Patterns of association and habitat use by migrating shorebirds on intertidal mudflats and saltworks on the Tavira Estuary, Ria Formosa, southern Portugal

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Patterns of association and habitat use were studied on intertidal mudflats and adjacent saltworks during spring and autumn migration in 1999 on the Tavira estuary, Ria Formosa, southern Portugal. Twenty of the thirty species studied, mainly Charadriiformes, winter in and/or migrate through Tavira. The species distribution patterns were highly influenced by habitat – mostly because of the vast diversity of habitats available such as intertidal mud, mud/sand flats and saltworks – and to a lesser degree by tide and month. Migrant species, all gregarious, were the most characteristic of the saltworks during low tide. Non-tidal habitats were used as alternative foraging sites at high tide in summer, but these were also the main foraging sites used during migration periods, significantly supporting several migrant shorebird populations. Overall, this study reinforces the idea that even small estuaries, like that at Tavira, play a crucial role for considerable numbers of shorebirds during migration.

INTRODUCTION

The past century has seen massive alteration and loss of natural intertidal habitats that are of prime importance to large numbers of migrant shorebirds during the nonbreeding season (Masero & Pérez-Hurtado 2001). However, worldwide, it has been shown that man-made and man-modified wetlands, such as saltworks, can provide alternative foraging and/or roosting habitats (Velasquez & Hockey 1991, Masero *et al.* 2000).

The relative importance of saltworks in relation to mudflats has been studied by various authors (Múrias *et al.* 1997, Masero *et al.* 2000, Masero & Pérez-Hurtado 2001) including Rufino *et al.* (1984) and Biljsma *et al.* (1985) who demonstrated the importance of the saltworks in Ria Formosa, Portugal, as feeding and/or roosting areas for shorebirds. Batty (1992) also studied the wader communities using a small saltpan site and a nearby intertidal site in Ria Formosa, but concluded that his study areas were too small in relation to the habitats they represent for broad conclusions to be drawn; nevertheless his results serve as good reference points for further work. Moreover there have been no studies of migrant shorebird communities of intertidal and saltwork habitats on the Ria Formosa during spring that can give us an accurate picture of the relative value of each habitat for shorebirds in that season.

If we consider communities of shorebirds instead of single species, we can identify those estuaries that support similar communities. This information can be used in further studies that allow us to map changes in community composition over time (Hill *et al.* 1993).

This study compares the use of natural intertidal mudflats and adjacent manmade supratidal saltworks during the pre- and post-breeding periods by shorebirds and other important waterbird populations. We present data on species associations and discuss possible causes, as well as distribution patterns of waterbirds on both intertidal mudflats and nearby saltworks at the Tavira estuary. We also explore the relative importance of these habitats for birds during April–August and consider management recommendations for the area studied, especially during spring migration.

METHODS

This study was conducted at the saltworks and nearby intertidal mudflats of Tavira (37°02'N 7°38'W), near the Gilão estuary, a part of the lagoon system of the Ria Formosa Natural Park, Algarve, southern Portugal. Ria Formosa is a tidal lagoon system, comprising a narrow formation of wetland habitats separated from the sea by a range of barrier islands (Marcelo & Cancela da Fonseca 1998). The saltworks study area comprises 132 ha divided into nine separate saltpan systems (Fig. 1) each of which includes three sets of pans (for storage, evaporation and crystallization) connected via sluices. They differ mainly in their salinity, vegetation and water levels. The salinity of the first (storage) ponds is very similar to that of the marine environment (35–38‰), whereas in the last ponds, it reaches 250‰. The intertidal study area

comprises 1,500 ha of mud adjacent to the saltworks, which becomes submerged at high water (Fig. 2). Although the mudflats of the lagoon are very large at low tide, at high tide only a few sandbars remain exposed.

Fieldwork was conducted by day from 30 March to 5 August 1999 (but excluding June), by the same observer using a bicycle or on foot. To assess bird community composition and habitat selection, two censuses were carried out each month, one during low tide and one during high tide. The intertidal mud and saltworks shorebirds were counted on the same day and during the same tidal conditions. Censuses were carried out within ±2.5 hours before and after low and high tide in the two parts of the study site (intertidal mud and saltworks). Each census took 5 hours, which is similar to the census period used by Laursen & Frikke (1984). All the birds observed in these areas were counted and identified, and their positions plotted on a map based on aerial photos.

To identify species associations the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) cluster technique was used, since it generally maximizes the cophenetic correlation coefficient. We therefore assumed that species furthest apart were least associated.

Redundancy analysis (RDA) was used to identify species distributions that were related to habitat (saltworks or intertidal mud), tide-stage (high tide or low tide) and month (April, May, July and August). The multiple correlations of the canonical coefficients (based on the percentage of variance explained) and the correlation coefficient (inter-set correlation) were also used for the interpretation of this analysis, where the first one measures the species data variance along the axes and the second one correlates the environmental variables with those same axes. For the purpose of the present study, the abundance of 30 bird species was plotted along with intertidal/saltworks, low/high tide and month environmental variables. The abundances were log-transformed to give more weight to the qualitative aspects of the data (Ter Braak 1995).

As it was found that habitat accounts for most of the variation in distribution, a partial RDA omitting habitat was performed in order to isolate the effect of habitat. Thus, if habitat accounts for most of the variation, the partial RDA should show no relationship between species distribution and either tide-stage or month.
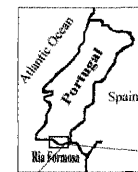
Fig. 1. Location map showing part of the Ria Formosa Natural Park, Algarve, on the south coast of Portugal and the study area near Tavira on the east side of Gilão estuary (37°02'N 7°38'W).
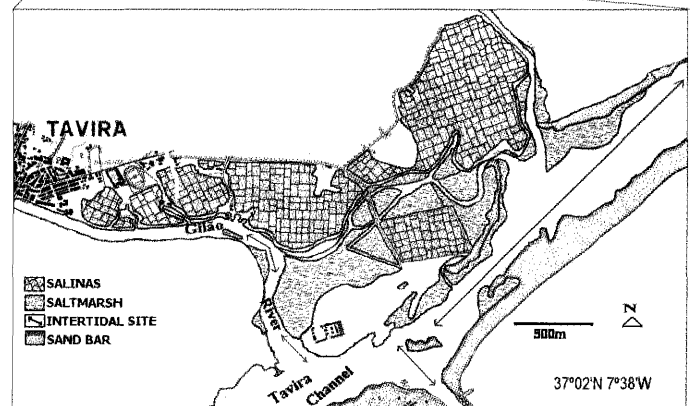
To investigate whether the observed relationships between bird communities, habitat type, tide-stage and month obtained through the RDA and partial RDA might have been obtained by chance, a MONTE CARLO permutation test with the first eigenvalue as the test statistic was carried out (Ter Braak 1995). We have considered as binary variables habitat type (saltworks = 0, intertidal mud = 1) and tide-stage (high tide = 0, low tide = 1) and the months, April–August, were coded 1–4.

RESULTS

Bird community composition

With one exception, neither the number of species nor the number of birds using the study sites varied significantly with either month or tide or habitat (p > 0.05). The exception is that the number of birds using the saltworks at high tide showed significant variation with month (p < 0.05, 3 d.f.) (Fig. 2).

Species association and distribution patterns

Cluster analysis allows us to identify three major groups of associated species, defined as A, B and C, among the 30
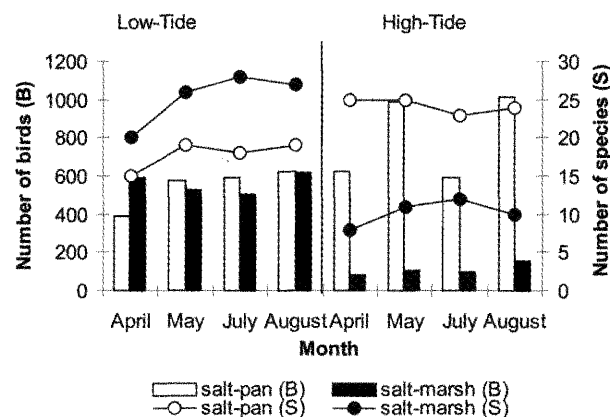
Fig. 2. Monthly variation in the number of birds (B) and species (S) at low tide and high tide, on the salt works and mud flats at Tavira, southern Portugal.

waterbird species that used the study sites (Table 1, Fig. 3). Group A is taxonomically and ecologically very diverse, comprising most of the shorebirds, terns and gulls and also four Ciconiiformes. At a lower level of dissimilarity, group A can be divided into three subgroups: one comprising Greater Flamingo, Little Egret, Grey Heron and Little Grebe (I), a second comprising Eurasian Spoonbill, Common Tern, Eurasian Curlew, Eurasian Oystercatcher and Bar-tailed Godwit (II) and a third comprising Black-headed Gull, Little Tern and eleven shorebirds (III). Group B (one duck, Eurasian Coot and two shorebirds) can be further divided into two subgroups: one comprising Eurasian Coot and Mallard (IV), the other Black-tailed Godwit and Pied Avocet (V) (Fig. 3). Group C comprised four species of relative dissimilarity (Lesser Black-backed Gull, Kentish Plover, Dunlin and Black-winged Stilt).

For species distribution patterns, a significant (p < 0.05) and fairly high (39.5%) proportion of bird community variability can be explained by the environmental variables tested (habitat, tide-stage and month). The major part of this variability (79.9%) is concentrated on the first RDA axis, which has a high correlation with habitat alone. The subsequent axes are correlated with tide-stage and month, respectively, and represent only a small proportion of the community variability, which can be explained by these environmental variables (Table 2).

Species like Black-winged Stilt, Pied Avocet, Kentish Plover, Dunlin, Curlew Sandpiper, Black-tailed Godwit, Little Tern, Common Tern, Lesser Black-backed Gull, Black-headed Gull, Coot and Greater Flamingo showed high and positive correlations with the first axis (Table 1), indicating that they have a positive association with the saltpan habitat (Fig. 4). In contrast, Bar-tailed Godwit and Eurasian Spoonbill showed negative correlations with the saltpan habitat, suggesting a positive association with the intertidal mud habitat.

Among the more abundant species in the saltworks, Black-winged Stilt, Pied Avocet, Black-tailed Godwit, Common Tern and Eurasian Coot, were only positively correlated with the first axis variables independently from the remaining variables.

Of the 30 species, only Eurasian Oystercatcher and Grey Heron showed a high and positive correlation with tide-stage, i.e. axis II (Table 1). Although they were associated with the intertidal mud (especially Eurasian Oystercatcher) they were only positively correlated with low tide (Fig. 4). The remaining species not already mentioned were correlated with both habitat and tide-stage simultaneously, although some only occurred in low numbers so the results for them should be treated with caution. None of the 30 species were correlated with the gradient representing month (Axis III).

Table 1. Correlation coefficients between numbers of 30 bird species occurring at the saltworks and intertidal study sites at Tavira and environmental variables resulting from full and partial Redundancy Analysis. In the full Redundancy Analysis, Axis I is highly correlated with habitat, Axis II with tide-stage; in the partial Redundancy Analysis, Axis I is highly correlated with tide-stage and Axis II with month.

Species (abbreviations used in Figs 3 & 4)	Full Redundancy Analysis		Partial Redundancy Analysis	
	Axis I	Axis II	Axis I	Axis II
Black-winged Stilt *Himantopus himantopus* (H hima)	0.86	−0.47	0.15	0.06
Pied Avocet *Recurvirostra avosetta* (R avos)	0.93	−0.22	0.0001	0.01
Kentish Plover *Charadrius alexandrinus* (C alex)	0.55	0.38	0.50	0.01
Little Ringed Plover *Charadrius dubius* (C dubi)*	0.03	0.13	0.14	−0.10
Grey Plover *Pluvialis squatarola* (P squa)*	0.08	0.06	0.086	−0.06
Eurasian Golden Plover *Pluvialis apricaria* (P apri)*	−0.01	0.01	0.01	−0.01
Dunlin *Calidris alpina* (C alpi)	0.62	0.32	0.46	−0.06
Curlew Sandpiper *Calidris ferruginea* (C ferr)	0.52	0.26	0.37	0.03
Little Stint *Calidris minuta* (C minu)	0.45	0.45	0.55	0.01
Red Knot *Calidris canutus* (C canu)	−0.02	0.49	0.04	0.02
Bar-tailed Godwit *Limosa lapponica* (L lapo)	−0.86	0.33	0.11	0.02
Black-tailed Godwit *Limosa limosa* (L limo)	0.87	−0.27	−0.06	0.12
Whimbrel *Numenius phaeopus* (N phae)*	−0.25	0.08	0.02	0.13
Eurasian Curlew *Numenius arquata* (N arqu)	−0.31	0.03	−0.04	0.22
Greenshank *Tringa nebularia* (T nebu)	0.39	0.21	0.30	−0.11
Redshank *Tringa totanus* (T tota)*	0.28	0.11	0.17	0.31
Spotted Redshank *Tringa erythropus* (T eryt)*	0.11	0.01	0.03	0.11
Ruddy Turnstone *Arenaria interpres* (A intr)*	−0.014	0.002	−0.03	−0.004
Eurasian Oystercatcher *Haematopus ostralegus* (H ostra)	−0.36	0.59	0.49	−0.07
Little Tern *Sterna albifrons* (S albi)	0.50	0.24	0.35	−0.02
Common Tern *Sterna hirundo* (S hiru)	0.31	−0.04	0.03	−0.04
Lesser Black-backed Gull *Larus fuscus* (L fusc)	0.80	0.20	0.38	0.08
Black-headed Gull *Larus ridibundus* (L ridi)	0.54	0.26	0.39	−0.27
Mallard *Anas platyrhynchos* (A plat)*	−0.01	−0.15	−0.15	0.10
Little Grebe *Tachybaptus ruficollis* (T rufi)*	−0.23	0.25	0.18	−0.28
Eurasian Coot *Fulica atra* (F atra)	0.53	−0.33	−0.19	0.01
Little Egret *Egretta garzetta* (E garz)	0.59	0.40	0.40	0.56
Grey Heron *Ardea cinerea* (A cine)	−0.16	0.73	0.67	−0.01
Eurasian Spoonbill *Platalea leucorodia* (P leuc)	−0.72	0.08	−0.095	0.39
Greater Flamingo *Phoenicopterus ruber* (P rube)	0.51	0.02	0.14	−0.11

* Species that only occurred in low numbers
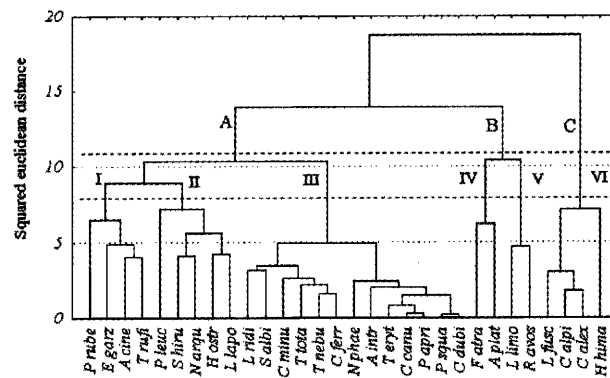
Fig. 3. Dendrogram showing dissimilarity in the distributions of thirty waterbird species at Tavira, southern Portugal, based on monthly censuses carried out at high tide and low tide (See Table 1 for species abbreviations). Letters and Roman numerals describe groups of associated species (see text). Squared Euclidean distance was used to compare similarities among species and the Unweighted Pair Group Method with Arithmetic Mean cluster analysis method was used to build the dendrogram.

In the absence of habitat, the partial RDA gradient explains only a small (13.4%) and non- significant (p > 0.05) proportion of the bird community variability (Table 2). In this gradient, axis I is associated with tide-stage and axis II with month. Here the responses of the different species to tide and month were unaltered. The result of the Monte Carlo permutation test in relation to the first axis of the partial RDA was non-significant (p = 0.413), showing that the residual tide-stage and monthly variation is not significantly related to the community structure (Tables 1 & 2).

DISCUSSION

Bird community composition

During spring and autumn migration, many birds use coastal wetlands to refuel (Erwin 1996) which is why there were high abundance peaks during May and August. The slight decrease in July is due to the fact that only resident or breeding species remain in coastal wetlands during this period. Nevertheless during the migration periods many birds may stopover for as long as one month or as little as one day. As a result, many more birds may use the area than is shown by periodic counts.

The increased numbers of birds at the saltworks in May and August is significant for the high tide period but not for low tide. It is well known that during high tide most waterbirds use saltworks for both foraging and roosting (Velas-

quez & Hockey 1992, Masero *et al.* 2000, Masero & Pérez-Hurtado 2001, Luís *et al.* 2001, 2002) but during spring migration these habitats are an alternative area with available food and less competition for space. Unfortunately, with an increasing human population along the Atlantic Coast, few wildlife refuges remain, especially during summer (Erwin 1996). In addition, the number of birds counted at low tide in the two habitats during this period remained unchanged; this suggests that birds might go to other saltworks or adjacent habitats.

Within several species, some individuals were resident, while others were migrants or breeders, which is the reason why the peak of abundance did not coincide with high species diversity. Indeed, 20 of the 30 species studied both winter in and migrate through southern Portugal. Most of these are Charadriiformes. The ducks (Anatidae), coots and grebes are present for most of the year and also breed, while the Ardeidae are mostly migrants.

Species association and distribution patterns

The species distribution patterns were highly influenced by habitat and much less by tide and month. This is largely accounted for the large diversity of available habitats such as intertidal mud- and sand-flats and saltworks and the feeding opportunities they provide (Velasquez & Hockey 1991, Velazquez 1992, Masero & Pérez-Hurtado 2001). Migrant species are shown to be most characteristic of the saltworks

Table 2. Full and partial Redundancy Analysis: percentage of variation in bird numbers explained by environmental variables and correlation coefficients for bird numbers and environmental variables.

	Axis: Environmental variable	% of variation explained	Correlation coefficients
Full RDA	Axis I: Saltworks/Mudflats	31.5	−0.91*
	Axis II: Low tide/High tide	6.1	0.59*
	Axis III: Month	1.9	0.84*
	TOTAL	39.5	
Partial RDA	Axis I: Low tide/High tide	10.7	0.60**
	Axis II: Month	2.7	0.84**
	TOTAL	13.4	

* p = 0.012 and p = 0.013 for the first and all three axes, respectively.
** p = 0.413 and p = 0.423 for the first and both axes, respectively.
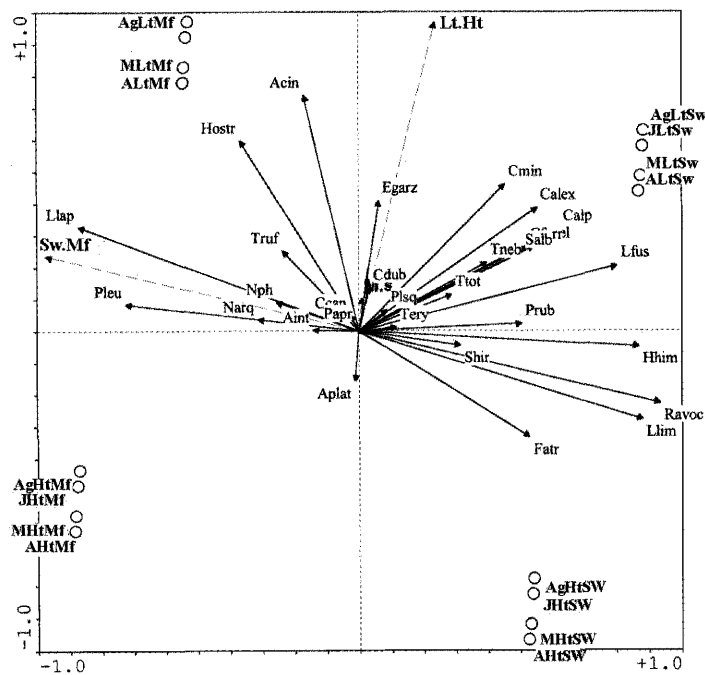
Fig. 4. Redundancy analysis ordination of bird distribution patterns (⟶) over three environmental variables (⟶): saltworks and mud flats on the first axis (Sw.Mf; Sw = saltworks, Mf = mudflats), low tide and high tide on the second axis (Lt.Ht; Lt = low tide, Ht = high tide) and month on the third axis (M.s; A = April, M = May, J = July, Ag = August). Open circles represents the month.tide.habitat gradient (See Table 1 for species abbreviations). The first axis (species–habitat) explains 80% of the data variability, the second axis (species–tide) 15% and the third axis (species–month) only 5%.

during low tide, which supports widely diverse species associations as shown by the cluster analysis. We found that the clusters were differentiated primarily by the most abundant species in relation to habitat and tide.

During spring and autumn migration periods, most of the Charadriiformes preferred the saltworks during low tide, showing associations between such diverse species as Greater Flamingos with Kentish Plovers and Dunlins with Curlew Sandpipers and Little Terns. Such associations arise in part because the resident species – Greater Flamingos, Kentish Plovers and Little Terns – are attracted to the saltworks because they provide both feeding and nesting sites in close proximity, and the former are also used by the migrant shorebirds. Species like Little Egret showed associations with other Ardeidae, since they prefer open areas with sparse vegetation also found in the saltworks (Cramp & Simmons 1977).

Most of the breeding populations were never seen on the intertidal mud, Black-winged Stilt, Pied Avocet and Common Tern tend to be associated with the saltworks, where they build their nests, find food and rarely leave. The occurrence of Black-tailed Godwit, Black-winged Stilt and Eurasian Coot in the saltworks is related to the presence of different food resources.

Curiously Pied Avocets did not use the intertidal mud study site at all, not even to feed. They tended to use only the high marsh and saltworks. This may be partly a reflection of the fact that most of the avocet population are local breeders and the saltworks provide both nest sites and convenient nearby feeding areas.

Several species favoured the intertidal site at low tide and used the saltworks either as a roosting site or as a feeding ground during high tide. Many shorebirds fed on the mud-

flats during low tide, especially Eurasian Oystercatcher, Ruddy Turnstone, Grey Plover, Redshank, Golden Plover, Red Knot, Little Ringed Plover, Little Stint, Whimbrel, Eurasian Curlew, Little Grebe, Grey Heron Greenshank, Redshank and Spotted Redshank. On migration these species characteristically feed on intertidal mud- or sand-flats (Cramp & Simmons 1983). Moreover it has been suggested that Eurasian Oystercatcher, Ruddy Turnstone, Grey Plover, Redshank and Little Ringed Plover often form feeding associations (Barnard & Thompson 1985), a feature that is confirmed by the Redundancy Analysis. In addition to this, non-breeders and migrants show wider habitat tolerance, with use extending to lagoons, estuaries and other suitable feeding areas more distant from breeding sites. Therefore, some of the associations we have found between habitats and species and between different species may be related to the availability of the same abundant prey resources that are exploited by a variety of birds (Battley et al. 2003).

Only few species, such as Mallard and Little Grebe, preferred the intertidal mudflats at high tide. However, while Little Grebes select sheltered vegetated waters with muddy and vegetated bottoms, Mallards prefer to feed on mudflats without vegetation (Moreira 1993). Mallards also showed a strong association with Eurasian Coots, mainly because they remained in the intertidal areas when they flooded.

The fact that several migrants, with their high energy requirements, showed a strong preference for feeding in the saltworks despite the availability of nearby natural intertidal habitats is most likely to reflect a greater availability of food in the saltworks compared with the mudflats (Velasquez & Hockey 1992, Múrias et al. 1997). The surface of intertidal areas in southern Portugal are exposed to high desiccation rates in summer, and this results in benthic prey becoming

less available as they bury themselves deeper. This affects saltpans much less as water levels are maintained.

Variation in the risk of predation is another reason why birds may choose to feed in one site or habitat rather than another (Zwarts 1978). However, it would appear that this is not the reason why many birds show a preference for feeding in the saltworks rather than the mudflats. The mudflats are open and have good visibility in all directions. In contrast, the saltworks would appear to be, if anything, more dangerous in that each saltpan is surrounded by banks that might give cover, especially to avian predators.

We found that throughout summer the non-tidal habitat – the saltworks – was used as an alternative foraging ground at high tide and was also the main foraging ground during the migration periods, contributing significantly to the maintenance of several migrant shorebird species.

Relative to adjacent natural intertidal or high marsh areas, salt works in the mid-Atlantic may provide superior feeding, nesting and roosting opportunities for many species of shorebirds all year round as pointed out by Luís *et al.* (2002). For that reason, allowing saltpans to evaporate, until they are dry, should be avoided at critical times and water controls maintained so that shallow water persists throughout the late July–August period when shorebirds and other waterbirds migrate through the region.

Southern Portugal occupies an important position on the East Atlantic flyway. It combines a highly favourable climate with abundant food resources and so creates uniquely beneficial conditions for migratory populations of many waterbird species (Smit & Piersma 1989). This study demonstrates that, even small estuarine areas with saltworks, like Tavira, play a crucial role for considerable numbers of waterbirds during migration periods, despite the fact that they are small compared with the Ria Formosa wetlands as a whole.

ACKNOWLEDGEMENTS

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