement Implementation of Water Framework Directive
Water eutrophication	Urban and industrial sewage Bad watershed soil practices Algae blooms	Implementation of watershed good practices Implementation of Water Framework Directive Public and coastal management institutions awareness Implementation of management plans for exotic species

(2) bottlenecks caused by heavy disturbance on pre-existing meadows followed by recolonization from a few local surviving clones. The previous reports of extensive seagrass meadows on the Algarve coast in the 1960s (see above, pers. obs., by Cancela da Fonseca) and the fact that the remaining meadows on the open Algarve coast are located on rock or around rocky areas suggest that these might be the survivors of heavy disturbance, spared from the intensive bivalve dredging (not done on rocky shores) that could be seen on the Algarve coast during the 1980s. The species *C. nodosa* is dioecious (plants are only male or female), which confers higher level of susceptibility to population bottlenecks. Most of the Ria Formosa is presently occupied by a huge single male plant of *C. nodosa* (Alberto et al., 2008); in Marinha Beach another single male was found. Single males cannot produce seeds, a likely reason for the lack of seed-based recovery following channel dredging monitored in 2001; *C. nodosa* recovered only where a few patches were left by the dredges on the sides of the channels, allowing for clonal propagation (Alberto and Billingham, pers. obs.).

5. Implications

Seagrass meadows provide critical habitat for a wide range of species and supports different and more abundant and diverse fish assemblages than non-vegetated habitats (e.g. Heck et al., 1989; Heck and Valentine, 2006; Connolly, 1994; Guidetti, 2000; Guidetti and Bessotti, 2000; Duarte, 2002). Despite efforts to quantify the economic value of the seagrass ecosystem (e.g. 19,004\$ ha⁻¹ y⁻¹; Costanza et al., 1997), it is evident that the economic losses so far published related to seagrass disappearance, are underestimated.

The declining of seagrasses along the Portuguese coast has been causing great marine biodiversity loss, contributed to coastal fisheries impoverishment, decrease in coastal water quality, and increased coastal erosion, with loss of a very valuable resource for the Portuguese economy: beach sand. The Portuguese estuaries currently have poor conditions for annular seabream (*Diplodus annularis* L.) juveniles due to low abundance of seagrass habitats (Vinagre et al., 2010). Fish assemblages associated with seagrass and sandy sites (as those left after seagrass loss) are substantially different, as the seagrass supported a much more abundant and diverse fish community, and was an important juvenile fish habitat for more species than sand, as quantified in Ria Formosa (Ribeiro et al., 2006). In the Mondego river, the *Z. noltii* meadow was quantified as the richest in macrofaunal abundance and biodiversity (Lillebø et al., 1999;

Pardal et al., 2000, 2004; Cardoso et al., 2004a,b, 2005; Dolbeth et al., 2003, 2007). In the Mira river, seagrass habitat was the most important feature in determining abundance and distribution of estuarine fishes (Almeida, 1988, 1999; Costa et al., 1994).

Management actions can be put in place to invert the decreasing trend observed (Table 2) notably because seagrasses have received recognition as important indicators of a good ecological status under the Water Framework Directive. Means to invert the seagrass decline along Portuguese coast would have to involve:

- a general raise in awareness among coastal users, managers, politicians, environmental groups, and the general public;
- real integration of coastal plans in political decisions;
- measures to minimize the impact of clam and bait harvesting (e.g. regulate permits for clam farms in seagrass meadows, regulating bivalve and bait collection, establishing protection zones around meadows);
- establishment of protected areas under the Habitat Directive where coastal impacts could be halted;
- increasing awareness of fishermen and nautical recreation groups to minimize seagrass meadow scarring by boat propellers and anchoring;
- implement best dredging practices and review dredging projects that have the potential to impact seagrass habitat, and coastal constructions (harbors, marinas, inlets) should consider alternative locations that minimize the impact on seagrass beds;
- work towards a full implementation of a good status for water quality as stated in the WFD.

A major involvement of society, scientists, politicians and resource managers is needed to invert the losses depicted in this paper. More effort is required into research and study of these ecosystems, in actions to promote seagrass self-recovery and restoration.

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