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Research Article

Cite this article: Salvador P, Fracaros S, Sponza S (2025). Interaction between small-scale fisheries and wintering seabirds in a Mediterranean Sea coastal area. *Bird Conservation International*, **35**, e4, 1–12
https://doi.org/10.1017/S0959270925000012

Received: 18 June 2024
Revised: 18 December 2024
Accepted: 05 January 2025

Keywords:
Adriatic Sea; Bycatch; Gaviidae; Gillnets; Longlines; Natura 2000 Network; Phalacrocoracidae; Podicipedidae

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Interaction between small-scale fisheries and wintering seabirds in a Mediterranean Sea coastal area

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Summary

Bycatch, the incidental capture of non-target species in fishing gear, has been recognised as the most significant global conservation threat affecting seabird species. Geographically, bycatch rates vary widely, depending on local fishing efforts, environmental features, and seabird community composition. Regional and local research is essential due to the complexity of accurately extrapolating general conclusions regarding the impacts of bycatch. Existing European bycatch research predominantly focuses on northern regions, leaving a significant knowledge gap regarding bycatch in the Mediterranean Sea. This work presents findings of wintering diving seabirds as bycatch of small-scale fisheries in a coastal area of the northern Adriatic Sea, based on data collected between 2021 and 2023. Seabird distribution varied along the depth profile. The bathymetric range between 3 m and 5 m was the most exploited by fishermen. Bycatch of seabirds was confirmed in the study area, with five species recorded, i.e. Black-necked Grebe *Podiceps nigricollis*, Red-throated Loon *Gavia stellata*, Black-throated Loon *Gavia arctica*, Mediterranean Shag *Gulosus aristotelis desmarestii*, and Great Crested Grebe *Podiceps cristatus*. Our results suggest that bathymetry likely plays a strong influence on bycatch occurrence. Incidental captures were not widespread but appeared concentrated in the shallowest depths <5 m and the range <2.5 m was identified as particularly susceptible due to the low associated fishing effort and the majority of bycatch events recorded. We estimate that between 46 and 108 birds were incidentally captured during the research period. This study identifies key factors shaping the areas of bycatch vulnerability and risk, proposing a spatial–temporal mitigation framework within Natura 2000 sites and highlighting the value of local stakeholders' engagement.

Introduction

Fishing has many implications for marine megafauna, including birds, mammals, turtles, and sharks, with varied effects on populations (Lewison et al. 2004, 2014; Pauly et al. 2005; Tasker et al. 2000; Žydelis et al. 2009), mainly linked to competition for the same resources (Grémillet et al. 2018). The industrialisation of fishing has drastically increased negative effects on prey availability due to the growing fishing effort at the spatial–temporal level (Furness 2003; Tasker et al. 2000). Whilst the sustainable management of fishing activities on a global scale is challenging, it is critical to ensure the conservation of marine biodiversity (Crowder et al. 2008).

Seabirds are the most vulnerable group of birds globally, having undergone a drastic decline over recent decades (Dias et al. 2019; Grémillet et al. 2018; Vulcano et al. 2024); approximately 30% of species are threatened and at risk of extinction (BirdLife International 2022). Bycatch, the incidental capture of non-target species in fishing gear, is the primary threat to seabird populations. It is recognised as the main cause of decline among populations worldwide (Anderson et al. 2011; Croxall et al. 2012; Dias et al. 2019; Paleczny et al. 2015; Pott and Wiedenfeld 2017; Votier et al. 2023). Several factors contribute to the extent of this threat, including the specifics of the local fishing effort, the composition of the seabird community, and varying foraging and diving strategies between species (Martin and Crawford 2015; Northridge et al. 2017; Richards et al. 2022; Sacchi 2021). The bycatch rate can vary significantly at different scales, even with the same seabird species and fishing gear (see Genovart et al. 2017). Some species are more vulnerable, and it is difficult to generalise the effects of bycatch on different seabird populations (Genovart et al. 2017). Accurate assessment of how bycatch occurs and the effective development of bycatch mitigation measures require standardised data and scientific evaluations of the extent of bycatch at a local scale. Moreover, many species affected by bycatch are migratory, indicating that its impact can be substantial not only for local populations but also across broader spatial scales (Courbin et al. 2024). Identifying where bycatch occurs and the spatial–temporal distribution of seabird species are essential to evaluate seabird–fishery interactions (Grémillet et al. 2018; Le Bot et al. 2018).

On a European scale, bycatch has been largely investigated in the Baltic Sea (Bellebaum et al. 2013; Glemarec et al. 2020; Marchowski et al. 2022; Morkūnas et al. 2022) and in the North Sea (Christensen-Dalsgaard et al. 2019; Cleasby et al. 2022), where it is estimated that between 100,000 and 200,000 seabirds die annually in gillnet fisheries (Žydelis et al. 2009). In the Mediterranean Sea, the estimated annual bycatch is around 8,000 seabirds annually (Ramírez et al. 2024). Studies highlight that bycatch drives seabird populations' decline and adult survival across several Mediterranean areas (Carpentieri et al. 2021) and close to Atlantic areas (Nascimento et al. 2023). In the western Mediterranean, bycatch rate by longlines reported for Scopoli's Shearwater *Calonectris diomedea* (Courbin et al. 2024; Genovart et al. 2018), Yelkouan Shearwater *Puffinus yelkouan*, and Balearic Shearwater *Puffinus mauretanicus* indicates a considerable threat to the survival of these species (Cortés and González-Solís 2018; Cortés et al. 2017). According to Genovart et al. (2017), bycatch in gillnets is responsible for 9% of the juvenile mortality of the Mediterranean Shag *Gulosus aristotelis desmarestii* population in the northern Adriatic Sea. Nevertheless, there is still a widespread lack of qualitative and quantitative data on seabird bycatch in the central and eastern Mediterranean (Ramírez et al. 2024), although there has been an increasing awareness within the fishing industry and authorities of this issue over recent years (Anderson et al. 2011; Carpentieri et al. 2021).

According to the European Parliament (2014), small-scale fisheries are defined as fishing vessels of an overall length of <12 m, excluding those using towed fishing gear. Small-scale fishing is an extremely heterogeneous sector in which a wide range of gear, including gillnets and longlines, can target fish species' availability and ecology (Lloret et al. 2018). It is considered one of the most sustainable fishing activities with a lower impact on marine ecosystems than industrial fishing (Jacquet and Pauly 2008; Lloret et al. 2020). At the same time, small-scale fisheries play a central role in the culture, traditions, and socio-economic health and provide employment opportunities to local European coastal communities (Guyader et al. 2013; Lloret et al. 2018, 2020). On a Mediterranean scale, small-scale fisheries are the dominant fishing sector in all Mediterranean sub-regions, representing approximately 82% of the total fleet, with the highest proportions observed in the west and east (FAO 2023). The small-scale fishery of the northern Adriatic Sea is very complex and diverse (Calò et al. 2023; European Commission 2021; Grati et al. 2018, 2022) and in the Friuli Venezia Giulia region (north-east Italy) it is widespread throughout the coastal area; this fishery is the most significant component of the regional fleet (69.4%), including 343 vessels in 2021, in which gillnets are commonly employed (ERSA 2022).

Current estimates of bycatch levels may be subject to underreporting by national authorities, showing potential inaccuracies and significant inconsistencies in the data (Merkel et al. 2022; Morkūnas et al. 2022), likely because small-scale fisheries are often overlooked and still poorly investigated, leading to a lack of essential information and basic data (Jacquet and Pauly 2008; Žydelis et al. 2009). The unique dynamics and features of actual activities in small-scale fisheries mean it is difficult to monitor and obtain information from these fleets (Žydelis et al. 2009). Moreover, they often lack remote navigation control and effective onboard monitoring systems as these are small vessels (Carpentieri et al. 2021). Although these knowledge gaps hamper understanding of the extent of overall seabird bycatch (O'Keefe et al. 2021), recent works demonstrate how this fishing sector poses a serious threat to certain seabird taxa (Cleasby et al. 2022; Morkūnas et al. 2022; Northridge et al. 2017; Rouxel et al. 2023; Žydelis et al. 2013).

The insufficient coverage of protected areas and the consequent infringement procedure regarding marine habitats is the stated priority for Italy's completion of the Natura 2000 Network (Baccetti et al. 2018; European Commission 2024). In Italy, 7.79% of coastal and marine areas are under protection (Claudet et al. 2020). In compliance with the Marine Strategy Framework Directive 2008/56/EC and the national indications for the expansion of the Natura 2000 Network at sea, several sites along the Italian coastline have been identified as potential new Special Protection Areas (SPAs) for breeding and wintering seabird populations (Baccetti et al. 2018). The coastal marine area of the Friuli Venezia Giulia region (northern Adriatic Sea) supports a relative abundance of wintering seabirds, making it a priority site of international importance for bird conservation (Baccetti et al. 2018; Zenatello et al. 2014). In response to the infringement procedure (European Commission 2024), the coastal area between the mouth of the Isonzo River and Grado city has been designed as SPA Banco del Becco, under the "Birds" 2009/147/EC Directive, due to the presence and consistency of wintering populations of five species: Black-necked Grebe *Podiceps nigricollis*, Red-breasted Merganser *Mergus serrator*, Velvet Scoter *Melanitta fusca*, Common Scoter *Melanitta nigra*, and Black-throated Loon *Gavia arctica* (Baccetti et al. 2018). At the time of writing, no existing research pertaining to bycatch in this area can be found. The fishing effort, distribution of fishing activities, and incidental bycatch rate were unknown. The only information available is from anecdotal reports of incidents and findings of beached birds within the local harbour whereby mortality was attributed to fisheries interaction (Biodiversity Office Friuli Venezia Giulia Region 2023).

Knowledge gaps and a lack of standardised data indicated the need for a bycatch investigation and scientific and technical assessment in this coastal area of the Mediterranean Sea (European Commission 2024). Establishing this new protected area with significant natural and ornithological value prompted the initiation of the study. Nevertheless, the regional management of small-scale fisheries and conservation of local seabirds require an accurate evaluation of the issue. This study investigated the extent of bycatch by small-scale gillnets and longline fisheries on wintering diving seabird species in a Mediterranean Sea coastal zone. The main aims were to analyse the seabirds' bycatch rate in small-scale fisheries during ordinary fishing operations and characterise the primary elements defining high-risk areas to establish a framework for further mitigation actions to reduce bycatch.

Methods

Study area

The study area is located in the northernmost part of the Mediterranean Sea, within the geographical sub-area GSA17 (FAO 2022) in the northern Adriatic, between Grado and Monfalcone cities (45° 40'48.9"N 13°22'04.1"E and 45°47'04.7"N 13°32'36.1"E) (Figure 1). It is specified within the administrative borders of coastal-marine waters. It includes marine extensions of two Natura 2000 sites, SPA "Foce dell'Isonzo – Isola della Cona" and SPA "Val Cavanata e Banco Mula di Muggia", the recently set up SPA "Banco del Becco" and the bordering zone, for a maximum of 5 km offshore from the coastline. The study area covered about 9,355 ha. It is regarded as one of the most significant areas for wintering and migratory seabirds internationally (Zenatello et al. 2014). The seabed, which extends up to -13.5 m, is mainly shallow due to the presence of two sedimentary bodies, i.e. the Mula di Muggia sandbank and the

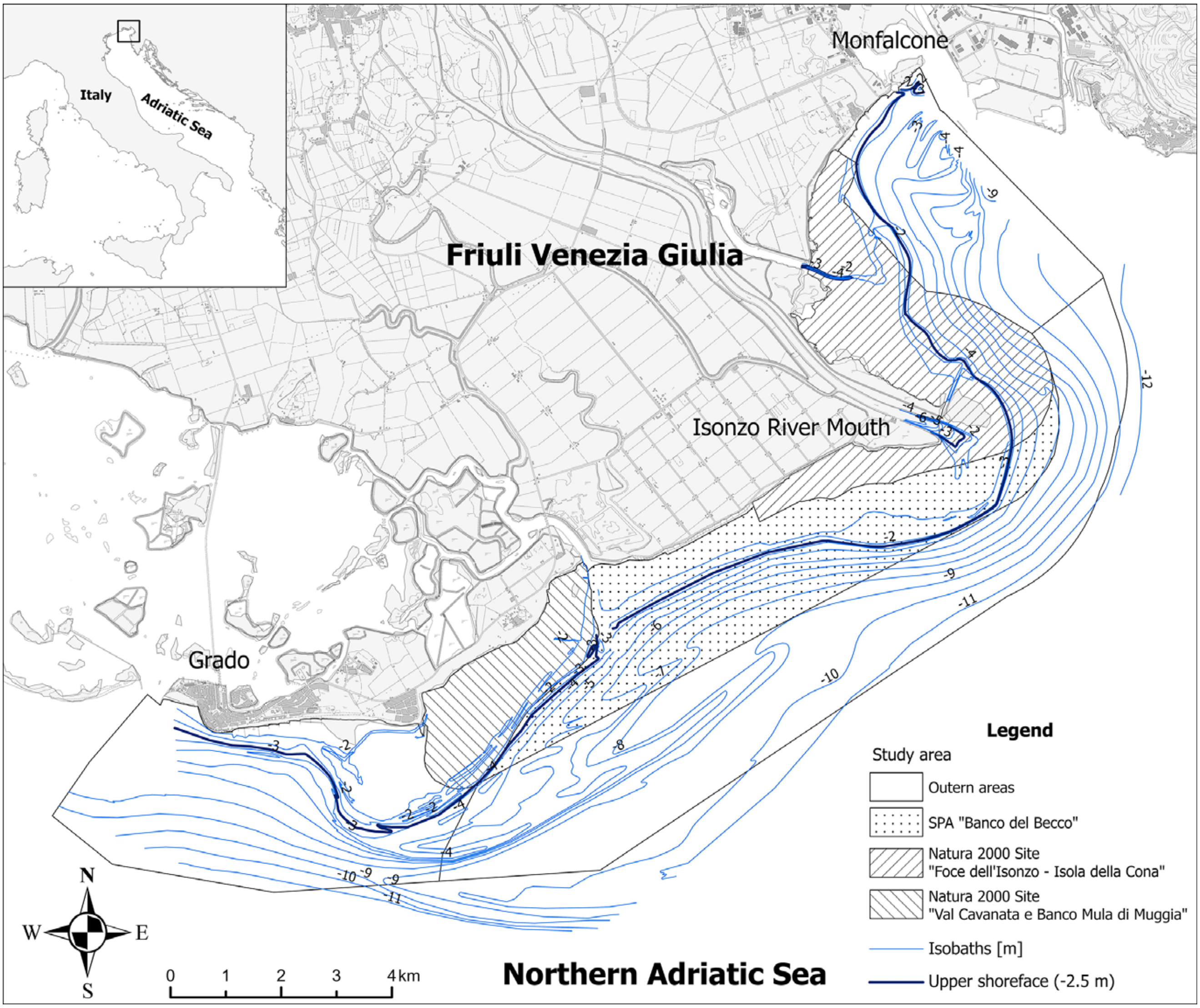

Figure 1. Location of the study area in the northern Adriatic Sea.

Isonzo River delta. These areas extend up to 2 km seawards and are bordered by a set of sandy bars within a 2–3 m depth, representing the upper shoreface's limit (Bezzi et al. 2021). The marine stretch between Grado and the Isonzo River mouth has historically served as one of the primary locations utilised by the local Grado Fishermen Cooperative, the central hub for fishermen from Grado. The fleet operating in the area comprises 19 boats, ranging in length from 6 m to 12 m. In this coastal area gillnet fishing is prevalent, whereas longline activities, mainly targeting the European seabass *Dicentrarchus labrax*, are carried out by a restricted number of vessels under specific winter weather conditions, generally consisting of slightly rough sea and moderate winds.

Wintering seabird community

Eleven wintering diving seabirds with regular occurrence in the study area (Zenatello et al. 2014), and potentially exposed to the threat of bycatch were studied: Sandwich Tern *Thalasseus sandvicensis*, Mediterranean Shag, Common Scoter, Velvet Scoter, Red-breasted Merganser, Black-throated Loon, Red-throated Loon *Gavia stellata*, Red-necked Grebe *Podiceps grisegena*, Horned Grebe *Podiceps auritus*, Great Crested Grebe *Podiceps cristatus*, and Black-necked Grebe. Data collection covered the two winters of 2021–2022 and 2022–2023. The analysis focused on the period between 10 November and 10 March, a highly representative interval for the wintering of the target species. We employed visual census techniques during ship-based surveys at sea to quantify the distribution and abundance of wintering seabirds. Observations were conducted using 10 × 42 binoculars and a high-resolution camera with a zoom capability of up to 1,000× to facilitate species identification for distant birds. Monitoring activities were systematically conducted along 500-m apart standard transects, with accurate attention given to minimising instances of double counting, thereby ensuring the accuracy and reliability of the data collection process. The area was separated into two sectors for logistical and sample purposes (Grado-Isonzo River mouth and Isonzo River mouth-Monfalcone), possibly monitored on consecutive days. In 2021–2022, we conducted 18 ship-based surveys totalling 96 monitoring hours and 16 ship-based surveys totalling 71 monitoring hours in 2022–2023. This allowed us to analyse nine complete sessions in 2021–2022 and eight in 2022–2023 across the whole study area with an approximate interval of 15 days. Each

https://doi.org/10.1017/S0959270925000012 Published online by Cambridge University Press

individual or flock observed on the water surface was marked as a punctual data position, estimating the distance from the observer with a global positioning system (GPS) device. Distance assessment was calibrated using known seamarks, landmarks, and boat routes registered by the GPS device.

Fishing effort data

Fishing effort data were collected in collaboration with the Grado Fishermen Cooperative along the marine stretch between Grado and the Isonzo River mouth. Data were gathered between 10 November and 10 March during both winters 2021–2022 and 2022–2023. The data set encompassed fishing activity duration (set and hauling hours), type of gear deployed (gillnet or longline), gear design (total length, mesh, total number of hooks), gear profile locations, and eventual resulting bycatch events. A form was developed, provided to fishermen, and subsequently compiled by them. The form comprised a map of the study area, an overlaid grid of 500 m × 500 m and a set of spatial references useful for fishermen to identify the fishing area. Each fishing gear was spatially digitalised by as many geographical points as the number of cells occupied by the drawn gear profile. We based the points positioning inside the cells on the geographical coordinates provided or the profiles drawn by fishermen in the corresponding form. The kernel method was used for the spatial analysis of the Utilisation Distribution (UD) calculation, which is the distribution probability of a determined entity/object from geographical position data (Worton 1989). Each fishing activity was assigned a bathymetric value corresponding to the mean depth of the respective fishing points. We obtained *Exposition (E)* by multiplying the *Gear length* by the *Submersion time.* Then, we obtained the *overall Fishing Effort (oFE)* by summing the expositions of each gear. Similarly, we calculated the *diurnal Fishing Effort (dFE)*, extrapolating the *diurnal Exposition (dE)* component, considering nautical dawn and dusk hours recorded at Grado (https://albatramonto.com/).

$$Exposition\ (E) = Gear\ length\ (km) \times Submersion\ time\ (day)$$

$$overall\ Fishing\ Effort\ (oFE)\ = \sum Exposition\ (E)$$

Sampled fishing effort and bycatch rate

No previous knowledge about fishing effort in the study area was known to date. Bycatch analysis, which results from directly sampling fishing activities, is considered the most reliable and unbiased method (FAO 2019; ICES 2024). For accurate and reliable bycatch estimates, the optimum sampling coverage should range between 2% and 7% of the total fishing operations completed (FAO 2019; ICES 2024). We closely tracked with our boat the vessels of fishermen available to participate in the investigation throughout their ordinary fishing activities. Thus, it was unfeasible to formulate a monitoring plan in advance; nevertheless, we scheduled a minimum of one survey per week. During 2021–2022, we conducted 18 ship-based surveys at intervals of approximately seven days, and 22 ship-based surveys at intervals of approximately six days in 2022–2023. Eight boats were involved. We recorded the geographical coordinates of each bycatch event. We calculated the *Bycatch Rate (BR)* (birds/1,000 m/day) by dividing the *total number of Bycaught Birds* (BB) by *sampled Fishing Effort (sFE)*, obtained by summing the *sampled Exposition (sE)* of each gear. We estimated potential incidental catches in the area by multiplying *BR* and *oFE* in relation to the water depth, an environmental factor likely linked to the bycatch rate (Northridge et al. 2017). In addition, we obtained the bycatch prevision only for the diurnal timeframe. Finally, we calculated the *derived Fishing Effort* (*deFE*) by projecting the characteristics of the sampled data set, specifically the submersion time, across the entire length of the gear used by the fleet. The *deFE* represents a different scenario of bycatch rate, eliminating the need for daily reports of gear submersion time by fishermen.

$$BR = \frac{total\ number\ of\ Bycaught\ Birds(BB)}{sampled\ Fishing\ Effort(sFE)}$$

$$deFE = \frac{sFE}{overall\ sampled\ lenght\ of\ gears}\ x\ overall\ lenght\ of\ gears$$

Vulnerability and risk area

We developed maps of vulnerability and risk. Identification and characterisation of critical bycatch areas were based on the integration of values of three layers: (1) distribution of bycaught species (kernel method; Worton 1989), obtained by the combination of reclassified concentration maps of each species, to align distribution species regardless of their population size (*Kspecies*); (2) distribution of total fishing activities (kernel method; Worton 1989) (*Kfisheries*); (3) *Bycatch Rate* calculated as a function of bathymetry.

The vulnerability map illustrates zones with a potential threat in the whole study area, as determined by the combined effect of bathymetry and bird distribution. The risk map depicts the actual risk spots linking the vulnerability factor to the actual threat posed by fishing activities. We integrated layers via the Raster Calculator tool with the following expressions:

$$Vulnerability = (Bycatch\ Rate\ \mathrm{x}\ 100) + Kspecies$$

$$Risk = Vulnerability\ \mathrm{x}\ Kfisheries$$

In the vulnerability assessment, a multiplicative factor of 100 was used to align the orders of magnitude of *BR* and *Kspecies*, balancing their numerical value weights.

Data analysis

The statistical analysis was performed in STATISTICA software. Cartographic analysis was carried out through ArcGis 10.8 and QGis 3.22.6. We applied the contingency tables tested by the chi-square test to compare the observation frequencies of species according to bathymetric ranges of 1 m intervals. Furthermore, we used a Generalised Linear Model (GLM) to test if the bathymetric profiles differ between species. Spearman's rank correlation was used to test the spatial correlation between bird and fishing point distribution with cell analysis. The significance threshold was set at $P < 0.05$.

Results

We collected 1,754 records of seabirds' presence. The highest abundance of birds was registered in December. In the 2021–2022 season, a maximum of 1,425 individuals was recorded in December and a minimum of 411 in March. In the 2022–2023 season, a maximum of 1,493 individuals was registered in December and a minimum of 361 individuals in March. Great Crested Grebe was the most

Table 1. Monthly maximum abundance of the 11 wintering diving seabirds considered in the study area

Species	Study period									
	2021–2022					2022–2023				
	Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar
Sandwich Tern	141	148	1	0	1	151	77	44	14	1
Mediterranean Shag	456	66	19	11	9	102	47	8	19	4
Common Scoter	2	4	8	5	3	0	0	0	1	0
Velvet Scoter	0	27	27	54	53	0	9	13	35	43
Red-breasted Merganser	91	140	162	155	94	81	126	143	278	212
Black-throated Loon	87	95	79	26	11	91	284	34	16	7
Red-throated Loon	7	12	6	1	0	0	6	8	1	1
Red-necked Grebe	5	6	2	18	10	2	4	5	2	0
Horned Grebe	1	5	8	0	0	3	4	3	1	0
Great Crested Grebe	252	799	626	521	127	138	806	678	86	67
Black-necked Grebe	97	123	156	259	103	62	130	106	134	26
TOTAL	1,139	1,425	1,094	1,050	411	630	1,493	1,042	587	361

abundant species, with 806 individuals registered during one single survey (Table 1). Seabird distribution varied significantly with bathymetric range between species (GLM, $R^2 = 0.184$, $F_{1,1732} = 29.570$, $P < 0.0001$). The frequency of species observations within bathymetric classes exhibited significant differences throughout the survey period ($X^2 = 68.29$, df = 110, P <0.0001). Main contributions to the total chi-square were made by four species, i.e. Red-breasted Merganser, Red-necked Grebe, Black-throated Loon, and Horned Grebe, among the 11 species monitored. The Red-breasted Merganser's distinctive coastal habitat association provided the major contribution (species contribution/total contribution = 32.0%) followed by Red-necked Grebe, the most exclusively marine species (species contribution/total contribution = 14.2%). Other relevant contributions were the Black-throated Loon's marine distribution (species contribution/total contribution = 10.6%) and the Horned Grebe's coastal occurrence (species contribution/total contribution = 7.1%). Five species were spatially correlated with fishing activities: Mediterranean Shag (Spearman's rank correlation: $N = 161$, $r_s = 0.352$, $P < 0.0001$), Red-breasted Merganser (Spearman's rank correlation: $N = 161$, $r_s = 0.234$, $P < 0.001$), Black-throated Loon (Spearman's rank correlation: $N = 161$, $r_s = 0.172$, $P < 0.0001$), Great Crested Grebe (Spearman's rank correlation: $N = 161$, $r_s = 0.331$, P <0.0001), and Black-necked Grebe (Spearman's rank correlation: $N = 161$, $r_s = 0.401$, $P < 0.0001$).

We analysed 991 fishing trips, 961 linked to gillnets and 30 to longlines, collecting 3,095 fishing points to digitalise (Figure 2). The total gear length deployed was 1,984 km, consisting of 1,939 km of gillnets and 45 km of longlines. No instances of bycatch were recorded as a result of completion of the forms by fishermen. The bathymetric range between 3 m and 5 m was the most used frequency class for fishing points (Figure 3). We gathered fishing effort data for all the days with recorded fishing activity by the fleet ($n = 203$), accounting for 84.6% of the entire study period; the remaining non-fishing days were ascribed to bad weather conditions. The highest monthly *oFE* was registered in December (Figure 3). The bathymetric range <7.5 m contained 96.0% of the total length of the fishing gear employed and 98.1% of the *oFE.*

We completed 40 monitoring surveys of fishing activities and possible bycatch events along the bathymetric range <7.5 m. A total of 82.64 km of fishing gear was surveyed, including 67.62 km of gillnets and 15.02 km of longlines equipped with around 1,400 hooks. Small-scale fisheries correspond to 4% of the total fishing trips recorded. We recorded nine incidental catches of diving seabirds, eight in gillnets and one in longlines. Five species were recorded: Black-necked Grebe ($n = 4$), Red-throated Loon ($n = 2$), Black-throated Loon ($n = 1$), Mediterranean Shag ($n = 1$), and Great Crested Grebe ($n = 1$). Each bycatch record included a single entangled individual with no multiple-catch events. Seven events were recorded in depth <2.5 m, coinciding with the upper shoreface, and the remaining two cases were between 2.5 m and 5 m. Given that the *oFE* and *sFE* were concentrated below the 7.5 m depth, the limited bycatch events recorded and the specific morphological features of the area, the estimate of incidental catches was calculated for three equal bathymetric ranges (Table 2). The percentage sampling of *sFE* and *BR*, reported as numbers of bycaught birds/1,000 m/day to enable comparison with other studies, are presented in Table 2.

The generated vulnerability map indicates predominantly shallow zones throughout the study area, where a dense and notable concentration of seabirds was evident (Figure 4). The presence of emerged sandbanks and underwater morphologies characterised those zones, representing a further element in defining a high vulnerability area. In conjunction with the actual threat posed by fishing activities, the risk map delineates limited zones, primarily along the upper shoreface isobaths, where fishing effort is relatively more concentrated.

Discussion

Seabird community and bycatch rate

Bathymetry emerges as a highly significant element in the distribution of the wintering diving species studied. Red-breasted Merganser and Horned Grebe displayed a purely coastal distribution, while Red-necked Grebe and Black-throated Loon were connected

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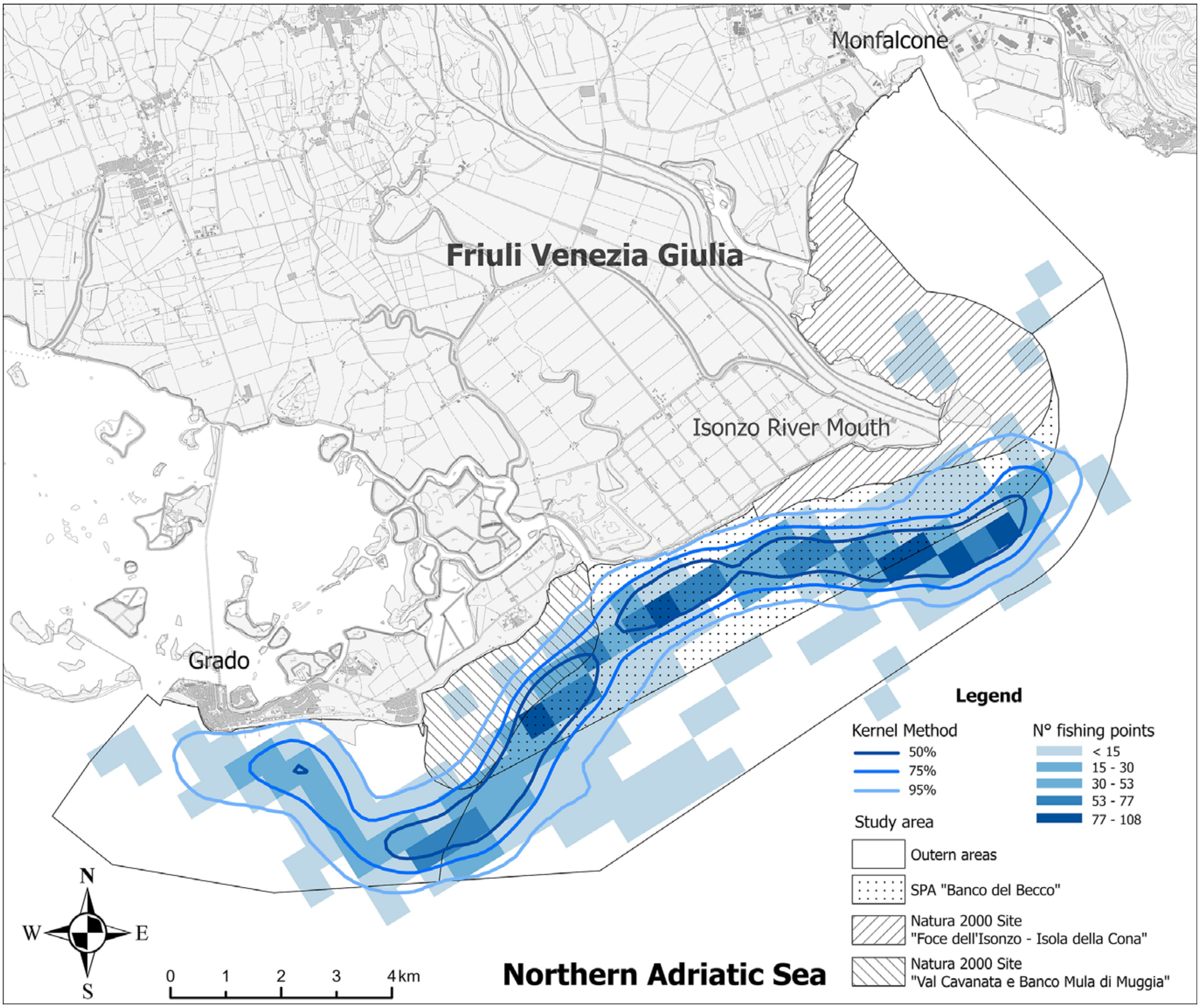

Figure 2. Distribution of the small-scale fisheries fishing effort in the study area.

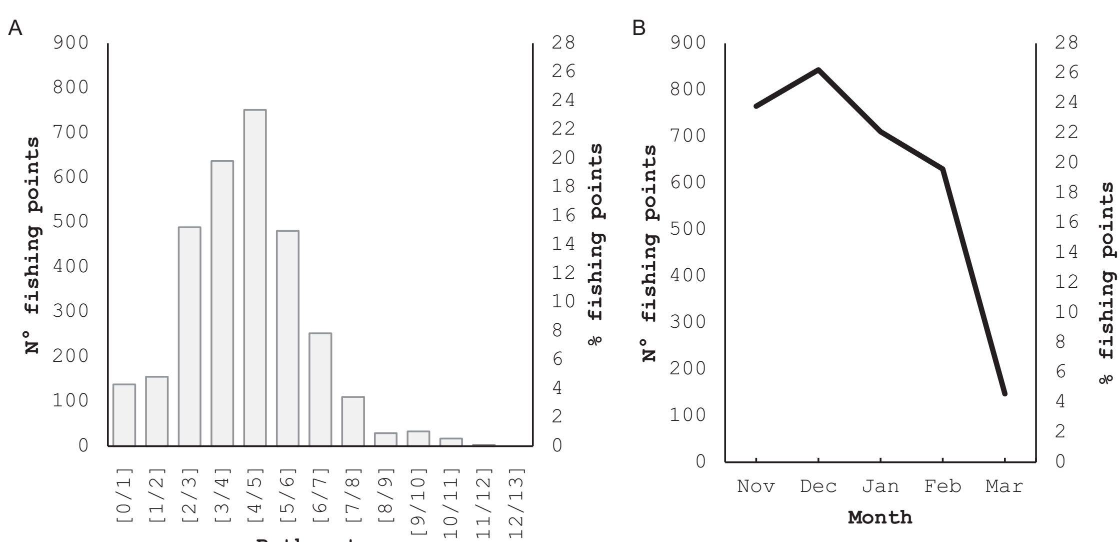

Figure 3. Spatial distribution of fishing points employed to digitally record fishing trips across the bathymetric range (m) within the study area (A) and temporal distribution throughout the study period, categorised by month (B).

Table 2. The estimated incidental catches in relation to various fishing effort metrics for the whole study period. Data are for the three sampled bathymetric ranges with the related bycatch rates reported as bycaught birds/1,000m/day

		Estimated incidental catches				
Bathymetry	Bycatch Rates (*BRs*)	diurnal Fishing Effort (*dFE*)	overall Fishing Effort (*oFE*)	derived Fishing Effort (*deFE*)	% overall Fishing Effort (*oFE*)	% sampled Fishing Effort (*sFE*)
<2.5 m	0.22	28	32	53	12.4%	29.9%
2.5 m–5 m	0.03	18	22	55	61.7%	62.3%
5 m–7.5 m	0	0	0	0	24.0%	7.8%
TOTAL	-	46	54	108	98.1%	100%

to deeper waters. This ecological feature might be connected to resource competition, niche diet portioning or diving efficiency at different depth ranges (Morkūnė et al. 2016). For instance, Red-throated Loon tends to forage on pelagic prey across its wintering distribution range, yet there is evidence of heterogeneity in feeding strategies (Duckworth et al. 2022; Kleinschmidt et al. 2022), while the Great Crested Grebe shows a broad prey spectrum as a result of its benthic to pelagic diving activities (Morkūnė et al. 2016). In the Adriatic Sea, however, the Mediterranean Shag bottom-foraging technique has only been investigated (Cosolo et al. 2011; Sponza et al. 2010). Similarly, the concentration map of fishing effort appears to be substantially influenced by environmental features. The combination of depth, submerged and emerged features, such as sandbars (Bezzi et al. 2021) and tide cycles, shape the areas suitable for fishing and the appropriate gear.

The bycatch issue for five seabird species has been documented within the study area. The absence of bycatch records in the fishermen-forms data highlights the importance of direct visual sampling methods for a more comprehensive assessment of bycatch events (FAO 2019). The effectiveness of this approach is proven by recent studies that revealed significantly higher bycatch rates from onboard observer programmes than from fisheries self-reporting data (Bellenbaum et al. 2013; Fangel et al. 2015; Oliveira et al. 2015). Incidental catches did not occur in a widespread and homogeneous manner but were located within specific bathymetric ranges. The phenomenon, therefore, seems to be strongly influenced by the physical environment (bathymetry) rather than the ecology or foraging behaviour of species. Bycatch risk appears likely related to the morphology of the study area and the shallowest waters. The bathymetric range <2.5 m emerges as the most critical zone in highlighting the phenomenon of bycatch with the highest *Bycatch Rate* [0.22 (birds/1,000 m/day)], even though linked to a low fishing effort (12.4%). Conversely, only two bycaught birds were documented within the range 2.5–5 m, despite the maximum *oFE* value (Table 2). The adequacy of monitoring efforts following official guidelines, the frequency, and the temporal pattern of surveys and regular data collected by fishermen support the reliability of the recorded bycatch rates at the different depth classes (<2.5 m, 2.5–5 m, 5–7.5 m). Gillnets anchored on the seabed can span the entire water column throughout tide cycles. Thus, diving seabirds could fail to detect the gear, leading to entanglement during underwater foraging. Research on underwater visual acuity and resolution on the Great Cormorant *Phalacrocorax carbo* suggests that diving birds have limited capacities at their disposal to detect prey (Strod et al. 2004; White et al. 2007), although it is not a totally limiting factor for hunting efficiency (Grémillet et al. 2012). Consequently, it may be that diving birds cannot see gillnets in most foraging situations, particularly at high water turbidity levels, unless they are very close (Martin and Crawford 2015). Fortunately, forecast catches of 46–108 individuals and reported bycatch rates (Table 2) over the two-year surveys are more contained than in other European contexts (Glemarec et al. 2020; Merkel et al. 2022; Morkūnas et al. 2022; Žydelis et al. 2013), despite the large fishing effort registered. However, we cannot minimise and dismiss this issue as irrelevant because it simultaneously involves local conservation concerns and migratory species, therefore with broader scale consequences. For example, Red-throated Loon shows a high individual site fidelity and low adaptability to abiotic changes (Kleinschmidt et al. 2019). Consequently, anthropogenic stressors, such as marine traffic disturbance (Burger et al. 2019; Jarrett et al. 2021), offshore wind farm development (Heinänen et al. 2020) or bycatch could cause cumulative negative impacts on loons. The wintering population is locally low, with a fluctuation of only 8–12 individuals in the peak period of occurrence between December and January. Recorded incidental catch rates might represent a notable conservation problem for the population and wintering occurrence in this Mediterranean coastal site. Moreover, longlines and gillnets bycatch can be combined with other factors that endanger the already declining Adriatic Mediterranean Shag population (Genovart et al. 2017; Karris et al. 2013; Scridel et al. 2023; Sponza et al. 2013) and the threatened western Mediterranean population (Satta et al. 2023). This study highlights a spatial correlation between four bycaught species and small-scale fisheries activity suggesting that the most vulnerable group of species is piscivorous. The Red-throated Loon was perhaps not spatially correlated with fisheries due to its low numbers and wide range of occurrence. Benthic-feeding species such as Velvet Scoter and Common Scoter seem to be unaffected by the bycatch issue. Their ecological preference for habitats that do not spatially or temporally overlap with fishing activities is probably the driving factor, together with their relatively small population sizes. Despite significant spatial correlation and its numerical consistency, it should be emphasised that the Red-breasted Merganser was not captured incidentally and has never previously been reported in fishery interactions in the area. The wintering population is almost entirely concentrated in the <2 m range. We can likely hypothesise that the diving behaviour or prey preference enables the Red-breasted Merganser to avoid unfavourable interactions with fisheries, despite the restricted coastal range.

SPA "Banco del Becco"

Six bycatch events out of nine (67%) were registered within the new SPA "Banco del Becco". The SPA includes about 23% of the records of monitored species, about 51% of the fisheries points analysed, and 63% of those within the critical bathymetric range <2.5 m. Therefore, delineating fisheries management measures within the SPA boundaries should represent a useful and practical tool for addressing the

https://doi.org/10.1017/S0959270925000012 Published online by Cambridge University Press

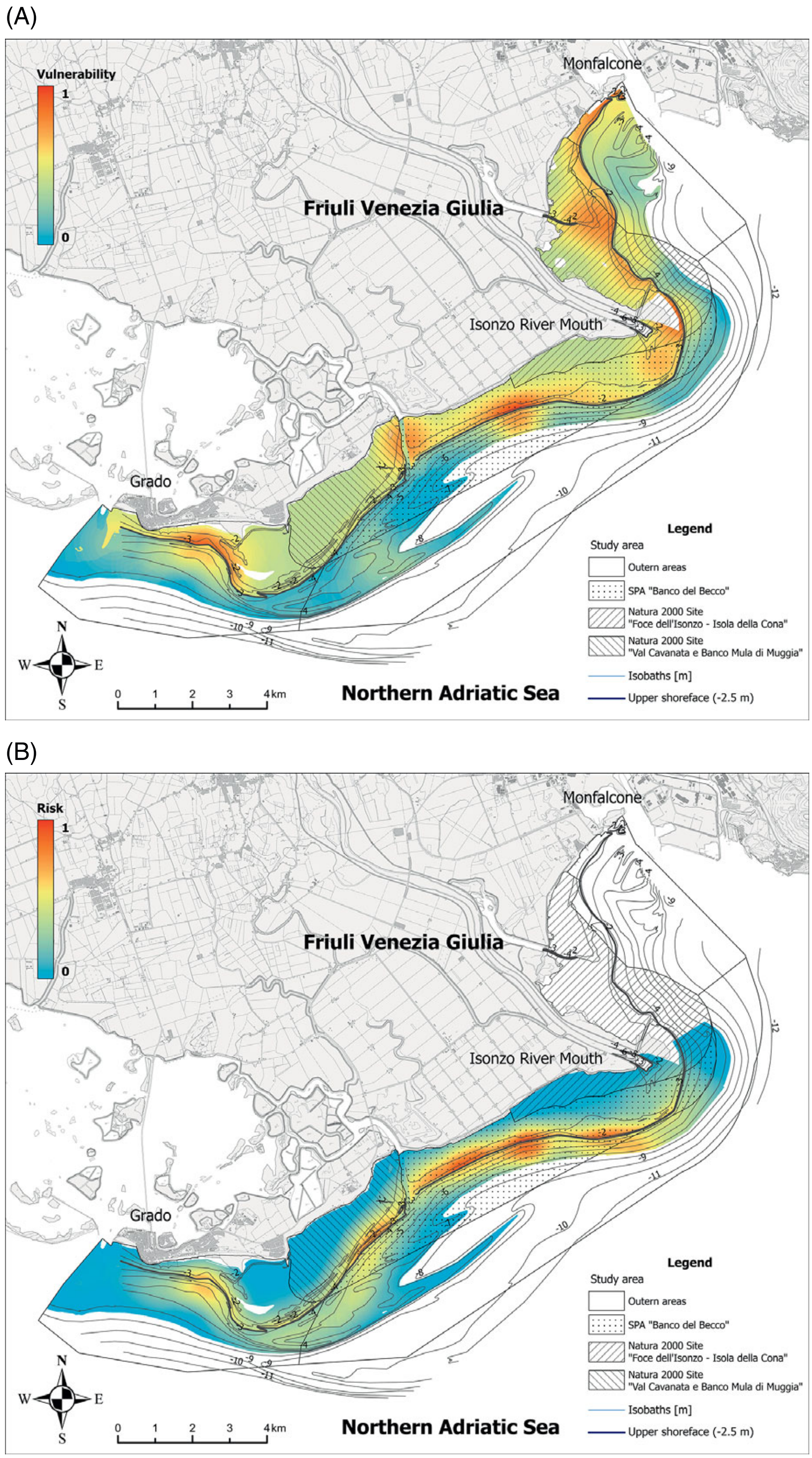

Figure 4. Vulnerability map (A) and risk map (B). The graduated scale from 0 to 1 shows the increasing degree of vulnerability and risk, respectively.

problem of incidental catches. Its designation under the Community Directives “Birds” 2009/147/EC can also be seen as an opportunity for the protection and conservation of its biodiversity and for the sustainability of the small-scale coastal fishing sector.

Small-scale fisheries and seabird bycatch mitigation

Nevertheless, studying and testing possible mitigation measures for the bycatch issue is challenging, the demand for finding mitigation solutions for seabird bycatch requires many project-testing efficacy

https://doi.org/10.1017/S0959270925000012 Published online by Cambridge University Press

tools. Several studies report experimental analyses of different mitigation measures to reduce the incidence of incidental catches (Sacchi 2021). The spatial–temporal restrictions of gillnet and longline fishing activity in critical areas (Gilman et al. 2023; Merkel et al. 2022; O'Keefe et al. 2021), and the use of visual deterrents, such as bird scarer devices or tori lines, are currently the most promising and recommended methods (Almeida et al. 2023; Lucas and Berggren 2022; Martin and Crawford 2015; Villafáfila et al. 2024). Nevertheless, some trials failed to reduce bycatch (Field et al. 2019; Rouxel et al. 2023), indicating the difficulty of generalising the effectiveness of such measures, as they depend heavily on local variables and regional fishing activity variations (Richards et al. 2022; Villafáfila et al. 2024). This research raises one potential effective solution to mitigate bycatch in the study area, i.e. the reduction of gear exposure time, limiting deployment to the period between dawn and dusk on deep seabed beyond the 3-m bathymetric line. This measure, however, may have implications for the fishery. Restricting fishing to depths beyond 3 m could reduce fish captures and landings. Hence, compensation schemes or financial incentives should be considered to address potential economic losses for the affected fishermen. According to local fishermen, the optimal times for catching fish are during sunrise and sunset. Their practice of setting gillnets during daylight hours is primarily driven by convenience and competition for better fishing areas among fishermen, rather than by an increase in catch effectiveness. This highlights the significance of collaborative efforts with fishermen in developing optimal conservation measures. Secondly, the enhancement of gear detectability could be implemented, equipping gear with floats, potentially improving underwater visibility and allowing for active avoidance by diving seabirds. Given the lack of local research regarding mitigation strategies (Villafáfila et al. 2024), and our field experience, this visual underwater solution might need to be evaluated in these shallow water contexts. Participatory actions between all the project's components are deemed essential to achieving this objective. Management decisions should be guided by a balance between stakeholders (fishermen) with their on-the-ground experience and the available scientific evidence (Barbato et al. 2021; Grati et al. 2022). There is no desire by fishermen to capture birds in their nets. Indeed, fishermen dislike finding entangled birds since it requires time to untangle, and the fishing gear could be damaged, causing economic losses. Our experience suggests that local fishermen may be apprehensive about potential repercussions, discouraging them from accurately documenting bycatch events. This fear emphasises the need for a more supportive environment that promotes reporting without the threat of consequences. By so doing, we could improve data acquisition and ultimately enhance the management and conservation of marine resources. Another useful development would be, subject to their approval, to provide fishermen with GPS tracking systems for recording fishing routes (Tassetti et al. 2022), and onboard cameras to register fishing activities and bycatch events. It is worth noting that small-scale fisheries play a key role in the economy of the coastal community and constitute a valuable cultural heritage, with years of history and tradition to be valued and preserved (Calò et al. 2023; Lloret et al. 2018). Addressing this issue requires the multifaceted engagement and trust-based cooperation of all stakeholders to establish a continuous collaborative framework that fosters joint responsibility for monitoring and mitigating the phenomenon (Jenkins et al. 2022; Vulcano et al. 2024). Integrating scientific research with commercial endeavours and social values is crucial. Finally, vulnerability and risk maps identify potential and real bycatch hotspots, mostly in the shallowest waters (<3 m). Consequently, they should represent a valuable tool in planning desirable conservation measures in the area (Votier et al. 2023; Zhou and Brothers 2021). Rapid access to the maps would greatly facilitate prompt evaluation by local and regional administrative authorities. Furthermore, they can be easily integrated with other data on fishing effort and seabird distribution to enhance their value. Such diverse and detailed information would be helpful in formulating territorially targeted actions in this area where economic and conservation efforts overlap significantly. Additionally, the maps highlight the ecological significance of submerged morphologies (i.e. sandbanks, sandy bars) as crucial habitats for fishing operations and seabird diving activities, likely driven by the availability of trophic resources in these environments.

Conclusions

Environmental features are the likely responsible factors for the vulnerability of seabirds to the risk of bycatch in the area. This study provides one of the first comprehensive descriptions and quantitative analyses of small-scale fisheries bycatch in the Mediterranean Sea, with outcomes of significant national and international importance. It emphasises how crucial it is to develop future links with the fishing community to give accurate information and raise awareness of bycatch at the national level (Votier et al. 2023). This research provides essential information for planning protected marine areas at the local level. Furthermore, it fosters a method for analysing small-scale fisheries and their possible impacts that may be replicated in other sites with similar characteristics. Finally, it emphasises the relevance of the integrated social-ecological approach for future studies on interactions between small-scale fisheries and coastal diving seabirds in the Mediterranean range. Further investigations will be required to deepen understanding of the drivers of bycatch in this area. Identifying the most significant feeding areas, diving behaviour, and diet of wintering species in the Mediterranean Sea and assessing overlap with fishing activities with implementing biologging data (Clay et al. 2019), specifically in the Adriatic Sea, is undoubtedly one of the priorities.

Acknowledgements. We are thankful to the Grado Fishermen Cooperative and all the participating fishermen for their essential collaboration in collecting data, which made the research possible. We particularly acknowledge the leadership and support provided by the Cooperative's President, Antonio Santopolo, in facilitating this research on a potentially divisive topic. We acknowledge Dr Giovanni Dean for facilitating communication with the Grado Fishermen Cooperative. We thank the Friuli Venezia Giulia region, which funded the project; particularly thanks to Dr Mauro Cosolo and Dr Umberto Fattori. We express our gratitude to Prof. Stanislao Bevilacqua and Prof. Giorgio Fontolan for coordinating the project MITFISH - N2K. Relevant suggestions and enhancements were provided on the first draft of the manuscript by Rasa Morkūnė, Julius Morkūnas, and Paola Forni (Klaipėda University). We are grateful to Zoe Jacobs (Royal Society for the Protection of Birds) for her invaluable assistance in revising the English language structure of the manuscript. Her expertise in the field provided insightful comments that significantly improved the clarity and accuracy of the writing. Finally, we would like to thank the anonymous referee and the Associate Editor for valuable criticism.

Author contribution. PS: investigation; data curation; data collection; formal analysis; writing original draft preparation; SF: data curation; formal analysis; writing review and editing; SS: conceptualisation; funding acquisition; project administration; methodology; investigation; data curation; data collection; formal analysis; writing review and editing. This research was financially supported by the Friuli Venezia Giulia region through the project "Mitigazione e monitoraggio dell'interazione tra pesca artigianale e la Fauna Ittica, le Specie protette dell'avifauna acquatica e gli Habitat bentonici nei siti Natura 2000 (MITFISH – N2K)" – FEAMP 071/RBC/20 – CUP: D48D20000730009. The work was carried out within the "European Maritime and Fisheries Fund FEAMP 2014-2020 – Measure 1.40. Protection and restoration of marine biodiversity, ecosystems and compensation schemes in the context of sustainable fishing activities". All the authors included in this manuscript have agreed to be listed and approve the submitted version of the manuscript.

References

Almeida A., Alonso H., Oliveira N., Silva E. and Andrade J. (2023). Using a visual deterrent to reduce seabird interactions with gillnets. *Biological Conservation* **285**, 110236.

Anderson O., Small C., Croxall J., Dunn E., Sullivan B., Yates O. et al. (2011). Global seabird bycatch in longline fisheries. *Endangered Species Research* **14**, 91–106.

Baccetti N., Zenatello M. and Pezzo F. (2018). Uccelli Marini: Indicazioni per il Completamento della Rete Natura 2000. ISPRA 09/07/2018. Technical Report.

Barbato M., Barría C., Bellodi A., Bonanomi S., Borme D., Ćetković I. et al. (2021). The use of fishers' local ecological knowledge to reconstruct fish behavioural traits and fishers' perception of conservation relevance of elasmobranchs in the Mediterranean Sea. *Mediterranean Marine Science* **22**, 603–622.

Bellebaum J., Schirmeister B., Sonntag N. and Garthe S. (2013). Decreasing but still high: bycatch of seabirds in gillnet fisheries along the German Baltic coast. *Aquatic Conservation: Marine Freshwater Ecosystems* **23**, 210–221.

Bezzi A., Casagrande G., Fracaros S., Martinucci D., Pillon S., Sponza S. et al. (2021). Geomorphological changes of a migrating sandbank: multidecadal analysis as a tool for managing conflicts in coastal use. *Water* **13**, 3416.

Biodiversity Office Friuli Venezia Giulia Region (2023). Censimento degli Uccelli Acquatici Svernanti in Friuli Venezia Giulia nell'Ambito dell'International Waterbird Census (IWC) – Anni 2015–2021. Technical Report.

BirdLife International (2022). *State of the World's Birds 2022: Insights and Solutions for the Biodiversity Crisis*. Cambridge: BirdLife International.

Burger C., Schubert A., Heinänen S., Dorsch M., Kleinschmidt B., Žydelis R. et al. (2019). A novel approach for assessing effects of ship traffic on distributions and movements of seabirds. *Journal of Environmental Management* **251**, 109511.

Calò A., Di Franco A., Dimitriadis C., Piacentini L., Ventura P., Pey A. et al. (2023). Social-ecological features of set nets small-scale fisheries in the context of Mediterranean marine protected areas. *Mediterranean Marine Science* **24**, 491–509.

Carpentieri P., Nastasi A., Sessa M. and Srour A. (2021). *Incidental Catch of Vulnerable Species in Mediterranean and Black Sea Fisheries – A Review.* General Fisheries Commission for the Mediterranean. Studies and Reviews. No. 101. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/documents/card/en/c/cb5405en

Christensen-Dalsgaard S., Anker-Nilssen T., Crawford R., Bond A., Sigurðsson G.M., Glemarec G. et al. (2019). What's the catch with lumpsuckers? A North Atlantic study of seabird bycatch in lumpsucker gillnet fisheries. *Biological Conservation* **240**, 108278.

Claudet J., Loiseau C., Sostres M. and Zupan M. (2020). Underprotected marine protected areas in a global biodiversity hotspot. *One Earth* **2**, 380–384.

Clay T.A., Small C., Tuck G.N., Pardo D., Carneiro A.P.B., Wood A.G. et al. (2019). A comprehensive large-scale assessment of fisheries bycatch risk to threatened seabird populations. *Journal of Applied Ecology* **56**, 1882–1893.

Cleasby I., Wilson L., Crawford R., Owen E., Rouxel Y. and Bolton M. (2022). Assessing bycatch risk from gillnet fisheries for three species of diving seabird in the UK. *Marine Ecology Progress Series* **684**, 157–179.

Cortés V., Arcos J. and González-Solís J. (2017). Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates. *Marine Ecology Progress Series* **565**, 1–16.

Cortés V. and González-Solís J. (2018). Seabird bycatch mitigation trials in artisanal demersal longliners of the Western Mediterranean. *PLOS ONE* **13**, e0196731.

Cosolo M., Privileggi N., Cimador B. and Sponza S. (2011). Dietary changes of Mediterranean Shags *Phalacrocorax aristotelis desmarestii* between the breeding and post-breeding seasons in the upper Adriatic Sea. *Bird Study* **58**, 461–472.

Courbin N., Besnard A. and Grémillet D. (2024). Transnational mortality from Spanish longline fisheries bycatch is shaping the decline of a vulnerable French seabird. *Biological Conservation* **293**, 110597.

Crowder L.B., Hazen E.L., Avissar N., Bjorkland R., Latanich C. and Ogburn M. B. (2008). The impacts of fisheries on marine ecosystems and the transition to ecosystem-based management. *Annual Review of Ecology, Evolution, and Systematics* **39**, 259–278.

Croxall J.P., Butchart S.H.M., Lascelles B., Stattersfield A.J., Sullivan B., Symes A. et al. (2012). Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* **22**, 1–34.

Dias M.P., Martin R., Pearmain E.J., Burfield I.J., Small C., Phillips R.A. et al. (2019). Threats to seabirds: A global assessment. *Biological Conservation* **237**, 525–537.

Duckworth J., O'Brien S., Petersen I.K., Petersen A., Benediktsson G., Johnson L. et al. (2022). Winter locations of red-throated divers from geolocation and feather isotope signatures. *Ecology and Evolution* **12**, e9209.

ERSA (2022). *ARGOS Strategic Project. Schema Comune per la Gestione delle Attività di Pesca a Livello Locale per le Regioni dell'Alto Adriatico. Friuli Venezia Giulia e Veneto.* Pozzuolo del Friuli: Agenzia Regionale per lo Sviluppo Rural. Available at https://www.ersa.fvg.it/export/sites/ersa/aziende/sperimentazione/Statistica-agraria/Allegati_statistica/Schema-comune-per-la-gestione-delle-attivita-di-pesca-a-livello-locale-per-le-regioni-dellAlto-Adriatico.-Friuli-Venezia-Giulia-e-Veneto.pdf (accessed 16 December 2024).

European Commission (2021). *Annual Report on the Efforts Made by Italy in 2021 to Reach a Sustainable Balance Between Fishing Capacity and Fishing Opportunities.* Available at https://oceans-and-fisheries.ec.europa.eu/system/files/2022-09/2021-fleet-capacity-report-italy_en.pdf (accessed 16 December 2024).

European Commission (2024). February Infringement Package: Key Decisions. Available at https://ec.europa.eu/commission/presscorner/detail/EN/inf_24_301 (accessed 16 December 2024).

European Parliament (2014). *Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund and Repealing Council Regulations (EC) No 2328/2003, (EC) No 861/2006, (EC) No 1198/2006 and (EC) No 791/2007 and Regulation (EU) No 1255/2011 of the European Parliament and of the Council.* Brussels: European Parliament. Available at https://eur-lex.europa.eu/legal-content/lt/TXT/?uri=CELEX:32014R0508.

Fangel K., Aas Ø., Vølstad J.H., Bærum K.M., Christensen-Dalsgaard S., Nedreaas K. et al. (2015). Assessing incidental bycatch of seabirds in Norwegian coastal commercial fisheries: Empirical and methodological lessons. *Global Ecology and Conservation* **4**, 127–136.

Food and Agriculture Organization of the United Nations (FAO) (2019). *Monitoring the Incidental Catch of Vulnerable Species in Mediterranean and Black Sea Fisheries: Methodology for Data Collection*. FAO Fisheries and Aquaculture Technical Paper No. 640. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO) (2022). *The State of Mediterranean and Black Sea Fisheries 2022*. General Fisheries Commission for the Mediterranean. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO) (2023). *The State of Mediterranean and Black Sea Fisheries 2023 – Special Edition*. General Fisheries Commission for the Mediterranean. Rome: FAO.

Field R., Crawford R., Enever R., Linkowski T., Martin G., Morkūnas J. et al. (2019). High contrast panels and lights do not reduce bird bycatch in Baltic Sea gillnet fisheries. *Global Ecology Conservation* **18**, e00602.

Furness R.W. (2003). Impacts of fisheries on seabird communities. *Scientia Marina* **67**, 33–45.

Genovart M., Bécares J., Igual J., Martínez-Abraín A., Escandell R., Sánchez A. et al. (2018). Differential adult survival at close seabird colonies: The importance of spatial foraging segregation and bycatch risk during the breeding season. *Global Change Biology* **24**, 1279–1290.

Genovart M., Doak D.F., Igual J.-M., Sponza S., Kralj J. and Oro D. (2017). Varying demographic impacts of different fisheries on three Mediterranean seabird species. *Global Change Biology* **23**, 3012–3029.

Gilman E., Evans T., Pollard I. and Chaloupka M. (2023). Adjusting time-of-day and depth of fishing provides an economically viable solution to seabird bycatch in an albacore tuna longline fishery. *Scientific Reports* **13**, 2621.

Glemarec G., Kindt-Larsen L., Lundgaard L.S. and Larsen F. (2020). Assessing seabird bycatch in gillnet fisheries using electronic monitoring. *Biological Conservation* **243**, 108461.

Grati F., Aladzuz A., Azzurro E., Bolognini L., Carbonara P., Çobani M. et al. (2018). Seasonal dynamics of small-scale fisheries in the Adriatic Sea. *Mediterranean Marine Science* **19**, 21–35.

Grati F., Azzurro E., Scanu M., Tassetti A.N., Bolognini L., Guicciardi S. et al. (2022). Mapping small-scale fisheries through a coordinated participatory strategy. *Fish and Fisheries* **23**, 773–785.

Grémillet D., Nazirides T., Nikolaou H. and Crivelli A. (2012). Fish are not safe from great cormorants in turbid water. *Aquatic Biology* **15**, 187–194.

Grémillet D., Ponchon A., Paleczny M., Palomares M.-L.D., Karpouzi V. and Pauly D. (2018). Persisting worldwide seabird-fishery competition despite seabird community decline. *Current Biology* **28**, 4009–4013.

Guyader O., Berthou P., Koutsikopoulos C., Alban F., Demanèche S., Gaspar M. B. et al. (2013). Small scale fisheries in Europe: A comparative analysis based on a selection of case studies. *Fisheries Research* **140**, 1–13.

Heinänen S., Žydelis R., Kleinschmidt B., Dorsch M., Burger C., Morkūnas J. et al. (2020). Satellite telemetry and digital aerial surveys show strong displacement of red-throated divers (*Gavia stellata*) from offshore wind farms. *Marine Environmental Research* **160**, 104989.

International Council for the Exploration of the Sea (ICES) (2024). EU Request on Appropriate Bycatch Monitoring Systems at Member State Level and on Regional Coordination. ICES Advice: Special Requests. Report. Available at https://doi.org/10.17895/ices.advice.25562220.v1.

Jacquet J. and Pauly D. (2008). Funding priorities: big barriers to small-scale fisheries. *Conservation Biology* **22**, 832–835.

Jarrett D., Calladine J., Cook A.S.C.P., Upton A., Williams J., Williams S. et al. (2021). Behavioural responses of non-breeding waterbirds to marine traffic in the near-shore environment. *Bird Study* **68**, 443–454.

Jenkins L.D., Eayrs S., Pol M.V. and Thompson K.R. (2022). Uptake of proven bycatch reduction fishing gear: perceived best practices and the role of affective change readiness. *ICES Journal of Marine Science* **80**, 437–445.

Karris G., Fric J., Kitsou Z., Kalfopoulou J., Giokas S., Sfenthourakis S. et al. (2013). Does by-catch pose a threat for the conservation of seabird populations in the southern Ionian Sea (eastern Mediterranean)? A questionnaire based survey of local fisheries. *Mediterranean Marine Science* **14**, 19.

Kleinschmidt B., Burger C., Bustamante P., Dorsch M., Heinänen S., Morkūnas J. et al. (2022). Annual movements of a migratory seabird—the NW European red-throated diver (*Gavia stellata*)—reveals high individual repeatability but low migratory connectivity. *Marine Biology* **169**, 114.

Kleinschmidt B., Burger C., Dorsch M., Nehls G., Heinänen S., Morkūnas J. et al. (2019). The diet of red-throated divers (*Gavia stellata*) overwintering in the German Bight (North Sea) analysed using molecular diagnostics. *Marine Biology* **166**, 77.

Le Bot T., Lescroël A. and Grémillet D. (2018). A toolkit to study seabird–fishery interactions. *ICES Journal of Marine Science* **75**, 1513–1525.

Lewison R., Crowder L., Read A. and Freeman S. (2004). Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology & Evolution* **19**, 598–604.

Lewison R.L., Crowder L.B., Wallace B.P., Moore J.E., Cox T., Žydelis R. et al. (2014). Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. *Proceedings of the National Academy of Sciences – PNAS* **111**, 5271–5276.

Lloret J., Biton-Porsmoguer S., Carreño A., Di Franco A., Sahyoun R., Melià P. et al. (2020). Recreational and small-scale fisheries may pose a threat to vulnerable species in coastal and offshore waters of the western Mediterranean. *ICES Journal of Marine Science* **77**, 2255–2264.

Lloret J., Cowx I.G., Cabral H., Castro M., Font T., Gonçalve J.M.S. et al. (2018). Small-scale coastal fisheries in European Seas are not what they were: Ecological, social and economic changes. *Marine Policy* **98**, 176–186.

Lucas S. and Berggren P. (2022). A systematic review of sensory deterrents for bycatch mitigation of marine megafauna. *Reviews in Fish Biology and Fisheries* **33**, 1–33.

Marchowski D. (2022). Bycatch of seabirds in the Polish part of the southern Baltic Sea in 1970–2018: a review. *Acta Ornithologica* **56**, 139–158.

Martin G.R. and Crawford R. (2015). Reducing bycatch in gillnets: A sensory ecology perspective. *Global Ecology Conservation* **3**, 28–50.

Merkel F., Post S., Frederiksen M., Bak-Jensen Z., Nielsen J. and Hedeholm R. (2022). Bycatch in the West Greenland lumpfish fishery, with particular focus on the common eider population. *Marine Ecology Progress Series* **702**, 123–137.

Morkūnas J., Oppel S., Bružas M., Rouxel Y., Morkūnė R. and Mitchell D. (2022). Seabird bycatch in a Baltic coastal gillnet fishery is orders of magnitude larger than official reports. *Avian Conservation Ecology* **17**, 31.

Morkūnė R., Lesutienė J., Barisevičiūtė R., Morkūnas J. and Gasiūnaitė Z.R. (2016). Food sources of wintering piscivorous waterbirds in coastal waters: A triple stable isotope approach for the southeastern Baltic Sea. *Estuarine, Coastal and Shelf Science* **171**, 41–50.

Nascimento T., Oliveira N. and Luís A. (2023). Spatial overlap between the European Shag and commercial fisheries in a special protected area: implications for conservation. *Fisheries Research* **263**, 10668.

Northridge S., Coram A., Kingston A. and Crawford R. (2017). Disentangling the causes of protected-species bycatch in gillnet fisheries. *Conservation Biology* **31**, 686–695.

O'Keefe C.E., Cadrin S.X., Glemarec G. and Rouxel Y. (2021). Efficacy of time-area fishing restrictions and gear-switching as solutions for reducing seabird bycatch in gillnet fisheries. *Reviews in Fisheries Science & Aquaculture* **31**, 29–46.

Oliveira N., Henriques A., Miodonski J., Pereira J., Marujo D., Almeida A. et al. (2015). Seabird bycatch in Portuguese mainland coastal fisheries: An assessment through on-board observations and fishermen interviews. *Global Ecology and Conservation* **3**, 51–61.

Paleczny M., Hammill, E., Karpouzi, V. and Pauly D. (2015). Population trend of the world's monitored seabirds, 1950–2010. *PLOS ONE* **10**, e0129342.

Pauly D., Watson R. and Alder J. (2005). Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B Biological Sciences* **360**, 5–12.

Pott C. and Wiedenfeld D.A. (2017). Information gaps limit our understanding of seabird bycatch in global fisheries. *Biological Conservation* **210**, 192–204.

Ramírez I., Mitchell D., Vulcano A., Rouxel Y., Marchowski D., Almeida A. et al. (2024). Seabird bycatch in European waters. *Animal Conservation* **27**, 737–752.

Richards C., Cooke R., Bowler D.E., Boerder K. and Bates A.E. (2022). Species' traits and exposure as a future lens for quantifying seabird bycatch vulnerability in global fisheries. *Avian Conservation Ecology* **17**, 34.

Rouxel Y., Arnardóttir H. and Oppel S. (2023). Looming-eyes buoys fail to reduce seabird bycatch in the Icelandic lumpfish fishery: depth-based fishing restrictions are an alternative. *Royal Society Open Science* **10**, 230783.

Sacchi J. (2021). *Overview of Mitigation Measures to Reduce the Incidental Catch of Vulnerable Species in Fisheries.* Studies and Reviews No. 100. General Fisheries Commission for the Mediterranean. Rome: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cb5049en

Satta V., Pira A., Cherchi S., Nissardi S., Rotta A., Pirastru M. et al. (2023). Adaptive response to gillnets bycatch in a North Sardinia Mediterranean Shag (*Gulosus aristotelis desmarestii*) population. *Animals* **13**, 2142.

Scridel D., Utmar P., Koce U., Kralj J., Baccetti N., Candotto S. et al. (2023). Conservation status of the Mediterranean Shag *Gulosus aristotelis desmarestii* in the Adriatic Sea during the non-breeding period: baseline population, trends, threats and knowledge gaps. *Ardeola* **71**, 19–42.

Sponza S., Cimador B., Cosolo M. and Ferrero E.A. (2010). Diving costs and benefits during post-breeding movements of the Mediterranean shag in the North Adriatic Sea. *Marine Biology* **157**, 1203–1213.

Sponza S., Cosolo M. and Kralj J. (2013). Migration patterns of the Mediterranean Shag *Phalacrocorax aristotelis desmarestii* (Aves: Pelecaniformes) within the northern Adriatic Sea. *Italian Journal of Zoology* **80**, 380–391.

Strod T., Arad Z., Izhaki I. and Katzir G. (2004). Cormorants keep their power: visual resolution in a pursuit-diving bird under amphibious and turbid conditions. *Current Biology* **14**, R376–R377.

Tasker M., Camphuysen C.J., Cooper J., Garthe S., Montevecchi, W.A. and Blaber S.J.M. (2000). The impacts of fishing on marine birds. *ICES Journal of Marine Science* **57**, 531–547.

Tassetti A.N., Galdelli A., Pulcinella J., Mancini A. and Bolognini L. (2022). Addressing gaps in small-scale fisheries: a low-cost tracking system. *Sensors* **22**, 839.

Villafáfila M., Carpio A.J. and Rivas M.L. (2024). Mitigating the effect of by-catch on endangered marine life. *Animal Conservation* acv.12968.

Votier S.C., Sherley R.B., Scales K.L., Camphuysen K. and Phillips R.A. (2023). An overview of the impacts of fishing on seabirds, including identifying future research directions. *ICES Journal of Marine Science* **80**, 2380–2392.

Vulcano A., Rutherford C.A., Mitchell D., Dias M., Puymartin A. and Staneva A. (2024). *Seabirds of Europe: Current Status, Main Threats and Way Forward*. BirdLife Europe and Central Asia Summary Report. Brussels: BirdLife Europe.

White C.R., Day N., Butler P.J. and Martin G.R. (2007). Vision and foraging in cormorants: more like herons than hawks? *PLOS ONE* **2**, e639.

Worton B.J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* **70**, 164–168.

Zenatello M., Baccetti N. and Borghesi F. (2014). *Risultati dei Censimenti degli Uccelli Acquatici Svernanti in Italia. Distribuzione, stima e trend delle popolazioni nel 2001–2010*. ISPRA, Serie Rapporti 206/2014. Rome: Istituto Superiore per la Protezione e la Ricerca Ambientale.

Zhou C. and Brothers N. (2021). Seabird bycatch vulnerability in pelagic longline fisheries based on modelling of a long-term dataset. *Bird Conservation International* **32**, 259–274.

Žydelis R., Small C. and French G. (2013). The incidental catch of seabirds in gillnet fisheries: A global review. *Biological Conservation* **162**, 76–88.

Žydelis R., Wallace B.P., Gilman E.L. and Werner T.B. (2009). Conservation of marine megafauna through minimization of fisheries bycatch. *Conservation Biology* **23**, 608–616.