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Exploitation of trawler discards by breeding seabirds in the north-western Mediterranean: differences between the Ebro Delta and the Balearic Islands areas

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Local trawler fisheries operate around the seabird colonies of the Ebro Delta and Majorca. The use made of the discards produced by this fishery by scavenging breeding seabirds was examined from 1992 to 1996. All breeding species at each site (except little terns at the Ebro Delta) were observed following trawlers while fishermen were discarding fish: Audouin's, yellow-legged, lesser black-backed, black-headed and slender-billed gulls, common and Sandwich terns in the Ebro Delta area; and Audouin's and yellow-legged gulls, Cory's and Balearic shearwaters, storm-petrel and common shags in the Majorca area. Some non-breeding seabird species, such as gannets, skuas, and *Chlydonias* spp. terns were also recorded in small numbers. Nevertheless, species diversity of the seabird community associated with trawlers was significantly higher at the Ebro than at Majorca, because Procellariiformes, which breed only in the latter area, were displaced by large numbers of gulls. In Majorca, Audouin's gull was significantly more abundant than expected from the size of its breeding population, and in the Ebro area the same was true for the lesser black-backed gull, the black-headed gull, and the common tern. However, the success rates of feeding on trawler discards were not related to species' Presence Indices. In the Ebro area, Audouin's gull took greatest advantage of discards, whereas in Majorca only the yellow-legged gull consumed significantly higher amounts of discards than expected from its Presence Index. The consumption rate of fish discards was significantly higher in the Ebro area (72%) than in the Majorca area (64%). Although the size of fish consumed was associated with seabird body mass, most of the discard items were of a suitably small size. Crude estimates of the weight of fish discarded throughout a breeding season suggest that seabirds, especially Audouin's gulls at the Ebro Delta, may obtain a substantial part of their energy demands from this fishery, while discard availability at the Balearic Archipelago does not support the energy requirements of seabirds breeding there.

Key words: discards, energy requirements and availability, feeding ecology, fisheries, Laridae, Procellariiformes.

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Introduction

Many seabird species exploit waste from commercial fishing vessels in many oceans of the world (e.g. SW Pacific: Blaber and Wassenberg, 1989; Central Pacific: MacCall, 1984; N Pacific: Jones and DeGange, 1988; NE Atlantic: Furness *et al.*, 1992; Camphuysen, 1994; Garthe and Hüppop, 1994; SE Atlantic: Crawford *et al.*, 1992; SW Atlantic: Thompson and Riddy, 1995). These studies, carried out from research or commercial fishing vessels, have shown the distribution at sea of ship-following seabirds, their utilization of discards, and the significance of discards as food for the scavenging species. However, the utilization of fishery waste by seabirds in the Mediterranean Sea has received little attention (Fasola *et al.*, 1989; Sarà, 1993), although several studies on the diet of different seabird species have recorded such utilization (Fasola *et al.*, 1989; Bosch *et al.*, 1994; Ruiz *et al.*, 1996a). Following the establishment of a trawling moratorium around the Ebro Delta area in 1991, which overlapped with the breeding season, the breeding performance of some typical

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Table 1. Characteristics of the trawler fisheries in the two areas (Ebro Delta and Majorca) considering the average foraging range of seabirds exploiting discards (50 km). The relative sizes of trawler fisheries, both in numbers of vessels and their power, with respect to the total fisheries in each area are also shown. HP – horse power.

Area	No. ports	No. trawlers	%	Total HP	%	Landings*
Ebro Delta	4	169	81	57 920	87	297 ± 51
Majorca	6	47	10	12 154	45	363 ± 190

*Expressed as mean ± S.D. kg of fish (vessel day)$^{-1}$. n = 13 (Ebro Delta cruises), n = 10 (Majorca cruises).

scavenging species, such as the lesser black-backed gull (*Larus fuscus*) and the yellow-legged gull (*L. cachinnans*), was negatively affected (Oro, 1996; Oro *et al.*, 1995). Seabirds such as Audouin's gull (*L. audouinii*), considered a specialist predator on shoaling clupeoids, also exploit trawler and purse-seine discards to a large extent (Oro *et al.*, 1996). The results presented here complement previous research by comparing seabird exploitation of discards from trawlers at the Ebro Delta area, where the fleet is one of the most important in the western Mediterranean (Demestre *et al.*, 1988), with an area where a small number of trawlers operate (Majorca). The aim of the work was to assess the utilization of discarded fish by scavenging seabirds behind trawlers in both areas. Large amounts of fish are, at present, discarded in these areas (Ruiz *et al.*, 1996b), but Spanish and European Community fishery policies include reduction in fishing fleets (number of vessels and/or their power), changes in net mesh size, and exploitation of fish species for which there is presently no commercial demand. Similar changes will also affect North Sea fisheries (see Furness, 1992), with expected decreases in the availability of discard at least for some scavenging seabird species.

Study area and methods

Data were obtained from 28 commercial trawler cruises in the two study areas (15 at the Ebro Delta and 13 at Majorca) during the seabird breeding season (April–July) from 1992 to 1996 (Fig. 1). The trawler fleet of the Ebro Delta area comprised 169 trawlers, and that of Majorca, 47 trawlers (Table 1). Fishing trips typically lasted one day. The continental shelf is wider at the Ebro Delta than at Majorca (Fig. 1), and this determined that in the former area all trawlers operated within the limits of the continental shelf (at ca. 110–165 m deep). At Majorca, some of them operated on the upper continental slope (350–500 mm deep), fishing mostly for commercial shrimp species. Breeding seabird numbers in the two areas were obtained from the literature. Only colonies within the foraging range of the fishing grounds of the two ports were considered (average 50 km, following Fasola and Bogliani, 1990; Oro and Ruiz, unpublished data).

Stern counts designed to assess the numbers of ship-following seabirds assembling at the ship during discarding were carried out from the position that offered the best view (Camphuysen *et al.*, 1995). Since (a) bird densities are much lower than those recorded in other areas, e.g. the North Sea, and (b) seabirds are seen mostly when fishermen are discarding (Ruiz *et al.*, 1996b), we recorded in a 360° scan around the ship. The species and number of seabirds actively following the vessel every 15 min from the beginning of the haul to the end of discarding were recorded. Thus, only censuses carried out during discarding were analysed. In addition to descriptive statistics of number of seabird species (median and range) for each area, the numerical percentage of each species (%N), the percentage of occurrence (proportion of censuses in which the species was recorded, %P), and species diversity (using Brillouin's diversity index; Pielou, 1975) were calculated. A jack-knife procedure was used to estimate species diversity at population level, together with the associated variance (Zahl, 1977).

Consecutive censuses of seabirds following fishing vessels may not be statistically independent (see Fowler and Cohen, 1990; Hairston, 1989; von Ende, 1993), and thus assumptions of many statistical methods may be violated. In order to minimize this problem, we have used the average number of seabirds censused at well-spaced intervals (every 15 min) for each discard period (from hauling to the end of discarding).

Experimental discards

In order to assess the efficiency of the different species following the vessels, experimental discarding was carried out as the boat steamed to a new trawling location, and while the fishermen were discarding and sorting the fish caught in the previous haul. Fish and invertebrates selected from discards were thrown behind the boat; both species and length of fish were recorded, and whether the fish sank, was or was not picked up by a

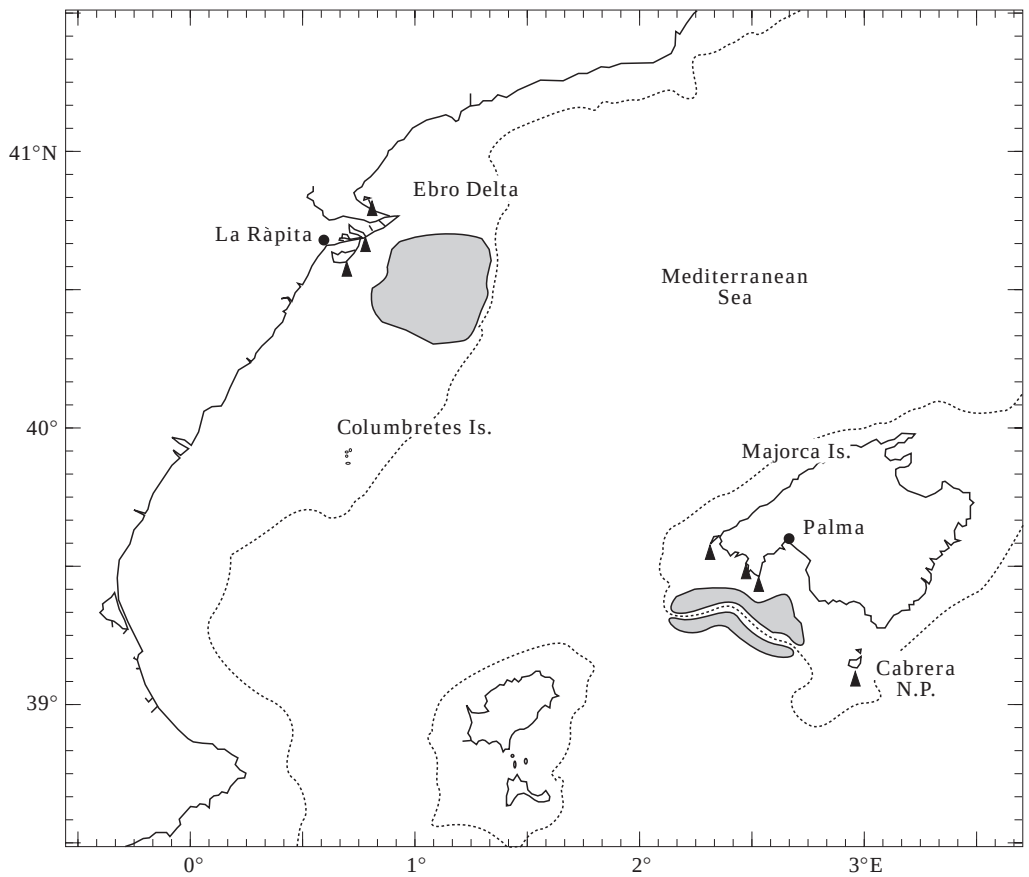

Figure 1. Map of the two study areas (Ebro Delta and Majorca) showing the ports from which the trawler cruises began (Sant Carles de la Ràpita and Palma de Mallorca). The dotted line shows the 200 m isobath, indicating the limit of the continental shelf, whereas the shaded areas show the fishing grounds of the trawlers in the two study areas. The arrows show the location of the breeding colonies, including those of the Cabrera National Park Archipelago.

bird, and, if so, the species of seabird. When fishermen finished discarding, we stopped our experiment because most seabirds ceased to follow the vessel and rapidly dispersed until the next haul (Ruiz *et al.*, 1996b). Since composition of the experimentally discarded fish did not overlap exactly with the composition of the fish discarded by the fishermen, we corrected the total success rate at each colony in relation to the proportion of each species in the discard composition.

A Presence Index (PI) was computed, based on the average numbers of ship-following seabirds and the number of breeding seabirds around the fishing area. Since we assumed that all breeding species are equally likely to follow a ship, the null hypothesis was that the observed relative frequency of each species mirrored their respective breeding numbers. Similarly, a Success Index (SI) was calculated based on the average numbers of ship-following seabirds and the number of fish swallowed by each species. The null hypothesis here was that birds of all species following the boat have an equal likelihood of obtaining fish (see Camphuysen, 1994). These indices were expressed via the residuals of the chi-square distribution obtained from the standardized difference between the observed and the expected frequencies of birds following the trawlers. This ensured the symmetry of the indices, ranging potentially from $-\infty$ to $+\infty$; values below -2 or above $+2$ were considered significant (Zar, 1984).

We also collected fish samples from discards to identify and quantify their composition and length. In total, 3223 and 7836 fish were measured and identified at the Ebro Delta and Majorca areas, respectively.

In order to assess the sizes of discarded fish selected by seabirds, we used Manly's Preference Index (Krebs, 1989), grouping the length of the discarded fish into three categories: small (2–10 cm), medium (11–19 cm), and large (20–40 cm):

$$\alpha_j = \frac{\log p_j}{\sum_{j=1}^{m} p_j}$$

where j = Manly's alpha (Preference Index) for the size class of fish j; m = number of fish size classes; e_j = number of fish of size j that are not consumed at the end of the experiment; n_j = initial number of fish of size j in the experiment; and p_j = proportion of the size class of the fish j that are not consumed at the end experiment (j = 1, 2, 3, . . ., m) = e_j/n_j.

Each discarded species was assigned to one of the following categories: roundfish, benthic fish (lacking a swimbladder), thorny fish, flatfish, snake-like fish, Chondrichthyes, Cephalopoda, and Crustacea. A Consumption Index (CI), similar to the Presence and Success Indices, was also calculated, and expressed as the residuals of the chi-square distribution obtained from the standardized difference between the observed and expected frequencies of swallowed items consumed by birds following the trawler. Expected frequencies were calculated on the basis of the relative abundance of categories from discard composition.

Availability of fish waste

Fishermen from the two study areas discarded fish using their hands or a small plastic shovel. On every cruise, we estimated the amount of fish discarded using two methods: (a) by counting the number of times that fishermen threw the fish overboard with a shovel; or (b) filled plastic boxes instead of directly throwing the fish overboard. The weight of discarded fish was estimated in method (a) by weighing between 5 and 10 shovels in every discard period and using their average weight, and in method (b) by directly weighing the plastic boxes containing the total amount of fish that was to be discarded. In order to assess whether there was an association between the amount of fish discarded and the amount of fish landed, the total number of fish landed from every cruise was also recorded. We used the catch statistics in every area (an average of the fish landed between April and June during the period 1981–1987) to obtain a crude estimate of the total amount of fish discarded during a breeding season. We recorded the statistics of the fishing ports within the average foraging range for the Ebro Delta seabird community, and similar data for the whole Balearic Archipelago, for which we took into account the entire seabird breeding numbers of scavenging seabirds.

From Furness *et al.* (1988), we assumed an average calorific value for discards of 5 kJ g^{-1}, and a food utilization efficiency of 75%. Since there are no measures of basal metabolic rate (BMR) consumption for Mediterranean seabirds, we used data from Scottish seabirds recorded by Bryant and Furness (1995): BMR (kJ d^{-1}) = 2.3 (body mass)$^{0.774}$. Energy requirements of Mediterranean seabirds are probably lower because of the lower latitude and higher average temperatures (Birt-Friesen *et al.*, 1989; Montevecchi *et al.*, 1992). Body mass of yellow-legged and Audouin's gulls was obtained in the Ebro Delta area, but for the other species we used published data (del Hoyo *et al.*, 1992, 1996). Field metabolic rate (FMR), including BMR and cost of physiology, reproduction and activity, was assumed to be 3.9 × BMR for breeding seabirds (see Garthe *et al.*, 1996). Energy required was calculated as the sum of the energy required for each seabird species, taking into account its body mass. The SIs of capturing discards by seabirds in each area (calculated from the experimental discarding) were also included in the calculations.

Presence and success indices were analysed by means of goodness-of-fit tests; contingency tables (together with the chi-square statistic), Mann-Whitney U- and Student's t tests were performed when appropriate. Correlation between fish landed and fish discarded was assessed by Spearman rank correlation, and to compare the slopes of the resultant functions an analysis of covariance was carried out. All statistical tests were two-tailed.

Results

Breeding seabird numbers of the study areas are given in Table 2. At the Ebro Delta, Audouin's gull represents half of the total breeding population; terns (common and Sandwich) are also abundant (28% of the total number), whereas the yellow-legged gull represents only 8% of the total number. In the Majorca area, the yellow-legged gull is the most common species (66% of total numbers), but the total number of seabirds is lower (ca. 5000 pairs), and they breed in more scattered and smaller colonies (Aguilar, 1991).

Although the mass of fish landed per vessel and per day was not significantly different between areas (Mann-Whitney U = 60.0, p = 0.97, Table 1), the fleet is much larger in the Ebro Delta than in Majorca, in terms of both the number of vessels and their power.

At the Ebro Delta, Audouin's gull was the most common species recorded following trawlers during discarding, being present at all hauls (Table 3). Other large scavengers, yellow-legged and lesser black-backed gulls, were recorded at most hauls. However, some species, such as the smaller gulls and terns, were present at fewer hauls. In the Majorca area, only yellow-legged and Audouin's gulls were recorded at most hauls, although small numbers of Balearic shearwaters (*Puffinus yelkouan mauretanicus*) and Cory's shearwaters (*Calonectris diomedea*) were also commonly recorded. Species diversity at population level was significantly higher in the Ebro Delta than in the Majorca area (modified Hutcheson Student's t statistic = −6.69, p < 0.001; Table 3; Zar, 1984). The numbers of seabirds recorded during a discarding period at the Ebro Delta were significantly higher than those recorded at Majorca

Table 2. Seabird breeding numbers in the two study areas (n = number of breeding pairs).

Seabird species	Ebro Delta*		Majorca†	
	n	%	n	%
Balearic shearwater (*Puffinus yelkouan mauretanicus*)	0	0	422	8.0
Cory's shearwater (*Calonectris diomedea*)	0	0	640	12.2
Storm-petrel (*Hydrobates pelagicus*)	0	0	77	1.5
Shag (*Phalacrocorax aristotelis*)	0	0	250	4.8
Lesser black-backed gull (*Larus fuscus*)	63	0.3	0	0
Yellow-legged gull (*Larus cachinnans*)	1426	7.6	3454	65.8
Audouin's gull (*Larus audouinii*)	9360	50.1	408	7.7
Slender-billed gull (*Larus genei*)	582	3.1	0	0
Black-headed gull (*Larus ridibundus*)	2000	10.7	0	0
Sandwich tern (*Sterna sandvicensis*)	1220	6.5	0	0
Common tern (*Sterna hirundo*)	4048	21.7	0	0
Total	18 699	100	5251	100

*Data from Oro (1996).
†Data from Aguilar (1991).

Table 3. Numbers of seabirds following trawlers while fishermen were discarding. %N = numeric percentage, %P = percent occurrence, n = number of hauls when censuses were carried out, N = total number of seabirds censused.

Seabird species	Ebro Delta n = 52 N = 5362		Majorca n = 22 N = 881	
	%N	%P	%N	%P
Balearic shearwater	3.0	57.7	2.0	31.8
Cory's shearwater	0.0	1.9	15.1	77.3
Storm-petrel	0.2	11.5	0.2	9.1
Gannet	0.1	3.9	0	0
Shag	0	0	0.3	13.6
Great skua	0.0	1.9	0	0
Pomarine skua	0.1	5.8	0	0
Arctic skua	0.1	7.7	0	0
Lesser black-backed gull	8.7	78.9	0	0
Yellow-legged gull	13.7	94.2	62.0	100
Audouin's gull	44.9	100	20.2	86.4
Slender-billed gull	3.4	48.1	0	0
Mediterranean gull	0.1	5.8	0	0
Black-headed gull	12.1	67.3	0	0
Black tern	0.5	21.2	0	0
White-winged tern	0	0	0.2	4.6
Sandwich tern	1.2	44.2	0	0
Common tern	11.9	65.4	0	0
Population diversity (SE)	2.46(0.10)		1.49(0.11)	

(Mann-Whitney $U = 181.5$, $p < 0.001$; Table 4). In the former area, the maximum number of ship-following seabirds was ca. 500, whereas at Majorca it was much lower at ca. 110 birds. The number of species recorded behind trawlers during discarding was also significantly higher at the Ebro Delta than in the Majorca area (Mann-Whitney $U = 113.0$, $p < 0.001$).

Presence Indices indicated which species were observed more than expected, given their breeding numbers. In both areas, highly significant differences

Table 4. Numbers of seabirds associated with trawlers in the two study areas 1992–1995. Censuses were carried out when fishermen were discarding fish. N = number of ship cruises; n = number of counts.

	Ebro Delta		Majorca	
	N = 15 n = 113		N = 13 n = 103	
Seabird species	Median	Maximum	Median	Maximum
Balearic shearwater	1	28	0	7
Cory's shearwater	0	2	3	45
Storm-petrel	0	8	0	2
Gannet	0	12	—	—
Shag	—	—	0	3
Great skua	0	1	0	1
Pomarine skua	0	4	—	—
Arctic skua	0	2	—	—
Lesser black-backed gull	2	189	—	—
Yellow-legged gull	9	117	20	110
Audouin's gull	36	207	4	30
Slender-billed gull	0	51	—	—
Mediterranean gull	0	2	—	—
Black-headed gull	3	110	—	—
Black tern	0	8	—	—
White-winged tern	—	—	0	1
Sandwich tern	0	18	—	—
Common tern	6	135	—	—
Total	75	504	39	112

were found between observed and expected seabird frequencies (Ebro Delta: $\chi^2 = 26\,116$, df = 6, $p < 0.001$; Majorca: $\chi^2 = 330$, df = 3, $p < 0.001$). Yellow-legged gulls followed trawlers significantly less than expected in both areas but Audouin's gull showed a different pattern in each area, being recorded in significantly fewer numbers than expected at the Ebro Delta, and significantly higher numbers in the Majorca area. Lesser black-backed gull, black-headed gull, and common tern in the Ebro Delta, and Cory's shearwater in Majorca, were also recorded in significantly higher numbers than expected.

Highly significant differences were recorded between the observed (as measured by SI) and expected success of birds feeding on discards in both areas (Ebro Delta: $\chi^2 = 88.7$, df = 6, $p < 0.001$; Majorca: $\chi^2 = 96.2$, df = 3, $p < 0.001$). However, the SIs and PIs recorded in each area seemed not to be related. At the Ebro Delta, only Audouin's gull showed a significantly higher success index. At Majorca, the yellow-legged gull was the only species taking advantage of discards, whereas Audouin's gull obtained significantly fewer discards than expected given its abundance. Smaller gulls, such as the slender-billed gull (*Larus genei*) and, especially, the black-headed gull, and Procellariiformes (shearwaters and storm-petrels) obtained few or no discarded whole fish (Table 6).

Experimental discards

Overall, 20 and 32 discard experiments were carried out at the Ebro Delta and Majorca, respectively. Tables 5 and 6 give the numbers of fish that were discarded (Ebro Delta, n = 2075; Majorca, n = 924) and the success rates of the scavenging seabirds. Discard composition was different between the two areas, there being a higher diversity of fish species at Majorca than at the Ebro Delta. Flatfish, especially some Citaridae, was the most common discard at the Ebro Delta (33% of total fish discarded), whereas at Majorca, boar fish (*Capros aper*), sardines, horse mackerel (*Trachurus* sp.), and non-commercial shrimps constituted the bulk of discards (ca. 55% of total). Fish discarded at Majorca were significantly larger than those discarded at the Ebro Delta (t test, $t = -19.3$, $p < 0.001$). The birds' success rate was significantly higher at the Ebro Delta than at Majorca (72% and 64%, respectively, $\chi^2 = 18.4$, df = 1, $p < 0.001$). The most commonly discarded species at Majorca, the boar fish (25% of the total number of discarded species), was often rejected by scavenging seabirds. At the Ebro Delta, blennies (*Blennius* sp.) also constituted 25% of trawler discards, and the success rate was only 25%. This was because the species have no swimbladder, and, therefore, sink rapidly. At a

Table 5. Number and length (mean ± S.D. in mm) of fish from samples collected at the trawlers in the Ebro Delta area (eight samples collected during 1993–1995). NA = not available. The number of fish discarded and the percentage known to be swallowed by seabirds are also shown.

Fish species	n	% n	Length	No. discarded	% success
Flatfish, Pleuronectiformes, Fam. Botidae	1068	32.8	81 ± 22	678	94
Blenny (*Blennius* sp.)	976	24.4	60 ± 13	440	25
Sardine (*Sardina pilchardus*)	643	19.7	135 ± 22	388	100
Dragonet (*Callionymus* sp.)	258	7.9	80 ± 28	69	46
Comber (*Serranus* sp.)	118	3.6	120 ± 71	70	81
Crabs (*Carcinus* sp. + *Xantho* sp.)	65	2	57 ± 30	28	21
Horse mackerel (*Trachurus* sp.)	61	1.9	135 ± 28	57	93
Red bandfish (*Cepola rubescens*)	44	1.3	221 ± 48	30	93
Rufus snake eel (*Ophichthus rufus*)	42	1.3	238 ± 77	37	84
Goby (*Gobius* sp.)	34	1	66 ± 15	38	97
Anchovy (*Engraulis encrasicolus*)	16	0.5	101 ± 35	53	89
Bogue (*Boops boops*)	16	0.5	154 ± 69	89	93
European squid (*Loligo vulgaris*)	16	0.5	44 ± 15	8	50
Cuttlefish (*Sepia* sp.)	13	0.4	45 ± 18	4	100
Conger eel (*Conger conger*)	13	0.4	218 ± 38	2	50
Sea bream (*Pagellus* sp.)	9	0.3	130 ± 34	9	67
Boar fish (*Capros aper*)	9	0.3	43 ± 6	8	75
Gilt sardine (*Sardinella aurita*)	8	0.2	172 ± 52	2	50
European hake (*Merluccius merluccius*)	7	0.2	118 ± 24	17	65
Garpike (*Belone belone*)	6	0.2	172 ± 64	6	67
Stargazer (*Uranoscopus scaber*)	6	0.2	158 ± 29	11	45
Greater weaver (*Trachinus draco*)	4	0.1	NA	4	0
Blotched picarel (*Spicara maena*)	3	0.1	NA	1	100
Atlantic mackerel (*Scomber scombrus*)	3	0.1	NA	3	100
Gurnard (*Aspitrigla* sp.)	2	0.1	NA	12	17
Blue whiting (*Micromesistius poutassou*)	1	—	NA	3	100
Mullet (*Mullus* sp.)	1	—	NA	1	100
Trumpet fish (*Macroramphosus* sp.)	1	—	NA	1	100
Mantis shrimp (*Squilla mantis*)	1	—	NA	6	17
Total	3223	100	92 ± 44	2075	72

typological level, highly significant differences were recorded between the discard composition of the two areas ($\chi^2 = 545$, df = 8, $p < 0.001$). Standardized residuals of the contingency table showed that benthic fish, snake-like fish, and flatfish were significantly more abundant at the Ebro Delta, while at Majorca, thorny fish and Chondrichthyes were significantly more common than at the Ebro Delta. There were highly significant differences between the observed consumption and that expected from discard composition as measured by CI at both the Ebro Delta ($\chi^2 = 692$, df = 6, $p < 0.001$) and Majorca ($\chi^2 = 5631$, df = 5, $p < 0.001$). In the two study areas, scavenging seabirds consumed significantly lower quantities of thorny fish, crustaceans, and benthic fish than was expected given their abundance. However, there were significantly high CIs for flatfish, roundfish, and Chondrichthyes.

Seabird consumption of the three size classes of fish differed significantly at the Ebro Delta (small: $\chi^2 = 32.3$, df = 6, $p < 0.001$; medium: $\chi^2 = 56.7$, df = 6, $p < 0.001$; large: $\chi^2 = 22.3$, df = 6, $p < 0.001$). Audouin's and yellow-legged gulls at Majorca consumed similar amounts of fish of any size (small: $\chi^2 = 0.8$, df = 1, $p = 0.4$; medium: $\chi^2 = 1.7$, df = 1, $p = 0.2$; large: $\chi^2 = 0.1$, df = 1, $p = 0.7$). Manly's Preference Index indicated that large fish were selectively taken by the yellow-legged gull only at the Ebro Delta, whereas snake-like fish, such as red bandfish (*Cepola rubescens*) or rufus snake eel (*Ophithchus rufus*), longer than 20 cm (Table 5), were preferred at Majorca (Fig. 2). At the Ebro Delta, some small seabird species, such as black-headed gull and terns, also consumed large discarded fish, but neither the slender-billed gull nor the Balearic shearwater preyed upon this size category of fish (Fig. 2).

Availability of fish waste

In the two study areas, the amount of fish discarded was positively associated with the amount of fish landed (Fig. 3). The amount of fish landed per trawler and per

Table 6. Number and length (mean ± S.D. in mm) of fish from samples collected at the trawlers in the Majorca area (five samples collected during 1993–1995). NA = not available. The number of fish discarded and the percentage known to be swallowed by seabirds are also shown.

Fish species	n	% n	Length	No. discarded	% success
Boar fish (*Capros aper*)	1940	24.8	70 ± 19	29	55
Horse mackerel (*Trachurus* sp.)	820	10.5	132 ± 16	87	87
Plesionika sp.	788	10.1	74 ± 20	20	10
Gilt sardine (*Sardinella aurita*)	790	10.1	158 ± 35	13	100
Sardine (*Sardina pilchardus*)	777	9.9	158 ± 8	2	50
Bogue (*Boops boops*)	694	8.9	164 ± 23	200	95
Comber (*Serranus* sp.)	271	3.5	106 ± 77	67	79
Cod, Gadidae	268	3.4	113 ± 51	38	80
Squat lobster (*Galathea* sp.)	228	2.9	27 ± 4	32	22
Smallspotted catshark (*Scyliorhinus* sp.)	176	2.2	224 ± 62	127	88
Hatchet fish, Sternoptychidae	143	1.8	77 ± 12	40	48
Scorpion fish, Scorpaenidae	120	1.5	96 ± 13	—	—
Gurnard (*Aspitrigla* sp.)	101	1.3	122 ± 23	4	100
Maurolicus sp.	100	1.3	85 ± 12	8	62
Picarel (*Spicara* sp.)	80	1	145 ± 30	19	63
Axillary seabream (*Pagellus acarne*)	73	0.9	99 ± 21	—	—
Jellyfish	63	0.8	39 ± 17	9	0
Shrimp, Pasiphaeidae	62	0.8	74 ± 15	11	18
Velvet belly (*Etmopterus spinax*)	52	0.7	161 ± 28	5	60
Flatfish, Pleuronectiformes	38	0.5	113 ± 19	161	78
Common sea bream (*Sparus pagrus*)	36	0.5	90 ± 24	—	—
Crabs, Portunidae + Paguridae	37	0.5	24 ± 8	22	5
Dragonet (*Callionymus* sp.)	24	0.3	136 ± 40	11	82
Grenadier (*Coelorhynchus* sp.)	22	0.3	109 ± 19	3	67
Trumpet fish (*Macroramphus* sp.)	21	0.3	NA	—	—
Sea bream (*Diplodus* sp.)	17	0.2	129 ± 29	—	—
Red bandfish (*Cepola rubescens*)	16	0.2	169 ± 79	1	100
Cyclothone sp.	12	0.2	111 ± 19	—	—
Skate *Raja* sp.	12	0.2	NA	7	0
Cuttlefish (*Sepia* sp.)	9	0.1	51 ± 15	1	0
Mullet (*Mullus* sp.)	8	0.1	87 ± 37	1	0
Angler fish (*Lophius piscatorius*)	7	0.1	110 ± 46	—	—
Ling (*Molva elongata*)	5	0.1	NA	1	0
Greater weever (*Trachinus draco*)	4	0.1	NA	2	0
Octopus (*Octopus* sp.)	3	0.0	NA	1	0
Gobies, Gobidae	3	0.0	—	—	
Mantis shrimp (*Squilla mantis*)	2	0.0	NA	—	—
Conger eel (*Conger conger*)	2	0.0	NA	—	—
Lizardfish (*Synodus* sp.)	2	0.0	NA	—	—
Sea-horse (*Sygnanthus* sp.)	2	0.0	NA	—	—
Long-legged crab (*Inachus* sp.)	2	0.0	NA	1	0
Atlantic mackerel (*Scomber scomber*)	1	0.0	NA	—	—
Sea urchin (*Echinoaster* sp.)	1	0.0	NA	1	0
Stomiatidae	1	0.0	—	—	—
John Dory (*Zeus faber*)	1	0.0	—	—	—
Stargazar (*Uranoscopus* sp.)	1	0.0	—	—	—
Barracuda (*Sphyraena* sp.)	1	0.0	NA	—	—
Total	7837	100	121 ± 59	924	64

day did not differ significantly between the two sites (Table 1), nor was the amount of fish discarded significantly different (Mann-Whitney $U = 48.0$, $p = 0.4$). The amount of fish discarded at every area was therefore related only to the size of the trawler fleet, which is about nine times larger at the Ebro Delta than at the whole Balearic Archipelago (Table 7). The yellow-legged gull is the largest scavenger (in terms of body size) and comprises 94% of the total breeding numbers of scavenging seabirds at the Balearic Archipelago.

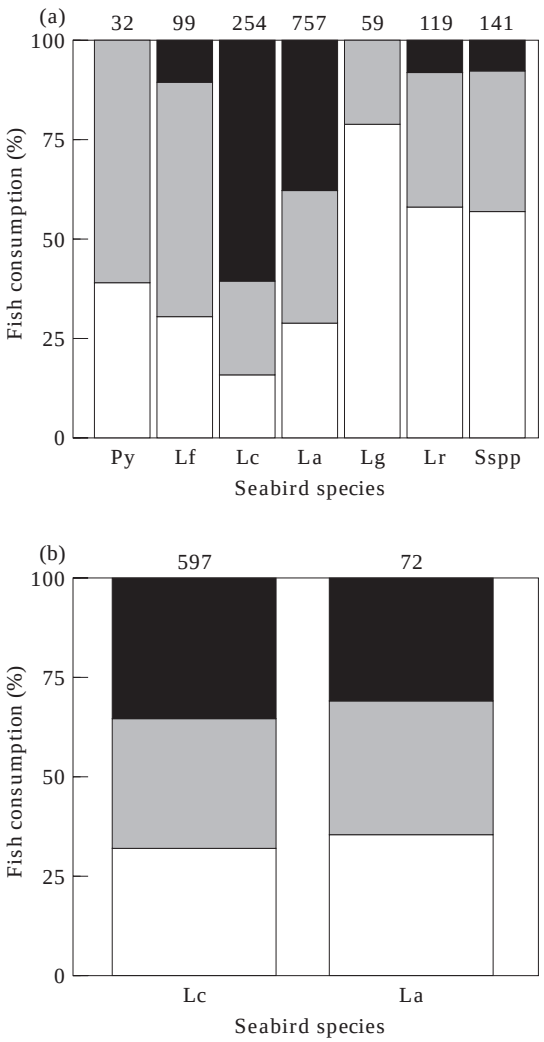

Figure 2. Manly's alpha preference index (in percentage, %) for the three classes of fish-size, at the two study areas: (a) Ebro Delta; and (b) Majorca. Seabird species: Py—Balearic shearwater (Puffinus yelkouan); Lf—lesser black-backed gull (Larus fuscus); Lc—yellow-legged gull (Larus cachinnans); La—Audouin's gull (L. audouinii); Lg—slender-billed gull (L. genei); Lr—black-headed gull (L. ridibundus); Sspp—common and sandwich terns (Sterna spp). Since very few discards were taken by Cory's shearwater at Majorca, only Audouin's and yellow-legged gulls were considered in this area. ■ >20 cm; □ 11–19 cm; □ 2–10 cm.

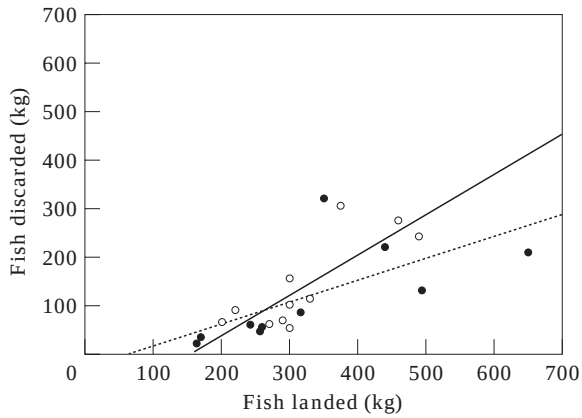

Figure 3. Comparison between discarded and landed fish at the two study areas. In both cases, the correlation is significant (Ebro Delta: $r^2=0.76$, $n=11$, $p<0.01$; Majorca Is.: $r^2=0.81$, $n=11$, $p<0.01$). Analysis of covariance showed that the slopes of the two functions (Ebro Delta: $y=0.837x-130.2$; Majorca: $y=0.454x-28.87$) were not significantly different between the two areas ($F=0.66$, $df=1$, $p=0.43$). · · · · ● Majorca Is.; —— ○ Ebro Delta.

Therefore, the energy requirements here are higher than at the Ebro Delta, where the commonest species (Audouin's gull, 50% of total seabird numbers, see Table 2) has half the biomass of the yellow-legged gull (Table 7).

Discussion

In our study, gulls and terns aggregated and foraged behind the trawlers, whereas Procellariiformes were observed further away from the stern of the vessels. Skuas moved all around the trawlers and often kept away from them. All local breeding species (except little terns (*Sterna albifrons*) at the Ebro Delta) were observed following trawlers. Although the number of breeding species was similar in the two areas, the diversity of species following trawlers was higher at the Ebro Delta than at Majorca. This is probably because truly pelagic seabirds such as shearwaters and storm-petrels (which breed only in the Majorca area) do not exploit discarded fish to the same extent as some gulls or terns (Camphuysen *et al.*, 1995). Audouin's gull at the Ebro Delta, and yellow-legged gull at Majorca, were the commonest species associated with trawlers, appearing at all the hauls in each respective area. However, considering their breeding numbers, both Audouin's and yellow-legged gulls had a significantly negative PI, whereas the lesser black-backed gull and common tern at the Ebro Delta, and Cory's shearwaters at Majorca, were more frequent than expected given their breeding numbers. Large numbers of lesser black-backed gulls at the Ebro Delta may be explained by the presence of non-breeding adults and sub-adults that spend the breeding season there (Oro and Ruiz, unpublished). Discards from fisheries (both trawler and shellfish) also constitute the main foraging resource for the species at this colony, and, indeed, is the only resource capable of meeting its energy demands (Oro, 1996). Nevertheless, results suggest that success in picking up fishery waste was related to the absolute and not the relative abundance of each species, since Audouin's gull at the Ebro Delta and yellow-legged gull at Majorca were the only

Table 7. Energy requirements of scavenging seabird species and energy equivalents of trawler discards in the two areas ($\times 10^9$ kJ). An index of energy required v energy available (corrected by discard consumption rate and utilization efficiency) is also shown (see Garthe *et al.*, 1996). Breeding population is expressed as number of breeding pairs. Average biomass of total seabird breeding population was calculated in relation to the breeding population of each seabird species. Energy required was the sum of the energy required for each seabird species. Only scavenging seabird species were taken into account.

Area	Breeding population	Average biomass (g)	Energy required	Energy available	Index
Ebro Delta	18 699	504	3.38	7.04	0.48
Balearic Arch.	12 800	1072	4.57	0.80	5.71

species that showed significantly high SIs. Other factors, such as body size, may affect the PIs and SIs of each species following trawlers (see, e.g. Furness *et al.*, 1992; Dunnet *et al.*, 1990; Garthe and Hüppop, 1994). Thus, black-headed or slender-billed gulls, smaller species that followed the trawlers at the Ebro Delta in large numbers, obtained significantly lower amounts of discards than expected by their abundance. However, there was no correlation between a species body mass and its SI (Spearman rank correlation, $r = 0.40$, $n = 10$, $p = 0.26$). The availability of alternative foraging resources may also affect the use made by each species of trawler discards (Furness *et al.*, 1992). For the three large gull species at the Ebro Delta (lesser black-backed, yellow-legged, and Audouin's), it seems that the species with fewer foraging options (lesser black-backed gull) exploited trawler discards to a greater extent (Oro *et al.*, 1996). Shearwaters and storm petrels recorded in our study seemed to avoid trawlers, probably because they were outcompeted by large numbers of gulls.

The observations on terns at the Ebro Delta were surprising Despite their small body size (they were the smallest species), they obtained discards to the same extent as the yellow-legged gull. Curiously, common terns followed trawlers in large numbers (supporting the suggestion that absolute abundance may benefit the exploitation of discards), but Sandwich terns did not. These results are similar to those obtained by Fasola *et al.* (1989) in the Adriatic Sea and by Walter and Becker (1994) in the Wadden Sea. Both species feed on shoaling clupeoids in the Mediterranean, especially on the sardine and anchovy (*Engraulis encrasicolus*), have similar foraging ranges and probably similar flight capacities. However, they seemed to differ in their exploitation of trawling discards. Interspecific competition through abundance, body size, and foraging strategy may affect the trade-off between costs and benefits derived from associating with trawlers for each species, and seabirds may change their foraging range and/or daily activity patterns in order to avoid this competition.

Experimental discards

Contrary to what is often recorded in the North Sea or around the Falkland Islands (Thompson and Riddy, 1995), most of the fishery waste in the study area was composed of discarded fish and invertebrates, whereas no offal, except the guts of angler fish (*Lophius piscatorius*), was generated. Differences in the fish species composition of trawler discards between the two areas seemed to determine their overall consumption rate by scavenging seabirds; the difference was significantly higher at the Ebro Delta than at Majorca. Oceanographic features of both sites are different, those of the Ebro Delta area being typified by the large amounts of nutrients and sediments discharged by the Ebro river, which result in both high clupeoid densities (e.g. Palomera, 1992; Palomera and Pertierra, 1993; I. Palomera, pers. comm.) and a sandy seabed, where Pleuronectiformes, especially scaldfish (*Arnoglossus* spp.) are abundant. In fact, at the Ebro Delta, about half of the discards comprised flatfish and sardines, both with a high consumption rate. Sardines were caught by trawlers when they were fishing for anchovy, but the sonar was unable to distinguish between shoals of the two species. Since trawlers at the Ebro Delta were not allowed to land sardines, large amounts of these were systematically discarded. However, at Majorca, ca. 40% of discards were crustaceans and boar fish, which were seldom consumed by seabirds. Boar fish have already been recorded as being commonly discarded, but they are seldom consumed by Cory's shearwaters associating with trawlers in the Sicily Channel, central Mediterranean (Sarà, 1993).

Overall discard consumption rates at both study areas (72% at the Ebro Delta, 64% at Majorca) were within the range recorded in the North Sea (35–85%, corrected from revision in Garthe *et al.*, 1996). In our

study, category of fish determined the selection made by scavenging seabirds, since the size of most discarded fish (<20 cm in length) was suitable. Similar results were obtained in the Firth of Clyde by Furness *et al.* (1988). Surprisingly, Chondrichthyes and flatfish had a high rate of consumption in our study (ca. 80% and 90%, respectively), with few differences between the two study areas. Such fish, especially flatfish, are seldom selected by scavenging birds (see revision in Garthe *et al.* (1996) and references therein). When they are taken by seabirds, flatfish are selected on the basis of fish width rather than length (Camphuysen, 1994). Camphuysen (1994) reported 8 cm as the limit wider than which the consumption rate of flatfish greatly decreased. As this is the average length of flatfish in the study area, it is likely that the small size of this discard allowed scavenging seabirds to exploit it heavily.

Discard experiments are biased, especially when performed from research vessels, by the fact that fish are discarded one by one, thereby probably causing overestimation of seabird consumption rates (Garthe and Hüppop, 1994; Garthe *et al.*, 1996). However, the experiments in this study were carried out while fishermen were discarding, and the discarding method used at the two study areas, by hand or using small plastic shovels (holding ca. 500 g of fish), along with a low discarding rate, probably allowed seabirds to obtain most of the suitable discarded fish. Our results are probably not greatly biased, therefore, although in some parts of the study areas, fishermen filled large plastic boxes (containing ca. 10 kg of fish) with non-commercial species before discarding them, thereby probably decreasing their availability for seabirds. Similarly, Furness *et al.* (1988) noted that differences in gutting methods between Canadian, Scottish, and Irish fishermen explained the ability of scavenging seabirds to exploit offal on different fishing grounds.

Availability of fishery waste

The proportions of total fish catches that were discarded in the two study areas were similar (15–45% at the Ebro Delta, 11–48% at Majorca). This large variation was generated by changes in fish target species, which may vary seasonally or even daily. This is related to market demand and fish prices, which determine the fishing gears and procedures employed, and, consequently, the amounts and species of fish discarded (Ruiz *et al.*, 1996b). It is widely assumed that the amount of fish discarded depends on the fishing fleet and its fishing methods, but even within the same fishing fleet large variations in the fish discarded are found, depending on the target species or the season (Furness *et al.*, 1988; Walter and Becker, 1994; Garthe *et al.*, 1996). Discarded fish represented ca. 41% and 34% (by weight) of fish landed in the Ebro Delta and Majorca areas respectively, figures slightly higher than those recorded for seine net, motor trawl, and light trawl fisheries in the North Sea (Furness *et al.*, 1988), but much lower than those recorded at shrimp trawl fisheries in the North Sea, for both Norway lobster (*Nephrops norvegicus*; 50–300% of lobster landed, Furness *et al.*, 1988) and brown shrimp (*Crangon crangon*; 90% of catch, Walter and Becker, 1994).

Although the estimates of the total mass of discards are crude, they provide a preliminary assessment of the numbers of seabirds supported by trawler fisheries in the Ebro Delta and in the Balearic Archipelago. The results suggest that discards from the respective trawler fleets may readily support all scavenging seabirds breeding at the Ebro Delta, but not at the Balearic Archipelago. Future analyses should include fish and invertebrate availability from other fleets, such as purse-seine, shellfish, and gillnet fisheries, and even the discard method employed by each vessel, as mentioned above. Nevertheless, it seems clear that large gulls and common terns at the Ebro Delta obtain a great amount of discarded fish, and this extra food availability may be a major cause of seabird population increases at the Ebro Delta (Oro, 1996; Oro *et al.*, 1995, 1996). In the Balearic Archipelago, trawler fisheries do not provide enough discards to meet the energy requirements of scavenging seabirds. The small number of trawlers in this area and competition with the more abundant and larger yellow-legged gull precluded Audouin's gull and Procellariiformes from exploiting discards to a large extent. This, together with the low availability of suitable breeding sites, probably explains why the Audouin's gull population in the Balearic Archipelago increases at a much lower rate than that of the Ebro Delta.

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References

Aguilar, J. S. 1991. Resum de l'atlas d'ocells marins de las Balears, 1991. Anuari Ornitològic de les Balears, 6: 17–28.

Birt-Friesen, V. L., Montevecchi, W. A., Cairns, D. K., and Macko, S. A. 1989. Activity-specific metabolic rates of free-living northern gannets and other seabirds. Ecology, 70: 357–367.

Blaber, S. J. M. and Wassenberg, T. J. 1989. Feeding ecology of the piscivorous birds *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii* in Moreton Bay, Australia: diets and dependence on trawler discards. Marine Biology, 101: 1–10.

Bosch, M., Oro, D., and Ruiz, X. 1994. Dependence of yellow-legged gulls (*Larus cachinnans*) on food from human activity in two western Mediterranean colonies. Avocetta, 18: 135–139.

Bryant, D. M. and Furness, R. W. 1995. Basal metabolic rates of North Atlantic seabirds. Ibis, 137: 219–226.

Camphuysen, C. J. 1994. Flatfish selection by herring gulls *Larus argentatus* and lesser black-backed gulls *Larus fuscus* scavenging at commercial beamtrawlers in the southern North Sea. Netherlands Journal of Sea Research, 32: 91–98.

Camphuysen, C. J., Calvo, B., Durinck, J., Ensor, K., Follestad, A., Furness, R. W., Garthe, S., Leaper, G., Skov, H., Tasker, M. L., and Winter, C. J. N. 1995. Consumption of discards by seabirds in the North Sea. Final report EC DG XIV. Netherlands Institute for Sea Research, Texel. 202 pp. + LVI.

Crawford, R. J. M., Underhill, L. G., Raubenheimer, C. M., Dyer, B. M., and Martin, J. 1992. Top predators in the Benguela ecosystem: implications of their trophic position. South African Journal of Marine Sciences, 12: 675–687.

del Hoyo, J., Elliot, A., and Sargatal, J. (Eds) 1992. Handbook of the birds of the world, vol. 1. Lynx Edicions, Barcelona. 696 pp.

del Hoyo, J., Elliot, A., and Sargatal, J. (Eds) 1996. Handbook of the birds of the world, vol. 3. Lynx Edicions, Barcelona. 821 pp.

Demestre, M., Lleonart, J., Martín, P., Recasens, L., and Sánchez, P. 1988. La pesca en Cataluña. FAO Rapport sur les Pêches, 395: 101–103.

Dunnet, G. M., Furness, R. W., Tasker, M. L., and Becker, P. H. 1990. Seabird ecology in the North Sea. Netherlands Journal of Sea Research, 26: 387–425.

Fasola, M. and Bogliani, G. 1990. Foraging ranges of an assemblage of Mediterranean seabirds. Colonial Waterbirds, 13: 72–74.

Fasola, M., Bogliani, G., Saino, N., and Canova, L. 1989. Foraging, feeding and time-activity niches of eight species of breeding seabirds in the coastal wetlands of the Adriatic Sea. Bollettino di Zoologia, 56: 61–72.

Fowler, J. and Cohen, L. 1990. Practical statistics for field biology. Open University Press, Buckingham, UK. 227 pp.

Furness, R. W. 1992. Implications of changes in net mesh size, fishing effort and minimum landing size regulations in the North Sea for seabird populations. JNCC Report No. 133.

Furness, R. W., Ensor, K., and Hudson, A. V. 1992. The use of fishery waste by gull populations around the British Isles. Ardea, 80: 105–113.

Furness, R. W., Hudson, A. V., and Ensor, K. 1988. Interactions between scavenging seabirds and commercial fisheries around the British Isles. *In* Seabirds and other marine vertebrates: competition, predation and other interactions, pp. 240–268. Ed. by J. Burger. Columbia University Press, New York, USA. 339 pp.

Garthe, S., Camphuysen, C. J., and Furness, R. W. 1996. Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. Marine Ecology Progress Series, 136: 1–11.

Garthe, S. and Hüppop, O. 1994. Distribution of ship-following seabirds and their utilization of discards in the North Sea in summer. Marine Ecology Progress Series, 106: 1–9.

Hairston, N. G. 1989. Ecological experiments: purpose, design and execution. Cambridge University Press, Cambridge, UK. 370 pp.

Jones, L. L. and DeGange, A. R. 1988. Interactions between seabirds and fisheries in the North Pacific Ocean. *In* Seabirds and other marine vertebrates: competition, predation and other interactions, pp. 269–291. Ed. by J. Burger. Columbia University Press, USA. 339 pp.

Krebs, C. J. 1989. Ecological methodology. Harper and Collins, New York, USA. 654 pp.

Montevecchi, W. A., Birt-Friesen, V. L., and Cairns, D. K. 1992. Reproductive energetics and prey harvest of Leach's storm-petrels in the northwest Atlantic. Ecology, 73: 823–832.

MacCall, A. D. 1984. Seabird-fishery trophic interactions in eastern Pacific boundary, currents: California and Peru. *In* Marine birds: their feeding ecology and commercial fisheries relationships, pp. 136–149. Ed. by D. N. Nettleship, G. A. Sanger, and P. F. Springer. Canadian Wildlife Service. 220 pp.

Oro, D. 1996. The effects of trawler discard availability on the egg-laying and the breeding success of the lesser black-backed gull *Larus fuscus* in the western Mediterranean. Marine Ecology Progress Series, 132: 43–46.

Oro, D., Bosch, M., and Ruiz, X. 1995. Effects of a trawling moratorium on the breeding success of the yellow-legged gull *Larus cachinnans*. Ibis, 137: 347–349.

Oro, D., Jover. L., and Ruiz, X. 1996. Influence of trawling activity on the breeding ecology of a threatened seabird, Audouin's gull *Larus audouinii*. Marine Ecology Progress Series, 139: 19–29.

Palomera, I. 1992. Spawning of anchovy *Engraulis encrasicolus* in the northwestern Mediterranean relative to hydrographic features in the region. Marine Ecology Progress Series, 79: 215–223.

Palomera, I. and Pertierra, J. P. 1993. Anchovy biomass estimate by the daily egg production method in 1990 in the western Mediterranean Sea. Scientia Marina, 57: 243–251.

Pielou, E. C. 1975. Ecological diversity. New York, John Wiley and Sons. 165 pp.

Ruiz, X., Jover, L., Oro, D., González-Solís, J., Pedrocchi, V., Genovart, M., Abella, J. C., and Sanpera, C. 1996b. Ecologia y dinámica de la población de la gaviota de Audouin *Larus audouinii*. ICONA-Universidad de Barcelona, Barcelona. 630 pp.

Ruiz, X., Oro, D., Martínez-Vilalta, A., and Jover, L. 1996a. The feeding ecology of Audouin's gull *Larus audouinii* in the Ebro Delta. *In* Ecology, conservation and management of colonial waterbirds in the Mediterranean region, pp. 68–74. Ed. by A. J. Crivelli, H. Hafner, M. Fasola, R. M. Erwin, and D. A. McCrimmon, Jr. Colonial Waterbirds, 19, Special Publication 1.

Sarà, M. 1993. Feeding habits of Cory's shearwater (*Calonectris diomedea*) in the central Mediterranean Sea. *In* Estatus y conservación de aves marinas, pp. 213–220. Ed. by J. S. Aguilar, X. Monbailliu, and A. M. Paterson. SEO, Madrid. 386 pp.

Thompson, K. R. and Riddy, M. D. 1995. Utilization of offal and discards from ''finfish'' trawlers around the Falkland Islands by the black-browed albatross *Diomedea melanophris*. Ibis, 137: 198–206.

von Ende, C. N. 1993. Repeated-measures analysis: growth and other time-dependent measures. *In* Design and analysis of ecological experiments, pp. 113–137. Ed. by S. M. Scheiner and J. Gurevitch. Chapman and Hall, New York. 445 pp.

Walter, U. and Becker, P. H. 1994. The significance of discards from the brown shrimp fisheries for seabirds in the Wadden Sea – preliminary results. Ophelia Supplement, 6: 253–262.

Zahl, S. 1977. Jack-knifing – an index of diversity. Ecology, 58: 907–913.

Zar, J. H. 1984. Biostatistical analysis. Prentice Hall International. New Jersey. 718 pp.