USE OF TRADITIONAL SALINES BY WADERS IN THE MONDEGO ESTUARY (PORTUGAL): A CONSERVATION PERSPECTIVE

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SUMMARY.—Use of traditional salines by waders in the Mondego estuary (Portugal): A conservation perspective. Traditional salines are important and threatened feeding habitats for migratory and wintering waders in most Mediterranean estuaries. The salines of Mondego estuary (Western Portugal) are among the last ones of this type in Portugal. They were used as feeding areas by 42% (over low-tide) to 71% (over high-tide) of all waders present in the estuary. Although most species showed a flexible response to the habitat's heterogeneity, and can still use the salines for a long time after salt production has ceased, there was a strong tendency for salines that are still producing salt ('active salines') to be used more by waders than inactive or abandoned ones. The loss of feeding opportunities resulting from the abandonment of the salines could amount to a 90% loss of space and a 38% loss of feeding time for some species. If all the active, inactive and abandoned salines were to be totally removed, the extra number of bird feeding-hours that the remaining intertidal flats would have to provide would be an additional average of 37% of those that they provide at present, although varying across bird species from 0.5% to 90%. The loss of all the salines could therefore be detrimental, in the long-term, for several wader species.

Key words: feeding, habitat loss, management, Mondego estuary, traditional salines, waders.

RESUMEN.—Uso de salinas tradicionales por limícolas en el estuario del Mondego (Portugal): una perspectiva de conservación. Las salinas tradicionales son hábitats de alimentación importantes y amenazados para los limícolas migradores e invernantes en la mayor parte de los estuarios mediterráneos. Las salinas del estuario del Mondego (oeste de Portugal) están entre los últimos restos de este tipo de hábitat en Portugal, y fueron usadas como áreas de alimentación por entre el 42% (en marea baja) y el 71% (en marea alta) de todos los limícolas presentes en el estuario. Aunque la mayor parte de las especies presentaron un comportamiento flexible y pueden usar las salinas durante bastante tiempo tras su abandono, hubo una fuerte tendencia por parte de los limícolos a usar más las salinas activas, donde aún se produce sal, que las salinas inactivas o abandonadas. La pérdida de oportunidades de alimentación resultante del abandono de todas las salinas podría ser del orden del 90% en términos de superficie y del 38% en términos de tiempo de alimentación para algunas especies. Si todas las salinas activas, inactivas y abandonadas fuesen eliminadas, las llanuras intermareales del estuario deberían proporcionar un 37% más tiempo de alimentación en promedio que en la actualidad, aunque este porcentaje podría variar entre especies del 0,5% al 90%. La pérdida de las salinas tradicionales tendría por tanto un efecto negativo a largo plazo sobre varias especies de limícolas.

Palabras clave: alimentación, estuario del Mondego, limícolas, manejo, pérdida de hábitat, salinas tradicionales.

Introduction

Migrating waders wintering or on passage through an estuary must find enough food for self-maintenance and/or for putting on fat to continue their migratory journey. Being mostly constrained to feed in soft intertidal sediments, they are often confined to obtaining their energy requirements at low-tide, when these areas are exposed for up to 8.5 hours per tidal cycle (Prater, 1981; Puttick, 1984). A series of biotic and abiotic factors, such as high bird densities, short daylength, low temperatures and adverse weather conditions, acting in iso-

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lation or combination, may further constrain the potential rate of food consumption (Burger, 1984; Evans & Dugan, 1984; Puttick, 1984). When they do, waders feed for longer over low tide (see Puttick, 1984 for a review). However, this alternative method may sometimes still be insufficient for them to fulfil their energetic demands (Davidson & Evans, 1986) and many may use supplementary man-made or man-modified supratidal habitats when low-tide feeding habitats are unavailable or their use is restricted (Davidson & Evans, 1986; Goss-custard *et al.*, 1996).

The salines, or saltworks, are among the most important man-made habitats for shorebirds in parts of southern Europe (Rufino et al., 1984; Martínez-Vilalta, 1985; Britton & Johnson, 1987; Rufino & Neves, 1992; Pérez-Hurtado & Hortas, 1993a, 1993b; Casini et al., 1995; Aymerich, 1996; Múrias *et al.*, 1997; Sadoul et al., 1998). They are used both at lowtide, as alternative feeding areas to the intertidal mudflats, and at high-tide, for supplementary feeding, depending on the species concerned and/or the time of the year (Masero et al., 2000). Recent findings suggest that this habitat may be of particular value for waders preparing for the pre-nuptial migration (Masero et al., 2000; Masero & Pérez-Hurtado, 2001).

In Portugal, the salt industry has been in a deep crisis since the 1930s (Rufino & Neves, 1992; Neves & Rufino, 1995). Despite government intervention and mechanisation in 1950-60, salines have been increasingly abandoned or, more recently, converted to more profitable activities, such as rice production or fish-farming (Rufino & Neves, 1992; Neves & Rufino, 1995). These changes would be expected to have direct, and possibly significant, impacts on wading birds. Such impacts, however, are likely to vary according to the type of saline that is removed. Although traditional salines are smaller than the mechanised industrial or partially mechanised semi-industrial ones, they consist of a large number of ponds and pond types, thus providing more diversified environmental conditions (Vieira, 1989; Neves & Rufino, 1995). Moreover, as each saline is individually owned, the management actions, such as the emptying and flooding of the ponds, usually differ between salines during the 'salt season' of March to October. This diversity means that one or more of the ponds is

usually available for waders at any one time and also provides the birds with a variety of ponds where they can feed.

Such temporal reliability and spatial heterogeneity in the feeding conditions may be beneficial to waders. For example, although the precise species of invertebrate prey available to waders may vary from place to place, the most abundant species across all types of salines are aquatic insects (e.g. Dytiscidae), aquatic forms of terrestrial insects such as dipteran larvae, crustaceans (Artemia spp.) and gastropods (e.g. Hydrobia ulvae) (Rufino et al., 1984; Britton & Johnson, 1987; Amaral & Costa, 1999; Masero et al., 1999). Other invertebrates, such as polychaetes (Nereis spp., Capitella spp.), are also common. However, the occurrence and/or abundance of each species/group vary from pond to pond and seasonally, according to their life-cycles (Britton & Johnson, 1987; Amaral & Costa, 1999). The net result of this temporal and spatial heterogeneity in the habitat is that, at any one time, there is usually at least one pond which contains a good supply of available food for wading birds.

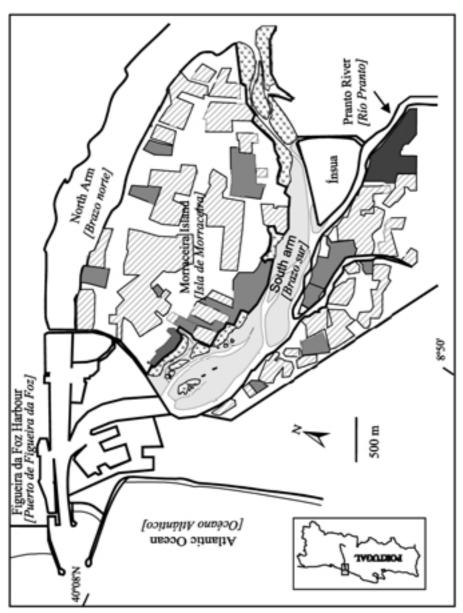
Most Portuguese work on the significance of salines for waders (Rufino *et al.*, 1984; Batty, 1992; Kew *et al.*, 1995; Neves & Rufino, 1995) refers to industrial or semi-industrial salines in the Southern estuaries of the Tagus, Sado and in the Algarve. Information from the northern Portuguese estuaries of the Mondego and Ria de Aveiro, where the traditional type of salines is predominant, is still scarce (Múrias *et al.*, 1997; Luís, 1999). This paper aims to begin filling that gap.

Accordingly, this study was developed (i) to investigate the importance of the traditional salines as feeding areas for waders in the Mondego estuary throughout the year; (ii) to establish the possible relationship between the use made of salines by birds and their management; and (iii) to make an appraisal of the potential effect of the destruction of the salines on the feeding opportunities for waders provided by the estuary.

MATERIAL AND METHODS

The Mondego estuary and its system of salines

The Mondego estuary is located on the Western coast of Portugal (40°08' N, 8°50' W) and



Mapa del estuario del río Mondego en el que se indica la zona principal de salinas tradicionales (gris claro), piscifactorías (gris oscuro) y salinas industriales (negro), así como las áreas de fangos intermareales de la desembocadura del brazo sur del río. Las salinas abandonadas del brazo norte y de la Ínsua Fig. 1.—Map of the Mondego estuary showing the location of the main area of traditionally-managed salines (light-grey), fish-farms (dark-grey) and industrial salines (black), as well as the mudflat area of South arm. The abandoned salines in the North arm and in the "Insua" are not represented. no están representadas.]

is presently about 7 km long by 2-3 km wide, covering an area of approximately 1131 ha of wetland habitats (Múrias *et al.*, 1997). Seawards, the river is divided into two arms surrounding an alluvium-formed non-tidal island, the Morraceira (Fig. 1). Of the total area of wetlands available for waders, only 134 ha (11.8%) is intertidal. The remainder is formed by saltmarshes (5.5% of the area) and humanmade or modified supra-tidal habitats: salines (27.0%), fish-farms (17.0%) and channels (38.7%; Múrias *et al.*, 1997).

The Mondego's salines extend upstream for approximately 5 km from the estuary mouth and occur in three groups: (1) the Vila Verde group (constructed in the XIIth century), situated in the north arm (12.8 ha) and levelled or abandoned in the late 1980s; (2) the Morraceira Island group (xVIth century), representing 82.5% (191.0 ha) of today's salines; and (3) the Lavos group (XIIIth-XIVth centuries), in the south arm (101.3 ha; Múrias, 1997). Most (73.7%) of the salines are, or were, of the traditional type, but many have been abandoned in the past two de-

cades (30.0% of the present area), being converted to fish-farms (17.6%) or levelled for various purposes (3.0%; Table 1).

A typical traditional saline in the Mondego is formed by a series of small ponds (storage, evaporation and preparation, or crystallisation ponds) of decreasing depth (from 20 cm down to 2-3 cm) and increasing salinity, connected by drainage channels and sluices. The sluices opening to the estuary usually remain functional in the abandoned salines, thereby converting them into saltlakes and/or saltmarshes. Storage and evaporation ponds are the preferred feeding places for waders in the saline. The ponds are connected to the estuary through a reservoir 80 cm deep (Lopes, 1955). An average saline, including all pond types but excluding the reservoir, has an area of 4.0 ha (Lopes, 1955). The "salt extraction season" usually lasts from April to September/October (Lopes, 1955; Rufino & Neves, 1992; Neves & Rufino, 1995). During this period, the water level in the ponds is carefully controlled in the managed salines, whereas in the inactive or abandoned ones is totally depen-

Present-day land use (1993-1995) of the salines that existed in 1955 in the Mondego estuary, and area covered by each land-use (*: Excluding two salines for which there were no data available on current uses). [Usos actuales (1993-1995) de las salinas que existían en 1955 en el estuario del Mondego, y área dedicada a cada uso (*: excluidas dos salinas sobre las que no existen datos sobre usos actuales).]

TABLE 1

	Morra	ceira*	La	vos	Vila V	Verde*		estuary estuario]
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Salines, marine [salinas marinas]								
Active	72.0	37.7	55.5	54.8		_	127.5	41.8
[activas]								
Inactive	83.1	43.5	4.5	4.4	5.9	46.0	93.5	30.7
[inactivas]								
Levelled	2.5	1.3	_	_	6.8	54.0	9.3	3.0
[rellenadas]								
Total marine salines	157.6	82.5	60.0	59.2	12.7	100.0	230.3	75.5
[total salinas marinas]			20.0	20.6			20.0	
Salines, rock-salt	_	_	20.9	20.6	_	_	20.9	6.9
[salinas de sal gema] Fish-farms	22.4	17.5	20.4	20.2			£2.0	17.6
[piscifactorías]	33.4	17.5	20.4	20.2	_	_	53.8	17.6
Total Area	191.0	100.0	101.3	100.0	12.7	100.0	305.0	100.0

dent on the rainfall and evaporation cycle. After salt extraction, from November to March, the water level in both the active and inactive salines is controlled only by natural processes (rainfall and evaporation conditions).

In general, active salines present more stable environments than the inactive ones (Neves & Rufino, 1995), at least outside winter. After abandonment, a saline goes through a series of successional steps that usually end up in a brackish lagoon or an area of salt-water marshland. The fate of each individual saline, as well as the rate of transformation, is highly variable, depending on a combination of factors, such as the degree of connection between the ponds and river, the soil permeability and the pattern of colonisation by halophytic plants (Neves & Rufino, 1995). Therefore, amongst those abandoned within the last 20 years or so, a variety of habitats is provided by salines that were actually abandoned at the same time.

Bird counts

All the birds in the study area were counted by censuses made over the intertidal flats and on 26 salines on one or two occasions each month from July 1993 to May 1995, at both high-tide and low-tide. The counts covered the mudflats and all of the salines in the South arm and 91% of those on Morraceira island, and were made from the banks of each saline and at three points along the South arm of the estuary, using $10 \times$ 50 binoculars and a $30-90 \times 50$ telescope. Each count begun one hour before the peak tide, and lasted approximately for two hours, depending on the number of birds present. To control for possible seasonal time-of-day effects, all counts were performed in mid to late morning. In each count, whether the saline was active or inactive was noted, along with whether birds were feeding and their location within the saline. We used the total numbers of birds counted in all habitats, whether feeding or not, as an estimate of the total number of birds in the study area. For this we used the low-tide counts, rather than the high-tide ones, because some flocks of roosting birds occurred at high-tide outside our study area. In contrast, at low-tide, frequent widespread checks showed that all the birds in the Mondego occurred in the 26 salines and the intertidal mudflats that we counted.

Basic analysis

Counts were grouped by year and season, the latter being defined as follows: spring: March to May inclusive, 12 counts; summer: June and July inclusive, 5 counts; autumn: August to October inclusive, 8 counts; and winter: November to February inclusive, 13 counts. However, for most analyses, we divided the year into two periods: spring to autumn and winter. This was done in order to explore the differences between the "salt extraction" period and the rest of the year. In some cases, count data were transformed into densities, expressed as the number of birds/10 ha rather than the numbers of birds/ha due to the often very small densities involved. Except where stated, only low-tide counts were used to calculate densities in order to minimise the chances of including non-feeding birds which had moved to the salines to roost over the high-tide period. Statistical tests used included one- and multi-way ANOVA's, simple and multiple regressions, preceded, whenever necessary, by data transformations ($\log_{10}(n+1)$).

To assess the dispersion of the waders between the salines, we calculated a simple variance-to-mean ratio, the Index of Dispersion (I.D.; Eliott, 1977), testing for random distribution (see Table 3 for details). All species occurring in winter, spring and autumn in the 26 salines of Morraceira Island surveyed during 1994-95 were included in the analysis.

Calculating the feeding opportunities provided by the salines

The importance of an area for feeding can be viewed in terms of both its spatial and temporal dimensions. The combined dimensions of feeding space and time available for feeding were termed, in this study, *feeding opportunities*, although, for the sake of the analysis, they were treated separately.

The spatial dimension

It is not easy to assess clearly the value of an area for feeding, as its quality will largely depend on the availability of food and on the way it changes throughout the tidal cycle, from sea-

son to season, and from year to year (Zwarts & Wanink, 1993). However, an approximate idea can be obtained by calculating the total amount of feeding done by waders in that area over a given period. The easiest and least ambiguous measure to use is the total number of bird-feeding hours during a complete tidal cycle, i.e., the number of bird feeding x the number of hours available for feeding in a given habitat over a single tidal cycle. This measure is easy to understand and can be readily used to assess the effect of the loss of space: if the area is destroyed, the birds will lose the number of feeding-hours that they previously used in that area. The duration of an average tidal cycle for the Mondego estuary, as calculated from published tide-tables (Anonymous, 1995), was set at 12.5 hours.

Three main assumptions were made in these calculations. First, birds were assumed to be either salines birds (SB), those that remained in the salines throughout the tidal cycle (12.5 hours), or mudflat birds (MB), those which fed on the mudflats at low-tide but moved to the salines at high-tide, where they could feed for up to 4.5 hours before returning to the mudflats on the receding tide. Second, it was assumed that birds displaced from the salines by a change in their use would settle preferentially on the mudflats rather than in the fish farms. Finally, it was assumed that the data we obtained during a single census applied to the whole stage of the tidal cycle represented by such census. For the MB group, this means that we assumed that the entire high water period, for example, was represented by the single census made over high tide. For the SB group, whose activities were unaffected by the ebb and flow of the tide, we assumed that a census made at low water represented their activities over the entire tidal cycle.

On the basis of these assumptions, the following equations were used to calculate the number of feeding-hours of each group in the mudflats and/or salines:

$$SFH = FS_{LW} \times 12.5 \text{ h}$$
 [Eq. 1]
 $MFH = M_{LW} \times 8 \text{ h} + [(FS_{HW} - FS_{LW}) \times 4.5 \text{ h}]$ [Eq. 2]

where:

SFH: number of bird-feeding hours of the SB group,

MFH: number of bird-feeding hours of the MB group,

M_{LW:} number of feeding birds in the mudflats at low-tide,

FS_{HW}: number of feeding birds in the salines at high-tide,

FS_{LW}: number of feeding birds in the salines at low-tide.

The temporal dimension

The removal of the salines would remove all the feeding space presently used by the SB group, which would lose all the current feeding time as well, as all their feeding takes place in this habitat. The MB group, on the other hand, would only lose part of their present feeding time, i.e. the one corresponding to the feeding in the salines at high-tide. Therefore, to calculate the loss of feeding time for the MB group we first calculated the average number of hours that the birds spent feeding per tidal cycle in both habitats:

$$FT = (FM \times 8 \text{ h}) + (FS \times 4.5 \text{ h})$$
 [Eq. 3]

where

FT: time (in hours) spent feeding by an average mudflat bird over a 12.5 hr tidal cycle.

FM: proportion of the mudflat birds that were feeding when censused during the 8 hr low-tide period when the mudflats were exposed.

FS: proportion of the mudflat birds that were counted feeding in the salines over the 4.5 hour high-tide period.

Were all salines to be lost, the mudflat birds would only have 8 hours available per tidal cycle in which to feed. If FT = 8 h for a particular species, mudflat birds were assumed to be able to satisfy most of their energetic requirements during the time for which the mudflats were exposed over the low-tide period. But for the birds for which FT > 8 h, it was necessary to calculate the amount by which their present-day feeding time exceeded the maximum possible available feeding time in the mudflats alone (8 hours), as would be the case if the salines were removed. We call this the Lost Feeding

Time (LFT), the percentage of total feeding time of the MB group that is presently spent in the salines at high-tide and so would be lost if the salines were to disappear. To do this, the following equation was used

LFT =
$$[(FT_1 - 8 h) / 8 h] \times 100$$
 [Eq. 4]

RESULTS

How much do waders use the salines for feeding?

The salines were used for feeding at both low-and high-tide by most of the species examined (Table 2). In all species, the average proportions of the total population that were recorded feeding when censused over low-tide and over high-tide were very similar (Table 2). Excluding the large-bodied species Whimbrel Numenius phaeopus, Avocet Recurvirostra avosetta and Grey Plover Pluvialis squatarola, between 42% and 71% of all birds present on the estuary, on average, fed in the salines, whether it was at high-tide or low-tide. For most species, these proportions did not vary between the seasons or years. There were, however, some exceptions, both at low-tide and at high-tide. The proportion of Little Stints Calidris minuta feeding in the salines at low-tide significantly increased in 1994-95, as compared to the previous year (two-way ANOVA, $F_{1,14}$ = 5.84, P = 0.046). Also, a significant, albeit weak interaction between season and year in the proportion of feeding birds was found in the Redshank *Tringa totanus* ($F_{1.9} = 5.29$, P =0.046). This might have been due to the small proportions of birds that fed in the autumn 1993 as compared to the spring that year and to the spring and autumn of 1994. However, a multiple comparison (Tukey test) did not detect any significant groups that might confirm this hypothesis. At high-tide, the exceptions to the general pattern were the Black-winged Stilt Himantopus himantopus, which tended to feed more in the salines in spring $(F_{214} = 14.98, P =$ 0.0003) and the Kentish Plover *Charadrius ale*xandrinus and the Dunlin Calidris alpina, for which an interaction term between season and year was significant ($F_{2,24} = 3.77$, P = 0.037 and $F_{2,25} = 4.13$, P = 0.016, respectively). While it was not possible to establish how this significant interaction occurred in the Kentish Plover, in the Dunlin it was entirely due to an increase in the proportion feeding in autumn of 1994 as compared to the previous year (Tukey test). Overall, the Morraceira's salines seemed to provide feeding opportunities to a large proportion of the waders that use the Mondego estuary during this study, irrespective of the season.

How do the birds disperse themselves within the salines system?

Not all salines were used at a given time, however, by all individuals of a species. Every species, except Whimbrels, exhibited a clumped dispersion irrespective of the seasonof the year (Table 3), indicating that each species used a limited number of salines. Of the four species that were present throughout the year, Kentish Plovers and Little Stints showed a reduction in their Index of Dispersion (I.D.) from the winter to the spring - autumn periods, while Dunlins and Ringed Plovers showed an increase.

Use of salines by feeding waders in relation to human management

Active salines *vs.* abandoned/inactive salines: global patterns of use

The data above suggest that the birds selected particular salines for feeding. Given the more predictable water level in active salines, it was hypothesised that most birds would select these salines to feed during the "salt season". In winter, on the other hand, there should be no differences in the proportion of birds feeding in both types of salines, as both were subjected only to the unpredictable rainfall and evaporation cycle. To test the hypothesis that the management regime, or the lack of it, influenced the birds' choice, the use of each type of saline in the Morraceira Island by the birds was compared in both seasons.

Active salines in the island were indeed more attractive than inactive ones as feeding grounds for most wader species. In all but one species, and irrespective of the season, active salines were used by more than 50% of the birds present (Table 4). Only the Black-winged Stilt showed no particular tendency for fe-

TABLE 2

Mean percentage of the total number of birds (N) of selected species counted in the whole study area that fed in the salines at either high-or-low-tide. N was determined from counts made at low-tide, when all the birds in the Mondego were either on the mudflats or on the salines. Values represent the average numnas bien durante la marea baja o bien durante la marea alta. N se determinó mediante censos realizados durante la marea baja, cuando los aves presentes en el estuario se encuentran en los fangos intermareales o en las salinas. Los valores de la tabla son medias (±SE) de las aves presentes en conteos realizados Porcentaje del número total de aves (Ñ) de especies seleccionadas, censadas en el total del área de estudio, que se encontraron alimentándose en las salia lo largo de todo el periodo de estudio (n: número de conteos). Sólo se dan resultados para las especies con más de cinco individuos censados por estación ber of birds present per count in the estuary over the whole study period (n: number of counts). Only species with a minimun of five birds present both per season and per year were considered. S: spring; Su: summer; A: Autumn; W: Winter. y por año. S: primavera; Su: verano; A: otoño; W: invierno.]

			Porcentage f [porcentaje de av	Porcentage feeding (±SE) [porcentaje de aves alimentándose]	
	N±SE	u	Low-tide [marea baja]	High-tide [marea alta]	Occurence [época del año]
Dunlin Calidris alpina	451.6 ± 74.4	37	70.1 ± 10.1	71.2 ± 3.8	All year [todo el año]
Conference Comment Conference Cittl Himantopus himantopus Cities of Conference Conference Cities of Cities	62.4 ± 9.9	22	68.9 ± 3.7	70.0 ± 1.1	S, Su
Redshank Tinga totanus	12.4 ± 3.7	26	65.0 ± 18.9	67.4 ± 6.2	S, Su, A
IAI Chibebe Comunj Ringed Plover Charadrius hiaticula [Chorlitaio Grando]	66.7 ± 11.3	34	61.5 ± 3.9	50.7 ± 11.2	W, A, S
Little Stirt Calidris minuta footselings Mandal	25.3 ± 11.1	21	59.3 ± 2.9	59.3 ± 2.9	M
Corretinus menual Kentish Plover Charadrius alexandrinus (Chorliteio Patinegro)	91.5 ± 10.6	38	48.3 ± 0.1	42.4 ± 2.1	All year [todo el año]
Whimbrel Numerius phaeopus (Zaranito Trinador)	7.9 ± 3.4	7	5.0 ± 3.5	3.6 ± 3.6	S, Su, A
Grey Plover Physialis squatarola [Chorlin Gris]	86.6 ± 10.8	28	3.8 ± 3.6	8.4 ± 5.8	W, S, A
Avocet Recurvirostra avosetta [Avoceta Común]	388.6 ± 53.4	18	0.5 ± 0.5	3.7 ± 3.7	A

TABLE 3

sos en cada estación. El valor de 😿 correspondea la prueba de bondad de ajuste de la distribución observada a una distribución de Poisson (aleatoria) para muestras pequeñas (n < 31). Se acepta el ajuste a esta distribución con una probabilidad del 95% si el valor de 🗜 se encuentra dentro del rango de valores Distribution of wader species among the Morraceira's salines in the winter and in the spring to autumn periods of 1994-95. The mean and variance (s²) of the total number of birds counted in all salines for each species in each count is given, along with the Index of Dispersion (I.D.). The number of counts was 26 a Poisson series is accepted at a probability level of 95% if χ^2 lies between the appropriate 5% significance levels for n – 1 degrees of freedom. Below the lode significación al 5% para n – 1 grados de libertad. Por debajo de este límite se acepta una distribuciónn regular (Rg) de la población entre salinas, por encima se considera una distribución agregada (C) y dentro del rango una distribución aleatoria (R). Los valores superior e inferior de 😤 se estimaron vior each season. The χ^2 value to assess its goodness-of-fit to a Poisson series (random distribution) for small samples (n < 31) is presented. Agreement with wer limit the distribution is regular (Tg), and above the upper limit is clumped (C), being random (R) between them. The upper and lower limits of χ^2 when Distribución de las especies de limícolas entre las salinas de ls isla de Morraceira en invierno y en primavera-otoño de 1994-95. Se indica la media y la varianza (s²) del número total de aves censadas en todas las salinas, así como el Índice de Dispersión (LD.) que se obtiene de su cociente. Se realizaron 26 censualmente siguiendo a Elliot (1977). Para 25 grados de libertad, estos valores fueron aproximadamente 13,0 (límite inferior) y 40,3 (límite superior). re estimated visually, according to Elliot (1977). For 25 degrees of freedom they are roughly 13.0 (lower limit) and 40.3 (upper limit).

	vnI]	[Invierno]			[Prima	[Primavera-otoño]		
	Mean No. of birds [Número medio de aves]	2	I.D.	χ^{2}	Mean No. of birds [Número medio de aves]	2 S	I.D.	χ^2
Kentis Plover	4.18	141.78 33.95	33.95	848.68 C	7.97	72.12	9.05	226.32 C
Ringed Plover	1.53	5.89	3.85	96.27 C	4.19	5.16	12.21	305.37 C
Dunlin	8.12	165.61	20.40	510.03 C	34.04	4822.95	141.86	3456.41 C
Little Stint	3.41	28.76	8.43	210.72 C	0.47	1.17	2.48	61.90 C
Whimbrel T	l	[0.24	0.36	1.50	37.53 R
Redshank	l	I			4.71	101.10	21.47	536.81 C
Black-winged Stilt (Cigüeñuela Común)	I	1			7.13	103.10	14.47	361.63 C

Table 4

Total density of feeding birds of selected species of waders in the Morraceira's salines and percentage of these that that fed in the active salines in the spring to autumn and winter periods. Data for the two year were averaged by season (spring to autumn, n = 14 (1993-94) and n = 11 (1994-95) counts; winter n = 8 and n = 5 counts, respectively). The letter **a** denotes significant differences (P < 0.05) in the wader densities (birds/10 ha, arcsin-transformed) in active and abandoned salines, for a given species and season (one-way ANOVA with data combined for the two years). The letter **b** shows where differences were found between seasons (spring to autumn *versus* winter), considering only the proportion of birds in active salines (two-way ANOVA testing for annual and seasonal differences). These values represent the maximum number of counts; individual species may have lower values. * Data for the first study year (1993-94) only.

[Densidad total de aves alimentándose en las salinas de la isla de Morraceira para una serie de especies seleccionadas, y porcentaje de este total que se alimentaron en salinas activas, para los periodos primaveraotoño e invierno. Los datos de ambos años de estudio se promediaron según periodos (primavera: n = 14
(1993-94) y n = 11 (1994-95) censos; invierno: n = 8 y n = 5 censos, respectivamente). La letra **a** indica diferencias significativas (P < 0,05) en las densidades de limícolas (aves/10 ha, transformadas angularmente)
entre salinas activa y abandonadas para cada especie y periodo (ANOVA de clasificación simple con datos
combinados entre años); la letra **b** muestra diferncias significativas entre periodos (primavera-otoño vs invierno), considerando sólo las aves censadas en salinas activas (ANOVA de clasificación doble, con año y periodo como factores). Los valores mostrados representan los conteos máximos, de manera que ciertas especies pudieron mostrar valores inferiores. *: datos del primer año de estudio (1993-94) únicamente.]

	Spring to [Primave		Winter [Invierno]		
	Birds/10 ha (± SE) [N° aves/10 ha]	% in active salines [% en salinas activas]	Birds/10 ha (± SE) [Nº aves/10 ha]	% in active salines [% en salinas activas]	
Kentis Plover	1.4 ± 0.1	58.6a	2.6 ± 0.8	95.4a,b	
[Chorlitejo Patinegro] Ringed Plover [Chorlitejo Grande]	1.4 ± 0.2	59.6a	2.2 ± 0.8	89.9a	
Dunlin [Correlimos Común]	8.0 ± 4.9	58.1a	20.7 ± 7.9	89.7a,b	
Little Stint [Correlimos Menudo]	4.8 ± 1.2	62.6a	1.5*	100.0a	
Redshank	0.6 ± 0.5	62.6a	_	_	
[Archibebe Común] Black-winged Stilt [Cigüeñuela Común]	2.2 ± 0.3	54.1	_	_	

eding in any particular type of saline. Contrary to expectation, the two species that were abundant in the Mondego in both seasons, the Kentish Plover and the Dunlin, fed in the active salines significantly more in winter than in spring or autumn.

Long-term use of inactive/abandoned salines

Even a saline that has been abandoned for many years can still be used by waders. However, usage by waders is likely to decline ultimately over time due partly to the development of an impenetrable layer of vegetation and partly to unpredictable fluctuations in the water level. Despite this, the usage of abandoned salines by the species analysed did not correlate with the period of time elapsed since the salines had been deserted (Fig. 2). This suggests that inactive salines may provide adequate feeding conditions over a long period. Even a saline deserted for 25 years can support birds. In fact, only the salines that had been abandoned for more than 40 to 50 years, and which by now had changed into brackish-water marshes and

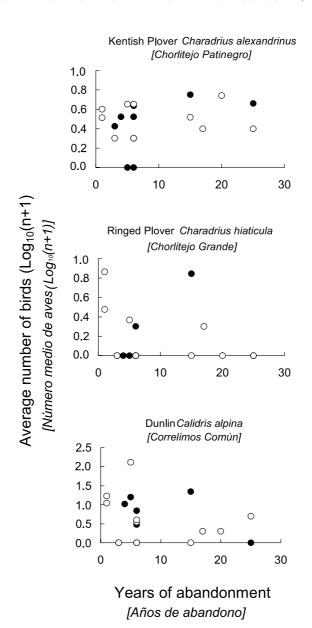


Fig. 2.—Relationship between the number of birds of selected species feeding at low-tide in abandoned (inactive) salines and the time elapsed since the salines were abandoned. Data were plotted separately for 1993-94 (closed dots) and 1994-95 (open dots), and represent the average of the spring and autumn means for each species. Linear regressions were used for the Kentish Plover and the Ringed Plover, whereas a non-linear model (exponential decline) was used to fit the data for Dunlin. In all cases, non-significant results (*P*>0.05) were obtained.

[Relaciones entre el número de aves de algunas especies alimentándose en marea baja en salinas abandonadas (inactivas) y el tiempo transcurrido desde su abandono. Los círculos rellenos corresponden a datos de 1994-94 y los vacíos a 1994-95, siendo los promedios de las medias primaverales y otoñales para cada especie. Se emplearon regresiones lineales para los Chorlitejos Patinegro y Chico y un modelo no lineal (exponencial negativo) para el Correlimos Común. No se obtuvieron resultados significativos en ningún caso.] so were not included in our study, were not used by waders.

The loss of feeding opportunities

The impact of the complete disappearance of the salines seems likely to differ between the different species examined, and also according to the group concerned (Fig. 3). Considering the SB group, the Little Stint and the Redshank would be particularly affected, losing about 73% and 70% of their present-day feeding-hours, respectively. The SB populations of Ringed and Kentish Plovers and Dunlins would lose between 10% and 24% of their total feeding opportunities. As for those birds that fed on the mudflats over low-tide and used the

salines only as supplementary feeding at hightide (the MB group), the effects would naturally be smaller. Little Stints, Dunlins and Ringed Plovers would be most affected, losing 19%, 18% and 16% of their present-day feeding opportunities in the estuary, respectively. Redshanks, Kentish Plovers and Dunlins would lose between 10% and 12% of their present bird-feeding hours. Those species that seldom use the salines (Grey Plovers, Avocets and Whimbrels) would only lose between 0% (Avocet) and 10% (Whimbrel) of their presentday feeding opportunities.

The time available for feeding throughout a complete tidal cycle for the mudflat populations of some species would also be reduced by the loss of the salines (Fig. 4). Dunlins and Redshanks would be the most affected, with

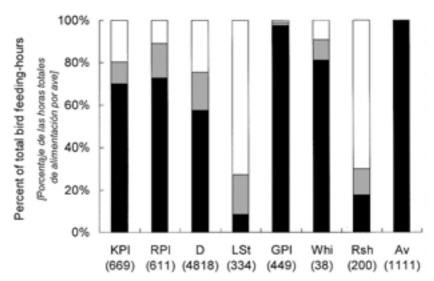


Fig. 3.—Percentage of total bird feeding-hours in the estuary and salines combined that were spent in the mudflats at low-tide (black area) or in the salines, either by the "mudflat birds" at low-tide (striped area) and by the "salines birds" throughout the tidal cycle (white area). The total number of bird-feeding hours for each species is shown in brackets. Values are the means of the mean counts for autumn, winter and spring in 1993-94 and 1994-95 separately. Therefore, n = 6 for all species, except for Whimbrel (n = 2) and Avocet (n = 5). KPl: Kentish Plover; RPl: Ringed Plover; D: Dunlin; LSt: Little Stint; GPl: Grey Plover; Whi: Whimbrel; Rsh: Redshank; AV: Avocet.

[Porcentajes del total de horas de alimentación de las aves en el estuario y en las salinas que emplearon los individuos de cada especie en los fangos intermareales durante la marea baja (áreas negras) o en las salinas, bien por las 'aves de los fangos' durante la marea alta (área rayada) o por las 'aves de las salinas' durante el ciclo mareal completo (áreas blancas). El número total de horas de alimentación para cada especie se muestra entre paréntesis, y es la medie de los censos medios de atoño, invierno y primavera de los dos años de estudio. Por tanto, n = 6 para todas las especies excepto para el Zarapito Trinador (n = 2) y la Avoceta Común (n = 5). KPl: Chorlitejo Patinegro; RPl: Chorlitejo Grande; D: Correlimos Común; LSt: Cigüeñuela Común; GPl: Chorlito Gris; Whi: Zarapito Trinador; Rsh: Archibebe Común; AV: Avoceta Común.]

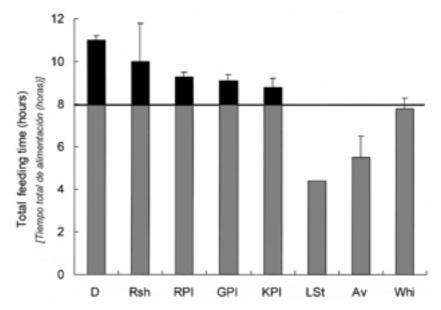


Fig. 4.—Total feeding time used at present by the mudflat birds (mudflats and salines combined) and the proportion of it that would be lost were the Morraceira's salines to be removed (area in black). The horizontal line indicates the approximate duration of the emersion period in the intertidal mudflats. Values are means (+SE) of up to three seasons (autumn, winter and spring) averaged for 1993-94 and 1994-95 years. Sample sizes as in Table 4, ans species abbreviations as in Fig. 3.

[Tiempo total de alimentación empleado en la actualidad por las aves de los fangos intermareales (tiempos en fangos y en salinas combinados) y la proporción de este tiempo que se perdería si se eliminasen las salinas de la isla de Morraceira (área en negro). La línea horizontal indica el period aproximado en que los fang sintermareales están emergidos. Los valores son medias (+SE) de un máximo de tres periodos (otoño, invierno y primavera) promediados para 1993-94 y 1994-95. Tamaños de muestra como en la Tabla 4 y abreviaturas de las especies como en la Fig. 3.]

some 3 and 2 hours (38% and 25%, respectively) of their present daily feeding time removed. Once again, the larger species (Avocet and Whimbrel) would be the least affected. The Little Stint is a special case, as its population only uses the mudflats for some 4.4 hours, the remaining time being spent in the salines. Thus, for the mudflat-feeding population of this species, the loss of the salines could probably be compensated by spending much more time on the mudflats that they do now.

Extra-feeding pressure on the mudflats: how many feeding-hours would have to be provided by the mudflats if all the salines were lost?

The destruction of the salines would mean that all feeding would subsequently be concentrated on the mudflats. The most affected species would be the Little Stint. Up to 306.2 of this species' present-day estuary total of 334 bird feeding-hours (BFH) are currently used in the salines, by both SB and MB populations. This corresponds to some 92% of its presentday total BFH to be provided by the mudflats if all the salines were destroyed (Fig. 5). As the mudflats at present provide only 8% of the feeding-hours, the loss of all salines would increase the contribution provided by the mudflats 12-fold (100%/8%). Several other species would also require a substantial increase in the amount of their feeding-hours to be carried out on the mudflats. For example, Redshanks, for which 164.6 BFH (82%) of their total of 200 BFH are at present carried out in the salines, would have to increase its use of the mudflats six-fold (100%/18%). The equivalent values for the other most affected species are: Dunlin -

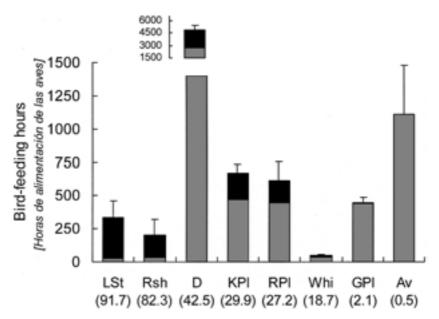


Fig. 5.—Mean number (+SE) of the hours spent feeding at present by the main species of waders in the Mondego estuary (mudflat and salines combined) and, were the salines to be destroyed, the predicted increase (black areas) in the bird-feeding hours that would have to take place over the low-tide on the mudflats for the present-day amount of bird-feeding hours to be maintained. Data are means of the seasonal averages for winter, spring and autumn of 1993-94 and 1994-95, arranged by descending order of predicted increases in feeding hours (percent increases indicated in brackets). Species abbreviations as in Fig. 3. The column for Dunlin is cut at 1500 BFH to allow a more clear presentation of the other species.

[Número medio (+SE) de horas de alimentación empleadas en la actualidad por las principales especies de limícolas del estuario del Mondego (tiempos en fangos intermareales y en salinas combinados), e incremento predicho que debería producirse durante la marea baja en los fangos intermareales para mantenerlas si se destruyesen las salinas tradicionales (áreas negras). Los datos presentados son medias estacionales de los inviernos, primaveras y otoños de 1993-94 y 1994-95, ordenados de mayor a menor incremento predicho (porcentajes de incremento indicados entre paréntesis). Abreviaturas de las especies como en la Fig. 3. La columna del Corrlimos Común se ha cortado en las 1500 horas de alimentación para facilitar la comparación con las otras especies.]

2045.3 BFH (42.5%) in the salines out of a total of 4818 BFH, representing a 1.7-fold increase in use of the mudflats; Kentish Plover - 200.1 BFH (29.9%) out of 669 BFH, or a 1.4-fold increase: Ringed Plover - 165.8 BFH (29.9%) out of 611 BFH, a 1.4-fold increase. On the other hand, the larger species (Grey Plover, Avocet and Whimbrel) would require less than 5% of the present feeding-hours available to be provided by the mudflats, a mere 1.05-fold increase. Therefore, depending on the species, the complete loss of the salines would mean that the bird-feeding hours provided by the mudflats, for the mudflat birds, would have to increase by up to 90%, although the average increase across all species would be around 37%.

DISCUSSION

The use of the artisanal salines by waders in the Mondego estuary and its relation with the management regime.

The traditional salines of the Mondego estuary proved to be important feeding areas for most wader species. The proportion of the total number of birds that, at one time or another, used the salines for feeding during the study period was consistently high (42.4% to 71.2%) for six species in nine. Although these figures are within the range (0.8% to 74% at low-tide and 0.9% to 88% at high-tide) recorded in salines elsewhere in the Iberian Peninsula (Rufino

et al., 1984; Pérez-Hurtado & Hortas, 1991, 1993a, 1993b; Masero et al., 2000) and in South Africa (Velásquez & Hockey, 1990), they illustrate, nevertheless, the importance of the traditional salines as a feeding habitat for waders in this particular estuary.

However, despite the fact that the Mondego's salines seem to be generally attractive as feeding areas to waders, suitable pond habitats may not be equally distributed at any one time, as the clumped distribution of almost all species suggests. The seasonal change (increase) in the dispersion of Kentish Plovers may have been linked to birds being more dispersed during the nesting period and preferring to feed near to their nests. In Dunlins and Ringed Plovers, which were not attached to nesting sites, it may reflect either a decrease in the available ponds due to dryness in the summer and autumn months or the use of a limited number of ponds with exceptionally good feeding conditions. In either case, the net result would have been a shrinkage in the species' I.D. As for the Little Stint, the opposite trend occurred: the birds originally clumped in a few accessible salines in winter, dispersed throughout the area as more and more salines became available. Although this was not specifically addressed in this study, several authors have shown that the choice of feeding area of birds using hypersaline supratidal or non-tidal habitats is affected by factors such as the water level and salinity (Britton & Johnson, 1987; Smit et al., 1987; Verkuil et al., 1993; Rubega et al., 1997), which determine the prey species and their abundance (Britton & Johnson, 1987; Smit et al., 1987). In our study, the clumped distribution of waders in the salines in winter was probably related to such factors, as most salines were flooded at that time of year and therefore not usable by the birds. However, later in the year, when most salines had been emptied and were thus accessible, habitat availability was probably not so important in restricting the distribution of waders. Active habitat choice could instead occur, probably enabling the birds to use those salines where the feeding conditions were most favourable. However this idea has yet to be tested in the Mondego estuary.

Because the management regimes of the salines were out of phase with each other, there was always a suitable depth of water present at least in one saline at any one time, even in winter. A

main feature of the Mondego salines is, therefore, the diversity of micro-habitats that can be found even in the abandoned salines. The maintenance of this diversity is perhaps the key consideration if these important supratidal habitats of the Mondego estuary are to be maintained in a way that maximises their benefit to waders. This, in turn, implies that the integrity of the whole area of salines should be maintained.

The clumping of birds in a few salines can lead to the emergence of intra-specific densitydependent competition for food (Goss-Custard, 1996; Masero & Pérez-Hurtado, 2001). If it increases above a certain treshold of bird densities (50-100 birds/ha; Triplet et al., 1999; Yates et al., 2000), the birds are no longer able to fulfill their energetic needs. If they cannot relocate themselves to the surrounding mudflats, they either will die or will be forced to leave the estuary. At present, it seems that this is not an issue for concern. In fact, there is no indication that competition is already taking place in the mudflats (or, if occurring, is too weak to be detected; (Múrias *et al.*, in prep.). On the other hand, the densities of birds observed in the Mondego's salines (0.24 to 34.00 birds/ha) are well below the critical values defined by Triplet et al. (1999) and Yates et al. (2000).

There is at present very little information on the relative use made of the active and inactive artisanal salines by feeding birds, although there are indications that inactive salines are less favoured feeding places (Luís, 1999; Peixe, pers. comm.). The data of the present study seemed to confirm this, at least for the traditional salines of the Mondego, where the active salines were used more as feeding places than the inactive ones. However, this study has shown that inactive salines can continue to support waders for many years after they have ceased to be actively used to produce salt. Nonetheless, if required, a deserted saline is nearly always recoverable, either for salt production or to provide feeding places for waders (Neves & Rufino, 1995). In contrast, a saline transformed into a fish-farm is largely lost to waders as a feeding area (Múrias et al., 1997). This is due to the narrow shape and depth of most fishfarm ponds in the Mondego estuary, which means that the water in filled ponds is too deep for feeding waders and hinders the birds' ability to detect approaching predators when ponds are empty and thus usable by birds.

The importance of the salines in providing feeding opportunies for the birds: possible consequences of the compete removal of this habitat

Given the importance of the salines in providing feeding opportunities for waders in the Mondego estuary, what could be the consequences for the wader populations if this habitat were to be destroyed? The preliminary calculations undertaken here suggest that the loss of the habitat would not have the same effect on all species. There were some indications that the smaller species could be more affected than the larger ones. Not only do the small waders in general require more time to fulfill their energy requirements than do the larger ones (Zwarts *et al.*, 1990) but, during our study, the smaller species spent a higher proportion of their feeding-hours in the salines than the larger ones,

Such conclusions are, however, preliminary, as they are based on several untested assumptions, as detailed in Methods. The first one is that the birds were assigned to either a "salines group" or a "mudflat and salines group". This assumption is probably quite realistic. Luís (1999) showed that, in Ria de Aveiro, a wetland 60 km North of the Mondego estuary, a sample of radio-tagged Dunlins remained in salines throughout the tidal cycle in winter. However, this site fidelity needs to be established now for the migratory periods. A second assumption is that the birds displaced from the salines would preferentially re-establish themselves on the mudflats and not in the remaining supratidal areas. This is also a fair assumption, as the fish-farms in the Mondego are not much used for feeding at present (Múrias et al., 1997) and the rice-fields in the vicinity are not accessible for most of the year and are not used by many species of waders anyway (pers. observ.). Finally, it was assumed that the proportion of birds that were feeding in either the salines or on the mudflats did not vary over the stage of the tidal cycle during which the census was made. This is a less reliable assumption, because many studies (Rufino et al., 1984; Davidson & Evans, 1987; Zwarts et al., 1990; Kalejta, 1992; Hötker, 1995) have shown that activity patterns may vary through a given stage of the tidal cycle. Because of this, the present estimates should be regarded with some caution until more reliable data are obtained. However, a recent and detailed study by Masero *et al.* (2000) on the overwintering feeding activity of waders in the Cádiz Bay salines achieved the same general conclusions, thus providing support to our estimations.

Assuming that the present estimates capture the main potential impact of the loss of all the salines, and that the smaller species would indeed be more affected by the loss than would be the large ones, the destruction of the Morraceira's salines could imply that most birds would be driven to the mudflats - as the other estuarine supratidal habitats are not able to replace the Morraceira's salines - with a corresponding increase in the competition for feeding in these areas. This could make it more difficult for birds to fulfill their food requirements which, in turn, could reduce bird fitness through increased rates of mortality or reduced amounts of fat being stored to fuel migration (Goss-Custard & Durell, 1990). A full and quantitative evaluation of the fitness consequences of the loss of part or all of the salines requires a modelling approach as has been applied to some estuary birds wintering in more northern latitudes (Pettifor et al., 2000; Stilmann et al., 2000, 2001).

The conclusions of this study contrast with the generalisation made by Smit *et al.* (1987) that the construction of salines inevitably causes the loss of feeding habitats, since they are usually built on intertidal mudflats or saltmarshes. While this is probably true for the large industrial Mediterranean salines (Britton & Johnson, 1987; Aymerich, 1996; Sadoul et al., 1998), the traditional salines in Portugal are mainly built inland (Lopes, 1955), and even industrial salines are usually built in areas formerly occupied by traditional salines. This does not only avoid the loss of intertidal areas but, as the present study has shown, even increases the amount of feeding area that is available for waders.

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