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Can Human-made Saltpans Represent an Alternative Habitat for Shorebirds? Implications for a Predictable Loss of Estuarine Sediment Flats

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Abstract Estuarine areas worldwide are under intense pressure due to human activities such as upstream dam building. Shorebirds strongly depend on estuarine intertidal flats during migration and wintering periods and so are particularly vulnerable to such impacts, whose magnitude will depend on the availability of alternative feeding habitats. In this study we analyze if man-made saltpans can represent an alternative habitat for wintering and migrating shorebirds in the Guadiana estuary, a wetland that is already experiencing environmental changes due to the building of the Alqueva reservoir, the largest in Western Europe. We compared the use of mudflats and saltpans as feeding areas by several shorebird species before the construction of the dam. A dataset with 26 years of counts data was also analyzed in order to detect any long-term trend in shorebirds abundance. We concluded that saltpans, in particular the fully mechanized, can be used as an alternative habitat by larger species during winter and southward migration, thus playing a major role in minimizing the possible effects of sediment loss due to dam building. In contrast, smaller species were particularly dependent on mudflats to feed. A significant change in population trends, from positive to negative, was detected for two species. Although we still have no evidence that this is directly linked to dam building, this result and documented changes that limit primary productivity justifies the implementation of a long-term monitoring scheme of shorebird populations in this estuary. We also reinforce the need to manage the saltpans as key habitats for shorebirds.

Keywords Alqueva dam · Estuaries · Foraging ecology · Management · Shorebirds

Introduction

Estuaries are among the most important areas for shorebirds during the winter and the migration periods (van de Kam et al. 2004). Many shorebirds are highly adapted to the tidally structured environment of estuarine habitats, using the intertidal sediment flats to forage during low tide (where they prey mainly upon macrobenthic invertebrates), and moving to supratidal areas to rest when the tide rises (Burger et al. 1977).

Estuaries worldwide are also under intense human pressure, mainly related with land reclamation (Goss-Custard and Yates 1992), pollution (Wolff 2000), and disturbance (West et al. 2002; Stillman et al. 2007). Dam building (even if several kilometers upstream) may also have a large impact on estuaries, mainly caused by a decrease in freshwater inflow and sediment input (e.g., Guillen and Palanques 1992; Carriquiry et al. 2001; Frihy et al. 2003; Yang et al. 2005). As a consequence, after dam construction the sediment flats on the estuary downstream

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tend to shrink and to experience a change in its granulometric composition, which in turn can strongly affect the benthic community (e.g., Ysebaert and Herman 2002). Additionally, dam construction *per se* and the filling process as well can have a considerable ecological impact (such as on salinity levels and chlorophyll-*a* concentration), mainly due to the environmental instability experienced during these phases (Domingues et al. 2007; Morais et al. 2009). Shorebirds play an important role on the estuarine food web as secondary consumers (Moreira 1997; Kuwae et al. 2012) and, for that reason, are particularly vulnerable to changes in the estuarine environment (Sutherland et al. 2012), namely in salinity levels and primary productivity variations (both known to directly influence the availability of their prey; e.g., McLusky et al. 1993; Cardoso et al. 2002). In such cases, the existence of alternative feeding areas for shorebirds may offset the decrease on the availability and quality of their natural (mudflat) feeding grounds (Masero 2003).

In fact, many birds use supratidal habitats such as human-made saltpans, as a complementary feeding habitat during the high-tide period, when sediment flats are submersed (Britton and Johnson 1987; Masero et al. 2000; Masero and Pérez-Hurtado 2001; Yasué and Dearden 2009). Some species may even prefer to feed in saltpans instead of mudflats during the low tide period (Múrias et al. 2002; Masero 2003; Dias 2009; Yasué and Dearden 2009). Therefore, saltpans can potentially act as an alternative feeding habitat for some shorebird species in case of reduction or degradation of the intertidal flat area (Sripanomyom et al. 2011), as that related with an upstream dam building.

The major aim of this study was to analyze if man-made saltpans can represent an alternative feeding habitat for wintering and migrating shorebirds in Guadiana estuary, Portugal. This wetland is already experiencing changes in its intertidal habitats due to the creation of the largest reservoir in Western Europe (the Alqueva reservoir, Guadiana River, Southeast Portugal; Fig. 1), and so our results also provide relevant baseline information for future assessments of the impact of the dam. We analyzed two different phases of the annual cycle of shorebirds—winter and southward migration—, when major abundances were recorded in the area (Dias 1999). We also present the first analysis of the shorebird population trends before and after the dam construction, using a dataset of bird counts collected during the last 26 years (1987–2012).

Methods

Study Area

The study was carried out on the estuary of the Guadiana River (Castro Marim, Algarve, southeast Portugal; Fig. 1). This estuary has a narrow morphology mainly due to its postglacial evolution and is in an advanced state of sediment infilling (Morales et al. 2006). The tidal regime in the estuary is semidiurnal, with amplitude ranging between 1.3 and 3.5 m (Faria et al. 2006).

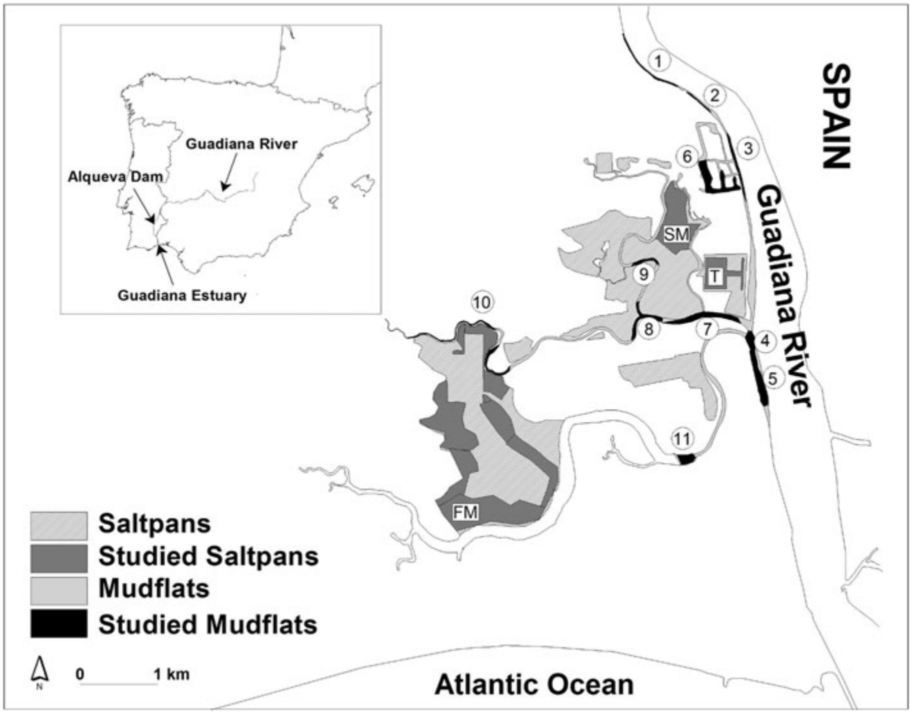

Fig. 1 Study area and its location in Iberian Peninsula. Mudflat sectors numbers (*1–11*) and types of saltpans (*T* traditional, *SM* semimechanized, *FM* fully mechanized) are indicated

The area is classified as a Natural Reserve and as a Special Protected Area (part of the EU Natura 2000 network) due to its international importance for shorebirds during winter and migration periods (Heath and Evans 2000). It is characterized by a large saltpan area (ca. 576 ha) and a few intertidal sediment flats, mainly mudflats (ca. 88 ha) (Fig. 1). There are three major types of saltpans in Castro Marim: traditional, fully mechanized, and semimechanized. They differ in some structural features that are known to affect the occurrence of shorebirds (Dias et al. 1999, 2009). Traditional saltworks (where the salt is totally extracted by hand) have comparatively smaller pans (in general less than 0.5 ha), deeper waters (ca. 8 cm in average), lower salinity (approx. 90 g/L), and higher walls with denser vegetation cover. In contrast, fully-mechanized saltworks have the larger pans (in general more than 5 ha), shallower waters (approx. 5 cm in average), higher salinity (approx. 100 g/L), and lower and bare walls. The semimechanized saltworks represent an intermediate situation between the others in most features, with pans with ca. 1–2 ha. These three types occupy ca. 50, 20, and 30 % of the total saltpan area, respectively. There are no studies of the invertebrate fauna present in the saltpans of Guadiana, but in other saltpans (including some located in a nearby area, in Ludo, Faro) the macrofauna community is composed essentially by few, super abundant species with high salinity tolerance such as Chironomidae and Ephydridae larvae and *Hydrobia* mudsnails (Rufino et al. 1984; Batty 1992; Pedro and Ramos 2009).

The Alqueva dam began to be built in 1995, and its floodgates were closed in February 2002, submerging (at maximum storage level) an area of 25,000 ha and creating one of the largest reservoirs in Europe (Morais et al. 2009). A number of ecological changes have been documented since then (e.g., Morais 2008). The freshwater inflow and the transport of suspended sediment have considerably decreased (Morais 2008; Barbosa et al. 2010; Garel and Ferreira 2011). The structure of phytoplankton community has experienced several shifts (Domingues et al. 2012) which were mainly driven by environmental instability felt during and soon after the filling of the dam (Domingues et al. 2007, 2012; Barbosa et al. 2010). This instability also affected the fish community, with a decline in the abundances of planktivorous and omnivorous fishes and an increase in carnivorous fishes (Chícharo et al. 2006; Morais et al. 2009), probably linked to a marked decrease in chlorophyll *a* concentration during this period (Morais et al. 2009, Barbosa et al. 2010). An increase in salinity levels was also recorded in the upper estuary during the filling of the dam (Chícharo et al. 2006; Domingues et al. 2007). This environmental variability seems to be now stabilized, and resulted in a decrease in nutrient concentrations and in cyanobacteria occurrence (Domingues et al. 2012). Although not yet documented, an accelerated erosion rate is also expected to occur (Morales et al. 2006; Garel and Ferreira 2011).

Bird Counts

We conducted low-tide bird counts (within ±2 h from low tide, when birds are usually actively foraging and their between-habitat movements are minimal; our own previous observations) in 11 mudflat sectors located in the major intertidal areas of the Guadiana estuary (Fig. 1; total area counted: 45 ha, which correspond to approx. 51 % of the total mudflat area within the Nature Reserve; mean area of each sector: 4.1 ha; min: 0.7 ha; max: 9.4 ha) and in three different types of saltworks: traditional (30 ponds in “Cepo Velho”; 13.31 ha), semimechanized (18 ponds in “Venta Moinhos”; 27 ha), and fully mechanized (16 ponds located in “Cerro do Bufo” complex; 118 ha). The total area of saltpan counted corresponds to ca. 27 % of the saltpan area in the Reserve. Counts were conducted during diurnal spring low tides on seven counting sessions before the dam closure: four during winter 2000/2001 (December and January) and three during southward migration period in 2001 (August and September). Each counting session was performed by two experienced observers using binoculars and telescopes (located on specific positions), and lasted from 1 to 3 days. The behavior of the birds (as feeding or resting) was registered during the counts, but as more than 80 % of the birds were actively foraging and because the main goal of this study was to compare the use of both habitats as foraging grounds, only these records were included in the analyses.

Winter high-tide counts have been carried out in the Natural Reserve, since 1987 (Costa and Rufino 1994; 1997; ICNF unpublished data). These counts are conducted annually during the highest spring tide of January by one or two experienced observers (with binoculars and telescopes) that survey all the supratidal habitats within ±3 h from the time of high tide, when most birds are gathered in high-tide roosts.

Data Analysis

In order to compare the use of both habitats as foraging areas, we estimated the bird densities in mudflats (considering the joint values for the total area) and in different types of saltpans. We performed repeated measures ANOVAs using the several values obtained during the low-tide counts carried out within each season ($n = 4$ in winter and $n = 3$ in southward migration). Whenever appropriate, data were log transformed in order to meet the ANOVA assumptions. These analyses were carried out using the R software (R Development Core Team 2010).

The long-term trends (1987–2012) of the most common shorebird species in Guadiana estuary were analyzed using the software TRIM (Trends and Indices for Monitoring Data; Pannekoek and van Strien 2001; van Strien et al. 2001), using the high-tide annual counts data. We compared the population trend slopes in three different periods: 1987–1995 (pre-dam), 1996–2002 (dam construction), and 2003–2012 (after the closure of the floodgates), using Wald-tests (based on the estimated variance–covariance matrix extracted from the fitting function; a description of the formula used can be found in Pannekoek and van Strien 2001).

Results

Comparison Between Mudflats and Saltpans

A total of 24 shorebird species were observed in the Guadiana estuary during the 2000/2001 study period (Table 1); the 10 most abundant are listed in Table 2 (jointly, these species represented 94 % of the total shorebirds counted).

The overall density of feeding shorebirds during the low tide was 5–10 times higher in mudflats than in saltpans (Fig. 2). The major differences between the two habitats were found in winter (significant differences between densities in mudflats and in all types of saltpans; repeated measures ANOVA, $F_{3,9} = 14.55$; $P < 0.001$), but densities were particularly high in mudflats during Southward migration, reaching near 80 birds ha^{-1} in some cases (significant differences between mudflats and saltpan densities, and between densities in fully mechanized and traditional saltpans; repeated measures ANOVA, $F_{3,6} = 33.62$; $P < 0.001$; Fig. 2).

Six out of the ten most abundant species (the three plovers *Charadrius alexandrinus*, *Charadrius hiaticula* and *Pluvialis squatarola*, the dunlin *Calidris alpina*, the curlew sandpiper *Calidris ferruginea*, and the redshank *Tringa totanus*) occurred in higher densities in mudflats than in saltpans, both during the winter and migration (Table 2). In contrast, the European avocet *Recurvirostra avosetta* occurred in higher abundances in saltpans than in mudflats in both seasons. Saltpans were also more used by black-winged stilt *Himantopus himantopus*, black-tailed godwit *Limosa limosa*, and little stint *Calidris minuta* during migration (Table 2).

Long-Term Trends in Shorebird Numbers

We found a significant difference in the slope trends before and after 1996 for redshank, and before and after 2003 for black-winged stilt (Table 3), in both cases due to a shift from a positive to a negative trend (Fig. 3). We did not detect any other significant change in the slope trends among the studied periods (Table 3). A very large year-to-year variation in the abundances recorded was observed in almost all species (Fig. 3).

Table 1 Mean abundance (±SD) of each of the 24 species recorded in the Guadiana estuary during the 2000/2001 counting sessions

	Winter	Migration
Black-tailed godwit *Limosa limosa*	66.00 ± 48.67	1287.00 ± 74.65
European avocet *Recurvirostra avosetta*	123.00 ± 78.24	679.33 ± 14.19
Redshank *Tringa totanus*	252.75 ± 89.63	663.67 ± 91.56
Dunlin *Calidris alpina*	597.00 ± 189.81	367.33 ± 39.25
Black-winged stilt *Himantopus himantopus*	140.25 ± 18.25	360.67 ± 75.98
Curlew sandpiper *Calidris ferruginea*	35.25 ± 28.50	327.67 ± 10.50
Common ringed plover *Charadrius hiaticula*	115.00 ± 34.91	299.33 ± 105.12
Little stint *Calidris minuta*	89.75 ± 67.61	217.33 ± 25.32
Snowy plover *Charadrius alexandrinus*	124.00 ± 34.55	216.67 ± 35.64
Black-bellied plover *Pluvialis squatarola*	60.25 ± 15.82	37.00 ± 5.57
Spotted redshank *Tringa erythropus*	9.75 ± 3.50	109.67 ± 106.04
Sanderling *Calidris alba*	6.00 ± 4.97	46.33 ± 21.22
Common sandpiper *Actitis hypoleucos*	12.00 ± 5.60	15.67 ± 7.37
Turnstone *Arenaria interpres*	14.75 ± 10.69	8.67 ± 1.53
Common greenshank *Tringa nebularia*	8.25 ± 3.77	14.33 ± 2.52
Ruff *Philomachus pugnax*	3.75 ± 2.87	13.33 ± 8.74
Whimbrel *Numenius phaeopus*	2.50 ± 1.73	10.00 ± 4.36
Eurasian curlew *Numenius arquata*	7.00 ± 4.90	0.67 ± 0.58
Bar-tailed godwit *Limosa lapponica*	2.25 ± 3.20	3.00 ± 4.36
Little ringed plover *Charadrius dubius*	0.00 ± 0.00	1.67 ± 2.08
Eurasian oystercatcher *Haematopus ostralegus*	0.00 ± 0.00	1.33 ± 2.31
Red knot *Calidris canutus*	0.25 ± 0.50	0.33 ± 0.58
Wood sandpiper *Tringa glareola*	1.00 ± 0.00	0.00 ± 0.00
Green sandpiper *Tringa ochropus*	0.25 ± 0.50	0.00 ± 0.00

Species are ordered by their abundance

Table 2 Shorebird densities (birds ha^{-1}; mean ± SE) recorded on mudflats and different types of saltpans in the Guadiana estuary during winter (2000/2001) and southward migration (2001)

	Period	Mudflats	Fully-mechan. Saltpans	Semi-mechan. Saltpans	Traditional Saltpans	ANOVA F
Black-winged stilt	Winter	0.01 ± 0.01	0.94 ± 0.13	0.99 ± 0.61	0.03 ± 0.07	2.06^{ns}
	Migr.	1.05 ± 0.38^{AC}	1.88 ± 0.37^{A}	3.39 ± 0.32^{B}	0.13 ± 0.09^{C}	17.18**
European avocet	Winter	0.04 ± 0.04^{A}	1.03 ± 0.35^{B}	0.01 ± 0.01^{A}	0.00 ± 0.00^{A}	9.27**
	Migr.	0.28 ± 0.12^{A}	5.41 ± 0.08^{B}	1.17 ± 0.25^{C}	0.00 ± 0.00^{A}	245.21***
Common ringed plover	Winter	2.43 ± 0.35^{A}	0.06 ± 0.04^{B}	0.00 ± 0.00^{B}	0.00 ± 0.00^{B}	(128.81***)
	Migr.	6.03 ± 1.17^{A}	0.25 ± 0.19^{B}	0.01 ± 0.01^{B}	0.00 ± 0.00^{B}	25.63***
Snowy plover	Winter	2.62 ± 0.35^{A}	0.06 ± 0.04^{B}	0.00 ± 0.00^{B}	0.00 ± 0.00^{B}	169.78***
	Migr.	4.53 ± 0.45^{A}	0.11 ± 0.02^{B}	0.04 ± 0.04^{B}	0.03 ± 0.03^{B}	(370.39***)
Black-bellied plover	Winter	1.03 ± 0.14^{A}	0.06 ± 0.01^{B}	0.25 ± 0.04^{B}	0.04 ± 0.04^{B}	53.70***
	Migr.	0.75 ± 0.11^{A}	0.03 ± 0.02^{B}	0.00 ± 0.00^{B}	0.00 ± 0.00^{B}	40.72***
Little stint	Winter	1.15 ± 0.40^{A}	0.28 ± 0.16^{AB}	0.20 ± 0.17^{AB}	0.00 ± 0.00^{B}	5.37*
	Migr.	0.11 ± 0.01^{A}	1.60 ± 0.12^{B}	0.83 ± 0.22^{C}	0.10 ± 0.10^{A}	23.72**
Curlew sandpiper	Winter	0.41 ± 0.13^{A}	0.12 ± 0.09^{AB}	0.11 ± 0.07^{AB}	0.00 ± 0.00^{B}	4.17*
	Migr.	3.82 ± 0.22^{A}	1.33 ± 0.13^{B}	0.00 ± 0.00^{C}	0.05 ± 0.05^{C}	139.80***
Dunlin	Winter	10.96 ± 2.10^{A}	0.48 ± 0.12^{B}	1.92 ± 1.75^{B}	0.02 ± 0.02^{B}	(14.18***)
	Migr.	6.23 ± 0.48^{A}	0.73 ± 0.30^{B}	0.04 ± 0.02^{B}	0.15 ± 0.15^{B}	78.80***
Black-tailed godwit	Winter	0.11 ± 0.02	0.25 ± 0.14	1.20 ± 1.14	0.00 ± 0.00	(0.80^{ns})
	Migr.	3.77 ± 0.76^{A}	9.17 ± 0.69^{B}	1.51 ± 0.47^{AC}	0.00 ± 0.00^{C}	17.18**
Redshank	Winter	3.79 ± 0.83^{A}	0.54 ± 0.14^{B}	0.40 ± 0.15^{B}	0.73 ± 0.36^{B}	10.98**
	Migr.	6.78 ± 0.78^{A}	2.94 ± 0.40^{C}	0.52 ± 0.47^{B}	0.05 ± 0.05^{B}	42.19***

Letters represent the results of pos-hoc tests (same letter represents non-significant differences). Statistics results between brackets denote models based in log-transformed data. df = 3,9 (winter comparisons) and df = 3,6 (migration comparisons)

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; n.s. $P > 0.05$

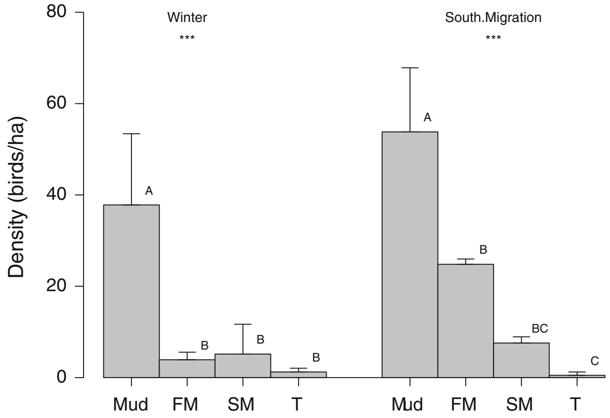

Fig. 2 Density of shorebirds (number of birds ha^{-1}; mean ± SE) in each type of saltpans (*T* traditional saltpans, *SM* semimechanized saltpans, *FM* fully-mechanized saltpans) and in mudflats (Mud) during the 2000/2001 winter and southward migration periods, in Guadiana estuary. *Symbols* represent the results of repeated ANOVA tests (***$P < 0.001$), and *letters* represent the results of pos-hoc tests (*same letter* represents non-significant differences)

Discussion

The overall density of shorebirds was much higher in the mudflats than in the saltpans of Guadiana estuary, particularly during the winter. In fact, the densities found in mudflats are very high (reaching 100 birds ha^{-1} in some cases) when compared with majority of other European estuarine areas, and only comparable with those found in Cadiz sediment flats (Masero et al. 2000). Such high densities are probably related with the low availability of sediment flats in the Guadiana estuary and also with the presence of suitable high-tide roosts—the saltpans—nearby (Masero et al. 2000; Dias et al. 2006). The high densities found were mainly determined by the highest use of this habitat by some of the most abundant shorebird species, such as the dunlin and the redshank; other small sized species such as the plovers, also had highest use of mudflats at low tide. In contrast, larger species (black-winged stilt, European avocet, and black-tailed godwit) mainly fed in saltpans during the low tide, even before the dam building (when the counts in both habitats were carried out). The little stint was the only small sized species that was found in higher densities in the saltpans during the migration, as also recorded in other estuaries (Velasquez 1992; Masero et al. 2000).

The European avocet and the black-tailed godwit are typically associated with intertidal flats in other estuaries (e.g., Granadeiro et al. 2007). Nevertheless, their use of man-made saltpans in detriment of the natural habitat had already been recorded in this estuary during previous studies (Dias 1999, 2009), and it is probably related with the low availability of mudflats and with their confined characteristics. This narrow configuration can decrease the bird safety perception of the area (Dias 2009) for which the largest species are particularly vulnerable (Blumstein et al. 2005; Dias et al. 2008). On the other hand, by feeding on saltpans, birds avoid to move between feeding and resting areas, given that saltpans are not submerged when the tide rises (Yasué and Dearden 2009); once again, the largest species are the ones for whose commuting between areas would represent a higher proportion of the daily energy expenditure (Bennett and Harvey 1987). Another factor that is known to influence the distribution of the shorebirds is prey abundance (e.g., Yates et al. 1993). Saltpans typically hold a community dominated by few, super abundant prey species (Rufino et al. 1984; Pedro and Ramos 2009), whose densities have usually a nonlinear relationship with salinity (Warnock et al. 2002), but that in optimal conditions are probably above the threshold limit at which intake rates are expected to decline (following the Holling type II functional response model typical of the shorebird species, Goss-Custard et al. 2006).

Table 3 Average abundances (mean ± SE) of shorebird species in Guadiana estuary in the periods 1987–1994 (before Alqueva dam closure), 1995–2002 (during the construction of Alqueva dam), and 2003–2012 (after Aqueva dam closure)

	Mean abundance			Wald test (df = 1)	
	1987–1995	1996–2002	2003–2012	1996	2003
Black-winged stilt	111 ± 32	317 ± 46	193 ± 44	2.85$^{\text{ns}}$	4.69*
European avocet	290 ± 73	385 ± 126	472 ± 124	1.30$^{\text{ns}}$	1.90$^{\text{ns}}$
Common ringed plover	54 ± 12	60 ± 36	120 ± 66	0.10$^{\text{ns}}$	0.92$^{\text{ns}}$
Snowy plover	116 ± 51	185 ± 103	65 ± 16	0.16$^{\text{ns}}$	0.00$^{\text{ns}}$
Black-bellied plover	40 ± 8	84 ± 16	94 ± 27	0.00$^{\text{ns}}$	0.46$^{\text{ns}}$
Little stint	70 ± 30	81 ± 26	37 ± 8	0.36$^{\text{ns}}$	0.03$^{\text{ns}}$
Dunlin	455 ± 81	891 ± 258	642 ± 150	2.23$^{\text{ns}}$	1.77$^{\text{ns}}$
Black-tailed godwit	704 ± 120	560 ± 134	853 ± 86	0.08$^{\text{ns}}$	0.22$^{\text{ns}}$
Redshank	118 ± 12	215 ± 66	184 ± 31	3.86*	3.12$^{\text{ns}}$

The results of the TRIM analyses to detect changes in the population trends between these periods (Wald tests to compare slopes before and after change points 1995 and 2002) are also shown (*$P < 0.05$; n.s. $P > 0.05$)

By providing alternative and complementary foraging habitats for shorebirds, saltpans (particularly the mechanized and semimechanized ones) have the potential to minimize the impact of mudflats degradation on some species. Nevertheless, it is important to note that the available foraging area within the saltpans can vary several folds, depending on the environmental conditions found in the pans that can limit their carrying capacity, both through the availability and the accessibility to prey (Dias et al. 2009). This emphasizes the importance of a correct management of the conditions in Guadiana saltpans in order to

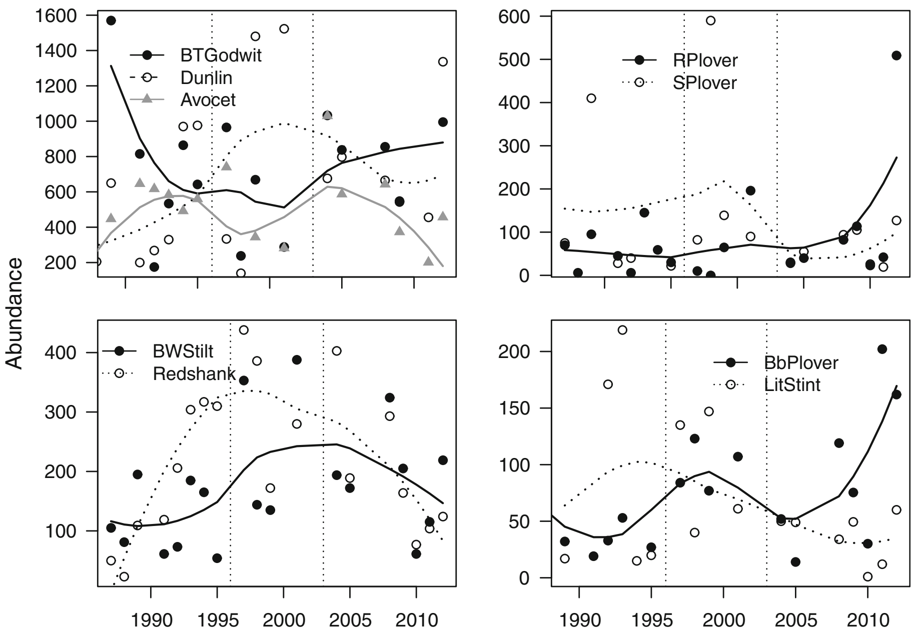

Fig. 3 Variation in the abundance of the most abundant shorebird species (number of birds) in Guadiana estuary during the winter (1987–2012). *Solid and gray dashed lines* represent loess regressions (smoother functions based on local linear polynomial fits, carried out using the loess function in R; Cleveland et al. 1992; only showed to help the visualization of the overall trends). *Vertical dashed lines* represent the beginning and end (gates closure) of Alqueva dam construction

maintain their importance as feeding habitats for shorebirds, what can be achieved through (1) the manipulation of the water levels, salinity, and whenever possible, the area of the ponds (Martin and Randall 1987; Velasquez 1992; Warnock et al. 2002; Dias 2009) and (2) the maintenance of low levels of human disturbance (West et al. 2002; Dias et al. 2008). The larger species would probably be the ones that would benefit more from these measures, but smaller species which are particularly vulnerable to the modification of the mudflats, can also respond well to water level manipulation in the ponds, both during the winter and migration (Velasquez 1992). The control of salinity levels can also maximize the biomass of available prey (Warnock et al. 2002) and minimize the high energetic cost of coping with salt stress (Masero 2002; Gutiérrez et al. 2011). It is also important to highlight that besides their importance as alternative habitats during low tide, saltpans can also represent important supplementary habitats during high tide (Masero et al. 2000), a fact that enhances the importance of their correct management for shorebirds.

The analysis of the long-term counts that have been conducted in the Guadiana estuary, since the late 80s has revealed a significant change in the slope trends of the population of black-winged stilts before and after 2003 (1 year after the closure of Alqueva floodgates), and of redshanks before and after 1996 (beginning of the dam construction). Although we did not have evidence of any change in the abundance of black-winged stilts wintering or passing through Portugal (neither ours nor other studies have addressed this issue), the redshank population seems to be decreasing also in other Portuguese wetlands, such as the Tagus estuary and in Ria de Aveiro, as shown by other studies (Catry et al. 2011). It is important to note, however, the large amount of interannual variation in the estimates for all the studied species, which could have weakened the detection of other trends. Such amount of variability in estimates based on count data is relatively common in long-term monitoring programs of shorebird populations (e.g., Atkinson et al. 2006; Catry et al. 2011), and can result from a combination of methodological error and natural population variability (Atkinson et al. 2006). Most of these species are long-distance migrants, whose abundance is highly variable due to the range of environmental conditions found in several different areas, some located thousands of kilometers apart (e.g., Delany et al. 2009). This can also pose problems in identifying the real triggers of a decline, given that any observed reduction in local numbers can be associated to causes as diverse as a global population decline, a shift in the winter distribution due to external causes (as for example the improvement of the conditions elsewhere), or a decrease in local habitat quality (Catry et al. 2011). Nevertheless, the redshank is a species particularly vulnerable to winter habitat loss (Burton et al. 2006) so we cannot discard the possibility of a link between the observed decline (Fig. 3) and a change in the estuarine conditions as a consequence of the Alqueva dam, and potentially of the cumulative effect provided by many other dams located upstream in the Guadiana (Barbosa et al. 2010). The freshwater inflow, for example, has decreased considerably as consequence of the Alqueva dam (Morais 2008) and so did the nutrient input, which is currently limiting the primary productivity (Domingues et al. 2012) and likely (although not yet documented) the abundance of shorebird prey.

Some of the species more typically associated with mudflats such as the common ringed and black-bellied plovers (Velasquez and Hockey 1992; Dias 2009; this study), and so particularly vulnerable to a degradation (either through a reduction in area or a change in granulometric composition) of intertidal flat areas due to sediment retention in the Alqueva dam, seem not to be experiencing any decline so far (Fig. 3). The populations of both species are declining worldwide (Delany et al. 2009), so the pattern in Guadiana estuary suggests that no major decrease in mudflat quality to shorebirds has been experienced so far, at least for these species (in Southern European estuaries, smaller plovers such as ring and snowy plovers can be associated to sandier sediment flats; e.g., Granadeiro et al. 2007). Nonetheless, given the high vulnerability and overall declining trend of shorebird species (Delany et al. 2009; Sutherland et al. 2012), and considering the potential temporal delay between the building of the dam construction and its impacts in estuarine mudflats (Garel et al. 2009), it is strongly recommended a maintenance of the monitoring program and the implementation of conservation measures in this estuary.

Conclusions

Saltpans, particularly the fully mechanized ones, can constitute an important alternative habitat for some species, both during winter and southward migration. Nevertheless, the potential role of saltpans in minimizing the predictable effects of the construction of the Alqueva dam should be enhanced through their correct preservation and management as key habitats for shorebirds, particularly for the smaller species, which can be particularly affected by a change in the estuarine sedimentary regime.

Although our study has not shown a loss of shorebird habitat (or habitat quality) as a direct consequence of the dam building, we should highlight that the impact of the Alqueva dam can assume a greater (cumulative) significance for these species in the future, especially if associated with other predictable causes of loss of sediment flats, such those resulting from climate changes or habitat reclamation (Galbraith et al. 2002; Durell et al. 2006; West and Caldow 2006; Kilsby et al. 2007).

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References

Atkinson PW, Austin GE, Rehfisch MM, Baker H, Cranswick P, Kershaw M, Robinson J, Langston RHW, Stroud DA, Van Turnhout C, Maclean IMD (2006) Identifying declines in waterbirds: the effects of missing data, population variability and count period on the interpretation of longterm survey data. Biol Conserv 130:549–559. doi:10.1016/j.biocon.2006.01.018

Barbosa A, Domingues RB, Galvão HM (2010) Environmental forcing of phytoplankton in a Mediterranean estuary (Guadiana estuary, South-western Iberia): a decadal study of anthropogenic and climatic influences. Estuar Coast 33:324–341. doi:10.1007/s12237-009-9200-x

Batty L (1992) The wader communities of a saline and an intertidal site on the Ria Formosa, Portugal. Wader Study Group Bull 66:66–72

Bennett PM, Harvey PM (1987) Active and resting metabolism in birds: allometry, phylogeny and ecology. J Zool 213:327–363

Blumstein D, Fernández-Juricic E, Zollner P, Garity S (2005) Inter-specific variation in avian responses to human disturbance. J Appl Ecol 42:943–953. doi:10.1111/j.1365-2664.2005.01071.x

Britton R, Johnson A (1987) An ecological account of a Mediterranean salina: the salin de Giraud, Camargue (S. France). Biol Conserv 42:185–230. doi:10.1016/0006-3207(87)90133-9

Burger J, Howe M, Hahn D, Chase J (1977) Effects of tide cycles on habitat selection and habitat partitioning by migrating shorebirds. Auk 94:743–758

Burton NK, Rehfisch MM, Clark NA, Dodd SG (2006) Impacts of sudden winter habitat loss on the body condition and survival of redshank *Tringa totanus*. J Appl Ecol 43:464–473. doi:10.1111/j.1365-2664.2006.01156.x

Cardoso PG, Lillebø AI, Pardal MA, Ferreira SM, Marques JC (2002) The effect of different primary producers on *Hydrobia ulvae* population dynamics: a case study in a temperate intertidal estuary. J Exp Mar Biol Ecol 277:173–195. doi:10.1016/S0022-0981(02)00338-6

Carriquiry JD, Sánchez A, Camacho-Ibar VF (2001) Sedimentation in the northern Gulf of California after cessation of the Colorado River discharge. Sediment Geol 144:37–62. doi:10.1016/S0037-0738(01)00134-8

Catry T, Alves JA, Andrade J, Costa H, Dias MP, Fernandes P, Leal A, Lourenço P, Martins R, Moniz F, Pardal S, Rocha A, Santos CD, Encarnação V, Granadeiro JP (2011) Long-term declines of wader populations at the Tagus estuary, Portugal: a response to global or local factors? Bird Conserv Int 21:438–453. doi:10.1017/S0959270910000626

Chícharo MA, Chícharo L, Morais P (2006) Inter-annual differences of ichthyofauna structure of the Guadiana estuary and adjacent coastal area (SE Portugal/SW Spain): before and after Alqueva dam construction. Estuar Coast Shelf Sci 70:39–51. doi:10.1016/j.ecss.2006.05.036

Cleveland WS, Grosse E, Shyu WN (1992) Local regression models. In: Chambers JM, Hastie TJ (eds) Statistical models in S. Wadsworth & Brook/Cole, Pacific Grove

Costa LT, Rufino R (1994) Contagens de aves aquáticas em Portugal. Janeiro de 1994. Airo 5:8–16

Costa LT, Rufino R (1997) Contagens de aves aquáticas em Portugal. Janeiro de 1997. Airo 8:25–32

Delany S, Scott D, Dodman T, Stroud D (2009) An atlas of wader populations in Africa and western Eurasia. Wetlands International and International Wader Study Group, Wageningen

Dias MP (1999) Aves aquáticas das salinas de Castro Marim—fenologia, utilização do habitat, prioridades de conservação e propostas de gestão. Dissertation, Faculty of Sciences, University of Lisbon

Dias MP (2009) Use of saltpans by wintering shorebirds along the tidal cycle. Waterbirds 35:531–537. doi:10.1675/063.032.0406

Dias MP, Granadeiro JP, Lecoq M, Santos CD, Palmeirim JM (2006) Distance to high-tide roosts constrains the use of foraging areas by dunlins: implications for the management of estuarine wetlands. Biol Cons 131:446–452. doi:10.1016/j.biocon.2006.02.020

Dias MP, Peste F, Granadeiro JP, Palmeirim JM (2008) Does traditional shellfishing affect foraging by waders? The case of the Tagus estuary (Portugal). Acta Oecol 33:186–196. doi:10.1016/j.actao.2007.10.005

Domingues RB, Sobrino C, Galvão H (2007) Impact of reservoir filling on phytoplankton succession and cyanobacteria blooms in a temperate estuary. Estuar Coast Shelf Sci 74:31–43. doi:10.1016/j.ecss.2007.03.021

Domingues RB, Barbosa AB, Sommer U, Galvão HM (2012) Phytoplankton composition, growth and production in the Guadiana estuary (SW Iberia): unraveling changes induced after dam construction. Sci Total Environ 416:300–313. doi:10.1016/j.scitotenv.2011.11.043

Durell SEAV, Stillman RA, Caldow RWG, McGrorty S, West AD, Humphreys J (2006) Modelling the effect of environmental change on shorebirds: a case study on Poole Harbour, UK. Biol Conserv 131:459–473. doi:10.1016/j.biocon.2006.02.022

Faria A, Morais PP, Chícharo MA (2006) Ichthyoplankton dynamics in the Guadiana estuary and adjacent coastal area, South-East Portugal. Estuar Coast Shelf Sci 70:85–97. doi:10.1016/j.ecss.2006.05.032

Frihy OE, Debes EA, Sayed WRE (2003) Processes reshaping the Nile delta promontories of Egypt: pre- and post-protection. Geomorphology 53:263–279. doi:10.1016/S0169-555X(02)00318-5

Galbraith H, Jones R, Park R, Clough J, Herrod-Julius S, Harrington B, Page G (2002) Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. Waterbirds 25:173–183. doi:10.1675/1524-4695(2002)025

Garel E, Ferreira Ó (2011) Effects of the Alqueva dam on sediment fluxes at the mouth of the Guadiana estuary. J Coast Res 64:1505–1509

Garel E, Pinto L, Santos A, Ferreira Ó (2009) Tidal and river discharge forcing upon water and sediment circulation at a rock-bound estuary (Guadiana estuary, Portugal). Estuar Coast Shelf Sci 84:269–281. doi:10.1016/j.ecss.2009.07.002

Goss-Custard JD, Yates MG (1992) Towards predicting the effect of salt-marsh reclamation on feeding bird numbers on the wash. J Appl Ecol 29:330–340

Goss-Custard JD, West A, Yates MG et al (2006) Intake rates and the functional response in shorebirds (Charadriiformes) eating macro-invertebrates. Biol Rev 81:501–529. doi:10.1017/S1464793106007093

Granadeiro JP, Santos CD, Dias MP, Palmeirim JM (2007) Environmental factors drive habitat partitioning in birds feeding in intertidal flats: implications for conservation. Hydrobiologia 587:291–302. doi:10.1007/s10750-007-0692-8

Guillen J, Palanques A (1992) Sediment dynamics and hydrodynamics in the lower course of a river highly regulated by dams: the Ebro river. Sedimentology 39:567–579. doi:10.1111/j.1365-3091.1992.tb02137.x

Gutiérrez JS, Masero JA, Abad-Gómez JM, Villegas A, Sánchez-Guzmán JM (2011) Understanding the energetic costs of living in saline environments: effects of salinity on basal metabolic rate, body mass and daily energy consumption of a long-distance migratory shorebird. J Exp Biol 214:829–835. doi:10.1242/jeb.048223

Heath MF, Evans MI (2000) Important bird areas in Europe: priority sites for conservation. BirdLife International, Cambridge

Kilsby CG, Tellier SS, Fowler HJ, Howels TR (2007) Hydrological impacts of climate change on the Tejo and Guadiana rivers. Hydrol Earth Syst Sci 11:1175–1189. doi:10.5194/hess-11-1175-2007

Kuwae T, Miyoshi E, Hosokawa S, Ichimi K, Hosoya J, Amano T, Moriya T, Kondoh M, Ydenberg RC, Eln RW (2012) Variable and complex food web structures revealed by exploring missing trophic links between birds and biofilm. Ecol Lett 15:347–356. doi:10.1111/j.1461-0248.2012.01744.x

Martin AP, Randall RM (1987) Numbers of waterbirds at a commercial saltpan, and suggestion for management. South African J Wildl Res 17:75–81

Masero JA (2002) Why don't knots *Calidris canutus* feed extensively on the crustacean Artemia? Bird Study 49:304–306. doi:10.1080/00063650209461280

Masero JA (2003) Assessing alternative anthropogenic habitats for conserving waterbirds: salinas as buffers against the impact of natural habitat loss for shorebirds. Biodivers Conserv 12:1157–1173. doi:10.1023/A:1023021320448

Masero JA, Pérez-Hurtado A (2001) Importance of the supratidal habitats for maintaining overwintering shorebirds populations: how redshanks use tidal mudflats and adjacent salt works in southern Europe. Condor 103:21–30. doi:10.1650/0010-5422

Masero JA, Pérez-Hurtado A, Castro M, Arroyo GM (2000) Complementary use of intertidal mudflats and adjacent salinas by foraging waders. Ardea 88:177–191

McLusky DS, Hull SC, Elliott M (1993) Variations in the intertidal and subtidal macrofauna and sediments along a salinity gradient in the upper forth estuary. Nether J Aquat Ecol 27:101–109. doi:10.1007/BF02334773

Morais P (2008) Review on the major ecosystem impacts caused by damming and watershed development in an Iberian basin (SW-Europe): focus on the Guadiana estuary. Ann Limnol 44:105–117. doi:10.1051/limn:2008012

Morais P, Chícharo MA, Chícharo L (2009) Changes in a temperate estuary during the filling of the biggest European dam. Sci Total Environ 407:2245–2259. doi:10.1016/j.scitotenv.2008.11.037

Morales JA, Delgado I, Gutierrez-Mas JM (2006) Sedimentary characterization of bed types along the Guadiana estuary (SW Europe) before the construction of the Alqueva dam. Estuar Coast Shelf Sci 70:117–131. doi:10.1016/j.ecss.2006.05.049

Moreira F (1997) The importance of shorebirds to energy fluxes in a food web of a south European estuary. Estuar Coast Shelf Sci 44:67–78. doi:10.1006/ecss.1996.0112

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

Pannekoek J, van Strien AJ (2001) TRIM 3 manual. TRends and Indices for Monitoring data. Research paper no. 0102. Statistics Netherlands, Voorburg

Pedro P, Ramos JA (2009) Diet and prey selection of shorebirds on salt pans in the Mondego estuary, western Portugal. Ardeola 56:1–11

Rufino R, Araújo A, Pina JP, Miranda PS (1984) The use of salt pans by waders in the Algarve, South Portugal. Wader Study Group Bull 42:41–42

Sripanomyom S, Round PD, Savini T, Trisurat Y, Gale G (2011) Traditional salt-pans hold major concentrations of overwintering shorebirds in Southeast Asia. Biol Conserv 144:526–537. doi:10.1016/j.biocon.2010.10.008

Stillman RA, West AD, Caldow RWG, Durell SEAV (2007) Predicting the effect of disturbance on coastal birds. Ibis 149:73–81. doi:10.1111/j.1474-919X.2007.00649.x

Sutherland WJ, Alves JA, Amano T, Chang CH, Davidson NC, Finlayson CM, Gill JA, Gill RE, Gonzalez PM, Gunnarsson TG, Kleijn D, Chris CJ, Szekely T, Thompson DBA (2012) A horizon scanning assessment of current and potential future threats to migratory shorebirds. Ibis 154:663–679. doi:10.1111/j.1474-919X.2012.01261.x

R Development Core Team (2010) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org

van de Kam J, Ens BJ, Piersma T, Zwarts L (2004) Shorebirds. An illustrated behavioural ecology. KNNV Publishers, Utrecht

van Strien AJ, Pannekoek J, Gibbons DW (2001) Indexing European bird population trendsm using results of national monitoring schemes: a trial of a new method. Bird Study 48:200–213

Velasquez CR (1992) Managing artificial saltpans as a waterbird habitat: species's responses to water level manipulation. Colon Waterbirds 15:43–55

Velasquez CR, Hockey PAR (1992) The importance of eupratidal foraging habitats for waders at a south temperate estuary. Ardea 80:243–253

Warnock N, Page G, Ruhlen TD, Nur N, Takekawa JY, Hanson JT (2002) Management and conservation of San Francisco bay salt ponds: effects of pond salinity, area, tide, and season on Pacific flyway waterbirds. Waterbirds 25:79–92

West AD, Caldow RWG (2006) The development and use of individuals-based models to predict the effects of habitat loss and disturbance on waders and waterfowl. Ibis 148:158–168. doi:10.1111/j.1474-919X.2006.00520.x

West AD, Goss-Custard JD, Stillman RA, Caldow RWG, Durell SEAV, McGrorty S (2002) Predicting the impacts of disturbance on shorebird mortality using a behaviour-based model. Biol Conserv 106:319–328. doi:10.1016/S0006-3207(01)00257-9

Wolff W (2000) Causes of extirpations in the Wadden sea, an Estuarine area in The Netherlands. Conserv Biol 14:879–885. doi:10.1046/j.1523-1739.2000.98203.x

Yang SL, Zhang J, Zhu J, Smith JP, Dai SB, Gao A, Li P (2005) Impact of dams on Yangtze river sediment supply to the sea and delta intertidal wetland response. J Geophys Res 110:F03006. doi:10.1029/2004JF000271

Yasué M, Dearden P (2009) The importance of supratidal habitats for wintering shorebirds and the potential impacts of shrimp aquaculture. Environ Manag 43:1108–1121. doi:10.1007/s00267-008-9255-7

Yates MG, Goss-Custard JD, McGrorty S et al (1993) Sediment characteristics, invertebrate densities and shorebird densities on the inner banks of the wash. J Appl Ecol 30:599–614

Ysebaert T, Herman PMJ (2002) Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. Mar Ecol Prog Ser 244:105–124. doi:10.3354/meps244105