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Balearic shearwater and northern gannet bycatch risk assessment in Portuguese Continental Waters

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ABSTRACT

Even though incidental captures in fisheries are one of the major threats to seabirds, bycatch has been difficult to quantify and specific risk areas are rarely identified. The present study evaluates the potential fisheries bycatch effect on two of the most emblematic seabird species wintering off continental Portugal, the critically endangered Balearic Shearwater and Northern Gannet. Information was collected by on-board observers and voluntary logbooks kept by fishing boat captains. Each species' Potential Biological Removal (for the study area) was based on the respective population abundance estimated through aerial surveys. The analysis of bycatch mortality identified the Fixed Gear in the Polyvalent fleet and Purse Seiners as the fisheries with the highest Balearic Shearwater bycatch rate. Longline and Fixed Gear fisheries had the highest Northern Gannet bycatch rate. The Potential Biological Removal thresholds were 41 Balearic Shearwaters per year (CI = 20–83) and 2345 Northern Gannets per year (CI = 2049–2680). The overlap between the predictive species distribution maps and fisheries density maps allowed for a seabird Bycatch Risk Assessment. The higher Balearic Shearwater bycatch risk was obtained for Fixed Gear and Purse Seines and the highest Northern Gannet bycatch risk was obtained for Longline and Fixed Gear fisheries. Bycatch mitigation measures should be applied in fisheries presenting the higher bycatch risks. This study identifies the potential areas where Balearic Shearwater and Northern Gannet bycatch is more likely to occur, including some of the already designated Special Protection Areas where management and conservation measures should urgently be applied.

1. Introduction

Seabirds are the most threatened group of birds, with nearly half of the species experiencing population declines (Croxall et al., 2012; Dias et al., 2019). The main threats to seabirds are invasive alien species at breeding sites (particularly rats and cats), climate change/severe weather impacts (due to habitat shifting and alteration, and temperature extremes), pollution (i.e. light pollution from coastal and insular communities, ships at sea and oil platforms) and bycatch (Phillips et al., 2016; Dias et al., 2019; Rodríguez et al., 2019). Fisheries bycatch has been postulated as the most serious threat to many large marine megafauna species (Moore et al., 2009; Lewison et al., 2014). Worldwide, hundreds of thousands of seabirds are annually bycaught in Trawl (e.g. Baker et al., 2007; Maree et al., 2014), Longline (e.g. Anderson et al., 2011), Gillnet (e.g. Žydelis et al., 2013) and Purse Seine (e.g. Suazo et al., 2017) fisheries.

There are several studies that focused on identifying which fishing gears produce the highest seabird bycatch estimates, particularly in gillnets and longline gears (see Pott and Wiedenfeld, 2017) whereas the effects of other gears such as purse seines or other fixed gears are less known (e.g. Wise et al., 2019). Worldwide, bycatch rates vary considerably by fishing gear and by area (Tuck et al., 2011). For example, whereas the highest and lowest estimated seabird bycatch rates have been respectively attributed to trawl fisheries and set-net fisheries in

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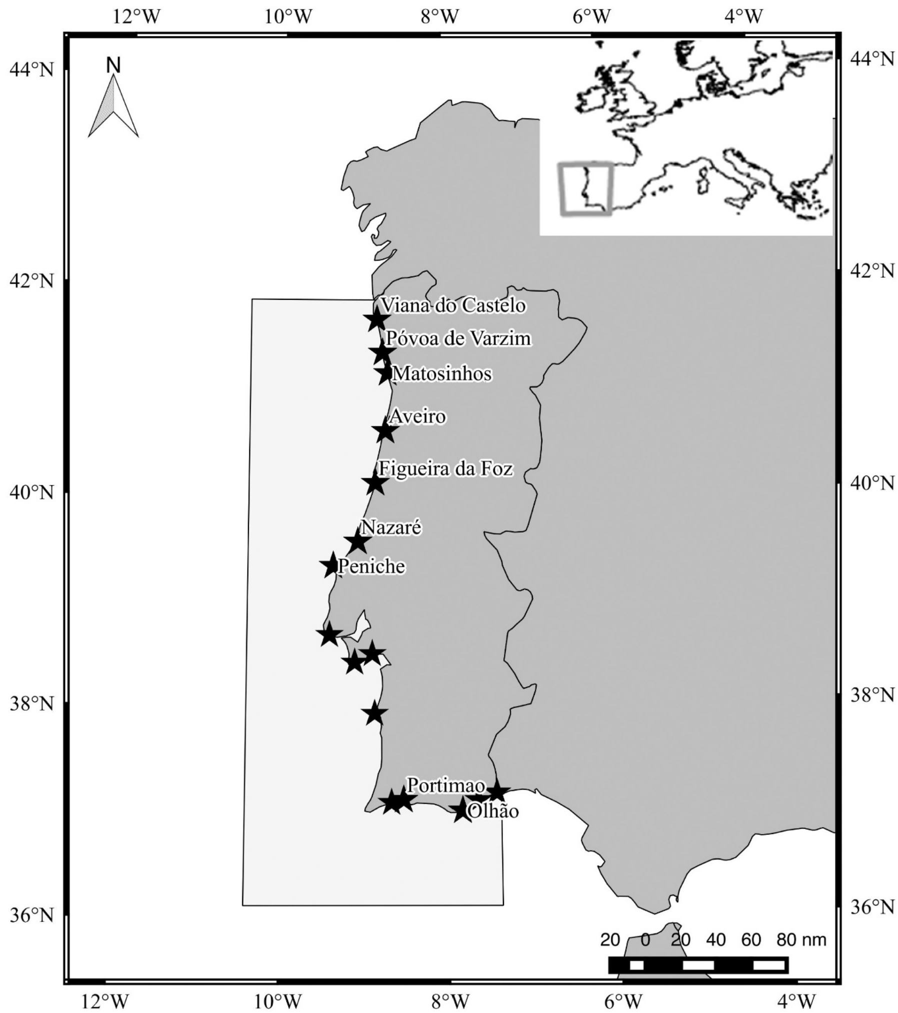

Fig. 1. Overview of the study area. Grey rectangle indicates the IXa ICES division. Stars indicate the 15 major fishing harbors in continental Portugal. Harbour names indicate the places where observations and/or voluntary logbooks were performed.

New Zealand (Richard et al., 2017), in the United Kingdom the highest estimated seabird bycatch rates were attributed to static nets and offshore longlines, and the lowest estimated bycatch rates were attributed to midwater trawls (Northridge et al., 2020). In Portuguese Continental Waters (PCW), bycatch rate estimates are available for marine birds in general (Oliveira et al., 2015) and for a particular region around the Berlengas Special Protection Area (SPA) (Calado et al., 2021; Oliveira et al., 2020). However, to date there were no bycatch rate estimates and average removal values concerning particular species across the entire Portuguese Continental Waters.

Seabirds are sometimes attracted to fishing vessels (Dunn and Steel, 2001; Anderson et al., 2011) and seabird's morphologies, sizes, sensory features and their behaviour may contribute to bycatch (Heswall et al., 2021). Furthermore, potential competition for resources may lead to seabird and fisheries overlap (Karpouzi et al., 2007).

In the last years, assessing the spatio-temporal overlap between fisheries and seabirds has been increasingly used to identify areas of potential interactions (e.g. Waugh et al., 2016; le Bot et al., 2018; Clay et al., 2019). A recent study, conducted in Portuguese Continental Waters (PCW) shows an overlap between fishing activity and marine predators, reflecting competition for resources in some cases (Wise et al., 2019). Another study also conducted in PCW, showed a low spatial overlap between Cory's Shearwater and purse seiners, trawlers and fixed gear and (Pereira et al., 2021).

Worldwide, several studies assessed spatio-temporal overlap using seabird distribution data obtained from biologging overlapped with fishing vessels' data obtained from the Automatic Identification System (AIS) (e.g Clay et al., 2019; Fischer et al., 2020; Pereira et al., 2021) or the Vessel Monitoring System (VMS) (e.g. Sugishita et al., 2015; Sztukowski et al., 2017). However, in the present study, to understand seabird interaction levels with fisheries in Portuguese Continental Waters, we performed a spatial-temporal assessment, overlapping AIS fisheries data with seabirds distribution models, based on aerial survey data collected in the study area.

In Portuguese continental waters, although other seabird species are accidentally captured by fisheries (e.g. Cory's Shearwaters, Common Scoter and Alcids), Balearic Shearwaters (*Puffinus mauretanicus*) and Northern Gannets (*Morus bassanus*) present the most representative bycatch levels in several fisheries (Vingada and Eira, 2018). In fact, both Balearic Shearwaters and Northern Gannets are widely affected by incidental captures in fisheries (Arcos et al., 2008; Abelló and Esteban, 2012; Boué et al., 2013, Oliveira et al., 2015; Genovart et al., 2016; Pott and Wiedenfeld, 2017; BirdLife International, 2021). Also, the study area represents very important post-breeding, migratory or wintering grounds for both species (Ramírez et al., 2008; Meirinho, 2009; Fort et al., 2012; Guilford et al., 2012; Oppel et al., 2012; Santos et al., 2013; Meirinho et al., 2014; Araújo et al., 2017). Considering the global Balearic Shearwater population values reported by Arroyo et al. (2014), 24.43% to 39.16% of the global population was present in Portuguese Continental Waters between 2010 and 2015 (Araújo et al., 2017). During the same period, the Northern Gannet was found to be the most abundant pelagic seabird in Portuguese Continental Waters (Araújo

Table 1
Characterisation of fishing fleets on ICES IXa division - Portuguese Continental Waters.

Fishing gear	Type of effort	Boats/ fishing licenses	Fishing days per boat	Hauls per boat	Hauls per year	Days at sea[a]
Fixed gear	Fishing event	320	180	4[b]	230,400	
Purse seine	Fishing event	88	115	2	20,240	
Trawl	Fishing days	80	152			12,160
Longline	Fishing days	39	183			7137
Beach seine	Fishing event	36	150[c]			5400

[a] It was assumed that all the days at sea were fishing days.
[b] Based on observers' reports, each boat uses on average 4 gill and/or trammel nets per day.
[c] The fleet operates 60 days with a mean of 2.5 trips per day.

et al. Unpublished results). Furthermore, the Balearic Shearwater is one of the most threatened seabirds in the word (BirdLife International, 2018a), with an evaluated annual decline of approximately 14%, and an average extinction time of 61 years if the current trend is maintained over time (Genovart et al., 2016; BirdLife International, 2021).

In this study we will evaluate whether Balearic Shearwater and Northern Gannet fisheries removal rates are sustainable in Portuguese continental waters. We will also evaluate which fisheries contribute more to Balearic Shearwater and Northern Gannet removal rates and where is bycatch more likely to occur within Portuguese Continental Waters.

2. Methods

2.1. Study area and characterisation of the ffshing fieet

The study was conducted within Portuguese Continental Waters - latitudes ranging from 36.5°N to 41.5°N (Fig. 1). The study area represents the Portuguese IXa ICES division, where the majority of the Portuguese continental fishing fleet operates. Recent data indicate that 3249 fishing vessels operate in Portuguese Continental Waters, which land 137,669 tons of fish per year representing 295,341,000 euros (INE, 2020). In the study period, 2010–2015, the most representative fishing fleets included the Polyvalent fleet using Fixed Gears (including gill and trammel nets) followed by the Purse Seine, Bottom Trawl and Bottom Longline fleets, as well as the artisanal Beach Seines (INE, 2016).

The Polyvalent fleet (hereafter referred as Fixed Gear fisheries) officially included 1802 fishing boats, most of them (1447) with LOA (Length Overall) < 10 m and 355 with LOA > 10 m (INE, 2016). This fleet uses a large variety of fishing gears including fixed nets (gill and trammel nets). Official statistics referred the existence of 1363 trammel net and 1443 bottom gill net licenses issued during the study period. In this analysis, we considered boats with LOA > 10 m. Following a conservative approach, to avoid overestimating the Fixed Gear fleet impact (considering the difficulty in estimating the number of days at sea and/or gear being used) and to account for unforeseen problems that may prevent fishing operations, we considered that 10% of this fleet does not operate each year (Vingada and Eira, 2018). The Purse Seine fleet was represented by 138 fishing boats (INE, 2016). In addition to the fleet dedicated exclusively to purse seining, there is a part of the Fixed Gear fleet that periodically use purse seine gears. However, due to the small size of these vessels, it was not possible to monitor Polyvalent boats operating purse seines. In the Purse Seine fleet, effort and bycatch were extrapolated to a group of 88 vessels, since onboard observers and logbooks monitored vessels over 18 m. The number of Bottom Trawlers (hereafter Trawlers) has not changed meaningfully in the last years, with 80 licenses issued for bottom trawls targeting demersal fish and crustaceans (INE, 2016). The Bottom Longline fleet (hereafter Longliners) was composed by 39 fishing boats that essentially captured black swordfish in deep waters beyond the slope (INE, 2016). Beach Seine is an artisanal fishing gear with 50 fishing licenses during the study period (INE, 2016), although only 36 boats - operating to the north of Nazaré - were monitored (Table 1). Information regarding fishing gear characteristics for each fleet (e.g., mesh size, net size and soak time) is available in DGRM (2018).

2.2. By-catch assessment

By-catch can be defined as capture of non-target species by a particular fishery that can lead to mortality (Hall, 1996). Estimates of accidental mortality in fisheries can be obtained through surveys, observers on board of fishing boats, electronic monitoring systems, fishers' voluntary declarations and analyses of stranded animals (Moore and Žydelis, 2008). In general, it is assumed that the standard method to assess fisheries bycatch relies on direct motorization performed by on-board observers (Moore and Žydelis, 2008; American Bird Conservancy, 2011; Pierre, 2019). Despite the broad use of this methodology, there are several aspects that might bias data collection, such as observers experience and awareness, fishers' behavioral change in the presence of onboard observers, observers' operational constraints (e.g. reduced space on small fishing boats or crew size limitations) and inadequate sampling designs (cost reduction might lead to insufficient monitoring efforts).

By using data previously obtained during several conservation projects (SafeSea www.safeseaproject.org, FAME www.fameproject.eu, LIFE+ MarPro www.marprolife.org), it was possible to maximize the amount of available information, to increase fleet coverage effort and to compare and validate different research techniques. Thus, data was obtained through onboard observers and voluntary logbooks kept by fishing boat captains.

The total mortality rate (Mr_{total}) per monitored fishing event was calculated as the total of reported bycaught animals (n_{total}) divided by the total number of monitored events (e). The mortality rate per events monitored by observers (Mr_{obs}) was calculated as the number of bycaught animals reported by observers (n_{obs}) divided by the number of events monitored by observers (e_{obs}). The mortality rate per events monitored by logbooks (Mr_{logb}) was calculated as the number of reported bycaught animals in logbooks (n_{logb}) divided by the number of events monitored by logbooks (e_{logb}).

$$\text{Mr}_{\text{total}} = n_{total}/\text{e}_{\text{total}}, \text{ or } \text{Mr}_{\text{obs}} = n_{\text{obs}}/\text{e}_{\text{obs}}, \text{ or } \text{Mr}_{\text{logb}} = n_{\text{logb}}/\text{e}_{\text{logb}}$$

Average removal (Ar): it results from scaling up the Mortality rate (Mr_{total}) for each fishing gear annual effort (*Ef*), assuming that mortality rates are homogeneous across the area and throughout the year (as in Anderson et al., 2011).

$$\text{Ar} = Mr_{\text{total}} \times Ef$$

Fishing event: in the case of the Fixed Gear, Purse Seine and Beach Purse Seine, fishing effort (*Ef*) corresponds to the annual number of hauls (fishing events) per year. In the case of Trawls and Longlines, the fishing effort was estimated considering the number of fishing days (Table 1).

Uncertainties of estimated mortality rates and Average Removal values, expressed as 95% confidence intervals, were obtained through standard non-parametric bootstrapping techniques (Canty and Ripley, 2012).

2.2.1. Onboard observers

The dedicated fishery observer scheme and the placement of onboard observers were preceded by all necessary authorisations. Observers were placed on-board fishing boats from April 2010 to December 2015,

Table 2
Fisheries monitoring effort (events or days) and bycatch of Balearic Shearwater and Northern Gannet. n_{otal}, total number of individuals recorded as bycatch; n_{obs}, number of individuals recorded as bycatch by observers; n_{logb}, number of individuals recorded as bycatch by logbooks. Mortality rate total (Mr_{total}), bycaught individuals per monitored fishing event. Mr_{Obs}, bycaught individuals per events monitored by observers; Mr_{Logb} bycaught individuals per events monitored by logbooks. Average removal (Ar), Annual average number of individuals removed by gear type. Confidence intervals (CI) and Coefficient of Variation (CV) are presented between brackets.

Fishery	Monitored events (e)		Balearic shearwater					Northern gannet				
	Total	Observers / Logbooks	n_{total}	n_{Obs} / n_{Logb}	Mr_{total} (CI, CV)	Mr_{Obs} (CI, CV) / Mr_{Logb} (CI, CV)	Ar[b] (CI, CV)	n_{total}	n_{Obs} / n_{Logb}	Mr_{total} (CI, CV)	Mr_{Obs} (CI, CV) / Mr_{Logb} (CI, CV)	Ar[b] (CI, CV)
Fixed gear	9659		71		0.004 (0.001–0.009, 0.49)		924 (215–2077, 0.49)	58		0.006 (0.002–0.011, 0.41)		1383 (457–2571, 0.41)
		8462		30		0.026 (0.004–0.057, 0.60)			14		0.012 (0.003–0.023, 0.48)	
		1197		41		0.005 (0–0.011, 4.73)			44		0.005 (0.002–0.010, 0.41)	
Purse seine	5167		94		0.018 (0.006–0.038, 0.44)		356 (121–768, 0.44)	40		0.008 (0.004–0.014, 0.34)		155 (74–286, 0.34)
		812		56		0.070 (0–0.169, 0.62)			11		0.0134 (0.003–0.032, 0.58)	
		4355		38		0.009 (0.003–0.019, 0.47)			29		0.007 (0.002–0.015, 0.48)	
Trawl	529[a]		0		0		0	12		0.022 (0.009–0.039, 0.35)		272 (115–483, 0.35)
		315		0		0			5		0.015 (0–0.041, 0.74)	
		214		0		0			7		0.033 (0.009–0.056, 0.38)	
Longline	128[a]		0		0		0	41		0.321 (0.109–0.649, 0.43)		2288 (779–4629, 0.43)
		30		0		0			31		0.848 (0.098–1.833, 0.57)	
		98		0		0			10		0.101 (0.020–0.184, 0.46)	
Beach seine	6996		11		0.002 (0–0.004, 0.72)		9 (0–22, 0.72)	0			0	0
		778		11		0.014 (0–0.004, 0.66)			0		0	
		6218		0					0			
Total	22,479		176					151				
		3132		97			1289		61			4098
		19,347		79			(226–2867)		90			(1415–7969)

[a] Fishing days.
[b] Based on fleet effort, see Table 1.

covering four types of fishing gear: Trawl, Longline, Fixed Gear (gill nets, trammel nets) and Purse Seine. Beach Seiners were monitored between May and October by inland observers (herein included in the onboard observer group). When onboard, the observers systematically recorded the vessel's activity, position (using a handled GPS), weather and sea conditions. This process was interrupted whenever the vessel changed its activity. The observer was located in the most favourable position to observe the operation and the sea surface, looking for cetaceans and seabirds including Balearic Shearwaters and Northern Gannets. Observers recorded every interaction and bycatch event. Data collected by on-board observers for the period 2010–2012 were partially presented in Oliveira et al. (2015).

2.2.2. Voluntary logbooks

Between January 2010 and December 2015, fishing events and incidental bycatch were reported in voluntary logbooks kept by boat captains using trawls, longlines, fixed Gear (gill nets, trammel nets), purse seines and beach seines. Bycatch events were usually registered in a simple but time-consuming form, detailing only the strictly necessary information, such as: date, boat position, species involved, and the number of animals captured. In cooperation with handpicked fishing boat captains, displaying a high level of confidence in terms of information accuracy, this data collection system allowed to substantially increase bycatch datasets.

Table 3
PBR values for the Balearic Shearwater and the Northern Gannet (confidence intervals between brackets). Demographic parameters: abundance (N), coefficient of variation (CV), Minimum abundance estimate (N_{min}), Maximum potential annual growth rate (λ_{max}). Abundance and coefficient of variation values for the Balearic Shearwater were obtained from Araújo et al. (2017) for the period 2010 to 2014.

	Period	Overall	2010	2011	2012	2013	2014	2015
Balearic shearwater	N	10,182 (4902–20,436)	2338 (1099–4271)	6250 (3128–12,055)	23,221 (10423–49,279)	8053 (1922–35,329)	9783 (4962–18,475)	10,819 (5654–24,703)
	CV	0.27	0.35	0.35	0.42	0.83	0.34	0.38
	N_{min}	8171 (3934–16,400)	1757 (826–3210)	4704 (2354–9073)	16,575 (7740–35,176)	4380 (1046–19,218)	7419 (3763–18,132)	7941 (4150–18,132)
	λ_{max}	1.101						
	f	0.1						
	PBR	41 (20–83)	9 (4–16)	24 (12–46)	84 (38–178)	22 (5–97)	41 (19–71)	40 (21–92)
Northern gannet	N	82,405 (71993–94,175)	75,139 (59392–94,595)	66,921 (52033–85,531)	77,746 (62171–96,805)	99,765 (79169–125,255)	50,485 (37369–67,433)	120,615 (95535–151,805)
	CV	0.06	0.11	0.11	0.10	0.10	0.13	0.11
	N_{min}	78,165 (68289–89,329)	68,735 (54330–86,532)	60,911 (47360–77,850)	71,395 (57091–88,895)	91,193 (72367–114,493)	45,335 (33557–60,555)	110,049 (87166–138,507)
	λ_{max}	1.12						
	f	0.5						
	PBR	2345 (2049–2680)	2062 (1630–2596)	1827 (1421–2336)	2142 (1713–2667)	2736 (2171–3435)	1360 (1007–1817)	3301 (2615–4155)

2.3. Seabird abundance and predictive distribution maps

Aerial survey campaigns have proved to be an effective method to provide unbiased seabird abundance estimates and probability distribution maps (e.g. Pettex et al., 2017; Rogan et al., 2018). Those unbiased seabird abundance estimates are essential to assess the impact of accidental or intentional removals of individuals from their respective population (Garthe and Hüppop, 2004). Aerial surveys were conducted within the Portuguese Continental waters during September and/or October between 2010 and 2015, following the methodology described in Araújo et al. (2017). Habitat predictive models for Balearic Shearwaters and Northern Gannet were computed using a maximum entropy algorithm on MaxEnt 3.3.3 and the obtained predictive distribution maps were based on occurrence probability. Model performance was compared using different sets of predictive variables, i.e., Sea Surface Temperature (SST), Chlorophyl Concentration (Chla), Bathymetry and Slope.

2.4. Potential biological removal

The relationship between estimates of accidental mortality in fisheries and population estimates can be used to estimate the highest number of individuals removed from a given population by accidental catch - Potential Biological Removal (PBR) - which should not compromise the population at biological level (Wade, 1998). PBR is a measure of sustainable human-caused mortality to a population (Wade, 1998) and is calculated as:

$$\mathrm{PBR} = N_{\min}\ 1/2\ \mathrm{R}_{\max}\ f$$

where R_{max} is the maximum annual recruitment rate, equaling ($\lambda_{max}-$ 1), where λ_{max} is the maximum potential annual growth rate,f is a recovery factor between 0.1 and 1, andN_{min} is the minimum population estimate, which is calculated taking the 20th percentile of the distribution of population size, following the equation (Dillingham and Fletcher, 2008):

$$N_{\min} = N/exp\left[0.842\sqrt{ln\left(1+\mathrm{CV}_N{}^2\right)}\right]$$

Balearic Shearwater and Northern Gannet population estimates (N) and respective Coefficient of Variation (CV_N) were obtained from aerial surveys during the period 2010–2015. For the Balearic Shearwater we set f at a conservative value of 0.1, typical for endangered species and for the Northern Gannet we set f at a conservative value of 0.5, typical for stable populations (Dillingham and Fletcher, 2008).

2.5. Fisheries-seabird overlap assessment

We quantified the spatiotemporal overlap between Balearic Shearwater and Northern Gannet distributions and fishing effort, to evaluate the potential for interactions between fisheries and the studied seabirds.

The AIS-based fishing effort dataset (Version 1.0) for the period 2012–2016 equated to 50–70% of the global fishing effort ($n > 70{,}000$ vessels, Kroodsma et al., 2018). Data on daily fishing effort and vessel presence were obtained from the Global Fishing Watch's community page (https://globalfishingwatch.force.com/gfw/s/data_download) (accessed 1st July 2017). These data were binned into grid cells 0.01 degrees on a side, measured in hours by flag state and gear type, for September and October (aerial surveys' period) of 2012–2015 (available fishing effort data for the study period). The data derived from AIS contained date, latitude and longitude, the flag state of the fishing effort, gear type, vessel hours and fishing hours (for more information see Kroodsma et al., 2018). This AIS data was converted into shape file format using Global Mapper 13 and clipped on to the study area. Values with fishing hours equal to zero were removed.

Fishing density maps (distribution of fishing effort) were created for each type of fishing gear (except for Beach Seiners, which are not equipped with AIS transmitters), for the overall period (September and

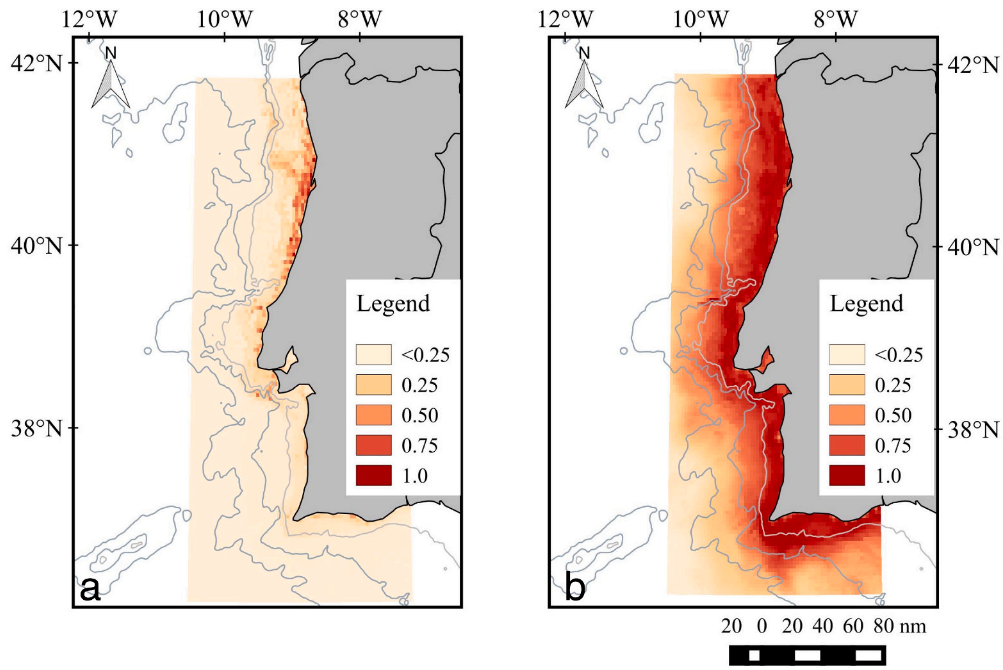

Fig. 2. Overall predictive distribution map for (a) Balearic Shearwaters and (b) Northern Gannets. Bathymetric profile of the area showing the 200 m (dark grey line), 1000 m (grey line) and 3000 m isobaths (light grey line).

October of 2012–2015) and for independent years (September and October data only), using the Gaussian Kernel featured in the Density Grid tool in Global Mapper 13. Density maps were resampled to 4 × 4 km grids to fit the Balearic Shearwater and Northern Gannet predictive distribution map.

The fishing density maps, per fishing type and all types combined, were intercepted with the 50th percentile distribution of the overall predictive distribution maps of the Balearic Shearwater and Northern Gannet in Portuguese Continental Waters. The 50th percentile is often used to define the core area of use (Ford and Krumme, 1979; Soanes et al., 2013; Sansom et al., 2018). For each pair-wise comparison, we calculated the degree of overlap, defined between 0 (no overlap) and 1 (strong overlap) by multiplying the fishing effort by the species predictive distribution maps (Raster Calculator tool in QGIS 2.12.0). This methodology is commonly used to measure the overlap between fishing effort and seabird density (e.g., Waugh et al., 2016).

The Bycatch Risk Index corresponds to the overlap of the species occurrence probability and the fishing density. According to the overlap degree, the Bycatch Risk Index was low (0–0.25), moderate (0.25–0.75) or high (0.75–1).

3. Results

3.1. Bycatch assessment

Between 2010 and 2015, 22,479 fishing events were monitored, including 3132 events directly monitored by onboard observers and 19,347 events declared by fishing boat captains through voluntary logbooks (Table 2). Records show a total of 176 Balearic Shearwaters incidentally captured in the fishing events monitored during the study period, of which 97 were reported by observers and 79 by logbooks. With respect to the 151 incidentally captured Northern Gannets, observers reported 61 and logbooks reported 90 individuals.

No Balearic Shearwater bycatch was recorded in Trawlers and Longliners and no Northern Gannet bycatch was recorded in Beach Seines. The highest Balearic Shearwater total annual mortality rate was obtained in Purse Seines (0.018, CI = 0.006–0.038) while the highest Northern Gannet total annual mortality rate was obtained in Longlines (0.321, CI = 0.109–0.649). Whereas the Balearic Shearwater mortality rate estimate based on observer data ranged between 0.014 and 0.070, mortality rate estimates based on logbook data ranged between 0.005 and 0.009 for all fisheries. With respect to Northern Gannet mortality rates based on observers and on logbook data, the respective values were 0.012 and 0.005 in Fixed Gear, 0.013 and 0.007 in Purse Seines and 0.848 and 0.101 in Longlines. Following an inverse pattern, in Trawls the Northern Gannet mortality rate based on observers was 0.0033 and the mortality rate based on logbook data was 0.015 (Table 2).

The CV for the for Balearic Shearwater mortality rate estimates based on logbooks was overly high and therefore logbook data was not used to calculate average removal (Table 2). With respect to Balearic Shearwaters, estimates of average annual bycatch mortality predicted that 924 (215–2077) individuals were removed by the monitored fisheries. Likewise, the Northern Gannet average annual bycatch mortality predicted that 4098 (1415–7969) individuals were removed by the monitored fisheries (Table 2).

3.2. Potential biological removal

The Balearic Shearwater population estimate N for the overall period was equal to 10,182 individuals (CI = 4902–20,436), and CV_N was equal to 0.27 (see Table 3 for annual data details). A conservative estimate of N_{min} was calculated at 8171 (CI = 3934–16,400) Shearwaters for the overall period, ranging between 1757 (2010) (CI = 826–3210) and 16,575 (2012) (CI = 7740–35,176). Considering the $\lambda_{max} = 1.101$ estimated by Genovart et al. (2016), we obtained a PBR of 41 (CI = 20–83) individuals per year considering the overall period, with a minimum of 9 individuals in 2010 (CI = 4–16) and maximum of 84 in 2012 (CI = 38–178) (Table 3).

For the overall period, the Northern Gannet population estimate N was 82,405 individuals (CI = 71,993–94,175) and CV_N was 0.06 (see Table 3 for annual data details). The Northern Gannet minimum abundance population (N_{min}) was 78,165 individuals (CI = 68,289–89,329) for the overall period, varying between 45,335 (2014) (CI = 33,557–60,555) and 110,049 (2015) (CI = 87,166–138,507). Considering the $\lambda_{max} = 1.12$ estimated by Russell (1999), we obtained a PBR of 2345 (CI = 2049–2680) individuals per year considering the overall

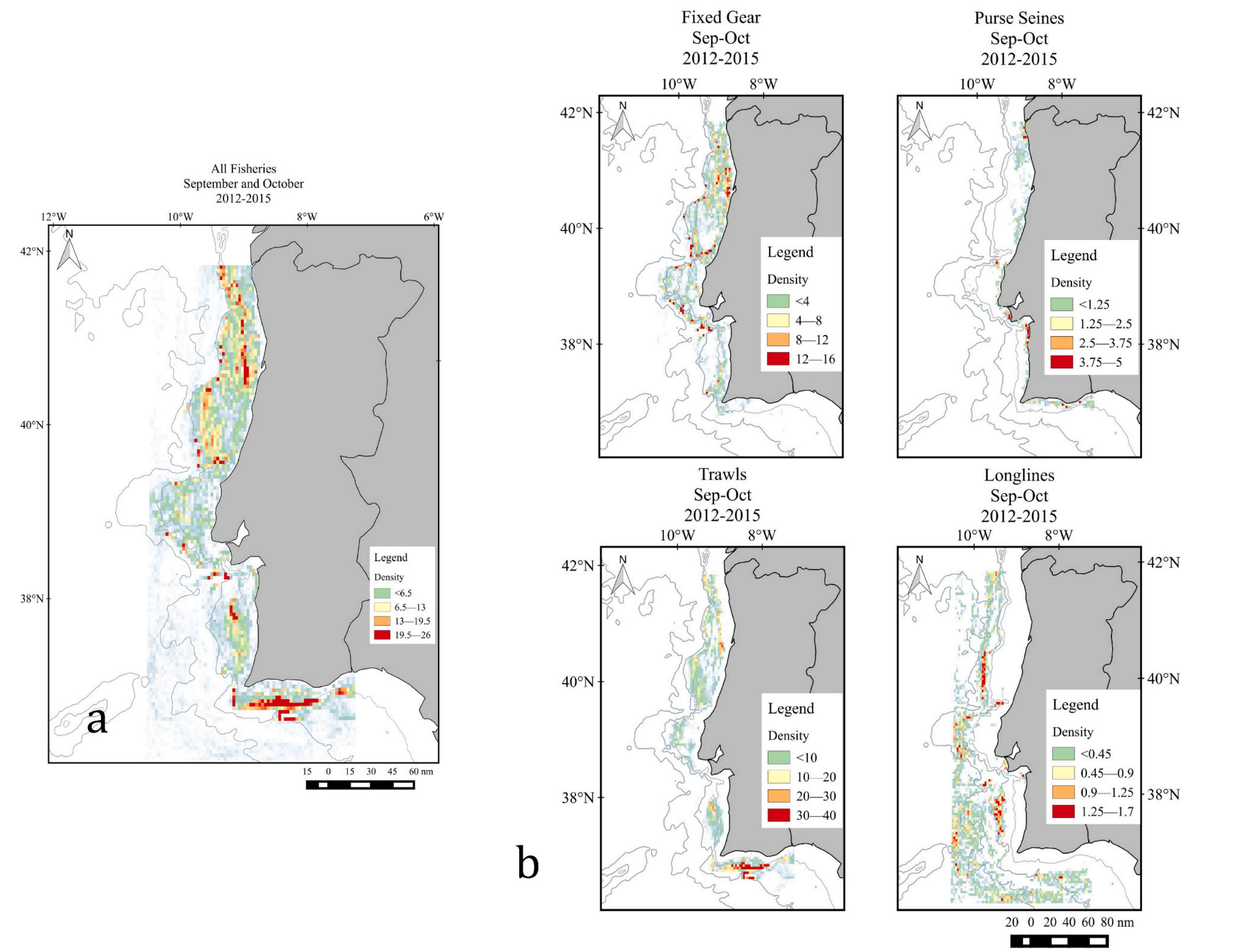

Fig. 3. Fishing Density Map with (a) all fishing gear types combined and (b) the different fishing fleets, in September and October for the period 2012–2015. Bathymetric profile of the area showing the 200 m (light grey line), 1000 m (grey line) and 3000 m isobaths (dark grey line).

period, ranging between 1360 (CI = 1007–1817) individuals in 2014 and 3301 (2615–4155) in 2015 (Table 3).

3.3. Species occurrence probability

According to the species predictive distribution maps, the Balearic Shearwater occurrence probability was generally higher in wider areas of the continental shelf, particularly close to the coastline in the center and north regions of the Portuguese coast (Fig. 2a). As for Northern Gannets, individuals were distributed throughout the Portuguese continental shelf, particularly in areas located 3 to 20 nm away from the shore (Fig. 2b). Predictive distribution models for both species showed good performances (Balearic Shearwater: AUC = 0.929, SD = 0.013; Northern Gannet: AUC = 0.876, SD = 0.003). Chla presented the highest contribution to explaining Balearic Sheawater occurrence probability followed by SST, Bathymetry and Slope. Chla was also the most important predicting variable in the Northern Gannet model followed by Bathymetry, SST and Slope (Data not show).

Table 4
Percentage (%) of overlap between seabird (Balearic Shearwater and Northern Gannet) distribution maps and fisheries. Seabird bycatch risk for each of the pair-wise overlap.

			Bycatch risk (%)		
		Area overlap (%)	Low	Moderate	High
Balearic shearwater	All fisheries combined	47.3	55.1	33.7	11.2
	Fixed gear	42.0	67.1	26.6	6.3
	Purse seine	27.7	53.8	38.5	7.7
	Trawlers	15.4	69.0	24.1	6.9
	Longliners	0	0	0	0
Northern gannet	All fisheries combined	34.6	73.1	23.6	3.4
	Fixed gear	25.5	74.1	21.6	4.3
	Purse seine	11.8	76.3	20.1	3.6
	Trawlers	20.4	76.7	19.6	3.7
	Longliners	4.2	67.2	26.8	6.0

3.4. Fisheries-seabird overlap assessment

3.4.1. Fisheries effort

Fishing density maps, for the September and October months between 2012 and 2015, show different hotspots for all fishing types combined and for each of the gear types (Fig. 3a, b). The Purse Seine fleet is mostly concentrated in the Continental shelf up until a 6 nm distance from shore (inside the 200 m bathymetry) in the extreme north of the area, around the Berlengas archipelago, south of the Tejo estuary and south of the Sado estuary, and in the Algarve region. The highest Trawler fishing effort varies regionally according to their operating depths: in the south and southeast regions they concentrate between the

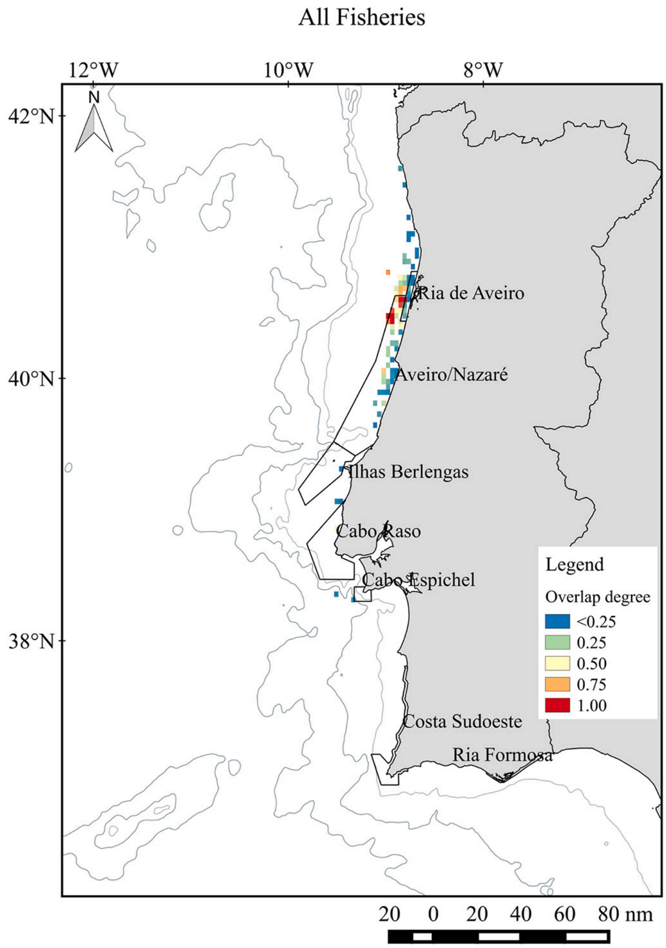

Fig. 4. Overlap between Balearic Shearwater predictive distribution models and all fishing gear types for the period 2012–2015; black polygons show SPAs with identifying labels. Bathymetric profile of the area showing the 200 m (light grey line), 1000 m (grey line) and 3000 m isobaths (dark grey line).

200 m and 1000 m bathymetry and in the North and Central areas of Portugal they concentrate inside the continental platform until the 200 m bathymetry, in all cases beyond the 6 nm distance from the shore. The Longliner fleet presents the highest fishing effort beyond the 25 nm distance from shore, and it is distributed across the study area (around the 1000 m bathymetry), with exception of the Nazaré canyon (see Fig. 3b). Fixed gear fisheries have a more concentric distribution around the major harbors in the western Portuguese coast.

3.4.2. Balearic shearwater

There was a 47.3% overlap between the 50th percentile Balearic Shearwater predictive distribution map and the fishing density map. The overlap with fisheries was particularly noticeable off the Aveiro Region and in the Aveiro-Nazaré SPA (Table 4 and Fig. 4). The most important overlap involved Fixed Gear (42.0%) and Purse Seines (27.7%). The Balearic Shearwater distribution also overlapped with Purse Seines at the north of Cape Raso and inside the Cape Raso SPA. There was no overlap between Longliners and Balearic Shearwaters. Their overlap with trawlers (15.4% overlap) occurred mostly in the area in front of Aveiro Region and south of Figueira da Foz, within the Aveiro-Nazaré SPA (Table 4 and Fig. 5).

The Balearic Shearwater bycatch risk was high for all fisheries combined in 11.2% of the overlap and moderate in 33.7%. For Fixed Gears, 6.3% of the overlap was considered as high risk and 26.6% as moderate. For Trawlers, 10.3% of the overlap was considered as high risk and 24.1% as moderate risk (Table 4). The Purse Seine shows moderate risk also in front of Aveiro Ria and in the shallow waters of Aveiro-Nazaré SPA, with high risk also in the Aveiro-Nazaré SPA and inside of the Cabo Raso SPA (7.7% of the total overlapped areas of high risk and 38.5% of moderate risk).

3.4.3. Northern gannet

There was a 34.6% overlap between all fisheries combined and the 50th percentile of the Northern Gannet distribution map. Overlap occurred mainly between the 14 and 35 nm distances from shore (Table 4 and Fig. 6). The most expressive overlap occurred with Fixed Gear (25.5%), Trawls (20.4%) and Purse Seines (11.8%). The Fixed Gear fishery overlapped with the Northern Gannet predicted distribution throughout the west coast, showing areas of strongest overlap between Aveiro and the northern Portuguese Continental Waters limit, with scattered high overlap areas within the Aveiro-Nazaré SPA. With respect to Longlines, the overlap occurred mostly around the 1000 m bathymetry, between the 30 and 50 nm distances from shore, except around the Nazaré Canyon and to the south of the Tejo and Sado estuary, where this overlap occurs closer to the shoreline. Purse Seines overlap with Northern Gannets mostly in areas near the shoreline in the extreme north of the study area, to the south of the Sado estuary, to the South of the Tejo estuary and around Berlengas islands (inside of the Ilhas Berlengas SPA). The Trawler fishery overlap with Northern Gannets occurred most intensely in the southern region between the 200 m and 1000 m bathymetries and 10 nm off Ria the Aveiro in the edge of the Aveiro-Nazaré SPA (Table 4 and Fig. 7).

The bycatch risk was high for all fisheries combined in 3.4% of the overlap with Northern Gannet distribution and Moderate in 23.6% of the distribution. For Purse Seines the bycatch risk was high in 3.6% and moderate in 20.1% of the overlap with gannet distribution. For Fixed Gear, 4.3% of the overlap was considered of high risk and 23.6% as moderate. For Trawls, 3.7% of the overlap was considered as high risk and 19.6% as moderate risk overlap. Considering high and moderate risk overlap as a whole (6.0 + 26.8%), Longliners present the greatest bycatch Risk (32.8%) for Northern Gannets.

4. Discussion

Worldwide, hundreds of thousands of seabirds are captured in various types of fishing gear every year (Anderson et al., 2011; Žydelis et al., 2013) resulting in the decline of many pelagic seabirds (Croxall et al., 2012; Phillips et al., 2016). This unsustainable level of bycatch mortality is even more concerning when dealing with Balearic Shearwaters, one of the most threatened seabirds in the world. In the study period, the estimated Balearic Shearwater average bycatch mortality exceeded the PBR threshold. Furthermore, the estimated Northern Gannet average bycatch mortality also exceeded the PBR threshold in the study area. Bycatch risk for each species varied across fishing gear types and location within the study area, with some Special Protection Areas presenting concerning degrees of bycatch risk.

In the study area, the highest Balearic Shearwater bycatch rate was produced by the Purse Seine and Fixed Gear fleets in agreement with Oliveira et al. (2015) but in contrast with other studies performed in the Bay of Biscay (Ruiz et al., 2021) and in the Berlengas archipelago in Portugal (Calado et al., 2021) where there were no bycatch events leading to mortality. However, in the Mediterranean (where breeding areas are located) demersal Longlines seem to be the most problematic gear causing Balearic Shearwater bycatch (Cortés et al., 2017; BirdLife International, 2021). The different type of gear causing the largest bycatch rates in different study areas is probably related with the variation in the distribution of the species over different areas of their breeding and wintering range. In the study area, the Balearic Shearwater is mostly present in shallow shelf and coastal waters particularly in the widest portions of the continental shelf (Araújo et al., 2017). This area is not widely used by Trawlers or demersal Longliners. Furthermore, demersal Longliners in Portugal are mainly small boats, rarely allowing

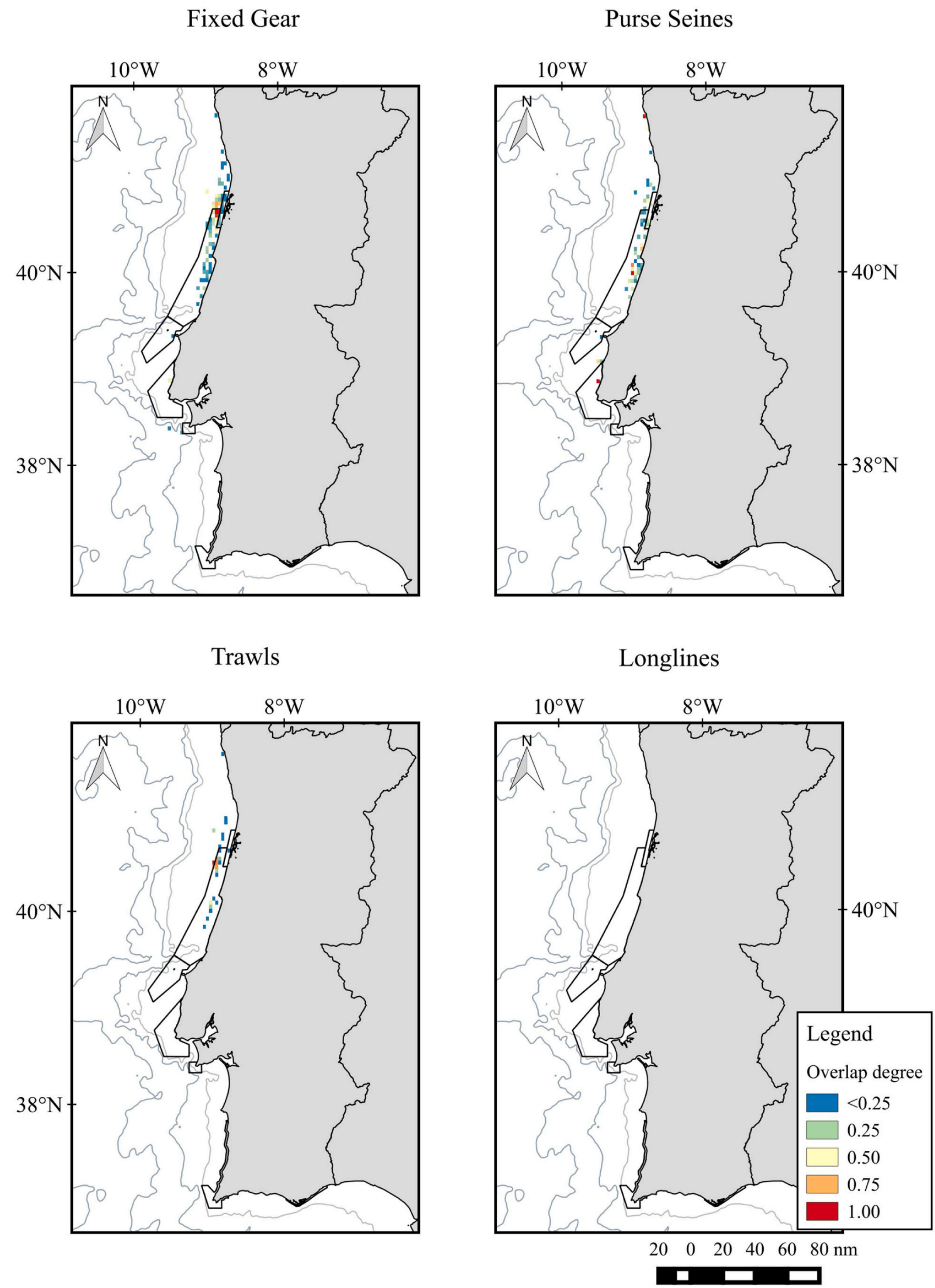

Fig. 5. Overlap between Balearic Shearwater predictive distribution models and different fishing gear types for the period 2012–2015. Bathymetric profile of the area showing the 200 m (light grey line), 1000 m (grey line) and 3000 m isobaths (dark grey line).

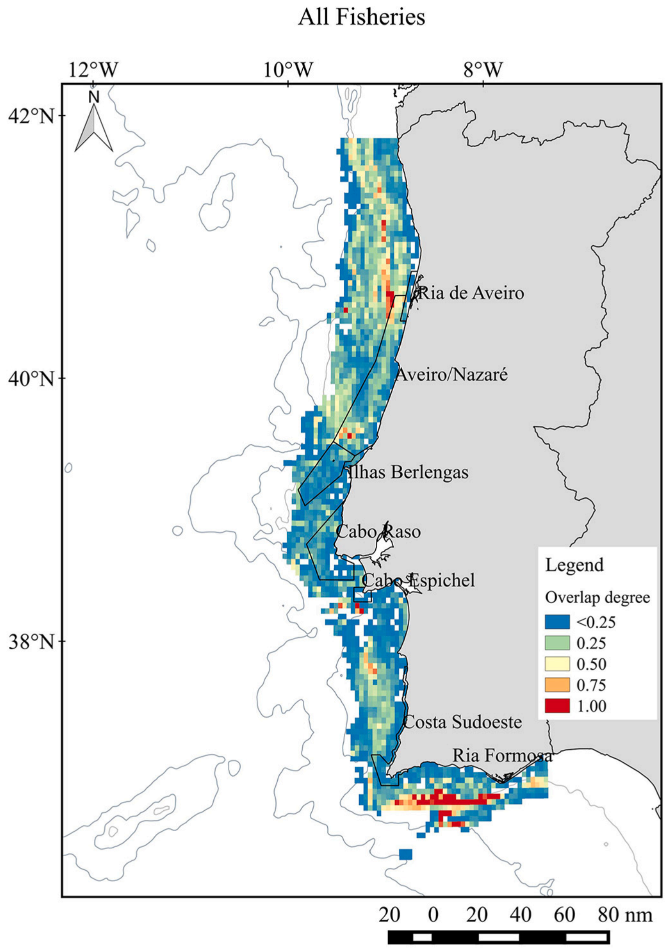

Fig. 6. Overlap between Northern Gannet predictive distribution models and all fishing gear types combined for the period 2012–2015; black polygons show SPAs with identifying labels. Bathymetric profile of the area showing the 200 m (light grey line), 1000 m (grey line) and 3000 m isobaths (dark grey line).

observers on board, leading to a possible uncounted bycatch.

In the present study, the purse seine fleet presented a lower Balearic Shearwater bycatch rate in relation to the Fixed gears fleet. However, the highest number of bycaught individuals was recorded in Purse Seines. According to Louzao et al. (2011), in the Mediterranean bycatch events in Purse Seines may involve up to a hundred or more birds in a single event but usually occur on an irregular basis. The artisanal Beach Seine fishery presented the lowest mortality rate and does not seem to have a high impact on species mortality.

Our PBR estimates point to an overall sustainable removal of 41 (CI = 20–83) Balearic Shearwaters per year (ranging between 9 individuals in 2010, CI = 4–16 and 85 individuals in 2012, CI = 38–178). However, our estimates revealed that on average, 1289 (CI = 226–2867) individuals were removed annually due to bycatch, a much higher value than the estimated PBR value. Even when using a conservative approach for Fixed Gear fishing effort estimates, our results indicate that the impact of bycatch in PCW, considering the global fishing efforts, may well exceed the estimated thresholds of the potential Biological Removal particularly for the Balearic Shearwater. We emphasise that this extrapolation should be faced with caution and considered as a mathematical exercise because we applied means of bycatch mortality rates from a subset of fisheries to the wider fleet what could overestimate bycatch (Luck et al., 2020). Also, data from logbooks in Fixed Gear were not considered due to the high uncertainty associated with the estimated results. In the future, the validity of using logbook data should be reassessed and the need for better fishing effort and bycatch monitoring methods should be reinforced. In order to improve data accuracy, an increase in fleet monitoring should be integrated with environmental and ecological variables effects on seabird bycatch (Zhou et al., 2020). One the other hand, we should also emphasise that there are other sources of accidental mortality, i.e. entanglement in marine debris (Costa et al., 2020), which were not considered in this study.

The number of Balearic Shearwaters in the study area in late summer/early autumn, the so-called post-breeding period, was used as the reference population abundance in the PBR estimate. Obviously, the global population is larger (24,000–26,500 individuals, Arroyo et al., 2014). However, by using the regional total numbers as reference points, the calculated thresholds yield the range of extra mortality likely sustained by the regional and total populations (Genovart et al., 2016).

All the examined fisheries potentially overlapped with the Balearic Shearwater predicted distribution areas, except for Longliners since they operate beyond the 25 nm distance from the shore (Larger AIS-equipped boats mostly operating in bottom longline areas). The largest overlap was found in Fixed Gears and Purse Seines, 42.0% and 27.7% respectively. In our study we obtained a higher overlap percentage between Balearic Shearwaters and purse seines (27.7%) than that reported in Wise et al. (2019) for similar periods and area. These differences are possibly related with the different data sources for seabird and fishery distributions and overlap methodology (airplane using line transects versus boat surveys using ESAS, fisheries distribution based on AIS versus data from VMS and logbooks, and 50th percentile overlap from the species modeled distribution versus the Morisita Index). Along with Trawlers (with an overlap of 15.4%), Fixed Gears and Purse Seines have the largest overlap with the Balearic Shearwater distribution inside or around the SPAs Ria de Aveiro, Aveiro-Nazaré, Cabo Raso and Berlengas. These areas are known Balearic Shearwater occurrence hotspots (Ramírez et al., 2008; ICNF, 2014; Meirinho et al., 2014; Araújo et al., 2017). Also, pelagic fish is abundant in these areas (Zwolinski et al., 2010) leading to potential resource competition with fisheries or to potential interaction due to feeding activity on fisheries discards (Meier et al., 2017). Purse Seine reveal the highest Balearic Shearwater bycatch risk (high and moderate risk combined), followed by Fixed Gear and Trawls. In the future, when planning for management measures dedicated to Balearic Shearwater bycatch mitigation, priority should be given to high and moderate risk areas. To address the concerning seabird bycatch scenario (Dias et al., 2019) several mitigation measures were already tested, including Tori lines and night setting in longline fisheries (Jiménez et al., 2020). In Portuguese Continental Waters a recent study in local fisheries tested a bird-scaring device in Purse seiners (Oliveira et al., 2020).

As for Northern Gannets, the highest observed bycatch and mortality rates were recorded for Fixed Gears (including gill and trammel nets) and Longlines. Data reported in the Fixed Gear fleet show that this fishery on average removes a significant number of individuals (58 observed individuals extrapolated to 1383 individuals, CI = 457–2571 and CV = 0.41). Considering Fixed Gear data (gill and trammel nets), our results for the whole area (PCW) indicate a gannet bycatch mortality rate of 0.006, which increases to 0.012 when discarding logbook data. This value is well in line with that reported to the Berlenga archipelago in Portugal, which monitored bottom gillnets only (Oliveira et al., 2020). Fixed Gear, or particular types of gears used by the Polyvalent fishery (e.g. gillnets) were previously identified as a threat to the species in the Northeast Atlantic (Žydelis et al., 2013). As for Longliners, even though this fleet had the lowest percentage of monitored fishing events, this fleet presented a high bycatch rate. Whereas the gannet mortality rate in longlines (Longliners with LOA >12 m) in the present study was 0.321, Oliveira et al. (2020) and Calado et al. (2021) obtained relatively higher mortality rates (both 0.59) in the Berlenga archipelago in demersal longlines operated by polyvalent boats. Despite the fishery related differences (Longliner vessels versus longlines in Polyvalent boats) these results emphasise that some areas concentrate higher bycatch mortality than others across the PCW. Our results on Gannet

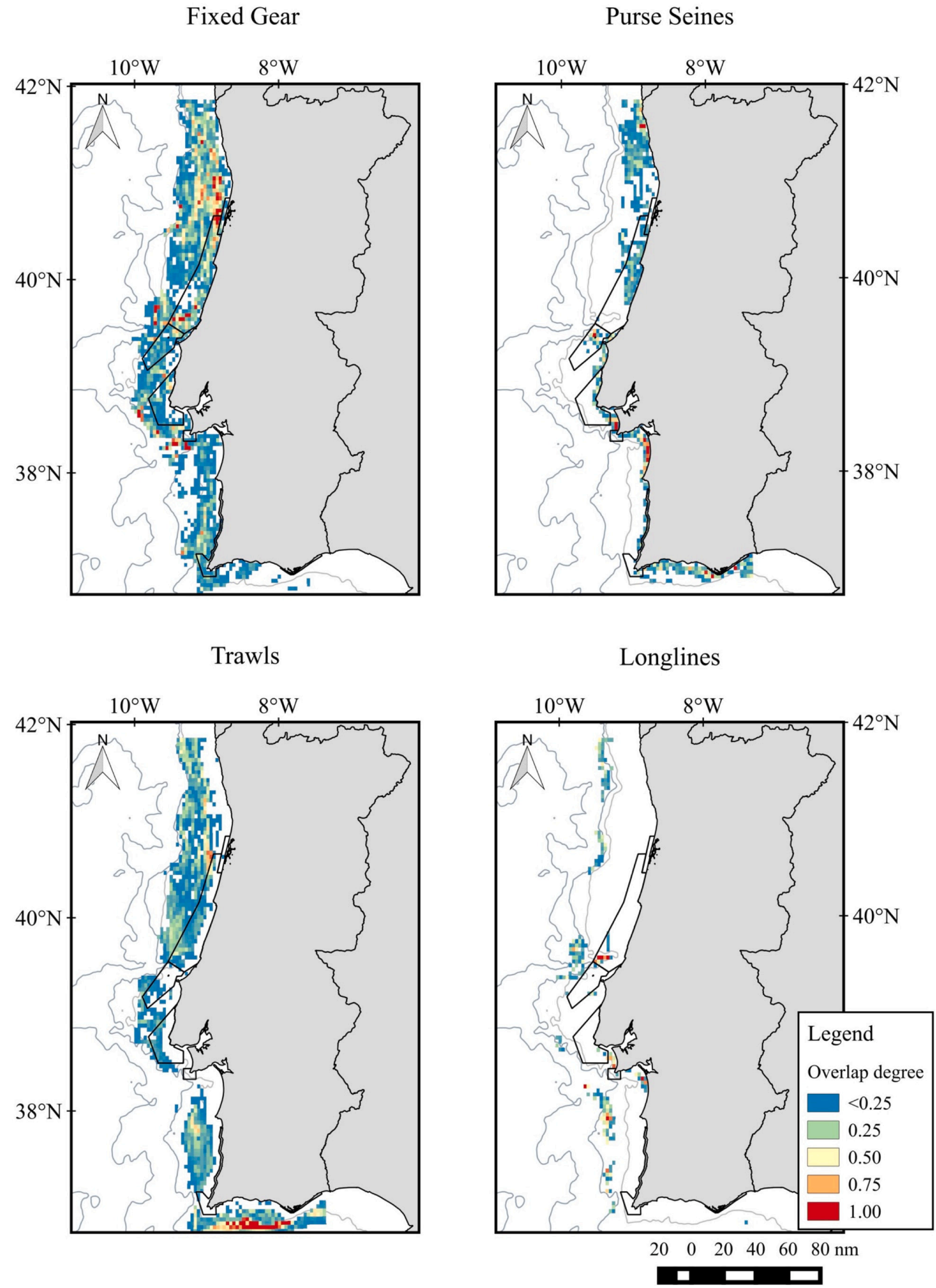

Fig. 7. Overlap between Northern Gannet predictive distribution models different fishing gear types for the period 2012–2015. Bathymetric profile of the area showing the 200 m (light grey line), 1000 m (grey line) and 3000 m isobaths (dark grey line).

mortality across the PCW revealed that 2288 (CI = 779–4629) individuals were annually bycaught in demersal longlines, which is in agreement with results (3000 individuals) for the neighboring area of Galicia (northwestern Spain) obtained from questionnaires (Arcos et al., 1996). This value amounts to nearly the total threshold PBR for the species in the study area (2345 individuals per year considering the overall period). Longlines had already been reported as the main responsible gear for plunge diving species bycatch, including the Northern Gannet (Oliveira et al., 2015; Cortés et al., 2017; Calado et al., 2021). Even though the Northern Gannet is currently a Least Concern species and the population trend seems to be increasing (BirdLife International, 2018b), bycatch is responsible for the decline of the population in some well-studied areas, such as the Rouzic colony in Brittany, France (Grémillet et al., 2020). Furthermore, the increase in breeding populations after the closure of Canadian gillnet fisheries supports the idea that bycatch may cause Northern Gannet population declines (Regular et al., 2013). Moreover, the Northern Gannet feeding ecology, which entails competition with fishing fleets for resources and feeding on fishing discards, makes this species extremely vulnerable to bycatch (ICES, 2013).

The overlap between the analysed commercial fisheries and Northern Gannet distribution revealed fishery-specific high risk areas. The percentage of overlap between Northern Gannet distribution and Purse Seiners was in line with that presented in Wise et al. (2019). Part of this overlap was detected inside the Berlengas SPA where Purse Seine interactions were found to involve adults in the migration period and immature individuals that remain in the area throughout the year (Calado et al., 2021). The overlap with Trawlers occurred mostly in the south coast between the 200 m and 1000 m bathymetry, where the trawling intense effort coincides with Northern Gannet migratory movements to the Mediterranean and to the western African coast (Fort et al., 2012). Fixed Gear fisheries overlapped with the Northern Gannet predicted distribution throughout the study area except for the south coast. This fishery can use several types of gear, usually not at the same time. A precautionary approach must be used since not all fixed gears have the same bycatch rate and AIS data does not detail effort by type of gear. Hence, future studies should be conducted to understand the overlap of the species distribution with the effort for each gear type used by this fleet. The Longline and Northern Gannet overlap was more pronounced around the 1000 m bathymetry, an area of high fishing activity. Overall, Longlines and Fixed Gear fisheries presented the highest Northern Gannet bycatch risk (areas of High and Moderate risk combined).

4.1. Conclusions

Balearic Shearwater and Northern Gannet fisheries removal rates are unsustainable in Portuguese Continental Waters. Fixed gear and Purse seines present the highest contributions to Balearic Shearwater removal rates whereas Longlines and Fixed gear present the highest contributions to Northern Gannet removal rates.

This study reveals the main areas of high bycatch risk in Portuguese continental Waters, thus providing essential information for Maritime Spatial Planning and sustainable management of fisheries. Bycatch mitigation measures should be applied in fisheries presenting the higher bycatch risks. In fact, area and fishery-specific mitigation measures are needed to decrease Balearic Shearwater and Northern Gannet bycatch in PCW, particularly within some SPAs aiming at the conservation of these species.

The Balearic Shearwater bycatch mortality may play a determinant role in the estimated population decline described by Genovart et al. (2016). Fisheries observer schemes, inside SPAs and focused on specific fishery types and periods (e.g. post-breeding period for Balearic Shearwaters and inter-breeding period for Northern Gannets) are recommended. This study used distribution data for vessels with AIS, which is mandatory in boats with LOA > 15 m (Directive 2011/15/EU). However, the PCW are also largely used by smaller boats mostly using Fixed Gear (INE, 2016) and some of them involved in IUU fisheries (Vingada and Eira, 2018). These smaller boats probably constitute a serious additional bycatch Risk for Balearic Shearwaters and Northern Gannets in the study area and further bycatch monitoring programmes would be welcome for these boats. Due to their small size, new methods or monitoring schemes must be envisaged.

CRediT authorship contribution statement

Hélder Araújo: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing - original draft; Writing - review & editing.

Pedro Correia Rodrigues: Formal analysis.

Philippe Debru: Formal analysis.

Marisa Ferreira: Methodology; Data curation; Writing - review & editing.

José Vingada: Conceptualization; Investigation; Methodology; Writing - review & editing; Funding acquisition; Supervision.

Catarina Eira: Conceptualization; Investigation; Methodology; Writing - review & editing; Funding acquisition; Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abelló, P., Esteban, A., 2012. Trawling bycatch does affect balearic shearwaters Puffinus mauretanicus. Rev. Catalana d'Ornitologia 28, 34–39.

American Bird Conservancy, 2011. Methodology to Assess Fisheries for Risk to Seabirds, 15 December 2011. American Bird Conservancy, The Plains, Virginia, USA. Unpublished report.

Anderson, O.R.J., Small, C.J., Croxall, J.P., Dunn, E.K., Sullivan, B.J., Yates, O., Black, A., 2011. Global seabird bycatch in longline fisheries. Endanger. Species Res. 14 (2), 91–106.

Araújo, H., Bastos-Santos, J., Rodrigues, P.C., Ferreira, M., Pereira, A., Henriques, A.C., Monteiro, S.S., Eira, C., Vingada, J., 2017. The importance of Portuguese continental shelf waters to balearic shearwaters revealed by aerial census. Mar. Biol. 164, 55.

Arcos, F., Velando, A., Moriño, J., 1996. Seabird mortality in fishing gear in Galicia (NW Spain). Available at. In: Poster - Seabird Group Conference. Glasgow, UK [Accessed 4 January 2022].

Arcos, J.M., Louzao, M., Oro, D., 2008. Fishery ecosystem impacts and management in the Mediterranean: seabirds point of view. In: Nielsen, J., Dodson, J., Friedland, K., Hamon, T., Hughes, N., Musick, J., Verspoor, E. (Eds.), Proceedings of the Fourth World Fisheries Congress: Reconciling Fisheries with Conservation, 49. American Fisheries Society, Symposium, Bethesda, MD, USA, pp. 587–596.

Arroyo, G.M., Mateos-Rodríguez, M., Muñoz, A.R., De La Cruz, A., Cuenca, D., Onrubia, A., 2014. New population estimates of a critically endangered species, the balearic shearwater Puffinus mauretanicus, based on coastal migration counts. Bird Conserv. Int. 26, 87–99.

Baker, G.B., Double, M.C., Gales, R., Tuck, G.N., Abbott, C.L., Ryan, P.G., Petersen, S.L., Robertson, C.J.R., Alderman, R., 2007. A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: conservation implications. Biol. Conserv. 137, 319–333.

BirdLife International, 2018. Puffinus mauretanicus. The IUCN Red List of Threatened Species 2018:e.T22728432A132658315. Downloaded on 15/01/2020.
BirdLife International, 2018. Morus bassanus. The IUCN Red List of Threatened Species 2018: e.T22696657A132587285. https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22696657A132587285.en. Downloaded on 22 /02/ 2021.
BirdLife International, 2021. Species factsheet: Puffinus mauretanicus. http://www.birdlife.org. Downloaded on 16/01/2021.
le Bot, T., Lescroël, A., Grémillet, D., 2018. A toolkit to study seabird–fishery interactions. ICES J. Mar. Sci. 75 (5), 1513–1525. https://doi.org/10.1093/icesjms/fsy038.
Boué, A., Louzao, M., Arcos, J.M., Delord, K., Weimerskirch, H., Cortes, V., Barros, N., Guilford, T., Arroyo, G.M., Oro, D., Andrade, J., Garcia, D., Dalloyau, S., Gonzalez-Solis, J., Newton, S., Wynn, R., Micol, T., 2013. First meeting of the Population and Conservation Status Working Group. Recent and current research on Balearic shearwater on colonies and in Atlantic and Mediterranean areas. In: Agreement on the Conservation of Albatrosses and Petrels. La Rochelle, France.
Calado, J.G., Ramos, J.A., Almeida, A., Oliveira, N., Paiva, V.H., 2021. Seabird-fishery interactions and bycatch at multiple gears in the Atlantic iberian coast. Ocean Coast. Manag. 200, 105306.
Canty, A., Ripley, B., 2012. Boot: Bootstrap R (S-plus) Functions. R Package Version 1.3-7 (November 2016).
Clay, T.A., Small, C., Tuck, G.N., Pardo, D., Carneiro, A.P.B., Wood, A.G., Croxall, J.P., Crossin, G.T., Phillips, R.A., 2019. A comprehensive large-scale assessment of fisheries bycatch risk to threatened seabird populations. J. Appl. Ecol. 56 (8), 1882–1893.
Cortés, V., Arcos, J.M., González-Solís, J., 2017. Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates. Mar. Ecol. Prog. Ser. 565, 1–16.
Costa, R., Sá, S., Pereira, A.T., Ângelo, A.R., Vaqueiro, J., Ferreira, M., Eira, C., 2020. Prevalence of entanglements of seabirds in marine debris in the central portuguese coast. Mar. Pollut. Bull. 161, 111746.
Croxall, J., Butchart, S., Lascelles, B., Stattersfield, A., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv. Int. 22, 1–34.
DGRM, 2018. Fishing gears. https://www.dgrm.mm.gov.pt/en/web/guest/artes-de-pesca.
Dias, M.P., Martin, R., Pearmain, E.J., Burfield, I.J., Small, C., Phillips, R.A., Yates, O., Lascelles, B., Borboroglu, P.G., Croxall, J.P., 2019. Threats to seabirds: a global assessment. Biol. Conserv. 237, 525–537.
Dillingham, P.W., Fletcher, D., 2008. Estimating the ability of birds to sustain additional human-caused mortalities using a simple decision rule and allometric relationships. Biol. Conserv. 141, 1783–1792.
Dunn, E., Steel, C., 2001. The impact of longline fishing on seabirds in the north-east Atlantic: recommendations for reducing mortality. Available at. In: NOF Rapportserie Rep No 5. The Royal Society for the Protection of Birds (RSPB), Sandy [Accessed 4 January 2022]. https://www.rspb.org.uk/globalassets/downloads/documents/positions/marine/the-impact-of-longline-fishing-on-seabirds-in-the-north-east-atlantic–recommendations-for-reducing-mortality.pdf.
Fischer, J., Debski, I., Spitz, D., Taylor, G., Wittmer, H., 2020. Year-round offshore distribution, behaviour, and overlap with commercial fisheries of a critically endangered small petrel. Mar. Ecol. Prog. Ser. 660, 171–187.
Ford, R.G., Krumme, D.W., 1979. The analysis of space use patterns. J. Theor. Biol. 76 (2), 125–155. https://doi.org/10.1016/0022-5193(79)90366-7.
Fort, J., Pettex, E., Tremblay, Y., Lorentsen, S.H., Garthe, S., Votier, S., Pons, J.B., Siorat, F., Furness, R.W., Grecian, W.J., Bearhop, S., Montevecchi, W.A., Grémillet, D., 2012. Meta-population evidence of oriented chain migration in Northern gannets (Morus bassanus). Front. Ecol. Environ. 10, 237–242.
Garthe, S., Hüppop, O., 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. J. Appl. Ecol. 41, 724–734.
Genovart, M., Arcos, J.M., Álvarez, D., McMinn, M., Meier, R., Wynn, R.B., Guilford, T., Oro, D., 2016. Demography of the critically endangered Balearic shearwater: the impact of fisheries and time to extinction. J. Appl. Ecol. 53 (4), 1158–1168.
Grémillet, D., Péron, C., Lescroël, A., Fort, J., Patrick, S.C., Besnard, A., Provost, P., 2020. No way home: collapse in northern gannet survival rates point to critical marine ecosystem perturbation. Mar. Biol. 167 (12), 189.
Guilford, T., Wynn, R., McMinn, M., Rodríguez, A., Fayet, A., Maurice, L., Jones, A., Meier, R., 2012. Geolocators reveal migration and pre-breeding behaviour of the critically endangered balearic shearwater Puffinus mauretanicus. PLoS ONE 7 (3), 1–8.
Hall, M.A., 1996. On bycatches. Rev. Fish Biol. Fish. 6 (3), 319–352. https://doi.org/10.1007/BF00122585.
Heswall, A.M., Friesen, M.R., Martin, A.L.B., Gaskett, A.C., 2021. Seabird bycatch risk correlates with body size, and relatively larger skulls, bills, wings and sensory structures. Mar. Biol. 168 (5), 70. https://doi.org/10.1007/s00227-021-03873-4.
ICES, 2013. Report of the Workshop to Review and Advise on Seabird Bycatch (WKBYCS), 14–18 October 2013. ICES CM 2013/ACOM:77.Copenhagen, Denmark.
ICNF, 2014. Proposta técnica de Zonas de Protecção Especial no meio marinho a designar em Portugal continental. http://www.icnf.pt/portal/icnf/participacao-publica/resource/zpe/ZPE_meio_marinho_participacao_publica.pdf. Accessed 05 February 2016.
INE, 2016. Instituto Nacional de Estatística - Estatísticas da Pesca: 2015. Lisboa. https://www.ine.pt/xurl/pub/261842006. ISSN 0377-225-x. ISBN 978-989-25-0354-7.
INE, 2020. Instituto Nacional de Estatística-Estatísticas da Pesca: 2019. Lisboa. https://www.ine.pt/xurl/pub/435690295. ISSN 0377-225-x. ISBN 978-989-25-0354-7.
Jiménez, S., Domingo, A., Winker, H., Parker, D., Gianuca, D., Neves, T., Coelho, R., Kerwath, S., 2020. Towards mitigation of seabird bycatch: Large-scale effectiveness of night setting and Tori lines across multiple pelagic longline fleets. Biol. Conserv. 247, 108642. https://doi.org/10.1016/j.biocon.2020.108642.
Karpouzi, V., Watson, R., Pauly, D., 2007. Modelling and mapping resource overlap between seabirds and fisheries on a global scale: a preliminary assessment. Mar. Ecol. Prog. Ser. 343. https://doi.org/10.3354/meps06860.
Kroodsma, D.A., Mayorga, T.J., Hochberg, N.A.Miller, Boerder, K., Ferretti, F., Worm, B., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C., 2018. Tracking the global footprint of fisheries. Science 359, 904–908. Masters Thesis.
Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydelis, R., McDonald, S., DiMatteo, A., Dunn, D.C., Kot, C.Y., Bjorkland, R., Kelez, S., Soykan, C., Stewart, K.R., Sims, M., Boustany, A., Read, A.J., Halpin, P., Nichols, W. J., Safina, C., 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. 111 (14), 5271 LP – 5276.
Louzao, M., Arcos, J.M., Laneria, K., Beldae, E., Guallartf, J., Sánchez, A., Giménez, M., Maestre, R., Oro, D., 2011. Evidence of the incidental capture of the Balearic Shearwater at sea. In: Proceedings of the 6 CONGRESS of GIAM and the International Workshop on Petrels and Shearwaters Ecology at Southern Europe, 34, pp. 165–168.
Luck, C., Jessopp, M., Tully, O., Cosgrove, R., Rogan, E., Cronin, M., 2020. Estimating protected species bycatch from limited observer coverage: a case study of seal bycatch in static net fisheries. Glob. Ecol. Conserv. 24, e01213. https://doi.org/10.1016/j.gecco.2020.e01213.
Maree, B.A., Wanless, R.M., Fairweather, T.P., Sullivan, B.J., Yates, O., 2014. Significant reductions in mortality of threatened seabirds in a South African trawl fishery. Anim. Conserv. 17, 520–529.
Meier, R.E., Votier, S.C., Wynn, R.B., Guilford, T., McMinn Grivé, M., Rodríguez, A., Newton, J., Maurice, L., Chouvelon, T., Dessier, A., Trueman, C.N., 2017. Tracking, feather moult and stable isotopes reveal foraging behaviour of a critically endangered seabird during the non-breeding season. Divers. Distrib. 23 (2), 130–145.
Meirinho, A.I.G., 2009. Distribução de Alcatraz (Morus bassanus) na costa continental portuguesa e sua relação com variáveis ambientais. Universidade Nova de Lisboa, Lisboa, Porugal. Masters Thesis.
Meirinho, A., Barros, N., Oliveira, N., Catry, P., Lecoq, M., Paiva, V., Geraldes, P., Granadeiro, J.P., Ramírez, I., Andrade, J., 2014. Atlas das Aves Marinhas de Portugal. Sociedade Portuguesa para o Estudo das Aves. Lisboa, Portugal.
Moore, J.E., Žydelis, R., 2008. Quantifying seabird bycatch: where do we go from here? Anim. Conserv. 11, 257–259.
Moore, J., Wallace, B., Lewison, R., Zydelis, R., Cox, T., Crowder, L., 2009. A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. Mar. Policy 33, 435–451.
Northridge, S., Kingston, A., Coram, A., 2020. Preliminary estimates of seabird bycatch by UK vessels in UK and adjacent waters. In: Report Prepared for the Department for Environment Food and Rural Affairs (Project Code ME6024).
Oliveira, N., Henriques, A., Miodonski, J., Pereira, J., Marujo, D., Almeida, A., Barros, N., Andrade, J., Marçalo, A., Santos, J., Oliveira, I.B., Ferreira, M., Araújo, H., Monteiro, S., Vingada, J., Ramírez, I., 2015. Seabird bycatch in Portuguese mainland coastal fisheries: an assessment through on-board observations and fishermen interviews. Glob. Ecol. Conserv. 3, 51–61.
Oliveira, N., Almeida, A.N.A., Alonso, H., Constantino, E., Ferreira, A., Gutiérrez, I., Santos, A.N.A., Silva, E., Andrade, J., 2020. A contribution to reducing bycatch in a high priority area for seabird conservation in Portugal. Bird Conserv. Int. 1–20. https://doi.org/10.1017/S0959270920000489.
Oppel, S., Meirinho, A., Ramírez, I., Gardner, B., O'Connell, A.F., Miller, P.I., Louzao, M., 2012. Comparison of five modelling techniques to predict the spatial distribution and abundance of seabirds. Biol. Conserv. 156, 94–104.
Pereira, J.M., Ramos, J.A., Marques, A.M., Ceia, F.R., Krüger, L., Votier, S.C., Paiva, V.H., 2021. Low spatial overlap between foraging shearwaters during the breeding season and industrial fisheries off the west coast of Portugal. Mar. Ecol. Prog. Ser. 657, 209–221. https://doi.org/10.3354/meps13549.
Pettex, E., Laran, S., Authier, M., Blanck, A., Dorémus, G., Falchetto, H., Lambert, C., Monestiez, P., Stéfan, E., Van Canneyt, O., Ridoux, V., 2017. Using large scale surveys to investigate seasonal variations in seabird distribution and abundance. Part II: the Bay of Biscay and the English Channel. Deep-Sea Res. II Top. Stud. Oceanogr. 141, 86–101 (November 2016).
Phillips, R., Gales, R., Baker, G., Double, M.C., Favero, M., Quintana, F., Tasker, M., Weimerskirch, H., Uhart, M., Wolfaardt, A., 2016. The conservation status and priorities for albatrosses and large petrels. Biol. Conserv. 201 (169–183), 1.
Pierre, J.P., 2019. Observer coverage for monitoring bycatch of seabirds and other ETP species in pelagic longline fisheries. In: ACAP - Ninth Meeting of the Advisory Committee. ACAP SBWG9 Inf 26 Rev 1. Florianópolis, Brazil.
Pott, C., Wiedenfeld, D.A., 2017. Information gaps limit our understanding of seabird bycatch in global fisheries. Biol. Conserv. 210 (Part A), 192–204. https://doi.org/10.1016/j.biocon.2017.04.002.
Ramírez, I., Geraldes, P., Merinho, A., Amorim, P., Paiva, V., 2008. Áreas Marinhas Importantes para as Aves em Portugal. Projecto LIFE04NAT/PT/000213. Sociedade Portuguesa Para o Estudo das Aves, Lisboa, Portugal.
Regular, P., Montevecchi, W., Hedd, A., Robertson, G., Wilhelm, S., 2013. Canadian fishery closures provide a largescale test of the impact of gillnet bycatch on seabird populations. Biol. Lett. 9 (4).
Richard, Y., Abraham, E., Berkenbusch, K., 2017. Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. In: New Zealand Aquatic Environment and Biodiversity Report No. 191, 104 p.
Rodríguez, A., Arcos, J.M., Bretagnolle, V., Dias, M.P., Holmes, N.D., Louzao, M., Provencher, J., Raine, A.F., Ramírez, F., Rodríguez, B., Ronconi, R.A., Taylor, R.S.,

Bonnaud, E., Borrelle, S.B., Cortés, V., Descamps, S., Friesen, V.L., Genovart, M., Hedd, A., Hodum, P., Humphries, G.R.W., Le Corre, M., Lebarbenchon, C., Martin, R., Melvin, E.F., Montevecchi, W.A., Pinet, P., Pollet, I.L., Ramos, R., Russell, J.C., Ryan, P.G., Sanz-Aguilar, A., Spatz, D.R., Travers, M., Votier, S.C., Wanless, R.M., Woehler, E., Chiaradia, A., 2019. Future directions in conservation research on petrels and shearwaters. Front. Mar. Sci. 6, 94. https://doi.org/10.3389/fmars.2019.00094.\.

Rogan, E., Breen, P., Mackey, M., Cañadas, A., Scheidat, M., Geelhoed, S., Jessopp, M., 2018. Aerial Surveys of Cetaceans and Seabirds in Irish Waters: Occurrence, Distribution and Abundance in 2015-2017. Department of Communications, Climate Action & Environment and National Parks and Wildlife Service (NPWS), Department of Culture, Heritage and the Gaeltacht, Dublin, Ireland.

Ruiz, J., Louzao, M., Oyarzabal, I., Arregi, L., Mugerza, E., Uriarte, A., 2021. The Spanish purse-seine fishery targeting small pelagic species in the Bay of Biscay: Landings, discards and interactions with protected species. Fish. Res. 239, 105951. https://doi.org/10.1016/j.fishres.2021.105951.

Russell, R.W., 1999. Comparative demography and life history tactics of seabirds: implications for conservation and marine monitoring. Am. Fish. Soc. 23, 51–76.

Sansom, A., Wilson, L.J., Caldow, R.W.G., Bolton, M., 2018. Comparing marine distribution maps for seabirds during the breeding season derived from different survey and analysis methods. PLoS ONE 13 (8), e0201797. https://doi.org/10.1371/journal.pone.0201797.

Santos, J., Araújo, H., Ferreira, M., Henriques, A., Miodonski, J., Monteiro, S., Oliveira, I., Rodrigues, P., Duro, G., Oliveira, F., Pinto, N., Sequeira, M., Eira, C., Vingada, J., 2013. Chapter I: baseline estimates of abundance and distribution of target species. In: Annex to the Midterm Report of Project LIFE MarPro PT/NAT/00038.

Soanes, L.M., Arnould, J.P.Y., Dodd, S.G., Sumner, M.D., Green, J.A., Frederiksen, M., 2013. How many seabirds do we need to track to define home-range area? J. Appl. Ecol. 50 (3), 671–679.

Suazo, C., Oliveira, N., Debski, I., Mangel, J., Alfaro Shigueto, J., Azocar, J., García-Alberto, G., Velarde, E., 2017. Seabird bycatch in purse seine fisheries: status of knowledge and mitigation measures. In: ACAP - Eighth Meeting of the Seabird Bycatch Working Group. SBWG8-Doc-INF26. Wellington, New Zealand.

Sugishita, J., Torres, L.G., Seddon, P.J., 2015. A new approach to study of seabird-fishery overlap: connecting chick feeding with parental foraging and overlap with fishing vessels. Glob. Ecol. Conserv. 4, 632–644.

Sztukowski, L.A., van Toor, M.L., Weimerskirch, H., Thompson, D.R., Torres, L.G., Sagar, P.M., Cotton, P.A., Votier, S.C., 2017. Tracking reveals limited interactions between Campbell Albatross and fisheries during the breeding season. J. Ornithol. 158 (3), 725–735.

Tuck, G.N., Phillips, R.A., Small, C., Thomson, R.B., Klaer, N.L., Taylor, F., Wanless, R.M., Arrizabalaga, H., 2011. An assessment of seabird–fishery interactions in the Atlantic Ocean. ICES J. Mar. Sci. 68 (8), 1628–1637. https://doi.org/10.1093/icesjms/fsr118.

Vingada, J.V., Eira, C., 2018. Conservação de Cetáceos e Aves Marinhas em Portugal Continental. O projeto LIFE+ MarPro. Relatório final do projecto NAT/PT/00038, 257 pp.

Wade, P.R., 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14, 1–37.

Waugh, S.M., Patrick, S.C., Filippi, D.P., Taylor, G.A., Arnould, J.P.Y., 2016. Overlap between flesh-footed shearwater Puffinus carneipes foraging areas and commercial fisheries in New Zealand waters. Mar. Ecol. Prog. Ser. 551, 249–260.

Wise, L., Galego, C., Katara, I., Marçalo, A., Meirinho, A., Monteiro, S.S., Oliveira, N., Santos, J., Rodrigues, P., Araújo, H., Vingada, J., Silva, A., 2019. Portuguese Purse Seine fishery spatial and resource overlap with top predators. Mar. Ecol. Prog. Ser. 617–618, 183–198.

Zhou, C., Brothers, N., Browder, J., Jiao, Y., 2020. Seabird bycatch loss rate variability in pelagic longline fisheries. Biol. Conserv. 247, 108590. https://doi.org/10.1016/j.biocon.2020.108590.

Zwolinski, J.P., Oliveira, P.B., Quintino, V., Stratoudakis, Y., 2010. Sardine potential habitat and environmental forcing off western Portugal. ICES J. Mar. Sci. 67 (8), 1553–1564. https://doi.org/10.1093/icesjms/fsq068.

Žydelis, R., Small, C., French, G., 2013. The incidental catch of seabirds in gillnet fisheries: a global review. Biol. Conserv. 162, 76–88.