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Marine megafauna bycatch in the Pelagie Archipelago fisheries (Strait of Sicily, central Mediterranean)

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Abstract

Seabirds rank among the most threatened long-lived marine species globally, with unintentional capture in fisheries (bycatch) being a major source of mortality. The Pelagie Archipelago, located in the Strait of Sicily in the central Mediterranean, hosts different fishing activities and is a hotspot f or marine megafauna biodiversity, including the second most important breeding colony of Scopoli's shearwater (*Calonectris diomedea*) in the Mediterranean. This study presents one of the first assessments of seabird bycatch in Italian waters, evaluating the impact of multiple fishing gears on marine megafauna, particularly seabirds, using data collected between 2021 and 2024. A total of 35 fishing trips (215 hauls) were monitored through onboard observations, and 29 structured interviews were conducted with local fishers. Bycatch rates were estimated using standardized metrics, including Bycatch Per Unit Effort (BPUE; birds per 1,000 hooks) for drifting longlines, which are the gear most frequently associated with seabird mortality. Overall, 27 *C. diomedea* and 9 yellow-legged gulls (*Larus michahellis*) were unintentionally caught during drifting longline operations, with an additional *C. diomedea* caught incidentally in bottom trawling. No seabird bycatch was observed in other gear types, such as gillnets, lines, and set longlines). However, a number of other long-lived species of conservation concern, including sharks, rays, and sea turtles were unintentionally caught, primarily through bottom trawling and drifting longlines. No cetaceans were caught by any gear during the monitoring fishing trips. During the interview survey, fishers reported several incidents of bycatch involving seabirds, elasmobranchs, and sea turtles, particularly related to drifting longlines. This represents the first preliminary investigation indicating that bycatch of different seabird species occurs in the Pelagie Archipelago. Overall, the data demonstrated that drifting longlines could pose a threat to the survival of these species in the area. Finally, more research and collaboration with fisheries are essential to gather additional data and evaluate the potential conservation implications for marine megafauna in the Pelagie Archipelago.

Keywords: bycatch; conservation; longline; Pelagie Archipelago; seabirds.

Introduction

The unintentional catch of non-target species during fishing operations, known as bycatch, is one of the major sources of mortality for marine megafauna across the globe (Lewison *et al*., 2014; Komoroske & Lewison, 2015). Seabirds are among the most threatened groups, with almost half of the species listed as globally "Threatened" with extinction or as "Near Threatened" according to the International Union for Conservation of Nature (IUCN) (Dias *et al*., 2019). There is often a strong correlation between seabird distribution and the world's most-fished seas, as both seabirds and fishing vessels tend to concentrate in areas with high biological productivity (Brothers *et al*., 1999). In European waters, an estimated 200,000 seabirds are accidentally killed each year due to entanglement in fishing nets, capture on baited hooks, or collisions with trawl warp cables (Žydelis *et al*., 2013; Genovart *et al*., 2017a; Ramirez *et al*., 2024). Due to their slow life-history traits (a single-egg clutch per season, strong philopatry, and low fecundity) (Brothers *et al*., 1999), Procellariidae (petrels and shearwaters) appear to be particularly vulnerable to bycatch mortality (Anderson *et al*., 2011; BirdLife International, 2017). Thus, such a threat can directly affect individual survival and subsequently the breeding success and productivity

of populations (Martín *et al*., 2019).

The Mediterranean Sea is home to a rich and valuable marine biodiversity, which includes sensitive species such as marine megafauna (Coll *et al*., 2010), and it sustains a variety of intense fishing activities. In particular, small-scale fisheries make significant contributions to regional food security, livelihoods, and economies. They account for an important portion of the Mediterranean fishery, comprising over 82% of the total fishing fleet and employing 61% of the total workforce on board fishing vessels (FAO, 2023). Interactions between sensitive species and fisheries are therefore likely to occur in the basin. The Mediterranean is regarded as one of the regions most affected by multi-taxa bycatch (Lewison *et al*., 2014; Bonanomi *et al*., 2022). In recent decades, this region has seen an increased focus on evaluating the bycatch of cetaceans (Silvani *et al*., 1999; Bearzi *et al*., 2002; Fortuna *et al*., 2010; Snape *et al*., 2018), sea turtles (Casale *et al*., 2007, 2016; Lucchetti *et al*., 2016, 2017a, 2017b; Pulcinella *et al*., 2019), elasmobranchs (La Mesa *et al*., 2016; Bonanomi *et al*., 2017, 2018; Nuez *et al*., 2021; Erguden *et al*., 2022), and seabirds (Dimech *et al*., 2009; García-Barcelona *et al*., 2010; Karris *et al*., 2013; Cortés *et al*., 2017). However, research efforts have been unevenly distributed among these taxa and limited to specific areas or types of fishing gear within the Mediterranean (Carpentieri *et al*., 2021). For instance, research on seabird bycatch has been mainly focused on the western Mediterranean, particularly in the Balearic Islands and along the Spanish Western Mediterranean coast) (García-Barcelona *et al*., 2010; FAO, 2016; BirdLife International, 2017; Cortés et *al*., 2017). Approximately 500 seabirds are caught annually by drifting longlines, 40% of which are Scopoli's shearwaters (*Calonectris diomedea*) (García-Barcelona *et al*., 2010).

Calonectris diomedea is regarded as one of the seabird species most susceptible to incidental catch (Cooper *et al*., 2003; Louzao & Oro, 2004; García-Barcelona *et al*., 2010). This procellariid is an endemic breeding species found in the Mediterranean Sea. Despite being classified as Least Concerned (LC) by the International Union for the Conservation of Nature (IUCN) in Europe (BirdLife International, 2021), this species is included in the list of endangered or threatened species in Annex II of the SPA/BD Protocol of the Regional Activity Center for Specially Protected Areas (RAC/SPA), in Annex I of the Species List of the EU Birds Directive 2009/147/EC, in Annex II of the SPA/BD Protocol of the Barcelona Convention, and in Annex II of the Berne Convention.

Population trends of many seabirds are declining at a global level, and in most cases at the European level, their population status is either unknown or also decreasing. While population estimates and interactions with human activities, particularly longline fisheries, are well documented for *C. diomedea* in the western Mediterranean (Belda & Sànchez, 2001; Cooper *et al*., 2003), information regarding other areas remains limited, such as in the eastern Mediterranean (Karris *et al*., 2013) and the central Mediterranean (Cianchetti-Benedetti *et al*., 2018). Depending on the breeding stage, this species can undertake either short or long-distance foraging trips (Cecere *et al*., 2013; Cianchetti-Benedetti *et al*., 2017) to consume a wide range of natural prey (Grémillet *et al*., 2014). The species mainly preys on medium-sized to small fish measuring 4-25 cm and squid ranging from 2-15 cm (Sara, 1989). It obtains its prey either through active hunting or opportunistically from fishery discards (Louzao *et al*., 2011; Cecere *et al*., 2015; Karris *et al*., 2018), often following trawlers and longline vessels (Sara, 1989; Laneri *et al*., 2010). Like other seabirds, *C. diomedea* may interact with fishing vessels during foraging trips, drawn by novel food sources such as discarded fish or bait. Consequently, the species is at risk of becoming a victim of bycatch.

The Pelagie Archipelago, located in the Strait of Sicily in the central Mediterranean, is a hotspot for marine megafauna biodiversity. It is home to several seabird colonies, including the second most important breeding colony of *C. diomedea* in the Mediterranean, which is also the largest in the European Union, including Italy. This colony comprises approximately 10,000 pairs (Baccetti *et al*., 2009). Yet, the Archipelago, whose major island is Lampedusa, is also regarded as one of the Mediterranean's most important fishing areas. Different fishing activities, primarily involving small polyvalent fishing vessels, operate along the continental shelf (Celona & Comparetto, 2009). Previous investigations have indicated that interactions between *C. diomedea* and fishing vessels are frequent in the area (Cecere *et al*., 2015; Cianchetti-Benedetti *et al*., 2018) and can significantly influence the individual foraging behavior of birds (Cianchetti-Benedetti *et al*., 2018). However, those studies did not investigate whether such interactions could lead to mortality for *C. diomedea,* and to date, no records of unintentional catches of seabirds or other vulnerable, long-lived species in the area have been found in the existing literature (Ramírez *et al*., 2024).

This study evaluates the incidental catch of marine megafauna in multiple gears, with a particular focus on seabirds and drifting longlines, in the sensitive area of the Pelagie Archipelago (Strait of Sicily, central Mediterranean). Onboard observations and questionnaire-based surveys were conducted to document comparable information on the bycatch phenomenon in the area. The study presents the findings and insights gained from this pilot initiative. Notably, this study represents one of the first comprehensive efforts to assess seabird bycatch in Italian waters. To date, only two studies have specifically examined this issue: one focusing on gillnet bycatch in a North Sardinian population of Mediterranean Shag (*Gulosus aristotelis desmarestii*) (Satta *et al*., 2023), and the other on interactions between small-scale fisheries and wintering seabirds in a coastal area of the Mediterranean Sea (Salvador *et al*., 2025). The limited evidence base underscores the urgent need for further research to fill this critical knowledge gap in the basin.

Materials and Methods

Study area

The Pelagie Archipelago (35.5° N, 12.6° E), located in the Strait of Sicily in the Central Mediterranean, forms part of the African and the Italian coastal plateaus (Fig. 1). This archipelago comprises a group of three islands: Lampedusa, Linosa, and the Lampione islet. The islands exhibit distinct geological formations and seabed profiles, resulting in a heterogeneous seascape that contributes to establishing the Pelagie Archipelago as a hotspot for marine biodiversity in the central Mediterranean (Pulcini *et al*., 2014; Tonielli *et al*., 2016; Cattano *et al*., 2021). Due to its strategic geographical position, acting as a gateway between the eastern and western Mediterranean basins, the archipelago serves as a crucial point for important migrations, including those of large marine mammals, large-bodied sharks, breeding sea turtles, and seabirds (UNEP-MAP-RAC/SPA, 2014; Di Lorenzo *et al*., 2017). Notably, Linosa Island is home to the second largest known colony of *C. diomedea* (Baccetti *et al*., 2009; Carpentieri *et al*., 2021), while the islet of Lampione hosts the fifth Italian colony of this species (Di Gangi *et al*., 2024). Additionally, Lampedusa supports an important colony of *Puffinus yelkouan,* comprising approximately 2,000 breeding pairs (Corso *et al*., 2009).

Concurrently, an important small- to medium-sized fishing fleet operates in the area. The archipelago's fishing fleet is almost entirely based in Lampedusa, with only one fishing vessel based in Linosa. Currently, it comprises around 80 vessels; of these, 46 are polyvalent small-scale vessels measuring ≤ 15 m LOA (length overall) and operate as drifting longlines (LLD), set longlines (LLS), lines (LHP), and gillnets (GN) (Celona & Comparetto, 2009 and data from the fishers' association). Around 35 vessels operate as bottom otter trawlers (OTB ≥ 15 m LOA). Hereafter, fishing gears will be collectively referred to using the alpha code established by the FAO International Standard Statistical Classification of Fishing Gear (ISSCFG).

Depending on weather and sea conditions, the fleet mainly operates between spring and early autumn along the continental shelf, where water depths range from 40 to 60 m. Fishers often change gear based on the season, the availability of target species, and market demands. The most important target species for LLD include pelagic resources such as swordfish (*Xiphias gladius*), Albacore tuna (*Thunnus alalunga*), and Atlantic little tuna (*Euthynnus alletteratus*) (Andaloro, 1998; Di Natale & Mangano, 2008). The main target species for OTB are demersal resources, including mullets (*Mullus* spp.), common octopus (*Octopus vulgaris*), and European squid (*Loligo vulgaris*), the latter also being caught by LHP [57] (FEAMP 2007-2013). Additionally, various target species such as scorpaenids (*Scorpaena* spp.), greater amberjack (*Seriola dumerili*), red porgy *(Pagrus pagrus*), common pandora (*Pagellus erythrinus*), and groupers (*Epinephelus* spp.) are typically caught using different gear types, including LLS, GN, and LHP (Andaloro, 1998; Di Natale & Mangano, 2008).

Data collection

This pilot study employed two different methods to collect data on marine megafauna bycatch in different fishing gears operating around the Pelagie Archipelago:

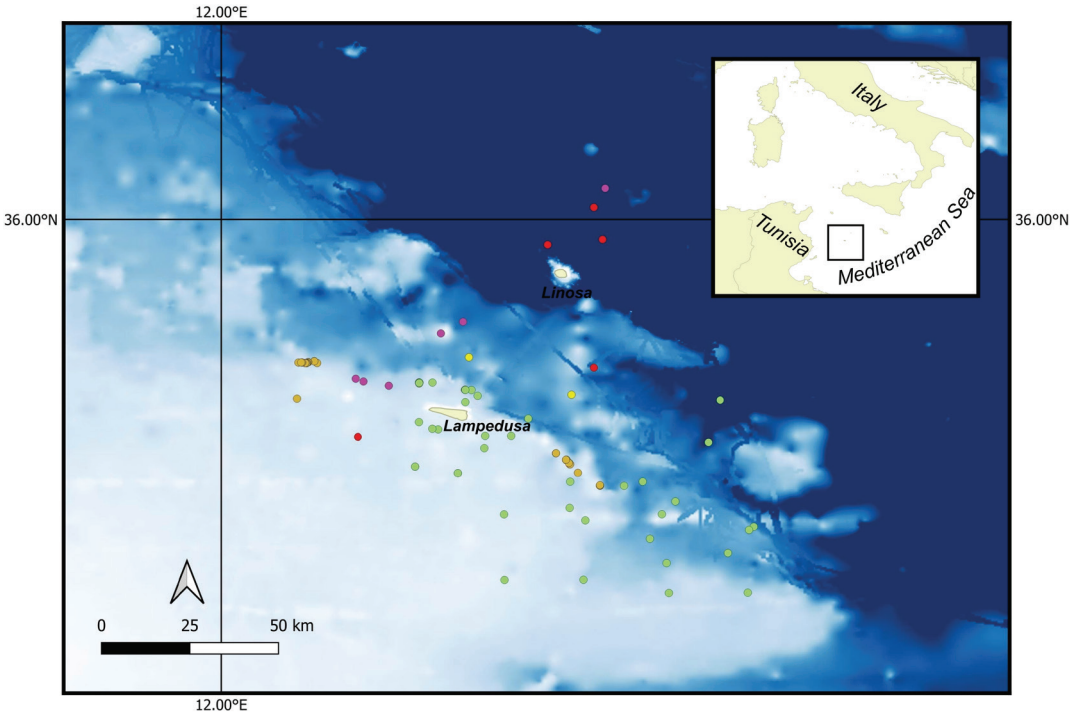


Fig. 1: Map showing the geographical distribution of hauls monitored between 2021 and 2024 across different fishing gears: bottom otter trawl (green dots), drifting longline (red dots), set longline (purple), gillnet (yellow dots), and line (orange dots).

onboard observations and questionnaire-based surveys. Both methods were conducted with the same fishing vessels and boat skippers sampled for this study (Table 1). Given that no official information on the fishing effort is available for the study area, the monitoring activity was designed and stratified per gear according to fleet dynamics. In the case of a major polyvalent small-scale fishery operating in a remote area like the Pelagie Archipelago, these dynamics can be highly variable in both space and time, as previously mentioned.

Onboard observations

Between June and October 2021, March and September 2022, May and June 2023, and March and October 2024, 3 trained observers monitored all fishing operations on board 10 fishing vessels (see Table 1) from Lampedusa, operating around the Pelagie Archipelago. A number of parameters were recorded for each haul, including haul duration, the time of net or line setting and hauling, vessel speed (nm), geographical coordinates (latitude and longitude in WGS84), water depth (m) and the date. Bycatch data of cetaceans, sharks, rays, sea turtles, and seabirds were collected in accordance with the protocol established by the General Fisheries Commission for the Mediterranean (GFCM) of the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2019). For each bycatch specimen, the physical condition during both the catch and release phases was assessed by examining locomotion.

Interview survey

The interview survey was conducted between March and September 2022, May and June 2023, and March and October 2024. Interviews were carried out in person or by phone by observers. Fishers were interviewed at least once a week using a standard questionnaire (see Annex 7 in FAO, 2019) drafted by the GFCM of the Food and the Agriculture Organization of the United Nations (FAO, 2019). Each interview lasted approximately 30 min and was conducted in Italian. Participation was entirely voluntary and anonymous to ensure the confidentiality of respondents' information and to minimize response bias. Fishers were asked about their current fishing activity, including the gear used, and to provide specific details regarding bycatch of marine megafauna. This included the estimated average number of bycatch specimens per fishing trip, as well as their status at capture and at release, pertaining to the period under monitoring.

Table 1. Summary table of the fishing vessels, onboard observations (number of monitored fishing trips and hauls with bycatch events) and interviews. LLD = drifting longline; LLS = set longline; LHP = line; GN = gillnet; OTB = bottom otter trawl. The alpha-code used for the different fishing gears is based on the FAO International Standard Statistical Classification of Fishing Gear (ISSCFG). LOA = overall length.

Fishing Vessel ID	Gear	LOA (m)	Power (kW)	Tonnage (GT)	N. fishing trips	N. hauls	N. hauls with bycatch events	N. hauls with bycatch events (sharks)	N. hauls with bycatch events (rays)	N. hauls with bycatch events (seabirds)	N. hauls with bycatch events (sea turtles)	N. interviews
AND	LLD	15	142	13	9	9	9	2	7	6	5	10
	LLS				1	1	0	0	0	0	0	0
	OTB				2	13	9	9	7	0	0	0
LEO	LLD	7.72	74	1	3	3	3	2	0	2	1	0
	LLS				2	5	3	2	2	0	0	3
	LHP				3	77	0	0	0	0	0	4
PAS	LHP	9.15	58.8	3	3	59	0	0	0	0	0	5
GBT	LLS	10.45	5.3	4	2	2	1	1	1	0	0	2
	LHP				1	7	0	0	0	0	0	1
ORI	GN	15	42	1	2	2	0	0	0	0	0	1
PLN	OTB	19	272	33	2*	29	20	17	9	0	0	2
ARG	OTB	11.5	61	8	1**	4	3	3	3	0	0	1
FRA	GN	9.13	58	1	1	1	1	1	1	0	0	1
IRE	LLD	10,02	74.2	5	2	2	1	0	1	0	1	1
SER	LLD	10,8	74	4	1	1	1	0	1	0	3	1

* As a OTB, in this case 2 fishing trips = 5 fishing days at sea.
** As a OTB, in this case 1 fishing trip = 2 fishing days at sea.

Data analysis

For each monitored fishing activity, the total bycatch rate for each recorded species was calculated as follows:

$$\frac{N}{h}$$

where N is the total number of animals caught, and h denotes the number of hauls or sets monitored.

Given that this study focuses on seabirds and the potential impact of LLD on these species in the Pelagie Archipelago, the annual seabird bycatch rate (Bycatch Per Unit Effort, BPUE; birds per 1000 baited hooks using *Sardinella aurita*) for the monitored LLD operations was calculated following the methodology outlined in García-Barcelona *et al*. (2010):

$$BPUE = \frac{N_s}{Hd \times 1000_b}$$

where N_s represents the total number of seabird catches observed in a year, and H_d denotes the number of hooks deployed on the monitored LLD vessels. The estimated annual seabird bycatch ($BPUE_a$) was then calculated as follows:

$$\mathrm{BPUE_a} = \mathrm{BPUE} \times \mathrm{E_{tot}}$$

where E_{tot} refers to the total annual effort, expressed as the number of hooks deployed by the LLD fleet each year. This estimate for 2024 was provided by the Shipowners' Association of Lampedusa. Due to the absence of direct data for the years 2021, 2022, and 2023, the estimated number of hooks for these years was derived from the data for 2024. While fleet activity varied across the years, the 2024 estimate was utilized as a proxy in the absence of more detailed effort data for the earlier period.

Given the small sample size of onboard observations, a bootstrapping non-parametric method was employed to estimate the 95% confidence interval (CI).

All analyses were performed using R software version 4.2.2 (R Core Team, 2023).

Results

Onboard observations

A total of 215 hauls were monitored during 35 fishing trips (see Table 1; for OTB, a single fishing trip may consist of one or more fishing days at sea, depending on the operation's duration −see notes below Table 1). The majority of monitored hauls were conducted using LHP (143) and OTB (46), followed by LLD (15), LLS (8), and a small number using GN (3) (Fig. 2). In total, 51 hauls recorded positive bycatch events (Table 1, Table S1). The bycatch rates per gear for each species are summarized in Table 2. The majority of incidental catches of marine megafauna were recorded on board OTB (140), followed by LLD (91), LLS (8), and GN (3) (see Table 2, Fig, 2). No bycatch was recorded for LHP. Sharks (94) and rays (40) were the most frequently captured taxa recorded with OTB (Table 2). This included 93 small spotted catsharks *(Scyliorhinus canicula)* with an average length of 25 cm (2.02 individuals per haul), 26 brown rays *(Raja miraletus*, 0.56 individuals per haul), and 19 rays *(Raja* spp.*,* 0.41 individuals per haul), with an average disc size of 40 cm, as well as 1 blue shark *(Prionace glauca,* 0.02 individuals per haul). The majority of these individuals were released alive by observers (Table 2). Additionally, 1 *C. diomodea* (0.02 individuals per haul) was captured with OTB and subsequently released alive. In contrast, for LLD, bycatch mainly consisted of large elasmobranchs, including 4 pelagic stingray (*Pteroplatytrigon violacea*, 1.53 individuals per set), 17 common stingrays (*Dasyatis pastinaca*, 1.13 individuals per set), 3 mako sharks (*Isurus oxyrinchus,* 0.20 individuals per set), 1 *P. glauca* (0.06 individuals per set), and 1 ray (*Raya* spp.,

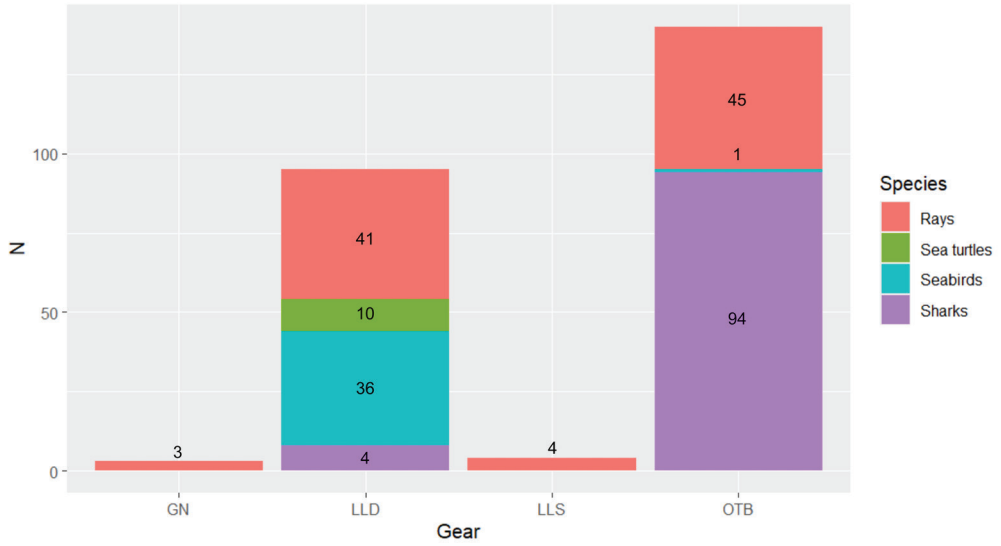


Fig. 2: Number of bycatch specimens: seabirds (light blue), sharks (purple), rays (red), and sea turtles (green) recorded per gear. LLD = drifting longline; LLS = set longline; GN = gillnet; OTB = bottom otter trawl. The alpha-code used for the different fishing gears is based on the FAO International Standard Statistical Classification of Fishing Gear (ISSCFG).

Table 2. Summary table reporting data collected during 215 hauls monitored between 2021 and 2024: total number of bycatch specimens, status at capture and at release recorded per gear and bycatch rate (n. individuals/n. sets).

Species	N. specimens	Status at capture		Status at release		Bycatch rate (ind/set)
		Alive	Dead	Alive	Dead	
LLD						
Calonectris diomedea	27	2	25	1	26	1.80
Larus michahellis	9	0	9	0	9	0.60
Isurus oxyrhincus	3	1	2	1	2	0.20
*Prionace glauca**	1	1	0	1	2	0.06
*Dasyatis pastinaca**	17	15	2	15	0	1.13
Caretta caretta	10	10	0	10	2	0.60
*Pteroplatytrygon violacea***	23	23	0	20	0	1.53
Raja sp.	1	1	0	0	0	0.06
LLS						
*Dasyatis pastinaca**	2	0	2	0	2	0.28
Raja spp.*	2	2	0	2	0	0.28
*Scyliorhinus canicula**	4	4	0	4	0	0.57
OTB						
Calonectris diomedea	1	1	0	1	0	0.02
*Raja miraletus**	26**	14	0	6	8	0.56
Raja spp.*	19**	17	1	12	7	0.41
*Prionace glauca**	1	1	0	1	0	0.02
*Scyliorhinus canicula**	93**	76	15	66	20	2.02
LHP						
0	0	0		0		0
GN						
*Dasyatis pastinaca**	3	3 Dead		3 Dead		1.00

* These species have low or no commercial value and are usually discarded at sea (Scacco *et al.*, 2015) or left dying at the stern during fish sorting (Bonanomi, unpublished data).

ND = Not Determined.

** For some specimens it was not possible to determine the status at capture and at release.

0.06 individuals per set; see Table 2). This was followed by seabird specimens, which included 27 *C. diomedea* (1.80 individuals per set) and 9 *Larus michahellis* (0.60 individuals per set) (see Table 2, Figs 3 and 4), captured during the day in 6 multiple-catch events. The observed effort, along with the annual catch of seabirds and BPUE (bycatch rate of seabirds per 1,000 hooks), varied across years (Table 3), with the highest rate recorded in 2023 at 4 birds per 1,000 hooks (see Table 3). The species-specific BPUE for *C. diomedea* ranged from 1.20 to 2.00 birds per 1,000 hooks, while for *L. michahellis,* it ranged from 0.53 to 2.00 birds per 1,000 hooks (see Table 3). The annual bycatch of seabirds within the LLD fleet ranged from approximately 423 to 961 individuals per year (Table 4). The highest estimate was recorded in 2023, with 960.6 seabirds (95% CI: 900-1,020), followed by 2022, which saw a bycatch of over 630 individuals (Table 4).

Sea turtles were also captured, specifically 10 loggerhead turtles (*Caretta caretta*, 0.60 individuals per haul), as shown in Table 2. The loggerhead turtles and the majority of elasmobranchs were captured and subsequently released alive (see details in Table 2), while almost all the seabirds were captured dead (Table 2). For LLS, sharks (4 *S. canicula,* 0.57 individuals per set) and rays (2 *Raja* spp. and 2 *D. pastinaca,* both 0.28 individuals per set; see Table 2) were the species encountered, with almost all individuals captured and released alive by observers (Table 2). In contrast, for GN, only 3 *D. pastinaca* (1.00 individual per haul) were recorded and were captured dead (Table 2). No cetaceans were caught by any fishing gear.

Questionnaire-based surveys

A total of 29 interviews were held with the captains of vessels involved in monitoring activities at sea (Table 1). Seabird bycatch was reported for the OTB and LHP fishing methods, with an average estimate of 3 *C. diomedea* caught and released alive per fishing trip for these gears, excluding LLD (Table 5). For the latter gear, fishers reported an estimated 8 *C. diomedea* per trip, with frequent incidents of multiple catches of dead seabirds

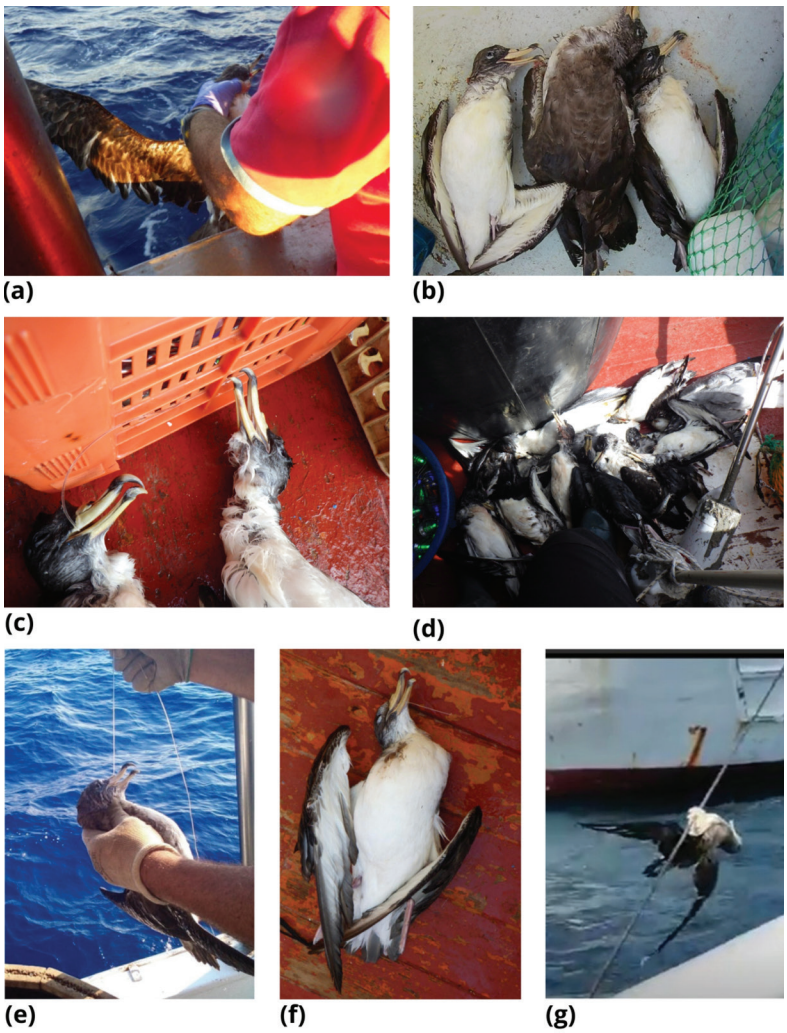


Fig. 3: Specimens of *Calonectris diomedea* photographed on board drifting longlines (a-f) and bottom trawlers (g).

Fig. 4a-c*: Larus michahellis* recorded on board drifting longlines.

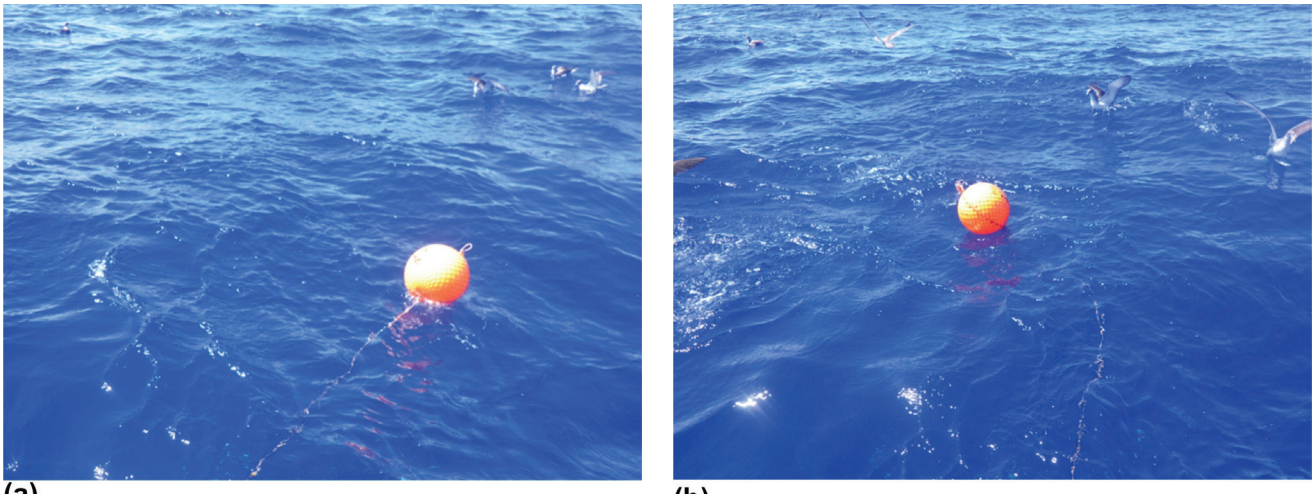
Table 3. Observation effort with annual catch of seabirds and BPUE (bycatch rate of seabirds per 1000 hooks).

Observed effort									
Year	**On board period**	**N. trips**	**N. hooks**	**N. birds captured**	**BPUE**	**N. *C. diomedea***	**BPUE *C. diomedea***	**N. *L. michahellis***	**BPUE *L. michahellis***
2021	Jun - Oct	3	4150	5	1.20	5	1.20	-	-
2022	Apr - Sep	2	1900	3	1.57	3	1.57	-	-
2023	May - Jun	2	2000	8	4.00	4	2.00	2	2.00
2024	Apr - Oct	8	9450	20	2.12	15	1.59	5	0.53

Table 4. Annual bycatch estimates of seabirds for LLD fleet.

Year	N. hooks	Annual estimate	95% CI
2021	400000*	481.92	437.04 - 522.96
2022	400000*	631.56	582.68 - 680.98
2023	240000*	960.63	900 - 1020
2024	200000	423.28	382.98 - 463.60

*Estimated number of hooks calculated from 2024 data (This information was gathered by the Shipowners' Association of Lampedusa).



(a) (b)

Fig. 5a-b: A floating buoy used by fishers to reduce seabirds' access to baited hooks.

(e.g., 2 *C. diomedea*, 1 *P. yelkouan,* and 1 *L. michahellis*) during LLD fishing operations on a single trip. Fishers mentioned that unintentional catches of *C. diomedea* can occur from the end of February to April for all gear types, with the exception of LLD where catches are observed between April (the start of LLD fisheries) and May. Additionally, two fishers mentioned using a floating buoy that functions like a scarecrow to deter seabirds from accessing baited hooks during LLD operations (Fig. 5a-b).

In addition, fishers reported a significant number of sharks and rays for LLD, LLS, and OTB (Table 5). Bycatch of small sharks and rays was reported across nearly all fishing gears. Among the sharks, fishers estimated between 10 to 50 individuals of *S. canicula,* with 90% reported as alive for OTB, while 2 *I. oxyrinchus* were dead (1 in LHP and 1 in LLD), and 1 *Alopias supercilliosus* was alive in LLD. With regard to rays, all specimens were caught and released alive for all gears. Fishers

Table 5. Summary table reporting data collected during 29 interviews performed between 2022 and 2024: estimated average specimens accidentally caught per fishing trip with status at capture and at release per gear reported by fishers.

LLD					
Species	**N. specimens**	**Status at capture**		**Status at release**	
		Alive	**Dead**	**Alive**	**Dead**
Calonectris diomedea	8	1	7	1	7
Larus michahellis	1	0	1	0	1
Puffinus yelkouan	1	0	1	0	1
Isurus oxyrinchus	2	1	1	1	1
Alopias superciliosus	1	0	1	0	1
Prionace glauca	1	0	1	0	1
Caretta caretta	3	3	0	3	0
Pteroplatytrygon violacea	1-10	All	0	All	0
Dasyatis pastinaca	10 - 50	All	0	All	0
LLS					
*Dasyatis pastinaca**	1 -10	All	0	All	0
*Raja clavata**	1 -10	All	0	All	0
Mustelus mustelus	7	0	7	0	7
OTB					
Calonectris diomedea	3	3	0	3	0
*Raja miraletus**	50 - 100	All	0	All	0
Raja spp.*	50 - 100	90%	10%	90%	10%
*Scyliorhinus canicula**	10 - 50	90%	10%	90%	10%
Caretta caretta	1	1	0	1	0
LHP					
Calonectris diomedea	3	3	0	3	0
Isurus oxyrinchus	1	1	0	1	0
GN					
0	0	0		0	

* These species have low or no commercial value and are usually discarded at sea (Scacco *et al.*, 2015) or left dying at the stern during fish sorting (Bonanomi, unpublished data)

estimated catching between 50 to 100 specimens of *R. miraletus* and *Raja* spp. using OTB. Additionally, fishers reported catching between 1 to 10 specimens and 10 to 50 specimens of *D. pastinaca* for LLS and LLD, respectively. Moreover, fishers estimated catching between 1 to 10 specimens of *R. clavata* for LLS and *P. violacea* for LLD. Sea turtle bycatch was mainly reported for LLD (3 individuals) and also for OTB (1 individual), as shown in Table 5. No cetacean bycatch was recorded for any gear type.

Discussion

This pilot study assesses the impact of multiple gears on different marine megafauna species, with a particular focus on seabirds inhabiting the Pelagie Archipelago in the central Mediterranean.

The onboard observations revealed that 23.7% of the 215 hauls monitored by observers resulted in bycatch of various marine megafauna. Notably, a considerable number of seabirds (mostly dead) were recorded during a few observations in LLD, often involving multi-catch events. This suggests that this fishery is the most detrimental fishing activity operating around the Pelagie Archipelago. Despite a general decline in the total number of hooks deployed annually over the study period, the bycatch rate appears to have increased in recent years. The estimated annual fishing effort, expressed as the number of hooks deployed, indicated that the annual bycatch estimates were quite high throughout the study period. The trend displayed concerning fluctuations, especially with the sharp rise in 2023 (around 960 individuals) followed by a decline in 2024 (around 423 individuals). This estimate, derived from the small sample size of onboard observations, should be interpreted with caution. Nevertheless, these results highlight the urgent need for long-term monitoring strategies to protect seabird populations from the potential negative impacts of fishing activities. It is important to note that the majority of seabird bycatch occurred in the spring, with *C. diomedea* identified as the most affected species. This pattern likely reflects the species' foraging behavior during the pre-breeding and incubation periods, when *C. diomedea* adults engage

in intensive foraging prior to laying eggs (Becciu *et al*., 2012; Reyes-González *et al*., 2017). This species has a relatively large population, estimated at around 10,000 pairs, which is confined to a small breeding area, such as the Pelagie Archipelago (Baccetti *et al*., 2009; Dell'Omo, 2020). *C. diomedea* lay a single egg during each breeding season in May, with hatching occurring in mid-July. Parent birds undertake foraging trips at sea between May and October (Cecere *et al*., 2013; Cianchetti-Benedetti *et al*., 2017). This time period coincides with the activities of the LLD fleet operating around the Pelagie Archipelago. The scavenging behavior of this species around fishing vessels increases the risk of bycatch, particularly when baited hooks are left accessible at the surface before sinking. In autumn, once breeding ends, *C. diomedea* begin their southward migration to wintering grounds in the Atlantic Ocean, which reduces their interaction with Mediterranean fisheries (Müller *et al.,* 2014). However, juveniles and non-breeding individuals may still be present in foraging areas, thereby maintaining a certain level of bycatch risk (Péron & Grémillet, 2013).

Similar information was gathered during the interview survey, with fishers reporting the incidental capture of at least 8 individuals, mainly *C. diomedea,* per fishing trip during LLD operations. Consequently, these findings suggest that bycatch events are common in LLD fisheries, which may impact the survival of *C. diomedea* in the area. Notably, the interview survey revealed that fishers appear to be aware of the interactions between seabirds and LLD operations. This work documents an initiative by a few fishers (a floating buoy) to reduce such interactions. However, greater attention needs to be given to the LLD fishery in the near future to determine its impact on seabirds, particularly *C. diomedea* that inhabit the area.

In this study, observers did not record any bycatch events involving seabirds during LLS operations. The monitoring covered only a small number of hauls (7) in the LLS fishery, suggesting that bycatch events for seabirds could be expected if the monitoring activity for this fishery increases. Fishers reported catching at least 1 *C. diomedea* per fishing trip during the interview survey. In other areas of the Mediterranean, the impacts of fisheries on seabirds have been widely documented for LLS. For instance, Lago *et al*. (unpublished data) reported high numbers of 3 species of shearwaters endemic to the Mediterranean Sea being bycaught in LLS and "palangrillo" in the Levantine-Balearic region of the Spanish Mediterranean. Militão *et al*. (2014) highlighted a massive bycatch of Yelkouan and Balearic shearwaters by longliners along the Catalonia coast. Additionally, Cortés *et al.* (2017) provided a conservative estimate of seabird bycatch, ranging from 274 to 2,198 seabirds annually in LLS in the Balearic Islands. García-Barcelona *et al*. (2010) calculated an average total bycatch estimate for the fleet during that period to be around 500 birds per year, including approximately 200 Cory's shearwaters. Data from Malta (Dimech *et al*., 2009) and Greece (Fric, 2013; Karris *et al*., 2018) also indicate that bycatch of shearwaters occurs in these waters. Bycatch is considered as one of the factors contributing to the decline of shearwaters; for instance, this has been documented for the Balearic shearwater in Spanish waters (Genovart *et al*., 2017b; Courbin *et al*., 2024). However, populations may also be negatively impacted by other factors, including introduced predators and invasive non-native species (e.g., rats and cats), traditional human consumption by local inhabitants, shooting, habitat degradation, and pollution (Yésou *et al*., 2011). Therefore, there is reason to believe that bycatch could have detrimental effects in the study area.

In the Mediterranean, incidental bycatch from longline fisheries is one of the major sources of seabird mortality (FAO, 2016). However, information regarding this threat remains limited to a few regions and species. This is particularly true for *C. diomedea,* which has been extensively documented in the western Mediterranean for both LLD and LLS (Belda & Sánchez, 2001; Cooper *et al*., 2003; Laneri *et al*., 2010; Igual *et al*., 2009; García-Barcelona *et al*., 2010) and in the central Mediterranean, particularly in Malta, at least for the LLD fishery (Dimech *et al*., 2009). However, data is scarce or absent for other areas within this sea basin. In the central Mediterranean, populations from different colonies of *C. diomedea* may act as a metapopulation that utilizes different regions, such as Malta, Sicily, and Tunisia for foraging (Cecere *et al*., 2014; Grémillet *et al*., 2014; Cianchetti-Bendetti *et al*., 2018; Campioni *et al*., 2022). These potentially overlap with fishing vessels in several of these areas, underscoring the importance of having a coherent network of well-managed protected areas. Four pelagic Important Bird Areas (IBAs) have been identified in Italy, which hold internationally significant numbers of breeding *C. diomedea.* Among these is the IBA that encompasses the Pelagie Archipelago. These areas have been designated under the Birds Directive as Special Protected Areas (SPA ITA040013) that extend over 110.66 km^2 and include the waters surrounding Linosa, located south of Sicily. The great concentration of important colonies of *C. diomedea* in the Strait of Sicily, along with their overlap with important fishing grounds, must be taken into account when evaluating potential threats to this species and other marine megafauna. Bycatch may pose a serious risk to several taxa, as demonstrated by various studies conducted in other parts of the Mediterranean Sea, and could ultimately contribute to the decline of certain populations (Simantiris *et al*., 2025).

Other marine megafauna was unintentionally caught during the study period, and similar information was gathered from interviews with fishers. Specifically, the most common bycaught species were demersal sharks and rays that have low or no commercial value, primarily *S. canicula* and *Raja* spp. (mostly *R. miraletus*), which were recorded for OTB, followed by *D. pastinaca* mainly bycaught using LLD. These species may therefore be threatened by multiple gears, and since their population status is uncertain or unknown (Serena *et al*., 2016; Dulvy *et al*., 2020; Finucci *et al*., 2021), there is an urgent need for further investigation in the area. In the case of pelagic sharks, only a few individuals of large-bodied species such as *I. oxyrinchus*, *A. superciliosus,* and

P. glauca were unintentionally caught using LLD. In addition, a concurrent investigation conducted between 2021 and 2022 documented the incidental capture of 15 *I. oxyrinchus* (including juveniles and young-of-the-year) with LLD around Lampedusa, Levante Shoal, and Linosa (Cattano *et al*., 2021, 2023). This suggests that bycatch may be contributing to the already documented decline of this species and other large-bodied sharks (De Santis *et al*., 2025). This highlights the need for a more concentrated effort to understand the current status of the population, which is crucial for implementing tailored conservation actions.

In addition, a small number of *C. caretta* individuals were also unintentionally caught during LLD operations, all of which were released alive by observers. Previous investigations have documented bycatch of sea turtles in LLD and OTB within the Pelagie Archipelago through a voluntary logbook program (This citation is missing from the references. Either indicate it or let us know if you intend to delete it. Please reply to this comment.). Mitigation measures, such as circle hooks, were initially identified as promising tools for reducing sea turtle bycatch in LLD. However, their popularity among fishers has declined due to the loss of significant sizes of commercially viable large pelagic fish, such as swordfish and albacore tuna. Therefore, further research and concrete actions are necessary to strengthen existing conservation measures and to reduce both bycatch and mortality rates of sea turtles in the Pelagie Archipelago.

This study is subject to a number of limitations. First, the information gathered should be regarded as very preliminary, due to the low number of observations and interviews conducted. Importantly, this study incorporates fishery-dependent data, which may be influenced by intrinsic bias associated with the stochastic nature of marine megafauna distribution, as well as a lack of a clearly defined sampling design for monitoring activities in space and time. Indeed, the unequal distribution of monitoring activities was conditioned by fleet dynamics (e.g., fish market preferences and price, with the majority of fishers also owning restaurants and other tourism-related businesses) as well as bureaucratic delays associated with the project. These factors affected both the observed patterns and the estimation of bycatch events. Nevertheless, it is important to highlight that a high bycatch rate has been recorded for both elasmobranchs and seabirds. Notably, seabird bycatch had not been previously reported in the Pelagie Archipelago and has been seldom documented in Italian waters in general (Salvador *et al*., 2025).

Second, there appears to be no official data on the Lampedusa fleet's fishing efforts. Currently, the only available data comes from the local Shipowners' Association of Lampedusa. It is likely that official data is amalgamated with that of the entire fleet of Sicily, the Italian region to which Lampedusa belongs. Nevertheless, most fishing vessels operating off Lampedusa are polyvalent small-scale vessels, which switch between different gear types depending on the target species and the season. The estimation of the actual fishing effort may be affected if a gear type is inaccurately recorded in the landing statistics. In this study, the available fishery statistics, which should represent the best available source of information, should be interpreted cautiously in relation to the total bycatch estimates that have been calculated. In addition, the absence of bycatch data for certain fishing gears may stem from several factors, such as the low probability of encountering marine megafauna during specific fishing activities and the limited availability of bycatch data from neighboring regions (i.e., Malta and Tunisia). This situation is common in fisheries, where data on non-target species, such as seabirds, some elasmobranchs, and sea turtles, are recorded less frequently than that of target species. However, over the past few decades, spatiotemporal changes in large-bodied sharks (De Santis *et al*., 2025) have been documented in the Pelagie Archipelago. Those changes may be influenced by various factors, such as historical target fishing activities in the area concerning large-bodied sharks (De Santis *et al*., 2025). In the case of seabirds, particularly *C. diomedea*, their breeding populations may be affected not only by fishing interactions but also by light pollution (Rodríguez *et al*., 2015a, b) and by predation from rats and cats (Baccetti *et al*., 2016; Ozella *et al*., 2016; Ječmenica *et al*., 2020). Furthermore, *C. diomedea* has long been classified alongside Cory's shearwater *Calonectris borealis*, as the two species were often referred to collectively as Cory's or had been treated as subspecies (Sangster *et al*., 2012). Therefore, given these considerations and the fact that previous estimates are outdated (Baccetti *et al*., 2009), a thorough assessment of the population size and structure of *C. diomedea* is clearly needed in the Pelagie Archipelago and neighboring areas.

Conclusion

Over the past decades, research has increasingly focused on marine megafauna bycatch in Italian fisheries. However, there has been less emphasis on seabird bycatch. To the best of our knowledge, this work represents one of the first comprehensive attempts to assess seabird bycatch in Italian waters. It clearly highlights the urgent need for enhanced observer coverage and reporting of bycatch information to accurately quantify the scale of the issue. Overall, a comprehensive monitoring program to assess the incidental catch of vulnerable species should be implemented throughout the area. This is also mandated by the Data Collection Framework (2008/2017) Directive of the Common Fisheries Policy (CFP), which requires Member States to gather data to assess the impact of EU fisheries on marine ecosystems both within and outside EU waters, including data on the bycatch of protected species (Art. 5). Currently, the Pelagie Archipelago is not included in such a comprehensive data collection program, and other regions may experience inadequate investigations (e.g., LIPU's initial survey on the west coast of Sardinia). This situation has become even more urgent following the European Commission's recent decision to initiate an infringement procedure by sending a letter of formal notice to Italy (INFR(2023)2181). This

action is due to Italy's failure to implement the necessary measures outlined in the Habitats Directive (Directive 92/43/EEC) for monitoring and preventing the bycatch of cetaceans, turtles, and seabirds by fishing vessels. Combining increased efforts for systematic data collection on both bycatch and fishing efforts, as required under the revised EU Fisheries Control Regulation (Regulation EU 2023/2842), along with the implementation of effective mitigation measures, is of paramount importance to minimize bycatch. This is crucial for achieving the ambitious national and international conservation commitments and goals set forth by the EU Biodiversity Strategy for 2030, the Birds and Habitats Directives (BHD), the Marine Strategy Framework Directive (MSFD), the Common Fisheries Policy (CFP), the Convention on Biological Diversity (CBD), and the Convention on Migratory Species (CMS).

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Supplementary Data

The following supplementary information is available online for the article:

Table S1. Summary table reporting the number of hauls (with zero and positive catches) and number of individuals caught (sharks, rays, seabirds, sea turtles) recorded during the onboard observations conducted between 2021 and 2024.