Synchronous Declines of Wintering Waders and High-Tide Roost Area in a Temperate Estuary: Results of a 10-Year Monitoring Programme

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Synchronous declines of wintering waders and high-tide roost area in a temperate estuary: results of a 10-year monitoring programme

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Abstract.—Migratory wader populations are declining across all major flyways, mostly due to habitat loss and human disturbance. Portuguese wetlands act as key wintering and stop-over sites for many waders due to their strategic location in the East Atlantic Flyway. Despite their importance, there are major knowledge gaps in some areas, such as the Sado Estuary**.** The main goal of this study was to identify the phenological patterns and wintering trends of the most abundant wader species in this wetland, and to compare the results with the population trends found at regional and flyway scales. A comprehensive dataset of count data collected monthly in high-tide roosts under a set monitoring programme (2010–2019) was used. The results revealed strong declines in the overall number of waders and of three of the most abundant species—Avocet (*Recurvisostra avosetta*), Dunlin (*Calidris alpina*), and Common Ringed Plover (*Charadrius hiaticula*)—associated with a 21% reduction of the suitable high-tide roosts across the study area. These trends are similar to those compiled from winter counts for the entire Sado Estuary, and at regional (Tagus Estuary) and flyway levels. Our results highlight the need to maintain suitable high-tide roosts to contribute towards reverting current declines in wader populations. *Received 25 Feb 2022, accepted 21 Sept 2022.*

Key words.— Habitat loss, Migratory Waders, Population Decline, Sado Estuary

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Many wader species (Order Charadriiformes, suborders Charadrii and Scolopaci) are declining globally, including across all major flyways (Andres *et al.* 2012; Studds *et al.* 2017; Schekkerman *et al.* 2018). Such declines may have multiple causes (Sutherland *et al.* 2012) which may be difficult as many wader species are long distance migrants, completing extensive journeys every year between their breeding (arctic/sub-arctic) and non-breeding (temperate/tropical) grounds (Van de Kam *et al.* 2004).

During the non-breeding season, many migratory waders depend heavily upon the availability and suitability of wetlands, particularly of tidal flats in estuarine areas (van de Kam *et al.* 2004). In these areas, they face habitat loss as a one of the main threats mostly due to increasing anthropogenic pressure (Goss-Custard and Yates 1992; Cayford 1993; Day *et al.* 2012), but also sea-level rise (Galbraith *et al.* 2002; dit Durell *et al.* 2006; Iwamura *et al.* 2013). Habitat loss has been shown to directly reduce demographic rates (Piersma *et al.* 2015) with associated population declines (Studds *et al.* 2017). It is therefore alarming that the global intertidal area has decreased by ca. 16% from 1984 to 2016 (Murray *et al.* 2019), resulting in an effective loss of prime wader feeding habitat. Moreover, high-tide roosting areas, which in temperate regions are often associated with saltpans, are being widely replaced by aquaculture ponds (Green *et al.* 2015), to respond to the increasing human population needs. The loss of these habitats therefore likely plays an important role in the reported declining trends of these populations.

Monitoring schemes form the basis for determining population trends, allowing the detection of fluctuations in population size, and can operate as warning systems to further investigate the causes of such change. These schemes also allow the determination of key sites for species conservation, with typically those sustaining 1% or more of the biogeographical population of a given species being designated of national or international importance (IUCN 2016). However, such schemes are difficult to implement as they require coordination at a local, national and international level, and funding for such long-term programmes is often difficult to secure (e.g. Birkhead 2018). Therefore, these long-term monitoring programmes often rely on volunteer groups and welcome the participation of citizen scientists, and thus they also have an important role in a community-based change in attitude towards a more sustainable living, regarding nature and biodiversity conservation (Danielsen *et al.* 2005).

Long-term monitoring has revealed shifts in abundance and distribution of waterbird populations through local colonization and extinction events (Méndez *et al.* 2018), and has also improved understanding of the role of local habitat changes on population trends (e.g. Catry *et al.* 2011). Wader monitoring schemes typically consist in counting individuals in roosts during high tide, when intertidal feeding areas are unavailable, and waders concentrate in specific locations. High-tide roosts play an important role in the ecology and conservation of waders in estuarine areas, since they determine which suitable intertidal foraging areas are used by waders that prefer to remain in its vicinity (Dias *et al.* 2006; Van Gils *et al.* 2006). Thus, monitoring wader roosts is a key tool in providing information about local conditions. For instance, long-term roost monitoring data may be used to infer population trends of waders using the intertidal mudflats of an estuary (e.g. Catry *et al.* 2011), or to assess shifts in their average seasonal abundance (e.g. Alves *et al.* 2009; Lourenço *et al.* 2018).

Mainland Portuguese wetlands are located at the southern edge of the European landmass along the East Atlantic Flyway (EAF) and host large numbers of waders annually, particularly during the non-breeding period (Alves *et al.* 2012). Several wetlands, such as the Tagus and Sado estuaries, act both as key wintering and stop-over locations, connecting Europe with Africa, and are ranked high (37^{th} and 62^{nd}, respectively) across all sites ($n = 110$), hosting more than 40.000 waders, in Africa and Western Eurasia (Delany *et al.* 2009) underlining their importance for the flyway level conservation of these species. Despite the Tagus Estuary receiving considerable attention (e.g. Alves *et al.* 2010; 2012; Catry *et al.* 2011; Lourenço *et al.* 2018), the Sado Estuary remains poorly studied (e.g. Alves *et al.* 2012) and more information on wader population trends and habitat availability is needed to fill this knowledge gap and better inform conservation and management at the second most important wetland of the country for these species.

In this study, we aimed at: (i) determining population trends for the most abundant wader species wintering in the Sado Estuary, one of the most important areas for waders in Portugal, while assessing monthly variation throughout the year, and (ii) quantifying monthly high-tide roost availability throughout the monitoring period. We also compared (iii) the local population trends with overall numbers and trends at the regional and flyway scales, using previously published information. In doing so, we were able to understand the population trends of waders using an important, though understudied, site.

METHODS

Study Area

The Sado Estuary (38° 27′ N, 8° 43′ W) is located in the Setúbal district, in the southern area of Portugal (Fig. 1), and is the second largest estuary in the country with an area of ca 240 km^2 (Elias *et al.* 2006). Its intertidal flats are mainly composed of soft sediments and are

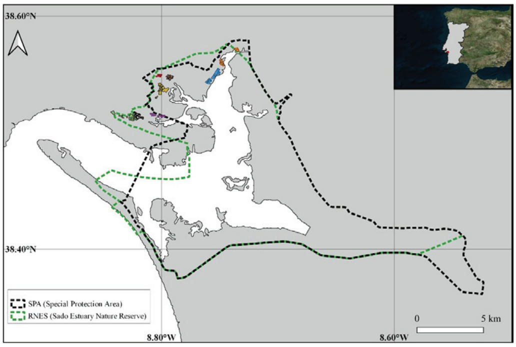

Figure 1. Sado Estuary, located in Portugal. Green and black dashed lines represent the borders of Sado Estuary Nature Reserve (RNES) and Special Protection Area (SPA), respectively.

surrounded by saltmarshes, saltpans and agricultural fields, which are used as roost sites by waders, mainly during the non-breeding period (Alves *et al.* 2012). It was classified as a Natural Reserve in 1980 and later received national and international designations such as Ramsar Site, under the Ramsar Convention (1996), Special Protection Area (SPA–Natura 2000) and Important Bird and Biodiversity Area (Costa *et al.* 2003).

Bird Counts and Habitat Availability

We carried out monthly counts between January 2010 and December 2019 at the most important roost sites located in the northern margin of the Sado Estuary (Alves *et al.* 2012; Fig. 2), covering an area of 192.93 ha. All roosts (old saltpan ponds) were surveyed each month (except when weather conditions impeded counting to proceed e.g., flooding of access due to heavy precipitation, which occurred in less than 0.5% of the counts), apart from Faralhão that was added to the scheme in 2012 (see Table S1, Supplementary Material). All counts were carried out simultaneously, 2 hours around the high-tide peak during spring tides (over 3 m, when all the intertidal flats are predicted to be submerged and therefore waders concentrate at high-tide roosts, Alves *et al.* 2012). Each count was performed using a zoom-telescope and we recorded the number of individuals of each species. All data used in the analyses are available in the Supplementary Materials (Table S2). At each visit to the counting areas (high-tide roosts), the observer recorded the number of ponds that were available for waders. Note that each roosting site is composed of several ponds (Fig. 2; Table S1). A roost area was considered to be lost when it was totally or partially converted to fish/shellfish farming (observable due to coverage of ponds with nets) or when tall vegetation was covering the pond area. The areas of each pond were estimated using GIS, as we georeferenced the available ponds using a GPS. When the observer recorded that a given area was lost (due to the reasons mentioned above), this area was subtracted from the total area.

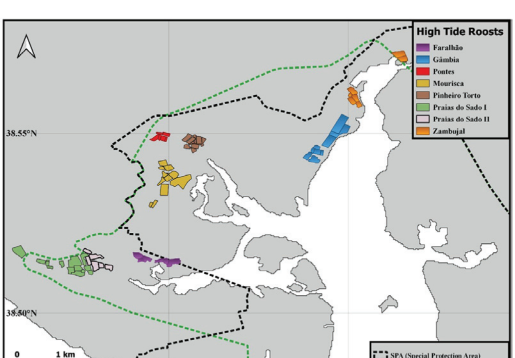

Figure 2. Most important wader high-tide roosts in the northern margin of the Sado Estuary, Portugal. Green and black dashed lines represent the borders of Sado Estuary Nature Reserve (RNES) and Special Protection Area (SPA), respectively.

Phenology

In order to assess the phenology of waders in the study area, we considered the average values (throughout the 10 years of counts) of each species in each month (i.e., 10-year monthly average). We analysed annual variation in the abundance of all waders combined (n = 25 species), and separately for the six most abundant species (representing 90% of the total waders counted during the study period, all being long distance migratory waders): Avocet (*Recurvirostra avosetta*); Dunlin (*Calidris alpina*), Black-tailed Godwit (*Limosa limosa*), Common Redshank (*Tringa totanus*), Common Ringed Plover (*Charadrius hiaticula*) and Grey Plover (*Pluvialis squatarola*). These species are currently classified as of Least Concern, except for the Black-tailed Godwit, which is classified as Near Threatened both at the European and Global level, and the Common Redshank, which is classified as Vulnerable in Europe but as of Least Concern globally (IUCN 2021).

Population Trends

To investigate population trends throughout the decade 2010–2019 we considered only data from the winter months (December to February), which is considered the most important period for wintering waterbirds in this region (Alves *et al.* 2012), although some individuals can also over-summer, as reported elsewhere (van Dijk *et al.* 1990; Navedo and Ruiz 2020). We estimated the number of birds per winter in each roost and each year by averaging the values for these three months. We then analysed the trends of the wintering populations of waders over the 10-year period using TRIM (TRends and Indices for Monitoring data) models (van Strien *et al.* 2004). TRIM determines population trends of species allowing for missing counts (for example due to exceptionally harsh weather conditions, see above) using estimation and yields yearly indices and standard errors using Poisson regression

(Ter Braak *et al.* 1992). We used the R package *rtrim* (Bogaart *et al.* 2020) to analyse the trends of the overall abundance of waders, and separately for each of the six most common species (Table S2) mentioned above which account for the vast majority of individuals from the wader community in the Sado Estuary. Finally, in order to understand if population trends recorded based on roost counts in our study area were due to estuary relocations (i.e., distribution shifts), we compared the population trends in the study area with the trends for the entire estuary (northern and southern margins) in the same decade, obtained from data on estuary-wide surveys carried out in January of each year, by the Portuguese Institute for Nature Conservation and Forestry (ICNF; data publicly available under request).

RESULTS

Annual Variation in Wader Abundance

The Sado Estuary is used mostly as a wintering area, with the highest number of waders occurring between December and February (Fig. 3). Two other smaller peaks of abundance were observed: one in September and, to a lesser extent, another in April. The phenology of the most common wader species varied between them, with Avocet, Common Redshank and Grey plover following the overall trend of peaking in winter, whereas Dunlin peaked during spring migration and Black-tailed Godwit and Common Ringed Plover peaked during autumn migration (Fig. S1).

Winter Population Trends

TRIM analyses revealed a strong decrease throughout the last decade in the overall number of waders wintering in the Sado Estuary (Fig. 4 and Table 1). This trend is mostly driven by the steep decline of three of the six most abundant species: Avocet, Dunlin and Common Ringed Plover (Fig. 5 and Table 1). In contrast, the population of Common Redshank increased significantly between 2010 and 2019, while the population of Grey Plover was relatively stable. It was not possible to derive a population trend for the Black-tailed Godwit (Fig. 5 and Table 1). The overall population trend in the study area is in line with the trend for the entire estuary based on the January counts carried out by ICNF, which also revealed a decrease, albeit moderate, over the same period (Fig. S2).

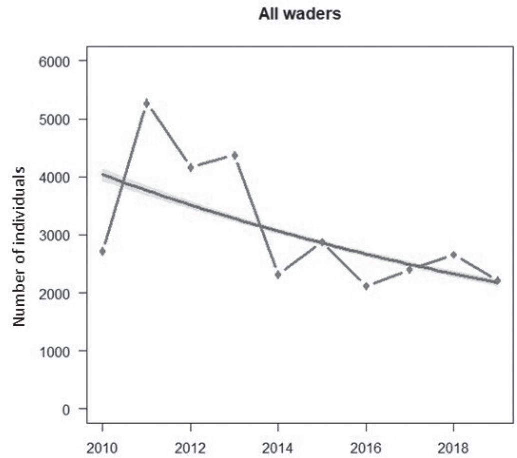

Figure 4. Variation in the number of wintering waders (*n* = 25 species) at high-tide roosts in the northern margin of the Sado Estuary between 2010 and 2019.

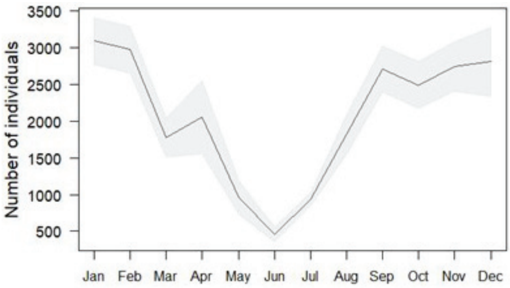

Figure 3. Monthly variation (mean ± standard error in grey) in the total abundance of waders in the northern margin of the Sado Estuary across the year.

Variation in the available High-tide Roost Area

The high-tide roost area lost between 2010 and 2019 in the northern margin of the Sado Estuary totals 21% (Table 2). The main causes of such loss were the conversion of saltpans into fish farms and, to a lesser extent, the vegetation growth inside the ponds resulting from the absence of management in abandoned saltpans. The Faralhão roost was the most affected, as all of its area was converted into fish farming (100% loss), followed by Zambujal (59% loss) and Gambia (34% loss; 16% converted into fish farming and 18% lost due to vegetation growth).

Table 1. Results of the TRIM analysis for all waders and the six most abundant species surveyed on high-tide roosts at the Sado Estuary. Lr corresponds to Likelihood ratio and AIC is given up to a constant.

	Goodness of fit							Wald test*			
	Chi-Square	df	p	Lr	Df	p	AIC	Wald	df	p	Trend
All species	9649.16	66	0.0000	9922.61	66	<0.001	9790.61	2077.23	1	<0.001	Strong decrease (p<0.01)
Avocet	7760.87	71	0.0000	7032.48	71	<0.001	6890.48	644.38	1	<0.001	Strong decrease (p<0.01)
Dunlin	8746.23	71	0.0000	7860.75	71	<0.001	7718.75	2485.58	1	<0.001	Strong decrease (p<0.01)
Black-tailed Godwit	4851.64	62	0.0000	4133.42	62	<0.001	4009.42	10.12	1	0.0014	Uncertain
CommonRedshank	1997.66	71	0.0000	1791.71	71	<0.001	1649.71	347.47	1	<0.001	Strong increase (p<0.01)
CommonRinged Plover	5248.67	71	0.0000	4481.98	71	<0.001	4339.98	134.82	1	<0.001	Strong decrease (p<0.01)
Grey Plover	1398.50	71	0.0000	1359.06	71	<0.001	1217.06	1.68	1	0.1950	Stable

*for significance of slope parameter

DISCUSSION

The results of our long-term monitoring scheme revealed, for the first time, population declines of several wader species in one of the most important wetlands in Portugal, the Sado Estuary. This study also revealed that these declines coincided in time with a decrease in the availability of high-tide roosts in the northern margin of the estuary.

High-tide roosts and intertidal flats play a fundamental role in supporting waders during their non-breeding season as these provide distinct ecological functions, all of which are essential for wader survival. These species are highly dependent on the availability of high-quality high-tide roosts in the vicinity of their intertidal feeding grounds (Dias *et al.* 2006), in order to minimize travel distance and thus reduce energy costs of commuting between them (Rogers 2003; Rogers *et al.* 2006). There is currently no information on the quality of the intertidal flats in the Sado Estuary, to the best of our knowledge. Thus, it was not possible to analyse potential changes in the foraging habitat, only in the roosting areas. Although it is known that the human population has increased in the area surrounding the Sado Estuary, particularly in the city of Setúbal, which may lead to wader habitat degradation simply due to increased disturbance (Cayford 1993), the implementation of the Water Framework Directive in the early 2000s may have contributed to improve the quality of the intertidal areas (Alves *et al.* 2012). The main causes of roost area loss and degradation in the northern margin of the Sado Estuary were the conversion of old saltpan ponds into fish/shellfish farming and the absence of management (Table 2). In Portugal, saltpans ponds have been progressively abandoned, leading to vegetation overgrowth within the ponds preventing their use by both wintering and breeding waders (Múrias *et al.* 2002) and are also being replaced by more profitable activities, such as fish/shellfish farming (Rufino and Neves 1992; Neves and Rufino 1995) that usually are too deep or covered by nets and thus inaccessible for waders (or other waterbirds), which is the case of our study area.

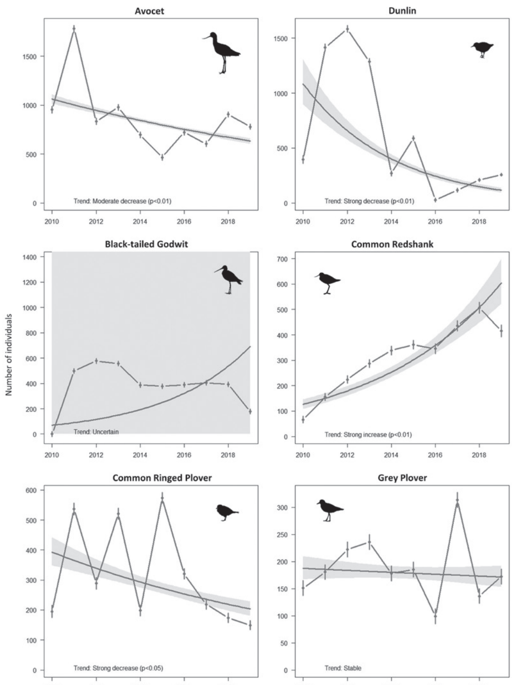

Figure 5. Variation in the number of individuals of the six most abundant species at high-tide roosts in the northern margin of the Sado Estuary between 2010 and 2019.

Although we did not establish a causal relationship between roost loss and the decline of waders, it has been shown elsewhere that habitat loss negatively affects wader population trends (e.g. Piersma *et al.* 2015). We show that the percentage of habitat loss in our study area was 21%, which represents a considerable proportion of the available roosts. Moreover, as each high-tide roost site is composed of several ponds (Fig. 2; Table S1 Supplementary Material), it is expected that those with some level of conversion into fish/shellfish farming will have higher levels of human activities, which will affect ponds that could still be suitable, therefore resulting in spillover disturbance effects that were previously absent. This is particularly alarming considering that these changes occurred over a period of only ten years. Thus, it is extremely important to reverse this trend in order to maintain a network of high-quality roost areas within the Sado Estuary to guarantee the conservation of wader species in this protected area.

Annual Variation in the Abundance of Waders

Data collected over the last ten years in the Sado Estuary reveals that this area is particularly important for waders during wintering and migration periods (Fig. 3; Fig. S1). This is in line with the patterns for the overall waders wintering in the Sado Estuary of a previous study (Alves *et al.* 2012) and also in the Tagus Estuary (Alves *et al.* 2012; Catry *et al.* 2011; Lourenço *et al.* 2018). However, we found some differences in the phenology of several species between the estuaries. For example, the abundance of Dunlin peaks during spring migration (particularly in April) in the Sado Estuary (Fig. S1), whilst in the Tagus Estuary this species is more abundant during the winter period (from November to December; Lourenço *et al.* 2018). Likewise, while the Grey Plover in the Sado Estuary is more abundant from November to

Table 2. Roost area and main causes of habitat loss (FF: Fish/shellfish farming and VG: Vegetation Growth).

		Area lost (ha)			Area lost (%)		
High-tide roost	Total area (ha)	FF	VG	Total	FF	VG	Total
Gambia	37.93	5.90	6.7	12.60	16	18	34
Mourisca	38.81	0	0	0	0	0	0
Praias do Sado I	39.36	0	0	0	0	0	0
Praias do Sado II	17.22	0	0	0	0	0	0
Pinheiro Torto	16.71	0	0	0	0	0	0
Zambujal	19.30	11.31	0	11.31	59	0	59
Pontes	7.32	0	0	0	0	0	0
Faralhão	16.28	16.28	0	16.28	100	0	100
Total	192.93	33.49	6.7	40.19	17	3	21

January (Fig. S1), in the Tagus Estuary its numbers remain constant until April (Lourenço *et al.* 2018). Thus, it is imperative to maintain the integrity of both areas, as they may play slightly distinct roles for different species throughout the non-breeding period. Future research should further investigate the level of movement between both wetlands (which are at ca. 30 km distance) and identify how frequently these are used by the same individuals, as little is currently known regarding such movements (but see: Lourenço and Alves 2009).

Population Trends

We documented a strong decrease in the overall abundance of wader species over the last ten years in Sado Estuary (Fig. 4 and Table 1). This trend is largely driven by the strong decline of three of the most abundant species in this area: Dunlin, Avocet and Common Ringed Plover (Fig. 5 and Table 1). Such particularly severe declines, coupled with high levels of site-fidelity (Dias *et al.* 2006; Alves *et al.* 2013; Lourenço *et al.* 2016) are therefore likely associated with high-tide habitat roost loss (Catry *et al.* 2011), which declined 21% in the monitored area over the study period. The areas counted do not encompass the total high-tide roost area that may be used by birds during high tide. However, estimates made over the whole estuary also revealed a declining trend, suggesting that waders are not simply relocating within the estuary, which would be expected given the very high levels of site fidelity recorded for these species (Alves *et al.* 2013; Lourenço *et al.* 2016; Méndez *et al.* 2018), but rather decreasing in the local population at the wetland level. In addition, the strong decline recorded for all waders on the monitored high-tide roosts, coupled with the moderate decrease recorded for the entire estuary, indicates that declines are particularly acute for waders using the monitored roosts than elsewhere in the estuary.

Our results are similar to those found for the Tagus Estuary (Alves *et al.* 2009; Catry *et al.* 2011; Lourenço *et al.* 2018) and for the whole East Atlantic Flyway (Schekkerman *et al.* 2018), supporting the idea that the declining trends of wader species are not a localized phenomenon, but rather widespread across several areas of the EAF (Schekkerman *et al.* 2018; Oudman *et al.* 2020), and also on other major flyways (Andres *et al.* 2012; Studds *et al.* 2017). Considering that many of these species are classified as Near Threatened and some of them as Vulnerable in Europe (e.g. Common Redshank, IUCN 2021), the negative trends will likely result in an increased extinction risk for these migratory species, highlighting the need for a better implementation of the already established international protocols between countries that share the responsibility for the conservation of aquatic birds (such as the Agreement on the Conservation of African-Eurasian Migratory Waterbirds).

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