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Seabird bycatch in Portuguese mainland coastal fisheries: An assessment through on-board observations and fishermen interviews

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ABSTRACT

Competition with fisheries and incidental capture in fishing gear are the major current threats for seabirds at sea. Fishing is a traditional activity in Portugal and is mainly composed of a great number of small vessels. Given the lack of knowledge on effects of the Portuguese fishing fleet on seabird populations, bycatch was assessed in mainland coastal waters for 2010–2012. Interviews and on-board data were divided into 5 strata, according to fishing gear: Bottom trawling, Bottom longline, Purse seine, Beach seine, Polyvalent (≥12 m) and Polyvalent (<12 m). Polyvalent included Setnets, Traps and Demersal longlines. Overall, 68 birds were recorded to be bycaught. The average catch per unit effort (CPUE) was 0.05 birds per fishing event. Polyvalent (<12 m), Polyvalent (≥12 m) and Purse seiners had the biggest seabird bycatch rates, with 0.5 (CPUE = 0.1), 0.11 (CPUE = 0.05) and 0.2 (CPUE = 0.11) birds per trip, respectively. Within Polyvalent gear, Setnets captured the largest diversity of seabird species (CPUE = 0.06), while Demersal longline had the highest CPUE (0.86). Northern gannet was the most common bycaught species. Although more observation effort is required, our results suggest that substantial numbers of Balearic shearwater might be bycaught annually, mainly in Purse seine and Setnets.

1. Introduction

Fishing is a traditional activity in Portugal and is mainly composed of a great number of small and local fishing boats (INE, 2013). Although the number of boats has decreased for the past decades, there has been an increase in mean power

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engine per boat. Portuguese fisheries are managed in accordance with the European Common Fisheries Policy. National fishing fleets have many types of segments, including a small-scale regional fleet, a purse-seine fleet, a trawl fleet and an artisanal/polyvalent fleet (ICES, 2008). Gillnets and trammel nets are usually used in polyvalent boats also licenced to operate with traps, hooks and lines. Despite a large fleet of declared polyvalent boats, the majority of these boats are smaller than 12 m and are used in inshore waters such as estuaries or near by the harbour. These boats normally are not cabinated (INE, 2013) and there are some logistic constraints to put observers on-board. Additionally, a large number of boats with licences may not be fishing, thus one way to correct estimate effort for the operating fleet is to obtain data from landings. However, the multi-gear problematic associated with this polyvalent fishery further increases because landings are not discriminated by metier, and one single polyvalent boat can land in one day captures of many different gears it was operating.

The Portuguese coast is influenced by a seasonal upwelling that strongly favours the fish market (Fiúza et al., 1982). Mainland waters are important for pelagic fish species such as Sardine *Sardina pilchardus*, Atlantic chub mackerel *Scomber colias*, Atlantic mackerel *Scomber scombrus*, Atlantic horse mackerel *Trachurus trachurus* and Blue whiting *Micromesistius poutassou*. The most important fish species in the demersal community are European hake *Merluccius merluccius*, Megrim *Lepidorhombus whiffiagonis*, Angler *Leophius piscatorius*, Common sole *Solea solea* and Sand sole *Pegusa lascaris* (Marques, 2012). Also, there are many elasmobranches species in the region, including rays and sharks, near the coast (e.g. Small-spotted catshark *Scyliorhinus canicula* and Blackmouth catshark *Galeus melastomus*).

There are 97 fishing ports in Portugal mainland (INE, 2011), used by more than 4500 fishing boats that landed 110,287 metric tons in 2012 (INE, 2013). Bottom longline fleet main target species is the black scabbardfish *Aphanopus carbo* (Bordalo-Machado et al., 2009). The Bottom trawl fleet is catching both fish and crustaceans (INE, 2013), while the Purse seine fleet mainly catches sardine and Atlantic chub mackerel (Feijó, 2013). Due to the high diversity of gears used by the Polyvalent fleet a great diversity of species is captured. However, recent data suggests the highest capture numbers are of Common octopus *Octopus vulgaris*, Atlantic mackerel, Atlantic chub mackerel, Sardine and Black scabbardfish (INE, 2013). The activity of this sector is difficult to quantify but is largely confined to the coastal zone.

Seabird species use the Portuguese mainland coast during their migratory routes and as feeding grounds, resting and wintering areas (Ramírez et al., 2008). The most common species include Northern gannet *Morus bassanus*, Balearic shearwater *Puffinus mauretanicus*, Cory's shearwater *Calonectris diomedea*, European storm-petrel *Hydrobates pelagicus*, Madeiran storm-petrel *Oceanodroma castro*, Great cormorant *Phalacrocorax carbo*, European shag *Phalacrocorax aristotelis*, Great skua *Stercorarius* skua, Mediterranean gull *Larus melanocephalus*, Yellow-legged gull *Larus michahellis*, Audouin's gull *Larus audouinii*, Lesser black-backed gull *Larus fuscus*, Little tern *Sterna albifrons*, Sandwich tern *Sterna sandvicensis* and Razorbill *Alca torda* (Ramírez et al., 2008). Common guillemot used to breed in Berlengas archipelago, where a population of 6000 breeding pairs was estimated in 1939 (Lockley, 1952). At the present date, this population is considered as virtually extinct and entanglement in gillnets is considered to be one of the factors behind the crash of the southern population (Munilla et al., 2007).

Incidental catch of non-target species represents 8% of global fisheries activity (Kelleher, 2005). Most fishing operations, whether employing towed or fixed gears, capture organisms that are not the primary target of the fishery such as non-target fish species, sea turtles, seabirds, and marine mammals (Alverson, 1999; Hall, 1996), as a consequence of exploiting the same interconnected prey (Cairns, 1992). Bycatch by longline and gillnet fisheries is considered an important threat to the conservation of several seabird species (Tasker et al., 2000). Worldwide, Procellariiformes appear to be particularly affected by bycatch mortality due to their life history traits (Brothers et al., 1999). Nonetheless, the incidence and scale of seabird bycatch in many parts of European waters are poorly known and there is an urgent need for understanding the nature and extent of interactions between seabirds and fisheries (Anderson et al., 2011; Žydelis et al., 2013).

The present study aimed to estimate the mortality caused to seabirds by fishing activities in coastal waters of Portugal mainland during 2010–2012, and to identify which fleets and seabird species are associated with high levels of bycatch.

2. Methods

2.1. Study area

The study area covered the main fishing harbours along the Portuguese mainland coast (Viana do Castelo, Póvoa de Varzim, Matosinhos, Aveiro, Figueira da Foz, Nazaré, Peniche, Sesimbra, Sines, Sagres, Lagos, Alvor, Portimão, Olhão and Tavira), about 15.5% of the 97 harbours (Fig. 1). In terms of area, this study encompasses approximately 40,600 km^2 of the continental shelf and adjacent waters. Despite trawls may operate at longer distances, all other boats have their fishing areas up to 20 nautical miles off the coast. Boats operating from all main harbours along the Portuguese coast were sampled for interview and observer programmes.

2.2. Data collection

The study involved two separate methodologies to evaluate bycatch in terms of type of gear and seabird species: interviews to boat skippers and on-board observations. Interview and on-board data collection covered all 15 fishing harbours, covering the entire mainland coast. Fishing boats to place observers and skippers to interview were selected randomly. Each set of data was analysed separately.

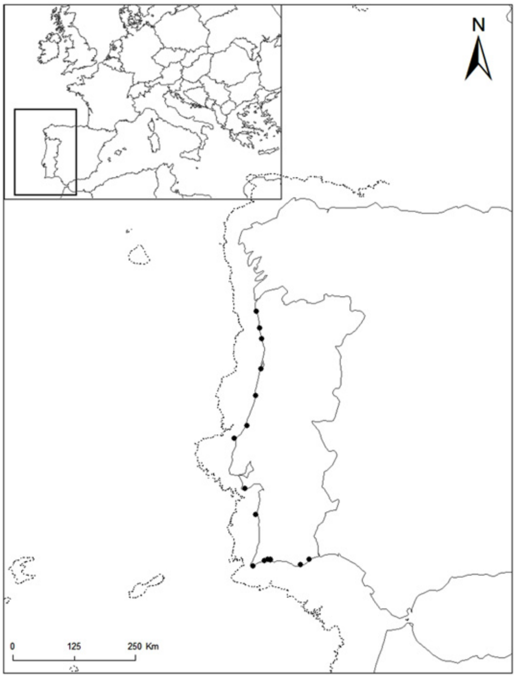

Fig. 1. Map of the study area. Black dots indicate the 15 fishing harbour locations sampled during the 3 years study. The dotted line marks the 1000 m isobath.

Table 1
The main sectors of Portuguese mainland fisheries, showing annual average number of boats operating within the period 2010–2012. The average of annual fishing trips per boat, the number of interviews conducted, the number of interviews reporting seabird bycatches, the number of reported individuals (all species) bycaught and the average bycatch per trip. Last column shows average bycatch with transformed outliers ($n = 11$).

Gear	Boats	Annual trips per boat	Interviews				
			Total	With bycatch	No of reported by-catch	By-catch per trip	w/out outliers
Bottom trawling[a]	79	171	29	19	2 130	0.43 (0.10–0.97)	
Bottom longline[a]	41	171	7	6	790	0.66 (0.15–1.27)	
Purse seine[b]	160	117	49	31	10 652	1.75 (0.50–3.71)	0.66 (0.28–1.12)
Polyvalente (<12 m)[a]	3523	71	145	63	11 187	1.04 (0.26–2.12)	0.28 (0.14–0.46)
Demersal longline		0	37	26	10 699		
Traps		0	33	2	2		
Setnets		0	76	35	486		
Polyvalente (≥12 m)[a]	330	170	99	72	7 036	0.39 (0.22–0.61)	
Demersal longline		0	12	11	2 023		
Traps		0	12	0	0		
Setnets		0	75	61	5 013		
All gears	4173	142	329	191	31 795	0.65 (0.39–1.00)	0.35 (0.24–0.46)

[a] Data on numbers of operating boats and average of annual fishing trips per boat from Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos.
[b] Purse seine data on number of operating boats and estimated annual numbers of fishing trips per boat from Feijó (2013).

2.2.1. *Interview survey*

The interview survey of boat skippers took place from June 2010 to December 2012. 329 interviews were performed to skippers operating bottom trawling, bottom longline, demersal longline, traps, bottom gillnets, trammel nets and purse seine. Skippers were interviewed only once mainly after a fishing trip after arriving at the fishing harbour. All interviews were carried out in person, by an experienced interviewer with extensive knowledge of the fishing sector and experience in seabird identification, following a standardized questionnaire and a list of photos of the most common seabird species. Questions were related to operation characterization, fish target species, sightings of seabirds on the fishing grounds, interactions between seabirds and fishing operations and related problems, incidence of seabird bycatch, species involved and the frequency/seasonality of such interactions. Skippers were asked to report occurrence of bycatch during the last year, in totals or in average per month. Number of interviews conducted by each fishery can be found on Table 1.

2.2.2. On-board observations

Trained observers were placed on-board fishing boats from April 2010 to December 2012, covering seven types of gear: bottom trawling, bottom longline, demersal longline, traps, bottom gillnets, trammel nets and purse seine. Regarding beach seiners, they were monitored from May to October 2010 from land observers. Records were obtained for 574 fishing trips. Observers recorded any bycatch of seabirds as well as their presence in the vicinity of the boat and the type of interactions with the fishing operations. The location of all fishing events, bycatch and interactions events with seabirds were also recorded. By the end of each fishing event, observers also recorded the amount of target species captured.

2.2.3. Interview data analysis

Interview data was analysed to estimate a "minimum" bycatch rate. Data was first divided into strata by gear type, year and boat length (see Table 1). Polyvalent gear stratum included Setnets (bottom gillnets and trammel nets were considered together), Traps and Demersal longlines due to the lack of knowledge on annual fishing effort (i.e. number of nights a boat spend on fishing per year) for each type of gear. Setnets, traps and demersal longlines may be used by the same fishing boat (some times during the same fishing trip) depending on the season, market fishing price variation, main target species abundance, etc. Data on number of operating boats and average of annual fishing trips per boat was gathered from the Portuguese maritime authority (Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos—DGRM). This data is originally split by boat length (<12 m and ≥ 12 m) and was used to improve analyses for Polyvalent gear, Setnets, Traps and Demersal longlines. Not all interview information on bycatch was fully quantitative. Some assumptions were made to include all information: (1) when bycatch was said to be "happens" or "some", or a generic answer such as "gannets", the figure of one animal was used, and this figure was applied to all species mentioned by the interviewee; (2) when a figure was given for the total number of seabirds by-caught in a specified time-period and including more than one species, the total was divided equally between the species. This relates to the fact that some seabird species are often not well distinguished by fishermen and so similar species were put together in the same group, namely "Storm-petrels" (may include European Storm-petrel, Leach Storm-petrel *Oceanodroma leucorhoa*, Madeiran Storm-petrel and Wilson's Storm-petrel *Oceanites oceanicus*), "Cormorant" (included Great Cormorant and European Shag), "Gulls" (included *Larus* species), "Terns" (included both *Sterna* and *Chlidonias* species) and "Alcidae" (included Razorbill, Common Guillemot and Puffin *Fratercula arctica*). Though other Procellariidae species may be present at least in some period of the year even in lowest numbers, fishermen were able to well identify both Cory's and Balearic shearwater using the seabird photo ID guide. However, Balearic shearwater may was confused with similar species, namely Manx shearwater *Puffinus puffinus*, Sooty shearwater *Ardenna grisea* and Great shearwater *Ardenna gravis*. Although the first two species are present in Portuguese waters in low numbers, Great shearwater is quite abundant at autumn season during the pre-breeding migration.

For each stratum (s), the bycatch rate (I) is given by the total number of animals reported to be caught per year (b), divided by the product of the number of interviews (n) and the annual average of trips per boat (t).

$$I_s = \frac{b_s}{n_s \times t_s}.$$

Data on estimated number of trips per boat were assigned by DGRM (*unpublished results*), exception for Purse seine stratum, where up-to-date information was consulted from Feijó (2013). Since the data is neither normally distributed nor transformable to normal, confidence limits of bycatch rate were estimated using a bootstrap procedure. All simulations were performed using R-software (R Core Team, 2013) and repeatedly re-sampled with replacement from the set of N interviews in a stratum to generate multiple sets of N interviews. In the present analysis, 2000 repeats were used, each yielding an estimate of the seabird bycatch rate in the stratum. The 2000 estimates are then sorted, and the 51st and 1950th values represent the 95% confidence limits (following López et al., 2003). Interviews were stratified by gear, year and boat length (in the case of polyvalent fleet, ≥ 12 m and <12 m), and confidence limits derived separately for each stratum and overall.

Also the proportion of boats with bycatch (γ) was calculated for each species or group of species, as the number of interviews with reported bycatch (r) divided by the total numbers of interviews (n) per stratum (s).

$$\gamma_s = \frac{r_s}{n_s}.$$

Using a version of the bootstrap analysis and actual interview data for the fleets, expected confidence limits for the bycatch rate were simulated for different numbers of interviews, including extrapolation to larger numbers of interviews than the actually carried out (5–500).

2.2.4. On-board data analysis

On-board data was also first divided into strata on the basis of gear type, year and boat length (see Table 2). Polyvalent gear stratum included Setnets (bottom gillnets and trammel nets were considered together), Traps and Demersal longlines to allow comparing with interview data. To allow a better comparison with the interview results, for each stratum (s), the bycatch rate per trip per year (λ) is given by the total number of animals caught per year (B) divided by the number of trips observed (T).

$$\lambda_s = \frac{B_s}{T_s}.$$

Table 2
The main sectors of Portuguese mainland fisheries, showing average number of boats operating during the period 2010–2012, the average number of annual fishing trips per boat, the number of observed trips and sets conducted, the number of observed bycaught individuals, the average bycatch per trip and the CPUE as the number of birds caught per set (except for demersal longline where CPUE is the number of birds caught per 1000 hooks set).

Gear	Boats	Estimated no. of trips per boat	On-board observations					
			No of trips	No of sets	Sets per trip	No of observed captured seabirds	By-catch per trip	CPUE
Bottom trawling[a]	92	514	42	179	4.3	0	0.00	0.00
Bottom longline[a]	39	514	30	131	4.4	0	0.00	0.00
Purse seine[b]	160	352	190	353	1.9	38	0.20 (0.04–0.44)	0.11 (0.02–0.26)
Beach seine[a]	40	450	149	292	2.0	6	0.04 (0.00–0.09)	0.02 (0.00–0.05)
Polyvalente (<12 m)[a]	3523	214	12	48	4.0	6	0.50 (0.00–1.50)	0.10 (0.04–0.18)
Demersal longline		0	4	7	1.8	6	1.50 (0.00–4.50)	0.86 (0.00–2.00)
Set nets		0	8	42	5.3	0	0.00	0.00
Polyvalente (≥12 m)[a]	330	510	151	340	2.3	18	0.11 (0.04–0.20)	0.05 (0.02–0.10)
Traps		0	14	53	3.8	0	0.00	0.00
Set nets		0	147	287	2.0	18	0.12 (0.04–0.23)	0.06 (0.02–0.11)
All gears	4184	2554	574	1343	2.3	68	0.12 (0.05–0.20)	0.05 (0.02–0.09)

[a] Data on numbers of operating boats and average of annual fishing trips per boat from Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos.
[b] Purse seine data on number of operating boats and estimated annual numbers of fishing trips per boat from Feijó (2013).

Bycatch per fishing event (i.e. Catches Per Unit Effort; CPUE) was also calculated with the purpose of comparing our results with other studies, which is given by the total number of animals caught (B) divided by the number of fishing events observed (e).

$$CPUE_s = \frac{B_s}{e_s}.$$

Since the data is neither normally distributed nor transformable to normal, confidence limits for bycatch rate and CPUE were therefore estimated using the same bootstrap procedure described for interview data analysis.

The proportion of trips with bycatch (γ) was calculated for each species as the number of trips where bycatch was observed (R) divided by the number of trips observed (T) per stratum (s).

$$\gamma_s = \frac{R_s}{T_s}.$$

Using a similar version of the bootstrap analysis and actual on-board data for the fleets, expected confidence limits for the bycatch rate were simulated for different numbers of on-board observing effort, including extrapolation to larger numbers of trips than were actually carried out (5–2000).

3. Results

3.1. Interview survey

Seabird bycatch was reported for all types of fishing gear, and overall bycatch rate was 0.65 birds/trip (Table 1). Variation between boats was high, as reflected in the wide confidence limits of bycatch rates. Bycatch in traps was very low for boats <12 m ($n = 33$), with only 2 individuals reported to be bycaught, and inexistent for boats ≥12 m ($n = 12$). Bycatch per trip rates for Demersal longline, Traps and Setnets were not possible to assess due to lack of data on annual estimated number of trips per boat for each single gear. Alternatively, bycatch per trip rates were assess to Polyvalent (<12 m) ($n = 145$) and Polyvalent (≥12 m) ($n = 99$) strata. Purse seine ($n = 49$) and Polyvalent (<12 m) were the strata with higher bycatch rate, 1.75 and 1.04 birds/trip, respectively. However, results for both of the strata are strongly influenced by single records ($n = 11$), well outside the typical range of values. If these extreme values are replaced by the next greatest values in the respective *stratum*, the revised bycatch rates for Purse Seine and Polyvalent (<12 m) come down to 0.66 and 0.28 birds/trip, respectively, as well as the overall bycatch rate, being 0.35 birds/trip.

The overall proportion of interviews reporting non-zero bycatches was 0.57 (Fig. 2). Within Polyvalent strata, Demersal longline ($n = 12$) and Setnets ($n = 75$) operated by boats ≥12 m length were the gears with higher proportion of bycatch. Skuas were the only group of species with no reported bycatch. The highest proportion of boats with bycatch was recorded for Northern gannet, namely in Bottom longline ($n = 7$, $\gamma = 0.86$) and Polyvalent (≥12 m) ($\gamma = 0.65$). Contribution for the last comes from Setnets ($\gamma = 0.76$) and Demersal longlines ($\gamma = 0.58$). Demersal longlines (<12 m) ($\gamma = 0.59$) and Bottom trawling ($n = 92$; $\gamma = 0.62$) either showed a high proportion of boats with Northern gannet bycatch. Proportion of boats with Balearic shearwater bycatch was highest in Bottom longline ($\gamma = 0.29$) followed by Purse seine ($\gamma = 0.18$) and Demersal longline (<12 m) ($n = 37$, $\gamma = 0.14$).

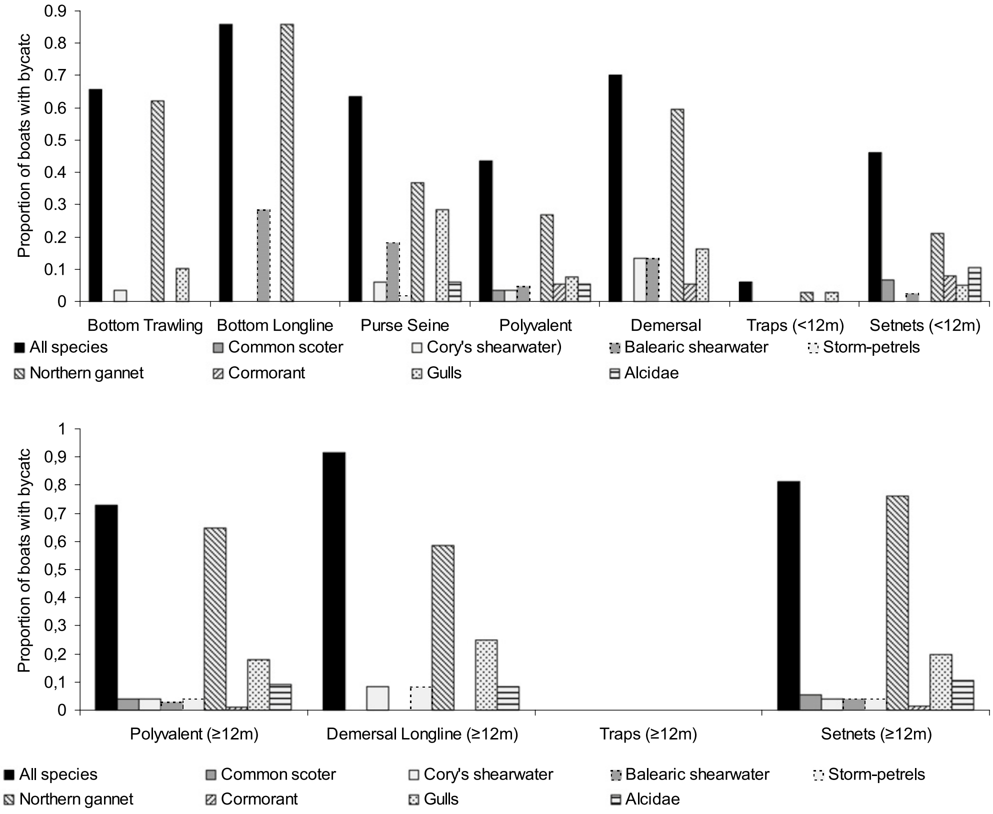

Fig. 2. Proportion of interviews reporting non-zero bycatches for fishing activities during all study period, 2010–2012.

Table 3
Seabird species reported by on-board observers to be bycaught during the study period, 2010–2012, including number of birds caught, sets that bycaught birds, range of birds caught per set, and average number of birds caught per set with bycatch.

Species	IUCN status	Capture of seabirds			
		Birds caught	Sets that caught birds	Average birds/set	Range
Common scoter	Least concern	6	3	2	1–3
Cory's shearwater	Least concern/Endangered	2	2	1	1
Balearic shearwater	Critically endangered	31	4	7.75	1–20
Northern gannet	Least concern	22	11	2	1–4
Great cormorant	Least concern	2	2	1	1
Unidentified gull		1	1	1	1
Black-headed gull	Least concern	1	1	1	1
Lesser black-backed gull	Least concern	2	2	1	1
Common guillemot	Least concern	1	1	1	1
Total		68	27	2.52	1–20

3.2. *On-board observations*

Total number of seabird bycatch recorded during 1343 observed fishing events in the 3-year period covered in this study amounted to 68 birds of at least 8 species (Table 3). These included Balearic shearwater (46%), Northern gannet (32%), Common scoter (6%), Cory's shearwater (3%), Great cormorant (3%), Lesser Black-backed gull (3%), Black-headed gull (1%), Common guillemot (1%) and 1 unidentified gull (1%).

No seabird bycatch was observed in Bottom trawling ($n = 179$), Bottom longline ($n = 131$), Setnets in boats <12 m (42) and Traps in boats ≥ 12 m (53) (Table 2). No observers were placed aboard boats <12 m setting Traps or boats ≥ 12 m operating Demersal longline.

Purse seine ($n = 353$) showed a CPUE average of 0.11 seabirds per fishing event, affecting mainly Balearic shearwater, Northern gannet, Cory's shearwater and Great cormorant. Seabird catches are not frequent; they occurred in 11 monitored purse seine fishing events, including one with 20 Balearic shearwaters and other two with 5 more individuals of the same species.

Beach seine ($n = 292$) had an average CPUE of 0.02, affecting Common scoter (83%) and Black-headed gull (17%).

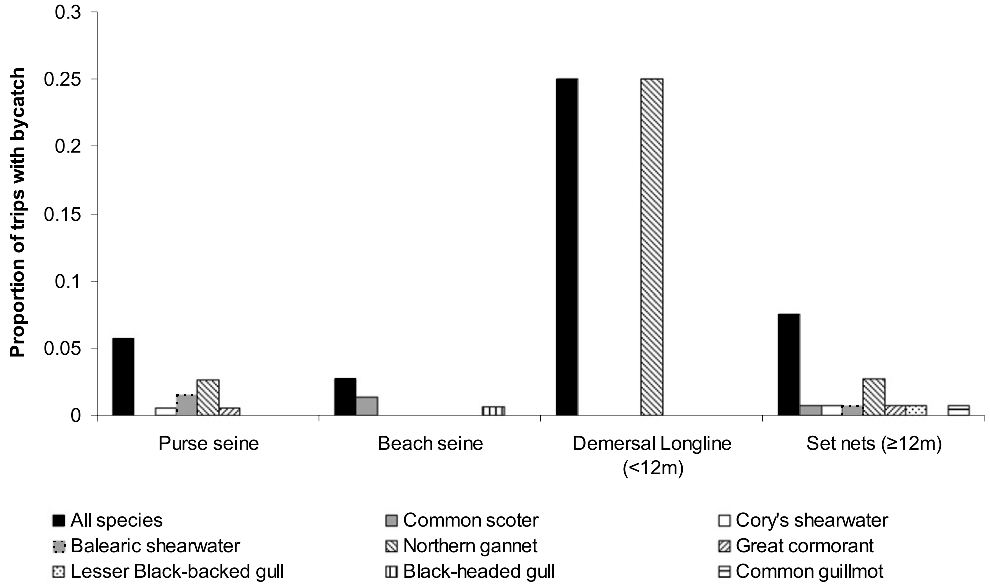

Fig. 3. Proportion of observed trips reporting non-zero bycatches for fishing activities during all study period, 2010–2012.

Setnets ($\geq$12 m) ($n = 287$) captured the largest diversity of seabird species, and showed an average CPUE of 0.06. This gear affected mainly Northern gannet (60%), Lesser black-backed gull (10%), Balearic shearwater (6%), Cory's shearwater (6%), Common scoter (6%), Great cormorant (6%) and Common guillemot (6%).

Despite the small observation effort ($n = 7$), Demersal longlines ($<$12 m) were responsible for the highest proportion of trips with bycatch, capturing only Northern gannets (Fig. 3). This gear had an average CPUE of 0.24 birds per 1000 hooks.

3.3. Power analysis

The interview data indicated an overall bycatch rate for all seabird species of 0.65 (0.39–1.00) birds/trip, while on-board observation data pointed to an average of 0.12 (0.05–0.20) birds/trip. Excluding outliers, the bycatch rate estimated with interview data come down to 0.35 (0.24–0.46) birds/trip. However, this last estimate stills to be approximately 3 times higher than bycatch rate resulted from on-board data. Perhaps is useful to consider the number of daily trips required to obtain a reliable estimate of bycatch rates. In case such low bycatch rate is real, sampling few fishing operations will tend to underestimate bycatch rates and confidence limits will be wide. Assuming the level of variability in reported bycatch in both interviews and on-board observations are realistic, simulation results indicate that estimated seabird bycatch and associated 95% confidence limits begin to stabilize after around 80 interviews (Fig. 4) and 200 boat trips per stratum (Fig. 5).

Bottom trawling and Bottom longline strong 95% confidence limits are reached after 189 and 21 interviews (representing 239% and 51% of each fleet), respectively, in other words when 95% confidence limits are below $\pm$50% of the estimated value.

Purse seine showed strong 95% confidence limits when the number of interviews and boat trips were around 66% and 7%, respectively, corresponding to 106 interviews and 1358 daily trips. Regarding Polyvalent ($<$12 m), only after 256 interviews (c.a. 7% of the entire fleet) and 232 daily trips (corresponding to less than 0.1% of annual fishing effort), 95% confidence limits were below $\pm$50% of the estimated value. While Polyvalent ($\geq$12 m) had strong confidence limits when the number of interviews and boat trips were around 46% (153 interviews) and 1% (530 trips), respectively. More, within those last two strata, Demersal longline ($<$12 m) and Setnet ($\geq$12 m) strong confidence limits are reached after 54 and 459 boat trips, respectively. Finally, Beach seine 95% confidence limits were below 50% of the estimated value only after 1219 fishing trips, corresponding to near 20% of the total fleet fishing effort.

4. Discussion

Competition for food resources and mortality on fishing gear are at present the major threats for seabirds at sea (Croxall et al., 2012). Considerable attention has been given to studies on seabird bycatch in the Pacific, South Atlantic, North Sea and Mediterranean seas (c.f. Barcelona et al., 2010; Lewison and Crowder, 2003; Orea et al., 2011; Žydelis et al., 2013), and not so much effort regarding Northeast Atlantic fisheries. To the best of our knowledge this study represents the first attempt to assess Portuguese fishing fleet impact on seabird populations in mainland coastal waters and suggests that substantial numbers of seabirds may be bycaught during the fishery activities. The most common species bycaught was the Northern gannet,

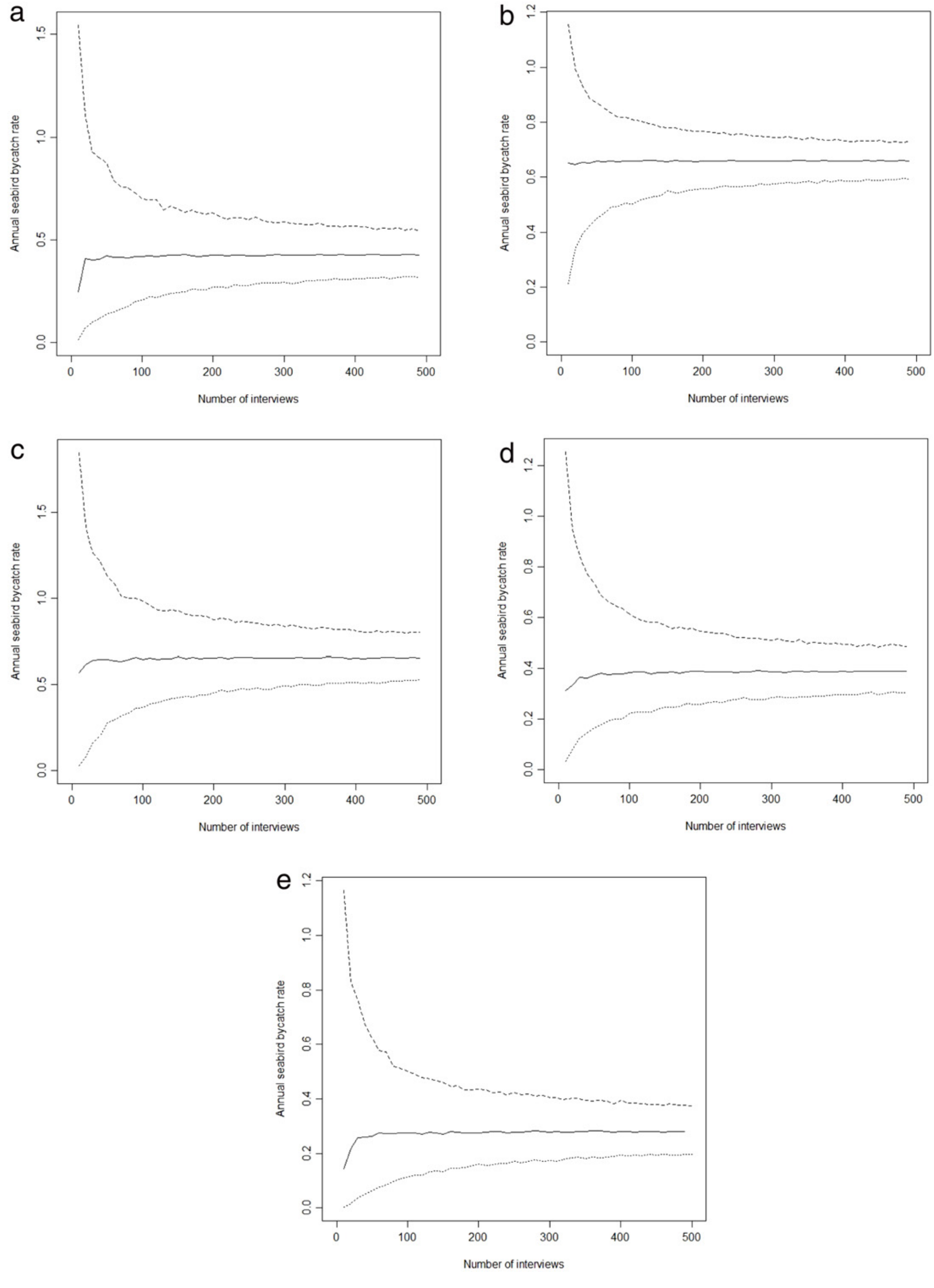

Fig. 4. Precision and accuracy of seabird bycatch rates from interviews in relation to number of simulated interviews. Median estimated seabird bycatch rate and 95% confidence limits for 5 of the studied strata, for different numbers of interviews. (a) Bottom trawls. (b) Bottom longline. (c) Purse seine. (d) Polyvalent (≥12 m) and (e) Polyvalent (<12 m).

followed by the Balearic shearwater, Lesser black-backed gull, Common scoter, Cory's shearwater, Great cormorant, Common guillemot and Black-headed gull. Purse seine and Setnets are confirmed to have a real impact on the critically endangered Balearic shearwaters, although interview data suggests all gears have also impact on the species, exception for Bottom trawling and Beach seine. As formerly stated, fishermen may confuse Balearic shearwater with similar shearwaters species,

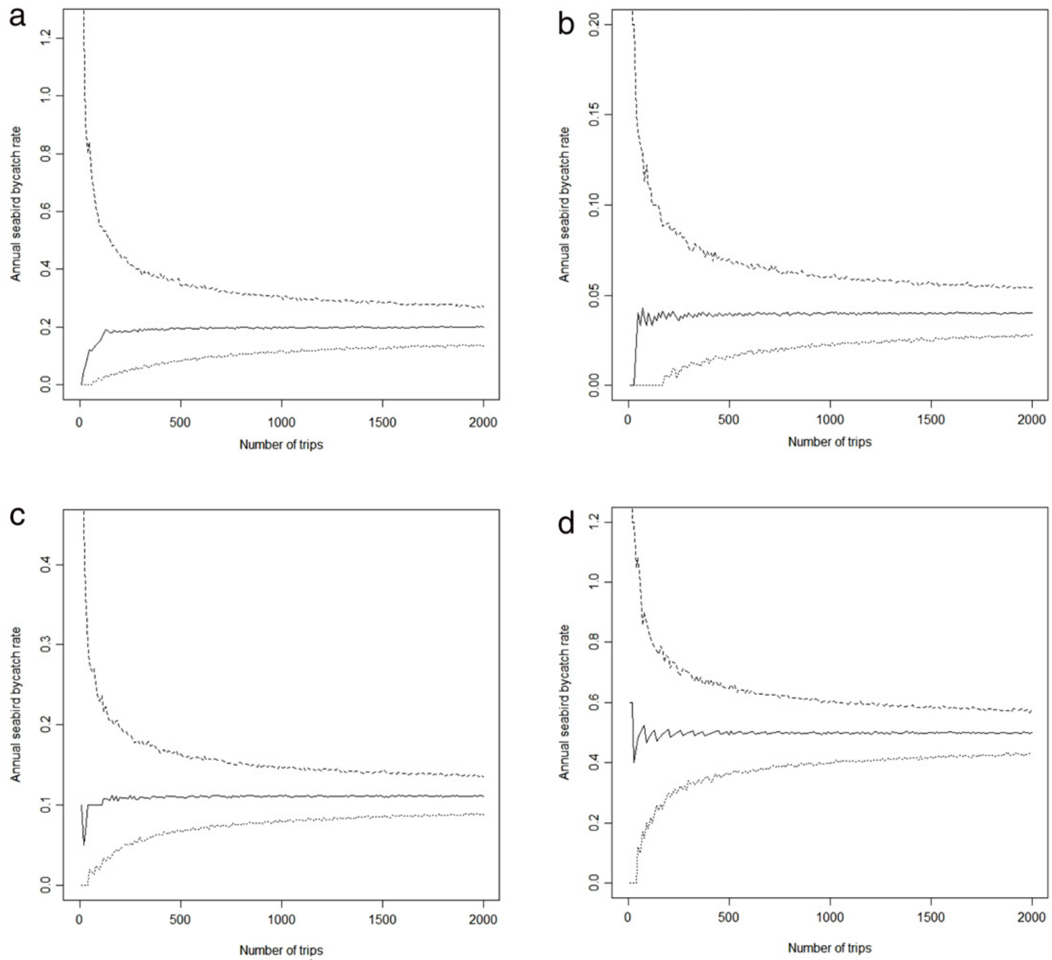

Fig. 5. Precision and accuracy of seabird bycatch rates from onboard observer data in relation to number of simulated trips. Median estimated seabird bycatch rate and 95% confidence limits for 4 of the studied strata, for different numbers of trips. (a) Purse seine. (b) Beach seine. (c) Polyvalent (≥12 m) and (d) Polyvalent (<12 m).

namely Manx, Sooty and Great shearwaters. Besides, such effect might have mislead some of the results as no bycatch was reported for any of those species by on-board observers. Also, Balearic shearwater attendance to fishing boats where observers were placed was much higher than any other shearwater species, individuals being observed feeding or foraging for food on 39.4% of observed trips, against 10.3% for Great shearwater, 3.6% for Sooty shearwater and 3.0% for Manx shearwater.

In our study, on-board observers recorded no bycatch in Bottom trawling and Bottom longline, contrasting with previous studies where bycatch on fisheries using the same gears was recorded for Balearic shearwater (Abelló and Esteban, 2012), Cory's shearwater (Báez et al., 2014), Cormorants (Barcelona et al., 2010), Audouin's and Yellow-legged gulls, Northern gannet (Belda and Sánchez, 2001) and Alcids (NMFS, 2006). Due to the fact that fishermen reported some seabird bycatch on both gears, although in lower proportions than for other gears, more attention should be paid to these gears in the future in order to determine its real impact on seabird populations. Also data simulations suggest that at least 500 boat trips/year per gear should be monitored by on-board observers in order to acquire valuable confidence limits.

The Purse seine CPUE in our study was 0.11 birds per fishing event, contrasting with no bycatch reported for other regions, namely Canada (Smith and Morgan, 2005), North Sea (ICES, 2013) and USA fisheries (Moore et al., 2009), although other studies found evidence that purse seines can be specially attractive to specific seabird species, specially for Audouin's gull (Arcos and Oro, 2002). Our results showed that this gear particularly affects Balearic Shearwater. Bycatch events do not seem to be frequent, however, when capture occurred, several individuals are caught together (in our study an average of 7.75 birds caught per set; see Table 3).

Beach seine was among the gears with less impact on seabird, when comparing with other gears where bycatch was recorded. Although no other studies found seabird bycaught in beach seine, bycatch of marine mammals and sea turtles were reported (Moore et al., 2010). Diving coastal birds are the most affected species by beach seine, namely Common Scoters.

The Portuguese Polyvalent fishing fleet has the majority of active boats, as well as a great diversity of fishing gear, driving to several kinds of constraints when estimates are required. The main problem is related to lack of information about the number of boats that are really operating each gear and the consequent annual fishing effort per each gear (number of nets/traps/longlines, length of gear, duration of time that gear is set at sea), which is needed to improve and extrapolate bycatch estimates for the entire fleet. Our results indicated that Setnets capture the largest diversity of seabird species, while Demersal longline have the highest CPUE. The Setnets ($\geq$12 m) bycatch rate in our study was 0.12 birds/trip, which is lower than that found by other authors in Baltic Sea (2.4; Kowalski and Manikowski, 1982) but similar with that found in Northwest Atlantic (0.10; Soczek, 2006). Contrary to other regions where diving birds are pointed as the main seabird species affected by Setnets (Žydelis et al., 2009), in our study Northern gannet is the species more often caught, followed by Lesser Black-backed Gull, which is in accordance with the findings of Soczek (2006). Balearic shearwater also appears to be affected by this type of gear, although only a single bycatch event was recorded with one entangled individual.

Our results indicate that Demersal longlines ($<$12 m) show the highest incidental catch of seabirds, affecting mainly Northern gannet. Average hook number set per fishing event was 174,667 with a minimum of 120 and a maximum of 2800 hooks. Despite the small number of rips, interviews also highlighted this gear as one with most impact on gannet population. In fact, CPUE found in this study was higher than that found in several other works (c.f. Barcelona et al., 2010; Smith and Morgan, 2005; Yeh et al., 2013) and lower than that found by Belda and Sánchez (2001), although partially agree with evidences found in Patagonian shelf waters (Favero et al., 2003). Increasing observation effort is needed and our data simulations suggest that at least 54 boat trips aboard Demersal longlines ($<$12 m) vessels should be carried on in order to achieve estimates with strong and stable confidence limits.

Balearic shearwater is classified as Critically Endangered by the International Union for Conservation of Nature, IUCN (BirdLife International, 2013), being fisheries bycatch pointed as the main source of threat at sea (Arcos, 2011). The species gregarious behaviour and its close association with fishing boats suggest that occasional ''mass mortality'' is likely to occur when longline boats and purse seiners operate close to flocks (Arcos et al., 2008). Bycatch is fairly common but often occurs on an irregular basis, with occasions of up to a hundred or more birds bycaught in a single purse seine event (Louzao et al., 2011). Our results support this statement, specially in terms of bycatch on purse seine gear. An extra source of mortality was found and our data suggests that also setnets contribute to reduce the adult survival rate of Balearic shearwater.

Despite the limitations of social survey data (Gilchrist et al., 2005), interviews have provided useful information about seabird bycatch in both artisanal and industrial fisheries when observer data was limited or not possible to collect (Lunneryd et al., 2004; Pro Delphinus, 2006; Smith and Morgan, 2005). Overall, bycatch rates estimated in the present study from interviews and on-board observations were quite different and the wide confidence limits of both estimates suggested more interviews and observation effort are needed. Bycatch rates from interviews were higher than rates from on-board observations, except for Polyvalent ($\geq$12 m). However, both data sources indicate Polyvalent boats and Purse seiners had the highest seabird bycatch rate. We advice that before any observation programme takes place, management authorities should consider developing a preliminary interview-based survey in order to get valuable details about the main fishing characteristics (e.g. gear, number of boats, fishing effort, main bycatch species, fishing areas). Also interview-based surveys drive researchers to get confidence from fishermen, allowing future implementation of on-board observation programmes and/or mitigation measures.

5. Final remarks

Coastal fisheries may contribute to global seabird population decrease. As formerly stated, further work should be developed in order to improve estimates of the real fishing effort per gear by the Portuguese fleet, mainly for boats using Setnets and Demersal longlines. Gathering reliable information on fishing effort will allow to estimate annual numbers of seabird caught in fishing gear, and assess the real impact of fisheries in seabird populations. An on-board observer programme should be implemented for Portugal fisheries, resembling other programmes which place observers aboard large pelagic longliners and trawls, ensuring long time-series and trends of bycatch estimates (c.f. Báez et al., 2014). Moreover, several studies have shown large inter-annual (Klaer and Polacheck, 1997; Weimerskirch et al., 2000), seasonal (Klaer and Polacheck, 1997), diurnal (Melvin et al., 2001) and spatial (Báez et al., 2014) fluctuations in seabird bycatch rates, and future models should incorporate such variables. Our study should be replicated in a pan-European prospective in order to assess accurate removal rates, in terms of bycatch, of European seabird populations. Finally, the study and implementation of mitigation measures is urgent and need to be included in fishermen, sea researchers, seabird conservationists, and policy makers agendas to minimize the impact of the fishing activity at sea on incidental bird bycatch.

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