Seabird-trawling interactions: factors affecting species-specific to regional community utilisation of fisheries waste

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ABSTRACT

Bottom trawl fishing provides substantial amounts of normally unavailable demersal prey to seabirds (e.g., discards), affecting their life-history traits and population dynamics, as well as community structure. Within this framework, we studied seabird-trawling interactions throughout the annual cycle in a poorly studied ecosystem in the Mediterranean, the Balearic archipelago, on a both species-specific and a community level. Whereas the species-specific approach showed a significant influence of season (phenology) on shaping seabird's trawling attendance patterns, the spatio-temporal coupling of regional community was a result of a complex interaction between fishery-related variables. The most frequent and abundant species were the yellow-legged gull *Larus michahellis* and Cory's shearwater *Calonectris diomedea*, the latter attending vessels in higher numbers than expected from local population figures. Conversely, the remaining breeding species occurred in lower numbers than expected according to their local breeding populations, suggesting that discards were of relatively little importance. Discarding activity took place over the entire shelf and continental slope surrounding Mallorca, but especially in the south-west, adjacent to the breeding grounds of approximately 12% of the Balearic total seabird breeding

population, including 13% the Balearic shearwater *Puffinus mauretanicus* world population. Overall discards corresponded to 0.74 of landings (range: 0.09–6.00) and consisted primarily of fish followed by crustaceans and molluscs (approximately 80, 15, and 5%, respectively). Seabird-trawling interactions should be taken into account in the frame of an ecosystem-based approach to fisheries management, and particular attention should be devoted to the critically endangered Balearic shearwater.

Key words: Balearic shearwater, discards, ecosystem-based management, generalized linear models, kernel analysis, *Puffinus mauretanicus*, seabird-fishery interactions

INTRODUCTION

Marine top predators such as seabirds play an important role in ecosystem functioning and are especially affected by environmental changes (including human-induced perturbations such as fishing) due to their high trophic position in the food web (Furness and Camphuysen, 1997; Boyd *et al.*, 2006; Arcos *et al.*, 2008). In particular, seabirds interact with commercial fisheries in different ways: in some cases, fisheries promote high mortality via incidental bycatch driving some species to near extinction (Brothers *et al.*, 1999; Igual *et al.*, 2009), while in other cases fisheries deplete fish stocks when targeting the same or interconnected prey of seabirds, and so reduce their availability (Furness, 2003). However, some fishing activities provide a naturally unavailable trophic resource to scavenging seabirds: demersal species in the form of offal and discards (Hudson and Furness, 1988). Availability of such fishery waste can influence life-history traits of seabirds and their population dynamics, as well as community structure (Oro *et al.*, 1999; Votier *et al.*, 2008). Indeed, discards provide an important food supply to scavenging species which could lead to change in movement patterns (Arcos and Oro, 1996; Bartumeus *et al.*, 2010), improve reproductive performance (Oro *et al.*, 1997; 1999) and increased survival (e.g., Oro and Furness, 2002; Oro *et al.*, 2004). Consequently, this human-induced food

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resource could potentially favour more generalist species, sustaining their increasing population numbers (Furness, 2003).

During the 1990s, approximately 27 million tons of fish were discarded worldwide each year (Alverson, 1998). In the European Union, incoming fisheries policies are directed at reducing discards and bycatch (Penas, 2007) and in turn decreasing the availability of this trophic resource for scavenging species. Thus, opportunistic seabirds would be forced to seek alternative foraging resources (Oro *et al.*, 1997; Stenhouse and Montevecchi, 1999) and affect seabird breeding performance and population sizes (Reeves and Furness, 2002). This fishing regulation could also influence community structure by promoting intra- and inter-specific competition as well as predation on more specialised and vulnerable taxa (Oro, 1996; Stenhouse and Montevecchi, 1999; Arcos *et al.*, 2001; Furness, 2003; Votier *et al.*, 2004). Particularly sensitive are those species with low foraging plasticity, i.e., species with energetically expensive foraging methods, restricted foraging ranges and/or poor diving ability (Furness and Ainley, 1984; Arcos, 2001). Moreover, a key gap in our knowledge is the understanding of seabird-trawling interactions during the inter-breeding period (but see Arcos, 2001). This is of particular relevance since the effects of resource availability can be crucial for over-winter survival, when the majority of seabird mortality occurs (Barbraud and Weimerskirch, 2003).

In the Mediterranean Sea, fishing activity is characterised by highly diverse catches and the absence of large single stocks, especially in the demersal fisheries (Farrugio *et al.*, 1993; Lleó and Maynou, 2003). In the western basin, most demersal stocks are fully exploited or overexploited, while some pelagic stocks also show overexploitation trends (Farrugio *et al.*, 1993; Coll *et al.*, 2006). Fishing discards are generated mainly in trawling and, to a lesser extent in purse-seine fisheries (e.g., Carbonell *et al.*, 1997; Arcos and Oro, 2002b; Tudela, 2004), totalling approximately 565 000 t yr⁻¹ in the whole Mediterranean and Black Sea (Alverson, 1998). Considerable attention has been devoted to the utilisation of fishery waste by seabirds, mostly during the breeding season in the Iberian continental shelf (Arcos, 2001; Martínez-Abraín *et al.*, 2002), although studies are scarce in other areas (e.g., the Balearic archipelago - but see Oro and Ruiz, 1997).

Here we studied fishing patterns of the trawling fleet of the Balearic Islands and their interaction with seabirds. Specifically:

- 1 We assessed trawling performance by analysing discards, landings and the discard ratio (i.e., a ratio of discards versus landings) differences by fishing tactics (coastal, deep shelf and upper slope).
- 2 We studied which were the main discarding grounds of the trawling fisheries of Mallorca, which represents the 67% of the total trawling fleet of the archipelago.
- 3 We explored the patterns of trawler attendance by seabirds throughout the annual cycle, on a species-by-species basis, taking into account the season, geographical area and type of habitat/fishing tactic. When do seabirds make most use of discards regarding their annual cycle? What are the species showing a major degree of association with trawlers? Where are seabird-trawling interactions most intense within the Balearic archipelago?
- 4 We estimated overall seabird abundance and local diversity in order to understand regional community dynamics: is there any dominant species? Moreover, we investigated how characteristics of the fishing fleet influence the community.

MATERIALS AND METHODS

Study area, trawling fishery and seabird community

The Balearic archipelago is characterised by a narrow continental shelf, with absence of submarine canyons, and lack of significant sediment input from the shelf (i.e., absence of river runoffs). Water masses circulating through its channels contribute to its high hydrographical variability (e.g., Pinot *et al.*, 2002). Since the archipelago is separated from the Iberian Peninsula by large geographical barriers (depths between 800 and 2000 m), it can be considered as an isolated demersal ecosystem (Massutí and Reñones, 2005).

Trawling is one of the most important fisheries, in catches and economic terms, in the western Mediterranean (Carbonell *et al.*, 1997; Lleó and Maynou, 2003). In the Balearic archipelago, the trawling fleet operates only on working days from 5 AM to 5 PM and comprised 55 vessels at 16 harbours in 2003, with a decreasing trend in recent years. The most important ports are located in the south and west of Mallorca (25 trawlers), followed by the north-eastern ports of Mallorca (12 trawlers), Eivissa-Formentera (11 trawlers) and Menorca (7 trawlers). No trawling moratorium has been established in the region, in contrast to other areas of the Mediterranean Iberian Peninsula (Tudela, 2004). Trawlers conduct different fishing tactics depending on the continental shelf section, fishing depth and target

species (Guijarro and Massutí, 2006; Ordines *et al.*, 2006; Palmer *et al.*, 2009):

- 1 Shallow shelf (SS, 40–80 m): *Spicara smaris*, *Mullus surmuletus*, *Octopus vulgaris* and a mixed-fish category.
- 2 Deep shelf (DS, 125–235 m): *Zeus faber*, *Mullus surmuletus*, *Merluccius merluccius*, and a mixed-fish category composed of species different from those of the category of the same name for the SS.
- 3 Upper slope (US, 350–600 m): targeting *Nephrops norvegicus* but with an important bycatch of *Merluccius merluccius*, *Lepidorhombus boscii*, and *Micromesistius poutassou*.
- 4 Middle slope (MD, 600–750 m): the only target species is *Aristeus antennatus*, which is taken along with a bycatch that includes *Galeus melastomus*, *Phycis blennoides* and *Geryon longipes*.

The level of endemism of the Mediterranean ecosystem is high, including seabirds, thus being of special conservation concern (Bianchi and Morri, 2000). The seabird breeding community presents small population sizes, and it is especially diverse at the Balearic archipelago, where six species breed regularly (Zotier *et al.*, 1999): three Procellariiform taxa endemic to the Mediterranean (the Balearic shearwater *Puffinus mauretanicus*, BS, Cory's shearwater *Calonectris diomedea diomedea*, CS, and the European storm-petrel *Hydrobates pelagicus melitensis*, ESP), the endemic Mediterranean shag *Phalacrocorax aristotelis desmarestii*, MS, and two gull species (Audouin's gull *Larus audouinii*, AG, which is also endemic to the Mediterranean, and the yellow-legged gull *L. michahellis*, YLG) (see Table S1; Aguilar, 1991; Viada, 2006). Total numbers are roughly estimated at approximately 31 000 breeding pairs (data for 1991). Non-breeding scavenging species also occur regularly at the Balearic archipelago in very small numbers, mostly during their non-breeding period (e.g., the Northern gannet *Morus bassanus*, and the great skua *Stercorarius skua*). During the post-breeding period, three species of the local breeding community (BS, CS and AG) leave the Mediterranean to their 'wintering' quarters in the Atlantic (northeast, central and south Atlantic, respectively) (Ruiz and Martí, 2004; González-Solís *et al.*, 2007). The MS and YLG are sedentary species which remains in the Balearic Islands, though many young disperse away from the archipelago. Finally, little information is available about the post-breeding distribution of ESP, although observations off the Balearic archipelago are exceptional.

Onboard data collection

Data were collected onboard 8 trawlers belonging to four different ports from Mallorca and two ports from

Eivissa and Formentera. In total, we randomly conducted 31 one-day cruises recording 46 fishing operations, from April 2002 to September 2003 (Fig. 1). We counted the number of seabirds attending trawlers during the discarding process, starting when the net was on the surface (i.e., end of the hauling process) and stopping when all discards were thrown overboard. For each discarding process, stern counts were carried out every 15 min, from the position that offered the best view over 360° (Camphuysen *et al.*, 1995), and the species, number and age (adults and immatures, only in the case of shags and gulls) of seabirds following the trawler were recorded. Since consecutive censuses of seabirds following vessels, as well as their geographic positions, may not be statistically independent, we considered the maximum number per species and the average position of each discarding process as the representative count and position for each process, respectively (cf. Oro and Ruiz, 1997). We divided the annual cycle of breeding seabirds in four different periods: December–February, March–May, June–August and September–November (winter, spring, summer and autumn hereafter, respectively). For each species, the mean, median and range of seabird counts were calculated, as well as the numerical percentage of each species (%N), and the percentage of occurrence (%P; proportion of hauls where the species was recorded) by season.

Vessels made only one haul (mainly in the slope) or a varying number of consecutive hauls (i.e., fishing operations) per day (up to three in the shallow shelf). Whenever possible, fishery-related information was also recorded for each fishing operation: (1) trawler's horsepower and (2) length, (3) the number of trawlers operating at the beginning of the discarding process in the fishing area (i.e., the number of vessels visually recorded over 360°), amount of (4) discards and (5) landings (i.e., marketable catches). Discards were thrown directly overboard most frequently using plastic shovels (but also by hand). Thus, we counted how many times plastic shovels were used and weighted the content approximately 5–10 times to obtain an average weight per shovel, which allowed us estimating a total weight of discards (cf. Oro and Ruiz, 1997; Arcos, 2001). Landings for each fishing trip were estimated from fishermen guild records and identified to major taxonomic groups and their contribution to landings by operation.

Finally, a sub-sample of the discard was separated for each fishing operation in order to estimate the proportion of major taxonomic groups (i.e., fish, crustacean and mollusc). By combining annual landings (provided by the Spanish Institute of

Figure 1. (a) Map of the western Mediterranean framing the study area (dotted square) and showing the main geographic references. (b) Total number of birds and (c) regional diversity per discarding process. Circle sizes are proportional to seabird numbers and diversity values. Background values represent mean SeaWiFS chlorophyll *a* concentration (mg m^{-3}) values from April 2002 to September 2003. Oceanographic data are available thanks to the Environmental Research Division, Southwest Fisheries Science Center and US National Marine Fisheries Service (<http://coastwatch.pfsl.noaa.gov/coastwatch/CWBrowserWW360.jsp>).

Oceanography, IEO), DR, and discard sub-sample proportions, we were able to estimate the annual discarded biomass for each taxonomic group for the study period in Mallorca.

Trawling fishery performance

In order to study trawling fishery performance, we calculated a ratio of discards versus landings (discard ratio, $\text{DR} = \text{discards/landings}$) and explored the influence of the season (winter was excluded due to the low sample size; see Table 1) and fishing tactic separately on discards, landings and DR. Landings, discards and DR were $\ln$ -transformed in order to meet a normal distribution and, in turn, ANOVA tests were run. Due to the low availability of hauls at the US and

MS fishing tactics, both strategies were analysed jointly. Thus, we considered three fishing tactics in our analyses: coastal (shallow shelf), shelf (deep shelf), and slope (upper and middle slope).

Discarding grounds

Thanks to the regular observer programme implemented at the Spanish Institute of Oceanography, we identified the spatial location of discarding grounds around Mallorca, which represents 67% of the Balearic trawling fleet. Onboard observations were conducted on all main harbours totalling 733 discarding processes from 2000 to 2008. We estimated the non-parametric fixed kernel utilisation distribution, which draws contours of equal density from the observed data (i.e.,

Table 1. Median (and range) of landings (kg), fish discards (kg) and discard ratio (DR = discards/landings) by season and fishing tactic.

Season	Fishing tactic				Total by season
	General information	Coastal	Shelf	Slope	
Winter	N	–	–	1	1
	Discards	–	–	97.4	97.4
	Landings	–	–	150.0	150.0
	DR	–	–	0.65	0.65
Spring	N	13	1	2	16
	Discards	70.0 (10.0–2000.0)	1200.0	52.2 (34.0–70.0)	70.0 (10.0–2000.0)
	Landings	149.0 (31.1–406.0)	207.5	101.5 (92.0–111.0)	138.2 (31.1–406.0)
	DR	0.40 (0.11–6.04)	5.78	0.54 (0.31–0.76)	0.58 (0.11–6.04)
Summer	N	9	3	4	16
	Discards	210.0 (20.0–550.0)	313.6 (200.0–550.0)	26.1 (10.0–40.0)	178.1 (10.0–550.0)
	Landings	193.7 (92.5–354.5)	162.0 (98.0–424.5)	112.4 (67.0–136.0)	144.3 (67.0–424.5)
	DR	1.19 (0.14–2.70)	2.04 (0.74–3.39)	0.21 (0.09–0.60)	0.92 (0.09–3.39)
Autumn	N	1	1	1	3
	Discards	35.0	300.0	39.5	39.5 (35.0–300.0)
	Landings	184.0	161.0	97.0	161.0 (97.0–184.0)
	DR	0.19	1.86	0.41	0.41 (0.19–1.86)
Total by tactic	N	23	5	8	36
	Discards	100.0 (10.0–2000.0)	313.6 (200.0–1200.0)	37.0 (10.0–97.4)	98.7 (10.0–2000.0)
	Landings	184.0 (31.0–406.0)	162.0 (98.0–425.0)	109.9 (67.0–150.0)	148.1 (31.0–425.0)
	DR	0.90 (0.11–6.04)	2.04 (0.74–5.78)	0.36 (0.09–0.76)	0.74 (0.09–6.00)

N: sample size.

starting position of the discarding processes; Worton, 1989; Selkirk and Bishop, 2002). Each contour represents a specific probability of finding a discarding process within that area, and we represented the contour of 50% (core area) and 95% (range) of the occurrence probability of discarding during the 9-yr period. The *adehabitat* package in R was used for kernel analysis (Calenge, 2006).

Breeding seabirds: a species-specific approach

For each seabird species, the spatial patterns of trawling attendance were explored using a Geographic Information System. Moreover, we independently assessed the influence of season and fishing tactic on the number of individuals attending trawlers using the non-parametric Kruskal–Wallis test. In addition, we assessed whether breeding species were making a greater use of discards than expected from the number of breeding pairs during spring off south-west Mallorca (main surveyed area, see Fig. 1), encompassing approximately 12% of the Balearic total seabird breeding population and 13% of the Balearic shear-water world population. After selecting the seabird attendance data corresponding to the breeding season

for this area (10 hauls in spring), we estimated the ratio of birds per species/total birds attending trawlers. Then, we filtered the number of breeding pairs from Sa Dragonera Island in the north and Ses Salines Cape – Cabrera Island limit in the south (see Table S1 and Fig. 1 for geographic references) and estimated the ratio of breeding birds per species/total breeding birds. Assuming that all breeding species were equally likely to follow a trawler, we tested the simple null hypothesis that the six breeding species followed trawlers proportionally to their breeding densities in the area (Oro and Ruiz, 1997).

Modelling seabird attendance to a trawling fishery: a regional approach

In this regional approach, seabird attendance to the Balearic trawling fishery was assessed by means of total abundance and regional community diversity. For both response variables, we pooled breeding and non-breeding birds. Regional diversity was estimated using the Shannon–Weaver index (Shannon, 1948), which takes into account both the number of species and the relative abundance of individuals of each species, calculated as follows:

$$H' = - \sum_{i=1}^k p_i \ln p_i$$

where H' = Shannon–Weaver index, k = number of species, and p_i = proportion of birds of species i relative to the total abundance.

Explanatory variables. We were interested in identifying the most important explanatory variables driving total abundance and diversity patterns. Explanatory variables included season (winter was excluded due to the low sample size), fishing tactic, horsepower, discarding process duration, amount of discards, number of trawlers at the beginning of the discarding activity in the fishing area, depth and distance to the nearest shoreline. We postulated that more powerful boats (higher horsepower) might catch more fish and provide larger amounts of discards (during a longer period), and ultimately enhance seabird attendance. Also, the same result was expected when an increased number of trawlers occurred simultaneously in the fishing area (even whether inter-specific seabird competition could occur). Since fishing tactic was defined on the basis of trawling depth, it could influence seabird distribution as bathymetry and the distance to the shoreline do (Schneider, 1997; Yen *et al.*, 2004; Louzao *et al.*, 2006). Depth was obtained from NOAA's ETOPO 5-min (spatial resolution of 7.5–8.2 km at 35°N and 42°N latitude, respectively) gridded elevation dataset. We also expected seasonal differences in seabird attendance since some breeding species largely leave their breeding sites after reproduction (the three petrel species and Audouin's gull), whereas the remaining tend to stay at the archipelago.

Modelling seabird regional community. Prior to modelling, all continuous environmental variables were standardized to have a mean of 0 and a SD of 1 due to their differing ranges and to allow an easier interpretation and comparison of model coefficients (Table 1) (Zuur *et al.*, 2007). Since we did not find strongly 'correlated' ($|r_s| > 0.6$) predictors (r_s , pair-wise Spearman rank correlation coefficient; Table S2), we considered all explanatory variables. Even whether total abundance represented count data, it better fitted a normal distribution and thus a linear model was applied here, as well as for the regional diversity (J.H. Zar, personal communications). Bootstrapped stepwise multiple linear regressions were used for both models, run in R using the MASS and the bootStepAIC packages (Venables and Ripley, 1998; R Development

Core Team, 2008; Rizopoulos, 2009; Dunn *et al.*, 2010). Based on 1000 bootstrap samples, the original dataset was sampled with replacement, fitted to a linear model, and models were selected based on the Akaike Information Criteria (Akaike, 1974). The interpretation of these results is based on the sign of the estimated response coefficients, where positive and negative signs are indicative of greater and smaller probabilities of recording higher or lower seabird abundance/diversity in a given discarding process. Categorical variables were calculated relative to the first category (indicated by null values of the estimated parameter and standard error).

RESULTS

Trawling fishery performance

The location of the 46 hauls recorded during the trawling-seabird study is shown in Fig. 1. Overall, discarding processes occurred over the continental shelf (median depth 127 m, range 4–259; $N = 45$) close to the coast (median distance to the shoreline 15.3 km, range 2.0–28.7; $N = 45$), which lasted a median of 75 min (range 30–195; $N = 46$). The surveyed trawling fleet was characterised by a median horsepower and vessel length of 170 (range: 75–430; $N = 8$) and 17.5 m (range: 13.2–21.7; $N = 8$), respectively. By fishing tactic, coastal hauls were more frequent (52.2%) than shelf and slope hauls (each representing 23.9% of the total).

Trawlers generated a median of 99 kg of discards (range: 10–2000) and 148 kg of landings (range: 31–425) per fishing operation (Table 1), which were significantly correlated (Pearson correlation coefficient, $r_p = 0.592$, $N = 36$, $P < 0.001$) (Fig. 2). The overall median of DR was estimated in 0.74 (range: 0.09–6.00). Discards, landings and DRs differed by season and fishing tactic (Table 1), even if we only found a significant fishing tactic effect in discards and DR ($F_{2,36} = 6.14$, $P = 0.005$ and $F_{2,36} = 5.88$, $P = 0.015$, respectively). Contrast analyses showed that the shelf tactic generated a significantly greater amount of discards in relation to the slope stratum (Table 1). The latter was more selective, discarding in overall 0.36 of landings (range: 0.09–0.76) whereas the shelf stratum discarded approximately twice the amount of landings (range: 0.74–5.78).

From the total landings recorded (8104 kg), fish, crustaceans, and molluscs represented by biomass 79.6, 15.3 and 5.1%, respectively. This was similar to the percentages obtained from the discard sub-sample (70.9% fish, 5.9% crustaceans, 1.5% molluscs and

Figure 2. Linear regression and 95% confidence intervals of fish discarded versus fish landed (both variables $\ln(x + 1)$ transformed). Pearson correlation coefficient between both $\ln$ -transformed variables was significant ($r = 0.592$, $N = 36$, $P < 0.001$).

1.1% echinoderms, out of 123.3 kg analysed). The remainder 20.6% of the discards corresponded to unidentifiable organic matter, inorganic waste and unidentifiable waste, apparently of little use to seabirds. Discard composition included 66 taxonomic groups of fish. For the study period, a total of approximately 1419 t were landed annually in Mallorca. Applying the global median of DR (0.74, range: 0.09–6.00) to the approximate total annual landings, an overall of 1050 t of discards (range: 127–8515) were estimated for Mallorca (Table 1), from which 744, 62, and 16 t corresponded to fishes, crustaceans and molluscs, respectively (based on the proportion of each taxonomic group in the discard sub-sample).

Discarding grounds

We recorded a median of 7 fishing operations per month (range: 0–14) over the 9-yr study period. Discarding activity took place over the entire shelf and continental slope surrounding Mallorca (except in the north), but especially in the southwest of Mallorca (the main core area identified by the contours of 50%) influencing 12% of the total breeding seabird numbers (in 1991). Additionally, two secondary core areas were also identified in the northwest and northeast of the island (Fig. 3a). All three fishing tactics occurred mainly in the southwest of Mallorca, whereas coastal discarding also occurred in the secondary northeast and slope discarding in the northwest (Fig. 3). By season, only the slope tactic showed a seasonal variation in the spatial distribution of the discarding activity: in summer all slope fishery concentrated in

the northwest of Mallorca leaving the fishing grounds of the southwest Mallorca (Cabrera)(Fig. S1).

Species-specific approach: spatiotemporal patterns of breeding species

The six local breeding species occurred in more than 25% of the discarding processes. The YLG (77%) and CS (18%) were the most abundant species following trawlers, as well as the most common breeding species (Table S1). We only found a significant effect of season (but not fishing tactic) explaining species-specific patterns (results of the former are only shown for the sake of clarity). We found significant seasonal differences for three of the six breeding species: BS (Kruskal–Wallis test, $H_{3,46} = 19.5$, $P < 0.001$), CS (Kruskal–Wallis test, $H_{3,46} = 17.6$, $P = 0.001$), and AG (Kruskal–Wallis test, $H_{3,46} = 21.5$, $P < 0.001$). BS occurred mainly during winter (pre-breeding stage, maximum 40 birds) and spring (incubation-early chick rearing, maximum 31 birds) (Table 2, Fig. 4a). CS was significantly more abundant during spring (i.e., pre-breeding and early laying) and autumn (i.e., end of the breeding season, when fledglings disperse and the local population prepares for migration) (maximum of 180 and 110, respectively) (Table 2, Fig. 4b). AG occurred mainly during spring (i.e., laying, incubation and hatching periods) (maximum of 75) and to a lesser extent in summer (chick rearing and dispersal/migration), while they were absent in autumn (Table 2, Fig. 4e). ESP and MS attended trawlers on a very irregular basis, most often being absent or present in very small numbers (Fig. 4c and 4d). YLG presented similar (the highest) abundances throughout the year (a maximum of over 300 birds was observed in all seasons) (Table 2, Fig. 4f). In relation to age, immatures of MS and adults of both AG and YLG were mainly involved in the exploitation of discards (60, 91 and 67%, respectively).

The main spatial aggregations of BS were found close to Palma, probably attracted by the confluence of trawlers returning to the harbour (Fig. 5a), whereas larger concentrations of AG were recorded in the west coast of Formentera (Fig. 5e). CS and YLG were the most abundant species in all areas (Fig. 5b and 4f). Although scarce, the ESP and the MS were mostly present in the continental slope and coastal waters of south-western Mallorca, respectively (Table 2, Fig. 5c and 4d).

During spring, we found overall differences between the observed and expected frequencies of breeding seabirds attending trawlers in south-west Mallorca ($\chi^2_5 = 579.38$, $P < 0.001$, $N = 10$). Contrast analyses showed that BS, ESP, MS and AG were significantly

Figure 3. Output of kernel analysis showing the main trawling areas at the Balearic archipelago (2000–08) for (a) the whole trawling fishery and by fishing tactic: (b) coastal, (c) shelf and (d) slope. Contours of 50 and 95% probabilities are shown (white and black lines, respectively). The grey line represents the limit of the continental shelf (i.e., 200 m depth).

less abundant than expected from their respective population densities. On the contrary, CS was significantly more abundant in relation to the breeding population in the area, whereas no significant difference was detected for YLG.

We observed five non-breeding species, previously unreported in association with trawlers (in very low numbers) at the archipelago (Oro and Ruiz, 1997): Northern gannet, Great skua, Mediterranean gull *Larus melanocephalus*, lesser black-backed gull *L. fuscus* and black tern *Chlidonias niger* (see Table 2).

Community approach: factors influencing abundance and species diversity

We recorded a total of 11 109 birds attending vessels with a median of 227 individuals (range: 31–530; $N = 46$) per haul (Table 3), whereas the regional diversity ranged from -5.41 to 1.33 (median: -0.08). Both community parameters were negatively correlated ($r_p = -0.886$, $P < 0.001$), which indicated that diversity was higher when the total number of birds following trawlers was lower. Specifically, this pattern might be driven by YLG abundance since diversity values were significantly higher when less YLG gulls were present behind trawlers ($r_s = -0.941$, $P < 0.001$).

The bootstrap modelling identified four important variables explaining seabird total abundance: season, fishing tactic, discards and distance to the coast

(Table 4). The probability of recording higher abundance of seabirds in a discarding process was higher in spring, at both the coastal and shelf fishing tactic (shorter distance from the coast) and when higher amounts of the catch were discarded (Table 3). Lower seabird abundances were recorded in summer while fishing over the insular slope. Regarding the second community parameter, two explicative variables better explained spatiotemporal diversity patterns: amount of discards and distance to shoreline (Table 4). Diversity was higher when both the amount of discards decreased at greater distances to the shoreline.

DISCUSSION

The present study is an effort to describe the complex processes that drive seabird-fisheries direct interactions. This is certainly an important topic and which represents an important challenge for the management of endangered seabird populations (Furness, 2003; Míguez *et al.*, 2003).

Seabird-trawling interactions

This study provides, for the first time, a year-round picture of seabird attendance to trawlers in the Balearic archipelago. Seabird attendance was higher in the shelf-slope area of south-western Mallorca independently of the fishing tactic considered. Even though

Table 2. Number, mean, median, maximum and the percentage of presence (%P) of seabirds attending trawlers are given by season for breeding and non-breeding (noted by *) species (sample size of 5,19,16 and 6 in winter, spring, summer and autumn, respectively).

Species	Winter					Spring					Summer					Autumn				
	N	Mean	Median	Max	%P	N	Mean	Median	Max	%P	N	Mean	Median	Max	%P	N	Mean	Median	Max	%P
Balearic shearwater	49	9.8	2.0	40	100.0	85	4.5	2.0	31	89.5	10	0.63	0.00	3	43.7	1	0.17	0.00	1	16.7
Cory's shearwater	32	6.4	0.0	32	20.0	1349	71.0	40.0	180	100.0	274	17.13	8.00	70	100.0	271	45.17	40.00	110	100.0
European storm-petrel						51	2.7	0.0	20	47.4	8	0.50	0.00	2	37.5					
Mediterranean shag	2	0.4	0.0	1	40.0	5	0.3	0.0	3	10.5	20	1.25	0.00	12	43.7	2	0.33	0.00	1	33.3
Audouin's gull	3	0.6	0.0	3	20.0	254	13.4	5.0	75	100.0	50	3.13	1.50	9	68.7					
Yellow-legged gull	1221	244.2	250.0	450	100.0	3527	185.6	170.0	500	100.0	2539	158.69	140.00	450	100.0	1010	168.33	135.00	300	100.0
Northern gannet*	5	1.0	0.0	4	40.0											2	0.33	0.00	2	16.7
Great skua*	6	1.2	0.0	3	40.0	8	0.4	0.0	2	36.8										
Mediterranean gull*	1	0.2	0.0	1	20.0															
Lesser black-backed gull*						1	0.1	0.0	1	5.3										
Black tern*						34	1.8	0.0	22	26.3										
Total	1320	264.0	290.0	453		5443	286.5	248.0	530		3060	191.3	161.0	466		1286	214.3	170.0	411	

our dedicated surveys on seabird-fishery interactions were temporally restricted to <2 yr, this dataset identified the same core discarding area as in the 8-yr database on trawling activity. Moreover, we also found another important slope fishing ground in the north-west of Mallorca where the trawling effort especially increases during summer (from May to September), targeting the large aggregations of mature females of the main slope target species, the red shrimp *Aristeus antennatus* (Guijarro *et al.*, 2008; Moranta *et al.*, 2008). The higher trawler-seabird breeding interaction found in the south and west of Mallorca was related to a higher fishing exploitation in these areas, as near half of the trawlers from the Balearic archipelago operated from the 3 ports located nearby.

One important characteristic of the seabird community attending trawlers at the Balearic archipelago was that it was formed mainly by local breeding species unlike other areas in the Iberian Peninsula (Arcos, 2001). In fact, yellow-legged gull abundance seemed to drive community metrics since it was the most abundant species following trawlers throughout the year. However, its abundance was also higher during winter when they are detached from the breeding colonies and can travel further in order to exploit trawling discards. Overall, total abundance and regional diversity showed opposite trends. Specifically, total abundance depended on the fishing tactic considered, being higher at coastal and shelf tactics which were performed closer to the coast and, in turn, to the breeding sites. Apart from the shoreline proximity, both fishing tactics might have attracted more birds since they were the less selective and threw higher amounts of discards overboard. Conversely, regional diversity was higher at the most selective fishing tactic (slope), when the amount of discards decreased at greater distances to the shoreline.

For the remaining breeding species, the temporal pattern of trawling attendance depended on their annual cycle. Moreover, it is worth noting that Procellariiformes show higher foraging ranges than gulls or shags. In fact, Cory's and Balearic shearwaters commute between the less productive waters around the breeding colonies (Balearic Islands) and the highly productive waters of the shelf-slope areas of the Iberian Peninsula (Louzao *et al.*, 2006, 2009). Thus, commuting (a natural foraging strategy) might influence the attendance of Procellariiformes to the Balearic trawling fleet. For instance, Cory's shearwaters showed higher numbers during spring at the archipelago (during the pre-laying period) when they are rare in the Iberian Peninsula (Arcos, 2001), showing lower numbers during the incubation and

Figure 4. Number of breeding species (median, 25–75% interquartile range, non-outlier range, and outliers) attending trawlers in the study area. Data are presented by season (winter $N = 5$, spring $N = 19$, summer $N = 16$ and autumn $N = 6$) for (a) Balearic shearwaters, (b) Cory's shearwaters, (c) European storm-petrels, (d) Mediterranean shags, (e) Audouin's gulls and (f) yellow-legged gulls. We divided the annual cycle of breeding seabirds in four different periods: December–February, March–May, June–August and September–November (winter, spring, summer and autumn hereafter, respectively).

chick-rearing periods (summer and autumn). Other species (European storm petrels and Mediterranean shags) only attended trawlers irregularly and in very low numbers, although the occurrence of shags (both adults and immature birds) was higher than previously reported in the Balearic Islands (Oro and Ruiz, 1997), which suggests that the species has recently incorporated this foraging strategy. Shags are considered strict coastal feeders (Wanless and Harris, 1997), even whether birds could occasionally attend trawlers at distances up to 20 km offshore. In summer, we recorded the lowest seabird abundance coinciding with the post-breeding movements of two breeding species (Balearic shearwater and Audouin's gull) out of the Mediterranean tracking highly productive marine areas (Le Mao and Yésou, 1993).

Seabird abundance at trawlers was higher in spring, when local species were breeding. During this period,

marine productivity, inter- and intra-specific competition and scavenging-behaviour might drive species-specific trawling interaction patterns in southwest Mallorca. Only Cory's shearwater recorded higher numbers than expected following trawlers, coinciding with the pre-breeding stage which corresponds to one of the two highest energetic demanding breeding stages (i.e., egg formation; Navarro *et al.*, 2007). Contrary to what could be expected, two well known discard foragers species such as the Balearic shearwater and Audouin's gull followed trawlers in lower numbers than expected from their breeding abundances. Even if the former foraged over the insular shelf-slope area, the main foraging ground of the species is located over the Iberian continental shelf (e.g., off the Ebro Delta) where far larger numbers were recorded during the breeding season attending trawlers (Arcos and Oro, 2002a). In fact, Balearic shearwaters respond to

Figure 5. Distribution of (a) Balearic shearwaters, (b) Cory's shearwaters, (c) European storm-petrels, (d) Mediterranean shags, (e) Audouin's gulls and (f) yellow-legged gulls per discarding process during the study period. Circles are proportional to the number of birds.

basin scale level productivity patterns following the distribution of their main prey (i.e., small pelagic fish) since the Ebro Delta area is one of their main spawning areas (Louzao *et al.*, 2006; Arcos *et al.*, 2009). Fishing activity also concentrates in this area and the proportion of small pelagic fishes within discards, and total biomass, might be higher and more attractive to Balearic shearwaters (Oro and Ruiz, 1997; Arcos, 2001; Arcos and Oro, 2002a). In the case of Audouin's gull, this species is highly affected by the competition with yellow-legged gulls when high abundances occurred and the ratio of yellow-legged/Audouin's gulls breeding population is higher at the Balearic Islands compared to the Ebro Delta area (Arcos, 2001; Oro *et al.*, 2006). Thus, discards might be of relative little importance for the species at the Balearic archipelago.

Management implications for Mediterranean fisheries

An integrative ecological model showed that the western Mediterranean ecosystem is highly con-

strained by predators (both natural and anthropogenic) and identified demersal trawling as the most impacting and less effective fishing gear on both target and non-target groups (Coll *et al.*, 2006). Discards in demersal trawling show high variability, both in terms of weight and in number of species affected, depending mainly on the depth at which trawlers operate and, in some cases, on the accidental high catches of certain species with very low commercial value (Sánchez *et al.*, 2004). The lower discard ratio found in the slope fishing tactic is in agreement with previous studies which found that discards are higher in the shallowest waters and lower in the deepest (Carbonell *et al.*, 1997; Sánchez *et al.*, 2004). Also, our discard ratio showed great variability, which is common to other trawl fisheries in the western Mediterranean, and thus should be interpreted with caution (Oro and Ruiz, 1997; Arcos, 2001 but see Martínez-Abraín *et al.*, 2002).

Historically, Mediterranean fisheries have been managed without paying much attention to ecosystem

Table 3. Number of fishing operations (*N*), discarding duration (median and range in minutes) and total number of birds attending discarding processes are given per season and fishing tactic, as well as total numbers.

Season	General information	Fishing tactic			Total by season
		Coastal	Shelf	Slope	
Winter	<i>N</i>	–	3	2	5
	Discarding duration	–	90.0 (30–90)	112.5 (105–120)	90.0 (30–120)
	Total number of seabirds	–	290.0 (208–453)	184.5 (35–334)	290.0 (35–453)
	Regional diversity	–	–1.26 (–4.89 to –0.64)	–0.85 (–2.20 to –0.50)	–1.26 (–4.89 to 0.50)
Spring	<i>N</i>	14	3	2	19
	Discarding duration	60.0 (30–135)	120.0 (60–120)	112.5 (45–180)	60.0 (30–180)
	Total number of seabirds	261.5 (128–530)	152.0 (120–495)	205.0 (178–232)	248.0 (120–530)
	Regional diversity	–0.17 (–5.41 to –0.93)	1.00 (–3.16 to –1.33)	0.870 (0.73–1.01)	–0.030 (–5.41 to 1.33)
Summer	<i>N</i>	9	3	4	16
	Discarding duration	90.0 (45–195)	75.0 (60–165)	75.0 (45–120)	75.0 (45–195)
	Total number of seabirds	136.0 (31–466)	239.0 (215–322)	114.5 (90–270)	161.0 (31–466)
	Regional diversity	0.64 (–4.57 to 0.93)	–0.51 (–1.13 to –0.26)	0.35 (–1.12 to 0.74)	0.03 (–4.57 to 0.93)
Autumn	<i>N</i>	1	2	3	6
	Discarding duration	105	90.0 (45–135)	105.0 (90–165)	105.0 (45–165)
	Total number of seabirds	411	260.5 (180–341)	131.0 (63–160)	170.0 (63–411)
	Regional diversity	–2.17	–0.91 (–1.88 to 0.07)	0.45 (0.37 to 0.67)	0.22 (–2.17 to 0.67)
Total by tactic	<i>N</i>	24	11	11	46
	Discarding duration	75.0 (30–195)	90.0 (30–165)	105.0 (45–180)	75.0 (30–195)
	Total number of seabirds	252.5 (31–530)	239.0 (120–495)	131.0 (35–334)	227.0 (31–530)
	Regional diversity	–0.17 (–5.41 to 0.93)	–0.64 (–4.89 to 1.33)	0.45 (–2.21 to 1.01)	–0.08 (5.41–1.33)

Note that no discarding process was recorded in the coastal stratum in winter.

components other than the targeted species (Tudela, 2004), thus contributing to the high degradation of this sea. In recent years, there has been a progressive change from the traditional approach of fishery assessment and management, which considers populations as independent and auto-sustainable, to a new ecosystem approach. This takes into account the complexity of the ecosystems, their natural variations and the factors that control these changes, as well as the habitat and other components of the ecosystem and their interactions (Pikitch *et al.*, 2004). Contrary to other trawl fisheries operating around the world (cf. Sullivan *et al.*, 2006; González-Zevallos *et al.*, 2007), the Mediterranean semi-industrial trawling does not seem to provoke significant direct mortality to seabirds. However, the western Mediterranean Sea is a highly exploited ecosystem where current levels of both fishing activities and environmental forcing are probably leading to important changes in the whole ecosystem (Tudela, 2004). In fact, it is already well known that trawling activity influences seabird food provisioning, by either providing food supplies

Table 4. Results of the community bootstrapped stepwise multiple linear regressions. Categorical variables were calculated relative to the first category (indicated by null values of the estimated parameter and standard error, SE).

Variable	Estimate	SE	<i>t</i> -value	Pr (> <i>t</i>)
Total seabirds				
Intercept	340.00	34.52	9.85	<0.001
Season				
Spring	0.000	0.000	0.000	0.000
Summer	–139.51	47.71	2.92	0.007
Autumn	–7.34	83.31	0.09	0.931
Fishery				
Coastal	0.00	0.00	0.000	0.000
Shelf	38.36	61.77	0.62	0.541
Slope	–99.42	56.52	1.76	0.092
Discards	31.48	23.50	1.34	0.193
Coast	–63.47	24.15	2.63	0.015
Community diversity				
Intercept	–0.77	0.22	–3.43	0.002
Discards	–0.94	0.23	–4.19	<0.001
Coast	0.59	0.23	2.62	0.014

(discarding annually approximately 1050 t only in Mallorca) and/or limiting natural prey availability (i.e., small pelagic fish), which in turn affects their life history (Mínguez *et al.*, 2003; Oro, 2003; Arcos *et al.*, 2008). Thus, it is reasonable to assume that fishery policy applied to specific fishing methods could have an impact on other seabird-fishery interactions. This is what is happening in the western Mediterranean. For instance, a recent study showed that the probability of longline bycatch of Cory's shearwaters increases in the absence of trawling activity (i.e., during trawling moratoria), jointly with fishing time (e.g., sunset; Laneri *et al.*, 2010).

Current fishery policies are directed to reduce discards (Penas, 2007), which represent a highly predictable foraging resource for seabirds (Bartumeus *et al.*, 2010). From seabird's point of view, the reduction of discards requires a precautionary management approach considering the influence of this resource on some seabird populations and the role that it plays at shaping the seabird community structure through inter-specific competition (Pikitch *et al.*, 2004; Norse *et al.*, 2005). Long-term effects of discard reduction, as a tool for ecosystem restoration, would be beneficial for seabird populations, although predicting the response of seabird communities is complex and it requires long-term time series to disentangle the confounding effects of other environmental perturbations. Moreover, the high level of endemism of the Mediterranean basin enhances the importance of the seabird community in this region and the need to integrate seabird conservation in the management of the Mediterranean trawling fishery, as well as the importance of top predators as keystone species (Coll *et al.*, 2009).

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SUPPORTING INFORMATION

Additional Supporting information may be found in the online version of this article:

Figure S1. Seasonal kernel analysis for the slope fishing tactic at the Balearic archipelago (2000–08) for (a) winter, (b) spring, (c) summer and (d) autumn. Contours of 50 and 95% probabilities are shown (white and black lines, respectively).

Table S1. Breeding pairs of seabirds estimated at the south-west coast of Mallorca, defined by Sa Dragonera Island as the northern limit and Ses Salines Cape – Cabrera Island as the southern limit (see Fig. 1).

Table S2. Bivariate Spearman rank *P*-values and correlations between vessel-related variables analysed in the GLMs. NS = non-significant.

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