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RESEARCH

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Insights into bycatch reduction based on underwater observations of Yelkouan shearwater (*Puffinus yelkouan*) and Atlantic Puffin (*Fratercula arctica*) interactions with the French pelagic longline fishery in the Western Mediterranean

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Abstract The Mediterranean Sea is a significant habitat for seabirds, including endemic and endangered species. However, French pelagic longline fisheries overlap with foraging zones of seabirds, posing risks of bycatch. Insufficient monitoring and reporting hinder efforts to understand and mitigate these interactions. To identify effective fisheries bycatch mitigation measures, documenting species-fishing gear interactions and foraging strategies for each species are needed. Seabird underwater interaction processes were investigated in situ on pelagic longline gears. Cameras affixed on branchlines 1–2 m above the hook were deployed between May 2022 and June 2024 to enable a precise description of interactions of various species with baited hooks, including the Yelkouan Shearwater (*Puffinus yelkouan*) and the Atlantic Puffin (*Fratercula arctica*). Foraging strategies are documented for the two pursuit-diving seabirds. The Yelkouan Shearwater foraged in association with conspecifics and competitive events were observed. Videos revealed cryptic events of successful and unsuccessful attempts in consuming the bait during the gear soak at depths to ca 10 m. Underwater interactions occurred during the gear soak on unattended gear, while the vessel was away from the site. The Yelkouan Shearwater and the Atlantic Puffin may have developed strategies to feed on pelagic longline bait. These observations suggest that bycatch mitigation approaches are needed during multiple phases of fishing operations, and not just during setting and hauling as is the prevailing paradigm. Technical seabird bycatch management measures tailored to regional fishing practices are proposed and discussed.

Keywords Bycatch · Foraging · Gear soak time · Pursuit-diving seabird · Underwater video

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Introduction

For seabirds, foraging remains their primary activity (Nelson 1980). Their high numbers are frequently observed near pronounced physical features such as eddies, current fronts, water mass boundaries, and frontal zones where temperature or salinity gradients exist or around seamounts that boost primary production and increase prey availability (Ballance et al. 2001). In addition, many seabirds can

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detect odour trails carried by ocean currents (Nevitt and Bonadonna 2005). Relying on visual cues, they tend to orient themselves toward areas with high concentrations of top predators or fishing vessels, actively seeking or recognizing these features (Martin and Prince 2001; Tremblay et al. 2014). It is also common for them to gather around fishing vessels to take advantage of non-retained fish, offal, and spent bait discarded during operations (Martínez-Abraín et al. 2002; González-Zevallos and Yorio 2006; Grémillet et al. 2008; Louzao et al. 2009; Cianchetti-Benedetti et al. 2018).

Interactions of seabirds with longline fishing gear can cause fatal outcomes. Seabirds may get hooked or entangled in the line and, unable to reach the surface during the gear soak, die by drowning. In some surface longline configurations, birds might remain on the surface after being caught and can be released during the hauling phase (Brothers et al. 1999a, b), not without potential long-term survival impacts (Zollett and Swimmer 2019). Seabird bycatch in longline fisheries is a major concern for their conservation globally. The resulting mortality can be unsustainable for certain species and populations, particularly petrels, albatrosses and shearwaters (Brothers et al. 1999b; Gilman et al. 2005; Anderson et al. 2011; Genovart et al. 2016; Gray and Kennelly 2018; Dias et al. 2019; Zhou et al. 2019).

The Mediterranean Sea provides critical habitat for seabirds, including several endemic and endangered populations. While these seabirds face threats from introduced predators such as rats and cats (Bourgeois et al. 2008), entanglement in marine litter (Bergmann et al. 2015; Alessi et al. 2024), impact from oil spills (Mahrer 2023) and plastic ingestion (Clark et al. 2023), there is a growing concern regarding their interactions with fisheries. In particular, the documentation of seabird bycatch has increased over recent decades (Thibault 1993; Cooper et al. 2003; Arcos et al. 2008; Garcia 2013; Karris et al. 2013; Soriano-Redondo et al. 2016; Cortes and Gonzalez-Solis 2018; Ramírez et al. 2024), and bycatch in longline fisheries is now considered a primary driver of population declines among the three shearwater species: Scopoli's (*Calonectris diomedea*), Balearic (*Puffinus mauretanicus*), and Yelkouan Shearwater (*Puffinus yelkouan*) (Dimech et al. 2009; Barcelona et al. 2010; Cortés et al. 2017, 2018).

A previous study found that 182 seabirds (seven species) were caught as bycatch in Spanish pelagic longline fisheries in the Western Mediterranean between 2000 and 2008. Most affected were the Yellow-legged Gull (37.4%) and the Scopoli's Shearwater (36.8%), with an average of 0.038 birds per 1000 hooks during the study (Barcelona et al. 2010). From 2003 to 2015, 639 shearwater carcasses were collected from Spanish longliners in the Northwestern Mediterranean, mostly adults caught during the pre-laying period, mainly from the Balearic Islands, but also from French and Italian colonies (Cortés et al. 2018). In the Maltese longline fishery, the total estimated annual by-catch for Maltese vessels was approximately 1220 Scopoli's shearwater and 17 Yelkouan shearwater (Dimech et al. 2009). Despite the development of various methodologies aimed at mitigating seabirds mainly in semi-industrial pelagic longline fisheries (Brothers et al. 1999b; Løkkeborg 2011; Melvin et al. 2014), the efficacy of some of these methods in reducing seabirds' lethal interactions remains uncertain for small scale vessels in the Mediterranean. Anderson et al. (2011) highlighted the fact that seabird bycatch could be reduced rapidly to negligible proportions by implementing accurate technical mitigation. Several provisions should be considered as there is no single solution and the efficacy of a measure is specific to each fishery.

In the French EEZ (Exclusive Economic Zone), little is known about the incidental catches due to very low observer coverage onboard longliners and the reluctance of fishers to declare interactions and bycatch data. Consequently, the French longline fisheries impact on Mediterranean Sea populations of seabirds remains understudied. To address this, mobile phone application for bycatch reporting and leaflets with guidelines for handling and releasing seabirds have been provided to fishers. These materials were intended to encourage greater collaboration between fishers and scientists (Poisson et al. 2016a, 2016b).

Along the French Mediterranean coast, in addition to pelagic longline fisheries, fishery resources are exploited by numerous fisheries with which seabirds could interact, particularly the French bottom trawl fishery, which operates along the entire coast of the Gulf of Lions (Aldebert 1997; Lleonart and Maynou 2003; Farrugio 2013; Dorémus et al. 2024). Trawlers operate near the port base, five days a week, and the catch is sold daily at local auctions (Hopkins et al. 2024). Around Corsica Island, four main metiers (fish net, spiny lobster net, bottom longline and pelagic longline) operate and are all considered to be small-scale fisheries (Bousquet et al. 2022).

At the regional level, the General Fisheries Commission for the Mediterranean (GFCM) made a recommendation in 2011 (Recommendation GFCM/35/2011/3) in line also with the FAO International Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (FAO-IPOA Seabirds), on reducing incidental bycatch of seabirds in fisheries. The GFCM measure proposed a list of mitigation measures in place in other regions (Recommendation GFCM/44/2021/13 on the mitigation of fisheries impacts for the conservation of seabirds in the Mediterranean Sea). As other recommendations dealing with sensitive species, it is not binding. The proposed mitigation measures have been tested at the regional level (Cortes and Gonzalez-Solis 2018).

Nevertheless, for stronger recommendations on specific seabird bycatch mitigation measure requirements in the Mediterranean pelagic longline fleet, there is a clear need to improve our understanding of the mechanisms that contribute to seabird bycatch risk in the fishery. Detailed documentation of species-specific interactions with fishing gear, as well as insights into their foraging strategies (Poisson et al. 2022) together with knowledge of their life history, ecology, and distribution (Richards et al. 2021) are essential for the development of effective bycatch mitigation measures.

In recent years, biological technology has sparked a revolution in elucidating key aspects of seabird life: spatiotemporal distributions, oceanographic preferences and migration routes, as well as foraging behaviours and strategies including diving abilities (Ballance et al. 2001; Péron et al. 2012; Yoda 2019; Michel et al. 2021; Poupart et al. 2025). Cameras attached to seabirds have provided valuable information on their diving behaviour, group dynamics and association with other predators during foraging (Takahashi et al. 2004; Watanuki et al. 2008; Sakamoto et al. 2009). While the development of bio-logging technology has enabled the recording of animal behaviour, attaching cameras to fishing gear allows for the recording of animal behaviour and interactions specific to the fishing gear. In this study, we applied an innovative approach by instrumenting pelagic longlines with cameras to document the in situ underwater dynamics of the gear components and to investigate the interactions of all individuals approaching the longline (Poisson et al. 2022). The aim of this study is to present and comment on three specific cases of underwater interactions between seabirds and surface longlines using different fishing practices in the French Mediterranean EEZ, the Gulf of Lions and the island of Corsica.

Whilst these events are by definition cryptic, analysis of the video footage has provided previously unavailable ecological insight. Management initiatives and technical mitigation measures based on this new understanding of interactions during gear soak are discussed.

Materials and methods

Fishing technique

Data were collected from two pelagic longline fishing grounds: Corsica Island and the eastern Gulf of Lions. In Corsica Island, a total of 27 shallow-set fishing operations were observed from May 2022 to February 2023. In the eastern Gulf of Lions, 13 sets were observed from May to July 2023 and in June 2024. Onboard scientists observed the presence of seabirds from the vessel deck during the setting and hauling phases.

The experiments were conducted aboard small-scale, artisanal, pelagic longline vessels targeting swordfish (*Xiphias gladius*) and bluefin tuna (*Thunnus thynnus*) using two different fishing gear configurations. In both cases, the mainline was fitted with pre-mounted hooks, which were stored in large buckets and cast manually during setting. Their fishing grounds ranged from 8 to 30 nautical miles (nm) from the coast.

Anchored surface longline—Japanese tuna hook and mackerel or squid as bait

In Corsica Island, experiments were conducted on a 10 m long vessel based in Bastia on the North eastern coast in the Tyrrhenian Sea. An anchored surface pelagic longline was used as currents can be strong in this fishing ground. The line was set before dusk for two consecutive days (600–800 hooks). On the second day, the line was checked for any caught fish (when floats had sunk), without necessarily hauling in the line ("line visit"). The gear was hauled on the third day. The monofilament 1.9 mm diameter main line was set at 3–4 knots (vessel speed = line setting speed) with branchlines attached at 30-m intervals. Floats were attached at every sixth branchline and the branchlines were made of 1.3 mm-diameter monofilament measuring 5 m in length. Japanese style tuna #4/00 hooks were baited with whole thawed mackerel (*Scomber scombrus;* 14–16 cm fork length) or whole thawed squid (*Illex sp*.; 15–18 cm mantle length) (Fig. 1). The hooks were threaded through the rear of the squid and through the mackerel back muscles.

Drifting surface longline – circle hook and sardine or squid as bait

The second campaign was conducted in the western Gulf of Lions onboard an 8.55 m long vessel based at Port-Vendres. The monofilament 1.8 mm diameter main line was set at 2–3 knots (vessel speed = line setting speed) with branchlines attached at 25 m intervals. Floats were attached every six branchlines, and branchlines were 1.4 mm diameter monofilament measuring 6 m. Stainless circle #12/0 hooks were baited with sardine (*Sardina pilchardus*) attached by the eye (5–8 cm fork length). Just-thawed sardines were placed on the hooks before departure. The line was set at around 3 am (night sets) and hauled after sunrise. In 2024, northern shortfin squid (*Illex illecebrosus*) (13–18 cm mantle size) was used for bait and was attached to the hook at the rear of the mantle. Between 350 and 600 hooks were deployed per set.

Fig. 1 Hook types used during the experiments: Circle hook (on the left) used in the Gulf of Lions, Japanese tuna hook (on the right) used in Corsica

Line-mounted video camera setup

Two types of high-definition underwater video cameras (Spydro and WaterWolf™2.1 underwater cameras) were used to document the underwater dynamics of the fishing gear and to record animal interactions with the baited hook. Spydro cameras were programmed in "continuous recording mode" with the footages automatically saved as one-minute clips (Video Resolution:1080P/30FPS). The Spydro cameras have built-in LED lighting to improve visibility in low light underwater conditions. The LEDs setting used was a sequence of continuous light and flashes. Water Wolf 2.1 cameras were programmed to record 10-min video clips (S1).

Cameras were attached to the branchline, facing downward, approximately 1–2 m above the hook during the line setting phase (Poisson et al. 2022). Some cameras were replaced during the "visit of the line", a day after setting. Between 4 and 38 cameras attached to the branchline facing downward toward the hooks were deployed during fishing operations.

Video analysis

All video segments were reviewed by at least two observers to detect the gear interactions with animals. To identify and to describe the behavioural patterns, videos were viewed several times, sometimes in slow motion, to pinpoint the beginning and end of each particular behaviour. BORIS software (Friard and Gamba 2016) was used to analyze video files and to generate ethograms and activity time budget.

Species biology and ecology

Our study focused on three species commonly observed in the fishing grounds namely the Yelkouan and Scopoli's Shearwaters and the Atlantic Puffin (Beaubrun et al. 2013; Garcia 2013). No underwater observations were obtained of Scopoli's Shearwaters. Along with the observations collected at sea, the collation of information on their biology helped us to confirm the shearwater species observed underwater. The Yelkouan Shearwater is able to dive frequently to at least 20 m while foraging, whereas the Scopoli's Shearwater rarely dives deeper than 4 m (S2) (Paiva et al. 2010; Péron et al. 2013). A wide review of the literature describing the endemic Yelkouan and Scopoli's Shearwaters behaviour and GPS (Global Positioning System) tracking data were conducted in order to identify overlap between the fishing fleets studied and seabird foraging grounds. The Atlantic Puffin is primarily a North Atlantic species, known for its breeding colonies in places like Iceland, Norway, and the British Isles and to winter in the Western Mediterranean. Although there have been more frequent sightings in the Western Mediterranean Sea in recent years, the information on the species in this region is still lacking.

Results

Observations of seabird interactions with fishing vessels and of bycatch

Two shearwater species, identified as Yelkouan and Scopoli's Shearwaters, were observed at the rear of the vessels skimming over the surface and making large loops during the line setting. They remained airborne near the baited hooks and landed on the water close to where the bait began to sink. While on the water, they submerged their heads to search for potential prey (Fig. 2), and then either dived to catch it or took off to approach the boat. These behaviours were observed when setting the line, but also when bait was discarded at sea during the hauling phase. No seabird captures were recorded on underwater video.

However, one Yelkouan Shearwater was bycaught during operations in Corsica Island, as detected by the onboard scientist during gear hauling. The hook had been ingested and the shearwater died from the extensive injuries, shortly after being taken onboard.

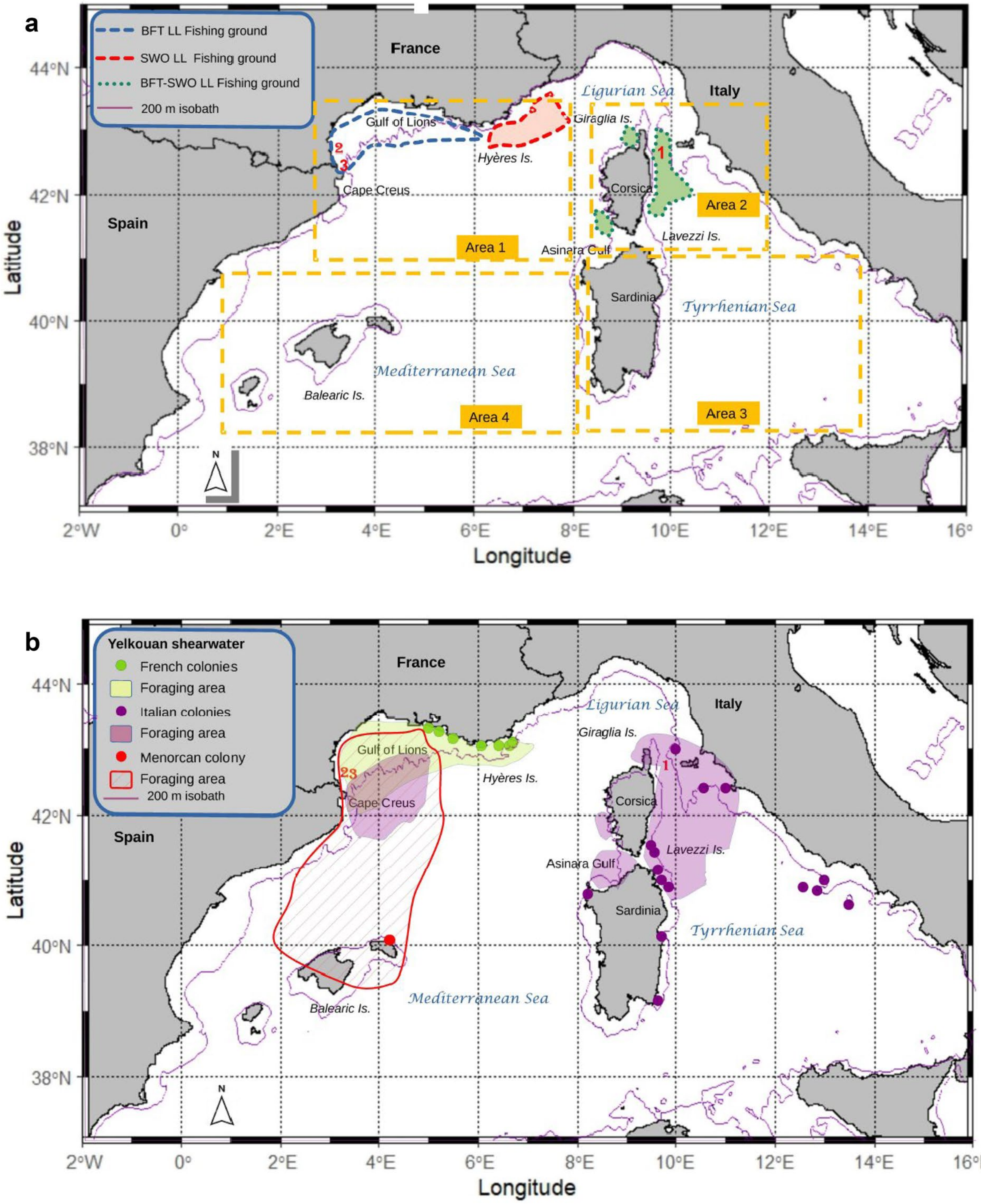
On 17 and 19 June 2024, around the full moon, more attention was paid to seabird behaviour. The light from the moon allowed us to see if any seabirds were present while hauling at night. Thus, we observed about 40 individuals flying around the baited hook coming to the surface, concentrated 150 m in front of the bow of the vessel. This behaviour continued until the end of the hauling phase at night at around 11 pm. Only a few entire or partial baits (squids) were retrieved on the hooks during hauling. The individual seabirds could not be identified to species level.

Overlap between French Longline fishing grounds and Yelkouan and Scopoli's Shearwaters foraging areas

Nesting colonies of the Yelkouan and Scopoli's Shearwaters are often associated. We have considered here four main breeding colonies areas for both species in the Central/Western Mediterranean (Fig. 3a, S3), they could be classified as such:

Breeding colonies of Yelkouan and Scopoli's Shearwaters are distributed across several key areas in the central and Western Mediterranean, notably along the French mainland (Hyères archipelago, Gulf of Lions) (Area 1), northern Corsica Island (La Giraglia) (Area 2), southern Corsica Island (Lavezzi Islands) (Area 3), and the Balearic Islands (Area 4). Tracking studies have demonstrated that adult Yelkouan Shearwaters, particularly during chick-rearing, routinely forage over broad areas extending from

Fig. 2 Pictures showing a Yelkouan Shearwater (*Puffinus yelkouan*) in the Gulf of Lions, foraging behind a longline vessel, actively searching for prey by peering under water before diving (photo François Poisson)



these colonies towards productive marine regions such as the Gulf of Lions and adjacent continental shelves, typically traveling up to 400 km per trip (Péron et al. 2013; Austin et al. 2019; Pezzo et al. 2021). These trips often lead them directly into active

◂**Fig. 3** Maps showing a—the French pelagic longline bluefin tuna and swordfish fishing grounds, seabird underwater observation sites 1: Shearwater (2022/05/24)- 2: Atlantic Puffin (2023/06/01)- 3: Shearwater (2023/06/04), the four main breeding colony areas identified, the 200 m bathymetry and breeding colonies of Yelkouan Shearwaters in the French mainland (Hyères archipelago, Gulf of Lions) (Area 1), northern Corsica Island (La Giraglia) (Area 2), southern Corsica Island (Lavezzi Islands) (Area 3), and the Balearic Islands (Area 4); b- the foraging area (in June-July) derived from the tracking data are also delineated for the Yelkouan Shearwater French (Péron et al. 2013), Italian (Pezzo et al. 2021) and Menorcan colonies (Austin et al. 2019)

French pelagic longline fishing grounds, as shown in Fig. 3.

Similarly, Scopoli's Shearwaters have been tracked frequently foraging close to their colonies but also along productive coastal areas, with individuals from Corsican and Balearic colonies regularly overlapping with the studied fishing regions (Zotier et al. 1999; Cecere et al. 2014).

The Atlantic Puffin overwinters in small numbers in the Western Mediterranean while its breeding colonies are in the Northern Atlantic.

Behavioural patterns observation

During video analysis, two types of behaviours have been defined, the "Point event behaviours" to document fast and sudden behaviours and "State event behaviours" for behaviours that occur over a period of time and when the behaviour start and stop can be recorded. A list of point and state event behaviours was defined for both species (Table 1).

Description of the sequences

Atlantic Puffin observed interactions

During the setting which occurred late afternoon on 1 June 2023 between 06:00 and 07:38 pm starting at 42° 37′ 0″ N; 3° 9′ 9″ E, no Atlantic Puffins were observed from onboard the vessel. The Water Wolf 2.1 camera which recorded the puffin interaction with the baited hook was set at ca 06:17 pm, while the interactions with the Atlantic Puffin occurred at around 07:05 pm local time, around 50 min after the camera deployment. At that time, the vessel was still setting the line about 4 nautical miles away from the interaction site. Pictures in Fig. 4 show typical behaviours identified for this species.

The complete ethogram for the observation period is presented in Fig. 5 and the corresponding activity budget is shown in Fig. 6.

The Atlantic Puffin's interaction with the baited hook was brief, lasting only two minutes. Initially, it appeared at the right bottom of the screen in the camera's field of view, at several meters below the hook, moving horizontally. Then, it re-appeared 19 s later seemingly coming from the surface. After a first contact with the sardine, it seized the bait to return to the surface, while the line got tight it released it. It repeated this operation 5 times.

The seabird returned after a 45-s gap and exhibited other behaviours. After grabbing the bait in its beak, it shook its head and engaged a complete turn along the branchline axis. Eventually, it unhooked, dropped it, then circled around it and ingested it before disappearing from view. After 38 s we can see it again, a few meters below the hook trying to feed on leftover sinking bait. It is also important to notice that the hook in this case is highly visible and not hidden by the bait. This seemingly does not repel the seabird.

Yelkouan Shearwater observed interactions

The interaction observations of Yelkouan Shearwaters with the baited hook occurred in Tyrrhenian Sea on the eastern coast of Corsica on 24 May 2022 and was recorded on two spydro cameras (9 and J) (Fig. 7) (Poisson 2022). The longline had been set the day before, the two cameras were deployed in the morning during the "visit phase" at 42° 48′ 17″ N; 9° 32′ 41″ E, at 08:06 am and 08:09 am respectively. The images of two individuals interacting with the hook baited with mackerel were recorded at around 10:00 am, almost 1h50 minutes after their deployment. At that time, the vessel was far away from the location of theses interactions.

Spydro 9:

One Yelkouan Shearwater coming from the surface appeared to head towards the hook but went back before reaching its target. After several unsuccessful attempts to grab the bait, it started a rotation followed by a second one around the bait.

Spydro J:

Table 1 Classification of behaviour patterns of seabirds towards a hooked bait

Species	Event status	Behaviour patterns	Description of the seabird behaviour
Atlantic Puffin	State events	Apparition/disappearing	Enters in the camera range (Horizontal-upwards, downwards)
		Bait lifting sequence	Grabs the bait and pull upwards
		Circling around the bait	Looping on its axis
		Turn	Changing direction
	Point events	Eating	Grabbing the bait and shaking its head
		Off-hook	Removing bait from the hook
		Contact-bait	Contact with the bait/pinching the bait
Yelkouan Shearwater	State events	Apparition/disappearing	Entering in the camera range (Horizontal-upwards, downwards)
		Bait lifting sequence	Attempts to grab the bait with its beak and to lift it at the surface
		Surfacing	Moving towards the surface
		Circling around the bait	Looping on its axis
	Point events	Pinching bait	Attempts to plant its beak into the bait
		Heading towards camera	Moving towards the camera
Both	Point event	Contact-camera	Touching the camera

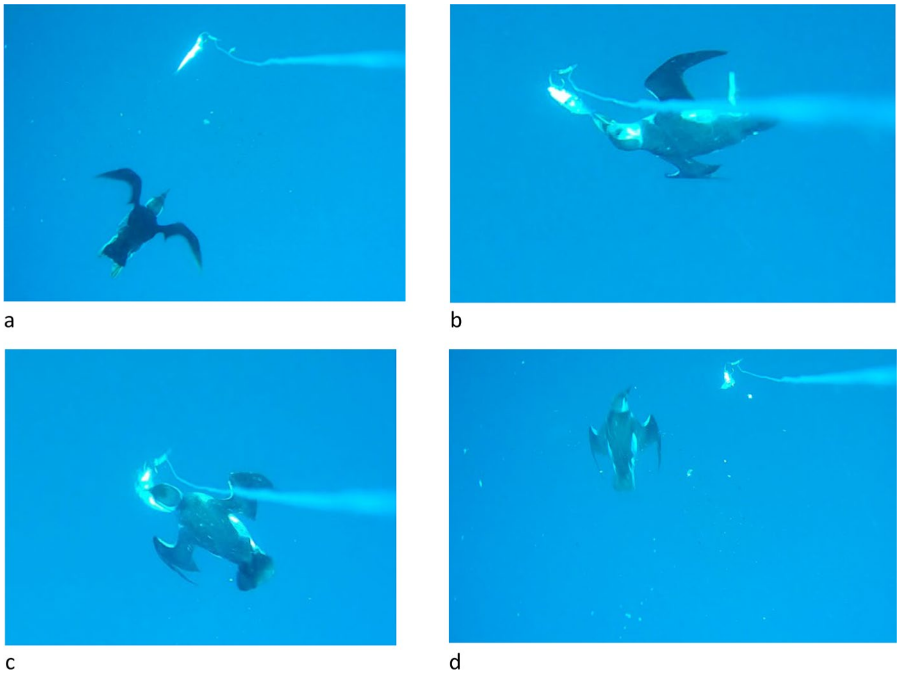


Fig. 4 Details of the underwater observation of the Atlantic Puffin (*Fratera artica*) in the vicinity of the baited hook which occurred at around 7 pm: at a depth of ca. 10 m in the Gulf of Lions on 1 June 2023 a-appearing-, b-contact-bait, c- bait lifting sequence, d-turn –(Video ID 54085; https://doi.org/10.24351/99950) (Poisson 2023)

In the second case, the camera was attached higher on the branchline, giving a broader perspective. It allowed us to see that the bird arriving horizontally at a depth below the hook. The Yelkouan Shearwater moved upward to reach the baited hook, slowed down to approach the bait from above and then headed down to try and catch the mackerel with its beak. It then swam away as a congener arrived from the surface. A competitive event between conspecifics were observed (Fig. 7c).

The complete ethogram for the observation period is presented in Fig. 8 and the corresponding activity budget is shown in Fig. 9.

The third interaction of a Yelkouan Shearwater took place in the Gulf of Lions on 4/06/2023 recorded on one Water Wolf 2.1 (#7) deployed at

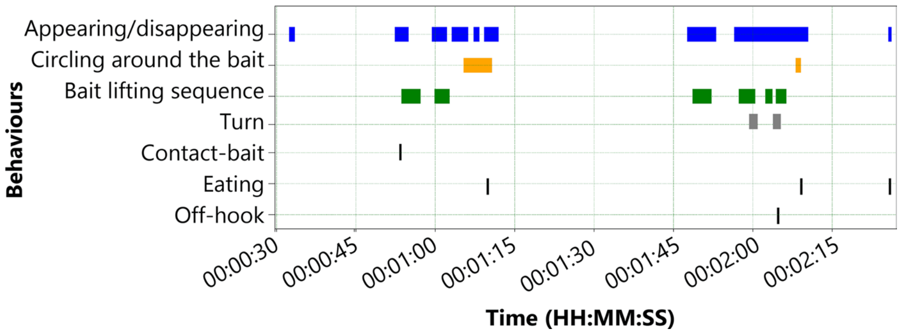


Fig. 5 Activity budget plot for the Atlantic Puffin (*Fratera artica*) during an interaction with a baited hook

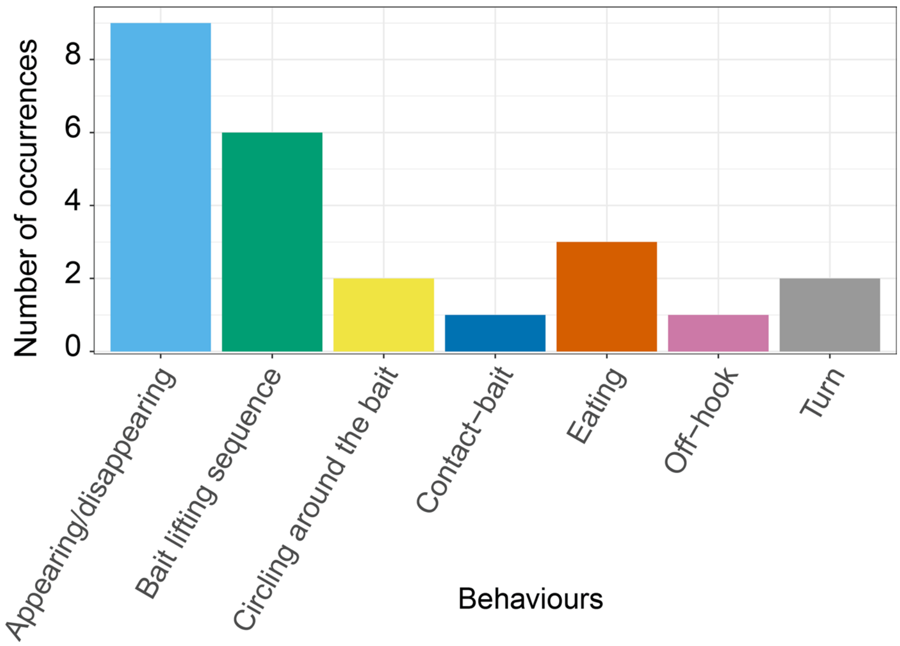


Fig. 6 Time budget for the Atlantic puffin (*Fratera artica*) during an interaction with a baited hook

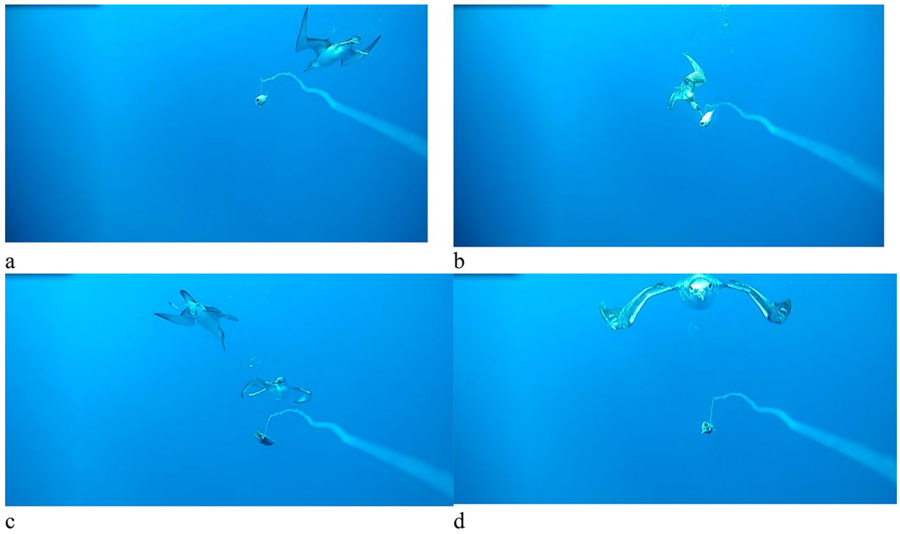


Fig. 7 Details of the underwater observations of Yelkouan Shearwater (*Puffinus yelkouan*) around Corsica Island, which occurred at around 8 am on 24 May 2022. Observations were made at two baited hooks, about 150m apart, fitted with separate cameras, attached 1–2 m above the hooks: a-appearing, b- approach to the bait, c-competitive event with one conspecific, d -heading towards camera (videos https://doi.org/10.24351/101595 ID 54178 and ID 54176) (Poisson 2022)

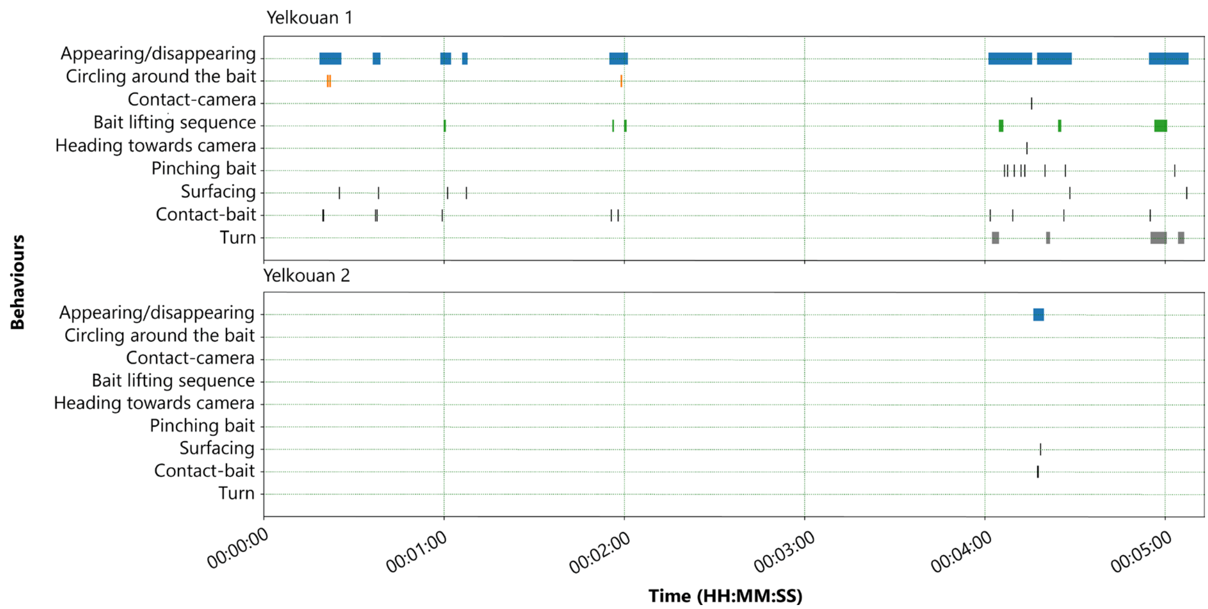
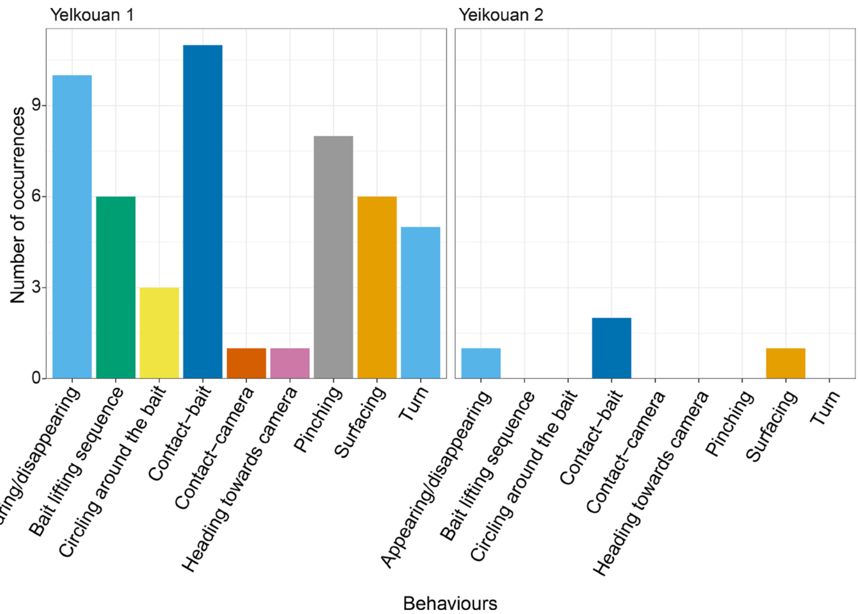


Fig. 8 Activity budget plot for the two Yelkouan Shearwaters (*Puffinus yelkouan*) during an interaction with a baited hook detected by camera spydro camera J

Fig. 9 Time budget plot for the two Yelkouan Shearwaters during an interaction with a baited hook detected by camera spydro camera J



4:19 am at 42° 37′ 19.16"N and 3° 12′ 42.12"E. The longline setting started at 3:44 am and finished at 5:09 am. The hauling phase started at 6:34 am but shearwaters were seen flying around the vessel from 6:00 am going back and forth far away from the vessel. The attack occurred at 7:09 am and was very quick (10 s), the bird grabbed the sardine, went up pulling the line upwards, unable to detach the bait, it disappeared from the screen (Fig. 10, S3).

Fig. 10 Attack of a Yelkouan Shearwater (*Puffinus yelkouan*) on hook baited with sardine in the eastern part of the Gulf of Lions at 7:09 am on 4 June 2023 (Complete video provided in S3)

Discussion

There is growing concern over the sustainability of seabirds exposed to bycatch fishing mortality in the Mediterranean Sea. The impact of the French pelagic longline fishery on seabirds is poorly understood as well as the circumstances of contacts with the fishing gear that may or may not lead to capture. Although observations at sea are essential, they are limited in terms of both space and time, as it is difficult to see what is happening below the surface once the vessel has left the fishing zone. To remedy the lethal interactions of seabirds with longlines, we first need to document: (1) How seabirds find their food at sea; (2) When and where each species interacts with baits; (3) What tactics seabirds adopt when approaching and foraging on bait. This information should enable the identification of mitigation methods adapted to the fishing activity for each species. Seabirds employ diverse foraging strategies and diving behaviours to efficiently locate and capture prey in marine environments. Their tactics vary based on species, habitat, and prey availability.

Our underwater observations have provided a rare opportunity to accurately document seabird interactions with baited hooks during the soaking phase of a surface longline fishery, intra-specific behaviours, and how seabirds differ in their foraging behaviour depending on bait type (i.e.mackerel, sardine and squid) commonly used by longliners.

Foraging strategies and diving behaviours

The alcids (Alcidae family) including the Atlantic Puffin, are wing-propelled divers that are able to fly in the air and dive underwater by propelling themselves with their wings (Johansson and Aldrin 2002; Watanuki et al. 2003; Kennerley 2023). The underwater behaviour of this “pursuit plunging” seabird has remained poorly understood until recent advancements in biologging technology. The propulsion mechanism of diving Atlantic Puffin was investigated in captivity by analysing their three-dimensional kinematics using digital analysis of sequential video images of dorsal and lateral views (Johansson and Aldrin 2002). Unprecedented information has resulted from these studies but no conservation and mitigation measures to reduce lethal interactions were proposed for this species. Early attempts to describe puffin diving behaviour were performed by counting the dive durations of puffins encountered at the surface or by studying the distribution of alcids caught as bycatch in fishing nets that had been set at known depths (Piatt and Nettleship 1985). Sixty metres was approximately the maximum dive depth for Atlantic Puffins (Piatt and Nettleship 1985). Lower values were estimated using sensors (48 m) (Shoji et al. 2015). For this species, the mean (± 1 SE) dive depth was estimated at 11.8 ± 0.45 m and the mean dive duration was 40 ± 0.45 s while they can perform more than 300 dives per day (Kennerley 2023).

In line with this information, we assumed that during the two-time gaps of 45 and 38 s respectively, noticeable in the ethogram (Fig. 5), the Atlantic Puffin rose to the surface to breath to reappear much lower down to seize the remaining pieces of bait which had sunk (Fig. 4). Finally, the Atlantic Puffin observed in this study succeeded in two consecutive dives, for a total duration of 78 s, to feed on the hooked sardine. Fishermen have never reported by-catch of Atlantic Puffins and further research is needed to understand how often the species interacts with pelagic longlines. More investigations are needed to confirm this assumption which may still be subjective at this stage. In the case of the Atlantic Puffins, attacks were obviously disconnected from the breeding season. Interactions and incidental catches for this species were reported in drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic (Rogan and Mackey 2007) and in nets (Piatt and Nettleship 1985) but seemingly very rare in the pelagic longline (Zhou et al. 2019) and never mentioned in the Mediterranean (García-Barcelona et al. 2010).

The diving behaviour of the Scopoli's shearwaters is typically shallow and brief. Based on observations from bird-borne video recordings, most of their dives occur in the first 0.5 m of depth, and approximately 78% of them are less than 1 m deep, lasting under two seconds (Michel et al. 2021). Therefore, they primarily exploit food on or right beneath the water surface, making them less likely to target deeper or more agile prey. This reliance on surface feeding highlights the importance of their foraging associations with other marine predators such as tunas, which push prey closer to the surface (Grémillet et al. 2014; Cianchetti-Benedetti et al. 2018). Using bird-borne video cameras, Michel et al (2021) documented fine-scale foraging behaviours, intra-, and interspecific associations. In that sense, video footages from seabirds' perspective were quite informative. Meanwhile, video footages showing interactions of seabirds with fishing gear underwater are rather limited as the observation of such events in marine ecosystems is difficult. Scopoli's and Yelkouan Shearwaters tend to forage within similar trophic levels while possibly diverging slightly in their foraging behaviours (e.g., differences in dive depth) (Austad et al. 2025).

Regarding case 2 of our study, the Yelkouan Shearwater, footage analysis clearly showed vertical and horizontal movements in a similar way to the Atlantic Puffin. From the observed horizontal and below the hook orientation of the shearwaters' trajectories, we infer that these birds may have previously visited the nearest hook. Such U-shaped dives most likely represent a hunting strategy (Wilson 1995). We also suspect that shearwaters may follow the mainline and interact with multiple hooks in sequence. Given that hooks are only 30 m apart, they could not only detect bait horizontally but also move towards it. Seabirds' eyes are adapted to focus both in air and underwater, allowing them to spot prey efficiently while diving (Martin and Wanless 2015). In case 3, the foraging event was very quick and looked like a V-shaped dive with limited horizontal movement (Shoji et al. 2015), perhaps because no conspecifics or other seabird competitors for bait were present. Apart from feeding on discarded bait and catch from fishing boats, seabirds are known to forage in associations with conspecifics and other species (sea turtle, marine mammals, tunas, other fishes) as it increases their foraging success (Thiebault et al. 2016; Veit and Harrison 2017; Michel et al. 2021). Many seabird species are known to adapt their foraging strategies and effort in response to prey quality and availability and so modify the frequency and depth of foraging dives (Tremblay and Cherel 1999; Garthe 2004; Thiebault et al. 2016; Loredo et al. 2019; Symons and Diamond 2022).

Our results showed that interactions can continue after the setting phase when the vessel is no longer on the fishing ground. This leads to the assumption that the seabirds could detect the components of the fishing gear during soaking such as buoys and baited hooks at a depth of around 10 m. This depth was estimated from the echosounder on board, which can detect the main line. The use of Temperature-Depth recorders will be considered in future experiments to confirm this information.

In addition, competitive events between shearwaters were observed. Video footage showed several shearwaters underwater near the baited hook; when one shearwater attempted to grab the bait, it was replaced by another. Competition for the bait occurred in a similar way as often observed on the surface, which could be affected by individual dominance traits. The effect of hierarchical competitiveness between seabird species, as well as between individual birds of the same species, can affect seabird bycatch rates (Jiménez et al. 2012; Melvin et al. 2014).

The video footage revealed previously unobserved events, including both successful and unsuccessful attempts of "pursuit plunging" species to grab and consume bait during the gear soak at depths of up to 10 m. These underwater interactions occurred when the gear was unattended and the vessel was away from the site. These findings suggest the need for bycatch mitigation strategies across all fishing operation phases, not just during gear setting and hauling as traditionally expected.

Interactions: area, season, time of day and sea condition

Area

Foraging areas of shearwaters species are characterized by shallow waters near the colony (Afán et al. 2014). As shearwaters are also long-distance travellers, individuals foraging in the French longline fishing grounds can come from several breeding colonies occurring beyond the national EEZ. Maps resulting from this review present insights into potential interactions between different French pelagic longline fishing segments and seabirds from different colonies. This information could assist coastal management stakeholders in formulating policies that could promote ecosystem-based fisheries management. Tracking data from Yelkouan Shearwaters have revealed predictable feeding areas and highlighted areas of potential spatial overlap with the French pelagic longline fishing grounds in the Gulf of Lions and in Corsica (Fig. 3).

Sea condition

Both species have good visual acuity and can detect drifting surface longlines. However, their underwater foraging success may be limited by environmental factors that reduce their ability to find prey (Darby et al. 2022). For example, high waves can make it more difficult for seabirds to access bait, discards, and offal around fishing vessels (Seco Pon et al. 2023).

Proposed best practice and bycatch mitigation measures

During our campaigns, seabirds were frequently observed around the vessels during line setting and hauling operations. Most interactions consisted of attempts to take the bait, with no apparent injury or capture. Our results indicate that the risk of interactions with shearwaters is likely to be highest during the breeding season. These interactions occurred both during the day and at night under full moon condition.

Underwater cameras documented direct interactions with baited hooks at a depth of around 10 m after the vessel had left the fishing area. While the Atlantic Puffin was able to ingest the small bait (sardine), despite repeated attempts by several individuals, the shearwaters were unable to grab the large bait (mackerel) or remove it from the hook to eat it. In Corsica, the bycaught Yelkouan Shearwater brought onboard, had ingested a hook baited with a sardine. We tentatively tried to remove the hook, but there was considerable bleeding and the shearwater died quickly. Current knowledge of shearwater ecology and habitat, based on tagging, clearly showed the high probability of interactions with various fisheries, particularly pelagic longlines, in the French EEZ (Dorémus et al. 2024). Our observations confirmed the threat to seabirds. According to our results, during the setting and hauling phases, the aim would be to prevent surface feeding seabirds and deep divers from interacting with and reaching the baited hook from the surface to the first 15 m of depth. During the soaking period, it would be necessary to reduce the birds' ability to detect the bait in the water column. Seabird bycatch mitigation trials conducted in artisanal demersal longline fisheries showed that mitigation measures commonly proposed in other regions, such as tori lines, weighted lines or artificial bait, were not conclusive in the Western Mediterranean (Cortés et al. 2018). Recommendations for technical measures are based on the results of this study.

Bycatch monitoring

These results highlight the need for continuous monitoring of the longline fishing activity and the attendance and interactions of seabirds in the frame of the national data collection program. This would require particular training in seabird species identification for on-board observers or fisheries electronic monitoring analysts. A suitable on-board observer coverage rate is required to collect reliable seabirds bycatch estimates for the pelagic longline but also for demersal fisheries since the rate of bycatch might be higher (Dimech et al. 2009). A particular effort should be made during peak interactions season.

Raising fishers' awareness

As for the other endangered species, the self-reporting by fishermen in logbooks is almost non-existent in the French longline fisheries. The persistent data gaps prevented adequate assessments of the scale of the impact for endangered species in general. Without data it is difficult for national scientists to defend the cause of their fisheries. Even if the phenomenon seems to be seasonal with apparently low capture, the impact on particular colonies could still be significant. Therefore, additional information is still needed. Fishers should be trained to release birds in good conditions.

Good releasing practices and offal management

While offal dumping tends to increase the number of birds around fishing vessels (Weimerskirch et al. 2000; Poisson et al. 2016b), the retention of offal and spent bait during the longline hauling phase should therefore be widely adopted to avoid seabirds becoming habituated to feeding.

Large sized bait and hook

Bait is the centrepiece of any successful longlining fishing operation. Three types of bait were used in the trials, varying in size and attractiveness through smell, appearance or movement. It was clear from our observations that shearwaters did not ingest hooks baited with mackerel of a relatively large size. They could not get the bait in pieces either. The hook embedded in the mackerel muscle also did not injure the seabirds when they tried to grab the bait.

The use of this particular bait could obviously reduce the risks of capture of seabirds. This simple practice should be adopted, at least during the peak season of seabird interactions. As with bait, the larger the hook, the lower the risk that relatively smaller seabird species will be able to ingest it (Hata 2006; Li et al. 2012; Gilman et al. 2018).

Attaching bait to a pelagic longline involves precise methods to ensure the bait remains secure and attractive underwater to simulate the natural behaviour of prey. We observed that the Atlantic Puffin managed to remove the bait from the hook without getting hooked, which may have been due to crew having improperly threaded the bait onto the hook, so that the sardine was perhaps not securely attached to the hook. The impact of bait attachment to the hook on the bait retention and ability of species to take the bait avoiding the hook entirely should be investigated.

Non-working days

It has been demonstrated that seabirds can adapt to the human activities, especially fisheries, being a possible source of easy food (Cianchetti-Benedetti et al. 2018). Thus, during non-working days of particular fisheries, seabirds change their target (Sato et al. 2012, 2013; Soriano-Redondo et al. 2016). The activity of non-longline fisheries especially trawlers are known to also attract seabirds scavenging for discards and offal (Bartumeus et al. 2010). While this trawl fishery does not operate during weekends, there is no non-working days regulation for longliners. For this reason, in Spanish waters it has been demonstrated that seabirds modify their foraging behaviour and increase the probability to be caught by longliners (García-Barcelona et al. 2010). And so could be the situation in the Gulf of Lions when trawlers do not work during weekends. Moreover, the implementation of the landing obligation in EU waters and the drastic reduction of the fishing effort by trawlers could exacerbate this trend (Soriano-Redondo et al. 2016). Therefore, limiting the surface longline fishing activity to working days could be a measure to implement if the impact of these fisheries proved to be detrimental for seabirds.

Night setting

Underwater interactions occurred in the morning around 8 am in June and in the evening around 7 pm in May. Yelkouan Shearwater in the Mediterranean are predominantly diurnal and crepuscular, meaning that they are particularly active at dawn and dusk and the Atlantic Puffin do not forage at night

(Spencer 2012), so the night setting will definitely reduce their bycatch risk without affecting the target catch of swordfish.

Blue-dyed bait

Dyed bait refers to bait that has been coloured, typically blue. Blue-dyed bait has been investigated as a method of reducing seabird bycatch in longline fisheries, as it can reduce the visibility of bait to seabirds during the soaking phase, as it blends more effectively with the background of the sea, preventing them from detecting and attempting to take the bait. However, the effectiveness of blue-dyed baits varies depending on the type of bait used—fish or squid. Studies have shown that squid absorb the blue dye more effectively than fish, making them less visible to seabirds (Cocking et al. 2008). A significant reduction in albatross interactions has been demonstrated compared to undyed squid. No underwater interactions with squid bait were recorded in this study and dyed fish bait is less effective because the dye is lost rapidly over time (Boggs 2001; Minami and Kiyota 2001; Gilman et al. 2003; Cocking et al. 2008). Therefore, the method is not an option for the moment.

Small-scale longline tori line

A tori line, also known as a bird-scaring line, is a device used in fisheries to reduce seabird bycatch during the setting phase. It consists of a line with streamers attached, which is towed behind a vessel over the area where baited hooks are sinking. The streamers act as a visual deterrent, preventing seabirds from diving and getting caught on the hooks (Abraham et al. 2009; Yokota et al. 2011). Their success depends on proper design and deployment, as factors such as vessel size, line length, streamer type, and pole height can influence performance. These devices are mainly designed for large vessels (> 24 m). Experimental studies have been carried out successfully to refine the specifications of tori-lines and tori-poles for these smaller vessels (Pierre et al. 2016; Ochi 2022). Similar trials should be carried out in the Mediterranean context to ensure that the practical solutions proposed for small-scale fisheries are also effective.

Conclusion

Using cameras affixed to fishing gear, the study documented cryptic events of seabirds attempting to grab bait at depths of up to 10 m. These interactions are not detectable by onboard observers, highlighting the importance of in situ monitoring. The driver behind our experiments was the need to document and to understand the interactions of seabirds with the longline gear. Studying seabirds' behaviours at the surface but also underwater is important to document these interactions and to propose accurate management and conservation actions, this approach has been little explored in the case of pelagic longlines. The documentation of a bycatch event of a Yelkouan Shearwater by onboard observers shows the need for closer monitoring of the French longline fleet. Our study depicted and decrypted the underwater behaviours of seabirds providing new insights into their interactions during the soaking phase with the pelagic longline fishing gear. We have documented for the first time how an Atlantic Puffin managed to eat the sardines used as bait without being caught and, thus bringing to light a previously unknown predation event by this particular species. We witnessed predation attempts of Yelkouan Shearwaters trying to feed on large sized bait without success. Yelkouan Shearwater foraged in association with conspecifics and competitive events were observed. According to observation in situ, we assumed that the two species could have developed new strategies to feed on pelagic longline bait while the vessel was away from the site. This highlights their adaptability and the complex dynamics of their foraging strategies. These events may have gone unnoticed until now. We highlight the fact that if mitigation must be implemented, they should be designed to prevent the seabirds to interact with the baited hook not only during the setting and hauling phases but also during the soaking phase. These observations have also confirmed the effectiveness of simple changes in fishing practices to avoid incidental catches of seabirds.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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