Universidade de Aveiro Departamento de Biologia

2015

Liliana Medeiros Gomes

A importância das salinas da Ria de Aveiro como local de invernada para aves limícolas migratórias

The importance of Ria de Aveiro's saltpans during winter for migratory waders

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia Aplicada, realizada sob a orientação científica do Prof. Dr. Carlos Manuel Martins Santos Fonseca, Professor Associado com agregação do Departamento de Biologia da Universidade de Aveiro e do Doutor José Augusto Alves, investigador de pós-doutoramento, membro integrado do CESAM no Departamento de Biologia da Universidade de Aveiro.

o júri

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palavras-chave Habitats intertidais, salinas, aves limícolas, salicultura ativa, refúgio, alimentação, limícola invernante, migracao.

resumo As zonas húmidas intertidais são habitats altamente produtivos e suportam milhares de aves aquáticas em todo o mundo, contudo são também um dos habitats mais ameaçados globalmente. A perda de habitats intertidais é considerada um dos principais fatores que contribui para o atual declínio da maioria das populações de aves aquáticas. Habitats artificiais supratidais como as salinas costeiras, podem funcionar como zonas tampão contra a perda de habitats costeiros naturais. Uma vez que o abandono das salinas pode conduzir à perda da sua qualidade como habitat para as aves limícolas, este trabalho pretende contribuir para o estudo da sua importância, de forma a tentar prever as implicações que a atual tendência de abandono da exploração do sal pode ter nas populações de limícolas. Foram efetuadas contagens da avifauna limícola em 3 diferentes regimes de salinas – salicultura ativa, aquacultura ativa e salinas abandonadas/arrombadas - em situações de preia-mar e baixa-mar, entre Outubro de 2014 e Março de 2015. Verificou-se que um elevado número de limícolas na Ria de Aveiro utiliza as salinas independentemente do ciclo de maré, contrariando, assim, a ideia da sua utilização apenas como refúgio de preia-mar. Contudo, verificam-se diferenças substanciais entre as fases de preia-mar e baixa-mar. Durante a maré enchente a abundância de aves limícolas aumenta em tanques com salinas ou aquacultura ativas e diminui nas abandonadas, sendo que o inverso ocorre na maré vazante. As salinas ativas são um importante local de alimentação para espécies maiores como o perna-longa (*Himantopus himantopus*) e o milherango (*Limosa limosa*), tanto em situações de preia-mar como de baixa-mar. Estes resultados vêm reforçar a importância da manutenção de salinas ativas como estratégia de gestão e conservação da avifauna limícola invernante da Ria de Aveiro.

keywords Intertidal habitats, saltpans, waders, active saltpans, roosting, feeding, wintering waders, migration.

abstract Intertidal wetlands are among the most productive habitats and support large numbers of waterbirds worldwide, however they are also one the most threatened habitats on the planet. The loss of intertidal habitats is considered a key factor in explaining the current decline of many waterbird populations. Anthropogenic supratidal habitats such as coastal saltpans can operate as buffer zones against the loss of natural coastal habitats. Therefore, saltpan abandonment can lead to a loss of the quality of these areas for waders. This study aimed to evaluate the implications that the current trend of traditional salt works abandonment can have on wader populations. Wader surveys were undertaken in saltpan tanks currently under one of 3 different regimes – active saltpans, active aquaculture and inactive/shattered – during both high tide and low tide between October 2014 and March 2015. The observations showed that a larger number of wintering waders use the active saltpans both during high and low tide. Nevertheless, the study of wader distribution in the different saltpans revealed differences between high tide and low tide. During rising tide, wader abundance significantly increases in active saltpans and aquaculture tanks and decreases in inactive tanks, whereas the opposite occurs during dropping tide. Active saltpans are an important feeding habitat for large waders, particularly for the black-winged stilt (*Himantopus himantopus*) and the black-tailed godwit (*Limosa limosa*), in both high tide and low tide. These results highlight the importance of artificial habitats such as active saltpans for wintering waders and the value of its correct management towards the conservation of waders in Ria de Aveiro.

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1. General Introduction

1.1Waders & estuaries

Waders are a widespread group of birds that contains more than 200 species belonging to 12 families within the Order Charadriiformes (Hayman *et al.* 1991). Most species are typically associated with wetland and/or coastal environments, being also frequently referred to as "shorebirds". Waders are very gregarious during the non-breeding season often forming large feeding and roosting flocks, sometimes totalling several thousands of individuals being thus a very conspicuous group of birds (Dias 2008). Despite recognizable whilst in large flocks, waders are small to medium-sized birds with slender and probing bills and relatively long legs. Many are cryptically coloured, but some are boldly patterned particularly in the breeding season (Evans & Davidson 1990). During the non-breeding season (that includes the wintering and migratory phases of the annual-cycle) most wader species concentrate in estuaries and other coastal wetlands. In estuarine areas their daily cycle is constrained by the movement of the tides (Burger *et al*. 1977), typically feeding on intertidal flats exposed during the low-tide period, and moving to supra-tidal areas when the tide rises, such as salt marshes or saltpans. The tidal cycles thus imply regular movements between tidal flats and supra tidal roosts where they mostly rest and, in some habitats, (e.g. saltpans) can also forage.

Most estuaries have a series of landscape subcomponents: a river (or fresh water) source, a tidal-estuarine segment (or intertidal area), marshes (or mangroves depending on latitude), and a pass to the sea. They are characterized by having considerable variation in temperature and salinity. The distribution and abundance of waders in these areas depends on the pattern of occurrence of the invertebrates (on which they prey) and also on the physical features of their habitat (Granadeiro *et al*. 2004) which, in turn, dependent greatly on the tide cycle (Granadeiro *et al*. 2006). Most notably, these systems have extremely high primary and secondary productivity and support a great abundance and diversity of fish and invertebrates. Because of their effects on the diversity and productivity of macrofauna, coastal estuaries serve as nursery grounds for many migratory species of marine fish and as feeding and resting areas for many species of waders and other water birds (Beck *et al*. 2001; Correll 1978). One of the most important characteristics of estuaries is the fact that these form a mosaic of inter-linked habitats that should not be considered in isolation (Morrisey *et al*. 2003), each one being of particular value for the different species that use it.

Important primary producers in estuaries are phytoplankton and submerged vascular plants. Periphyton and benthic thalloid algae provide significant amounts of productivity in shallow water areas. In addition, relatively small amounts of organic matter are transferred to the estuary from tidal marshes and uplands. The particle consumers include benthic molluscs, zooplankton, larval and juvenile fish, adult filter-feeding fish, and certain benthic invertebrates such as bryozoa and polychaetes. Top predators in estuarine systems are wades, other waterbirds (e.g. heron, ducks) and some species of fish, which might also feed at other trophic levels. (Correll 1978; Wolanski 2007). Intertidal mudflats are a dominant habitat in many estuarine systems often covering a considerable part of their area. They have long been recognised as a key habitat for the estuarine food web because of their disproportionately high productivity in comparison with subtidal areas (França *et al*. 2009). Coastal waders depend on intertidal areas for their survival as they feed on macrobenthic invertebrates buried in the sediment, which only become available during low water. The most common prey items for waders in temperate estuaries are bivalves (Mollusca: Bivalvia), mudsnails (Mollusca: Gastropoda), polychaete worms (Annelida: Polychaeta) and crustaceans (Arthropoda: Crustacea) (Van the Kam *et al.* 2004). In order to take advantage of all these prey items, waders exhibit numerous adaptations to forage in soft sediments. For example, Scolopacidae species (particularly genus *Limosa* and *Numenius*) have long bills that allow them to catch prey living deep in the sediment column; plovers (Charadriidae) have large eyes which allow them to search for food during both diurnal and nocturnal low-tides (Mcneill *et al*. 1992); some have heavily muscled stomachs (as knots *Calidris canutus* and purple sandpipers *Calidris maritima*) which allow them to efficiently crush mollusc shells (Piersma *et al.* 1993). Beside these features waders present a large amount of variation in bill morphology (Durell 2000), which allows them to exploit several different niches.

In some sexually dimorphic species the sexes segregate, with each having a distinct diet (Alves *et al.* 2013). In order to exploit their prey items and to avoid competition waders also diverge in the strategy used to search and capture prey. Plovers tend to perceive their prey by sight, whilst Scolopacidae species mostly use tactile cues (Piersma *et al*. 1998). Avocets (genus *Recurvirostra*) employ a different strategy, consisting of sweeping their bill in the sediment surface to acquire small prey items. Although each species tends to adopt a particular type of foraging strategy, they can switch feeding behaviour in response to environmental conditions (Mcneill *et al*. 1992; Lourenço *et al*. 2008).

Estuarine sediment flats are highly dynamic environments where accessibility to foraging grounds is continuously changing due to the tide movement. This can have impacts on the distribution and behaviour of waders, since they are limited to the exposure period of the mudflats to acquire food (Burger *et al*. 1977; Connors *et al*. 1981; Folmer *et al*. 2010). Within an estuary, the exposure period of the flats can differ, so waders move from one area to another in order to maximize foraging opportunities. On the feeding grounds, the distribution of waders is largely determined by the distribution of food, the substrate type and the distance from feeding areas to roosting sites (Zwarts & Wanink 1993; Dias *et al.* 2006). Species differ in their response to this periodical change in flats availability, whilst some concentrate their feeding effort near the tidal line, others tend to arrive to their foraging grounds well after the tidal passage (Burger *et al*. 1977; Connors *et al*. 1981; Folmer *et al*. 2010; Evans & Harris 1994).

As the tidal cycle constrains the time available for feeding, some species are only able to match their energetic requirements by feeding in alternative habitats during high tide, such as saltpans (Velasquez & Hockey 1992; Masero *et al*. 2000). In fact, waders foraging in intertidal habitats sustain intake rates at high levels in order to fulfil their daily energetic demands, which are amongst the highest found in birds (Piersma 2002; Rogers *et al*. 2006).

1.2 *Migrating and wintering waders in Southwest Europe*

Waders perform some of the longest migratory flights amongst all birds and despite the relatively narrow latitudinal span in breeding distribution, most species show extensive wintering ranges and along their migratory routes they use numerous sites for refuelling, termed "stopover areas". Migration stopover sites provide a crucial link between wintering and breeding areas. Food attained at stopovers provides energy for continued migratory flight and nutritional reserves that may be essential for successful reproduction upon arrival at the breeding grounds in Spring (Lourenço *et al*. 2010; Alves *et al*. 2012). Coastal wetlands provide abundant food for thousands of migratory waders (Farmer & Parent 1997).

Several wader species are long-distance migrants, undertaking some of the most exceptional journeys of any bird species. Most undertake annual migrations from their breeding grounds, usually located in high Arctic tundra, to the wintering quarters located in the southern limits of Western Europe, Australasia, Africa and South America making several stopovers during their journey. Others, like the bar-tailed godwits *Limosa lapponica baueri*, are able to perform a nonstop flight of more than 11 000 km, by far the longest ever recorded in birds (Gill *et al*. 2005). In these journeys between breeding and wintering areas waders usually follow species-specific migration routes, which together with their breeding and wintering areas are designated flyways (IWSG 1992). There are ten major flyways currently recognized, with waders in Western Europe belonging to the East Atlantic Flyway (Van the Kam *et al*. 2004). The East Atlantic flyway (EAF, Figure 1) comprises breeding areas from Siberia, Northern Europe and Russia, Iceland, Greenland and Northeast Canada and wintering areas in the Atlantic and West Mediterranean coasts of Europe and West Africa (Boere & Stroud 2006).

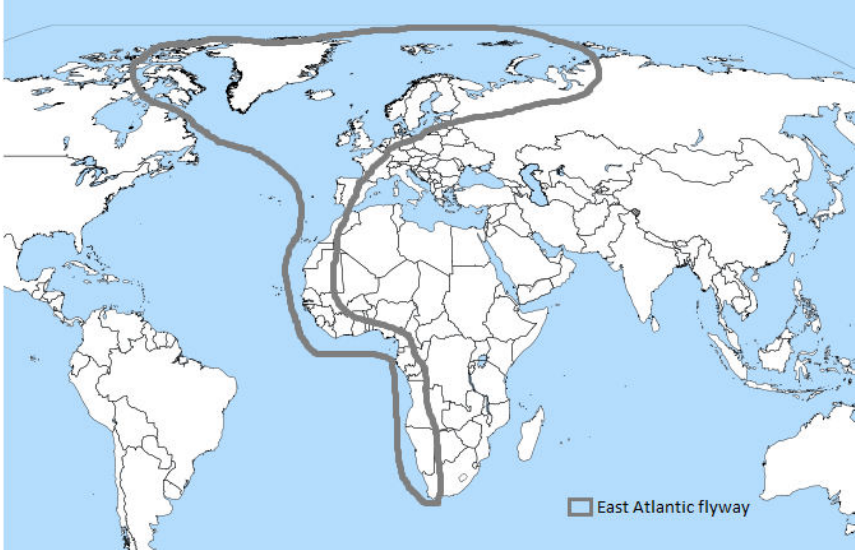

Figure 1. The East Atlantic flyway (adapted from Boere & Stroud 2006).

The wetlands of the East Atlantic flyway provide wintering areas for almost 7.5 millions waders (Pérez-Hurtado & Hortas 1992) and the migratory behaviour of these species is quite diverse. Several species go as far as West and South Europe during winter, but just about as many winter in the tropics (Boere & Stroud 2006). Some species display wide winter distribution ranges, as is the case of the sanderling (*Calidris alba*), which winters from Scotland to South Africa (Van the Kam *et al*. 2004). Wintering waders are relative scarce in the far north of Europe (e.g. northern Scandinavia) as low temperatures in winter promote ice formation on the sediments making it difficult if not impossible for waders to access their food. As an example, the Eurasian oystercatcher *Haematopus ostralegus* is a wader with wide breeding and wintering ranges, distributed along the estuaries and coasts of Europe in which all populations partly share the same wintering grounds, particularly in the Wadden Sea, in Netherlands (Van the Kam *et al.* 2004). Both resident and migrant birds can suffer from cold spells that reduce feeding opportunities inducing massive mortality. Although all populations are commonly faithful to their wintering areas they can move long distances in order to escape cold weather (Duriez *et al*. 2012).

In Southwest Europe there is quite a very different situation as the coasts are filled with hundreds of thousands of wintering waders throughout the winter. These coasts are ice-free and thus tidal waters uncover large expansions of suitable sand- and mudflats.

Around the world, almost half of the wader populations are declining (48%), whilst only 16% of populations are increasing (Delany *et al.* 2009). The reasons for such widespread decline are diverse, but they are mostly caused by loss or degradation of breeding sites, and notably loss of critical stopover and wintering habitats (Zockler *et al*. 2003; Stroud *et al*. 2006). For instance, in the Wadden Sea, the unsustainable levels of industrial shellfishing led to the redistribution of birds from the high quality feeding areas, to less favorable feeding habitats (Van the Kam *et al.* 2004). Declines in the biogeographical populations of long-distance migrant waders have occurred and are ongoing (Davidson 2003). At a global scale, anthropogenic habitats such as rice fields, extensive aquaculture ponds and saltpans may play a significant role as buffer areas against the loss of natural coastal habitats for declining wader populations (Masero 2003; Zwarts *et al.* 2009).

As most migratory taxa, waders have to cope with the challenge of finding food in a variety of habitats, enduring dramatically different environmental conditions. Feeding resources, in particular, show high variability in composition and availability across the latitudinal gradient of breeding, stopover and wintering areas (Piersma *et al*. 1993). In estuarine and coastal wetlands, prey abundance and availability also varies seasonally, with prey biomass usually peaking during the warmer periods of the year (Scheiffarth & Nehls 1997). In order to respond to these rather short term variations in prey abundance and accessibility, waders generally show a strong behavioural plasticity, allowing them to explore a wide range of feeding resources throughout the annual cycle (Beninger *et al*. 2011).

1.3 ***Ria de Aveiro and its importance for wintering waders***

The Ria de Aveiro (400 38'N, 080 45' W) is a mesotidal estuarine system, with considerable regional and national economic importance (port facilities, industries, aquaculture, salt production, fishing). In addition, it also supports artisanal fishery, shellfish collecting and sport fishing activities. With respect to environmental quality, Ria de Aveiro has a moderate degree of eutrophication and also moderate overall human influence in comparison to other estuarine systems in Portugal (Silva 2010). The implementation of EU environmental policies has aided in reducing anthropogenic sources and activities (Silva 2010).

The Ria extends for 45 Km along the west coast of Portugal from Ovar to Mira. The total area of Ria which is covered at high tides varies from 83 Km^2 in spring tides to 66 Km^2 in neap tides (Dias *et al*. 1999). The average river flow tributary to the Ria is 40 m^3/s, corresponding to a volume of 1.8×10^6 m^3. The river system from Ria de Aveiro is dominated by Vouga river, which delivers the lagoon an average annual flow of 25 m^3/s. The river Antuã submits an annual average flow of only 2 m^3/s (Dias *et al*. 1999). The other watercourses flowing into this lagoon are relatively small in length or in flow. During the rainy season the freshwater flow can reach values in the order of 820 m^3/s (ARH Centro, 2011). Ria de Aveiro wetland has one of the largest areas of contiguous salt marsh in Portugal and one of the largest in Europe and hosts important resident and wintering population of waders (Silva 2010).

Ria de Aveiro is a major wetland regarding the number of wintering species and is also relevant in the Iberian context, supporting more than 1% of the wintering European population for several waders (Morgado *et al*. 2009). The most abundant waders in Ria de Aveiro are *Calidris alpina* and *Charadrius hiaticula* which combined make roughly 80% of the total waders present. Of the remaining waders species, several compose 1 to 3% of the total wintering numbers, such as *Pluvialis squatarola*, *Limosa limosa*, *Tringa totanus*, *Recurvirostra avosetta* and *Calidris alba* (Morgado *et al*. 2009). The Ria de Aveiro is one of the most important ecological coastal wetlands in Portugal particularly for the conservation of migratory waders, functioning as an important wintering site for many species. Application of the EU Bird Directive granted the Special Protection Zone (PTZPE0004) status, with inclusion in the Natura 2000 Network (Rodrigues *et al.* 2011).

In Ria de Aveiro, it is important to highlight the significance of the saltpan areas for waders. Although an artificial habitat, it homes a very important percentage of the total number of waders of the Ria, mainly operating as a roosting habitat during the high tide (Velasquez & Hockey 1992; Pérez-Hurtado & Hortas 1992; Masero 2003; Morgado *et al*. 2009).

2. The use of saltpans under distinct regimens by wintering waders

2.1Introduction

Estuarine intertidal areas often support a large and diverse macrozoobenthic fauna and are the main foraging habitats for waders during the non-breeding season. However, throughout the last century, these habitats have been altered and considerably reduced by anthropogenic activities (Picado *et al*. 2010; Sutherland *et al*. 2012). As a consequence, the density of birds on the remaining areas has tended to increase, potentially increasing also the impact of shorebirds on the remaining food supplies as well as the interference between foraging birds (Stillman 2003; Goss-Custard *et al.* 2006).

Estuarine sediment flats are essential foraging areas for waders, but their use is constrained by the movements of tides. In this cyclic environment, the sediment exposure period varies considerably with the descending tidal line creating suitable conditions for waders to capture their prey only to cover the sediments once again after the turn of the tide. In these wetlands, the feeding rhythms of birds are partly determined by the tidal cycle, which causes predictable temporal and spatial changes in their foraging environment (Burger *et al.* 1977; Fleischer 1983). In general, twice a day wader feeding grounds progressively expand to the lower reaches of intertidal flats during ebbing tide, and contract to upper areas during the rising tide forcing waders to move into high tide roosting areas, such as salt marshes and saltpans.

Worldwide, saltpans act as roosting and complementary feeding areas, especially for small waders (Masero *et al.* 2000; Múrias *et al.* 2002; Sripanomyom *et al.* 2011) therefore buffering the degradation and ongoing reclamation of natural intertidal habitats (Masero 2003). Nevertheless, saltpans are frequently also used by feeding waders during low tide (Rufino *et al.* 1984; Masero *et al.* 2000; Masero & Perez-Hurtado 2001; Warnock *et al.* 2002). Saltpans are favoured high-tide roost habitats for several reasons: the large expanses of water facilitate taking flight and predator avoidance and the shallow, sheltered impoundments create a favourable microclimate for roosting (Warnock & Takekawa 1996). Despite tidal mudflats being the prime foraging habitat for waders the lack of nearby high-tide roost sites is known to constrain wader ability to exploit distant mudflats (Dias *et al.* 2006). Therefore, serving as foraging and roosting areas during high tide, saltpans help maintain high densities of shorebirds on mudflats (Masero *et al.* 2000).

Although traditional saltpans are well known to operate as beneficial supra-tidal habitats for waders (Fonseca *et al.* 2004), salt extraction has gradually declined over the last century and only relatively few saltpans remain active in Europe. Most have either been totally abandoned and the remaining ones had their tanks converted into aquaculture tanks. However, converted tanks are rarely suited to high yielding aquaculture and many have also been abandoned. The decreasing use of saltpans for active salt extraction is likely to impact waders that traditionally used these tanks as high-tide roosts. But other regimens might also be favourable, if for instances, abandoned saltpans become tidal areas due to the influx of water via destructed walls and/or sluice gates.

From a peak of 500 active saltpans in the 15th century at Ria the Aveiro, this number has decreased considerably and only eight remain currently active (Silva 2010). Most traditional saltpans are now either abandoned or have been converted to aquaculture tanks for fish or shrimp production, due to the low profitability on the saline sector. These aquaculture tanks result from the flooding of traditional saltpans tanks often with high water levels suitable only to a few bird species. But, these tanks are also regularly emptied to allow extraction of fish or shrimps unravelling high densities of macro benthos which become accessible to waders. The lack of maintenance of inactive saltpans results in the destruction of their protective walls and/or sluice gates by the strong currents, tides and even by vessel's wake waves. This destruction results in a significant increase of flooded area which also increases the current velocities in the adjacent channels and lagoon tidal prism (Picado *et al*. 2010), resulting in a positive feedback quickly accelerating the destruction rate of the remaining walls. However, in these inactive and destructed saltpans tidal waters gradually deposit sediments which are likely to be colonized by macrobenthos, potentially creating new tidal foraging areas for waders in the estuarine mosaic, during low tide.

In order to be attractive to waders, saltpans require an active ecological management. The general aim of ecological management is to provide the birds with food, protection and suitable nesting sites. It is partly a question of managing the water levels to prevent the nests from being flooded and the pools from drying out (Rodrigues *et al.* 2011). In this study we explore how wintering waders use saltpan tanks under distinct management regimens. We aim to establish which saltpan regimen is most favoured by waders across the tidal cycle and provide recommendations towards the conservation role that saltpans can have for wader species.

2.2 ***Methods***

2.2.1 Study area

Aveiro saltpans extend over the municipalities of Aveiro (Glória, Aradas, Vera-Cruz e Esgueira) and Ílhavo (S. Salvador), but currently active saltpans are located exclusively in Aveiro municipality. In 1956 the saltpans in Ria de Aveiro encompassed 1500 ha of production area. By 2007 this area was reduced to 1152 ha, but only ca. 20% of that were used for salt extraction due to the construction of road infrastructures (Multiaveiro 2007), resulting in five groups of saltpans (Fig. 2): Grupo do Norte (61 saltpans); Grupo do Mar (52 saltpans); Grupo do Monte Farinha (8 saltpans); Grupo de S. Roque (63) and Grupo do Sul (68) (Project Interreg IIIB Sal 2004-2007). The Aveiro saltpans usage regimen has undergone several changes over the most recent years with a progressive reduction of salt production and increase usage for aquaculture or complete abandonment.

Figure 2. Map and status of Ria de Aveiro saltpans in the vicinities of the urban area (adapted from Silva 2010). Inset shows the 9 selected salt-pans for this study according to their regimen: Inactive with shattered walls (1,2 and 57); Active aquaculture (11,15 and 56) and Active saltpan (12, 18 and 55).

For this study 9 representative tanks, 3 under each of the following regimes were selected, covering on average similar areas: saltpans (average area= 5.0 ha ± 0.2 SE; total area = 15.0 ha) - active saltpans managed for salt extraction; aquaculture (average area = 4.5 ha ± 0.9 SE; total area = 13.6 ha) - tanks traditionally used for salt production, currently converted into fish production; inactive (average area = 4.1 ha ±1 SE; total area = 12.2 ha)- abandoned saltpans tanks subjected to tidal waters as walls and/or sluice gates have been destroyed. These regimens differ greatly allowing comparison of how these are used by waders providing an understanding of how waders use these anthropogenic habitats throughout the current cycle of tank conversion or abandonment. The three regimes also reflect all the conditions available to waders wintering throughout the Ria de Aveiro larger saltpan complex.

2.2.2 Bird surveys

Surveys were carried from November 2014 to March 2015 (with the exception of January) and for each tank the total number of waders of each species was quantified, as well as the number of individuals displaying one of the following behaviours: feeding, roosting, preening & vigilant. As flamingos (*Phoenicopterus roseus*) have similar prey types as waders and often use saltpans, this specie was also included in the surveys and will henceforward be treated as a "wader".

Surveys were made once/twice every week with two counts made on the same day for each of the 9 tanks, during the twelve hour tide cycle: one during high tide and another one during low tide, when the weather was favourable. Each survey was done with at least one day interval and no counts were made in January. Counts were made at different tide times on each tank so that the entire tidal cycle was surveyed and each count was classified as high tide or low tide when within 3 hours of high or low water peak, respectively. Count time was also converted into minutes to/from high or low water peak. All counts were made with the help of binoculars and a telescope.

2.2.3 Data Analysis

We firstly checked for differences between months for each tank regimen (for low tide and high tide counts) using a Kurskal-Wallis test, as count data was not normally distributed.

To test for the effect of regimen for each period of tide (high and low) on bird abundance we used a second Kurskal-Wallis test and significant differences were then explored with a post-hoc Dunn test applying Bonferroni correction. We then estimated Shannon's diversity index which accounts for both abundance and evenness of species, to explore which regimen holds higher diversity.

We also checked how different sized waders used the 3 regimes during high or low tide, for foraging and roosting. To do so, bird species were grouped by their size, quantified as exposed leg length according to Ntiamoa-Baidu *et al.* (2008): small shorebirds (< 45 mm) resulting in 8 species; medium shorebirds (71-86 mm) 6 species; large shorebirds (111-174 mm) 3 species; and waterbirds (>200 mm, swimmers or divers) 1 species (Table A1).

We tested if birds use each regimen similarly throughout the tidal cycle by constructing two generalized linear models, one for high tide and another for low tide. Predictors were regimen and minutes to/from high or low water peak. Here we considered counts from 3 hours before tidal peak (when the tidal flats are mostly uncovered at low water and mostly covered at high water) up to 6 hours after peak (when the tide shifts from low to high water or vice-versa). We used poison error distribution to account for bias on our count data and log link function. All data was analysed in R (version 3.2.2).

2.3 **Results**

A total of 17 surveys were done on each regimen during high tide, but during low tide fewer surveys were possible: active saltpan, 16; aquaculture tanks, 14 and inactive, 15. A total of 17 waders species were observed during the surveys on the 9 different focal tanks. Total counts for each species ranged from one individual, the Ruff (*Philomachus pugnax*) to 3361 individuals for the Dunlin (*Calidris alpina*). Active saltpans and aquaculture had maximum abundances of 2686 and 4028 individuals respectively, whereas inactive tanks had a maximum of only 922 individuals.

Table 1. Results of Kruskal-Wallis test on bird abundance between months, on each tide period for each regimen.

	H	df	p
Low tide			
Saltpan	3.024	3	0.388
Acquaculture	1.259	3	0.739
Inactive	2.104	3	0.349
High tide			
Saltpan	3.208	3	0.361
Acquaculture	1.398	3	0.706
Inactive	5.185	3	0.121

There were no significant differences in bird abundance between months for any of the regimens on either low or high tide (Table 1), hence values were averaged across the non-breeding season for all subsequent analysis.

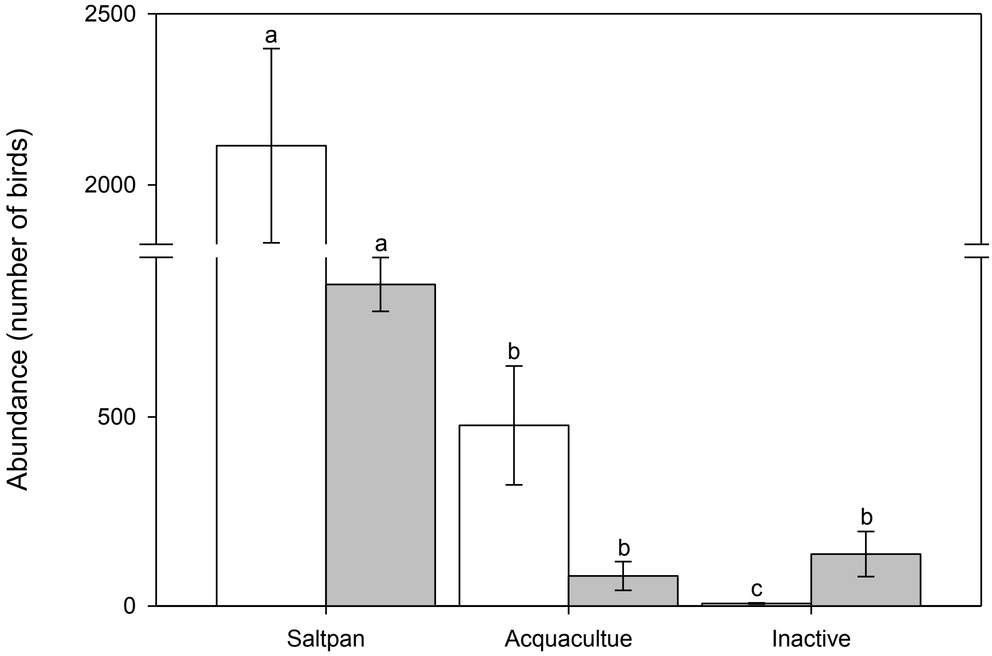

Figure 3. Average (±SE) number of wintering birds during high tide (white) and low tide (grey) using tanks under different regimens. Different letters show significant differences between regimens within each tidal stage from Dunn post-hoc test.

On both high and low tide, significantly higher numbers of birds used active saltpans (Figure 3, Table 2). During low tide, no significant differences were found between aquaculture and inactive saltpans, but during high tide a higher abundance was found in aquaculture and very few birds used inactive saltpans.

Table 2. Results of Kruskal-Wallis testing differences on wader abundance across regimens (see Figure 3 for graphical representation).

	H	df	p
Low tide	24.14	2	**<0.001**
High tide	33.6	2	**<0.001**

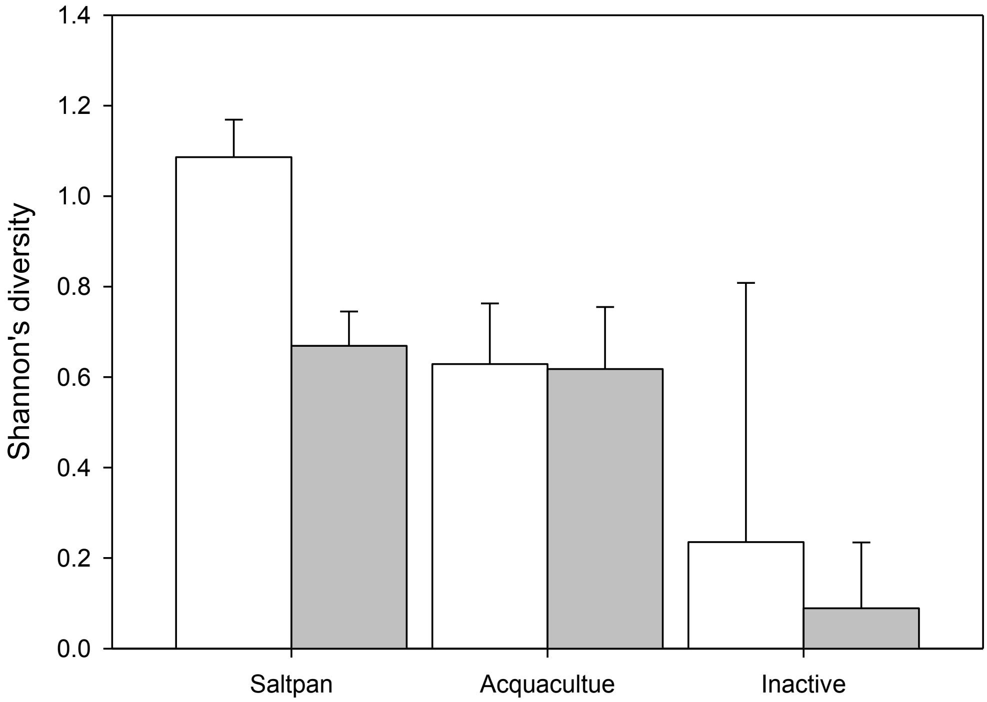

Figure 4. Average (±SE) Shannon's diversity index for wader species during high tide (white) and low tide (grey) using tanks under different management regimens.

Active saltpans have the highest levels of Shannon's diversity overall and also during high and low tide, with a similar value achieved on aquaculture tanks during low tide (Figure 4). The lowest diversity levels were recorded in inactive tanks, although during high tide it shows considerable variation.

The majority of waders use active saltpans for roosting, both during low (53.5% ± 6.6 SE) and high tide (67.0% ± 4.4 SE; Figure 5). However, both aquaculture and inactive tanks are mainly used for foraging in any tidal stage (> 73.5% in all cases). Some waders also forage on active saltpans (low tide - 35.3% ± 6.3 SE; high tide -28.2 % ± 4.6 SE) with foraging being consistently higher during low tide within the same regimen (Figure 5).

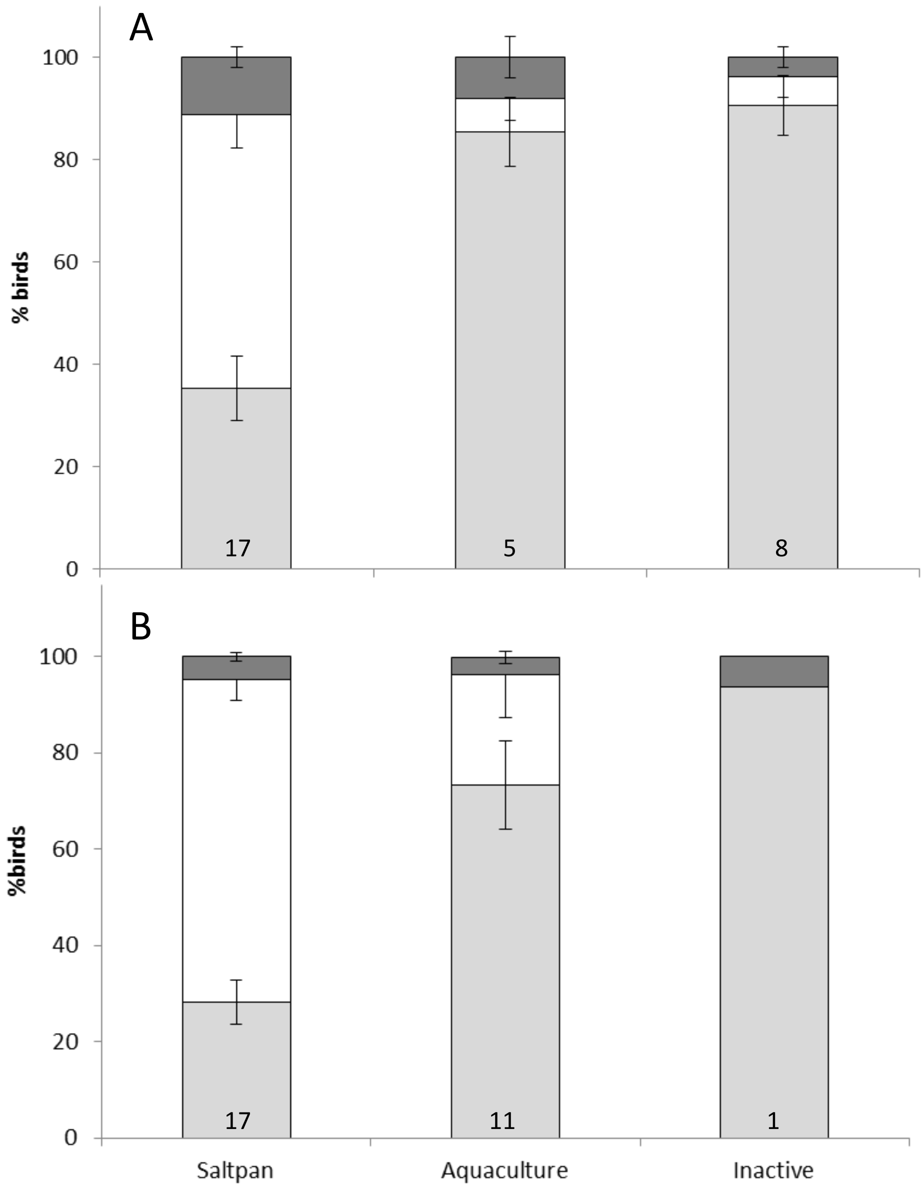

Figure 5. Average percentage of birds foraging (light grey), roosting (white) and preening or vigilant (dark grey), during low tide (A) and high tide (B). Only surveys with more than 30 individuals recorded were considered. Sample size given inside each bar.

Different sized species also differ in the way they use the tanks (Fig. 6). Whereas the majority of small and medium sized waders used all regimens for foraging (with the exception of active saltpans during high tide for small waders and of inactive saltpans for medium size waders, when they mostly roost), large waders use primarily active saltpans for roosting during both high and low tide periods using aquaculture and inactive tanks mostly for foraging.

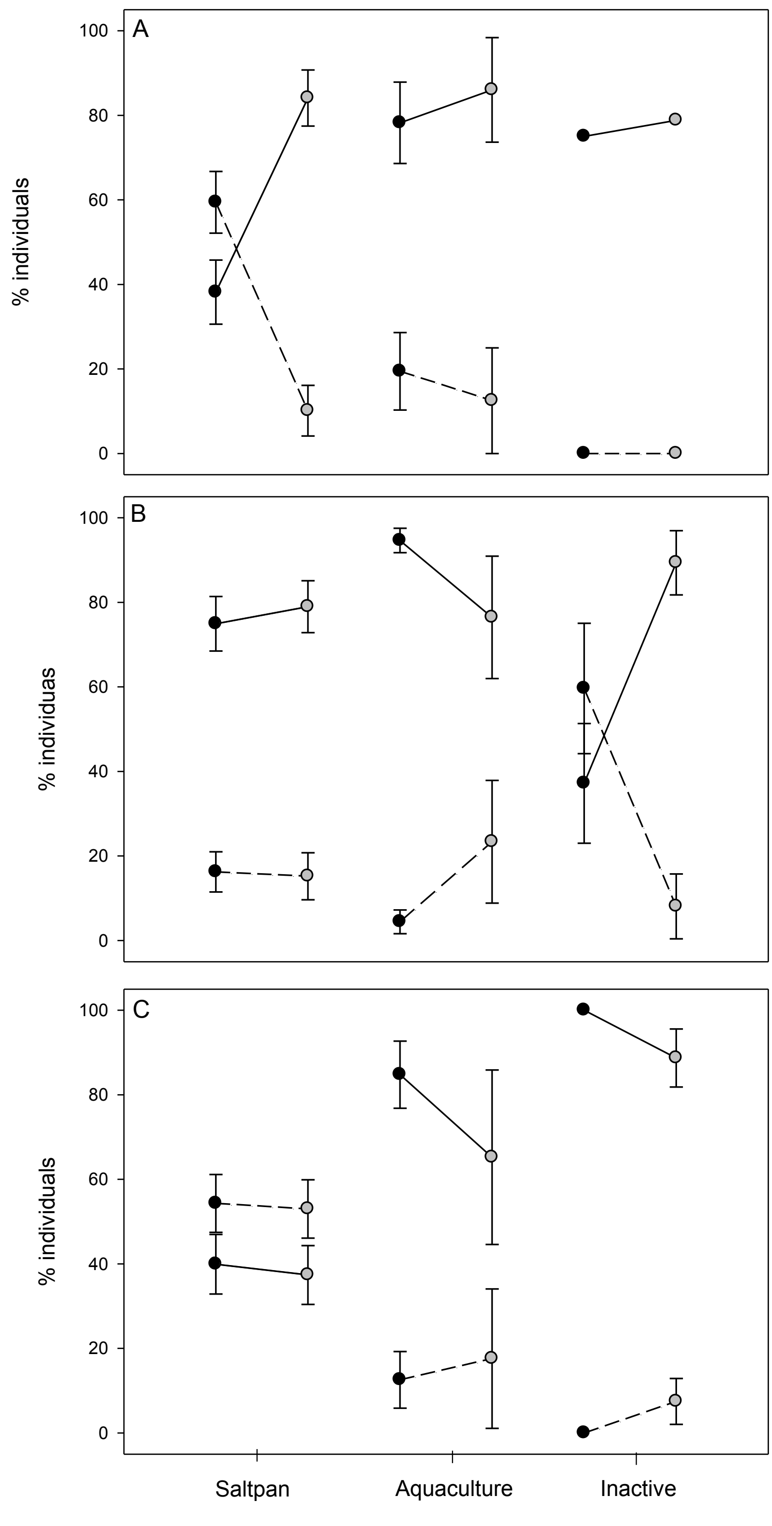

Figure 6. Average percentage (± SE) of small (A), medium (B) and large (C) sized waders foraging (straight line) or roosting (dashed lines) during high tide (black circles) and low tide (grey circles) across different management regimens.

Table 3. Results of GLM tests on the variation of bird abundance from low to high tide and vice versa (time) and t regimen (type).

	Df	Deviance	Residual Df	Residual Deviance	P
Low to high tide					
time	1	64161	91	115744	**< 0.05**
type	3	89757	88	25987	**< 0.05**
time*type	2	496	86	25490	**< 0.05**
High to low tide					
time	1	79992	92	492609	**< 0.05**
type	3	429100	89	63509	**< 0.05**
time*type	2	143	87	63366	**< 0.05**

The number of waders varies throughout the tidal cycle and across regimen, both during low and high tide (Table 3). Wader abundance increases significantly from low to high tide on all regimens (Figure 7, Table 4). Conversely, it decreases from high tide to low on active saltpans and aquaculture regimens and increases slightly on inactive tanks.

Table 4. Parameter estimates and regimen specific results from GLMs presented in table 3.

	Intercept	Error	Slope	Error	p
Low to high tide					
Saltpan	5.3580	0.0115	0.0042	0.0001	**< 0.05**
Acquaculture	3.0630	0.0522	0.0095	0.0003	**< 0.05**
Inactive	4.4289	0.0322	0.0022	0.0004	**< 0.05**
High to low tide					
Saltpan	6.6910	0.0057	-0.0024	0.0001	**< 0.05**
Acquaculture	5.9486	0.0124	-0.0015	0.0001	**< 0.05**
Inactive	1.4810	0.1534	0.0046	0.0008	**< 0.05**

*2.4**Discussion***

The number of waders using Ria de Aveiro confirms the importance of this wetland as a wintering site for these birds. Besides being relevant in the Iberian context, this wetland supports more than 1% of European wintering populations of several wader species (Morgado *et al.* 2009). Relevant to the capacity of this wetland to host so many individuals during winter are its saltpans, which serve as shelter for a very important percentage of the total birds of the Ria despite being an anthropogenic habitat. This has already been highlighted by several authors, indicating the value of saltpans as a high tide roost for waders (Velasquez & Hockey 1992; Pérez-Hurtado *et al.* 1990; Masero 2003).

Our results demonstrated that it is indeed during high tide that active saltpans hold the highest abundance of birds and diversity of species in Ria de Aveiro. But, its importance during the low tide cannot be neglected, as the abundance of waders in saltpans is also the highest recorded amongst the three regimens. During high tide, aquaculture tanks hosted, on average significantly more waders than inactive saltpans but during low tide this difference was not apparent. It is therefore clear that active saltpans are favoured by most waders during any stage of tide, and although aquaculture tanks also support some individuals throughout the tidal cycle, inactive saltpans are only used during low tide. This is likely due to the fact that inactive saltpans are subjected to tidal waters and are therefore submerged during high tide. Conversely, during low tide these areas act almost as "restored tidal flats" providing food resources to waders. During low tide, almost all waders using inactive saltpans are actively foraging. Masero *et al.* (1999) reported that the average value of biomass in the saltpans is poorer than in intertidal zones, and if these inactive saltpans become re-naturalized after human intervention, these might indeed have higher biomass abundance and thus be more attractive than active saltpans to foraging waders.

Interestingly, active saltpans are mostly used by roosting waders at any stage of tide demonstrating its role as a versatile habitat where birds take refuge and forage (Velasquez & Hockey 1992; Masero 2003). This is mostly driven by large sized waders, and to a lesser extent by small sized species during high tide. In aquaculture tanks foraging is the most common behaviour across all sizes and often with higher or similar proportions to active saltpans. This is distinct from the findings by Pérez-Hurtado & Hortas (1992) which found that active saltpans hosted a higher proportion of feeding birds than fish-farms, both at high and low tide. The same authors noted, however, that the number of waders that feed in fish-farms increases considerably in the days following the emptying of the tanks. The difference in our findings could be due to the fact that in several occasions our counts of aquaculture tanks occurred shortly after emptying of those tanks. These events create a short-term bonanza of food that is readily exploited by foraging waders.

The abundance of waders also varies with respect to the phase of the tidal cycle and differently so across the distinct management regimens. From low to high tide abundance increases significantly on all tanks, indicating that waders use these tanks mostly after foraging elsewhere, most likely on the tidal flats. The variation in abundance on all three regimens from high to low tide, shows that birds quickly leave the active saltpans and aquaculture tanks which can be explained by waders dispersing as quickly as possible to a wider area, potentially to minimize competition for food resources. By leaving those tanks, waders can occupy much larger foraging areas in which inactive tanks are included, hence the increase in abundance during this phase in inactive tanks.

3. Conclusions

A large number of human activities are known to impact the intertidal areas where most waders feed, such as - development of coastal wetlands for industry, infrastructure and aquaculture; habitat loss and modification, agricultural intensification, increasing predation pressure, pollution, hunting and other forms of direct human disturbance (Evans *et al*. 1979; Piersma *et al.* 2001; Zockler *et al*. 2003). The decline of waterbird populations throughout all regions does suggest as underlying global phenomena. But among the many causes of population decline often considered, the direct loss of habitat is frequently suspected (e.g Morrison *et al*. 2001; Johnston 2001). Other global phenomena such as eutrophication, with nutrient enrichment of wader habitats have also been considered (Zockler 2002). No doubt a complex matrix of many inter-correlated factors impacts wader populations. Therefore, sound management of estuarine areas requires detailed mapping of critical sites for waders and other biota, to support decisions concerning further developments.

In many estuaries and South-European coasts, saltpans are the most important man-made habitats for migratory waders (Masero 2003). These manmade wetlands are also of great interest because their ecological function exceeds their physical boundaries and integrates an important global network of wetland systems (López *et al.* 2009). Saltpans can be considered as particular ecosystems, where human intervention is tolerated and even necessary to maintain its characteristics, preserving the landscape and protecting the environment, while simultaneously generating economical profit (Multiaveiro 2007). Saltpans are thus integrated ecosystems that can effectively produce an economically viable product while serving a critical role in nature conservation and biodiversity (Korovessis & Lekkas 1999).

Given their particular characteristics the saltpans in the Ria de Aveiro are regularly occupied by more than 20,000 birds, mainly waterbirds, some of them protected by European Directives (Rodrigues *et al.* 2011). The ongoing abandonment of the Aveiro saltpans is of special concern, as the decline in artisanal salt production has led to increased saltpan degradation, with a consequent loss of cultural, landscape and ecological values (Crisman *et al.* 2009).

Many abandoned saltpans have been transformed into extensive or semi-intensive fish or shrimp farming units (e.g. in Spain, Portugal, Italy and Greece). Recent recovery of saltpan walls and sluice gates in Aveiro has been exclusively aimed at developing aquaculture tanks. Exceptions to this rule are two saltpans, one owned by the University of Aveiro (Santiago) and another owned by Municipality of Aveiro (Troncalhada), which were recovered and are maintained for the production of salt (Martins 2005).

In the Ria de Aveiro and during the 80's and 90's, semi-intensive fish-cultures replaced salt businesses at a rate of 13 saltpans per year. Reasons for this shift were financial incentives provided to aquaculture and the fact that fish offers a permanent activity as opposed to the seasonal salt production which only operates during summer (Multiaveiro 2007). Aquaculture on a large scale leads to the impoverishment of the saltpan landscape. It also often causes adverse environmental impacts by reducing the emerged area available for wader and other species, increasing organic load and nutrient concentrations, diminishing dissolved oxygen levels and introducing hormones, antibiotics, pesticides and various compounds that affect the food chain (Rodrigues *et al.* 2011).

The maintenance of the saltpan infrastructure, namely of the walls, sluices and channels, is essential to guaranty the sustainability of saline ecosystems and can be more easily guarantied if the salt production is maintained (Rodrigues *et al.* 2011). Saltpans have been regulated by human activity for millennia, and structurally, they comprise a series of interconnected shallow hypersaline ponds. The flow of water through these ponds creates a stable gradient of physicochemical characteristics, mainly salinity (Britton & Johnson 1987; López *et al*. 2009). The spatial organization of the ponds in the saltpans and of their different depths, necessary for the salt production process, favors a high degree of spatial heterogeneity and very productive microenvironments that are attractive to many primary and secondary consumers (Evagelopoulos *et al.* 2008; Hamdi *et al*. 2008).

Across the world, waterbirds use saltpans as sites of roosting, feeding and breeding (Velasquez & Hockey 1992; Batty 1992; Collazo 1995; Warnock & Takekawa 1996; Sadoul *et al.* 1998; López *et al.* 2009). The abundance, presence, or absence of waders has proven to be an effective indicator of a site's ecological condition and of environmental changes within them (Bradford *et al*. 1998).

In conclusion it is worth highlighting the importance of maintaining active saltpans as a measure of conservation for migratory waders. Saltpans proved to be an important habitat for these birds, which can minimize the losses occurring in their natural habitat. Although not fully replacing their natural environments, given than not all waders species used saltpans, these may be a supplement or even an alternative to a natural environment (Velasquez & Hockey 1992; Masero 2003). In fact, the waders differ in their usage of saltpans with some mostly using it as foraging site regardless of the tidal cycle, while others roosting in different percentages between high tide and low tide (e.g. small waders).

Conservation and management of these systems calls for the development of integrated methods aimed at understanding and assessing habitats and at defining and selecting ecological indicators related to species composition and diversity (López *et al*. 2009). The salt production process determines ecological partitions within the system. This ecological segregation is very important for conservation of these environments because spatial heterogeneity can provide species with a high diversity of habitats suitable for waders. Such habitats are link points of ecological connectivity. Thus, the management of these habitats should be done in an integrated way to cover the specific needs of the different species.

In wetlands such as the Ria de Aveiro, which lie along important migratory routes, it requires special care regarding the availability and quality habitats for migratory waders in order to try to reverse their declining population trends (Sanderson *et al.* 2006). The abandonment of tanks previously used for salt extraction or their conversion to other activities, such as aquaculture, appears to constitute a serious threat to the conservation of migratory waders.

4. References

Alves, J.A., Gunnarsson, T., Potts, P., Gélinaud, G., Sutherland, W., Gill, J., 2012. Overtaking on migration: Does longer distance migration always incur a penalty? *Oikos*, 121(3), pp.464–470.

Alves, J.A. Gunnarsson, T., Potts, P., Sutherland, W., Gill, J., 2013. Sex-biases in distribution and resource use at different spatial scales in a migratory shorebird. *Ecology and Evolution*, 3(4), pp.1079–1090.

Batty, L., 1992. The wader communities of a saline and an intertidal site on the Ria Formosa, Portugal. *wader study group Bull*, 66, pp.66–72.

Beck, M.W., Childers, D., Kenneth, H., Kenneth, A., Eggleston, D., Gilanders, B., Halpern, B., Hays, C., Hoshino, k., 2001. The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. *BioScience*, 51(8), p.633.

Beninger, P.G., Elner, R., Morançais, M., Decottignies, P., 2011. Downward trophic shift during breeding migration in the shorebird Calidris mauri (western sandpiper). *Marine Ecology Progress Series*, 428, pp.259–269.

Boere, G. & Stroud, D., 2006. The flyway concept: what it is and what it isn't. In G. C. B. C. A. G. & D. A. Stroud., ed. *Waterbirds around the world. A global overview of the conservation, management and research of the world's waterbird flyways*. The Stationery Office, Edinburgh, UK., pp. 40–47.

Bradford, D., Franson, S., Neale, A., Heggem, D., Miller, G., Canterbury, G., 1998. Bird species assemblagesas indicators of biological integrity in Great Basin rangeland. *Environmental Monitoring and Assessment*, (49), pp.1–22.

Britton, R.H. & Johnson, A.R., 1987. An ecological account of a Mediterranean salina: The Salin de Giraud, Camargue (S. France). *Biological Conservation*, 42(3), pp.185–230.

Burger, J., Marshall, A., Howe, D., Chase, D., 1977. Effects of Tide Cycles on Habitat Selection and Habitat Partitioning by Migrating Shorebirds. *American Ornithologists' Union*, 94(4), pp.743–758.

Collazo, J.A., 1995. Abundance and Distribution of Shorebirds At the Cabo Rojo Salt Flats, Puerto Rico. *Journal of Field Ornithology*, 66(3), pp.424–438.

Connors, P.G., Myers, J., Carolyn, S., Pitelka, F., 1981. Interhabitat movements by sanderlings in relation to foraging profitability and the tidal cycle. *Emerita*, (January), pp.49–64.

Correll, D., 1978. Estuarine productivity. *BioScience*, 28(10), pp.646–650.

Crisman, T.L., Takavakoglou, V. & Zalidis, G., 2009. Rehabilitation of Abandoned Saltworks to Maximize Conservation, Ecotourism and Water Treatment Potential. , 11(1), pp.24–31.

Davidson, N.C., 2003. Declines in East Atlantic wader populations: is the Wadden Sea the problem? *Wader Study Group Bulletin*, (101/102), pp.19–20.

Delany, S., Scott, D., Dodman, T., Straud, D., 2009. An Atlas of Wader Populations in At ica and Western Eurasia. *Wetlands International*.

Dias, J.M., Lopes, J.F. & Dekeyser, I., 1999. Hydrological characterisation of Ria de Aveiro, Portugal, in early summer. *Oceanologica Acta*, 22(5), pp.473–485.

Dias, M.A.F.P., 2008. *Factors affecting the use of estuarine areas by waders: implications for their conservation*. Universidade de Lisboa.

Dias, M.P., Granadeiro, J., Martins, R., Palmeirim, J., 2006. Low tide counts may give inaccurate estimates of habitat use; combining low and mid-tide counts yields better estimates. *Bird Study*, 53(March 2015), pp.32–38.

Durell, S.E., 2000. Individual feeding specialisation in shorebirds: population consequences and conservation implications. *Biological reviews of the Cambridge Philosophical Society*, 75(4), pp.503–518.

Duriez, O., Ens, B., Choquet, R., Pradel, R., Klaassen, M., 2012. Comparing the seasonal survival of resident and migratory oystercatchers: carry-over effects of habitat quality and weather conditions. *Oikos*, 121(6), pp.862–873.

Evagelopoulos, A., Koutsoubas, D., Basset, A., Pinna, M., Dimitriadis, C., Sangiorgio, F., Barbone, E., Maidanou, M., Koulouri, P., Dounas, C., 2008. Spatial and seasonal variability of the macrobenthic fauna in Mediterranean solar saltworks ecosystems. , 134(December 2007), pp.118–134.

Evans, P.R., Herdson, D., Knights, P., Pienkowski, M., 1979. Short-term effects of reclamation of part of Seal Sands, Teesmouth, on wintering waders and Shelduck - I. Shorebird diets, invertebrate densities, and the impact of predation on the invertebrates. *Oecologia*, 41(2), pp.183–206.

Evans, P.R. & Davidson, N.C., 1990. Migration Strategies and Tactics of Waders Breeding in Arctic and North Temperate Latitudes. *Bird Migration*, pp.387–398.

Evans, T. & Harris, S., 1994. Status and habitat use by American Avocets wintering at Humboldt Bay, California. *Condor*, 96(1), pp.178–189.

Farmer, A.H. & Parent, A.H., 1997. Effects of the landscape on shorebirds movements at spring migration stopovers. *The Condor*, 99(3), pp.698–707.

Fleischer, R.C., 1983. Relationships between tidal oscillations and Ruddy Turnstone flocking, foraging, and vigilance behavior. *The Condor*, 85(1), pp.22–29.

Folmer, E.O., Olff, H. & Piersma, T., 2010. How well do food distributions predict spatial distributions of shorebirds with different degrees of self-organization? *Journal of Animal Ecology*, pp.747–756.

Fonseca, V., Grade, N., Cancela, L., Fonseca, D., 2004. Patterns of association and habitat use by migrating shorebirds on intertidal mudflats and saltworks on the Tavira Estuary, Ria Formosa, southern Portugal. *Wader study group Bull*, pp.50–55.

França, S., Vinagre, C., Pardal, M., Cabral, H., 2009. Spatial and temporal patterns of benthic invertebrates in the Tagus estuary, Portugal: comparison between subtidal and an intertidal mudflat. *Scientia Marina*, 73(2), pp.307–318.

Gill, R.E., Piersma, T., Hufford, G., Servranckx, R., Riegen, A., 2005. Crossing the Ultimate Ecological Barrier: Evidence for an 11 000-Km-Long Nonstop Flight From Alaska To New Zealand and Eastern Australia By Bar-Tailed Godwits. *The Condor*, 107(1), p.1.

Goss-Custard, J.D., Triplet, P., Sueur, F., West, A., 2006. Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological*

Conservation, 127(1), pp.88–97.

Granadeiro, J., Andrade, J. & Palmeirim, J., 2004. Modelling the distribution of shorebirds in estuarine areas using generalised additive models. *Journal of Sea Research*, 52, pp.227–240.

Granadeiro, J.P., Dias, M., Martins, R., Palmeirim, J., 2006. Variation in numbers and behaviour of waders during the tidal cycle: implications for the use of estuarine sediment flats. *Acta Oecologica*, 29, pp.293–300.

Hamdi, N., Charfi, F. & Moali, A., 2008. Variation of the waterbird community relying to the Ichkeul National Park, Tunisia. , pp.417–424.

Hayman, P., Prater, T. & Marchand, J., 1991. *Shorebirds: An Identification Guide to the Waders of the World*, Houghton Mifflin Harcourt.

IWSG, 1992. *The Odessa Protocol on international co-operation on migratory flyway research and conservation*, Wader Study Group Bulletin, 65, 10–12.

Johnston, V., 2001. Arctic Shorebirds in North America. *Studies in Avian Biology*, (44), pp.3–34.

Van the Kam, J., 2004. *Shorebirds. An illustrated behavioural ecology* S. J. Moore, ed., KNNV, 2004.

Korovessis, N.A. & Lekkas, T.D., 1999. Solar saltworks production process evolution-wetland function. *Proceedings of the Post Conference Symposium SALTWORKS: Preserving Saline Coastal Ecosystems*, pp.11–30.

López, E., Aguilera, P., Schmitz, M., Castro, H., Pineda, F., 2009. Selection of ecological indicators for the conservation , management and monitoring of Mediterranean coastal salinas coastal salinas. *Environmental Monitoring and Assessment*, (December 2015).

Lourenço, P.M., Mandema, F., Hooijmeijer, J., Granadeiro, J., Piersma, T., 2010. Site selection and resource depletion in black-tailed godwits *Limosa l. limosa* eating rice during northward migration. *Journal of Animal Ecology*, 79(3), pp.522–528.

Lourenço, P.M., Silva, A., Santos, C., Miranda, A., Granadeiro, J., Palmeirim, J., 2008.

The energetic importance of night foraging for waders wintering in a temperate estuary. *Acta Oecologica*, 34(1), pp.122–129.

Martins, F., 2005. Haverá Vida sem Sal? Um futuro por contar... *I Seminário Internacional sobre o sal português - Instituto de História Moderna da Universidade do Porto*, pp.431–441.

Masero, J.A., Pérez-González, M., Basadre, M., Otero-Saavedra, M., 1999. Food supply for waders (Aves: Charadrii) in an estuarine area in the Bay of Cadiz (SW Iberian Peninsula). *Acta Oecologica*, 20(4), pp.429–434.

Masero, J.A., Pérez-Hurtado, A., Castro, M., Arroyo, G., 2000. Complementary Use of in Tertidal Mudflats and Adjacent Sal in As By Foraging Wader S. , (Velasquez 1992), pp.177–191.

Masero, J.A. & Perez-Hurtado, A., 2001. Importance of the Supratidal Habitats for Maintaining Overwintering Shorebird Populations: How Redshanks Use Tidal Mudflats and Adjacent Saltworks in Southern Europe. *The Condor*, 103(No 1), pp.21–30.

Masero, J.A., 2003. Assessing alternative anthropogenic habitats for conserving waterbirds: Salinas as buffer areas against the impact of natural habitat loss for shorebirds. *Biodiversity and Conservation*, 12(6), pp.1157–1173.

Mcneill, B.Y.R., Drapeau, P. & Goss-custard, J.D., 1992. Nocturnal Habits in Waterfowl. *Wildfowl*, (67), pp.381–419.

Morgado, R., Nobre, M., Ribeiro, A., Puga, J., Luís, A., 2009. A Importância do Salgado para a Gestão da Avifauna Limícola Invernante na Ria de Aveiro (Portugal). *Revista da Gestão Costeira Integrada*, 9(3), pp.79–93.

Morrisey, D., Skilleter, G., Ellis, J., Burns, B., Kemp, C., Burt, K., 2003. Differences in benthic fauna and sediment among mangrove (Avicennia marina var. australasica) stands of different ages in New Zealand. *Estuarine, Coastal and Shelf Science*, 56(3-4), pp.581–592.

Morrison, G., Butler, R., Beyersbergen, G., Donaldson, G., Gratto-Trevor, C., Hicklin, P., Ross, K., 2001. Declines in North American shorebird populations. *Wader Study Group Bulletin*, (94), pp.34–38.

Multiaveiro, 2007. Revitalização e Valorização Económica do Salgado de Aveiro. In *MULTIAVEIRO – Projectos de Formação e Investimentos, Lda.* pp. 17–56.

Múrias, T., Cabral, J., Lopes, R., Marques, J., Goss-Custard, J., 2002. Use of traditional salines by waders in the Mondego estuary (Portugal): a conservation perspective. *Ardeola*, 49(2), pp.223–240.

Ntiamoa-Baidu, Y., Piersma, T., Wiersma, P., Poot, M., Battley, P., Gordon, C., 2008. Water depth selection, daily feeding routines and diets of waterbirds in coastal lagoons in Ghana. *Ibis*, 140(1), pp.89–103.

Pérez-Hurtado, A., Hortas, F., Arroyo, G., Masero, J., 1990. Utilizacion De Salinas Y Cultivos Piscicolas Por Limicolas. *Ministerio de Medio Ambiente*, p.10.

Pérez-Hurtado, A. & Hortas, F., 1992. Cádiz Bay, South-West Spain as a potential amsar site: its importance for wintering waders. *wader study group Bull*, (72), pp.34–38.

Picado, A., Dias, J.M. & Fortunato, A.B., 2010. Tidal changes in estuarine systems induced by local geomorphologic modifications. *Continental Shelf Research*, 30, pp.1854–1864.

Piersma, T., Aelst, R., Kurk, K., Berkhoudt, H., Maas, L., 1998. A new pressure sensory mechanism for prey detection in birds: the use of principles of seabed dynamics? *Proceedings of the Royal Society B: Biological Sciences*, 265(1404), pp.1377–1383.

Piersma, T., 2002. Energetic bottlenecks and other design constraints in avian annual cycles. *Integrative and comparative biology*, 42(1), pp.51–67.

Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J., Dekker, R., Essink, K., 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. *Journal of Applied Ecology*, 38(5), pp.976–990.

Piersma, T., Koolhaas, A. & Dekinga, A., 1993. Interactions between stomach structure and diet choice in shorebirds. *Auk*, 110(3), pp.552–564.

Rodrigues, C., Bio, A., Amat, F., Vieira, N., 2011. Artisanal salt production in Aveiro/Portugal - An ecofriendly process. *Saline Systems*, 7(1), p.3.

Rogers, D.I., Piersma, T. & Hassell, C.J., 2006. Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological Conservation*, 133(2), pp.225–235.

Rufino, R., Araújo, A., Pina, J., Miranda, P., 1984. THe use of salinas by waders in the Algarve, South Portugal. *Wader Study Group Bulletin*, 42, pp.41–42.

Sadoul, N., Walmsley, J. & Charpentier, B., 1998. Salinas and nature conservation. *Wetland conservation*, 9, p.99.

Sanderson, F.J., Donald, P., Pain, D., Burfield, I., Van Bommel, F., 2006. Long-term population declines in Afro-Palearctic migrant birds. *Biological Conservation*, 131(1), pp.93–105.

Scheiffarth, G. & Nehls, G., 1997. Consumption of benthic fauna by carnivorous birds in the Wadden Sea. *Helgoländer Meeresuntersuchungen*, 51, pp.373–387.

Silva, A., 2010. *Estratégia para uma Gestão Sustentável do Salgado de Aveiro*. Universidade de Aveiro.

Silva, N., 2011. Critérios para a demarcação física do leito e da margem das águas de transição em sistemas lagunares, estuários e lagoas costeiras do Litoral Centro. In *ARH Centro*. pp. 18–34.

Sripanomyom, S., Round, P., Savini, T., Trisurat, Y., Gale, G., 2011. Traditional salt-pans hold major concentrations of overwintering shorebirds in Southeast Asia. *Biological Conservation*, 144(1), pp.526–537.

Stillman, R.A., 2003. Predicting wader mortality and body condition from optimal foraging behaviour. *Wader Study Group Bulletin*, 100(April), pp.192–196.

Stroud, D., Baker, A. & Blanco, D., 2006. The conservation and population status of the world's waders at the turn of the millennium. *Waterbirds around the world*, p.960.

Sutherland, W.J., Alves, J., Amano, T., Chang, C., Davidson, N., Max Filayson, C., Gill, J., Gill, R., González, P., Gunnarsson, T., Kleijn, D., Spray, C., Székely, T., Thompson, D., 2012. A horizon scanning assessment of current and potential future threats to migratory shorebirds. *Ibis*, 154(4), pp.663–679.

Velasquez, C.R. & Hockey, P.A.R., 1992. The importance of supratidal foraging habitats for waders at a south temperate estuary. *Ardea*, 80(2), pp.243–253.

Warnock, S. & Takekawa, J., 1996. Wintering site fidelity and movement patterns of Western Sandpipers Calidris mauri in the San Francisco Bay estuary. *Ibis*, (138), pp.160–167.

Warnock, N., Page, G., Ruhlen, T., Nur, N., Takekawa, J., Hanson, J., 2002. Management and conservation of San Francisco Bay salt ponds: effects of pond salinity, area, tide, and season on Pacific Flyway waterbirds. *Waterbirds*, 25(Special Publication 2), pp.79–92.

Wolanski, E., 2007. Estuarine Ecohydrology. In Elsevier Science, pp. 91–106.

Zockler, C., 2002. Declining Ruff Philomachus pugnax populations- a response to global warming? *Wader Study Group Bull*, (97), pp.19–29.

Zockler, C., Delany, S. & Hagemeijer, W., 2003. Wader populations are declining - how will we elucidate the reasons? *Wader Study Group Bulletin*, 100(April), pp.202–211.

Zwarts, L., Blomert, A. & Hupkes, R., 2009. Increase of Feeding Time in Waders Preparing for Spring Migration from the Banc D ' Arguin, Mauritania. *Ardea*, 78, pp.237–256.

Zwarts, L. & Wanink, J., 1993. How the Food Supply Harvestable By Waders in The Wadden Sea Depends On The Variation In Energy Density, Body Weight, Biomass, Burying Depth And Behaviour Of Tidal-Flat Invertebrates. *Netherlands Journal of Sea Research*, 31(4), pp.441–476.

Appendix I

Table A1. List of the grouped birds by exposed leg length.

Small Shorebirds	Medium Shorebirds	Large Shorebirds	Waterbirds
Calidris alpina	*Tringa totanus*	*Limosa limosa*	*Phoenicopterus roseus*
Charadrius hiaticula	*Philomachus pugnax*	*Himantopus himantopus*	
Calidris ferruginea	*Tringa erythropus*	*Recurvirostra avosetta*	
Calidris minuta	*Tringa nebularia*		
Calidris alba	*Pluvialis squatarola*		
Arenaria interpres	*Limosa lapponica*		
Calidris canutus			
Actitis hypoleucos			