WADERS DISTRIBUTION IN A SOUTHWESTERN IBERIAN PENINSULA ESTUARY: RELATIONSHIPS WITH SEDIMENT CHARACTERISTICS

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ABSTRACT

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Many studies have demonstrated that composition of macrobenthos is influenced by sediment characteristics and shore width. Moreover, the abundance and spatial distribution of waders in non-breeding season principally depend on the distribution, abundance and availability of their main prey species. According to this, it is possible to establish a relationship between sediment characteristics and bird numbers.

In an intertidal estuarine area of the Cadiz Bay (SW Spain), data on birds' number, sediment particle size, organic content and shore width were collected in 19 previously-determined sectors.

The mean sediment particle size and shore width decreased from the mouth to the internal bay while the amount of organic content increased. All the variables used for characterising the sediment were significantly correlated.

There was no clear differences between winter and prenuptial distribution of birds. In general, birds densities and sediment variables showed positive correlation with silt, clay and organic content, and negative – with D_{50} and other variables of the sediment particle size. This suggests that birds preferred silty feeding areas avoiding sandy ones.

Waders seemed to be more selective during prenuptial migration exploiting the macrobenthos spring bloom because of the increase of trophic requirements in this period.

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INTRODUCTION

Waders distribution in their feeding grounds is a non-random procedure, in which birds actively select different areas. Moreover, abundance and spatial distribution of waders in non-breeding season firstly depend on the distribution, abun-

dance and availability of their main prey species (Wolf 1969, Goss-Custard 1977, Goss-Custard *et al.* 1977, Bryant 1979, Rands and Barkman 1981) and secondly – on their dispersive ability and geographical barriers to dispersal, physiological limitations and competitive interactions (Wiens 1989). However, birds concentrate in places, where prey density, availability and intake rates are relatively high and where energy expenditure is relatively low (Goss-Custard and Charman 1976). According to this, several studies have shown the importance of physical habitat properties influencing the foraging efficiency of waders and hence their choice of foraging sites (Myers *et al.* 1980, Quammen 1982, Gerritsen and van Heezik 1985).

Besides, a number of studies have already demonstrated the influence of sediment particle size and shore width on the densities of macrobenthos, both separately (Longbottom 1970, Kay and Knights 1975, Sutherland 1982, Oyenekan 1986) and in combination (Anderson 1972, Boyden and Little 1973, Green 1975, Moore 1978, Shackley 1981, Rendell and Hunter 1986). This means that, in an indirect way, the characteristics of the sediments determines approximately the species and number of birds we are going to find in a particular area.

In a simple way, the model proposed by Yates *et al.* (1993) is:

shore width → broad sediment characteristics → birds number

The aim of this study is to find out what physical sediment characteristics determine spatial distribution of waders in winter and during prenuptial migration. This aspect is a part of global study of waders distribution and effects of human disturbance.

STUDY AREA

The Sancti-Petri Inlet is within the Cadiz Bay Natural Park (36°27'N, 6°10'W). It is the main and largest marsh inlet in the Cadiz Bay, and the only one that now connects the Atlantic Ocean with the inner bay with no artificial interruption. Its width ranges from 20 to 450 m, and it is about 18 km long, 15 of which are the object of our study. It is under the sway of typical semi-daily tide, with a maximum tidal range of 3.69 m, exposing an average area of 145 ha of mudflats for 12 hours every day (9% of the total intertidal bay area), and its shores range from 200 m to barely 2 m.

METHODS

A total of four winter censuses and two prenuptial censuses of birds were taken, between two hours before and two hours after the low tide at the time of maximum trophic activity. The study area had been previously divided into sections using landmarks such as smaller inlets and salt-works walls, so that they all would have similar length. We obtained a total of 19 sectors (Fig. 1). The results are expressed in densities (birds/ha), for which the area of each section at low tide had to be calculated.

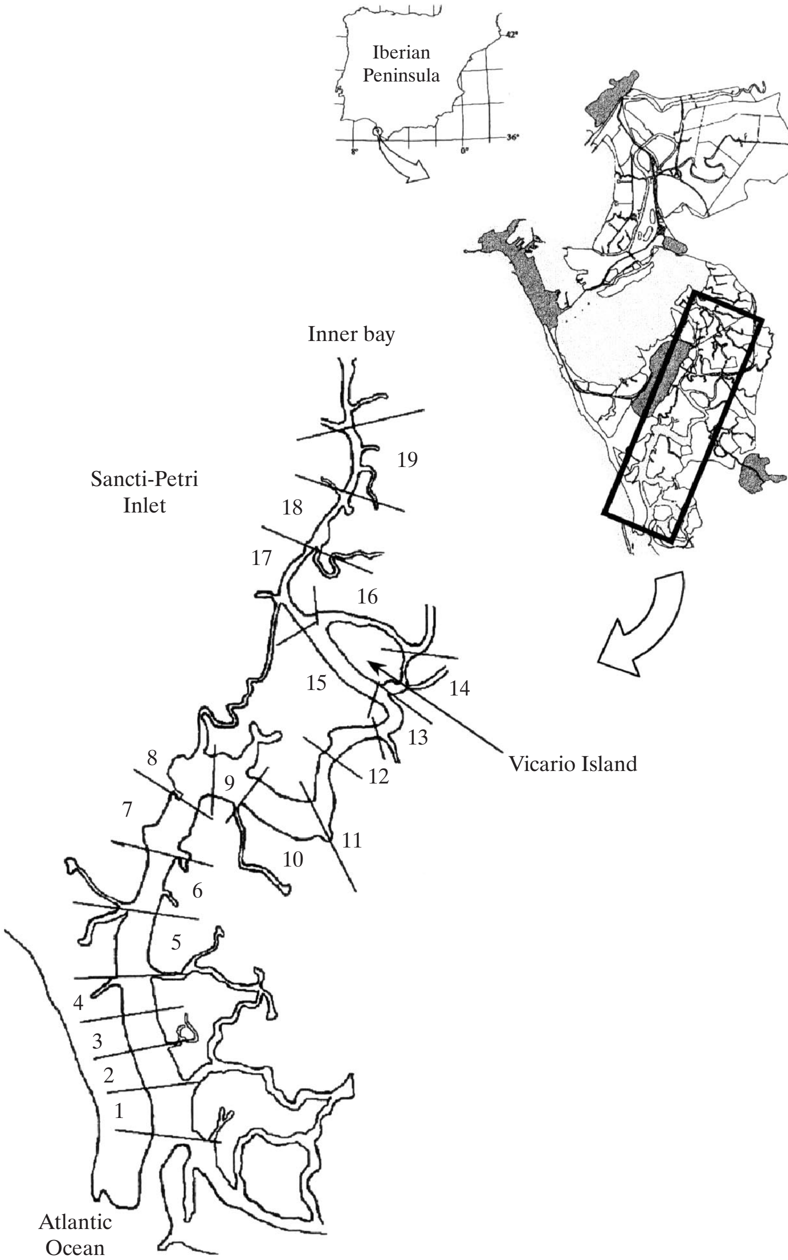

Fig. 1. Localisation of the study area. Numbering of sectors is given on a detail map.

In each sector, the percentage of clay, silt, very fine sand, fine sand, medium sand, coarse sand and very coarse sand, as well as the D_{50} value (median grain-size), according to the method proposed by Krumbein and Sloss (1963), were set. This last parameter was calculated by plotting cumulative dry-mass percentage (starting

with the largest grain-size fraction) on the logarithm of particle diameter. From this semilogarithmic plot the median grain-size can be read off starting at the 50% cumulative dry mass on *y*-axis. Moreover, values of sediment organic content were obtained by means of Crisp (1994) methodology, and shore width measured from air photos, maps and "*in situ*" corrections.

It was used Spearman's correlation coefficient as the variables did not fit into normal distributions.

RESULTS

The sediment results from each sector showed a general kind of fine particle size, mainly silty. There was relatively small, but significant, difference in the D_{50} between sectors nearer to the Atlantic Ocean (sandy) and the sectors nearer to the internal bay of the inlet (silty-clay). In plot 10 we found the most important exception to the general tendency (Fig. 2). Shore width followed the same tendency with a high decrease from plot 1 to the last one. On the contrary, the values of sediment organic content increased, starting from the first sector.

All the variables used for characterising the sediment were significantly correlated.

In general, distribution of birds showed smaller densities while prenuptial migration than in winter. However, in both periods, birds reached their highest densities in the surroundings of Vicario Island (from plot 12 to 17), which was a very silty place. The densities decreased when going away from this area (Fig. 3).

In winter, we found the highest density (nearly 123 birds/ha) in sector 15, while during prenuptial migration – in sector 18 (74 birds/ha).

Table 1
Spearman's rank correlation coefficients between bird densities and sediment variables. Bold numbers with asterisks show statistically significant values: * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$.

Parameters	Wintering	Migration	Total
Clay	0.19	**0.44****	**0.27****
Silt	0.21	0.30	**0.23***
Sand: very fine	**-0.26***	**-0.52*****	**-0.34*****
fine	-0.22	**-0.44****	**-0.29****
mean	**-0.41*****	**-0.46****	**-0.43*****
coarse	**-0.49*****	**-0.51****	**-0.50*****
very coarse	**-0.52*****	**-0.46****	**-0.51*****
D_{50}	-0.19	**-0.44****	**-0.27****
Organic content	0.06	**0.44****	0.18
Shore width	**-0.23***	**-0.58*****	**-0.33*****

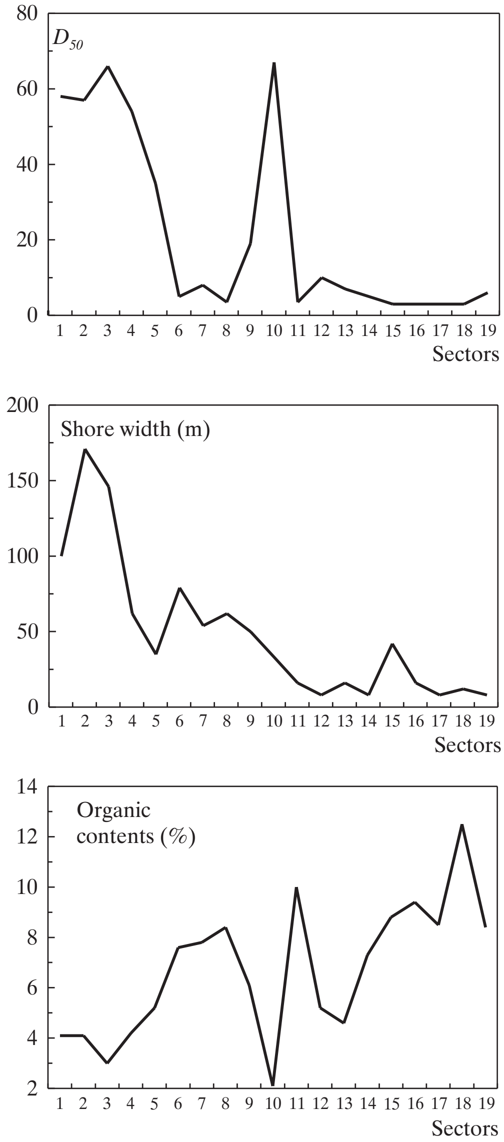

Fig. 2. Sediment variables in sectors

The correlation between bird densities and sediment variables are shown in Table 1. We found a high number of significant interactions. As a general rule, bird densities seemed to be positively correlated with silt, clay and organic content, and negatively correlated with D_{50}, the rest of the sediment particle size and shore width. Taking into account both periods, D_{50}, silt and organic content values were not significant during the winter, but highly significant during prenuptial migration.

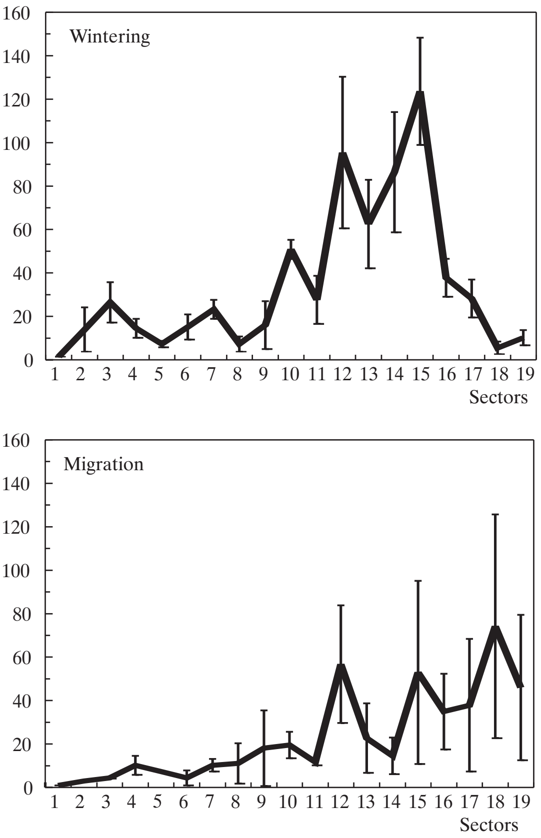

Fig. 3. Waders densities (birds/ha, ± SE) in sectors in winter and during spring migration

DISCUSSION

Distribution of sediment particle size in an estuary depends on the waves and currents action and, partly, on the geological history of the area, which determines the availability of sediment sizes. At the same time, the estuary width, and shore width, make the area more or less exposed to the waves and currents (Raffaelli and Hawkins 1996). As a consequence, Sancti-Petri Inlet is an area little influenced by waves and currents, and that is the reason why so small values are found for D_{50} (in this area the effect of salinity is minimal because of limited contribution of freshwater).

Even so, we found a gradient from the mouth (with bigger sediment sizes) to the highest part of the estuary (fundamentally silty-clayey one), as normally happens in many other areas (Evans 1965, Raffaelli and Hawkins 1996). This corresponds with the progressive narrowing of the estuary. Moreover, the organic content is closely related to the sediment particle composition (Fincham 1987), confirming the significant correlation, which has been obtained for both of them.

In general, in Sancti-Petri Inlet, birds preferably select silty and clayey areas, avoiding sandy sectors, where the sediment particle size is bigger. Besides, the first areas have also more organic content and narrower shores.

However, not all the species behave in the same way. The global tendency is determined by major species: Dunlin (*Calidris alpina*), Avocet (*Recurvirostra avosetta*) and Kentish Plover (*Charadrius alexandrinus*), in this order. However, behaviour of the less abundant species is not detected in global analysis and can not follow the general tendency. In our case, the best examples are Bar-tailed Godwit (*Limosa lapponica*) and Curlew (*Numenius arquata*). Both species feed principally near the mouth of the estuary, in sandy sectors with little organic content and wide shores (Cuenca and Hortas 1998). Nevertheless, the main prey species of these birds can be found in entire estuary, so, theoretically, they could feed also in areas, where they do not do it. Some factors, as bird morphology, interspecific competition and sensibility level towards disturbance, can help us to explain current distribution.

In addition, according to the results obtained in different periods, birds seem to be more selective during prenuptial migration than during winter. This agrees with the fact that during migration trophic requirements of birds are bigger than during winter (Zwarts *et al.* 1990). Moreover, the occurrence of significant positive correlation between distribution of birds and organic content in prenuptial migration *vs* winter can mean that birds exploit the invertebrate bloom from intertidal mud in this period (Masero 1998).

The choice of a feeding site, which is made by a bird, is based on existence of its prey species in that area and, in the affirmative case, on the density and accessibility of this prey enough to obtain favourable intake rates. Thus, it is obvious that areas where birds densities are higher have better food resources and, consequently, sediment characteristics of these areas gives better conditions for the maintenance of birds. Therefore, it is highly useful to know the characteristics of sediments (sediment particle composition, shore width and organic content) as a good device for estimating wader densities in an area.

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