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Food supply for waders (Aves: Charadrii) in an estuarine area in the Bay of Cádiz (SW Iberian Peninsula)

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Abstract — We studied the composition, density, size distribution and biomass of the food supply for waders in an estuarine area in the Bay of Cádiz (SW Iberian Peninsula), in winter (January-February) and in the pre-migratory period (late March). The estuarine area comprises an intertidal mudflat and an adjacent salina or salt-pan. On the intertidal mudflat, the biomass was 53 and 37 g AFDW·m^{-2} in winter and the pre-migratory period, respectively. The main food source on mudflat was the polychaete *Nereis diversicolor* (44–54 % of the total biomass). On the other hand, the biomass in the salina was comparatively very poor, ranging from 0.008 to 0.079 g AFDW·m^{-2} in winter and ranging from 0.011 to 0.09 g AFDW in late March. The main source of food in the salina was the crustacean *Artemia*. The total biomass on the mudflat during the pre-migratory period was 1.4 times lower than in February. This depletion could be caused by wader predation, mainly by *Nereis diversicolor* consumption. Although the potential food on the mudflats could allow high intertidal densities of waders, the availability of high tide foraging areas in the salina seems to contribute to the maintenance of these high intertidal densities. © 1999 Éditions scientifiques et médicales Elsevier SAS

Shorebirds / macrobenthos / *Nereis diversicolor* / salt-pans / intertidal mudflat / *Artemia*

1. INTRODUCTION

Many species of waders (Aves: Charadrii) depend on coastal intertidal areas for their survival, as they feed on macrobenthic invertebrates which become available at low tide [23]. These birds can have a substantial impact on their invertebrate prey [5, 6, 13, 25, 27], and play an important role in mass and energy fluxes across estuarine food webs [20].

Because the bird species depending on the tidal areas have recently lost a substantial part of their feeding areas in Europe and Asia, the problem of the carrying capacity of such feeding areas have become a main theme in many studies related to waders [30]. Thus, one of the first questions that should be answered, in order to establish whether the loss of intertidal feeding areas affect negatively the size of wader populations, is to assess the food supply potentially available to waders in these areas. This type of study should consider a specific depth of substrate according to the species being treated, as benthic prey are accessible to many waders only if they live within reach of their bill [34].

Although important populations of waders occur on the Atlantic coast of the Iberian Peninsula [19], studies on the food supply of birds foraging in the intertidal areas are very scarce [7, 26]. The Bay of Cádiz is the most important wintering site for waders in Spain, with an average population of 25 000 birds [22]. Many studies regarding macroinvertebrate fauna were performed in shallow coastal lagoons in the Bay of Cádiz [3, 4, 8, 9, 10], but such studies are very scarce in tidal areas [11, 24].

The aim of this study is to provide information on the food supply for waders in the Bay of Cádiz. The present study is part of a more extensive research programme, which intends to determine the causes of the high densities of waders existing in some intertidal areas in the Bay of Cádiz.

2. STUDY AREA

The study area comprises 25 ha of intertidal mudflat and 400 ha of an adjacent salina or salt-pan, in the northern part of the Bay of Cádiz (SW Iberian Peninsula, 36°23’–36°37’ N, 6°8’–6°15’ O). About 2 500–3 000 waders wintering regularly in the study area, and both zones are used as feeding grounds by many wader species [21]. The intertidal area is composed by muddy substrate, covered in some zones by *Ulva* sp. (8 % on average). This mudflat registers in winter one of the highest intertidal densities of waders in the East Atlantic Flyway (100 ha^{-1}) [17]. Dunlin *Calidris alpina*, Kentish plover *Charadrius alexandrinus* and ringed plover *Charadrius hiaticula* were the most abundant species on the mudflat in winter.

Salinas are man-made habitats used for obtaining salt by evaporating seawater. In this supratidal habitat, water is pumped from a tidal channel to storage pans, from where it circulates through a series of small concentration pans until it reaches shallower, larger crystallisation pans, where the salt precipitates and is collected. Salinity increases as the water goes through this circuit, from a concentration similar to seawater in the storage pans (33–35 g·L^{-1}) to practical saturation on the crystallisation pans (250–300 g·L^{-1}). During the study period, the storage pans remained dry, as it is usually emptied during this time of the year.

3. METHODS

The study was carried out in winter (January and February) and pre-migratory period (late March for the greater part of the populations in the study area). We distinguished these two periods because the latter is critical to migrant waders, as it coincides with the demanding pre-migratory fattening period [35].

3.1. Faunal sampling

The intertidal area was sampled on two occasions: 02-02-95 and 27-03-95. On each sampling occasion, four transects were set at low tide perpendicular to the shoreline. In each transect, three cores, regularly dispersed between the shoreline and the waterline, were taken from the substrate. Each core was 78.5 cm^2 and 10 cm depth. This depth represents the maximum depth that the wader species present in the study area in winter can access with their bills [34].

In the salina, macroinvertebrates were sampled monthly in the period January–March. Benthic and pelagic samples were taken from the different types of pans where waders were observed foraging during this period (concentration and crystallisation pans). Pelagic samples were taken with a zooplankton net (150-µm mesh) and the benthic samples with cores (depth: 2–5 cm; maximum penetrability for these pans). A sample consisted of five replicates (40 L filtered in each replicate of the pelagic samples).

The macrobenthic samples of both benthic and pelagic layers were washed through a 0.5-mm mesh sieve and preserved in 5 % formalin.

3.2. Estimation of biomass

The invertebrates were counted and measured, and their biomass estimated through equations relating prey size and biomass (see *appendix*). Measurements were taken under a binocular microscope equipped with an ocular micrometer. Large bivalves were measured with a digital caliper to the nearest 0.01 mm.

There is a seasonal variation of the body condition in the food supply for birds feeding on the intertidal areas [34]. For this reason, we have used the equations given by Moreira [19] in the Tagus estuary in winter to estimate the biomass of *Nereis diversicolor*, *Scrobicularia plana* and *Hydrobia ulvae*. For *Cerastoderma edule*, we used the equation derived for this species in summer by Zwarts and Blomert [31], to which a correction factor of 30 % was applied. According to Zwarts and Wanink [34], this is the percentage of variation of the body condition between winter and summer.

The length employed in the equation for *N. diversicolor* were estimated from the size of their mandibles. Fresh polychaetes collected in the field were relaxed in seawater with 5 % magnesium chloride, and their total length was measured with a digital caliper. Then, the mandibles were extracted, their length was measured using an ocular micrometer [18], and an equation of regression relating the total length and the mandible length was constructed (*figure 1*).

For *Artemia*, an regression analysis was performed relating body length and ash free dry weight, AFDW (*figure 2*). Fresh samples were collected in the study area and brought to the laboratory. Body lengths were

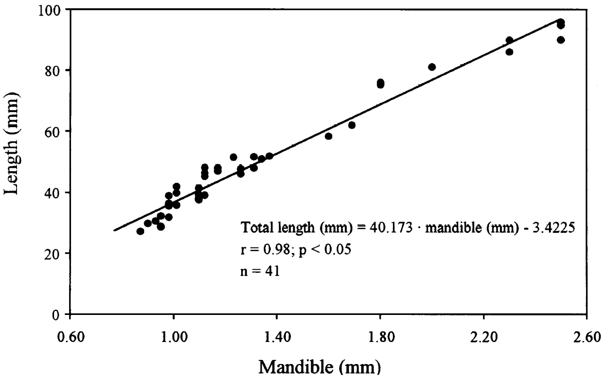

Figure 1. Total length (mm) of *Nereis diversicolor* as a function of mandible length (mm).

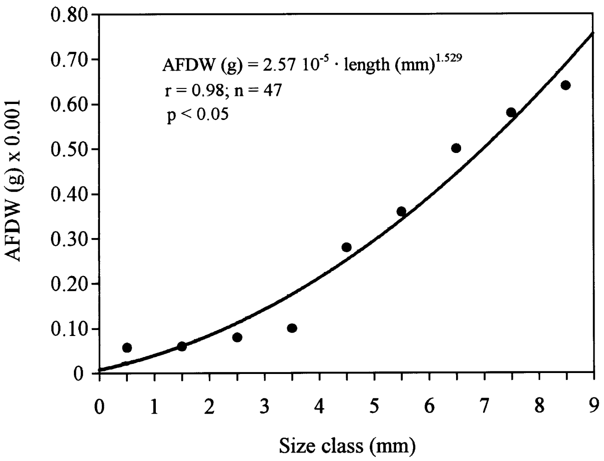

Figure 2. Relationship between total length (mm) and ash free dry weight (g), AFDW, in *Artemia*.

Table I. Composition and biomass of the macrozoobenthos on the intertidal mudflat.

Taxa	February (02-02-95) (g AFDW·m^{-2})	March (27-03-95) (g AFDW·m^{-2})
Nereis diversicolor	28.64 ± 1.84	16.16 ± 2.14
Polydora sp.	–	0.56 ± 0.00
Streblospio shrubsolsii	0.002 ± 0.00	0.149 ± 0.00
Capitella capitata	0.003 ± 0.00	0.013 ± 0.00
Scrobicularia plana	18.14 ± 2.16	17.81 ± 1.12
Abra sp.	–	0.003 ± 0.00
Cerastoderma edule	1.86 ± 0.18	0.123 ± 0.00
Hydrobia ulvae	1.16 ± 0.11	1.570 ± 0.10
Cyathura carinata	3.00 ± 0.31	0.231 ± 0.00
Terebellidae	–	0.003 ± 0.00
Total	52.8 ± 4.85	36.6 ± 5.64

Data are means ± SE, SE = 0.00 implies a SE < 0.05.

measured [12] and their dry weight estimated (DW, 60 °C for 24 h). The AFDW was calculated as the difference between the DW and the ashes (500 °C for 2 h). For Terebellidae and species numerically scarce (*Abra* sp. and *Polydora* sp.), the AFDW was obtained for each individual. The average weight assigned to an individual was thus the average of the obtained weights.

4. RESULTS

Tables I and *II* show the species and groups found on the mudflats and in the salina, respectively, as well as the average biomass in each one of these zones according to the periods considered. On the mudflat, *Nereis diversicolor* made up 54 and 44 % of the total biomass during February and pre-migratory period, respectively, being 1.7 times less in March than in February. This corresponds approximately to the amount that the total biomass has decreased in the pre-migratory period (1.4) with respect to winter.

In the salina, *Artemia* was the only species present in the sampled pans during February, increasing their density in the pre-migratory period. In March, Coleoptera larvae also appear in some concentration pans. No macroinvertebrates were found in the benthic samples of the salina.

Figure 3 shows the numeric distribution of sizes of the main species found in the mudflat and in the salina. The comparisons of the main prey sizes found in the mud between February and March are shown in *table III*. In general, the average sizes were similar, and only *Scrobicularia plana* was significantly different, being bigger in the pre-migratory period. *N. diversicolor* was smaller in March, but the difference was non-significant.

5. DISCUSSION

Piersma et al. [23] give the value of 25 g AFDW·m^{-2} as the average of the available bio-

Table II. Composition, density (ind·m^{-2}) and biomass (g AFDW·m^{-2}) of macroinvertebrates in pans where waders could feed during wintering season.

Type of pans	Species	January		February		March	
		Ind·m^{-2}	g AFDW·m^{-2}	Ind·m^{-2}	g AFDW·m^{-2}	Ind·m^{-2}	g AFDW·m^{-2}
Crystallisation	*Artemia* sp.	266	0.079	112	0.033	37	0.011
Concentration	*Artemia* sp.	28	0.0085	99	0.029	300	0.09
	Octhebius sp.*	–	–	–	–	41	0.001

* Coleoptera larvae.

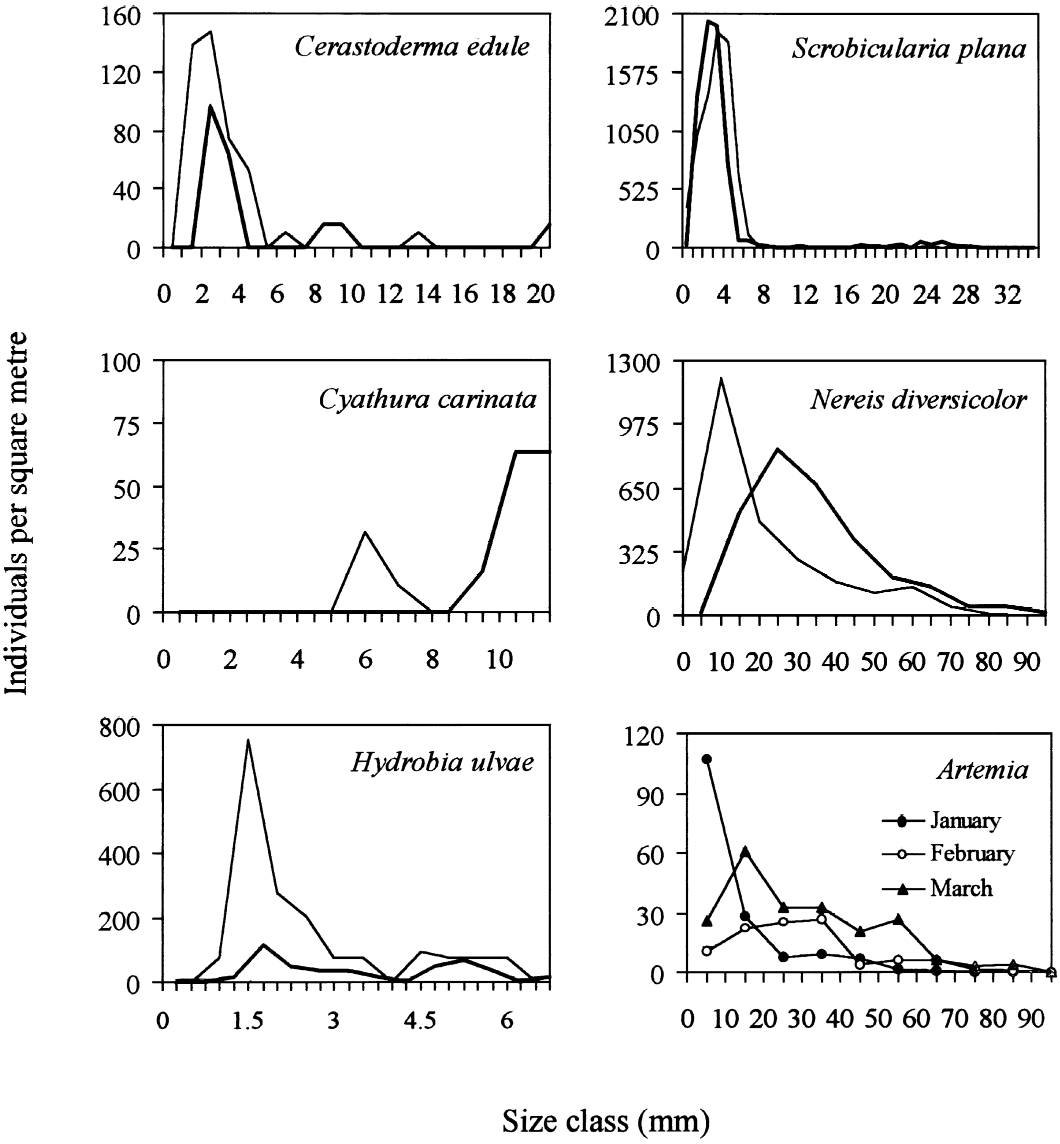

Figure 3. Size frequency distribution of six prey macroinvertebrates in the study area (February: thick line, March: thin line). Further explanations in text.

mass for waders on intertidal areas of soft sediment, after a revision of data at a world scale. In our case, the estimated value of 53 g AFDW·m^{-2} is more than double that amount, being similar to one found in a nearby area like Ria Formosa, in the south of Portugal [26]. Note that the total biomass of macrozoobenthos could be higher, as we studied the food supply potentially available for waders (upper 10 cm), and the size and body weight of many macroinvertebrates (e.g. *Nereis diversicolor* and *Scrobicularia plana*) increase

Table III. Mean sizes (± SE; mm) of several prey species in February and March (Mann-Whitney U-test). Size samples in parentheses.

Species	February	March	U	*P*
Cerastoderma edule	5.00 ± 1.13 (20)	3.27 ± 0.35 (34)	181	n.s.
Hydrobia ulvae	3.41 ± 0.34 (26)	2.70 ± 0.27 (26)	276	n.s.
Scrobicularia plana	3.80 ± 0.21 (415)	4.24 ± 0.15 (651)	95 724	< 0.001
Nereis diversicolor	34.41 ± 1.20 (181)	32.6 ± 1.39 (170)	13 730	n.s.

n.s. : Non-significant ($P > 0.05$).

with depth [33, 34]. The mild weather conditions and the absence of extreme temperatures in the Bay of Cádiz [2] may promote high production levels, as suggested Kalejta and Hockey [14].

Nevertheless, the actual harvestable food supply (profitable and available) by waders could comprise a lower fraction than the estimated value. In the study area, during the wintering season, exceptionally high intertidal densities of waders occurs on the mudflats (100 ind·ha^{-1}) [17]. Thus, the available fraction of prey could be negatively influenced by this high intertidal density because of the anti-predator responses of the prey, specially for visual predators [28]; for example, the polychaete *N. diversicolor* (44–54 % of the total biomass) can quickly take refuge into their burrows if they detect any visible stimulus or vibration in the substrate [32].

The results of wader exclosure experiments show that wader predation can reduce prey biomass in high percentages (> 50 %) over short time periods [27, 29]. On the mudflats, the total biomass in the pre-migratory period (late March) was 1.4 times lower than in February. This change could be due largely to wader predation, as the daily food consumption by waders on the intertidal area was exceptionally high in February (808 g AFDW·ha^{-1}·d^{-1}), especially for an European coast [17]. In fact, the decrease of total biomass (31 %) was mainly caused by the depletion of *N. diversicolor* (44 %), the main prey for many wader species (e.g. plovers) on the mudflat during the study period [17]. Although wader predation can also reduce mean prey size [29], our results were not statistically significant (see *table III*). Nevertheless, future wader exclosure experiments are needed to know the actual fraction of macrozoobenthos predated by waders (or effects in prey size).

In the supratidal habitat (salina), the crustacean *Artemia* seems to be the only macroinvertebrate able to live in high salinity (> 200 g·L^{-1}) of the pans in winter (there was practically no rain in the months of autumn-winter preceding the study) [1]. During wintering season, a considerable proportion of the total populations of several wader species fed at high tide in the salina [21], mainly in late March and parallel to the depletion of biomass on the mudflat [17]. Although the average density of *Artemia* in the pans was low, water management and wind effects can result in a very high local density, with up to 32 600 adult ind·m^{-2} in the wintering season [17]. Therefore, the availability of high tide foraging areas seems to contribute to the maintenance of high intertidal densities of waders on the mudflats.

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Appendix. Relationship used to predict prey biomass from prey size. For *Capitella capitata* and *Streblospio shrubsolii*, the ashes were not taken into account. DW : Dry weight; AFDW : ash free dry weight; L : total length (mm); APL : antero-posterior length (mm); CL : cephalic length (mm); M : maximun width (mm).

Species	Function	Source
Nereis diversicolor	$\log DW (g) = 2.53 \log L - 5.94$; $AFDW = 0.771 DW$	[19]
Scrobicularia plana	$\log DW (g) = 2.49 \log APL - 4.57$; $AFDW = 0.795 DW$	[19]
Cerastoderma edule[1]	$AFDW (mg) = 0.012 APL^{2.97}$	[31]
Hydrobia ulvae[2]	$\log AFDW (mg) = 2.204 \log L - 1.16$	[19]
Capitella capitata	$DW (g) = 0.517 M^{2.031}$	[16]
Streblospio shrubsolii	$DW (g) = 1.358 M^{2.701}$	[16]
Cyathura carinata	$AFDW (g) = 0.0190549 CL^{2.71815}$	[15]
Artemia	$AFDW (g) = 2.57 \cdot 10^{-5} L^{1.529}$	This study

[1] Corrected for 30 % seasonal variation in body condition [34].

[2] Corrected for 12.5 % organic matter in the shell.