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DIET AND PREY SELECTION OF SHOREBIRDS ON SALT PANS IN THE MONDEGO ESTUARY, WESTERN PORTUGAL

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Summary.—*Worldwide, salt pans provide an important foraging habitat for small migratory shorebird species.*

Aims: This study examines diurnal diet and prey size selection of kentish plover *Charadrius alexandrinus*, ringed plover *Charadrius hiaticula* and dunlin *Calidris alpina* on salt pans.

Location: The work was carried out on the salt pans of the Mondego estuary, western Portugal.

Methods: To study diet and prey availability, we collected bird droppings and sediment samples to a depth of 5 cm in salt pans heavily used by the birds. The proportion of each prey item was compared between faecal and sediment samples.

Results: The major patterns in diet among seasons and species were due to the consumption of Chironomidae and Ephydridae larvae, highly abundant during winter and spring, respectively.

Conclusion: All three shorebird species consumed the most abundant prey items and prey-sizes in the salt pans, notably larvae of *Chironomus spp*.

Keywords: Chironomidae, droppings, prey selection, salt pans, supratidal habitats.

Resumen.—A nivel mundial, las salinas ofrecen una importante área de forrajeo a las pequeñas especies de limícolas migratorios.

Objetivos: Se examina la dieta diurna y la selección en el tamaño de presa del chorlitejo patinegro *Charadius alexandrinus*, chorlitejo grande *Charadius hiaticula* y del correlimos común *Calidris alpina* en salinas.

Localidad: El trabajo se realizó en las salinas del estuario del río Montego, al oeste de Portugal.

Métodos: Para el estudio de la dieta y de la disponibilidad de presas se recolectaron muestras fecales y restos con un tamaño de unos 5 cm en las salinas utilizadas con asiduidad por las aves. La proporción de cada contenido se comparó entre las muestras fecales y los restos.

Resultados: El mayor consumo entre especies y estaciones fueron larvas de Chironomidae y Ephydridae muy abundantes en invierno y primavera respectivamente.

Conclusiones: Las tres especies de limícolas estudiadas capturaron a sus presas con más frecuencia en las salinas, sobre todo larvas de *Chironomus spp*.

Palabras clave: Chironomidae, restos fecales, salinas, selección de presas y hábitat.

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Introduction

Many shorebirds are long-distance migratory species and stop-over in intermediate geographic areas to meet their high energy requirements. The intertidal areas of estuaries support a large and diverse macrozoobenthic fauna and are the main stopover foraging habitats for shorebirds during the non-breeding season. During the last century, these habitats were altered and reduced by anthropogenic activities (Weber *et al*., 1999; Rogers, 2003; Burger *et al*., 2005). As a consequence of that reduction, the density of birds on the remaining areas has tended to increase, increasing also the impact of shorebirds on their food supplies and the interference between foraging birds (Davidson, 1990; Stillman *et al*,. 2003; Burger *et al*., 2005; Goss-Custard *et al*., 2006). Worldwide, supratidal habitats adjacent to intertidal areas such as salt pans may be complementary feeding areas, especially to small shorebirds (Masero *et al*., 2000; Múrias *et al.,* 2002; Lopes *et al.,* 2005), and they may help to buffer the degradation of natural intertidal habitats (Masero, 2003).

Most foraging studies on migratory shorebirds have concentrated on intertidal habitats (Stillman *et al*., 2005; Goss-Custard *et al*., 2006), so the diet of waders on intertidal areas is well known, especially in Northern Europe and North America (e.g. Pienkowski and Pienkowski, 1983; Mouritsen, 1994; Davis and Smith, 2001; Gillings *et al*., 2007; Dias *et al*., 2006). However, there is very little data on their feeding ecology and diet in salt pans. This study examines the diet and prey-size selection of the most abundant wader species (dunlin *Calidris alpina*, kentish plover *Charadrius alexandrinus* and ringed plover *Charadrius hiaticula*) in salt pans of the Mondego estuary, Portugal. Data were collected during the pre and post-breeding migrations as well as in the wintering period. As coastal salt pans may be an important foraging habitat for small shorebirds in periods of high energy requirements (Masero *et al.,* 2000; Masero, 2003; Sánchez *et al*., 2006), knowing the patterns of shorebird diet and prey selection in this supratidal habitat is relevant to the conservation of many declining shorebird species (Davidson, 1990; Piersma and Linström, 2004; Fox, 2003).

Methods

Study area

The Mondego estuary (1,131 ha) is located on the north-west side of Portugal (40º 08' N, 8º 50' W) and is divided into two arms, north and south, that surround an island, the Murraceira. It includes salt pans (305 ha; mostly traditional), mudflats (134 ha), salt marshes (62 ha), channels (438 ha) and fish farms (192 ha). Many salt pans and fish farms are located on the southern margin of the south arm and on Murraceira Island. A typical traditional salt pan in the in the Mondego is formed by a series of small pans (storage, evaporation and preparation, or crystallization pans) of decreasing depth (from 20 cm down to 2 - 3 cm) and increasing salinity, connected by drainage channels and sluices (Múrias *et al.,* 2002). The pans are connected to the estuary through a reservoir 80 cm deep. For more details about the study area see Múrias *et al.* (2002).

Diet and prey-size selection

Fresh faecal samples were collected during the spring and autumn migrations of 2002 and in the winter of 2002 - 03 at the high tide period on the most used salt pans. Storage and evaporation pans were the preferred feeding places for waders in the three studied seasons. Droppings were collected after confirming that single-species flocks were feeding in the area for at least 30 minutes (Cabral *et al*., 1999). We collected a total of 65 droppings of kentish plover (45 in May and 20 in February), 114 of ringed plover (42 in May, 27 in September and 45 in January) and 125 of dunlin (60 in April, 30 in September and 35 in January). Each sample was considered fresh if the faecal matter was still wet. All droppings were stored in groups of five per tube with 80 % alcohol for later examination in the laboratory. The hard parts in each group of droppings, mainly Diptera and Coleoptera larvae and adults, were separated from the other remains and identified to the lowest taxonomic level possible using identification guides (*e.g*. Richoux *et al.,* 2000).

The benthic fauna was sampled in April and September 2002 and in January 2003 by a series of five core samples (10.5 cm diameter) taken randomly from each salt pan where waders were observed foraging. Each core reached a depth of 5 cm which is the maximum penetrability for these salt pans, and corresponds also to the maximum depth that the three studied shorebird species can access with their bills (Zwarts and Wanink, 1993). Pelagic fauna was collected by a series of five samples (one per pan) with a zooplankton net (250-µm mesh), covering about 10 m distance on a diagonal direction through each salt pan. These samples were collected only in April 2002, since the water level in the most used salt pans was very low in autumn and winter. Samples were sieved through 0.5 mm mesh. The organisms collected were identified using identification guides and the abundance of benthic fauna was determined.

Statistical analysis

A principal component analysis (PCA) was used to describe patterns in the diet of waders among the seasons. The mean percentage (of the frequency of occurrence) of each invertebrate family found in droppings for each bird species and season were used as explanatory variables. The Ivlev index (E) = r - n / r + n was used to compare the proportion of ingested prey with their availability; where "r" corresponds to the abundance of a specific prey item in the diet and "n" corresponds to its abundance in the environment (Krebs, 1989). The Ivlev index values range from -1.0 to +1.0, revealing preference from +0.5 to +1.0 and rejection from -1.0 to -0.5. Some prey items were not collected in the sediment or in the water column (family Stratiomyidae and Dytiscidae), probably because of their rarity and therefore were excluded from the Ivlev index analysis. The extremely digested prey items and the pelagic fauna collected were also excluded from this analysis.

The total length of ingested *Chironomus spp.* larvae, the most abundant prey on the salt pans in winter, was estimated using a linear regression between the head maximal width (mm) and the total length (mm) of the larvae collected with the sediment. The percentage of abundance of each size class in the sediment was compared with that in the diet using a Spearman rank correlation (r_s), to test whether waders ingest *Chironomus spp*. larvae size classes in accordance with their abundance.

Results

We identified six insect families and two orders in the 304 droppings collected. The diet varied between species and seasons. In spring, Dytiscidae were very important for all shorebird species whereas Stratiomyidae and *Chironomus spp*. larvae were important for kentish plover and dunlin, respectively. In autumn, the Ephydridae larvae reached the highest frequency of occurrence in the diet of both ringed plover and dunlin. In winter Ephydridae and the *Chironomus spp*. were the most ingested prey by the three wader species (fig.1). The most abundant organisms in the sediment and water column during spring were Ephydridae and Chironomidae. Chironomidae were highly available in winter (fig. 2). Some drop-

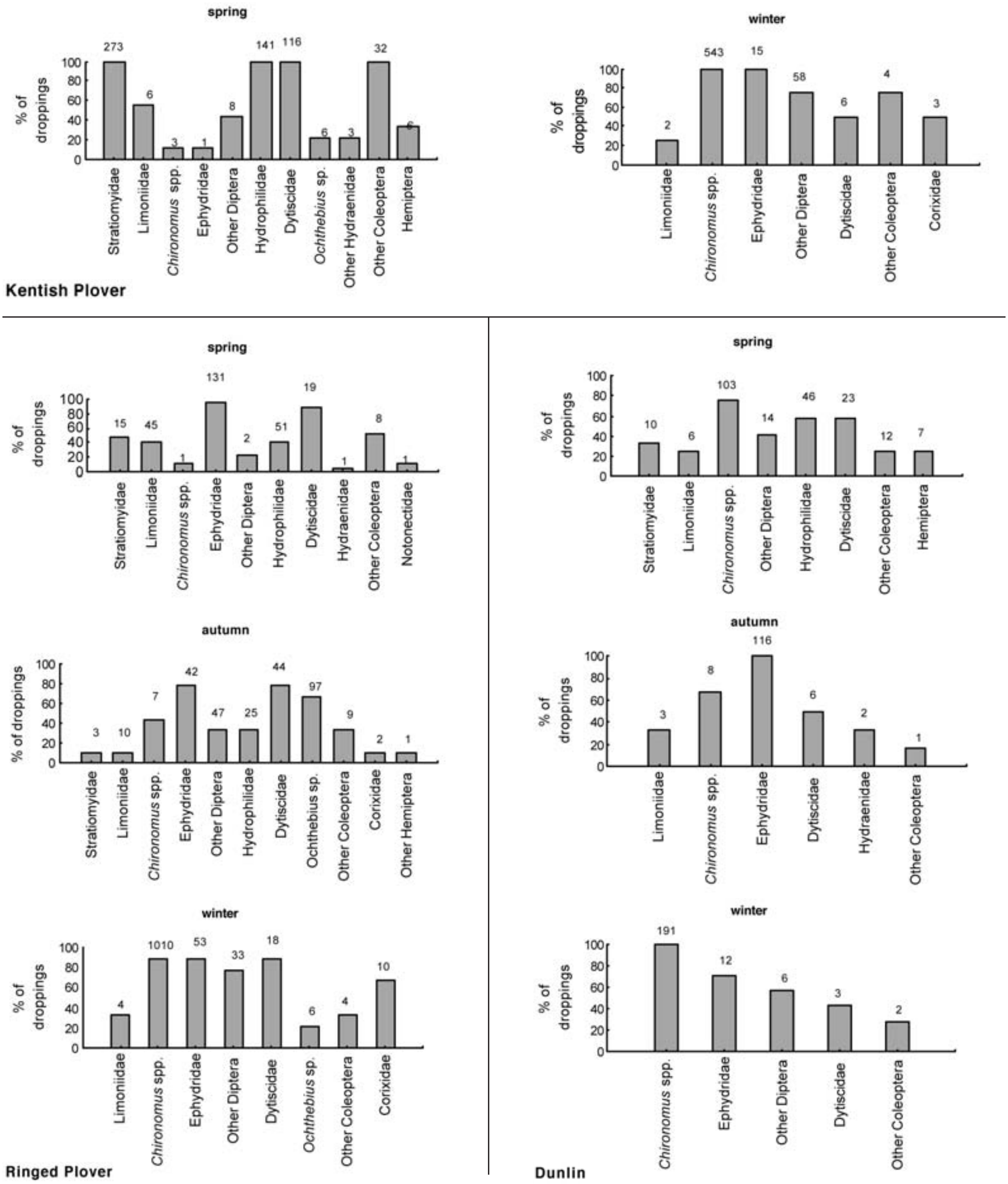

FIG. 1.—Diet of kentish plover, ringed plover and dunlin (% occurrence) in salt pans of the Mondego estuary. The number of each prey item that was present in droppings is indicated above the bars. Numbers of droppings collected: 65 from kentish plover (45 in spring and 20 in winter), 114 from ringed plover (42 in spring, 27 in autumn and 45 in winter) and 125 from dunlin (60 in spring, 30 in autumn and 35 in winter). *[Dietas del chorlitejo patinegro, chorlitejo grande y correlimos común (% de aparición) en las salinas del estuario del Montego. El número de cada contenido que apareció en los restos fecales se indica encima de las barras. Muestras: 65 en el chorlitejo patinegro (45 en primavera y 20 en invierno), 114 en el chorlitejo grande (42 en primavera, 27 en otoño y 45 en invierno) y 125 en el correlimos común (60 en primavera, 30 en otoño y 35 en invierno).]*

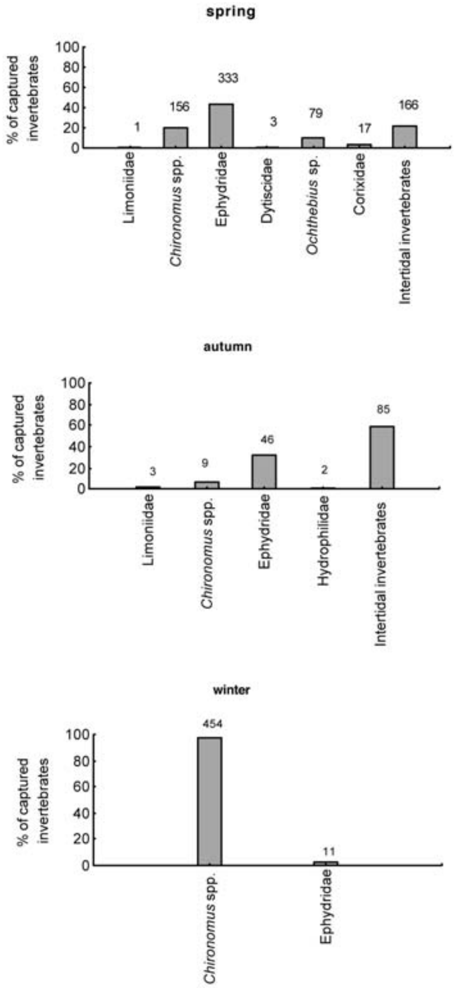

FIG. 2.—Prey abundance in the sediment of the salt pans during each season, sampled with sediment cores. The number of each prey item present in the samples is indicated above the bars. The category "intertidal invertebrates" include macrozoobenthos typical from intertidal mudflats (e.g. *Hydrobia sp*, *Scrobicularia plana*, *Amage adspersa*, *Corophium multisetosum*).

[Abundancia de presas en los sedimentos de las salinas en cada estación, muestreada en los sedimentos. El número de cada contenido presente en las muestras se indica encima de las barras. La categoría "invertebrados intermareales" incluye a los típicos del macrozoobentos de las marismas intermareales (p.e. Hydrobia sp, Scrobicularia plana, Amage adspersa, Corophium multisetosum*).]*

TABLE 1

Summary of the principal component analysis for the seven diet variables on salt pans. (* = significant correlations, $P < 0.05$). Eigenvalues, variance explained and correlation matrix of the original diet variables with the first two principal component axes are presented.

[Resumen del análisis de componentes principales para las siete variables en las salinas. (= correlaciones significativas, P < 0.05). Se presentan la porción de la varianza total explicada por un componente, la varianza explicada y la matriz de correlación de las variables originales de la dieta, con los dos ejes principales.]*

	PC1	**PC2**
Eigenvalues	3.47	1.89
Variance explained (%)	49.53	27.04
Cumulative variance (%)	49.53	76.57
Variables		
Chironomus spp. (larvae)	-0.79*	0.59
Ephydridae (larvae and pupae)	-0.10	-0.97*
Unidentified Diptera	0.89*	0.29
Hydrophilidae (larvae and adults)	0.90*	0.24
Unidentified Coleoptera	0.88*	0.02
Hemiptera	0.48	0.66
Other organisms	0.008	0.05

pings also contained marine prey. The percentage occurrence of marine prey items in the kentish plover spring faecal samples was 1.58; for the ringed plover spring, autumn and winter faecal samples it was 4.79, 8.65 and 0.17, respectively, and for the dunlin spring, autumn and winter faecal samples it was 4.69, 0.67 and 2.11, respectively.

The PCA reduced the seven original variables to two independent principal components that explained 76.57 % of the total variance (table 1). The first component (PC1) was positively correlated with the proportion of Hydrophilidae, "unidentified Diptera" and "unidentified Coleoptera" and negatively correlated with the proportion of *Chironomus spp*. The second component (PC2) was negatively correlated with the proportion of Ephydridae (table 1). Figure 3 represents the scores of the three wader species in each season on the two principal components. The first component separated the waders' diet into two groups. The first group includes the winter diet, dominated by *Chironomus spp.* and the dunlin autumn diet, whereas the second group includes all the spring diets and the ringed plover autumn diet. The separation on the second component was not very clear, but it seems that diets with more Ephydridae (dunlin diet in autumn and ringed plover diet in spring) were separated from the others.

In spring, the Ivlev index (IvI) suggested that the three wader species preferred Limoniidae larvae and Dytiscidae adults (IvI for Limoniidae: 0.71 for dunlin and kentish plover, and 0.96 for ringed plover; IvI for Dytiscidae: 0.89 for dunlin, 0.92 for kentish plover and 0.88 for ringed plover) and rejected *Ochthebius sp.* adults (-0.95 for dunlin, -0.93 for kentish plover and -0.98 for ringed plover). In autumn, ringed plovers showed also a higher preference for Limoniidae larvae and Hydrophilidae (0.54 and 0.92, respectively). In the case of dunlin, the prey items were probably eaten according to their availability because there was no selection and/or rejection by the birds. Finally, in winter, pupae of *Chironomus spp.* were a preferred prey item for all birds (0.66 for dunlin, 0.95 for kentish plover and 0.85 for ringed plover), in contrast with *Chironomus spp.* larvae that were rejected by dunlin and kentish plover (-0.59 and -0.62, respectively). The Ephydridae larvae were also preferred by ringed plover (0.88). The remaining prey items were apparently ingested in relation to its availability in the salt pans.

The length of ingested *Chironomus spp.* larvae was estimated from their maximum head width (mhw) visible in the faecal samples: larva length (mm) = -3.453 + 31.244 x mhw (mm), ($r = 0.9412$; $p < 0.00001$; $n = 62$). *Chironomus spp.* larvae from all size classes available in the sediment (and in the water column in spring) were eaten by dunlin, kentish plover and ringed plover, but the more abundant size classes in the sediment were taken in a greater proportion (fig. 4).

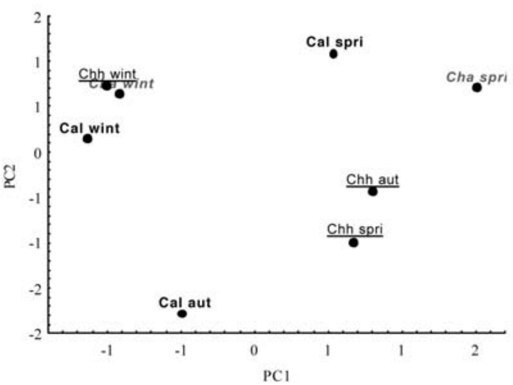

FIG. 3.—Distribution of the waders diet scores on salt pans for each season along the two principal components (PC1 and PC2). Cal, Cha and Chh correspond to *Calidris alpina*, *Charadrius alexandrinus* and *Charadrius hiaticula*, and spri, aut and wint correspond to the spring, autumn and winter, respectively.
[Distribución de la dieta de las limícolas en las salinas en cada estación a lo largo de los dos componentes principales (PC1 y PC2). Cal, Cha y Chh corresponden respectivamente a Calidris alpina, Charadrius alexandrinus *y* Charadrius histicula*, y spri, aut y wint a primavera, otoño e invierno.]*

DISCUSSION

The salt pans of the Mondego estuary provided important food resources for dunlin, kentish plover and ringed plover, especially in terms of insect larvae (*Chironomus spp.* and Ephydridae). Overall, the macroinvertebrate species found in salt pans were different and smaller than those of the surrounding mudflats (see Lopes *et al.,* 1998; Cabral *et al.,* 1999; Pardal, 1998; Cardoso *et al.,* 2004; Múrias *et al.*, 2005) but their abundance and availability provided

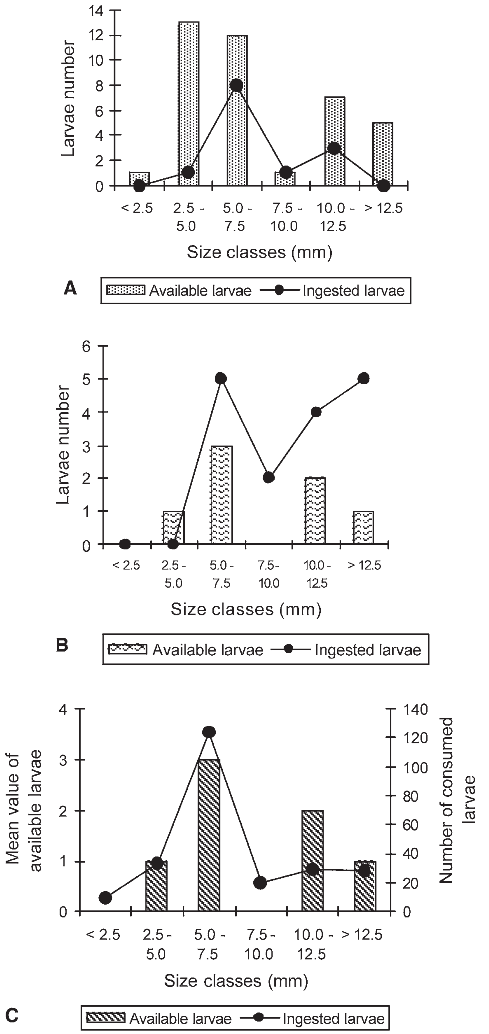

FIG. 4.—Comparison between the length distribution classes of ingested and available *Chironomus spp.* larvae in salt pans for dunlin in spring (A), kentish plover (B) and ringed plover (C) in winter. Spearman correlation coefficient: (A) $r_s = 0.57$, $n = 6$, $P = 0.24$; (B) $r_s = 0.65$, $n = 6$, $P = 0.16$ and (C) $r_s = 0.88$, $n = 6$, $P = 0.02$.

[Análisis comparativo entre las clases de distribución de la dieta y la disponibilidad de larvas de Chironomus spp. *en las salinas, para el correlimos común en primavera (A), y para el chorlitejo patinegro (B) y chorlitejo grande (C) en invierno. Coeficiente de correlación de Spearman: (A) $r_s = 0,57$, $n = 6$, $P = 0,24$; (B) $r_s = 0,65$, $n = 6$, $P = 0,16$ y (C) $r_s = 0,88$, $n = 6$, $P = 0,02$.]*

an easy food supply to the three shorebird species, in particular during the winter. The presence of marine prey in the droppings collected in salt pans suggests that shorebirds had been feeding in the mudflats and moved to salt pans to complement their foraging activities. Prey items in salt pans could even be more available to small shorebird species then those of intertidal mudflats for the following reasons: (i) they are more visible as a consequence of their high abundance and smaller dispersion area; (ii) they live in the water column and on the surface of the sediment and cannot hide from predators in the sediment and (iii) many species in larval or pupae stages move slowly and are easily captured by birds. Most wader studies use faecal analysis to study diet, because it allows the rapid collection of large samples and enables reliable comparisons between years and locations. The disadvantage of this method is the impossibility of identification and quantification of smooth prey (Mouritsen, 1994). However, almost all of the invertebrates that live in salt pans had hard structures that were easily found in birds droppings.

The principal component analysis showed that *Chironomus spp.* and Ephydridae larvae were the main differences in wader diet between seasons and species. In 1995, Múrias (1997) identified similar invertebrate organisms in one salina heavily used by waders in the Mondego estuary. Our results show that chironomid larvae (*Chironomus spp.*) were very abundant on the studied salt pans in spring 2002 and especially in winter 2002-03 (fig. 2). In other wetlands as in the Odiel salt pans area (composed of a traditional salina and an industrial salina complex), Spain, Sánchez *et al.* (2006) verified that chironomid larvae were present in the sediment throughout the year in 2001, but they showed a marked pattern in seasonal abundance with the first and strongest peak in May (mean of 11,835 ± 1,470 larvae m^2, mean ± SE, n = 804) and a second peak in November (9,933 ± 1,063 m^2). Batty (1992) confirmed the abundance of Chironomidae (more than 5,000 individuals/ m^2) in winter and in the autumn on other salt pans in the Algarve, Portugal. Many of the invertebrate organisms present in the samples were identical to those found in our study. The exceptions were coleopterans from the families Hygronemidae, Hygrobiidae and Hydrobiidae, and Hemiptera, family Corixidae, which, in our study, were found only during spring. In Ria Formosa, Algarve, Rufino *et al.* (1984) showed that, Chironomidae (0 - 1,300 ind/m^2) jointly with Ephydridae (0 - 440 ind/m^2) larvae and *Hydrobia ulvae* were the most potential prey for waders. The ingestion of *Chironomus spp.* and Ephydridae larvae appeared to be a consequence of its high abundance in winter and spring, respectively, which means that waders in the Mondego estuary had an opportunistic feeding behaviour.

As well as feeding on chironomids larvae, shorebirds also took pupae. The fact that during spring Chironomidae larvae were of little importance for kentish and ringed plovers and very important for dunlin, may be explained by the fact that the two plover species often foraged on the margins of the salt pans, where Chironomidae are less abundant (pers. observation). In the Mondego estuary Ephydridae larvae were abundant in spring but in the Algarve their density values were higher in winter (Rufino *et al*., 1984). In the salt pans of Cádiz Bay, Pérez-Hurtado *et al.* (1997) verified that the Diptera prey in the winter diet of kentish plover, ringed plover and redshank *Tringa totanus* were mainly Chironomidae larvae, and the most common Coleoptera prey were *Enochrus*, *Ochthebius*, *Potamonecte*, *Berosus* and *Girinus*. Previous studies in other regions have shown that shorebirds respond to variation in prey density, with a positive correlation between prey density and bird density in order to maximize energy intake and consequently their survival chances (Goss-Custard, 1970; Goss-Custard *et al*., 1977, 1991; Velasquez, 1992; Piersma *et al.,* 1993; Masero, 2002; Sánchez *et al*., 2006). *Chironomus spp.*, Ephydridae, Hydrophilidae and Hydraenidae (genus *Ochthebius*) are very resistant to drastic environmental variations, they can tolerate high salinity and low oxygen concentration and are therefore abundant in different kinds of salt pans (Armitage *et al*., 1995; Amaral and Costa, 1999). Overall, invertebrates inhabiting salt marsh sediments are generally eurecious species that can tolerate strong daily and seasonal fluctuations of environmental conditions (Kneib, 1984).

In relation to the size of ingested *Chironomus spp.* larvae, the results showed that most waders tended to eat the most abundant sized larvae. This feeding behaviour has been described for many shorebird species in relation to several prey items. For example, Davis and Smith (2001) showed that american avocets (*Recurvirostra americana*) and long-billed dowitchers (*Limnodromus scolopaceus*) at stopover sites located in 60 playa lakes on the Southern Great Plains (USA), selected small prey (0.1 – 5.0 mm) as a function of being more abundant in beaches than large prey (> 10 mm). Masero and Pérez-Hurtado (2001) also showed that in the interidal area of Cádiz Bay overwintering redshanks seemed to take the size of *Hydrobia ulvae* and *Nereis diversicolor* that was most abundant on the mudflats, below a maximum size of 5 mm and 80 mm, respectively. They also observed that the supratidal habitat was used as a supplementary foraging ground at high tide in winter, but was the main foraging ground in the pre-migration period, contributing significantly to the maintenance of the population of overwintering redshanks.

The importance of salt pans as a supplementary feeding habitat to small shorebirds at high tide depends on the species and/or the time of the year considered (Rufino *et al*., 1984; Múrias, *et al*., 1997, 2002; Luís, 1999; Lopes *et al*., 2001). For example, Masero (2003) at Cádiz Bay, Spain, verified that in the winter of 1994 - 95, dunlin, curlew sandpiper *Calidris ferruginea* and sanderling *C. alba* predominantly used the mudflats, whereas little stint *C. minuta* fed mainly on one available salt pan, but in the 1995 pre-migration fattening period, all species preferred to feed in the salt pan. On the other hand, the low use of salt pans by large shorebird species may be explained by their difficulty in capturing small prey items due to their heavy bills (Verkuil *et al*. 1993). A second possible explanation is salt stress, because the foraging mechanism of some shorebirds does not prevent the ingestion of large amounts of hypersaline water during the capture of small prey items in shallow saline waters. Therefore, the costs of salt processing may constrain the maximum amount of small prey that can be ingested (Masero, 2002).

Overall, considering that the salt pans are the most heavily used supratidal habitat by small shorebirds during the high tide period along all the coasts of the Iberian Peninsula (Masero and Pérez-Hurtado, 2001; Luís *et al*., 2002; Masero, 2003; Múrias *et al.,* 2005), this habitat represents a valuable buffer wetland against the impact of natural habitat loss (Weber *et al*., 1999). In the last ten years, the abandonment and/or replacement of traditional salt pans by fish ponds is increasing (Múrias *et al.,* 2002), and their maintenance is therefore important because it increases the area available for foraging during both tidal periods, the feeding time (Luís *et al*., 2002; Múrias *et al.,* 2002; this study) and provides superabundance of food resources (this study).

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