Conflictive uses of coastal areas: A case study in a southern European coastal lagoon (Ria de Alvor, Portugal)

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Conflictive uses of coastal areas: A case study in a southern European coastal lagoon (Ria de Alvor, Portugal)

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A B S T R A C T

Estuaries and coastal lagoons are naturally stressed and highly variable ecosystems, and are also frequently exposed to strong anthropogenic pressures. Such pressures can be particularly pronounced in small systems such as the Ria de Alvor, a small tidal lagoon in southern Portugal. The Ria de Alvor is a priority area for conservation, being a RAMSAR wetland of international importance since 1996 and is part of the European Ecological Network, *Natura 2000*. Nevertheless, intensive anthropogenic uses exert increasing pressures on its ecological features, causing stresses and challenges which are addressed in this paper. The resources that the Ria de Alvor provides are both marine and terrestrial in nature, and are subject to various kinds of exploitation. Urban, industrial and tourist developments, as well as agriculture and animal rearing, have resulted in habitat loss and change, altered morphology and hydrodynamics, and the discharge of effluents into the system. This paper reviews the key features and issues existing in the Ria and highlights the need for more research into this and other small estuaries and their management.

1. Introduction

The Ria de Alvor is a small meso-tidal estuary in Portugal's southern coastal region of the Algarve and, having some lagoonal characteristics, is often described as a coastal lagoon. Estuaries and tidal lagoons are transitional systems acting as buffers at the land–sea interface. These environments are highly dynamic, and are also notable for their biological diversity and valuable ecosystem services such as decomposition of organic matter, nutrient recycling, nursery for some fish species, and removal of pollutants. These particular features confer a high ecological value on coastal lagoons, a fact that is acknowledged by European legislation in the Habitats Directive and the Natura 2000 network (European Commission, 2011). Many of these coastal systems are also characterized by intense human occupation, population growth and economic development, frequently leading to significant transformation and degradation of natural resources. In Portugal, human occupation and associated land-use changes over the last two centuries have had higher impact on coastal ecosystems than sea-level rise or any other environmental change (Almeida et al., 2014b). The Ria de Alvor is a significant socio-economic resource for the western Algarve region based on tourism, aquaculture and fisheries.

Estuaries and coastal lagoons are naturally stressed and highly variable ecosystems, and are also frequently exposed to strong anthropogenic pressures (eg. Newton et al., 2014; Pérez-Ruzafa et al., 2013). The physical characteristics of many coastal lagoons, such as the limited exchange with adjacent coastal waters, make them particularly vulnerable to eutrophication (e.g. Cloern, 2001; Scanes et al., 2007). This can be as a direct consequence of increasing population density, but also throughincreased use of agricultural fertilizers in the surrounding watershed, or implementation of aquaculture production units within estuarine waters. Most of these pressures are expected to be aggravated under the predicted climate change scenarios (Brito et al., 2012a; Lloret et al., 2008).

Callaway et al. (2014) demonstrate that large estuaries tend to attract more attention than small estuaries owing to their size and

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socio-economic importance and the potentially large impacts they are often exposed to. Nevertheless, conclusions and managment practices are not always directly transferible to small estuaries (<50 km^2). In a small estuary environment, limited interventions can still be relatively big and of significant impact, and disturbances and changes in internal and external processes can affect the overall estuary, rather than damaging a limited area of a greater estuary. Small estuaries are also more vulnerable to point source pollution, and to the effects of morphological and ecological alterations (Callaway et al., 2014). In Portugal, with the exception of the Tagus and Sado estuaries, Ria de Aveiro and Ria Formosa, estuaries fall into the small estuary category, emphasising the importance of this current analysis of the conflictive uses of the Ria de Alvor.

The Ria Formosa is a coastal lagoon system in the eastern Algarve and has been the subject of many studies over the past decades (e.g. Brito et al., 2009; 2012a; Loureiro et al., 2006; Newton et al., 2003; Newton and Mudge, 2003), mostly because of its significant size and geographic location, since it surrounds the city of Faro, the regional capital. In contrast, the Ria de Alvor has only been the focus of a few published studies (Almeida et al., 2014b; Antunes et al., 1988; Brito et al., 2012b; Campos and Cachola, 2007) and is very different in character from the Ria Formosa which is a barrier island system (Vila-Concejo et al., 2002). As a result of its small size, the effects of natural and anthropogenic change are more pronounced and deserve more attention.

The aim of the paper is to identify the most relevant human activities and natural processes that disrupt the ecological status of the Ria de Alvor. We identify potential cause–effect relationships between the use of the Ria and the state of the system and go on to highlight the conflicting nature of the uses of the site. Scenarios of urban expansion suggest that the surrounding areas of the Ria will undergo a significant level of urbanization, highlighting the need for adequate management measures to cope with the vulnerability of the system (Martins et al., 2012; Vaz et al., 2012). As such, this paper can be seen as a first step in an integrative study towards a management model for this coastal lagoon.

2. The study site

2.1. Location

The Ria de Alvor (Fig. 1) is a shallow bar-built estuary or lagoon system located on Lagos Bay, on the south coast of the Algarve (37°08.22′N, 8°36.43′W). The system has a freshwater input from four tributaries within the watershed, all with origins on the south flank of the Serra de Monchique (altitude 902 m). The two largest are Rio de Arão and Ribeira de Odiáxere which drain southwards to the east and west of the central peninsula of Quinta da Rocha, giving the Ria its characteristic U shape. The Ria is separated from Lagos Bay by two barrier peninsulas, with sand dunes, and connects to the open sea by a single inlet which has been stabilized by the construction of two breakwaters since the early 1990s. With its surrounding farmland and market gardens, its total area covers approximately 15 km^2

2.2. Hydrodynamic regime

The Ria has some features that are typical of meso-tidal tide-dominated systems (where tides are 2–4 m in amplitude), such as the flood-tide delta inland of the mouth and the network of channels and mudflats fringed by saltmarsh vegetation in the inner areas. However, it also has some features of wave dominated systems, such as the almost complete closure by a barrier. Tides are semi-diurnal, with a mean spring tidal range of 2.85 m in Lagos Bay, and they are the main process generating currents in the Ria. The relatively low freshwater inflow, associated with the tide-dominated hydrodynamic regime, makes this system a euhaline (salinity range from 30 to <40) coastal lagoon (Perez-Ruzafa et al., 2011).

Outside of the navigation channel, the Ria has a maximum depth of approximately 2 m, depending on the tide, but the main channel has been extensively dredged to maintain navigability to the recreational and fishing port of Alvor. The total flooded area during high tide is estimated to be around 3 km^2 (including intertidal areas), and at low tide the surface area of the residual water is around 1 km^2 (Fig. 2). This means that, with the exception of tidal channels, most of the bed of the lagoon is exposed at low tide. Also during this phase of the tide, the residual water is mostly confined to the inner channels and creeks. Given these conditions, the water is almost entirely renewed at each tide in the outer part of the Ria, resulting in strong tidal currents (Quintino and Rodrigues, 1989). The flushing time, together with the topography of the Ria, is a modulating factor in terms of the hydrodynamics of the system and this, in turn, shapes the ecological patterns.

Freshwater input from the rivers shows strong seasonal variation, being torrential in wet months and dry in summer months, with the Rio de Arão and Ribeira de Odiáxere being the most significant in terms of flow (Table 1).

2.3. Sediments

Sand facies predominate in the sediment, with more than 65% of the area (almost the entire outer Ria) covered by medium clean sand (Quintino and Rodrigues, 1989). A gradual increase in the proportion of fine sediments is observed along the longitudinal axis of the system (from the mouth towards both the western and eastern extremities of the inner regions). Mud facies predominate in the inner areas.

2.4. Main ecological features

Ria de Alvor is listed as a priority area for conservation, being a RAMSAR site (Wetland of International Importance)[1] since 1996 and is part of the European Ecological Network, Natura 2000, as a Special Area of Conservation.[2] The Planning and Management Authority for the Algarve Region (CCDRA) highlights the Ria de Alvor as the most important wetland in the western Algarve area (CCDRA, 2005). The Ria contains a diversity of habitats and species, including 15 habitats listed in Annex 1 of the EU Habitats Directive as of ‘European interest’. Estuary, coastal sand spits, sand and mud banks, and the saltmarshes are some of the most significant features that confer the Natura 2000 status on the Ria. Of these Annex 1 habitats there are a number of priority habitats to be found in the Ria, such as coastal lagoons (habitat 1150), Mediterranean salt steppes - *Limonietalia* (habitat 1510) fixed coastal dunes with herbaceous vegetation - grey dunes (habitat 2130) and *Crucianellion maritimae* fixed beach dunes (habitat 2210).

The lagoon is a nursery area for a number of fish species and supports a highly diverse and ecologically significant shoreline biota. Approximately 250 species of birds have been recorded, and the Ria is an important staging post during spring and autumn bird migrations. Three aquatic species (Kentish plover *Charadrius alexandrinus*, Little tern *Sterna albifrons*, and Black-winged stilt *Himantopus himantopus*) nest in the sand dunes, salt pans and

[1] Under the 1971 Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).

[2] Under Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (EU Habitats Directive).

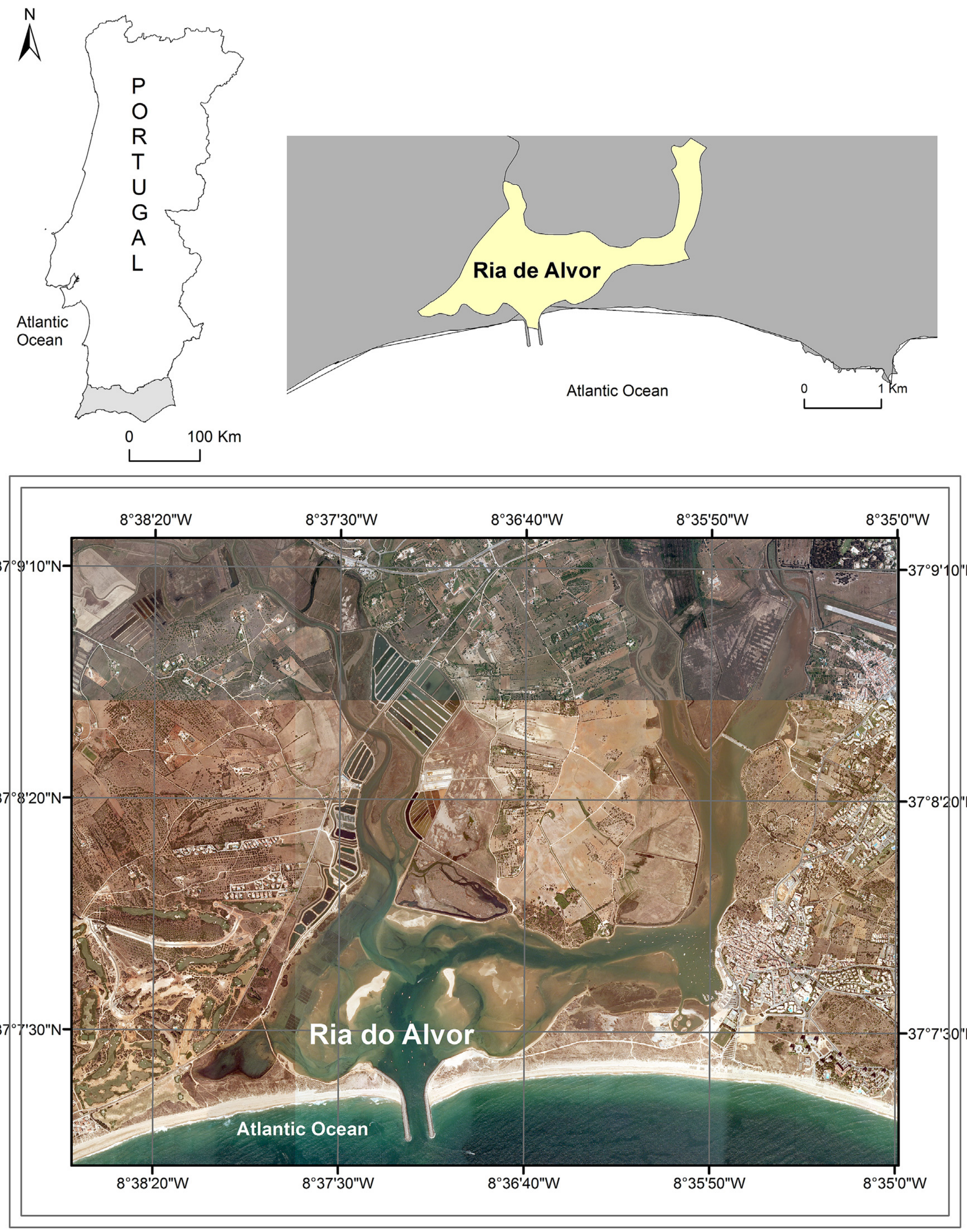

Fig. 1. The Ria de Alvor.

saltmarshes.

The benthic invertebrate community composition has a clear spatial variability pattern (Quintino and Rodrigues, 1989). Species richness increases from the entrance channel inward, up to a maximum value in regions where the sediment is more diverse (up to 2 km from the entrance). From this point inland the number of benthic species gradually decreases, reaching the lowest values in the innermost regions. Invertebrate densities show a similar distribution pattern, although highest values are associated with the mud facies in the inner estuary. Consequently, along the axis from the entrance channel to the inner regions, species richness attains maximum values before the highest densities are observed.

The water column is characterized by low turbidity all year round but particularly during dry months. The hydrodynamic regime of the inner Ria does not favour sediment resuspension, so providing optimal conditions for light penetration in such a shallow system. In addition, the water surface is exposed to a cumulative mean of approximately 3040 light hours (equivalent to 68% of the maximum). Together these features suggest that primary production is not light limited. The presence of fragmented patches of

Fig. 2. The Ria de Alvor coastal lagoon surface area covered by water at high tide (A) and at low tide (B).

Table 1
Mean annual flow of the tributaries located in the Alvor watershed (MAOT, 2000).

Tributaries	Mean annual flow ($m^3 s^{-1}$)
Odiáxere	0.56
Arão	0.30
Farelo	0.22
Torre	0.25

Zostera noltii in the subtidal channels denote optimal light conditions given the dependence of this seagrass on significant amounts of light radiation (Brun et al., 2008). Shellfish communities may play an important role in the control of light penetration in water, by removing a significant part of phytoplankton by filtration (Brito et al., 2012b).

3. Main pressures on the system

3.1. Introduction

According to the European Water Framework Directive (WFD; Council Directive, 2000/60/EC), the assessment of the pressures on water bodies is necessary to evaluate the risk of no compliance with 'good ecological status'. In broad terms, the identification of pressures provides relevant clues on how human activities may impact the ecosystems and how the ecosystem functions may be perturbed (Borja, 2006; Borja et al., 2006).

Conflicts arising from the multiple-use of coastal zones are common in Europe, and the Ria de Alvor is no exception. The Ria faces the same challenges as most coastal lagoons worldwide, mainly as a consequence of growing human influence on these systems. Population expansion, increase in waste (part of it as polluted effluents), nutrient addition from agriculture and aquaculture, are canonical examples. Based on the thorough reviews recently made by Newton et al. (2014) and by Newton and Weichselgartner (2014) on coastal systems, we address the main challenges that the Ria faces, focusing firstly on the drivers/pressures on the system, and then their known or potential impacts on its state.

The analysis is not an application of the DPSIR model (Newton and Weichselgartner, 2014; OECD, 1994), by which a systematic evaluation of driving forces (D), pressures (P), states (S), impacts (I) and policy responses (R) is performed. However, we make use of this framework to discuss the topics we have identified as being conflictive with respect to the use and conservation of the Ria.

The drivers and associated pressures described in this section are: (1) agriculture and animal rearing; (2) tourism, urban and industrial development; (3) land reclamation and coastal engineering (often undertaken for the purposes of (1) and (2); and (4) aquaculture and shellfishing. In section 4 we go on to describe the associated impacts on the Ria in terms of water pollution and eutrophication, changes to the hydrodynamics and sedimentology, and habitat loss. We then make some comments about climate change as a longer term driver of change of anthropogenic origin, before making some concluding observations on the implications of these multiple challenges on future management and research priorities.

3.2. Agriculture and animal rearing

Traditional agriculture associated with the region includes the cultivation of dryland tree crops (principally almonds, figs, carobs, olives), as well as some cereal cultivation, vineyards and vegetable growing in market gardens. Such farming has been in decline in recent decades, and the most commercially profitable farming is citrus cultivation. Improved irrigation technology and infrastructure has led to the marked expansion of irrigated land along the waterways that reach the Ria. These intensive production systems lead to a high levels of nutrients (from fertilizers) and pesticides reaching the estuary system.

Many residents in rural areas in the watershed rely on animal rearing for income. Besides the extensive production of sheep and goats, there are also several intensive piggeries scattered in the northern part of the of the Mexilhoeira Grande municipality and on the southern slopes of the Serra de Monchique. In fact, the highest density of intensive piggeries in the Algarve are to be found in the Monchique and Silves districts, both located in the Ria de Alvor watershed. Many areas in the Odiáxere sub-watershed are used as pastures for cattle, while horse-riding activities are also abundant. It has been observed that many feedlots for these animals have illegal connections discharging untreated effluents to the Ribeira de Odiáxere and Ribeira de Arão (Campos and Cachola, 2007). Until recently, the untreated effluents from most production units were discharged directly into the system.

3.3. Tourism, urban and industrial development

The Algarve region has been one of the most significant regions for tourism in Portugal because of its attractive landscapes and coastline, and its moderate climate. The demand for better infrastructures for mass tourism has led to land exploitation and an increasing population, ultimately resulting in the conversion of natural habitat into urban areas or touristic attractions. Significant urban expansion occurred between 1987 and 2001, mainly in the most important tourist centres such as Lagos and Portimão, between which the Ria de Alvor is located. Tourism in these areas is a significant local economic driver and is continually stimulating the development of new attractions such as a motor racing circuit in the municipality of Portimão (Petrov et al., 2009). Recent studies suggest ongoing growth in the region within the framework of current policies and regressive spatial trends (Vaz et al., 2012).

Human occupation in the Alvor sub-watershed is mainly seasonal, peaking with the tourism occupancy in summer (from June to September), and falling sharply in winter. Nevertheless, the town of Alvor reflects a tendency for soft occupation driven by residential tourism (mainly from northern Europe) during the low season, although tourism occupation is less notable in Mexilhoeira Grande and Odiáxere. The surrounding area of the Ria is one of the places in the Algarve that has undergone intense urban development in the past four decades. Hotel and apartment complexes, a camping park and an aerodrome are some examples of this development in the vicinity of the Ria de Alvor, and some of these were built on former coastal habitats. Several golf courses have also been developed in the area, and golf courses are known to be a potential source of nutrients to the surrounding water systems via groundwater or surface runoff. Industrial activities in the area include several quarries and concrete producing units located on the margins of Ribeira do Arão, and a printing factory located near the Ribeira de Odiáxere.

3.4. Land reclamation and coastal engineering

The demand for land for agriculture, saliniculture, aquaculture, tourism and recreation has led to considerable loss of inter-tidal areas of the Ria through enclosure and drainage. A map of 1884 shows the enclosure with dykes of substantial areas of saltmarsh during the 19th century (Pullan, 1988). Comparison of historic maps shows further extensive reclamation continued between 1884 and 1952, and again in the late 1960s with the construction of a dyke around Quinta de Rocha. The Agriculture Development Plan was responsible for a significant area of this saltmarsh reclamation. Apparently, land reclamation around the Ria ended mainly as a consequence of the failure of the Portuguese Agriculture Development Plans (Almeida et al., 2014b), as well as a consequence of Portuguese accession to the former CEE, in which agricultural policies were determined by European-scale objectives. Aquaculture activities also contributed to the transformation of the system when, in the mid-1980s, some areas of former saltpans were transformed into aquaculture production units.

In 1988, a plan for the improvement of boat navigation in the estuary was put into motion by the Direcção Geral de Portos (DGP, 1988). The first phase of the plan, which was carried out between 1989 and 1992, was marine works and estuarine ‘correction’ considered necessary for the hydraulic functioning and the survival of the Ria. This involved the dredging of the navigation channel up to the port of Alvor, dumping of dredge spoil on the dunes, and the construction of jetties. The mouth was canalised by means of paired jetties, 550 m long, producing a channel 120 m wide, 400 m long and with a depth of c.-3 m OD. The initial dredging operation started in autumn 1989 in the estuary mouth and near Alvor and took approximately 3.8 million m^3 from the ‘lagoon’ at an estimated cost of nearly 5 million euros (Port, 1988). The jetties were completed towards the end of 1991.

3.5. Aquaculture and shell-fishing

The natural conditions of the Ria de Alvor are optimal for aquaculture. The estuary is one of the main intertidal culture sites for clams (*Venerupis decussatus*) in Portugal (Campos and Cachola, 2006; Muehlbauer et al., 2014). Production of oysters in the Ria has also been high, especially after the clam populations were nearly decimated as a result of frequent mortality episodes at the end of the 1990–2000 period (Leite et al., 2004).

Estimated annual production of clams (bottom culture beds) and oysters (tables) in the Ria reach 120 and 400 tons respectively, with most of the production exported to Spain and France (Campos and Cachola, 2007). Clams, razor clams and cockles harvested from open access natural banks are sold on local markets or collected for home consumption.

The Ria is of national importance for the commercial production of bivalves, given the quantities harvested from the intertidal areas. This activity comprises wild harvesting of clams, cockles and razor clams in open access areas, and extensive culture of oysters on tables and clams in bottom cultured beds in plots leased from the State.

4. Main impacts on the system

4.1. Introduction

The drivers and pressures on the Ria as described above lead to a range of impacts on the ecological characteristics, functions and dynamics of the Ria. The most significant of these, which we describe below, are on the water quality, on the hydrodynamics and sedimentology, and on aquatic and terrestrial habitats.

4.2. Water pollution and eutrophication

4.2.1. The vulnerability of the Ria as a coastal lagoon

Coastal lagoons are naturally enriched areas (Orfanidis et al., 2005), but small systems such as the Ria de Alvor can still be easily disturbed by natural processes and by pollution originating from adjacent urban and industrial development. Coastal lagoons have three main sources of allochthonous inputs of organic matter that contribute to nutrient enrichment: tidal import, riverine sources, and sewage and waste disposal (Wilson, 2002).

The sheltered nature of coastal lagoons, their often restricted exchange with the adjacent sea, and the cumulative effect of nutrients exported by the watershed provide conditions for the accumulation of nutrients (Roy et al., 2001) and, potentially, the onset of eutrophication. In this way, nutrient enrichment is often one of the immediate consequences of effluent input into any system.

The Ria de Alvor is similar to other Portuguese coastal lagoons such as Ria Formosa (Newton et al., 2003) and Óbidos Lagoon (Malhadas et al., 2014) I being impacted by pollution derived from the watershed. Excess loading of nutrients, originating from human activities, enter the Ria as effluents. These include urban sewage, industrial effluents, agricultural runoff and aquaculture effluents, entering the Ria from both diffuse and point sources. Runoff from golf courses is an additional nutrient input and the high number of tourists places increased stress on the sewage disposal system, particularly during the summer. Given its small size and limited water volume, it is not surprising that the Ria is particularly susceptible to nutrient enrichment. However, a significant exchange of water occurs at each tidal cycle, contributing to the renewal of the water volume and reducing the potential effects of nutrient enrichment in the main channels.

4.2.2. Urban effluents

The recent redirection of urban effluents to the Waste Water Treatment Plant (WWTP) in Portimão is an example of efforts undertake by local authorities to minimize human impacts on the Ria. Along with a reduction in faecal coliform (FC) contamination of the natural and cultured bivalve species, this development has also reduced the organic matter loads entering the system, thus minimizing eutrophication. However, the problem of FC has not been mitigated. Campos and Cachola (2007) reported high FC levels in clams harvested near the most urbanized watershed and, inversely, low FC values in the least urbanized watershed. Consequently, it can be assumed that organic matter is still being added to the Ria via domestic effluents.

4.2.3. Effluents from aquaculture

Aquaculture sites produce large quantities of allochthonous dissolved and particulate organic matter capable of causing environmental problems such as oxygen depletion and enhancement of planktonic processes due to eutrophication (Islam and Tanaka, 2004; Wu, 1995). As a result, an overall impact of fish farms can be a deviation of trophodynamics from normal ambient conditions (Modica et al., 2006).

Intensive feeding in fish farms effects the neighbouring areas within the Ria. Outflows from the culture ponds enrich the lagoon with a steady source of organic matter, and the hydrodynamics of the estuary is responsible for spreading the organic matter throughout the system (Cromey et al., 2002a; 2002b; Modica et al., 2006). In open bays, for example, physical processes such as water exchange tend to dominate (Yokoyama, 2003), promoting a faster dispersion of the organic load. In closed systems, like coastal lagoons, higher retention times of water in the inner areas strengthen the impact of the loads, creating conditions for eutrophication and oxygen depletion. The link between the presence of aquaculture and an increase in phytoplankton abundance is well established (Modica et al., 2006; Yoshikawa et al., 2007), but has yet to be confirmed in the case of the Ria de Alvor.

The incidence of parasitism and disease is high in aquaculture and associated chemical use can be a further source of pollution to surrounding waters. Studies have reported accumulation of pesticides and heavy metals in the vicinity of aquaculture areas (Edwards, 1998). Episodes of mass mortality in aquaculture species have occurred in the Ria de Alvor (Bernardino, 2000) and the presence of the peridinean dinoflagellate *Amyloodinium ocellatum*, an ectoparasite found in many aquacultures in Portugal (Pereira et al., 2011), has been reported to occur in production units here. If such outbreaks of parasites have been or are treated by the addition of algaecides to water, a common procedure to cope with the incidence of this parasite (Paperna, 1984), these substances may eventually end up being dispersed throughout the entire system, potentially causing changes to the structure and composition of natural populations.

4.2.4. Eutrophication

Harmful algal blooms (HABs) are frequently a consequence of eutrophication, and comprise a range of algal species, from phytoplankton to macroalgae. The impacts of these events range from nuisance blooms to the production of lethal toxins (Wilson, 2002). These blooms are disruptive to the system and, at the same time, pose serious implications to human health. They may have severe economic consequences as a result of high mortality in fish aquaculture or prohibition of mussel harvesting.

No relationship between nutrients and phytoplankton has so far been found to occur at the Ria (Brito et al., 2012b), but this observation is based on scarce data and needs further corroboration. Chlorophyll concentration is expected to be higher inside the lagoon, compared with the coastal waters, although the phytoplankton community in the Ria is characterized by the presence of coastal species such as *Pseudo-nitzschia* sp. (Brito et al., 2012b), denoting the influence of coastal processes on the lagoon.

Nevertheless, the significant tidal water exchange noted above (4.1.1) reduces the potential for eutrophication in the Ria.

4.3. Hydrodynamics and sedimentology

Land reclamation, the construction of dams in the watershed, the fixing of the estuary mouth and the dredging of navigation channels have all led to considerable impacts on the hydrodynamics and sedimentology of the Ria, particularly given its small size. In turn, the altered hydrodynamic and sedimentary regime has led to significant geomorphological changes.

The extensive reclamation that took place up until the mid-1900s must have considerably reduced the tidal prism (the amount of sea water entering and leaving the Ria), causing sediment redistribution within the estuary. Reduction of the tidal prism by land claim frequently leads to shrinkage of the ebb delta and partial closure of the estuary mouth as a result of hydraulic adjustment. There may be a long delay between this cause and effect, with the hydraulic adjustment taking 80 years or more to achieve a new equilibrium (Carter, 1992). Between 1884 and 1952 the mouth of the Ria underwent significant changes, whereby major features of the ebb-tide delta were incorporated in a growing sand spit and the mouth moved eastwards to the more central position where it is today. At first the changes were relatively small, but between 1930 and 1952 the western sand spit grew rapidly to its modern position.

In addition, the completion of two dams in 1956 and in the late 1960s, has reduced the flow of the rivers Odiáxere and Torre and consequently the sediment transport capacity of the freshwater system.

Since the 1950s the shape and size of the Ria's morphological features have continued to alter considerably. There has been a net movement of sediment into the estuary, leading to increased sedimentation of the lagoon and erosion of the ebb-tide delta and adjacent beaches. A preliminary examination of aerial photographs (Batty, 1997) suggests that the flood tide delta has been considerably larger than the ebb-tide delta since at least the 1960s. It appears therefore, that between 1957 and 1967 there was a major influx of sediment as a result of disturbance to the estuary's equilibrium. This may be a continued response to the reduction in the tidal prism because of pre-1952 reclamations plus the reduced freshwater discharge following the completion of the first dam in 1957. However, further land claim in the 1960s may have given a particular stimulus to this process. Since then the estuary has been adjusting its morphology to produce a new equilibrium and the rapid changes in channels and landforms have been part of that process.

The foreshortening of the shore caused by the building of sea walls is likely to have resulted in an increase in the mean depth of the estuary through the removal of large shallow intertidal areas. This increases the tidal range, tidal current and wave activity impinging on the new embankments and the shore in front of them (Pethick, 1994), causing erosion as seen on the banks of the Rio Odiáxere. Also, sediment entering the estuary or being transported from the tide delta on the flood tide can no longer be dispersed over the upper flats but is deposited in the subtidal channel at slack water (high tide) and remains in the lagoon beyond the effects of ebb tide scour. The construction of a dyke around Quinta de Rocha in the late 1960s has also accentuated the formation of the new bed of the Ribeira de Odiáxere, which had already begun to alter its course westwards (Cabral et al., 1989).

With regard to the construction of the jetties in the late 1980s/early 1990s, experience in other locations (Carter, 1988) has shown that the effects of such jetties depend on the size, width and local conditions, but are likely to comprise changes in sediment transport patterns through the mouth and along the external shore. Dredging affects estuary morphology beyond the dredged channel, through effectively 'rejuvenating' the estuary by deepening it and increasing its capacity for sedimentation – its sediment demand. This deepening of the estuary then leads to erosion of the intertidal and the estuary banks as well as an increased flood risk (Pethick, 1994). As a result of this process, the dredged channel infills and leads to demands for further dredging, so setting up a 'vicious spiral'. The dredged channel of the Ria may also potentially exert a sediment demand not only within the estuary itself but also from Lagos Bay and its beaches.

It may be that, as a result of natural processes, the Ria would have followed many other former Portuguese estuaries and become a lagoon, with the inlet closed for at least part of the year. However, that process has been reversed by coastal engineering works and the features of the tidal delta have now been considerably disturbed by dredging and the building of the jetties at the mouth.

4.4. Habitat loss

4.4.1. Subtidal

The loss of habitat can be seen as one of the most serious consequences of all pressures mentioned above. Probably the most significant example of aquatic habitat loss is the gradual reduction of *Zostera noltii* over recent decades in the Ria, following the trend of other coastal lagoons in Portugal where the disappearance of this species has reached almost 75% (Cunha et al., 2013).

These seagrass losses represent an undeniable economic loss for most coastal systems. There is a clear link between the deterioration of the ecological quality of coastal and transitional water bodies, and the loss of seagrass (Marbà et al., 2013). *Z. noltii* is extremely important because it is a keystone habitat-structuring seagrass species on intertidal mudflats, as pointed out by Gamito (2008). Hence, its loss is expected to have serious impacts on the whole ecological dynamics of the Ria.

The main threats to seagrasses identified in the Ria are the changes in the morphology of the bed and shoreline (possibly associated with aquaculture practices and dredging activities), land reclamation, eutrophication (related to agriculture and golf courses), and intense collecting of bivalves and bait.

In 2009 *Z. noltii* was present in several fragmented patches at the upper intertidal level, near the salt marsh zone, and as a very few shoots in a central mudflat, covering an area of approximately 5000 m^2. However, these patches had almost disappeared by September 2010, covered by a layer of sediment, possibly originating in the dredging activities of a new channel (Cunha et al., 2013). Similar changes have taken place in other coastal systems in Portugal, such as the Ria de Aveiro where the increase in tidal currents resulting from channel dredging led to large changes in the sedimentary regime and, consequently, to the loss of almost all seagrass species that used to be abundant (Duck and da Silva, 2012).

The reasons for the disappearance of *Z. noltii* from the Ria de Alvor are still not clear, but the most likely candidates are mechanical removal arising from human activities such as bivalve culturing and harvesting, channel dredging and boat mooring, as has been reported for the Mondego estuary (Baeta et al., 2009; Lillebø et al., 2007). A similar situation has been observed for loss of seagrass in the Ria Formosa in relation to clam culture (Gamito, 2008), because the preparation of the clam-beds involves covering the intertidal *Z. noltii* meadows with coarser terrestrial sediment.

Eutrophication is also a likely candidate as a cause for this disappearance. Excess nutrient loading was shown to induce a shift in plant dominance from eelgrass to other algal forms such as phytoplankton, epiphytic algae, and macroalgae (Short et al., 1995). Thus, eutrophication reduces eelgrass growth through stimulation of various forms of algae that effectively compete with eelgrass for light. This relationship has been reported for the eelgrass *Zoostera marina* (Short et al., 1995) and for *Posidonia oceanica* seagrass meadows (Cancemi et al., 2003).

4.4.2. Intertidal

The negative impact of urbanization and tourism on coastal environments is well established (Burak et al., 2004). This impact is particularly relevant in estuarine systems because saltmarshes provide feeding habitats for a variety of organisms, nursery habitat for juvenile fish that support commercial fisheries and also protect developed shorelines by reducing the impact of severe storms (Harris et al., 2004). The Ria de Alvor is such a system (Antunes et al., 1988; Correia et al., 2012a; Mesquita et al., 2007).

Land claim and land-use changes not only result in the loss of saltmarsh areas, but have also created a process of transformation of natural marshes into new-subtypes (Almeida et al., 2014b). This implies changes in the floristic composition and in the marsh morphodynamics, creating new challenges for habitat management.

Almeida et al. (2014b) estimated a net loss of 73 ha of saltmarsh habitat between 1958 and 2010 in the Alvor estuary, and Pullan (1988) estimated a total historical loss of 826 ha, representing approximately 90% of the original area. At the beginning of the 17th century siltation resulting from the construction of dykes upstream of the Ria's affluents provided available debris for starting embankment (Vieira, 1911). The 1750's earthquake, and subsequent tsunami, recorded by Loureiro (1909) and Vieira (1911) reached the agricultural exploitation of Mexilhoeira Grande and the Arão irrigation perimeters. Tsunami waves entered 670 m inland, flooding the crop areas and modifying completely the estuary bar and the Ria's morphological profile. These changes posed some limitations on the Ria's affluent range, with consequences on sediment supply. Later on in the 19th century, reclamation processes extended to the salt wetlands of Abicada, Penina and east side of Quinta da Rocha (Pullan, 1988). In the first half of the 20th century, more saltmarshes were reclaimed: Vale da Lama, Odiáxere and the west side of Quinta da Rocha (Pullan, 1988). The main land uses started to be associated with salt and rice production, whose pans were later transformed into aquaculture units, and adjacent abandoned agricultural fields allowed the development of secondary halophytic vegetation (Almeida et al., 2014a, 2014b; Pullan, 1988). In addition, a significant area of saltmarsh habitat has been transformed into aquaculture cultivation ponds over the past few decades (Fig. 3).

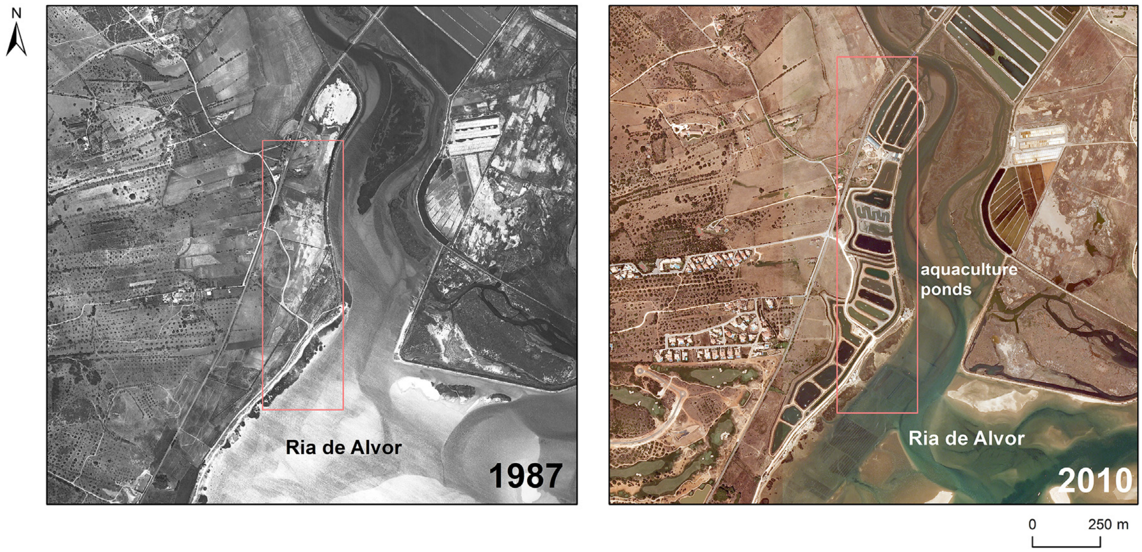

Fig. 3. Aerial photographs of a section of the Ria de Alvor during 1990s (left panel) and late 2000s (right panel). The right panel inset highlights the growth of the aquaculture ponds on the margins of the Ria.

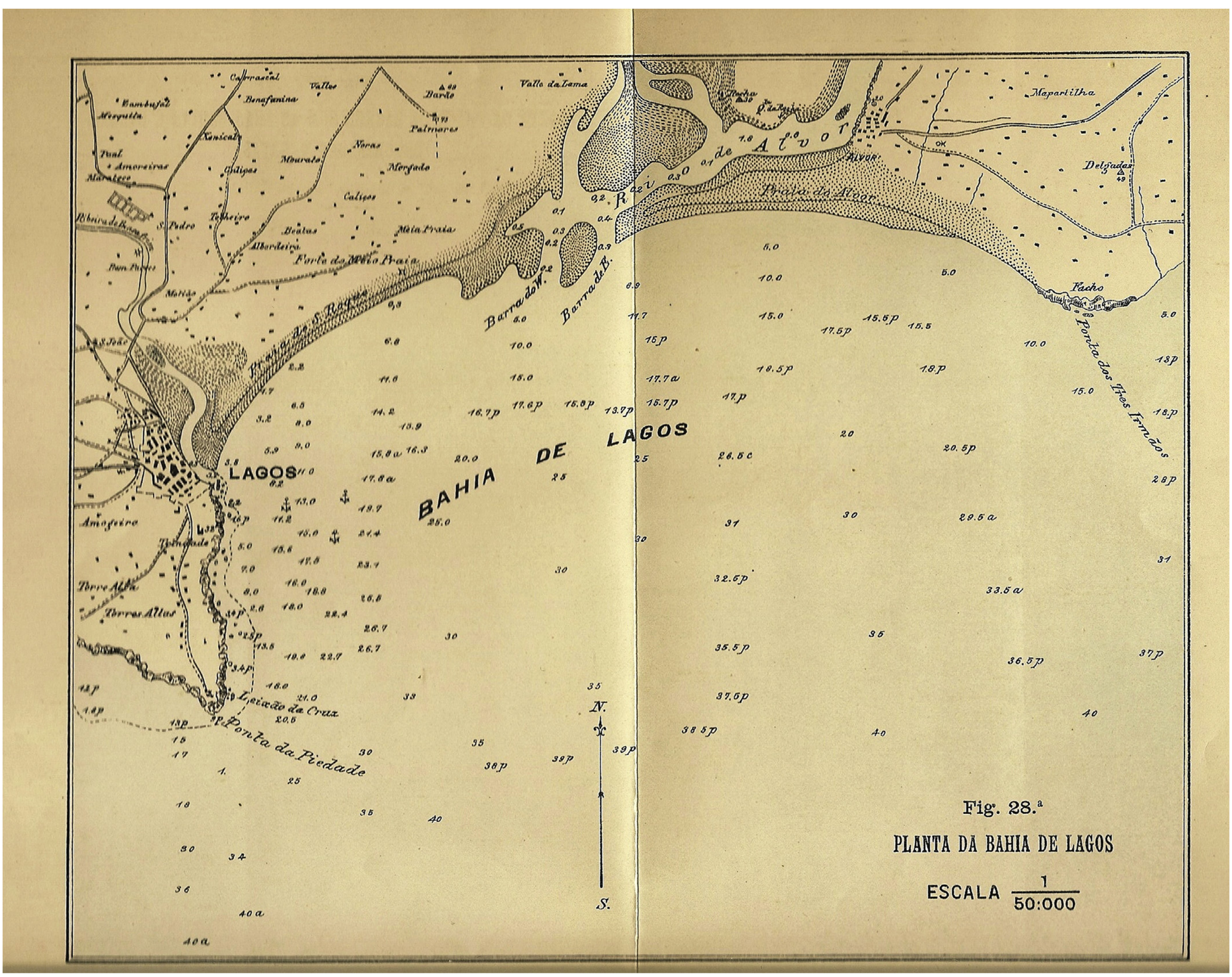

Fig. 4. Drawing by (Loureiro, 1909) showing Lagos Bay. Here can be seen the shape of the Ria de Alvor by the end of the 18th century, suggesting profound transformations in hydrological regime and land use, with implications for habitat loss and change.

The loss of such a large area of saltmarsh from this small estuary will have had profound consequences in terms of the flow of nutrients, organic matter and organisms around the whole estuary system, impacting severely on intertidal mudflat and also on saltmarsh ecosystem services (Foster et al., 2013) (see Fig. 4). Supporting services such as soil formation and nutrient cycling are the most affected by this substantial reduction of area. Additionally, regulating services such as erosion protection are critically endangered by the loss of saltmarsh habitat (Möller, 2006; van Loon-Steensma and Vellinga, 2013) and reclamation for aquaculture along the Ria's right margin. Saltmarsh habitats protected by the Natura 2000 network are: 1310 - *Salicornia* and other annuals colonising mud and sand; 1320 - *Spartina* swards *(Spartinion maritimae)* colonising a wide range of substrates, from very soft muds to shingle, in areas sheltered from strong wave action; 1410 - Mediterranean salt meadows *(Juncetalia maritimi)*, frequently found in estuaries and coastal lagoons; 1420 – Mediterranean and thermo-Atlantic halophilous scrubs *(Sarcocornetea fruticosi)*, a perennial vegetation of marine saline muds (schorre) mainly composed of scrub, essentially with a Mediterranean-Atlantic distribution (*Salicornia*, *Limonium vulgare*, *Suaeda* and *Atriplex* communities) and belonging to the *Sarcocornetea fruticosae* class; 1430 - Halo-nitrophilous scrubs *(Pegano-Salsoletea)*, *Pegano-Salsoletea* class, typical of dry soils under arid climates, sometimes including taller, denser bushes; and 1510 - Mediterranean salt steppes (*Limonietalia*), associations rich in perennial, rosette-forming sea lavenders (*Limonium spp*.), along Mediterranean coasts and on the fringes of Iberian salt basins. Pressures upon these habitats are transversal and shared by others around the outer border of the Ria system (i.e. pioneer vegetation of dune habitats, classes 2110, 2120, 2130). With respect to the challenges of avoiding habitat loss, these should be focused on ecological recovery of disturbed habitats in order to improve biological diversity, and assuring the role of saltmarshes in the ecological functioning of the Ria.

5. Climate changes

Coastal areas are particularly vulnerable to the profound physical, ecological, and associated societal disturbances that are expected to occur in response to future climate changes (Anthony et al., 2009; Lloret et al., 2008). It is now well established that coastal communities such as wetlands and seagrass meadows are particularly vulnerable to climate changes (Nicholls and Hoozemans, 1996; Nicholls et al., 1999; Short and Neckles, 1999). Some expected shifts in estuaries and coastal lagoons include changes in the flushing regime, freshwater inputs and water chemistry, and the loss of natural and human communities.

Unlike other coastal lagoon systems in Portugal (Brito et al., 2012a; Bruneau et al., 2011; Dias et al., 2014), no studies have ever been made to predict the effects of climate change on the Ria de Alvor. However, the volume of literature produced for this topic, along with findings for other lagoons in Portugal, can be used to infer some possible consequences for the Ria de Alvor arising from climate change.

If the prediction of a warmer and drier climate comes true, the current status of Ria de Alvor will probably degrade, as expected for other coastal areas (Lloret et al., 2008). The outcome will be a significant global deterioration of the system, with higher concentrations of nutrients, proliferation of phytoplankton and floating macroalgae and, possibly, even more drastic impacts such as hypoxia in the inner areas. The impact will extend to biological communities, but also to local economic activities such as fishing, aquaculture and tourism. The lagoon may also face a further reduction in freshwater input leading to an increased upstream intrusion of saline water, possible changes in sediment distribution and changes in habitats and species associated with a particular range of salinities. This would result in effects on the overall productivity of the system (Wilson, 2002).

In such shallow systems there is a significant relationship between air temperature and water temperature. Modelling assessments made for another shallow coastal lagoon in the Algarve point out that a significant change in microphytobenthos biomass is not expected as a consequence of the expected increase in water temperature (Brito et al., 2012a). However, the same study concludes that sea level rise and global warming associated with climate change are likely to affect shallow coastal lagoons such as Ria Formosa and Ria de Alvor.

It is also expected that human occupation will increase in coastal zones, and the Ria is unlikely to be an exception. An increase in human population density is likely to result in an increase in nutrient effluents. Also, an increase is expected in the use of fertilizers for agriculture in the surround watershed. Together, these two factors may lead to a rise in nutrient discharges to the Ria, and can be aggravated by the expected changes in precipitation patterns and, subsequently, in hydrological regimes (Béthoux et al., 1998; Dore, 2005; Sumner et al., 2003).

Predictions for the Mediterranean Region, in which southern Portugal and the Algarve are included, are of an increase in consecutive days with high temperatures and a reduction in humidity (IPCC, 2014a). There are expected changes in the hydric regime, long dry periods in the summer and torrential rain peaks in the winter (IPCC, 2014b). Disturbed and eroded coastal habitats such as those in Ria de Alvor face major challenges concerning sea storms and coastal flooding (LPN, 2014).

6. Concluding remarks

The Ria de Alvor, along with the Ria Formosa, has an indisputable high ecological and economic importance in the Algarve (Brito et al., 2012b). However, integrated study of the Ria de Alvor system, unlike other Portuguese coastal lagoons, is still emerging. There is little scientific output that brings together its physical, biogeochemical and ecological features, and coastal management studies for this coastal system are practically non-existent. Despite the lack of targeted environmental management from government, and several pressures from various sources (urban and industrial effluents, tourism, aquaculture, land reclamation, habitat loss, and environmental change among others) it is remarkable that Ria de Alvor has survived as an intact natural system, albeit a highly modified one.

Against such a background, this current paper is a step towards a more comprehensive study of the Ria de Alvor's environmental and socioeconomic dimensions and relationships. However, a thorough analysis of the evolution of the status of the Ria will have to address such topics as ecosystem services, societal benefits, economic revenue and other paradigms in ecology (Elliott and Whitfield, 2011).

There is an urgent need for a planning instrument capable of effective environmental management beyond achieving broad conservation targets. There is also a need to raise public awareness of the complex of habitat types that make up Ria de Alvor and the important ecosystem services that it provides. Whatever the methodology used and the priorities set for policy-making and management of the Ria, it is obvious that a holistic approach has to be considered, looking at the watershed-lagoon-coastal area continuum, and addressing this transitional water as a continuous land-water system, as proposed by Basset et al. (2013).

A key management challenge is faced by the future expansion of aquaculture. The environmental impact of the increase in intensive aquaculture is undoubtedly one of the most relevant issues related to conservation and sustainable development of coastal areas

(Buschmann et al., 2006; Modica et al., 2006). Like many other estuaries and coastal lagoons, the Ria de Alvor supports both intensive and extensive aquacultural exploitations (Pérez-Ruzafa and Marcos, 2012). Aquaculture here offers the prospect of continuing growth, and the immediate and long-term environmental effects of this cannot be ignored (Wilson, 2002). An important question for this coastal lagoon is how to allow the expansion of aquacultural activity without compromising other natural resources.

The Ria de Alvor may follow the example of Santo André lagoon, which became one of the less disturbed coastal lagoon systems in Portugal after its classification as a protected area (Correia et al., 2012b). Meanwhile, the presence in the Ria de Alvor of the main drivers and associated pressures found in most coastal lagoons throughout the Mediterranean basin, associated with its relatively small size, makes this system ideally suited as a site for pilot studies assessing different watershed-coastal management strategies. Indeed, the fact that small estuaries are generally under-researched makes the Ria de Alvor a particularly useful site for developing studies which will inform planning and decision making in other small estuaries.

Disclosure

All authors made substantial and equivalent contributions to the conception and design of the work, acquisition of data and information, and subsequent interpretation. The article was drafted and revised constantly by all authors, so that the intellectual content reflects the work of the team. All authors have approved the final article.

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